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ESTIMATION OF DOSE TO MAN FROM ENVIRONMENTAL TRITIUM

P. S. Rohwer and E. L. Etnier

Health and Safety Research Division
Oak Ridge National Laboratory*
Oak Ridge, Tennessee 37830

ABSTRACT

Factors important for characterization of tritium in environmental pathways leading to exposure of man are reviewed and quantification of those factors is discussed. Parameters characterizing the behavior of tritium in man are also subjected to review. Factors to be discussed include organic binding, bioaccumulation, quality factor and transmutation.

A variety of models are presently in use to estimate dose to man from environmental releases of tritium. Results from four representative models are compared and discussed. Site-specific information is always preferable when parameterizing models to estimate dose to man. There may be significant differences in dose potential among geographic regions due to variable factors. An example of one such factor we have examined is absolute humidity.

We conclude that adequate methodologies exist for estimation of dose to man from environmental tritium although a number of areas are identified where additional tritium research is desirable.

INTRODUCTION

Methodology for estimation of dose to man from environmental tritium evolved out of general concerns for radiation exposure of man from all sources. Specific interests in tritium have their origins across a broad span of time and programs, including: (1) basic radiobiology research studies, (2) nuclear weapons development and effects studies, (3) peaceful applications of nuclear explosives, PLOWSHARE, (4) fission based nuclear fuel cycles, and (5) studies related to the development of fusion reactors. Tritium has always attracted attention in nuclear power programs because it frequently is present in large quantities compared to most of the other radionuclides if isotopes with short radioactive half-lives are disregarded. Because of the relatively large quantities involved, the estimated dose contribution from tritium may be substantial even though the dose per unit activity is one of the lowest for all radioisotopes. Renewed interest in tritium at this time is the result of a combination of factors, not all of which are unique to tritium. First, today's more restrictive dose limits prompt reexamination of any radionuclide which contributes noticeably to the estimated total dose. Second, revised ternary fission yield data for fast reactor fuels suggest that previous estimates of tritium production via that process may have been low by as much as one order of magnitude (1,2). Third, recent experimental results suggest that it may be desirable to increase the quality factor (Q) for tritium beta particles from the present recommended value of 1 to a higher value (e.g., 2), particularly for low-dose rates and low-dose exposures (3,4,5). The estimated dose for tritium exposure would increase in direct proportion to any increase in the Q. The third point leads to the fourth and final point to be mentioned here: the complex and unanswered question of the relative significance to man of small radiation doses received at low-dose rates. All radiation dose to man is assessed against radiation safety standards established on the basis of dose-effect relationships observed at high-dose and high-dose rates, and linearly extrapolated to zero effect at zero dose. This fourth consideration is not unique to exposures coming from tritium; however, tritium comes under review in this regard because it is frequently used as a research tool in low-dose and -dose rate studies, and the dose-dose rate patterns anticipated for tritium encountered in the environment will be low. Our purpose here is to review and update our previous study of the radiological aspects of environmental tritium (6), review and compare representative examples of the methodologies available to estimate dose to man from tritium, and comment on the general application of this overall methodology to assess environmental releases of tritium.

RELEASE OF TRITIUM TO THE ENVIRONMENT

Tritium is difficult to concentrate and contain in a cost-effective manner, thus the tendency has been extensive escape/release to the environment. Typically these releases are to the atmosphere which affords rapid dispersion and dilution. This procedure is feasible because under normal environmental conditions, tritium is present primarily in the oxidized form as tritiated water (HTO) and thus it is ubiquitous in the circulating hydrosphere. There have been no limits on the quantities of tritium released to the environment so long as dose limits were not exceeded. Population dose estimates for tritium releases are small because facilities with significant potential for tritium release generally are located in sparsely populated areas. As stated above, most of the released tritium is believed to be in the form of HTO; however, at some facilities measurements have

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identified substantial quantities in the elemental form (HT) (7). For assessment purposes, the HT is assumed to be oxidized rapidly to HTO, a process which actually progresses at a rate determined by environmental conditions which prevail at the point and time of release. The rate of this oxidation process and the environmental factors which control the rate are prime candidates for additional study.

The principal point of tritium release in the nuclear fuel cycle is at the fuel reprocessing step (5). Tritium releases from light water reactors during normal operations are much smaller than those from reprocessing facilities but they are not negligible. Efforts directed at concentrating and containing tritium would be best applied to fuel reprocessing facilities. It remains to be established that such procedures at reactor sites would become cost-effective in the foreseeable future. The quantity of tritium to be released to the environment from nuclear fuel cycles is given some perspective by comparison with quantities estimated for other sources of environmental tritium. Table 1 provides estimates of source strength for the principal contributors of environmental tritium. Natural production at a rate of 0.15 EBq per year (4 MCi/year) is estimated to result in a world inventory of 2.6 EBq (70 MCi) (8). Contributions from nuclear weapons testing have provided a major perturbation in the world inventory of tritium. Depending on the scenario chosen for projected growth of the nuclear power industry, routine releases of tritium easily could equal natural production of the isotope by the year 1990 with much larger releases approaching a peak value some twenty years later (5).

INSERT TABLE 1

RADIOTOXICITY OF TRITIUM

Assuming that releases of tritium are going to occur, how toxic is tritium as a source of radiation exposure for man? The radiotoxicity of any radionuclide is determined by interplay of its many properties and behavior characteristics, some enhancing and others diminishing the overall effect. The radioactive half-life of tritium is 12.3 years (9), thus this radionuclide has the potential to remain available to expose man for many years following release (witness the presence of residual tritium from nuclear weapons activities). Tritium is a pure beta emitter and the intensity is very low, 3.0 fJ (18.6 keV) maximum (9). This decay characteristic suggests low radiotoxicity relative to other radionuclides which emit radiations of higher energy and/or a more penetrating type.

Metabolic processes determine the distribution of tritium among biological compartments once the radionuclide enters the body. In establishing dose to man from exposure to tritium, assumptions must be made concerning distribution of the isotope among the hydrogen pools of the body. Hydrogen is a biologically important element constituting approximately 10% of the total body by weight. Body hydrogen may be subdivided among three compartments: (1) tissue water hydrogen (TWH), 67%; (2) exchangeable tissue-bound hydrogen (ETBH), 11%; and (3) nonexchangeable tissue-bound hydrogen (NTBH), 22% (10). Tissue water hydrogen refers to all hydrogen atoms present in water molecules. Tissue-bound hydrogen refers to all hydrogen present in organic molecules such as proteins, fats and carbohydrates. Tritium from the tissue water compartment can enter tissue-bound compartments and the chemical reaction may be relatively rapid for the "exchangeable" components. In the nonexchangeable tissue-bound compartment however, where the hydrogen atoms are assumed to be bonded to carbon atoms of organic tissues, hydrogen turnover is much slower.

The chemical form of tritium at the point of exposure strongly influences radiotoxicity. As HTO, tritium readily enters the body and it is metabolized like ordinary water. Thus, tritium frequently is considered to have a biological half-time of 8 to 12 days in man equal to that of water. The International Commission on Radiological Protection (ICRP) recommends an Annual Limit on Intake (ALI) of 3 x 10^9 Bq (81 mCi) and a Derived Air Concentration (DAC) of 8 x 10^5 Bq/m^3 (2 x 10^{-5} μCi/cm^3) for HTO (11). Exposure to HT results in very little tritium entering the body. The lower radiotoxicity of HT relative to HTO is reflected in the much more liberal DAC recommended by the ICRP for HT (2 x 10^{10} Bq/m^3, 5 x 10^{-1} μCi/cm^3) (11).

ORGANIC BINDING OF TRITIUM

The mechanism of tritium uptake and binding has been extensively documented and reviewed (see 8, 12, 13). In summary, tritium present as HTO can become organically bound within the body as a result of metabolic processes. Tritium can also enter the body in the bound state as a result of chemical reactions which occurred at some previous step in the food chain. The importance of organic binding in terms of increasing the radiotoxicity of tritium over that it exhibits as HT or HTO is dependent on the location of the binding site and the binding fraction.

A fraction of the HTO entering the body, as was shown in the previous section, exchanges with hydrogen bound in organic molecules or is placed in nonexchangeable positions in the molecules via metabolic processes. The rate and extent of organic binding from HTO depend on the metabolic activity of the tissue. Timing, duration, and pathway of exposure are important. The probability of extensive organic labeling is maximized if the HTO is available during tissue formation and growth. As exposures to HTO are protracted, tritium concentrations approach equilibrium values with a single tritium to hydrogen ratio common to all parts of the hydrogen pool. It is estimated that following an acute intake of HTO, 1 to 2% of the tritium becomes organically bound (13, 14, 15). For continuous exposure, 25 to 40% labeling of the tissue-bound hydrogen compartment occurs (16, 17, 18).

Organic binding in the food chain has the potential to expose man to enhanced concentrations of tritium. A previous review by Elwood (19) of ecological aspects of environmental tritium behavior indicates that the isotope effects of tritium involved in most exchange reactions are negligible. Most studies using organic groups common in living tissue to determine the equilibrium concentration obtained via exchange with HTO show that tritium is unlikely to concentrate in exchangeable components. Vanderploeg et al. (20) reviewed bioaccumulation of tritium in aquatic systems. For incorporation into nonexchangeable sites various enzymatic reductions and oxidations of tissue organics are required (21). Photosynthesis and other reduction reactions at the base of the food chain incorporate tritium from tissue water into nonexchangeable components of plants, although data on total tissue bound tritium in plants show that there is discrimination against tritium (20). In his above cited review of ecological aspects of environmental tritium behavior, Elwood indicated that data from field studies of both acute and chronically exposed ecosystems support the conclusion that there is no tritium concentration in food or water at any level of a food chain that exceeds the environmental concentration. Researchers in this area are careful to emphasize that although most chemical reactions discriminate against tritium, the possibility of some concentration cannot be ruled out completely (22).

Food chain transfers may lead to direct intake and incorporation of tritium in nonexchangeable tissue-bound sites. Again most of the evidence suggests discrimination against tritium incorporation into nonexchangeable sites (20). Most components of the diet are broken down during absorptive and metabolic processes, and the products are used by the organism to synthesize its own building blocks. Some studies have shown enhanced tritium levels in subjects receiving diets totally labeled with tritium (23, 24); however, the practicality of these experimental conditions as a realistic simuation of exposure to environmental tritium remains to be established. This is also an area deserving of additional study.

Organic binding can place tritium atoms at key ocations in the labeled molecules. If the labeled ositions are important organic molecules such as ibonucleic acid (RNA) or deoxyribonucleic acid DNA), increased effectiveness or radiotoxicity is uspected (12, 25). However, results from numerous tudies searching for such added radiation effects ue to tritium labeled organic molecules show no uch effect (12, 22). Labeling position can be mportant for another reason: during its radioctive decay a tritium atom is transmuted to a helium atom regardless of position in a molecular tructure. Key positioning would seem to increase he possibility of significant effects occurring ue to transmutation; however, literature on celluar level studies and animal studies support the onclusion that transmutation effects do not add ignificantly to the radiation effects (22, 26 27).

DOSIMETRY OF TRITIUM

Calculation of dose resulting from exposure to tritium is not particularly complex. However, a number of factors, some of them already discussed here, influence the magnitude of the resulting dose conversion factors. Tritium is important as a source of internal exposure (radiation source within the body). External exposure is not an important consideration with tritium because the low energy beta emissions have a maximum range of only 0.005 mm (28) in water or soft tissue and the radiosensitive layer of the skin is located at a depth in excess of 0.04 mm below the surface (29). Exposure to HTO results in rapid and complete absorption of ingested and inhaled tritium (13). Skin absorption of HTO is also rapid, rivaling inhalation as a pathway for quantitative intake of atmospheric tritium in that form (8).

The intrinsic biological effectiveness of the weak beta emission from tritium is a point of disagreement among experts. To adjust for the varying biological effectiveness of different radiation types and energies the ICRP recommends that a quality factor (Q) be used. As the linear energy transfer (LET) for the low-energy tritium beta is higher than that for a more energetic beta or for gamma or x-irradiation, prior to April 1969, the ICRP recommended a Q of 1.7 for all beta radiation having a maximum energy ≤4.8 fJ (0.03 MeV) (30). Following reexamination of available information, the ICRP in April of 1969 revised the Q for tritium beta emissions to 1 (31). Clear interpretation of all data applicable in establishing the value for Q is very difficult for many reasons, principal among them are differences in experimental endpoint and in choice of reference radiation. The present ICRP recommended value of 1 for Q is being questioned (22) on the grounds that it lacks sufficient conservatism (conservatism is a characteristic which leads to overestimation of dose rather than underestimation). Our own most recent review of the literature leads us to conclude that a quality factor of 2 would be more defensible for tritium (5).

Most methods for estimating dose for tritium taken into the body involve a metabolic model to estimate the time-integrated radionuclide body burden. Typically, metabolic models are developed and parameterized by simulating excretion data from animal experimentation or from human exposure experience. In the instance of HTO, components of the excretion curve are ascribed to various compartments of the hydrogen pool in the body. The dynamics (half-times) of the three components usually identified in the excretion function for tritium are the following: (1) 8 to 12 days, tissue water hydrogen, (2) 30 to 40 days, exchangeable tissue-bound hydrogen, and (3) 300 to 600 days, nonexchangeable tissue-bound hydrogen (6).

Tritium which becomes organically bound contributes significantly to total dose. Many estimates exist for the incremental increase in dose due to the organically bound fraction as compared with the estimate of dose if all of the tritium is assumed to be present as HTO. The range of the estimates is from a few percent increase to a 50% increase (5, 6). Each estimate is dependent on the specific exposure conditions assumed, e.g., the duration of the exposure. When information is lacking specific to the exposure in question it seems reasonable, as a general rule, to increase dose estimates for tissue water tritium by approximately 20% to include the dose contribution due to organically bound tritium (5, 6, 8, 32).

As will be evident in the following section, there is some variation among the dose conversion factors included in dose estimation methodologies; however, the majority of them are near a value of 2.7 x 10^{-11} Sv/Bq (0.1 millirem/μCi).

METHODOLOGIES FOR ESTIMATING DOSE

A number of methodologies are available for estimation of dose to man from tritium released to the environment. Four representative examples of these methodologies have been compared (5) and will be discussed briefly. Before proceeding to the individual methodologies, several assumptions and conditions common to all of them are noted here. For purposes of comparison, the quality factor has arbitrarily been set at 1 in the dose conversion factors included in each of the methodologies. Similarly the absolute humidity assumed in each is arbitrarily set at 6 g H_2O/m^3. Each methodology is applied in a sample calculation to estimate the annual dose to man resulting from a continuous exposure concentration of 37 mBq/m^3 (1 pCi/m^3) of tritium in the atmosphere under equilibrium conditions. Three of the methodologies are applied in a second set of calculations for which two of the input parameters have been changed to simulate a site-specific dose estimate. The differences between the estimates from the two sets of calculations illustrate the sensitivity of the results to such changes in input assumptions. Those differences also emphasize the importance of using site-specific information to characterize the exposure whenever possible.

The first methodology is an application of the specific activity concept. A National Academy of Science - National Research Council Committee suggested use of specific activities to assess potential hazards from environmental releases of radionuclides (33). Evans (34) applied the concept to estimate dose from environmental tritium, assuming body hydrogen to be uniformly labeled under chronic exposure conditions. Extrapolating from tritium concentrations that he observed in tissue samples from deer living in the environment of the Savannah River Laboratory, Evans estimated a labeling fraction in the range of 0.85-1.0 for organically bound hydrogen in the body of man under chronic exposure conditions. The dose conversion factor implicit in Evans' calculations is 2.5 x 10^{-11} Sv/Bq (9.4 x 10^{-2} millirem/μCi). The resulting annual dose estimated for exposure to an atmospheric tritium concentration of 37 mBq/m^3 (1 pCi/m^3) is 1.6 x 10^{-4} mSv (1.6 x 10^{-2} millirem), see Table 2. The specific activity methodology is thought to provide conservative results in applications of this type (35).

The National Council on Radiation Protection and Measurements (NCRP) proposes a methodology for calculating the dose from tritium when concentrations of tritium are known for the water, food products, and air to which the individual is exposed (8). In this methodology it is assumed that the dose from tritium via the various pathways of exposure depends on the relative contribution to total water intake (3 liters/day) from each of the three media noted above. The dose conversion factor included in this methodology (2.3 x 10^{-11} Sv/Bq, 8.8 x 10^{-2} millirem/μCi) is based on a three-compartment model of hydrogen in the body, published by Bennett (32). According to Bennett, 84% of the dose is due to tritium in body water and 16% is due to organically bound tritium. Assuming that the concentration of tritium in water, food, and air are equal, the annual dose estimated for exposure to an atmospheric tritium concentration of 37 mBq/m^3 (1 pCi/m^3) is 1.6 x 10^{-4} mSv (1.6 x 10^{-2} millirem), see Table 2. This methodology is applicable to chronic exposure conditions in which differences exist in the concentration of tritium in water, food, and air, but where time-averaged concentrations remain constant. If the tritium concentration in drinking water is reduced to 1% of that in air and the concentration in all food products to 50% of that in air, the estimated dose is reduced in excess of a factor of three (see Table 2).

INSERT TABLE 2

A comprehensive computerized methodology (AIRDOS-EPA) has been prepared by Moore et al.(36) for estimating dose from environmentally released tritium and other radionuclides. The methodology includes an atmospheric dispersion model that predicts concentrations of tritium at distances up to 80 km from the release point. Tritium is assumed to move like water through the environment. Doses due to ingestion of food and drinking water at a particular location are assumed to be proportional to the concentration of tritium in air at that location. Dose from ingestion of food is proportional to the fraction of the total water intake (3.2 liters/day) entering the body via that pathway. Complete absorption is assumed for inspired tritium, and skin absorption is accounted for by adding 50% to the intake via inhalation. The average dose conversion factor included in the AIRDOS-EPA methodology is 2.2 x 10^{-11} Sv/Bq (8.3 x 10^{-2} millirem/μCi) (37). Assuming that all food products are grown at the point of interest, the estimated annual dose for chronic exposure in an atmospheric tritium concentration of 37 mBq/m^3 (1 pCi/m^3) is 1.7 x 10^{-4} mSv (1.7 x 10^{-2} millirem), see Table 2. If, as with the previous methodology, assumptions are changed to simulate site-specificity (i.e., the tritium concentration in food is reduced to 50% of that in air, and the concentration in drinking water reduced to 1% of that in air) the estimated dose is again reduced by a factor greater than three, see Table 2.

The fourth methodology to be compared is one proposed by the U. S. Nuclear Regulatory Commission (38). This methodology is based on a model by Anspaugh et al.(39). In this methodology the concentration of tritium in vegetation is assumed to be one-half that in surrounding air. The concentration of tritium in milk and meat depends on the tritium concentration in vegetation ingested by cattle, and it appears in the USNRC methodology that the resulting concentrations in milk and meat are approximately 50% of those in the vegetation. Since this methodology lacks specification for tritium exposure via drinking water when only atmospheric concentrations are known, for this comparison, the specific activity of tritium in drinking water is assumed to be the same as that in air, and exposure via that pathway is evaluated assuming an annual consumption rate of 370 liters (38). Total absorption of inhaled tritium is assumed. Skin absorption of tritium is assumed to equal 50% of the estimated intake via inhalation. The dose conversion factor included in this methodology is from Hoenes and Soldat (40), 1.7×10^{-11} Sv/Bq (6.2×10^{-2} millirem/μCi). Assuming that all ingested produce is grown locally, the estimated annual dose for chronic exposure in an atmospheric tritium concentration of 37 mBq/m^3 (1 pCi/m^3) is 5.9×10^{-5} mSv (5.9×10^{-3} millirem), see Table 2. Again, if the ingested produce is assumed to be grown where the air concentration is 50% of that at the point of interest and the concentration in drinking water is 1% of the atmospheric concentration, the resulting estimate of annual dose is reduced this time by approximately a factor of four, see Table 2.

SITE SPECIFICITY

Results presented in the previous section indicated that dose estimates for environmental tritium could be altered by a factor of 3 or 4 by changing assumptions for input parameters (i.e., assumptions about the relationships between the tritium concentration in the atmosphere and those in the food and drinking water). Other site-specific characteristics of the exposure can influence the resulting dose estimate similarly; one example is the absolute humidity. The absolute humidity is an important parameter in calculation of dose from environmental releases of tritium. Due to dilution of released tritium by airborne water vapor, dose is found to be inversely proportional to absolute humidity. In calculating the dose estimates presented here a value of 6 g H_2O/m^3 was assumed for the absolute humidity. Actual values may vary considerably depending on the geographical region in which dose is being estimated. Because of this variability we decided to assemble absolute humidity data from which appropriate values for performing radiological assessments could be estimated (41). Absolute humidity was estimated for 218 points across the United States using information from the 1977 Annual Summary of U. S. Climatological Data (42). The results of this analysis are presented in Fig. 1. The range of absolute humidity values estimated for regions of the continental United States is a factor of four. Thus we again see the importance of site-specific information and the magnitude of potential errors that can be introduced through reliance on default parameter values (e.g., the absolute humidity value of 6 g H_2O/m^3). In some instances the effect of parameter variations on dose may cancel one another, but on other occasions they may be multiplicative.

INSERT FIG. 1

GLOBAL DOSE

The approaches discussed in the section on methodologies for estimating dose are useful for estimating dose on local and regional scales. However, because of its 12.3-year physical half-life, and its ubiquitous nature in the hydrologic cycle, tritium is a source of potential exposure to the world's population. Therefore, to assess environmental releases of tritium, additional methodology is necessary to estimate dose on a global scale. Some of the models available for estimation of global dose for tritium are listed in Table 3. Also presented in Table 3 are estimates of annual global population dose calculated with those models for a continuous 1 kBq/sec (0.85 Ci/ year) atmospheric release of tritium. The estimates of Soldat and Baker (43), Bergman et al. (44), and Easterly and Jacobs (45) were obtained with environmental pathways models in which dispersion of tritium follows the hydrologic cycle. The estimate of the USEPA (46) is based on a simple dilution method where releases are uniformly diluted via aqueous pools. It can be seen from the table that the resulting dose estimates vary by a factor of 50.

Our own evaluation of global tritium distribution and its implication for global dose estimation is presented in the work of Gentry and Travis reported in Till et al. (5). Tritium concentrations

INSERT TABLE 3

in precipitation and surface water of the Atlantic Ocean have been observed to vary exponentially with latitude between 0° and 70° north (47). Tritium concentrations over land masses are also observed to increase from west to east with an average increase of approximately 3 over marine values (48). Gentry and Travis assume that tritium is continuously released to the atmosphere from a source located in the northern hemisphere with equilibrium conditions prevailing. A relatively simple model is used to simulate latitudinal dependence of tritium concentration. Land area, water surface area, and population are quantified in 5° latitudinal bands and tritium is assumed to disperse in the top 75 m of oceans and the top 0.5 m of land. An estimate of the global population dose is obtained by incorporating demographic data and a dose conversion factor (2.7×10^{-11} Sv/Bq, 1×10^{-1} millirem/μCi) with the tritium concentration predicted by the model. The population within a given band is exposed to the tritium concentration predicted for the midlatitude of the band. The total dose is obtained by summing across all bands. For a 1 kBq/sec (0.85 Ci/year) release rate the annual global population dose is estimated to be 1.1×10^{-5} man-Sv (1.1×10^{-3} man-rem), see Table 3. To obtain the upper and lower bounds given in Table 3 for this population dose estimate it was assumed that the entire population (3.04×10^{9} persons) is exposed to one of the two extreme tritium concentrations predicted by the distribution model (at 0° and 70° north latitude).

SUMMARY AND CONCLUSIONS

A number of factors related to the release of tritium were discussed: sources, quantities, chemical form, containment, and applicable regulations. The potential for large quantities of tritium to be released to the environment will remain. The probability and the extent of future releases will be influenced by decisions on nuclear fuel reprocessing, developments with fast breeders and fusion, and regulatory incentives for containment.

The principal determinants of the radiotoxicity of environmental tritium have been reexamined and the following conclusions are drawn from that review:

(1) Tritium does not bioaccumulate in the environment, in food chains, or in man;

(2) Incorporation of tritium into key molecular and cellular sites does not significantly enhance its toxicity;

(3) Transmutation effects are insignificant;

(4) The quality factor should be increased to 2;

(5) Organic binding results in approximately a 20% addition to the total dose potential.

Four methodologies for estimating dose to man from atmospheric release of tritium were reviewed and compared. Each of the four methodologies is appropriate for application to local and regional exposure conditions, and each is limited to chronic exposure situations where equilibrium conditions prevail. Acute releases of tritium must be evaluated with dynamic models on a case-by-case basis using site-specific information. Acute releases are expected to constitute a small percentage of the total tritium released to the environment. Variation among dose conversion factors included in the methodologies is less than a factor of two. Application of each methodology to a standard set of exposure conditions gave results which vary by a factor of three. Examples were used to show that site-specific information easily could alter the results obtained with these methodologies to a greater extent than those obtained when they are applied to a standard set of exposure conditions.

An additional set of models is identified for use in estimating global dose due to environmental release of tritium. When applied to a standard atmospheric tritium release rate under equilibrium conditions the results obtained with these models vary by a factor of fifty.

The methodologies available are judged to be adequate for performing the generic and comparative assessments required as input to the decision-making process at this time. Future evaluations may require a much heavier usage of site-specific information to achieve more realistic assessments although the methodologies probably will not differ radically from those reviewed here.

A number of areas were identified in the course of this review where additional tritium research is desirable to better establish radiotoxicity and estimate dose: (1) dependence of the quality factor on dose, dose rate, experimental endpoint, and choice of reference radiation; (2) bioaccumulation of tritium in complex food chains; (3) verification that most molecules discriminate against tritium incorporation into nonexchangeable sites; (4) effects of organically bound tritium; (5) confirmation of the lower toxicity of HT in certain exposure situations; (6) characterization of the conversion of HT to HTO in environmental systems; and (7) effects of exposures at very low doses and dose rates. However, it is not believed that work in these areas is essential at this time for adequate assessment of environmental release of tritium. These needs should be addressed in proper perspective as part of the broad desire for better understanding of the interaction of radiation and man. Radiation in turn is but one of the many insults needing recognition, quantification, and assessment as we develop a complete scenario of energy technologies.

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Table 1. Sources and estimated quantities for environmental tritium

Source	Quantity
Natural production[a]	0.15 EBq/year (4 MCi/year)
Nuclear explosives (1945-1975)[b]	70 EBq (1900 MCi)
Commercial products[b]	0.037 EBq/year (1 MCi/year)
Nuclear industry (1990)[b]	0.15 EBq/year (4 MCi/year)
(2010)	1.9 EBq/year (50 MCi/year)

[a] See ref. 8.

[b] See ref. 5.

Table 2. Summary of the dose estimates for chronic exposure to 37 mBq/m^3 (1 pCi/m^3) of tritium in air calculated using four methodologies

	Annual dose (mSv)	
Methodology	No site specificity	Limited site specificity
Specific activity[a]	1.6×10^{-4}	[b]
NCRP[c]	1.6×10^{-4}	4.8×10^{-5}
AIRDOS-EPA[d]	1.7×10^{-4}	5.3×10^{-5}
USNRC[e]	5.9×10^{-5}	1.4×10^{-5}

[a] See ref. 34.

[b] The specific activity methodology does not provide for the inclusion of site-specific data.

[c] See ref. 8.

[d] See ref. 36.

[e] See ref. 38.

Table 3. Summary of global population dose estimates for 1 kBq/sec (0.85 Ci/year) atmospheric release of tritium calculated using various methodologies[a]

Model	Annual global population dose (man-Sv)
Soldat and Baker (1979)[b]	1.9×10^{-4}
Bergman et al. (1979)[c]	$1.9 - 3.0 \times 10^{-5}$
Easterly and Jacobs (1975)[d]	1.2×10^{-5}
USEPA (1973)[e]	3.5×10^{-6}
Gentry and Travis (in press) Avg.[a]	1.1×10^{-5}
Lower bound	1.3×10^{-6}
Upper bound	5.5×10^{-5}

[a] See ref. 5.

[b] See ref. 42.

[c] See ref. 43.

[d] See ref. 44.

[e] See ref. 45.