DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

CONF-831032--3

UCRL--89766

DE84 002721

SELECTION OF TERRESTRIAL TRANSFER FACTORS FOR RADIOECOLOGICAL ASSESSMENT MODELS AND REGULATORY GUIDES

Y. C. Ng
F. O. Hoffman

This paper was prepared for submittal to
International Atomic Energy Agency and
Commission of the European Communities
Seminar on the Environmental Transfer
to Man of Radionuclides Released from
Nuclear Installations
Brussels, Belgium
17-21 October 1983

Lawrence Livermore Laboratory

This is a preprint of a paper intended for publication in a journal or proceedings. Since changes may be made before publication, this preprint is made available with the understanding that it will not be cited or reproduced without the permission of the author.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

IAEA-SR-85/56

SELECTION OF TERRESTRIAL TRANSFER FACTORS FOR RADIOECOLOGICAL ASSESSMENT MODELS AND REGULATORY GUIDES*

YOOK C. NG, Environmental Sciences Division, Lawrence Livermore National Laboratory, Livermore, California, USA

F. OWEN HOFFMAN, Health and Safety Research Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA

Abstract

SELECTION OF TERRESTRIAL TRANSFER FACTORS FOR RADIOECOLOGICAL ASSESSMENT MODELS AND REGULATORY GUIDES

A parameter value for a radioecological assessment model is not a single value but a distribution of values about a central value. The sources that contribute to the variability of transfer factors to predict foodchain transport of radionuclides are enumerated. Knowledge of these sources, judgment in interpreting the available data, consideration of collateral information, and established criteria that specify the desired level of conservatism in the resulting predictions are essential elements when selecting appropriate parameter values for radioecological assessment models and regulatory guides.

1. INTRODUCTION

Parameter values for radioecological assessment models are not single values but distributions. This presentation focuses on the radionuclide-specific transfer factors that characterize the transfer of radionuclides to terrestrial foods. We discuss the sources of uncertainty in estimates of transfer factors and examine the factors that contribute to their variability. An understanding of these relationships will facilitate the selection of appropriate values of transfer factors for environmental transport models and regulatory guides. In addition we illustrate the use of collateral information and judgment to estimate parameter values when the available data are sparse and suggest approaches that may be followed to enhance our understanding of terrestrial foodchain transfer of radionuclides.

2. SOURCES OF VARIABILITY IN THE TRANSFER FACTORS FOR TERRESTRIAL FOODS

Transfer factors to terrestrial foods include the transfer coefficient to cow's milk F_m, the transfer coefficient to meat F_f, and the plant to soil concentration factor, B_v [1-3]:

---

*Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-Eng-48.

- F_m is fraction of the animal's daily intake of the radionuclide that appears in each litre of milk at equilibrium (d • ltr^{-1}),

- F_f is the fraction of the animal's daily intake of a radionuclide that appears in each kg of flesh at equilibrium or at the time of slaughter (d • kg^{-1}), and

- B_v is the concentration factor for uptake of the radionuclide from dry soil by edible parts of crops (unitless). B_{v1} expresses the concentration ratio, dry vegetation to dry soil, B_{v2}, to express the concentration ratio, fresh vegetation to dry soil.

Values of F_m, F_f, and B_v for individual radionuclides are reasonably well characterized by lognormal distributions [1,2,3]. In general, F_m is less variable than F_f, which in turn is less variable than B_v (Table I).

When selecting transfer factors for radioecological assessments or planning experiments to derive site-specific values, one should be aware of the sources that contribute to their variability (Table II). For example, the chemical and physical form of the radionuclide may influence the observed transfer factor. Thus, the F_m of the citrate of plutonium exceeds that of the dioxide by a factor of >10. For cobalt and selenium, the F_m of the stable isotopes in feed exceeds that of the radioactive tracer by about a factor of 10. Variation in the dietary contents of the stable element related to the radionuclide or stable-element analogue can influence F_m. The F_m of ^{45}Ca and ^{89}Sr to cow's and goat's milk both decreased approximately in the proportion 3:2:1 as the calcium content progressively increased from a low calcium (0.25%) to a normal calcium (0.50%) to a high calcium (1.6% or 1.7%) diet [4,5]. The F_m of ^{131}I to cow's [6] and goat's [7] milk increased from several percent to almost a factor of two in response to moderate (mg) amounts of iodine supplement in the diet. When larger amounts (∿1 g/d) were given, F_m decreased by a factor of three [7].

The F_f values of cobalt to chicken based on the stable-element contents of the product and the ingested feed exceeded those based on ^{60}Co tracer studies by a factor of five [2]. Predictions of the transfer of a radionuclide to meat must be interpreted with caution when they are calculated from transfer factors based on the stable-element contents of meat and feed. The transfer coefficient to meat of a radioisotope incorporated into feed may differ from that of a specific chemical form of the radioisotope. For example, the F_f to fowl for technetium as pertechnetate exceeded that for technetium incorporated into vegetation by about a factor of three [2]. ^{137}Cs provides the prime example of how feed type and chemical and physical form can affect the transfer factor to animal products. The F_f to beef for ^{137}Cs from fallout for cattle on high-grain diet is about two times greater than that for cattle fed a diet high in roughage [8]. The F_m to cow's milk for ^{137}Cs from fallout was similarly two to three times greater on a high-grain diet than on a high-hay diet [9]. For both diets the F_m for orally administered tracer ^{134}Cs exceeded that for fallout ^{137}Cs.

The effect of chemical form on plant to soil concentration factors is well exemplified by the documented increases in the B_v values of chelated forms of actinides [10]. When relevant radioisotope data are sparse or unavailable, B_v values are often estimated from the stable-element contents in associated plants and soils. When the uptake of radioactive and naturally occurring forms of cobalt and iron was compared, there was preferential uptake of ^{60}Co and ^{59}Fe over the stable isotopes [4]. For some crops the difference in uptake was severalfold. The B_{v1} values of manganese, iron, cobalt, copper, and zinc were found to be inversely correlated with the stable-element contents in soil [12].

3. STATISTICAL ANALYSIS OF B_v VALUES

The relatively large variability exhibited by B_v values prompted us to analyze the available data to identify environmental factors that might be used to reduce the variability of the B_v distributions and enhance their value for site-specific assessments. Accordingly, analysis of variance [13] was applied to data sets derived from the logtransformed B_v data (both B_{v2} and B_{v1}) for strontium and cesium compiled in Ref. 3. The data were grouped according to (1) soil texture, (2) crop type, and (3) root-zone characteristics (indoor pot experiments vs field experiments). The effect of the exchangeable calcium in soil on the B_v values for strontium was also examined.

In the description of the statistical analysis below the terms "mean" and "variance" refer to the mean and variance of the logtransformed values. We have followed the practice of presenting box plots [14] to summarize the statistical results. Each box plot displays the range, quartiles, median, and 95% confidence interval of the median. The width of the box, which is proportional to the square root of the number of data points, gives an indication of sample size. In summarizing the statistical results we point out those situations where the mean or variance was found to be influenced by the particular grouping. The relationships are readily discernible in the box plots.

3.1 Effect of soil texture

A limited amount of data on B_{v2} for strontium and cesium in food crops suggested that B_{v2} may vary over a smaller range when the soils are fairly uniform in texture and that loose-textured soils are associated with the higher B_v values [1]. The data on B_{v1} and B_{v2} from Ref. 3 were grouped on the basis of three soil textures: loose (sandy, sandy loam, and fine sandy loam), medium (loam and silt loam), and fine (clay loam, sandy clay loam, silty clay loam, and silty clay). The analysis indicates that for strontium, the means of the B_{v2}

and B_{v1} for coarse-texture soils are significantly greater than those for fine-texture soils (Fig. 1). For pooled soils and coarse-texture soils the variance of B_{v1} is significantly greater than that of B_{v2}. For cesium the variance of the B_{v2} and B_{v1} for fine-texture soils is significantly less than that for coarse- and medium-texture soils.

3.2 Effect of crop type

The analysis of B_{v2} and B_{v1} for strontium in individual food crops reveals significant differences between the mean B_{v2} values for potatoes and barley and potatoes and radish (Fig. 2). The analysis reveals significant differences between the mean B_{v1} values for several pairs of crops (Table III).

The analysis of B_{v2} and B_{v1} for cesium in individual food crops indicates that mean B_{v2} values for barley and radish are significantly different from each other (Fig. 3). The mean B_{v1} value for lettuce is significantly different from those for barley and wheat. The variances of the B_{v2} and B_{v1} for barley significantly differ from those of the other crops except potato.

3.3 Effect of root-zone characteristics

The B_v values for ^{90}Sr, ^{137}Cs, ^{54}Mn, and ^{60}Co measured by Steffan et al. [15] from indoor pot experiments were higher by a variable factor than those from outdoor lysimeters. To evaluate the effects of root-zone characteristics on root uptake, the B_v data of Ref. [3] for strontium and cesium were grouped into those from indoor pot studies and those from field studies. For strontium, the means of the B_{v2} and B_{v1} values for indoor pot studies are significantly greater than those for field studies, and the variance of the B_{v2} values for indoor pot studies is significantly less than that for field studies.

3.4 Effect of exchangeable calcium

The exchangeable calcium (XCA) in soil has been considered the most important factor in determining the extent of ^{90}Sr absorption by plant roots. The B_v for strontium in various crops has been shown to be negatively correlated with the XCA in soil [16]. Accordingly, we determined the correlation coefficient (r) between the logtransformed B_v for strontium in food crops and XCA in soil from the data in Ref. 3. The analysis revealed weak negative correlations between B_{v2} and XCA (r=0.27) and between B_{v1} and XCA (r=0.20). The correlation between B_{v2} and XCA was significant at the 5% level. Comparisons involving subsets of the distributions of B_{v2} and B_{v1} associated with XCA levels of 5 mg/100 g of soil or greater revealed no significant changes in either the means or variances when the samples were grouped according to XCA. This finding is not entirely unexpected, since the B_v

data from Ref. 3 are literature-based data that span a broad range of crops, soils, environmental factors, and experimental conditions. The effect of a single factor, such as the exchangeable calcium, would easily be obscured by the combined effect of all the variables that are represented.

It would be extremely interesting, but beyond the scope of this presentation, to discuss the statistical results in terms of the role and behavior of strontium and calcium and cesium and potassium in plants. The relationships may be useful for specific situations in site-specific assessments. The overall importance of the results, however, is the support given to the principle of focusing on B_{v2}, the concentration factor based on the concentration of a radionuclide in fresh vegetation. The variances of the distributions of B_{v2} were always less than or equal to those of B_{v1}. Furthermore, the means of the B_{v2} values for individual pairs of crops were mostly indistinguishable. Finally, the intake of radioactivity via foods is based on the food-consumption rate expressed on a fresh-weight basis.

4. USE OF JUDGMENT AND COLLATERAL INFORMATION

The selection of transfer factors for a given application requires considerable judgment in interpreting the available data. When relevant data are not abundant, collateral information must be considered. Examples are shown below to illustrate the use of collateral information and judgment to estimate transfer factors when available data are sparse.

4.1 Estimating F_m

Studying lactating goats to obtain data to extrapolate to cows has often been proposed (e.g., Ref. 7). Table IV compares the transfer of radionculides to goat's milk and cow's milk. It lists milk transfer coefficients F_m and milk transfer fractions TFs where the TF is the fraction of the ingested radionuclide that is secreted in milk. Table IV also summarizes TF data for radiostrontium, radioiodine, and radiocesium to cow's milk. Inspection of Table IV reveals that although the F_m values to goat's milk exceed those to cow's milk by an order of magnitude or more, the TF values for the two animals are comparable within a factor of two or three. The order-of-magnitude difference in Table IV between the TF for radioiodine to goat's milk and cow's milk can be attributed to the wide range of milk-to-plasma ratios that can occur in individual animals, the thyroid's daily requirements for iodine, and variations in the dietary intake of iodine [37].

Table V lists estimates of the F_m to cow's milk calculated from the TF to goat's milk for radionuclides not previously measured in the cow. The probable range is approximately the 95% confidence interval of the value listed. The calculation assumes that the TF to goat's milk is associated with an s_g of 1.7, that the TF values to goat's milk and cow's milk are equal within a factor of three (i.e., a probable range of one-third to three), and that the daily milk production by the cow is 10 ltr - d^{-1} with a probable range of 5 to 20 ltr - d^{-1}. TF, the transfer factor, and milk production are treated as lognormal distributions. The default values of F_m from IAEA Safety Series No. 57 are also shown [38]. With the exception of that for neptunium, the IAEA values exceed the geometric mean, as was intended.

4.2 Estimating F_f

It would be worthwhile to evaluate transfer factors to meat and other animal products expressed in terms of the meat to feed concentration ratio and evaluate the variation of the concentration ratio with age and species. Meanwhile it seems reasonable to assume that different species similarly concentrate a given radionuclide in muscle so that the concentration ratios for the different species are approximately equal, and the F_f values vary inversely with the daily intake of feed. This seems reasonable in the case of cesium where the concentration ratio calculated from mean F_f values and standard consumption rates for cattle, hogs, lamb, and chicken were comparable (range, 0.26 - 0.88 and mean, 0.52, Ref. 2).

This approach was used to estimate the F_f to beef for iodine [39]. The concentration ratio calculated from the mean F_f values to pork, lamb, and chicken from Ref. 2 was 0.02 with a probable range of 0.0017 to 0.3. (The F_f value for chicken associated with a high-iodine intake was excluded.) Assuming that the feed consumption by beef cattle is 10 kg • d^{-1} with a probable range of 6.25 to 16 kg • d^{-1}, the estimate is 2×10^{-3} d • kg^{-1} for the F_f to beef for iodine with a probable range of 2×10^{-4} to 3×10^{-2} d • kg^{-1}. The IAEA default value in Safety Series No. 57 [38] is 1×10^{-2} d • kg^{-1}.

5. SUGGESTIONS FOR FURTHER STUDY

Experimental work and data analysis that should be performed to increase our knowledge of transfer factors include further studies on goats and chickens to improve our understanding of the transfer of radionuclides to animal products. These species are smaller, and therefore more manageable and economical to study than other species of livestock, and both are important in the foodchain worldwide. Integration of the existing data on the transfer of radionuclides to muscle of various species of livestock would aid in establishing systematic differences and interspecies correlations and facilitate the estimation of transfer factors for the larger species.

Additional correlations between transfer factors and readily measured site-specific factors should be obtained to reduce the variability in the estimates. Transfer factors should also be considered in relation to other parameters in a model. For example, B_v values are negatively correlated with soil retention, i.e., high B_v values are associated with low retention in soil (high mobility) and low B_v values are associated with high retention in soil (low mobility) [12].

High B_v values should not be used in conjunction with high residence times in soil unless the very conservative estimates are intended.

6. SELECTION OF DEFAULT VALUES

Data now available have corrected deficiencies in the documentation of transfer factors and provide a better basis for selecting values appropriate for radioecological assessment models or regulatory guides [1-3]. The actual selection of default values requires the establishment of criteria that specify the desired degree of conservatism in the predictions resulting from the models. In the selection of default transportation for the generic model in IAEA Safety Series No. 57, rules were adopted so as to produce a low probability of exceeding a relevant dose limit when predictions are at least an order of magnitude below the limit [38]. The resulting default values would be expected to be in the upper half of the probable range somewhere between the geometric mean and maximum value. In the selection of default values for regulatory guides, one possibility is to select conservative values. Another is to select the median or mean or some other midrange value with elements of conservatism to be incorporated separately. In any event a consistent approach that is compatible with the established criteria must be followed. The maximum value for each parameter in a radioecological assessment model must not be selected, however, as this practice would lead to extreme conservatism in the resulting predictions [16].

7. SUMMARY AND CONCLUSIONS

The selection of parameter values appropriate for radioecological assessment models and regulatory guides requires a knowledge of the sources that contribute to the variability of the parameter values, and sound judgment in interpreting the available data and collateral information. The selection also requires the establishment of criteria that specify the degree of conservatism in the resulting predictions and consistency in meeting these criteria. The use of goats and fowl to study the transfer of radionuclides to food products from larger species is advantageous. Transfer factors to terrestrial foods that cover a wide range of experimental and environmental conditions have been determined for relatively few radionuclides. Transfer factors for radionuclide transport models typically have been derived from studies designed for purposes other than the determination of transfer factors. More communication and interaction between model developers and experimenters studying transport processes and mechanisms would be desirable from the standpoint of deriving useful parameter values with minimal additional experimental effort.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the assistance of D. E. Bennett and D. H. Moore, who provided guidance in performing and interpreting the statistical analysis.

REFERENCES

[1] NG, Y. C., A review of transfer factors for assessing the dose from radionuclides in agricultural products, Nucl. Saf. 23 (1982) 57.

[2] NG, Y. C., COLSHER, C. S., THOMPSON, S. E., Transfer Coefficients for Assessing the Dose from Radionuclides in Meat and Eggs, Lawrence Livermore National Laboratory, Livermore, California, NUREG/CR-2976 (1982).

[3] NG, Y. C., COLSHER, C. S., THOMPSON, S. E., Soil-to-Plant Concentration Factors for Radiological Assessments, Lawrence Livermore National Laboratory, Livermore, California, NUREG/CR-2975 (1982).

[4] COMAR, C. L., WASSERMAN, R. H., "Radioisotope absorption and methods of elimination: differential behaviour of substances in metabolic pathways," Radioisotopes in the Biosphere (CALDECOTT, R. S., SNYDER, L. A., Eds.), University of Minnesota, Minneapolis, Minnesota (1960) 526.

[5] COMAR, C. L., WASSERMAN, R. H., TWARDOCK A. R., Secretion of calcium and strontium into milk, Health Phys. 7 (1961) 69.

[6] LENGEMANN, F. W., COMAR, C. L., Metabolism of I^{131} by dairy cows during long-term daily administration of the radioisotope, Health Phys. 10 (1964) 55.

[7] LENGEMANN, F. W., Metabolism of radioiodide by lactating goats given iodine-131 for extended periods, J. Dairy Sci. 53 (1970) 165.

[8] JOHNSON, J. E., TYLER, T. R., WARD, G. M., Transfer of fallout cesium-137 from feed to meat of cattle, J. Animal Sci. 29 (1969) 695.

[9] JOHNSON, J. E., WARD, G. M., FIRESTONE, E., KNOX, K. L., Metabolism of radioactive cesium (^{134}Cs and ^{137}Cs) and potassium by dairy cattle as influenced by high and low forage diets, J. Nutr. 94 (1968) 282.

[10] PIMPL, M., SCHUTTELKOPF, H., Transport of plutonium, americium, and curium from soils into plants by root uptake, Nucl. Saf. 22 (1981) 214.

[11] ROMANOV, G. N., RYABOVA, E. R., SIROTKIN, A. N., Use of stable and radioactive nuclide ratios in radioecological investigations, Sov. J. Ecol. 11 (1980) 36.

[12] BAES, C. F., III, SHARP, R. D., SJOREEN, A. L., SHOR, R. W., A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides Through Agriculture, Oak Ridge National Laboratory, Oak Ridge, Tennessee, ORNL-5786 (in press).

[13] BMDP STATISTICAL SOFTWARE, P7D-Description of Groups (Strata) with Histograms and Analysis of Variance, BMDP Statistical Software, Inc., Los Angeles, California (1982).

[14] MCGILL, R., TUKEY, J. W., LARSEN, W. A., Variations of box plots, Am. Stat. 32 (1978) 12.

[15] STEFFENS, W., FUHR, F., MITTELSTAEDT, W., "Evaluation of small scale laboratory and pot experiments to determine a realistic transfer factors for the radionuclides ^{90}Sr, ^{137}Cs, ^{60}C and ^{54}Mn," Radiation Protection, A Systematic Approach to Safety, Vol. 2, Pergamon Press New York (1980), 1135.

[16] LINDACKERS, H. H., BONNENBERG, H., (organizers), Workshop on Accuracy in Dose Calculations for Radionuclides Released to the Environment, GUW Gesellschaft fur Umweltuberwachung mbH, Aldenhoven, Federal Republic of Germany (1980).

[17] COMAR, C. L., WENTWORTH, R. A., LENGEMANN, F. W., Metabolism of Selected Radionuclides Fed in Various Physical Forms to Animals, Cornell University, Ithaca, New York, AD-626320 (1965).

[18] NG, Y. C., COLSHER, C. S., QUINN, D. J., THOMPSON, S. E., Transfer Coefficients for the Prediction of the Dose to Man via the Forage-Cow-Milk Pathway from Radionuclides Released to the Biosphere, Lawrence Livermore National Laboratory, Livermore, California, UCRL-51939 (1977).

[19] EKMAN, L., ABERG, B., Excretion of niobium-95, yttrium-91, cerium-144 and promethium-147 in goats, Res. Vet. Sci. 2 (1961) 100.

[20] ANKE, M., HENNIG, A., DIETTRICH, M., HOFFMAN, G., WICKE, G., PFLUG, D., Resorption, Exkretion, und Verteilung von ^{99}Molybdan nach oraler Gabe an laktierende Wiederkauer, Arch. Tierernahrung 2 (1971) 505.

[21] POTTER, G. D., Lawrence Livermore National Laboratory, Livermore, California, private communication (1977).

[22] LENGEMANN, F. W., Radioiodine in the milk of cows and goats after oral administration of radioiodate and radioiodide, Health Phys. 17 (1969) 565.

[23] COMAR, C. L., WENTWORTH, R. A., LENGEMANN, F. W., Control of Fission Products Ingested by Livestock, Cornell University, Ithaca, New York, AD-737281 (1971).

[24] WRIGHT, W. E., CHRISTIAN, J. E., ANDREWS, F. N., The mammary elimination of radioiodine, J. Dairy Sci. 38 (1955) 131.

[25] BINNERTS, W. T., LENGEMANN, F. W., COMAR, L. L., Radioiodine metabolism in the goat after simultaneous single and daily administration, J. Dairy Sci. 45 (1962) 427.

[26] LENGEMANN, F. W., Metabolism of radioiodine by lactating goats given iodine-131 for extended periods, J. Dairy Sci. 53 (1970) 165.

[27] EKMAN, L., Distribution and excretion of radio-cesium in goats, pigs, and hens, Actn Vet. Scand. 2 Suppl. 4 (1961) 1.

[28] GARNER, R. J., JONES, H. G., EKMAN, L., Fission products and the dairy cow 1. The fate of orally administered cerium-144, J. Agr. Sci. 55 (1960) 107.

[29] HOWE, S. M., MCGEE, J., LENGEMANN, F. W., Transfer of inorganic mercury to milk of goats, Nature 237 (1972) 516.

[30] POTTER, G. D., MCINTYRE, D. R., VATTUONE, G. M., Metabolism of ^{203}Hg administered as $HgCl_2$ in the dairy cow and calf, Health Phys. 22 (1972) 103.

[31] SELF, J. L., DAVISON, K. L., Metabolism of mercury, administered as methylmercuric chloride or mercuric chloride, by lactating ruminants, J. Agr. Food Chem. 23 (1975) 23.

[32] NEATHERLY, M. W., MILLER, W. J., GENTRY, R. P., STAKE, P. E., BLACKMON, D. M., Cadmium-109 and methyl mercury-203 metabolism, tissue distribution, and secretion into milk of cows, J. Dairy Sci. 57 (1974) 1177.

[33] JOHNSON, J. E., WATTERS, R. L., $^{210}PoO_2$ Metabolism in Ruminants, Final Report and Summary, 1969-1972, Colorado State University, Fort Collins, Colorado, COO-2044-5 (1972).

[34] SCHRECKHISE, R. G., WATTERS, R. L., Internal distribution and milk secretion of polonium-210 after oral administration to a lactating goat, J. Dairy Sci. 52 (1969) 1967.

[35] MULLEN, A.A., LLOYD, S.R., MOSLEY, R.E., POTTER, G.D., PATZER, R.G., "Absorption, distribution, and milk secretion of neptunium in the dairy goat," Transuranics in Desert Ecosystems (WHITE, M.G., DUNAWAY, P.B., WIREMAN, D.L., Eds.), U.S. Department of Energy, Las Vegas, Nevada, NVO-181 (1977) 267.

[36] SUTTON, W. W., PATZER, R. G., MULLEN, A. A., HAHN, P. B., POTTER, G. D., "Metabolism of americium-241 in dairy animals," Selected Environmental Plutonium Research Reports (WHITE, M. G., DUNAWAY, P. G., Eds.) U.S. Department of Energy, Las Vegas, Nevada, NVO-192 (1978) 19.

[37] LENGEMANN, F.W. WENTWORTH, R.A., COMAR, C.L., "Physiological and biochemical aspects of the accumulation of contaminant radionuclides in milk," Lactation (LARSON, B.L., SMITH, V.R., Eds.), Academic Press, New York (1974).

[38] INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA), Generic Models and Parameters for Assessing the Environmental Transfer of Radionuclides from Routine Releases, Exposures of Critical Groups, IAEA, Vienna, Safety Series No. 57 (1982).

[39] HOFFMAN, F.O., MILLER, C.W., NG, Y.C., "Uncertainties in environmental radiological assessment models and their implications," Environmental Transfer to Man of Radionuclides Released from Nuclear Institutions, International Atomic Energy Agency, Vienna, Austria (in press).

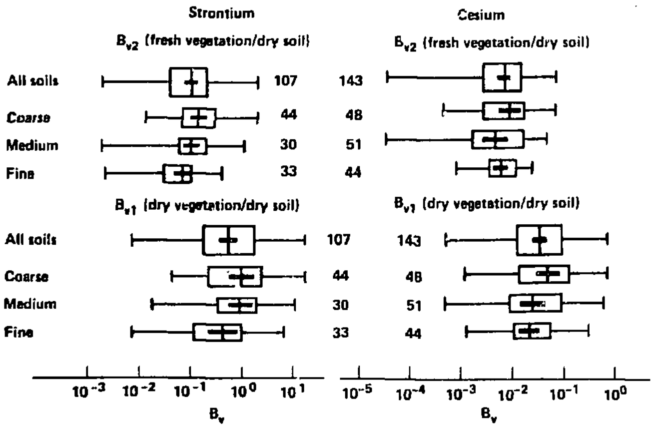

FIG. 1. Concentration factors for strontium and cesium--variation with soil texture.

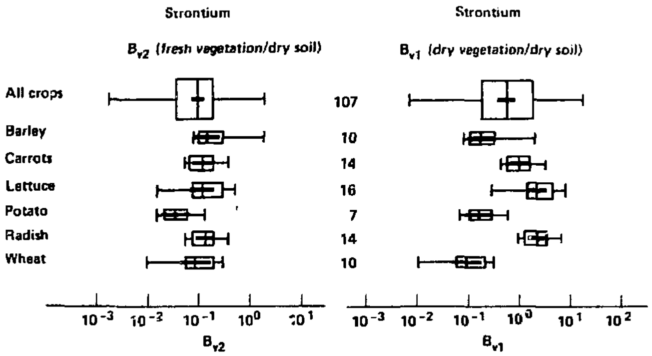

FIG. 2 Concentration factors for strontium in food crops.

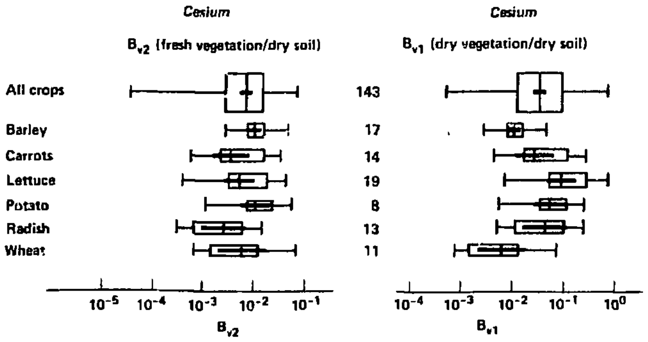

FIG. 3. Concentration factors for cesium in food crops.

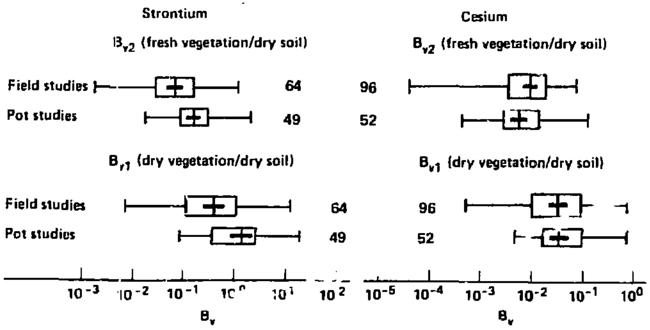

FIG. 4. Concentration factors for strontium and cesium in food crops--indoor pot studies versus field studies.

TABLE I. VARIABILITY OF TRANSFER FACTORS TO TERRESTRIAL FOODS [1-3].

	F_m (cow)		F_f(meat)[a]		B_{v2} (food)		B_{v1} (forage)	
Element	N[b]	s_g	N	s_g	N	s_g	N	s_g
Ca	8	1.6	--	--	--	--	--	--
Mn	--	--	--	--	21	4.9	20	7.6
Co	--	--	--	--	24	3.3	10	4.7
Zn	10	2.2	--	--	31	3.9	21	2.6
Sr	19	1.6	5	3.3(A)	107	3.7	54	3.9
	--	--	5	3.1(B)	--	--	--	--
	--	--	7	1.5(C)	--	--	--	--
	--	--	8	1.7(D)	--	--	--	--
I	20	1.7	5	1.4(E)	16	4.9	32	3.5
Cs	27	1.8	16	2.0(A)	143	3.8	42	3.5

---

[a] *A = beef, B = pork, C = lamb, D = chicken, and E = hen's eggs.*
[b] Number of mean values included in the distribution.

TABLE II. SOURCES OF VARIABILITY OBSERVED IN TRANSFER FACTORS OF RADIONUCLIDES TO TERRESTRIAL FOODS [1-3].

Sources of variability	F_m	F_f	B_v
Chemical and physical form: Radionuclide studied, form when incorporated into plants; and form of naturally occurring stable element in soil, plant, and animal products	X	X	X
Stable element in diet	X	X	
Type of feed (roughage versus concentrates)	X	X	
Experimental design	X	X	X
Stable element in soil			X
Crop type			X
Soil properties: Cation exchange capacity, exchangeable calcium, exchangeable potassium, pH, organic matter content, clay content, dominant clay mineral,etc.			X
Activity deposited on plant surfaces			X
Root-zone characteristics			X

TABLE III. SIGNIFICANT DIFFERENCES IN THE CONCENTRATION FACTORS FOR STRONTIUM IN INDIVIDUAL FOOD CROPS.[a]

	Barley	Carrot	Lettuce	Potato	Radish	Wheat
Barley		B	B		B	
Carrot						
Lettuce						B
Potato	A	B	B		B	
Radish						
Wheat		B			B	

---

[a] The "A" signifies that the means of the B_{v2} values are statistically different ($P < 0.05$). The "B" signifies that the means of the B_{v1} values are statistically different ($P < 0.05$). The column heading above the letter indicates the group associated with the greater mean value.

TABLE IV. TRANSFER OF RADIONUCLIDES TO GOAT'S AND COW'S MILK (F_m).

Radionuclide	Number of observations	Transfer fraction (%) Mean	Transfer fraction (%) Range	F_m (% d · ltr^{-1}) Mean	F_m (% d · ltr^{-1}) Range	Number of observations	Transfer fraction (%) Mean	Transfer fraction (%) Range	F_m (% d · ltr^{-1}) Mean	F_m (% d · ltr^{-1}) Range	Reference
^{45}Ca	2	4.6	4.2 - 5.0	12	10 - 13	2	10	8.3 - 12	0.82	0.68 - 0.97	[4,5]
^{89}Sr	2	0.54	0.53 - 0.55	1.4	1.1 - 1.7	2	0.90	0.84 - 0.96	0.080	0.079 - 0.080	[4,5]
^{85}Sr	3	0.97	0.85 - 1.2	1.0	0.57 - 1.4	2	0.76	0.62 - 0.89	0.065	0.062 - 0.069	[17]
^{85}Sr, ^{89}Sr						7^{a}	1.1	0.41 - $3.1^{b,c}$			[18]
^{91}Y	1	0.0015									[19]
^{99}Mo	4	2.4				1	1.7				[20,21]
^{125}I, ^{131}I	2	41	38 - 44	44	41 - 47	2	3.6	3.3 - 3.8	0.43	0.42 - 0.44	[22]
^{131}I	1	13		10		2	14	9.1 - 19	1.1	1.1 - 1.2	[23]
^{125}I, ^{131}I	3^{a}	27	12 - 37			14^{a}	7.5	4.0 - $13^{b,c}$			[24-26,18]
^{134}Cs	3	17	8.7 - 27	15	13 - 16	2	17	15 - 18	1.5	0.84 - 2.2	[17]
^{137}Cs	6	13	9.7 - 18	21	16 - 27	5^{a}	10	7.5 - $16^{b,c}$			[27,18]
^{144}Ce	1	0.003				2	0.013	0.010 - 0.016			[19,28]
147 Pm	1	0.002									[19]
^{203}Hg (^{203}HgCl$_2$)	3	0.019	0.006 - 0.039	0.01[illegible]	0.002 - 0.024	2	0.0094		0.00063		[29,30]
^{203}Hg (CH$_3^{203}$HgCl)	1	0.28		0.28		2	>0.17		>0.042		[31,32]
^{210}Po (^{210}PoO$_2$)	3			0.45		3			0.012		[33]
^{210}Po (^{210}PoO$_2$)	1	0.18		0.18							[34]
^{234}Np	2	00.1									[35]
^{95}Am	1	$5.6E-4^{d}$		3.8E-4		2	4.4E-4	4.4E-4 - 4.4E-4	3.8E-5	2.9E-5 - 4.6E-5	[36]

---

[a] Number of citations.
[b] Range of the mean values from a citation.
[c] The values of the transfer fraction correspond to the F_m values in Table I of Ref. 18.
[d] 5.6E-4 signifies 5.6 x 10^{-4}.

TABLE V. ESTIMATION OF THE TRANSFER COEFFICIENT TO COW'S MILK (F_m) FROM THE TRANSFER FRACTION (TF) TO GOAT'S MILK.

Radionuclide	TF (goat)[a] (%)	F_m (cow) % d • ltr^{-1}	Probable range % d • ltr^{-1}	IAEA value[b] % d • ltr^{-1}
^{95m}Tc		<<0.1[c]		1.0
^{91}Y	1.5×10^{-3}	1.5×10^{-4}	3×10^{-5} - 8×10^{-4}	2×10^{-3}
^{147}Pm	2×10^{-3}	2×10^{-4}	4×10^{-4} - 1×10^{-3}	2×10^{-3}
^{234}Np	1×10^{-2}	1×10^{-3}	2×10^{-4} - 5×10^{-3}	5×10^{-4}

[a] Value from Table IV.
[b] Default value from Ref. 38.
[c] Based on studies in progress on the secretion of ^{131}I and ^{95m}Tc in goat's milk.