

IMPACTS OF STABLE ELEMENT INTAKE ON ^{14}C AND ^{129}I DOSE ESTIMATES – IMPLICATIONS FOR PROPOSED YUCCA MOUNTAIN REPOSITORY

Dade W. Moeller,* Michael T. Ryan,[†] Lin-Shen C. Sun,[‡] and Robert N. Cherry, Jr.[§]

Abstract – The purpose of this study was to evaluate the influence of the intake of stable isotopes of carbon and iodine on the committed doses due to the ingestion of ^{14}C and ^{129}I . This was accomplished through the application of two different computational approaches. The first was based on the assumption that ground (drinking) water was the only source of intake of both ^{14}C and ^{129}I and stable carbon and stable iodine. For purposes of the second approach, the intake of ^{14}C and ^{129}I was still assumed to be only that in the ground (drinking) water, but the intake of stable carbon and stable iodine was assumed to be that in the drinking water plus other components of the diet. The doses were estimated using either a conversion formula or the applicable dose coefficients in Federal Guidance Reports No. 11 and No. 13. Serving as input for the analyses was the estimated maximum concentration of ^{14}C or ^{129}I that would be present in the ground water due to potential releases from the proposed Yucca Mountain high-level radioactive waste repository during the first 10,000 years after closure. The estimated concentrations of stable carbon and iodine were based on analyses of ground water samples collected in the Amargosa Valley, NV. Based on the accompanying analyses, three conclusions were reached. First, no dose estimate, using a conversion formula in which the ratios of the stable to radioactive isotopes of an element serve as input, should ever be made without including the stable element intake contributions from all components of the diet. Second, the study suggests that the dose coefficients for ^{129}I in Federal Guidance Reports No. 11 and No. 12 which, in turn, are based on publications of the ICRP, may not be appropriate for application in developed nations of the world, especially those in which relatively large amounts of seafood are consumed and the use of iodized salt is common. The estimated average daily intake of stable iodine by the adult U.S. population, for example, is 400 μg . This is twice the value listed by the ICRP for Reference Man. This leads to a dose estimate that is too high by a factor of two. Although the ICRP accounts for stable isotope contributions through the selection of a corresponding biological half-time for iodine, the selection in this case may need reevaluation especially with respect to assessments of potential ^{129}I releases from the proposed Yucca Mountain high-level radioactive waste repository. The third conclusion, which confirms earlier studies, is that an increase in the intake of either ^{14}C or ^{129}I will not lead to an increase in the dose if there is a corresponding increase in the intake of stable carbon or iodine such that the ratio of ^{14}C or ^{129}I to stable carbon or iodine does not change.

Key words: ^{14}C ; ^{129}I ; dose estimates; stable element influence; waste disposal; proposed Yucca Mountain repository.

INTRODUCTION

The purpose of this study was to evaluate the influence of the intake of stable isotopes of carbon and iodine on dose estimates due to the ingestion of ^{14}C and ^{129}I . Serving as an example for achieving this objective were data based on analyses and measurements related to the proposed high-level radioactive waste repository at Yucca Mountain.

ASSUMPTIONS AND ANALYTICAL APPROACHES

For purposes of the analyses, the following computational approaches and assumptions were applied:

- In all cases, the assumed intake of either ^{14}C or ^{129}I was limited to that arising through the ingestion of 2 L d^{-1} of ground (drinking) water. Any ^{14}C or ^{129}I present in other components of the diet was ignored.
- In contrast, the intake of *stable* carbon ($^{12}\text{C} + ^{13}\text{C}$) and *stable* iodine (^{127}I) was, for purposes of an initial dose estimate (#1a), assumed to be only that in the ground (drinking) water; for purposes of a second dose estimate (#1b), it was assumed to be that in the *total* diet, namely, that in the ground water plus other components of the diet.
- As a first computational approach (#1a and #1b), the doses were estimated using a conversion formula that incorporates the ratio of the intake of ^{14}C or ^{129}I to that for stable carbon or stable iodine.
- As a second approach (#2a and #2b), the doses were estimated using the coefficients provided in Federal Guidance Report (FGR) No. 11 (Eckerman et al. 1988) and FGR No. 13 (Eckerman et al. 2002), respectively.
- The assumed concentration of ^{14}C or ^{129}I in the ground water was the maximum estimated to result from postulated releases of ^{14}C and ^{129}I during the first 10,000 years after repository closure.
- The assumed concentrations of stable carbon and stable iodine in the ground water were based on analyses of samples collected in the Amargosa Valley, NV.
- All calculations were based on an assumption of steady-state conditions, that is, that the ratio of stable carbon or iodine to ^{14}C or ^{129}I in the environment was in equilibrium with that in the ground water and in the people who were ingesting it.
- All calculations were for an adult, which is in accord with the Reasonably Maximally Exposed Individual (RMEI) as specified in the regulations applicable to the proposed Yucca Mountain repository (USNRC 2001).

A summary of the two computational approaches is presented in Table 1. In the case of approaches #2a and #2b, the impacts of the ratio of ^{14}C or ^{129}I to the quantity of stable carbon or stable iodine in the total intake had already been implicitly incorporated into the dose coefficients as presented in FGR No. 11 and FGR No. 13. This was accomplished through the assignment of a biological half-time based on the turnover of carbon or iodine in the human body. Because, in applying this approach, there is no way to avoid taking into account the amount of stable carbon or stable iodine in other components of the diet, only one dose estimate was made in each of these two cases.

In addition, it is important to note the following differences in the assumptions underlying the dose estimates for ^{14}C and ^{129}I that were based on computational approaches #1a and #1b and involved the application of a dose conversion formula:

- For ^{14}C , the assumed daily intake of stable carbon was 300 g, the value for Reference Man provided by the International Commission on Radiological Protection (ICRP 1975). Assessments indicate that the daily intake for adults living in the United States is the same (Till 1983; NCRP 1984; 1985).
- For ^{129}I , the assumed daily intake of stable iodine was 400 μg . This value, which was based on the average of the estimates for adult men and women in the United States, was obtained from a report of the Agency for Toxic Substances and Disease Registry (ATSDR 2001). This estimate is twice the value (200 μg) provided for Reference Man (ICRP 1975). As will be noted below, this difference proved to be critical in calculating the dose estimates for ^{129}I .

COMMITTED DOSE ESTIMATES FOR ^{14}C

Based on data provided by the U.S. Department of Energy (DOE 2002), the maximum concentration of ^{14}C in the ground water during the first 10,000 years after repository closure is estimated to $2 \times 10^{-3} \text{ pCi L}^{-1}$. Based on the consumption of 2 L d^{-1} of ground water, this would yield a daily intake of $4 \times 10^{-9} \mu\text{Ci d}^{-1}$ ($1.48 \times 10^{-4} \text{ Bq d}^{-1}$). Based on site-specific analyses, the average concentration of stable carbon in the ground water in the Amargosa Valley is 56 mg L^{-1} (Peters 2004^{††}) which, assuming a consumption rate of 2 L d^{-1} , would yield an intake rate of 112 mg d^{-1} .

Carbon-14 – computational approach #1a

Applying the applicable dose conversion formula (Killough and Rohwer 1978) under the conditions specified in this approach, the *effective* dose rate (rem d^{-1}) due to the intake of ^{14}C , would equal:

$$0.57 \left(\frac{\mu\text{Ci } ^{14}\text{C}}{\text{g}_{\text{stable C}}} \right)$$

The constant, 0.57, expressed in units of rem d⁻¹, applies specifically to the dose rate to the whole body due to the ingestion of ¹⁴C. The only required input into the formula, in this case, is the ratio of the activity of ¹⁴C (μCi) to that of the ingested stable carbon (g) in the ground water being ingested. The ratio, itself, has no units.

Applying this formula under the conditions specified in approach #1a, the estimated dose rate would be:

$$\frac{(0.57 \text{ rem d}^{-1}) (4 \times 10^{-9} \mu\text{Ci } ^{14}\text{C d}^{-1})}{(112 \text{ mg}^{\text{stable C d}^{-1}}) (10^3 \text{ mg g}^{-1})} = 2.04 \times 10^{-8} \text{ rem d}^{-1}.$$

On this basis, the estimated annual dose rate would be:

$$\begin{aligned} (2.04 \times 10^{-8} \text{ rem d}^{-1}) (365 \text{ d y}^{-1}) &= 7.45 \times 10^{-6} \text{ rem y}^{-1} \\ &= (7.45 \times 10^{-6} \text{ rem y}^{-1}) (10^4 \mu\text{Sv rem}^{-1}) = 7.45 \times 10^{-2} \mu\text{Sv y}^{-1}. \end{aligned}$$

Carbon-14 – computational approach #1b

Computational approach #1b, as noted in Table 1, is the same as #1a, except that the total daily intake of stable carbon is assumed to be 300 g (ICRP 1975). Although this is not a realistic exposure scenario (since it would not be possible to ingest the stable carbon in the remainder of the diet without ingesting the accompanying ¹⁴C), the calculations were performed on the basis of this assumption so that the outcome could be reviewed, evaluated, and the accompanying insights revealed. Applying the dose conversion formula under the specified conditions, the estimated dose rate would be:

$$\frac{(0.57 \text{ rem d}^{-1}) (4 \times 10^{-9} \mu\text{Ci } ^{14}\text{C d}^{-1})}{(300 \text{ g}^{\text{stable C d}^{-1}})} = 7.60 \times 10^{-12} \text{ rem d}^{-1}.$$

On this basis, the annual estimated dose rate would be:

$$(7.60 \times 10^{-12} \text{ rem d}^{-1}) (365 \text{ d y}^{-1}) = 2.77 \times 10^{-9} \text{ rem y}^{-1} = 2.77 \times 10^{-5} \mu\text{Sv y}^{-1}.$$

Carbon-14 – computational approach #2a – FGR No. 11

Assuming the whole body as the critical organ, the value of the dose coefficient in FGR No. 11 for ¹⁴C is 5.64 x 10⁻¹⁰ Sv Bq⁻¹. Applying this coefficient to the annual intake of ¹⁴C, the estimated dose would be:

$$(1.48 \times 10^{-4} \text{ Bq d}^{-1}) (365 \text{ d y}^{-1}) (5.64 \times 10^{-10} \text{ Sv Bq}^{-1})$$

$$= 3.05 \times 10^{-11} \text{ Sv y}^{-1} = 3.05 \times 10^{-5} \mu\text{Sv y}^{-1}.$$

Because, as noted earlier, the impact of the total intake of stable carbon is incorporated into the dose coefficient from FGR No. 11, the contributions of stable carbon from other components of the diet are automatically included in this case.

Carbon-14 – computational approach #2b – FGR No. 13

Once again assuming the whole body as the critical organ, the value of the dose coefficient in FGR No. 13 is $5.81 \times 10^{-10} \text{ Sv Bq}^{-1}$. In this case, the estimated dose rate would be:

$$(1.48 \times 10^{-4} \text{ Bq d}^{-1}) (365 \text{ d y}^{-1}) (5.81 \times 10^{-10} \text{ Sv Bq}^{-1})$$

$$= 3.14 \times 10^{-11} \text{ Sv y}^{-1} = 3.14 \times 10^{-5} \mu\text{Sv y}^{-1}.$$

As in dose estimate #2a, this result applies whether the stable carbon intake is based on ground (drinking) water, alone, or that in the drinking water plus other components of the diet.

The results of these four sets of calculations are summarized in Table 2. As may be noted, the dose rate estimate ($7.45 \times 10^{-2} \mu\text{Sv y}^{-1}$), based on computational approach #1a, is clearly not in agreement with the estimates derived on the basis of the assumptions and computational approaches applied in the other three cases. The reason for this difference can be explained as follows. The specific activity of ^{14}C is $1.63 \times 10^{-1} \text{ TBq g}^{-1}$. Based on the assumed daily drinking water consumption rate, this would yield a daily mass intake of ^{14}C of:

$$\frac{1.48 \times 10^{-4} \text{ Bq d}^{-1}}{(1.63 \times 10^{-1} \text{ TBq g}^{-1}) (10^{-3} \text{ g mg}^{-1})} = 9.08 \times 10^{-13} \text{ mg d}^{-1}$$

On this basis, the ratio of the mass in the ground water of stable carbon to ^{14}C (which served as an input for computational approach #1a), would be:

$$\frac{112 \text{ mg d}^{-1}}{9.08 \times 10^{-13} \text{ mg d}^{-1}} = 1.23 \times 10^{14}.$$

If the corresponding ratio were calculated for computational approach #1b (based on the *total* intake of stable carbon), it would be equal to:

$$\frac{(300 \text{ g d}^{-1})(10^3 \text{ mg g}^{-1})}{9.08 \times 10^{-13} \text{ mg d}^{-1}} = 3.30 \times 10^{17}$$

On this basis, the ratio of the ratio of the mass relationship for total intake, versus that in the ground water, would be:

$$\frac{3.30 \times 10^{17}}{1.23 \times 10^{14}} = 2.68 \times 10^3$$

The corresponding ratio of the dose estimate for computational approach #1a, divided by that for approach #1b, is:

$$\frac{7.45 \times 10^{-2} \text{ } \mu\text{Sv y}^{-1}}{2.77 \times 10^{-5} \text{ } \mu\text{Sv y}^{-1}} = 2.69 \times 10^3$$

As would be anticipated, the ratio in each case is essentially the same. This observation, coupled with the fact that the dose estimate based on computational approach #1b closely agrees with the estimates based on computational approaches #2a and #2b, confirms, as previously noted, that the dose coefficients in FGR No. 11 and No. 13 were prepared, taking into account the relatively high daily intake contribution of stable carbon in other components of the daily diet. For this reason, the coefficients applied in dose assessment approaches #2a and #2b will, in all normal situations, yield the proper results regardless of the source of the ¹⁴C intake or the contribution of stable carbon from that particular source. In contrast, it is not possible for the dose estimate, based on approach #1a to be correct unless the contributions of stable carbon from other components of the diet are considered. Application of the dose conversion formula under the artificial constraint that contributions of stable carbon from other components of the diet be ignored (computational approach #1a), did not permit this to be done.

COMMITTED DOSE ESTIMATES FOR ¹²⁹I

Based on data provided by the U.S. Department of Energy (DOE 2002), the maximum concentration of ¹²⁹I in the ground water during the first 10,000 years after repository closure is estimated to $2 \times 10^{-5} \text{ pCi L}^{-1}$. Assuming a ground water consumption rate of 2 L d^{-1} , this would yield a daily intake of $4 \times 10^{-11} \text{ } \mu\text{Ci d}^{-1}$ ($1.48 \times 10^{-6} \text{ Bq d}^{-1}$). Based on site-specific analyses, the average concentration of stable iodine in the ground water in the Amargosa Valley, measured as the iodide, is $5.0 \text{ } \mu\text{g L}^{-1}$ (Peterman 2003^{††}). Since, under the conditions expected in the Yucca Mountain ground water, all the iodine will be present as the iodide, the consumption of 2 L d^{-1} would yield a daily stable iodine intake of $10.0 \text{ } \mu\text{g}$.

Iodine-129 – computational approach #1a

As in the case for ^{14}C , any potential contribution of ^{129}I in other components of the diet will be ignored in the application of this approach. Although this, as noted earlier, is not a realistic scenario, once again the calculations were performed so that the outcome could be reviewed and evaluated.

Applying the previously cited specific activity for ^{129}I ($6.53 \times 10^6 \text{ Bq g}^{-1}$; $6.53 \times 10^3 \text{ Bq mg}^{-1}$; $6.53 \text{ Bq } \mu\text{g}^{-1}$), the mass concentration of ^{129}I in the daily ground water intake would be:

$$\frac{1.48 \times 10^{-6} \text{ Bq d}^{-1}}{6.53 \text{ Bq } \mu\text{g}^{-1}} = 2.27 \times 10^{-7} \mu\text{g d}^{-1},$$

Accordingly, the ratio of the mass of stable iodine to that of ^{129}I in the assumed daily intake, at the time of the maximum estimated concentration of ^{129}I , would be:

$$\frac{10.0 \mu\text{g d}^{-1}}{2.27 \times 10^{-7} \mu\text{g d}^{-1}} = 4.41 \times 10^7.$$

Assuming that the average adult thyroid weighs 20 g and contains 10 mg of iodine (ICRP 1979), the mass of ^{129}I in the thyroid at equilibrium would be:

$$\frac{10 \text{ mg}}{4.41 \times 10^7} = 2.27 \times 10^{-7} \text{ mg}.$$

This would be equivalent to:

$$(2.27 \times 10^{-7} \text{ mg}) (6.53 \times 10^3 \text{ Bq mg}^{-1}) = 1.48 \times 10^{-3} \text{ Bq}.$$

Based on the dose conversion formula developed by Soldat et al. (1973), maintenance of a continuing burden of 1 pCi ($3.7 \times 10^{-2} \text{ Bq}$) of ^{129}I in the thyroid will impart a dose rate to that organ of 0.06 mrem y^{-1} ($6 \times 10^{-1} \mu\text{Sv y}^{-1}$). Under the conditions specified in computational approach #1a, the annual thyroid dose would be:

$$(6.0 \times 10^{-1} \mu\text{Sv y}^{-1}) \left(\frac{1.48 \times 10^{-3} \text{ Bq}}{3.7 \times 10^{-2} \text{ Bq}} \right) = 2.40 \times 10^{-2} \mu\text{Sv y}^{-1}$$

Iodine-129 – computational approach #1b

Based on the previously cited *total* daily intake of 400 μg of stable iodine, and taking into account the mass of ^{129}I being consumed each day (calculated immediately above), the ratio of the mass of stable iodine to that for ^{129}I in this case would be:

$$\frac{400 \mu\text{g d}^{-1}}{2.27 \times 10^{-7} \mu\text{g d}^{-1}} = 1.76 \times 10^9.$$

Following this approach, the amount of ^{129}I in the thyroid at equilibrium would be:

$$\frac{10 \text{ mg}}{1.76 \times 10^9} = 5.68 \times 10^{-9} \text{ mg},$$

and the total ^{129}I activity in the thyroid, based on its specific activity, would be:

$$(5.68 \times 10^{-9} \text{ mg}) (6.53 \times 10^3 \text{ Bq mg}^{-1}) = 3.71 \times 10^{-5} \text{ Bq}.$$

Applying the Soldat et al. formula, the dose rate to the thyroid would be:

$$(6.0 \times 10^{-1} \mu\text{Sv y}^{-1}) \left(\frac{3.71 \times 10^{-5} \text{ Bq}}{3.7 \times 10^{-2} \text{ Bq}} \right) = 6.02 \times 10^{-4} \mu\text{Sv y}^{-1}.$$

Iodine-129 – computational approach #2a – FGR No. 11

Based on the thyroid as the critical organ, the value of the dose coefficient for ^{129}I in FGR No. 11 is $2.48 \times 10^{-6} \text{ Sv Bq}^{-1}$. Applying this to the intake of ^{129}I through consumption of ground water, the estimated committed thyroid dose per year of intake would be:

$$\begin{aligned} & (2.48 \times 10^{-6} \text{ Sv Bq}^{-1}) (1.48 \times 10^{-6} \text{ Bq d}^{-1}) (365 \text{ d y}^{-1}) \\ & = 1.34 \times 10^{-9} \text{ Sv y}^{-1} = 1.34 \times 10^{-3} \mu\text{Sv y}^{-1}. \end{aligned}$$

Iodine-129 – computational approach 2a & b – FGR No. 13

Based on the thyroid as the critical organ, the value of the dose coefficient for ^{129}I in FGR No. 13 is $2.11 \times 10^{-6} \text{ Sv Bq}^{-1}$. In this case, the estimated committed thyroid dose per year of intake would be:

$$\begin{aligned} & (2.11 \times 10^{-6} \text{ Sv Bq}^{-1}) (7.4 \times 10^{-7} \text{ Bq L}^{-1}) (2 \text{ L d}^{-1}) (365 \text{ d y}^{-1}) \\ & = 1.14 \times 10^{-9} \text{ Sv y}^{-1} = 1.14 \times 10^{-3} \mu\text{Sv y}^{-1}. \end{aligned}$$

REVIEW AND COMMENTARY

As may be noted by the data for ^{14}C (Table 2), the dose estimate based on computational approach #1a is clearly not in agreement with those derived using the other three approaches. The same is true for ^{129}I (Table 3). In both instances, this is a direct result of the intentional omission from consideration of the contributions of stable carbon and iodine in other components of the daily intake. This was documented by the fact that the ratios of the mass intake of stable carbon to that of ^{14}C coincided exactly with the ratios of the dose estimates. The same was true for ^{129}I wherein a similar calculation would indicate that both ratios were equal to 39.9. Of even more interest, however, is that while the dose estimates for ^{14}C , derived through the application of the other three computational approaches, showed reasonably close agreement, those for ^{129}I , based on the application of the coefficients from FGR No. 11 and FGR No. 13, were approximately double that based on computational approach #1b.

Although there may be several factors that contribute to this difference, it appears that the primary one is that, as previously noted, the daily intake of stable iodine, based on Reference Man (ICRP 1975), is about half of the estimated average for adults in the United States. This fact, alone, would yield the observed factor of approximately two difference in the dose estimates based on computational approach #1b and those (#2a and #2b) in which the coefficients from FGR No. 11 and No. 13 were applied. At the same time, however, it is important to acknowledge that the ICRP has sought to address this difference by revising the biological half-time for iodine. During the past 25 years, for example, the half-time has been reduced from 120 d to 90 d (ICRP 1979; 1993). In between these two dates, the NCRP (1983) quoted a value of 100 d. Since people living in the developed countries of the world tend to have more readily available access to seafood (which contains relatively high quantities of stable iodine) and routinely consume iodized salt, it may well be that separate coefficients should be developed, depending on the amount of stable iodine being consumed by the population to whom the coefficients are being applied. This is confirmed by the fact that recent studies of populations in nine Asian countries, representing more than half of the world population, showed that their average total daily intake of stable iodine was only 90 μg , 45% of the ICRP value for Reference Man (Iyengar et al. 2004). In these cases, the application of the ICRP coefficient would yield a dose estimate that is less than half of the correct value.

CONCLUSIONS

There are three conclusions that can be derived from the analyses in this paper. The *first* is that no dose estimate, using a conversion formula in which the ratios of the stable to radioactive isotopes of an element serve as input, should be made using non-realistic computational approaches, exposure scenarios, or assumptions. If the dose estimates are to be accurate, it is mandatory that all components of the diet, that serve as significant contributors to the intake of the stable isotope(s) of the radionuclide being evaluated, are included in the analyses. The *second* is that the dose coefficients for ^{129}I in Federal Guidance Reports No. 11 and No. 13 which, in turn, were based on publications of the ICRP, appear

not to be appropriate for application in many of the developed nations of the world, especially those (as noted above) in which relatively large amounts of seafood are consumed and the use of iodized salt is common. This assumes special significance in reviews and evaluations of potential ^{129}I releases from the proposed Yucca Mountain high-level radioactive waste repository. The *third* conclusion, which confirms earlier studies, is that an increase in the intake of either ^{14}C or ^{129}I will not lead to an increase in the dose if there is a corresponding increase in the intake of stable carbon or iodine such that the ratio of ^{14}C or ^{129}I to stable carbon or iodine does not change (Moeller and Ryan 2004).

For these reasons, regulatory agencies in countries in which the average population intake rate of a specific stable element is suspected of being higher or lower than the value assumed by the ICRP (1975), may want to confirm this difference. If it proves to be significant, it may be appropriate to make appropriate adjustments in the relevant ICRP dose coefficients, prior to their application. Also worthy of consideration are similar modifications for addressing situations in which the intake of a stable element, for example, calcium, significantly influences the uptake in the body of a radionuclide, such as ^{90}Sr .

Acknowledgment – This study was supported in part by the Science and Technology Program, Office of Civilian Radioactive Waste Management, U.S. Department of Energy.

Footnotes:

* Dade Moeller & Associates Inc., 257 River Island Road, New Bern, NC 28562; †768 Glossy Ibis Lane, Kiawah Island, SC 29455; ‡Brookhaven National Laboratory, Building 535 A, Upton, NY 11973; §Dade Moeller & Associates Inc., 2750 Prosperity Avenue, Suite 500, Fairfax, VA 22031.

For correspondence or reprints contact: D. W. Moeller, Dade Moeller & Associates Inc., 257 River Island Road, New Bern, NC 28562.

** Eckerman, KF. Influence of stable carbon. E-mail transmission. Oak Ridge, TN: Oak Ridge National Laboratory; 13 September, 2004.

†† Peters M. Request for information on ¹⁴C. E-mail transmission. Washington, DC: U.S. Department of Energy (18 August); 2004.

‡‡ Peterman Z. Dissolved iodide in ground water. E-mail transmission. Las Vegas, NV: U.S. Department of Energy; Yucca Mountain Project; 19 June 2003.

REFERENCES

Agency for Toxic Substances and Disease Registry. Toxicological profile of iodine (draft for public comment). Atlanta, GA: U.S. Department of Health and Human Services; 2001.

Eckerman KF, Wolbarst AB, Richardson ACB. Limiting values of radionuclide intake and air concentration and dose conversion factors for inhalation, submersion, and ingestion. Washington, DC: Federal Guidance Report 11, Office of Radiation Programs, U.S. Environmental Protection Agency; 1988.

Eckerman KF, Leggett RW, Nelson, CB, Puskin JS, Richardson ACB. Cancer risk coefficients for environmental exposure to radionuclides. Washington, DC: Federal Guidance Report 13, CD Supplement, Rev. 1, Office of Air and Radiation, U.S. Environmental Protection Agency; 2002.

International Commission on Radiological Protection. Report of the task group on reference man. Oxford: Pergamon Press; ICRP Publication 23; 1975.

International Commission on Radiological Protection. Limits for intakes of radionuclides by workers. Oxford: Pergamon Press; ICRP Publication 30, Part 1 including Addendum; Ann ICRP 2(3/4); 1979.

International Commission on Radiological Protection. Age-dependent doses to members of the public from intake of radionuclides: Part 2, Ingestion dose coefficients. Oxford: Pergamon Press; ICRP Publication 67, Ann ICRP 23(3/4); 1993.

Iyengar GV, Kawamura H, Dang HS, Parr RM, Wang J, Akhter P, Cho SY, Natera E, Miah FK, Dojosubroto J, Nguyen MS. Dietary intakes of seven elements of importance in radiological protection by Asian population: Comparison with ICRP data. *Health Phys.* 86(6):557-564; 2004.

Killough GG, Rohwer, PS. A new look at the dosimetry of ^{14}C released to the atmosphere as carbon dioxide." *Health Phys.* 34(2):141-159; 1978.

Moeller DW, Ryan, MT. Limitations on upper bound dose to adults due to intake of ^{129}I in drinking water and total diet – Implications relative to the proposed yucca mountain high level radioactive waste repository. *Health Phys* 86:586-589; 2004.

National Council on Radiation Protection and Measurements (NCRP). Iodine-129: Evaluation of releases from nuclear power generation. Bethesda, MD: NCRP Report No. 75; 1983.

National Council on Radiation Protection and Measurements (NCRP). Radiological assessment: Assessing the transport, bioaccumulation, and uptake by man of radionuclides releases to the environment. Bethesda, MD: NCRP Report No. 76; 1984.

National Council on Radiation Protection and Measurements (NCRP). Carbon-14 in the environment. Bethesda, MD: NCRP Report No. 81; 1985.

Soldat, JK, Bauer, FP, Cline, JF, Fager, JT, Klepper B, Richard WH, Baughan BE, Watson DG. The Radioecology of Iodine-129: An Interim Report. Richland, WA: Battelle Pacific Northwest Laboratories; Report No. BNWL-1783; 1973.

Till, JE. Models for special-case radionuclides. In: Till JE, and Meyer HR. Radiological assessment: A textbook on environmental dose analysis, Chapter 9. Washington, DC: U.S. Nuclear Regulatory Commission; 1983: 9-1 to 9-29.

U.S. Department of Energy. Final environmental impact statement for a geologic repository for the disposal of spent nuclear fuel and high-level radioactive waste at Yucca Mountain, Nye County, Nevada. Washington, DC: U.S. DOE; Report DOE/EIS-0250, I; Chapter 5; February 2002.

U.S. Nuclear Regulatory Commission. Disposal of high-level radioactive wastes in a proposed geologic repository at Yucca Mountain, Nevada: Final Rule. Washington, DC: Federal Register, 10 CFR Part 63:55732 – 55816; 2001.

Table 1. Summary of computational approaches and assumptions used for estimating the committed doses per year of radionuclide intake.^a

Computational Approach	Stable Element Intake	Basis for Dose Estimate
#1a	Drinking water Only	Conversion formula based on intake ratio of stable element to its radioisotope
#1b	Drinking water plus other components of diet	Conversion formula based on intake ratio of stable element to its radioisotope
#2a	Implicitly incorporated through value assigned to biological half-time	Dose coefficients from FGR No. 11
#2b	Implicitly incorporated through value assigned to biological half-time	Dose coefficients from FGR No. 13

^aAll dose estimates are based on the quantity of ¹⁴C or ¹²⁹I ingested in the ground (drinking) water. The intake in other components of the diet is ignored.

Table 2. Comparison of committed *effective* dose estimates due to ingestion of ^{14}C , based on the several computational approaches.

Approach	Assumed Conditions	Committed Dose Per Year of Intake
#1a	Application of Killough & Rohwer dose conversion formula assuming a daily stable carbon (drinking water) intake of 112 mg	$7.45 \times 10^{-2} \mu\text{Sv}$
#1b	Application of Killough & Rohwer dose conversion formula assuming a daily stable (total) carbon intake of 300 g	$2.77 \times 10^{-5} \mu\text{Sv}$
#2a	Application of FRG No. 11 dose coefficient without explicit regard to the daily stable carbon intake	$3.05 \times 10^{-5} \mu\text{Sv}$
#2b	Application of FRG No. 13 dose coefficient without explicit regard to the daily stable carbon intake	$3.14 \times 10^{-5} \mu\text{Sv}$

Table 3. Comparison of committed *thyroid* doses due to the ingestion of ^{129}I , based on the several computational approaches.

Approach	Assumed Conditions	Committed Dose Per Year of Intake
#1a	Application of Soldat et al. dose conversion formula assuming a daily stable iodine (drinking water) intake of 10 μg	$2.40 \times 10^{-2} \mu\text{Sv}$
#1b	Application of Soldat et al. dose conversion formula assuming a daily stable (total) carbon intake of 400 μg	$6.02 \times 10^{-4} \mu\text{Sv}$
#2a	Application of FRG No. 11 dose coefficient without explicit regard to the daily stable iodine intake	$1.34 \times 10^{-3} \mu\text{Sv}$
#2b	Application of FRG No. 13 dose coefficient without explicit regard to the daily stable iodine intake	$1.14 \times 10^{-3} \mu\text{Sv}$