Uranium GI absorption coefficients for infants determined from bone-ash samples

J. Chen, C. Li, V. Vais, W. Hunt, B. Tracy, D. Meyerhof, and J. Cornett

E-mail: Jing_chen@hc-sc.gc.ca
Radiation Protection Bureau, AL 6302D1, Health Canada
775 Brookfield Road, Ottawa, K1A 1C1, Canada

Abstract. Uranium is ubiquitously found in drinking water and food. The absorption fraction \( f_1 \) is an important parameter in risk assessment of uranium burdens from ingestion. Although absorption of uranium from the gastrointestinal tract (GI) has been studied extensively in both animals and humans in the past, human data among young children are rare. Based on measurements of uranium concentration in bone-ash samples, this study provides human absorption coefficients of ingested uranium for infants. The preliminary results indicate that the absorption coefficient may be 6 times higher than the value recommended by ICRP for infants.

1. Introduction

Uranium is a naturally occurring element, which is both radiologically and chemically toxic. It is ubiquitously found in drinking water and food. The absorption fraction \( f_1 \) is an important parameter in risk assessment of uranium burdens from ingestion. Absorption of uranium from the gastrointestinal tract has been studied extensively in the past [1, 2, 3, 4, 5]. However, human data among young children are rare. Previous studies conducted at Health Canada [4, 5] showed a \( f_1 \) value of 0.009 for gastrointestinal absorption of uranium in humans more than 13 years of age.

For risk assessment due to uranium ingestion, the International Commission of Radiological Protection (ICRP) recommended the \( f_1 \) value of 0.04 for infants and 0.02 for anyone more than 1 year of age [6]. This recommendation was based on animal studies and some human studies in adults. The purpose of this study is to determine the \( f_1 \) values for chronic intake of uranium and for children under the age of 12 months. The analysis is based on measurements of uranium concentration in bone-ash samples collected at Health Canada.

2. Selection of bone-ash samples

Human bone samples were collected by Health Canada between 1957 and 1980 as part of a program to monitor strontium-90 fallout from nuclear weapon testing. The samples were taken from autopsies performed at various hospitals across Canada. Once the samples had been analyzed for strontium-90, the ash residues were archived for future studies. These samples are particularly useful in studying heavy metals such as uranium, which tend to concentrate in bone.

In order to determine uranium absorption coefficients, samples can be selected from residential areas where the uranium concentrations in drinking water were known during the period of exposure. A total of 11 bone-ash samples were selected for infants ranging in age from about 2 months to one year residing in a Canadian community known to have an elevated level of uranium in its drinking water supply. These were analyzed for total uranium by inductively coupled plasma mass spectrometry (ICP/MS).

3. Estimate of uranium intakes

Uranium exists in the environment. The uranium concentration in human bone is a result of chronic exposures to the uranium in air, drinking water and food. Uranium concentration in air is normally very low and negligible compared to that in drinking water and food [7]. Therefore, uranium intake by inhalation is not considered in this study.
Uranium in food and drinking water contributes to daily intake by ingestion. While uranium in drinking water varies significantly across Canada, intake from food is assumed to be consistent to all Canadian due to the global food supply. Dietary intake of uranium was estimated from data of total diet study [4, 5] conducted in Ottawa where the uranium concentration in drinking water is very low (consistently less than 1 µg/L). The median value of uranium intake from food for 20 Ottawa area participants was found to be 0.75 µg/day. This value was taken as an estimate of daily dietary uranium intake for adults across Canada. Infants consume less food than adults. Based on the ratios of energy expenditures between infants and adults [8], the uranium intake from food was adjusted to be 0.14 µg/day for infants.

Uranium in drinking water is another source of intake. The uranium concentrations in drinking water were based on Health Canada monitoring data and historical records of the community water supply. Infants under age 1 take 0.61 L of drinking water per day according to a statistical survey for Canadians [9]. The uranium intake from drinking water was assessed for each infant based on the daily water consumption and the uranium concentration in the water during the time that the infant was exposed.

For each infant, the daily uranium intake was the sum of intakes from food and drinking water. The estimated daily intakes are listed in Table I for the 11 subjects.

4. Estimate of uranium burdens at birth

Uranium taken up by a mother can be transferred to the unborn baby. At birth, there will be an initial skeletal burden of uranium depending on the mother’s intake. This initial value was determined from the median value of uranium concentrations in bone samples taken from three stillbirths to be 2.89 µg uranium for every µg of uranium ingested daily by the mother. With the assumption that pregnant women drink 1.5 L water per day [9], the daily uranium intake of the mother was determined to be the sum of the uranium from drinking water consumption and 0.75 µg uranium in food. Estimated initial values of uranium in bone at birth are given in Table I. The distribution of uranium in the body at birth is assumed to be the same as that at age 1 year.

5. Uranium burdens in bone for unit absorption

For each infant, the uranium concentration in bone accumulated to the time of death was calculated from the estimated initial value and from the daily intake, assuming unit absorption, \( f_i = 1 \).

Once absorbed into blood, the systemic transport of uranium is described by the biokinetic model given in ICRP Publication 69 [10]. This model has 17 compartments and includes recycling from organs or tissues back to blood. Based on this model, the uranium burden in bone is the sum of uranium in six compartments: non-exchangeable and exchangeable cortical volume, cortical surface, non-exchangeable and exchangeable trabecular volume, and trabecular surface.

To solve uranium transfer in multi compartments, the WinSAAM program (ver. 3.0.1) developed by the National Institute of Health USA [11] for biological systems was used. The WinSAAM program allows the study of uranium retention within each compartment and its transfer between compartments. The calculated results are listed in Table I.

5. Determination of \( f_i \) values

For each selected sample, the \( f_i \) value was estimated as the ratio of the measured uranium concentration in bone to the calculated uranium concentration in bone at unit absorption:

\[
f_i = \frac{C_m}{C_u}
\]
where \( C_m \) is the measured uranium concentration in bone-ash, and \( C_u \) the calculated uranium concentration based on the estimated daily intake assuming complete absorption. The resulting \( f_1 \) values are listed in the last column of Table I. The variation in individual values is large, ranging from 0.048 to 0.519. The median of all \( f_1 \) values is 0.256.

Table I. Estimated \( f_1 \) values together with the estimated uranium intakes, uranium concentrations in bone at birth and at death, and results of ICP/MS measurements.

<table>
<thead>
<tr>
<th>Date of death (yyyy-mm)</th>
<th>Age attained (months)</th>
<th>Estimated uranium intake by infant (µg/day(^*))</th>
<th>Estimated uranium in bone at birth (µg)</th>
<th>Calculated uranium in bone at death (µg)</th>
<th>Measured uranium in bone-ash (µg/g)</th>
<th>Calculated uranium in bone-ash (µg/g)</th>
<th>( f_1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1972-09</td>
<td>2.5</td>
<td>1.55</td>
<td>14.19</td>
<td>43.94</td>
<td>0.048</td>
<td>0.440</td>
<td>0.109</td>
</tr>
<tr>
<td>1972-09</td>
<td>2.5</td>
<td>1.55</td>
<td>14.19</td>
<td>43.94</td>
<td>0.189</td>
<td>0.440</td>
<td>0.430</td>
</tr>
<tr>
<td>1968-09</td>
<td>3.0</td>
<td>1.97</td>
<td>17.25</td>
<td>60.57</td>
<td>0.246</td>
<td>0.580</td>
<td>0.424</td>
</tr>
<tr>
<td>1968-10</td>
<td>3.0</td>
<td>1.97</td>
<td>16.73</td>
<td>60.25</td>
<td>0.148</td>
<td>0.577</td>
<td>0.256</td>
</tr>
<tr>
<td>1977-10</td>
<td>4.0</td>
<td>2.45</td>
<td>16.71</td>
<td>84.91</td>
<td>0.089</td>
<td>0.746</td>
<td>0.119</td>
</tr>
<tr>
<td>1977-01</td>
<td>5.0</td>
<td>1.96</td>
<td>14.39</td>
<td>77.95</td>
<td>0.030</td>
<td>0.625</td>
<td>0.048</td>
</tr>
<tr>
<td>1969-07</td>
<td>5.0</td>
<td>2.01</td>
<td>15.20</td>
<td>80.13</td>
<td>0.079</td>
<td>0.642</td>
<td>0.123</td>
</tr>
<tr>
<td>1973-08</td>
<td>5.5</td>
<td>1.18</td>
<td>11.70</td>
<td>50.43</td>
<td>0.054</td>
<td>0.389</td>
<td>0.139</td>
</tr>
<tr>
<td>1970-05</td>
<td>6.0</td>
<td>1.79</td>
<td>15.49</td>
<td>78.71</td>
<td>0.292</td>
<td>0.584</td>
<td>0.500</td>
</tr>
<tr>
<td>1975-11</td>
<td>8.0</td>
<td>1.63</td>
<td>8.99</td>
<td>79.90</td>
<td>0.179</td>
<td>0.514</td>
<td>0.348</td>
</tr>
<tr>
<td>1975-03</td>
<td>11.5</td>
<td>1.10</td>
<td>8.98</td>
<td>61.77</td>
<td>0.167</td>
<td>0.322</td>
<td>0.519</td>
</tr>
</tbody>
</table>

\(^*\): Includes a constant intake from food of 0.14 µg/day.
\(^\circ\): Assuming complete absorption, \( f_1 = 1 \).

6. Conclusion

The analysis of 11 bone-ash samples gives an estimated absorption coefficient of 0.256 for uranium ingestion by infants. This is about a factor of 6 higher than the \( f_1 \) value used in the current ICRP dose coefficients for infants [6]. While this estimate is tentative, due to the small number of samples, all values are higher than the ICRP recommendation. The calculated \( f_1 \) values are sensitive to the initial uranium burdens at birth. The current study estimated the initial burdens based on measurements of only 3 stillbirth samples. Therefore, the initial uranium burden could have a large uncertainty. More samples with known records of uranium concentrations in food and drinking water should be identified, and the study should be updated with more reliable data.

References

6. International Commission on Radiological Protection, Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 5 Compilation of ingestion and inhalation dose.


