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DIETARY AND BODY BURDEN DATA AND DOSE ESTIMATES FOR LOCAL SCHOOL CHILDREN AND TEENAGERS

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September 1972

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Introduction

For a number of years workers at the Hanford plant have been routinely counted in a whole-body counter to determine internal body burdens of certain radionuclides. This program led into a project of whole-body counting of selected groups of the general population living in the area of Hanford (see Fig. 1). The study of the general population concentrated on counting elementary, junior high, and high school children. It was assumed that the plant employees constituted a representative sample of the adult population of the area.

The main sources of radionuclides in the environment are the reactors and the chemical processing plants within the confines of the Hanford plant. The old Hanford production reactors are now shut down and no longer contribute radioactivity to the Columbia River. However, this study of body burden and dose to children and teenagers can be used as a guide for other studies dealing with environmental releases and dose estimates.

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The Hanford reactors are located on the Columbia River in southeastern Washington. During their operation, water from the river was treated, pumped through the reactors for cooling purposes, and discharged back into the Columbia River. In its flow through the tubes and around the fuel elements in the reactors, the water acquired radioactive material largely formed by neutron activation of certain impurities, chemicals, and corrosion products present within the reactor. Fission products were also present as a result of fissioning of "tramp" uranium picked up on the outside of the fuel elements during their manufacture and natural uranium present in the Columbia River.

Much of the radioactivity added to the cooling water was of short half-life and rapidly decayed as it flowed downstream in the Columbia River. A few constituents were of long enough half-life to be measurable by sensitive analytical techniques as far downstream as the Pacific Ocean. The concentration of these radionuclides was never sufficient to be of concern even though the Columbia River is used as a source of drinking water by downstream communities.

It is recognized that the population in the vicinity of a nuclear facility, such as Hanford, will receive a widely ranging distribution of radiation exposure depending on their particular diets and recreational habits. Atomic Energy Commission regulations, as well as those of other Federal agencies, require that the general population exposure be kept within prescribed limits.[14,15]

This survey was designed to determine more precisely the body burdens and doses received by school children and teenagers who were exposed to Hanford-produced radionuclides, and to determine whether or not body burdens and doses can accurately be calculated from dietary data.

During the period of time of this study, 1965 to 1969, the largest part of the body burden and dose was due to reactor effluents. Gaseous effluents such as ^{131}I contributed a relatively small amount to the total dose. This is particulary true in Richland after the fall of 1963 when the city began using water from the river for domestic purposes. Before September, 1963, Richland city water was obtained from wells which had no radionuclides present.

With a knowledge of the concentration of various radionuclides present in water, milk, and various foodstuffs as provided in the Hanford Environmental Annual Reports[1-13] it is possible to determine the intake of radionuclides in human subjects when dietary information is available. The ICRP Report of Committee II on Permissible Dose for Internal Radiation[16] provides information concerning the uptake and retention of the various nuclides of interest in the human body. With these three pieces of information, i.e. concentrations, consumption, and retention, it is possible to calculate the body burden and dose due to each of the radionuclides. As a check on the adequacy of the assumptions and dietary information ^{65}Zn body burdens were measured experimental and compared to the calculated body burdens. School children

from Richland, Kennewick, Pasco and Kiona-Benton City were included in the study.

Equipment

Whole-Body Counter Description

The mobile whole-body counter[17] used for this study utilizes a 6 x 11 1/2 inch NaI scintillation crystal to detect gamma rays from radionuclides within the body. The crystal is mounted in a shadow shield assembly to reduce interference from background radiation sources. Carefully selected photomultiplier tubes with low ^{40}K content are used to further reduce background radiation levels. The whole-body counting data are sorted in a multichannel pulse-height analyzer and stored for display on an oscilloscope and recoded on either printed paper or punch-paper tape. In this study the data were first viewed on the scope and then punched on paper tape after each count. Dietary data from the survey questionnaire are coded for computer compatibility by using decade switches and an information code. These output tapes are returned to the laboratory for computer processing.

The body burden measurement requires 10 minutes for each subject followed by 2 to 3 minutes for manipulating data and punching the paper tape. Thus, in a normal 6-hour school day it was possible to count 20-25 students. The students were instructed as to the purpose of the survey and motivated to participate in it during a special presentation made to individual classes.

The quantitative measurement of radionuclides in children depends on the derivation of a suitable calibration function for the shadow-shield counter. It cannot be assumed that the calibration factors derived for standard man are applicable to children's measurements. A calibration study was conducted concurrently with the measurement of children. In the absence of a definition for a standard child we developed an array of nine phantoms for children ranging in size from 48 to 107 pounds. The phantoms were constructed of 1-pound boxes of sugar. A phantom containing no added radioactivity was first constructed on the bed of the counter and measured to provide background data. Then a phantom using sugar boxes containing known amounts of radionuclides was constructed in an identical way and measured with the counter. After subtracting background readings, the measurements were used to calculate a calibration factor for the radionuclides and phantom size used. In this way, calibration factors for each of the nine phantoms for zinc-65, potassium-40, cesium-137 and sodium-24 were derived.

These data were used to develop an empirical function relating body size to calibration factor. This function was programmed for the computer so the absolute body burden could be quickly calculated from the counting data. Linear, exponential and power functions were examined for the calibration data. The goodness of fit of functions obtained with a parameter of pounds weight per inch of height as compared to functions involving simply pounds was also evaluated. A linear correlation technique

was used for selecting the best fit for each of these functions. The calibration curves that best fit the data were exponential functions. These curves were then used to determine a calibration for each subject counted. The whole-body counter is capable of detecting a body burden of less than 1 nCi of ^{65}Zn.

Experimental Method

Diet Information

A critical part of the total study is a determination of the solid food and liquid consumption of each subject. Special questionnaires were designed for the elementary and teenage school children surveys. Different questionnaires on food consumption were used for each of the two groups of subjects, and additional information was asked from the teenagers concerning their use of the Columbia River for fishing, swimming, water skiing and picnicing. The teenagers were asked to recall the diet, while the elementary students were asked to keep a record of their diet for one week. The questionnaires are shown in Appendix A. These consumption studies for children were required because the eating habits of the children, in many cases, are vastly different than adult data. The necessary dietary information was obtained in cooperation with the local schools.

In establishing a research procedure to investigate diets and radionuclide body burdens in local children, we had to provide motivation for the schools to cooperate with us, for the parents to give permission for their children's participation, and for the children to take part in the study. A serious attempt

was made to inform the children about radioactivity and radiation along with the introduction of the program. Questions that arose were answered frankly and information concerning the measurements and the results were made available to anyone interested. Most of the school children contacted in the elementary schools (grades 1-6) participated in the study. Students from 16 elementary schools took part in the study. The total number of 1-6 graders surveyed was 5,219. For the teenage survey, 247 students in 10-12 grades were counted. At a local junior high school, 180 students in the 7-9 grades were counted.

Questions requiring evaluation by the child of the amounts of various foodstuffs consumed cannot reliably determine consumption levels for children. Instead the child was asked to keep a record of the pertinent foodstuffs consumed during a consecutive 7-day period. This record was maintained by recording each helping or cup of foodstuff consumed. Some diet records, perhaps between 1 and 2 percent, were discarded because the child obviously did not understand what was required.

About 2 weeks after the classroom discussion, the Hanford mobile whole-body counter was moved to the school and parked in a convenient location on the schoolground. It required about 1 month to count the children in each elementary school.

The raw data from the questionnaires were compiled for computer processing and are given in Appendix B along with a summary of the dietary intakes of each food listed by age and by school. For the elementary school children, the dietary data

for ages 6 through 13 appears to be statistically valid in that 50 or more subjects of each age were included. Measured body burdens of ^{65}Zn, ^{137}Cs and ^{24}Na are also given in Appendix B. Since ^{137}Cs is present due to fallout from nuclear testing, it is not included in the body burden calculation or dose estimates.

Concentrations of Radionuclides

The data for determining concentrations of radionuclides in the foodstuffs and liquids consumed by the participants in this study were obtained from the annual reports, "Evaluation of the Radiological Conditions in the Vicinity of Hanford," for the years during which the study was conducted.[1-13] For the elementary school children, data on concentrations from the years 1962 through 1968 were used. For the teenagers who were all counted in the winter and spring of 1969, concentration data from 1966 through 1969 were required.

The most important pathway in the Hanford region for radionuclides to reach the human body is the sanitary water supply system. For the city of Richland, this pathway was not important until the fall of 1963 when the municipal water supply was changed from a well system to the Columbia River. Pasco and Kennewick have drawn their municipal water from the river since before 1959. The concentrations of radionuclides in water were obtained after the water was treated in each city's facilities. Treatment in the water plant reduces the concentrations of the radionuclides by as much as 80% but does not completely remove them. For example, in 1969 ^{65}Zn was reduced by about 50% in going through the Richland treatment plant.

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Other pathways considered for this study include: commercial and local milk, commercial and local beef, vegetables and fruits, fish from the Columbia River, game birds, commercial and local eggs and poultry, and fresh seafood. Concentrations of ^{65}Zn and ^{32}P are especially high in locally grown beef because cattle in some areas eat pasture grass irrigated with Columbia River water. High concentrations of these radionuclides were also found in Columbia River fish, for which annual data from perch, crappie and bass were combined to give an annual average. Game birds have also been found to contain high levels of ^{65}Zn and ^{32}P in some cases. For the purposes of this study the concentrations found in birds within the Hanford environs were reduced to 20% to allow for mixing by uncontaminated birds. The reduction to 20% seems reasonable in consideration of the large number of birds living in or migrating through the area.

Neither commercial nor local eggs and poultry have significant ^{65}Zn and ^{32}P concentrations except for those of one local farm on the river. This particular family consumes all of its own eggs and poultry, so for this study the concentrations of ^{65}Zn and ^{32}P in eggs and poultry were assumed to be zero since the concentrations had to be applied to several thousand subjects.

The relatively high concentrations of ^{65}Zn and ^{32}P found in fresh seafoods of certain types (oysters, crab, shrimp, clams) were reduced by a factor of 10 to allow for consumption of uncontaminated seafoods and for radioactive decay between time of harvest and time of eating.

The concentrations used for the ^{65}Zn body burden and dose calculations are shown in Appendix C.

Dose Equivalent Calculations

For this study, dose due to external sources of radiation has not been considered since the focus has been the uptake and retention of radionuclides in the human body. The basic approach for calculating internal dose is to determine the intake of each radionuclide for a specific period of time, then to extend that time period to one year and to apply an appropriate dose factor. After the dose is determined for each radionuclide the total dose equivalent is obtained by summing the individual doses, as illustrated in Fig. 2. The dose equivalent and dose-per-intake factors are listed in Appendix D. Dose factors are determined for whole-body, GI tract, thyroid and bone for each radionuclide of interest. Taken into account in the dose factor are the decay scheme of the radionuclide, the energy of the radiation released, the retention in the body, and concentration in particular organs of importance.

Equations for calculation of ingestion dose factors are given below as derived by Soldat.[18]

$$(D.F.)_{\substack{\text{ingestion,}\\ \text{internal}\\ \text{organs}}} = \frac{7.4 \times 10^4 \ \varepsilon \tau f_w \ 1-e^{\frac{0.693t}{\tau}}}{m} \qquad (1)$$

$$(D.F.)_{\substack{\text{ingestion,}\\ \text{GI-LLI}}} = \frac{2.56 \times 10^4 \ \varepsilon \tau' f^* \ e^{\frac{-0.693t'}{T_R}}}{m} \qquad (2)$$

where: D.F. = Dose Factor (mrem/nCi ingested).

ε = Effective energy of the specific nuclide in the specific organ under consideration (MeV/dis).

f^* = Fraction of the materials which escape absorption in the GI tract ahead of the LLI (lower large intestine). For insoluble material $f^* = (1.0 - f_1)$ as defined by the ICRP[16] as the fraction passing from the GI tract to the blood. If (f_1) was given as 1.0 (completely soluble nuclide), then (f^*) was taken as 0.05 rather than zero.

f_w = The fraction of the ingested nuclide reaching the organ of interest.

τ = The effective half-life of the nuclide in the organ under consideration (days).

t = Length of time over which the dose is calculated (days). For the present application, t was 365 days.

T_R = Radioactive half-life of the nuclide under consideration (days).

t' = Time of travel from mouth to entrance of LLI (days).

τ' = Travel time through LLI (days).

m = Mass of the organ (grams), or mass of contents of LLI.

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The value of the parameters required for these equations were taken from ICRP Report No. 2[16] for the adult. Because of the limited data available for children, the same parameters were also used for children and teenagers. Equations (1) and (2) apply for both food and water. All nuclides in these media were assumed to be in soluble form.

Body Burden Calculations

The calculation of ^{65}Zn body burden is based on the dietary intake of each individual studied. Each case is considered separately and the appropriate ^{65}Zn concentrations, as given in Appendix C, for each of the four years directly preceding the date of the whole-body count are applied to obtain a body burden at the end of that year due to the intake for that year. The body burden determined for each of these years is decayed exponentially to the time of the whole-body count. The contribution of years prior to the fourth year before the count is negligible.

In order to compensate for changes in dietary habits as children grow older, special serving size and age ratio tables were developed.[19] These tables show the ratio of the current year's consumption to the previous year's consumption for ages from 0 to 21 years and for three previous years. The ratios were computed from dietary data for four categories: meat, chicken or game birds, fish, and vegetables. These tables are given in Appendix E.

A serving size table is provided for meat, chicken, fish and vegetables as a function of age from age 0 to 18. Persons

18 and older are considered to be adult. The serving size table is used to convert dietary data from meals-per-week to actual amounts in kilograms. This simplifies calculation of radionuclide intake since the concentrations of the radionuclide are given in terms of pico curies per kilogram (pCi/kg). Consumption of liquid is in terms of cups-per-day and is converted in the computer program to annual consumption for the dose equivalent calculation and then back to daily consumption for the body burden calculation.

Values of fractional uptake (f_w) and effective half-life (τ_e) recommended by the ICRP[16] were used for computing ^{65}Zn body burden. For ^{65}Zn, $f_w = 0.1$ and $\tau_e = 194$ days.

Results

Dose Equivalent Calculations

Two different computer programs were used for the dose equivalent calculations: one for the teenage study and the other for the elementary school children. The only significant difference is that the teenage program does not calculate bone-dose equivalent.

Except in the case of two school districts (Edwin Markham and Kiona-Benton) where the residents drink well water, the primary pathway to the human body is sanitary water drawn from the Columbia River. In most cases for elementary school children, the percent of dose equivalent due to water varies from about 50% to 99%. These data are given in Appendix D for the elementary school children and listed by food for total body, GI tract, thyroid, and bone. For teenagers the dose equivalent calculations

shown in Appendix D are listed by organ and percent of maximum permissible dose. Other tables in Appendix D show the distributions as a function of food pathway. As an illustration of the dose equivalent distribution for the water pathway, Fig. 3 is given. The average percent of the total body dose equivalent from water is 82.3 percent for the junior high teenagers and 69.0 percent for the senior high teenagers. Other foods contribute varying percentages of the dose equivalent up to about 9 percent.

The highest dose equivalent noted in all the calculations was 48.9 mrem for the GI tract, about 3.5 percent of the maximum permissible dose equivalent. All other calculated dose equivalents are smaller than 48.5 mrem regardless of the organ of interest. For the teenagers, the GI tract dose equivalent is higher than either the whole body or thyroid dose equivalent because the dose factors reflect the fact that all of the radionuclides ingested pass through the GI tract. For the teenagers the concentration of radioactive iodine in the water is less because the study was conducted in 1969 after the radioactivity in the river had declined.

For the elementary school children (mostly 6 through 12 years), the concentration of radioactive iodine in the water is higher than in later years so that the thyroid dose equivalent is higher than the GI tract or whole body dose equivalent. The whole body dose equivalent is about an order of magnitude less than the dose equivalent for GI tract and thyroid mainly because the dose factors take into account the mass of the organ of

concern, and the mass of the whole body is much larger than the mass of the GI tract or thyroid. The concentration factor for iodine in the thyroid also plays an important part. Since the concentration of ^{32}P is fairly high in most of the foodstuffs, the relatively short range beta particle contributes much more to GI tract dose equivalent than it does to the whole body dose equivalent. Other beta emitters such as ^{122}Sb, ^{64}Cu and ^{76}As also help cause the GI tract dose equivalent to be much higher than the whole body dose equivalent.

Body Burden Calculations

The computer program calculates the ^{65}Zn body burden, as described in the experimental method section, from the input data on food consumption and radioactive ^{65}Zn concentrations in the foods. Computed and measured ^{65}Zn body burdens and measured-to-calculated body burden ratios are also given in Appendix D for each individual participant in the study.

The individual ratios of measured-to-calculated body burdens vary widely over a large range for each school but in most cases the median ratios are between 0.5 and 2.5. This is considered to be good correlation for population data. In Table II the average median measured-to-calculated ^{65}Zn body burden ratio is shown as a function of age for children from 6 through 12 years of age. These data vary from 1.8 to 2.2. The fact that the average median ratio is higher than 1.0 is due mainly to concentrations of ^{65}Zn in foodstuffs too low to be measured. Since the amount of ^{65}Zn, particularly in vegetables

and fruits, were below detection limits the concentrations were set to zero. It appears that some small amount of ^{65}Zn is actually present. Other biases such as seasonal variations in river flow and radionuclide concentrations and difference in the metabolism of each person helps to account for the ratios being about 2.0 rather than about 1.0. For teenagers the median ratios of measured-to-calculated ^{65}Zn is closer to 1.0. This may be partially explained if the f_w for the younger children is really larger than for teenagers, or may be a function of questionnaire type-recall or 1 week record.

A comparison of the measured-to-calculated ^{65}Zn body burdens is given in Fig. 4 for the teenagers. Although the distributions differ for the two schools (junior and senior high schools) the median ratios are less than 1.0 in both cases: 0.47 for the junior high and 0.99 for the senior high school.

To illustrate the distributions of ^{65}Zn body burden the body burden per pound of body weight is shown in Fig. 5. For an average junior high school student who weighs 100 pounds the body burden at the time of this study was about 3 nCi, which is a factor of 2000 below the maximum permissible amount. The body burdens for the senior high students are generally a little larger but still less than one percent of the maximum permissible body burden.

Summary and Conclusions

All of the dose equivalents calculated for total body and other body organs were far below the recommended limits. The

largest dose equivalent was 3.5 percent of the limit. The most significant pathway to the human body was the sanitary drinking water drawn from the Columbia River. Other significant pathways are locally grown beef, fish from the river, and game birds. Locally grown fruit and vegetables are probably of some importance but the concentrations of radionuclides were below the detection limits of the instruments used to analyze the samples. The method for calculating the dose equivalent is adequate for adults. For children the necessary information on limits, effective half-life, and fractional uptakes is not available for most radionuclides so the adult values had to be used.

Comparisons of measured and calculated ^{65}Zn body burdens show some variations by age group. The lowest median measured-to-calculated (M/C) ^{65}Zn body burden ratio is for junior high school students, who have the highest rate of growth and food consumption. The senior high school students have a median M/C ratio of 0.99 which is excellent and which compares very well with results for adults. For elementary school children the median M/C ratios vary from 1.8 to 2.2 when averaged for age 6 through 12. These children appear to have different metabolism for ^{65}Zn than the other groups studied. It is probable that the fractional uptake (f_w) and the effective half-life (τ_e) are indeed different for children of various ages. The values of τ_e and f_w used in the study were those recommended for adults by the ICRP.

Acknowledgements

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