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# QUANTITATIVE EVALUATION OF ENVIRONMENTAL FACTORS AFFECTING POPULATION EXPOSURE NEAR HANFORD

J.F. Honstead

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BATTELLE BOULEVARD P O BOX 999 RICHLAND WASHINGTON 99352

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Battelle Memorial Institute
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Richland, Washington 99352

## ABSTRACT

Radioactivity that reaches the nearby populated environment from a nuclear installation can be usefully evaluated in terms of the resulting population dose. The combined effects of exposure to external radiation sources and internal deposition of radioactivity must be calculated for the population affected. The calculation requires analysis of a complex system of exposure pathways which are controlled by the nature of the environment, the radionuclide mix involved, and the habits, occupations, and distribution of the people affected.

The environmental evaluations performed at Hanford estimate the annual dose received by people living near the site. The estimated average whole-body dose decreased from 18 mRem per year in 1964 to 5 mRem per year in 1968 as several Hanford production reactors were shut down. Hanford radioactivity reaches populated areas by way of the Columbia River and by transport with and deposition from the atmosphere. The local population is distributed through irrigated rural areas downstream and downwind from Hanford and in downstream communities using the river for sanitary water and recreation. The diet and recreation habits of various population groups have been studied through special surveys and related to the resulting dose received by these people.

The special surveys that have been performed at Hanford are discussed in this paper and the effect of some of the findings on dose measurements is illustrated by example. These calculations provide sound bases for evaluating the possible consequences of postulated accidents and also assist in the design of a realistic environmental monitoring program.

## INTRODUCTION

The environmental evaluation performed annually at Hanford (1) involves estimates of both the average population dose and that of a critical population group. The resulting estimated dose values are evaluated against the standards established by the AEC Manual, Chapter 0524 (2). These dose estimates are concerned only with population exposure to radionuclides originating from Hanford. The studies reported here were initiated in support of this annual dose estimation procedure.

The calculation of population dose from radionuclides in the environment must include both the external dose resulting from exposure of people to radiation from radioactivity deposited in the surrounding environment and the internal dose resulting from radionuclides within organs and tissues of the affected population. The chart in Figure 1

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0027942

illustrates the steps that might be required in such a calculation. A typical populated environment receives a measured amount of radioactivity and we wish to calculate the resulting dose to a person living in the environment. The environment consists of the buildings, roadways, gardens, and houses in which the person lives and works, including the soil, air, water and vegetation composing the setting. Radionuclides deposited in or on the materials of the environment may expose the person to a certain radiation level, which depends on the composition of the radioactivity and the activity of the person within the environment.

The incorporation of radionuclides into the tissues of the person involves a complicated array of breathing and diet pathways. For example, radioactivity in water in the environment may be picked up by insects, which in turn become part of the food for chickens, resulting in some of the radioactivity appearing in eggs, which make up part of the diet of the person being studied. To calculate the dose contributed by this pathway, one must know how frequently eggs are eaten, how much is consumed each time, the concentration and composition of the radioactivity in eggs, the fraction of the radioactivity absorbed, how long the radioactivity is retained in the person's body, and to what extent various organs concentrate the radioactive material.

The calculation of external and internal dose from a mixture of radionuclides obviously becomes a complex procedure and requires a good deal of information about the physical and chemical behavior of radionuclides in various exposure pathways, as well as dietary and behavioral information about the person being studied. When one realizes that we are expected to estimate the average dose received by the population living in the vicinity of a nuclear site, it is obvious that we are faced with a formidable task. At this point, we stop referring to "Dose calculations" and instead speak of "Dose estimations." We can only use the information available together with the most logical possible estimates of missing data and arrive at best estimates of the appropriate environmental dose figures.

## HANFORD POPULATIONS SURVEYS

During the past several years, a number of special surveys of selected population groups have been made at Hanford. These surveys were designed with the needs of the environmental dose evaluation program in mind. They were intended to collect pertinent diet, demographic, and recreational data. The analysis and utilization of the resulting mass of statistics is by no means complete. We plan to report most of the results in an appropriate form to be available for others concerned with such calculations. The Hanford environment possesses the distinction of having received measurable amounts of radioactivity for an extended period of time. The radioactivity is introduced into the environment by two principle pathways: through the atmosphere from various plant stacks and through the Columbia River from reactor cooling water discharge. The latter pathway is considerably more significant than the former on an annual average. A summary of the special population surveys conducted at Hanford is given in Table 1.

The presence of measurable radioactivity in various diet pathways permitted us to use a whole-body counter in conducting the surveys. For this purpose, we used a mobile shadow-shield instrument mounted in the back of a van-like truck. We utilized schools, 4-H Clubs, state fish

0027943

TABLE 1

POPULATION SURVEYS AT HANFORD

| Date | Population Group and Survey | Group Size |
|---|---|---|
| 1960-1968 | Plant employees measured with a Hanford whole-body Counter were asked to complete a diet survey form. A computer file of diet and whole-body counting data was prepared.(3)(4) | About 7000 persons |
| 1965-1968 | Elementary school children (5-12) in 17 local schools were surveyed with a whole-body counter and a 7-day diet record card. About 75% of the students voluntarily participated in the survey. (4) | About 5500 children |
| 1969 | Teen-aged students (12-17) in a high school and a junior high school were surveyed with whole-body counter and oral diet and river recreation questions. About 50% of the students responded. | 427 Teen-agers |
| 1967-1968 | A statistically derived sampling program was used to obtain information on Columbia River fishing. Stretches of the river were visited for 4-hour periods according to a schedule derived from random selection, and the fishermen interviewed. (5) | 2,132 Fishermen interviewed |
| 1966-1969 | Whole-body counter and diet surveys were made of fishermen located at popular fishing spots on 4 occasions. | 85 Fishermen |
| 1969 | A survey using the mobile whole-body counter and oral diet questions was conducted in a local rural area using Columbia River water for irrigation. Scheduling families to visit the whole-body counter became a community service project for 7 4-H Clubs in the area. | 343 Persons |
| 1969 | Students in Home Econ. classes in 2 local schools assisted in a survey of eating habits of family members. They estimated the size of servings taken by family members during the cours of 11 meals during a 1-week survey period using handbooks containing pictures of 5 weighed serving sizes for 25 different varieties of foods. | 250 Persons |
| 1970 | A survey was conducted in 2 coastal communities located near enough the mouth of the Columbia River that Zn-65 from Hanford could be detected in local marine organisms. Both communities were centers for commercial seafood production. | 462 Persons |

0027944

and game personnel, and other existing agencies in contacting the public for these surveys. An unexpected fringe benefit obtained from the surveys was improved public relations in the areas visited.

Another important source of data needed to estimate population dose is the Environmental Evaluations Section's monitoring data which provide information on the composition and concentration of radionuclides in various foodstuffs. The sampling frequency and analyses requested are decided on the basis of experience and the significance of a particular exposure pathways. Table II shows the radionuclides measured in various foodstuffs sampled in the Hanford environment. For purposes of calculation of environmental dose, some of the foodstuffs are divided into "commercial" and "locally produced." This usually implies that the "commercial" food is that presented for sale in local markets, where locally produced foods are sold together with large amounts of imported foods. Samples may or may not contain Hanford radionuclides, depending on the particular sample. In the case of vegetables, we examine "leafy vegetables," which may include radionuclides deposited from the atmosphere and "other fruits and vegetables" which must be irrigated with Columbia River water to contain Hanford radioactivity.

## SURVEY RESULTS

As is evident from Table I, the surveys performed in this study produce data which lends itself to treatment with an electronic computer. The complete analysis of the results of several surveys is beyond the space permitted this paper so I can only illustrate the results with a few examples. The survey of "serving sizes" performed for us by members of several Home Economics classes in Richland schools provided information on food consumption levels of various age groups used in the analysis of data from many other surveys. To calculate internal dose, each person interviewed is assumed to ingest radionuclides as indicated by their reported diet and the average concentration of radionuclides in each foodstuff for the year of ingestion.

For the surveys encompassing several years of work, such as the survey of adult employees or of local elementary school children, the diet data are generally considered examples that may be used to calculate the dose distribution for any year. The length of time each person has lived in the community must be considered in the case of radionuclides with long effective half-lives in human tissue. For example, in the case of Zn-65, the accumulation over a period of at least 4 years must be considered. This means that the dose calculation should include year to year changes in the environmental concentration, any metabolic and diet changes with age in the case of the individual being considered and mean organ diameter for the age and size of the individual. We generally do not have enough data to fully incorporate all of these parameters in the dose calculations. In the examples I am reporting here, I have considered variations in the annual concentration of radionuclides and age-dependent diet considerations, but have not included age-dependent metabolic changes or mean organ diameters. The doses are calculated simply on the basis of mean organ mass and calculated body burden. Few of the surveys obtained data that permitted realistic estimates of external dose. For this reason, the external dose is usually included in the

TABLE II

RADIONUCLIDES USED IN HANFORD ENVIRONMENTAL DOSE EVALUATION

| Pathway | Nuclides | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Na-24 | P-32 | Cr-51 | Cu-64 | Zn-65 | As-76 | Sb-122 | RE+Y | I-131 | Np-239 |
| Drinking Water | X | X | X | X | X | X | X | X | X | X |
| Commercial Milk | | X | | | X | | | | X | |
| Locally Produced Milk | | X | | | X | | | | X | |
| Commercial Meat | | X | | | X | | | | | |
| Locally Produced Meat | | X | | | X | | | | | |
| Commercial Leafy Veg. | | X | | | X | | | | X | |
| Locally Grown Leafy Vegetables | | X | | | X | | | | X | |
| Other Commercial Fruit & Vegetables | | X | | | X | | | | | |
| Other Locally Produced Fruit & Vegetables | | X | | | X | | | | | |
| Columbia River Fish | | X | | | X | | | | | |
| Game Birds | | X | | | X | | | | | |
| Chicken | | X | | | X | | | | | |
| Eggs | | X | | | X | | | | | |
| Seafood | | X | | | X | | | | | |

0027946

dose summation as a single average value calculated for the entire population.

One population group that is of particular interest because of the complete array of exposure pathways available to it is the small rural population living on suburban farms supplied by irrigation water from the Columbia River. Although most of the farmland near Hanford is irrigated, only a small area receives irrigation water from below the Hanford reactors. The calculated 1969 whole-body dose averages for 3 age groups are shown in Fig. 2. The external exposure resulting from fishing, hunting, swimming, and other recreational use represents a large part of the analysis. This does not include exposure to irrigated fields, the data being too scanty to permit analysis. The unusual contribution to internal exposure from eggs probably reflects the consumption of Columbia River insects by free-running farm chickens in the vicinity of the river's edge. A similar analysis of calculated 1969 bone dose for this population group is shown in Fig. 3. Note that no external dose contribution is included in this summation. Diet information was obtained from this rural population by oral questioning of an entire family, permitting the answers by different family members to reinforce each other. The 341 included in the survey are estimated to represent about 8% of the population living in the irrigation district.

A separate questioning technique was followed to obtain recreational data from part of the people surveyed. These results were used to estimate the exposure hours per year of various age groups to the Columbia River immersion dose rate and shoreline surface dose rate. For the recreational external dose analysis shown in Fig. 4, an immersion dose rate of 0.10 mR/hr and a shoreline surface dose rate of 0.022 mR/hr (3 ft) were used. These are typical measured values for local popular swimming and fishing areas respectively. The method used to estimate external dose probably exaggerates the recreational dose but may underestimate the total external dose for this particular population group because it omits that from irrigation ditches and irrigated fields. The external dose shown in Fig. 4 agrees well with the external dose value used in the dose distribution in Fig. 2 for the case of adults, but not for children or teen-agers.

In addition to diet and recreation information, each person surveyed was measured in the mobile whole-body counter. The whole-body counter truck provided a convenient base for conducting population surveys and was a scientific attraction for encouraging participation in surveys. The whole-body count seemed to impress participants by putting their contribution on a highly personal and individual level. It permitted us to display the results and explain the source and relative significance of the various radionuclides detected. We were able to usually identify no more than four radionuclides: Na-24, K-40, Zn-65, and Cs-137. Only two of these are of Hanford origin. In most cases, the natural K-40 peak was the most prominent one detected. The measurements of Hanford radionuclides permits us to compare the measured body burdens with those calculated with our dose estimation program. Such a comparison is shown in Fig. 5. To calculate the Zn-65 body burden, an effective half-life of 160 days and a fractional uptake of 32 percent was used. These values were measured at Hanford during a fish consumption experiment some time ago (7). The fractional uptake value used is about three times that

that recommended by ICRP (8), and the comparison in Fig. 5 tends to indicate that our value is too high. If a fractional uptake of 10% were used, the values of the measured to calculated Zn-65 ratio would be distributed much closer to 1.0. As a matter of fact, the data can be used to calculate a best fit value for fractional uptake. Of course, any other sources of variances in the data would also appear in the calculated values for fractional uptake.

The fractional uptake calculation was attempted for the case of survey data from a coastal population. Here the pathways were relatively simple, being limited to locally produced seafood. Using a least-squares regression analysis, it was possible to calculate the best fit values for fractional uptake for each of four types of seafood. The data indicate a Zn-65 fractional uptake of 2.4% for oysters, 11.1% for clams, 6.7% for crab and 16.6% for shrimp. These differences may be caused by a specific activity effect.

## CONCLUSIONS

Hanford population survey data include diet information, recreation habits, and whole body counter results. Analysis of the results of such surveys may be used to (1) permit improved population dose estimates, (2) assist with operational problems associated with non-standard operating conditions, (3) guide the design of the environmental monitoring program, (4) contribute to improved public acceptance of the nuclear facility, and (5) contribute to basic information concerning human uptake of radionuclides from the environment.

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FIGURE CAPTIONS

1. Dose Calculations - People Living in an Environment Having Trace Amounts of Radioactivity.
2. Sources of Environmental Whole-Body Dose from Hanford - 1969 - Rural Population.
3. Sources of Environmental Bone Dose from Hanford Rural Population - 1969.
4. External Exposure from Hanford Radioactivity from Recreational Use of the Columbia River.
5. Comparison of Measured and Calculated Zn-65 Body Burdens - Rural Population Survey.

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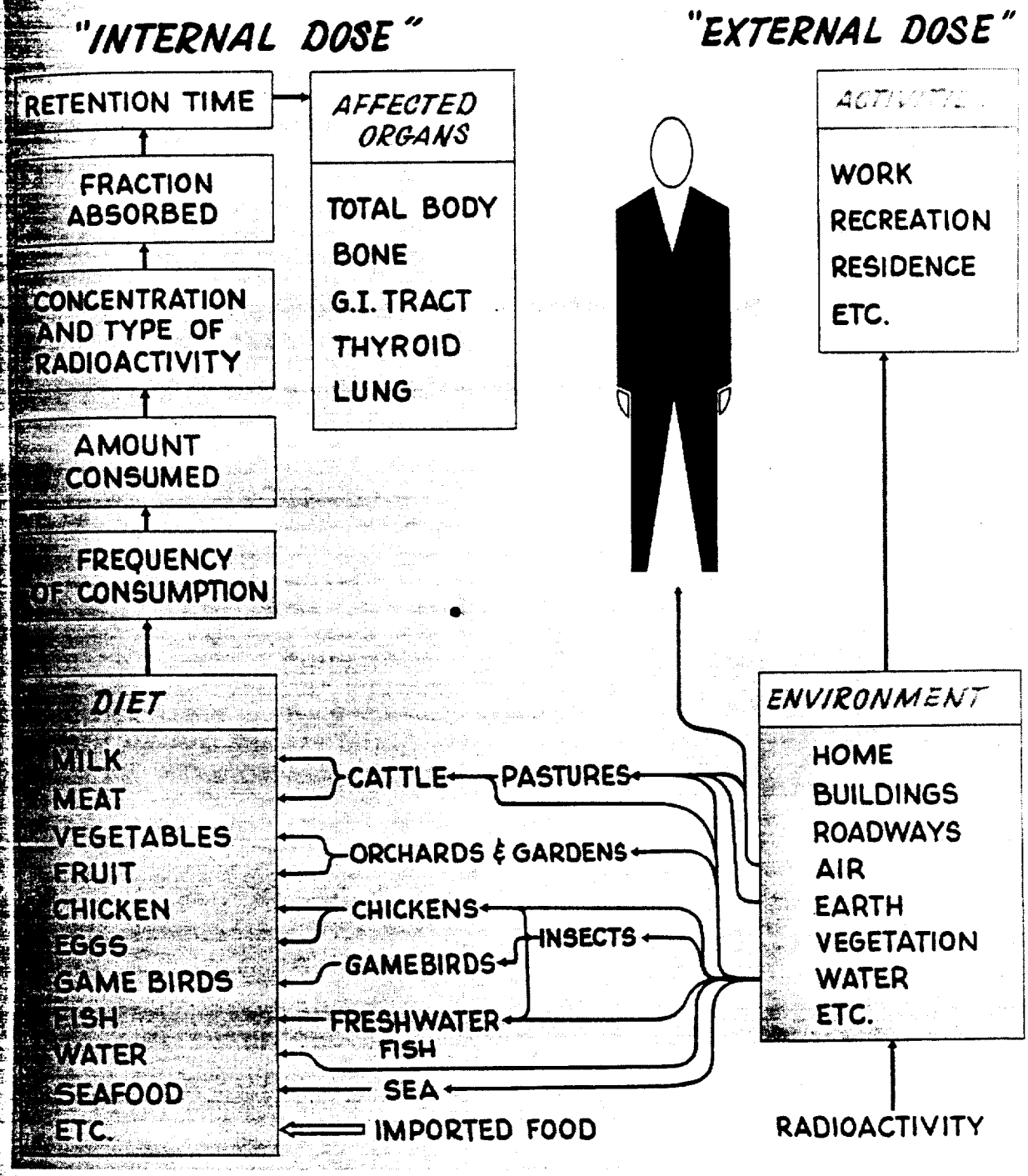
# DOSE CALCULATIONS
# PEOPLE LIVING IN AN ENVIRONMENT CONTAINING TRACE AMOUNTS OF RADIOACTIVITY

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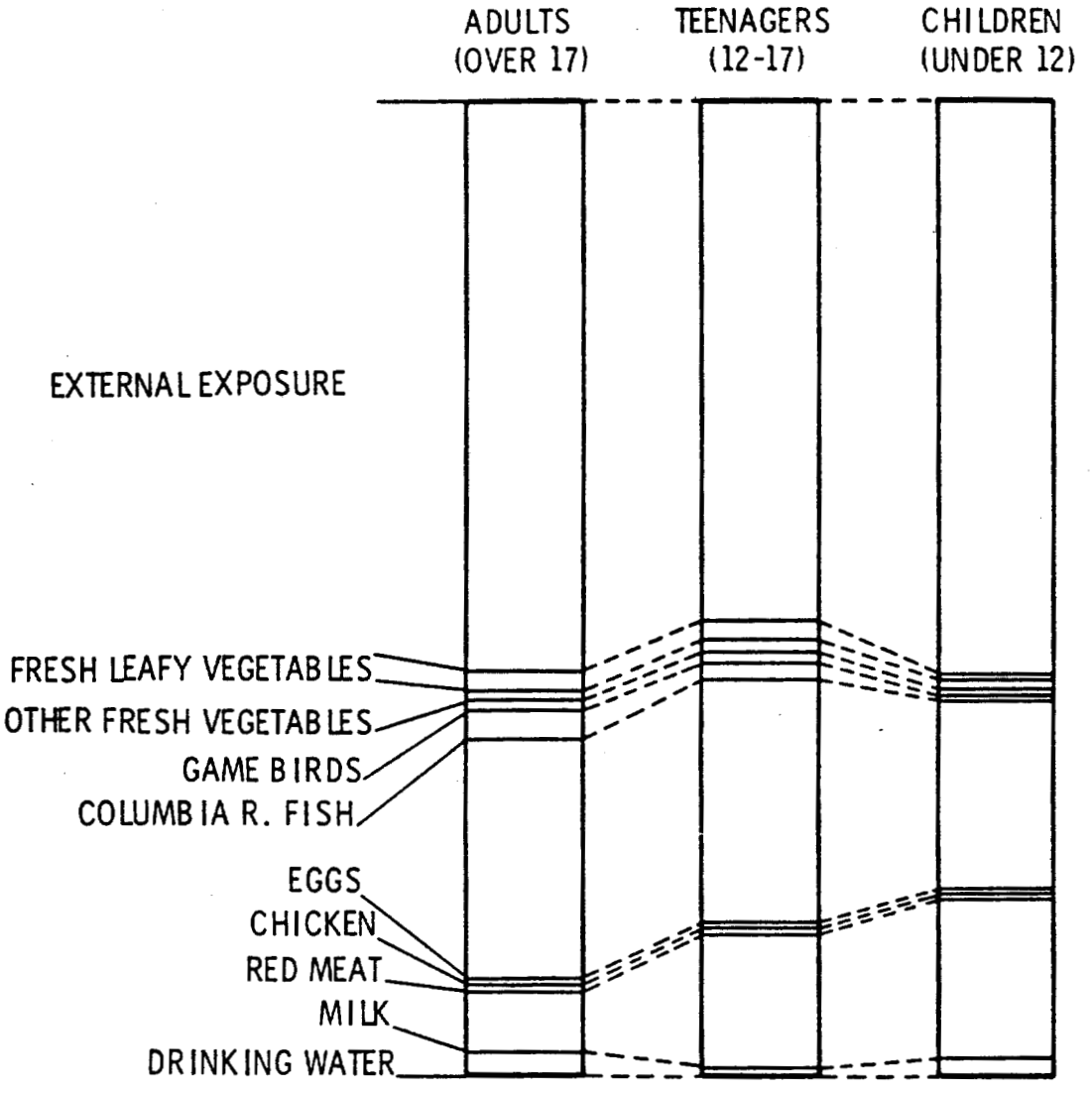
# SOURCES OF ENVIRONMENTAL WHOLE-BODY DOSE FROM HANFORD RURAL POPULATION – 1969




| | ADULTS (OVER 17) | TEENAGERS (12-17) | CHILDREN (UNDER 12) |
|---|---|---|---|
| NUMBER OF PERSONS | 166 | 83 | 92 |
| AVERAGE PERCENT OF PERMISSIBLE DOSE (170 mRem/YEAR) | 1.20 | 1.59 | 2.91 |
| MAXIMUM INDIVIDUAL PERCENT OF PERMISSIBLE DOSE (500 mRem/YEAR) | 1.14 | 2.07 | 2.57 |

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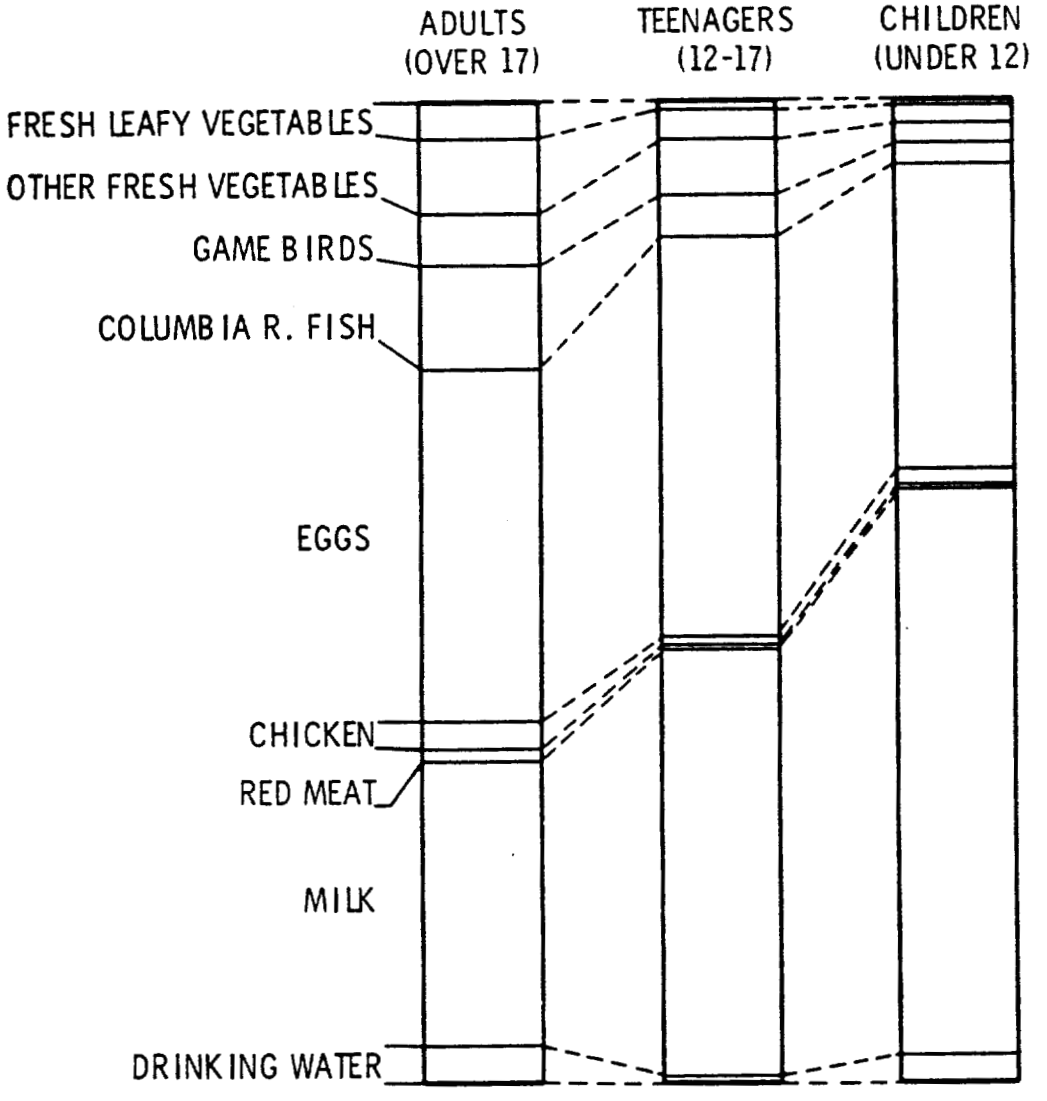
# SOURCES OF ENVIRONMENTAL BONE DOSE FROM HANFORD RURAL POPULATION – 1969




| | ADULTS (OVER 17) | TEENAGERS (12-17) | CHILDREN (UNDER 12) |
|---|---|---|---|
| NUMBER OF PERSONS | 166 | 83 | 92 |
| AVERAGE PERCENT OF PERMISSIBLE DOSE (500 mRem/YEAR) | 1.11 | 1.71 | 2.52 |
| MAXIMUM INDIVIDUAL PERCENT OF PERMISSIBLE DOSE (1500 mRem/YEAR) | 2.19 | 3.83 | 3.79 |

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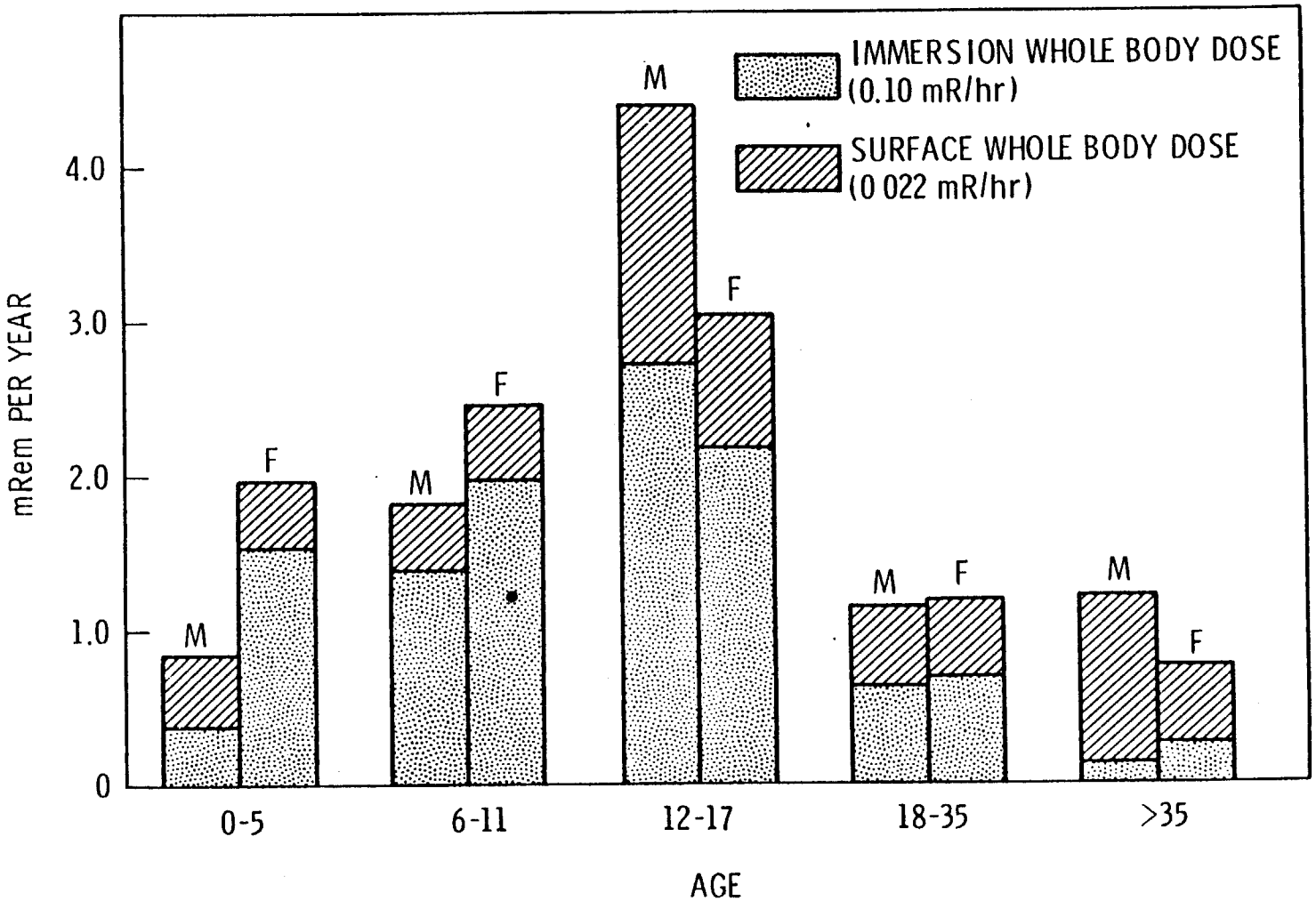
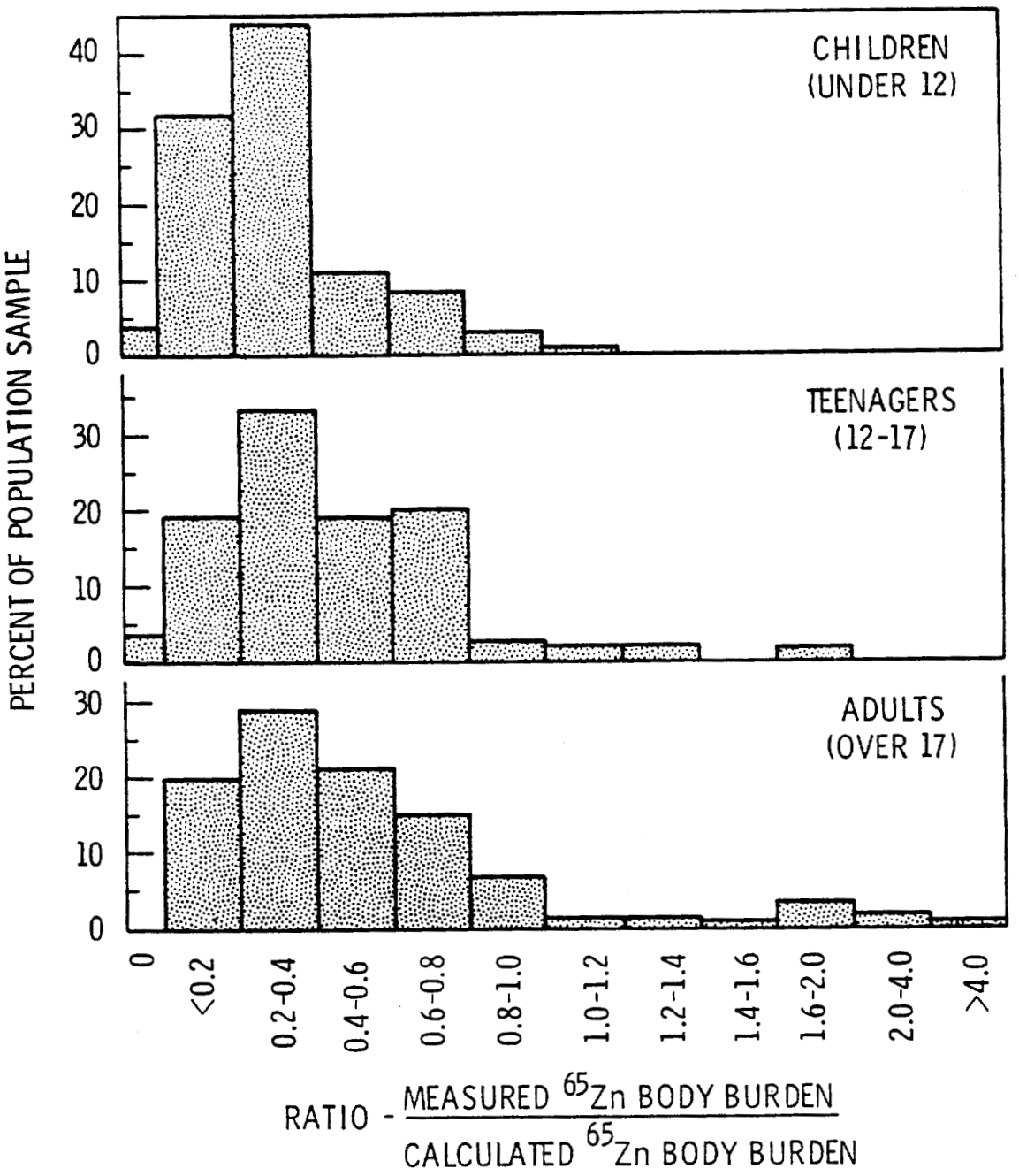
# EXTERNAL EXPOSURE FROM HANFORD RADIOACTIVITY FROM RECREATIONAL USE OF THE COLUMBIA RIVER



## COMPARISON OF MEASURED AND CALCULATED $^{65}Zn$ BODY BURDENS – RURAL POPULATION SURVEY