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EVALUATION OF THE EXPOSURE THAT RESULTS FROM THE DISPOSAL OF RADIOACTIVE WASTES INTO THE COLUMBIA RIVER

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R. F. FOSTER, J. K. SOLDAT

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EVALUATION OF THE IMPACT THAT RESULTS FROM THE DISPOSAL OF RADIOACTIVE WASTES INTO THE COLUMBIA RIVER[1]

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INTRODUCTION

The release of radioactive materials to the public domain must always be accompanied by an evaluation of the potential impact of the materials on the environment and especially on man. Where very small releases are involved, relatively simple calculations may be sufficient to show that the potential impact is negligible. Larger releases may require more sophisticated evaluation and reference to a variety of individual standards. Exposure evaluation for the (Hanford) atomic energy facilities near Richland, Washington is based on a comprehensive environmental surveillance program and reference to standards (or recommendations) published by the International Commission on Radiological Protection (ICRP)[1], the National Committee on Radiation Protection and Measurement (NCRP)[2], and the Federal Radiation Council (FRC)[3]. Since the plan was initiated prior to the start-up of the first reactor in 1944, the findings have been reported at regular intervals [4, 5, 6, 7].

Many of the observations made during the early years indicated that radionuclides released to the environment could potentially expose people living near the plants by a variety of pathways -- several of which were associated with the Columbia River. Recognition of the existence of these pathways has substantially influenced the scope of the routine surveillance program and has prompted special studies of the characteristics of the pathways. In view of the several possible sources

[1] This paper is based on work performed under U. S. Atomic Energy Commission Contract AT(45-1)-1830.

of exposure, our evaluations of the [illegible] on the environment [illegible] as a frame of reference, [illegible] dose received by people. This allows [illegible] significant environmental sources of [illegible] cations that are implicit in secondary standards such as "[illegible] permissible concentrations" in air or water.

EXPOSURE PATHWAYS FROM THE COLUMBIA RIVER

Sources of Radionuclides

The Single-Pass Reactors[2]

The use of Columbia River water to cool the [illegible] reactors has been described on several past occasions [illegible] brief review may be appropriate here because of the [illegible] ance to exposure pathways. Columbia River water, [illegible] ment, is pumped through the fuel channels of the reactors to remove the heat generated by the fuel elements. After a single pass through the [illegible] of the reactors, and brief retention in tanks or basins, the effluent water is discharged back into the Columbia River. The neutron flux of the reactor core activates a great variety of nuclides present in the cooling water and on the surfaces of the fuel channels and elements. These activation products, most of which are short-lived, are carried out of the reactors with the effluent water. Relatively small amounts of fission products are also present, partly because of occasional failures of the aluminum jackets of the fuel elements, but mostly because of the fissioning of natural uranium present in the Columbia River water.

After dilution with the flow of the Columbia River [illegible] trip from the reactors to the vicinity of Richland, the relative [illegible] of the more significant radionuclides in the river is about as follows: Chromium-51 is responsible for nearly half of the radioactivity; [illegible] ^{239}Np, ^{76}As, and ^{32}P together make up most of the remainder. [illegible] accounts for about one percent, ^{65}Zn about two percent, and [illegible] less than one percent. A variety of other nuclides released from the reactors are also present in the Columbia River [6, 7, 9, 10], but their importance to human exposure is comparatively insignificant.

Natural and World-Wide Fallout

As in all surface streams of the North American Continent, the

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[2] The last reactor constructed at Hanford (N-R) has a recirculating primary cooling system and contributes little to the radionuclide content of the river. It is not considered here.

Columbia carries a small burden [illegible] mineral deposits in the drainage [illegible] These nuclides are present in [illegible] river water above and below the [illegible] human exposure is either negligible [illegible] can be classed as natural background. [illegible] 1 μg/liter -- lower than many other [illegible] nificance in the formation of [illegible] through the cores of the reactors with the cooling water. [illegible] tions of ^{3}H and ^{90}Sr are respectively about 4,000 pCi/liter and [illegible]

Chemical Processing Plants

Chemical processing of the irradiated fuel elements [illegible] duction reactors results in some waste (intermediate level) [illegible] in the ground [9, 11]. Although most of the radionuclides, [illegible] and ^{137}Cs, are effectively retained near the point of [illegible] ^{106}Ru do seep through the soil column and enter the [illegible] the past two decades the ^{3}H and ^{90}Sr have moved with the ground water [illegible] more than ten miles toward the Columbia and can now [illegible] in the water of test wells adjacent to the river. The presence of these nuclides in very low concentrations in the water of the river is expected, but not confirmed because of the relatively greater [illegible] other nuclides already present in the river from other [illegible] bution of liquid wastes from the chemical processing plants to radiation exposure associated with the Columbia River is negligible.

Exposure from Drinking Water

The cities of Richland, Kennewick and Pasco, situated [illegible] about 30, 37 and 40 miles downstream from the production reactors, [illegible] derive their water from the Columbia River. Richland and Kennewick [illegible] the water by alum flocculation and rapid sand filtration. [illegible] the water from collectors placed beneath the bed of the river. The municipal water treatment plants reduce the concentrations of most of the [illegible] nuclides to less than half of their concentrations in the raw river water. Further, certain nuclides are much more important than others in relation to the dose delivered to persons who drink the water. Of the several "critical organs" for which dose estimates are made, the gastrointestinal tract is the one that receives the greatest exposure from the radioactive nuclides present in the water. In 1965 the average adult drinking 1.4 liters of water from the Richland supply each day received an estimated [illegible] rem to the GI tract. About one-third of this exposure was from [illegible], about one-third from ^{76}As, and most of the remainder was from [illegible]. The ^{131}I content of the water could have delivered an estimated 20 rem to the 2-gram thyroid of infants that drank 0.4 liters of the water daily throughout the year.

Pasco is several miles [illegible] from the [illegible] is required for the water to [illegible] the [illegible] Because of the additional time available for the [illegible] concentrations of the short-lived radioisotopes, such as ^{56}Cu and ^{24}Na, are lower in the Pasco water than at the [illegible] estimated dose to the GI tract in Pasco is relatively low (about [illegible] during 1965). The Kennewick water, obtained from the collector [illegible] beneath the river, has even lower concentrations of radionuclides.

Exposure from Columbia River Fish and Shellfish

Fish that live in the river below the reactors [illegible] small amounts of virtually all of the radionuclides present in the [illegible]. The only ones that accumulate in the fish flesh in appreciable [illegible] however, are ^{32}P and ^{65}Zn. Many of the most abundant nuclides in the river water are too short-lived to achieve any appreciable [illegible] in the fish, and others, such as ^{51}Cr, tend to be rejected by [illegible] of the food chain and thus do not concentrate in the fish.

In order to accumulate appreciable amounts of ^{32}P in the fish, the fish must feed for several weeks on organisms that have concentrated these nuclides. Thus, only the fish that are resident in the river below the reactors have significant amounts of them. The half-life of ^{32}P is comparatively short (14 days) and thus the concentration of ^{32}P in the fish diminishes quite rapidly whenever the fish slacken their rate of feeding. This results in substantial seasonal variations in the ^{32}P content of the fish [6]. For example, during 1965, the ^{32}P concentration in fish flesh was about ten-fold higher in October than in March. Because of such large variation, estimates of the quantities of this nuclide ingested by the people who eat the fish must consider the seasons of the year when fishing is most popular. Seasonal variations also occur in the concentration of ^{65}Zn ($T_{1/2}$ = 245 d) in the fish, but the range for this nuclide is only four-fold.

Fishing on the Columbia River is permitted throughout the year both above and below the region of the reactors. In the vicinity of Ringold, some 20 miles below the reactors, fishing for steelhead trout and whitefish is popular. Further downstream, in the backwaters of McNary Dam, large numbers of spiny-rayed species (such as bass, perch, and catfish) are caught. The fish that are caught from the Columbia River in the vicinity of the Tri-Cities are taken only by sportsmen for their personal use. Commercial fishing (for salmon) does not occur within 100 miles of the Hanford reservation.

With the assistance of the Washington State Game Department, considerable effort has been spent in determining upper limits for the consumption of locally-caught fish. A very few individuals think that

during a year they may eat as many as [illegible] the Columbia River. Therefore, this consumption [illegible] basis for dose estimates. In light of the effect of the [illegible] these 200, somewhat hypothetical, people could have [illegible] to provide about 10 percent of the [illegible] bone seekers, and, in combination with the [illegible], a dose to the body of about 20 mrem. The local [illegible] pathway of exposure for the [illegible] larly in substantial amounts. [illegible] as the salmon, that enter the Columbia River [illegible] grounds, do not contain enough radioactivity to [illegible] these dose evaluations. Line-5 and some [illegible] Columbia River water at the mouth and can be measured in [illegible] as oysters, harvested from adjacent areas of the Pacific Ocean. [illegible] small contribution that such shellfish can make to our [illegible] posure is also included in our evaluations.

Migratory waterfowl (ducks and geese) [illegible] River for at least a few days and feed on aquatic life [illegible] of the radioactive materials present downstream from the [illegible] The "resident" ducks that feed on the river may [illegible] actually accumulate concentrations of ^{32}P and ^{65}Zn [illegible] with those in the resident fish. However, as a potential [illegible] these radionuclides to people, the waterfowl are of less significance than the fish because they cannot be harvested in such large numbers individuals and because of "dilution" by the large flights of migrant birds that move through the region at the time of the year when hunting is allowed.

Exposure from Irrigated Farms

The southeastern portion of the State of Washington is a [illegible] region with extensive agricultural areas under irrigation. The vast majority of the irrigated land receives water that is diverted from the Columbia River at Grand Coulee Dam, some 145 miles upstream from the Hanford reactors or from the Yakima River -- a tributary that enters the Columbia at Richland. The amount of land that is irrigated with water pumped from the Columbia River downstream from the Hanford reactors is quite small. At Ringold, there are a few small farms that are irrigated with water pumped from the river [13]. Fruit is the principal product of these farms, but the farmers do have a few cows to supply their personal needs. Between Richland and Pasco is the Riverview farm area (about 5,300 acres) that is also irrigated with Columbia River water. Much of this area is actually a suburban-type development with some family gardens. The larger farms are devoted principally to hay, fruit, and beef, but some dairy farms are also present. The water pumped from the Columbia River

to irrigate the Ringold and Riverview [illegible]
radionuclides present in the river [illegible]
and relatively long-lived, ^{32}P and [illegible]
products in sufficient amounts to [illegible]
who drinks about one liter of milk [illegible]
garden in season, and eats about [illegible]
home-raised beef, could have consumed during 1965 [illegible]
about [illegible] percent of the maximum permissible dose of [illegible]
bone as the critical organ. The [illegible] ^{32}P and [illegible] would have contributed an estimated 6 mrem to the total dose.

Direct Exposure from the River and Shore

Some of the short-lived activation products present in the [illegible] decay with the emission of hard-gamma radiation, and can deliver an external dose to people that are in, or very near, the river in the vicinity of the Hanford project. Because this exposure component is [illegible] external source, it can be estimated more accurately from direct [illegible] measurements than from computations based on concentrations of the [illegible] nuclides present. Three different sets of [illegible] exposure [illegible] dose estimates: (a) swimming (total immersion dose), [illegible] relatively few people in the Tri-City area during the months [illegible] August and September, (b) boating and water skiing (partial immersion) [illegible] that includes a significant number of people -- mostly during the [illegible] of June through September, and (c) fishing (either dose from the river bank or semi-immersion dose if in boats or wading), [illegible] significant number of people during the summer and fall but very few individuals throughout the entire year.

The dose rates encountered by swimmers in the vicinity of Richland, (total immersion), were in the range of [illegible] to 190 [illegible] hour during 1965. A very ardent swimmer, spending as many as [illegible] in the river during the summer, could have received as much as [illegible] for the year. The ardent boaters and water skiers would have [illegible] less than half this amount. The potential dose to people who [illegible] the shore in the vicinity of Ringold is complicated by diurnal [illegible] tion in the level of the river that result from the regulation by [illegible] dam above the Hanford reservation. The dose rate at the [illegible] Ringold during 1965 was lowest during the freshet in June [illegible] per hour) and highest during hours of low river flow in the [illegible] (100 μR per hour). Recent measurements of the gamma spectrum made with portable equipment indicate that ^{65}Zn accumulated by algae growth on the substrait at the river's edge is responsible for a major proportion of the dose delivered to fishermen. If one assume that a fisherman spends as many as 500 hours a year on the river bank, his total dose could amount to about 15 mR.

EXPOSURE PATHWAYS FOR [illegible]

Evaluation of the total [illegible] neighborhood of the Hanford [illegible] contributions from pathways that [illegible] from the river. The chemical processing plants are the [illegible] source of airborne radionuclides [illegible] and most of the release is associated with [illegible] lution of the irradiated fuel elements. [illegible] removes nearly all of the airborne material before the [illegible] 200-foot stacks that discharge it to the atmosphere. [illegible] of the radioactive material released consists of [illegible] but other [illegible] fission products, such as ^{141}Ce and ^{144}Ce, [illegible] are also present. Tritium and noble gases are also released [illegible] contribution to exposure is negligible.

The ^{131}I released from the Hanford plants (which [illegible] about 0.3 curies per day during 1965) [illegible] with fallout materials from nuclear tests only [illegible] same exposure pathways. In the absence of [illegible] tests, ^{131}I from the Hanford plants can [illegible] milk from local farms in concentrations of a few picocuries [illegible]. In 1965 consumption of milk from the nearest farms [illegible] liter per day could have resulted in a dose of about [illegible] thyroid of a small child. This is substantially less than [illegible] to have resulted from the drinking water available to [illegible] during 1965.

Virtually all of the strontium and cesium in [illegible] City area comes from world-wide fallout. The contribution [illegible] Hanford plants is negligible. The concentrations of these fission products in local farm produce is usually below the [illegible] because of the very low rainfall in the Hanford area. The intake of ^{90}Sr from all foods during 1965 is estimated to be about [illegible] per day and the total body dose from ^{137}Cs to be about [illegible] mrem.

EXPOSURE EVALUATION

About 80,000 people live near the Hanford project -- either in the Tri-Cities or in the agricultural area nearby. Because of the variety of foods and beverages available to these people, the [illegible] amounts of radionuclides they contain, and because of [illegible] sites and recreational preferences, no two individuals have probably the same intake of radionuclides or encounter quite the same radiation exposure. The residents of Richland take in more radionuclides with their drinking water than do the residents of Pasco or [illegible], while the inhabitants of the agricultural areas, who derive their water from wells, receive virtually no exposure from their drinking water.

A major proportion of the milk consumed in the vicinity of Hanford is produced in this section of the state, but most of the [illegible] is used by the large market in the cities in the [illegible] area. Thus, the routine consumption of fluid dairy milk from the Columbia River and the heavy consumption of local farm produce tend to be mutually exclusive events. Some city dwellers do have backyard vegetable gardens, however.

Although fishing is a popular recreation in the vicinity area, only a small fraction of the total population actually catches and eats fish that inhabit the Columbia River downstream from the Hanford. The individuals that do catch substantial numbers are not always the same ones that spend a major part of their personal time fishing or hunting, but they can be residents of any of the local cities or towns. Assessment of the intake of nuclides with the consumption of local fish is especially complex because the quantity of fish consumed by individuals ranges from zero (many fishermen do not like to eat fish) to several meals a week at times when fishing is especially good.

So many possible combinations of the various exposure pathways are possible, that the general population in the vicinity of the Hanford plants cannot be considered to be "homogeneous" in respect to the "average" dose received as a result of plant operations. Most individuals acquire radionuclides that are transported by the Columbia River only via the drinking water supplies of the cities of Richland, Pasco, and Kennewick, but a very few individuals acquire much greater quantities of ^{32}P and ^{65}Zn from local fish and waterfowl.

Some appreciation of the variation in the intake of radionuclides from the Hanford plants that occurs among local residents can be gained from the amounts of ^{65}Zn actually found in people by whole-body counting. Zinc-65 provides a reasonably good index of the intake of all types of radionuclides transported by the river because: (a) the abundance in river water is relatively constant and it can be measured quite accurately, (b) it appears to be concentrated by all of the significant food chains and is readily measurable in fish, waterfowl, irrigated crops, milk and animal products even when other nuclides of Hanford origin are not detectable by conventional procedures, (c) following ingestion by people, it remains in the body long enough so that repeated intakes result in a gradual accumulation and therefore its presence and significance will not be missed even if the whole-body count is delayed for several months, (d) its 1.11 MeV photons are easily "seen" by whole-body counters. The routine whole body counting of people at Hanford from 1959 through 1964 has provided nearly six thousand observations on the body burdens of ^{65}Zn. Most of these observations are for plant employees but, with minor exceptions, their ^{65}Zn burdens resulted from

environmental rather than on-plant sources. [illegible] individuals who live on irrigated farms as well as for the farming, and of course, many people who catch and eat fish. [illegible] the ^{65}Zn body burdens were distributed in this broad sense.

A sophisticated interpretation of Figure 1 is not appropriate because several sub-populations are included in the data. Nevertheless, several significant features are apparent. [illegible] burdens of ^{65}Zn are less than 10 nCi, but [illegible] are predictable on the basis of drinking water alone. [illegible] that only about 5% of the people that received whole-body counts had significant intakes of waterborne nuclides from sources other than their drinking water. The proportion of the people that had ^{65}Zn burdens greater than 50 nCi was less than 0.5 percent, yet a body burden of 50 nCi could have been acquired by eating only about one meal of fish caught locally from the Columbia River. The highest body burden of ^{65}Zn associated with environmental sources was observed in 1971 and this resulted from the deliberate eating of local fish at a rate approximating one meal each week. These observations indicate that, at least for the Hanford case, a few individuals who live nearby receive at least 10 times as much exposure as most of the people. [illegible] the use of rational assumptions that maximize the potential dose, one can postulate that some individuals could receive on the order of 50 times the "average" exposure.

Because of the wide difference between the exposure received by most people who live in the environs of the Hanford plant and the very few individuals that receive the greatest exposure, [illegible] questions arise concerning the choice and application of [illegible]. The use of some "average" exposure for any significant number of people fails to call attention to the much larger exposure received by the few. On the other hand, the magnitude of exposure received by the very few certainly should not be viewed as characteristic of the vast majority. In order to satisfy both conditions, two separate dose estimates are made; one is for a representative population -- and for this [illegible] characteristics of a "typical" resident of Richland are used; the other is for a hypothetical individual whose place of residence and personal habits result in the highest exposure that is rational.

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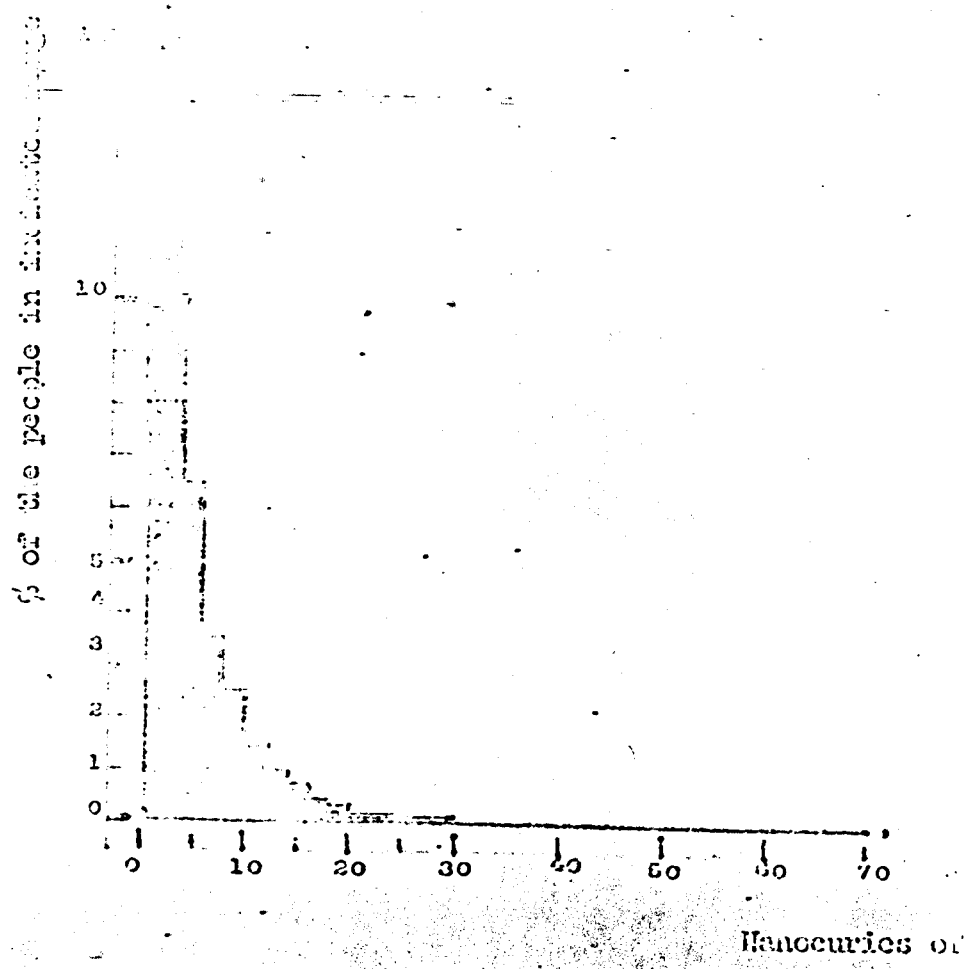
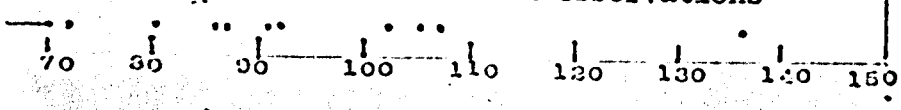
[3] The maximum permissible body burden of ^{65}Zn specified by the NCRP [illegible] for Group B(c) is 6000 nCi.


% of the people in the
10
5
4
3
2
1
0
0
10
20
30
40
50
60
70
Nanocuries of

Distribution of [illegible] of ^{65}Zn
Along Horizontal of the Reducing Axis

Sample Size = 5900

Individual observations



curies of ^{65}Zn

Exposure of the "Maximum Individual"

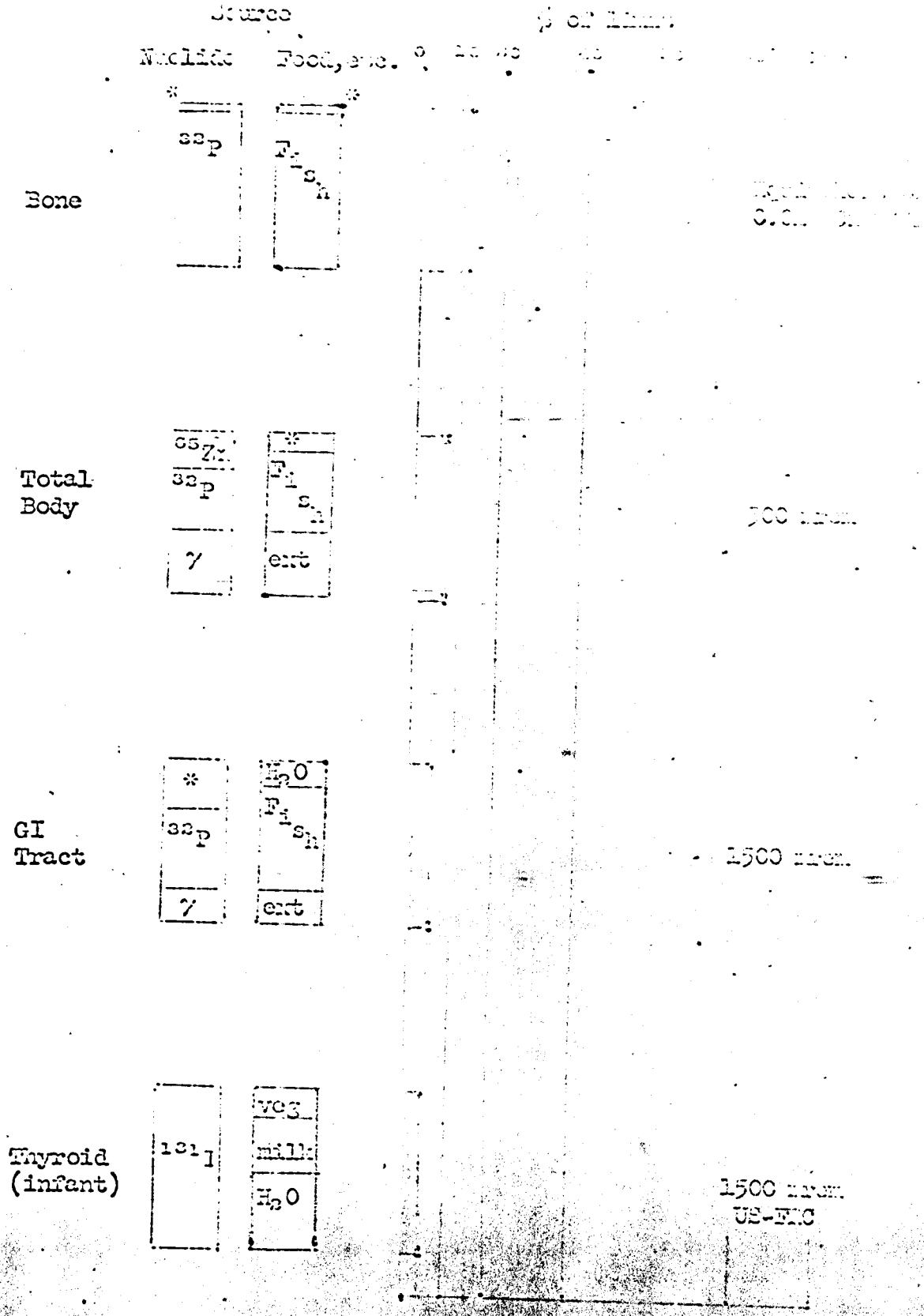
Because of the concentration of ^{32}P by salmon the river with the "maximum individual" will be a person who eats large quantities of fish that he catches by fishing from the shore down river from the reactors. Two or three fishermen have been identified who claim to eat as many as 200 meals of locally-caught fish each year. Although the whole-body counts of ^{65}Zn burdens indicate that such a consumption rate is undoubtedly a gross exaggeration, this rate has been used as a basis of computation. In order to further maximize the estimated exposure of the individual who eats the largest amount of fish, he is assumed to live in the Riverview Irrigation District and at the edge of Pasco so that he can drink water from the municipal supply, eat produce from a garden irrigated with river water, and drink milk and eat meat from cows grazed on irrigated pasture. Maximizing assumptions are also used for the quantities of such foods consumed.

Following the selection of a set of dietary and living habits that characterize the "maximum individual", the annual dose to various organs can be calculated in a relatively straight forward manner from environmental surveillance data on the concentrations of various nuclides in local foods and beverages. Figure 2 shows the results of these calculations for 1965 with reference to the ICRP standards for "Members of the Public Living in the Neighborhood of Controlled Areas" [Group 3 (c)].

The ^{32}P from fish is responsible for nearly all of the dose to bone but milk and other farm products also contribute. During 1965 the estimated intake of ^{32}P by the maximum individual amounted to about 12 percent of the ICRP limit which uses ^{226}Ra as a reference base. Zinc -65 also provides some dose to the bone, but its contribution is very small in relation to that from the ^{32}P. If the consumption of ^{90}Sr from fallout were included, the combined intake of bone seekers would amount to about 14 percent of the limit for 1965.

Most of the dose to the total body from ingested nuclides also results from the ^{32}P but the ^{65}Zn is of considerable importance in this case. Besides the dose from the internally-deposited emitters, the estimated 15 mR of direct exposure from the river and shoreline is included here. The combined dose amounts to about 35 mrem which, as indicated in Figure 2, is about 7 percent of the limit. More than half of the estimated dose to the gastro-intestinal tract also comes from ^{32}P consumed with fish, but significant contributions also come from drinking water, farm produce, and the direct external gamma. The total estimated dose to the GI tract of this "maximum individual" during 1965 amounts to about 80 mrem or about 5 percent of the limit.

Dose Received by "Maximum Individual" - 1965



The thyroid gland requires [illegible] is not the thyroid of an adult [illegible] dose, but rather that of an infant. [illegible] atomic explosions in the atmosphere, the air [illegible] to the greatest exposure, but in 1965 this pathway was of [illegible] less importance than the drinking water of Richland and [illegible]. [illegible] infants with 2-gram thyroids, a maximum exposure of about [illegible] estimated for 1965. This amounts to about 4 percent of the limit.

Exposure of the Typical Richland Resident

As mentioned earlier in this paper, the observed [illegible] in most Richland residents are so low that drinking water can be the only significant source of river transported nuclides to the "typical" resident. On this basis, dose estimates for various critical organs have been made and these are shown in Figure 3. Because a relatively large number of people are represented, the reference limits are taken as one-third of those recommended for individuals.

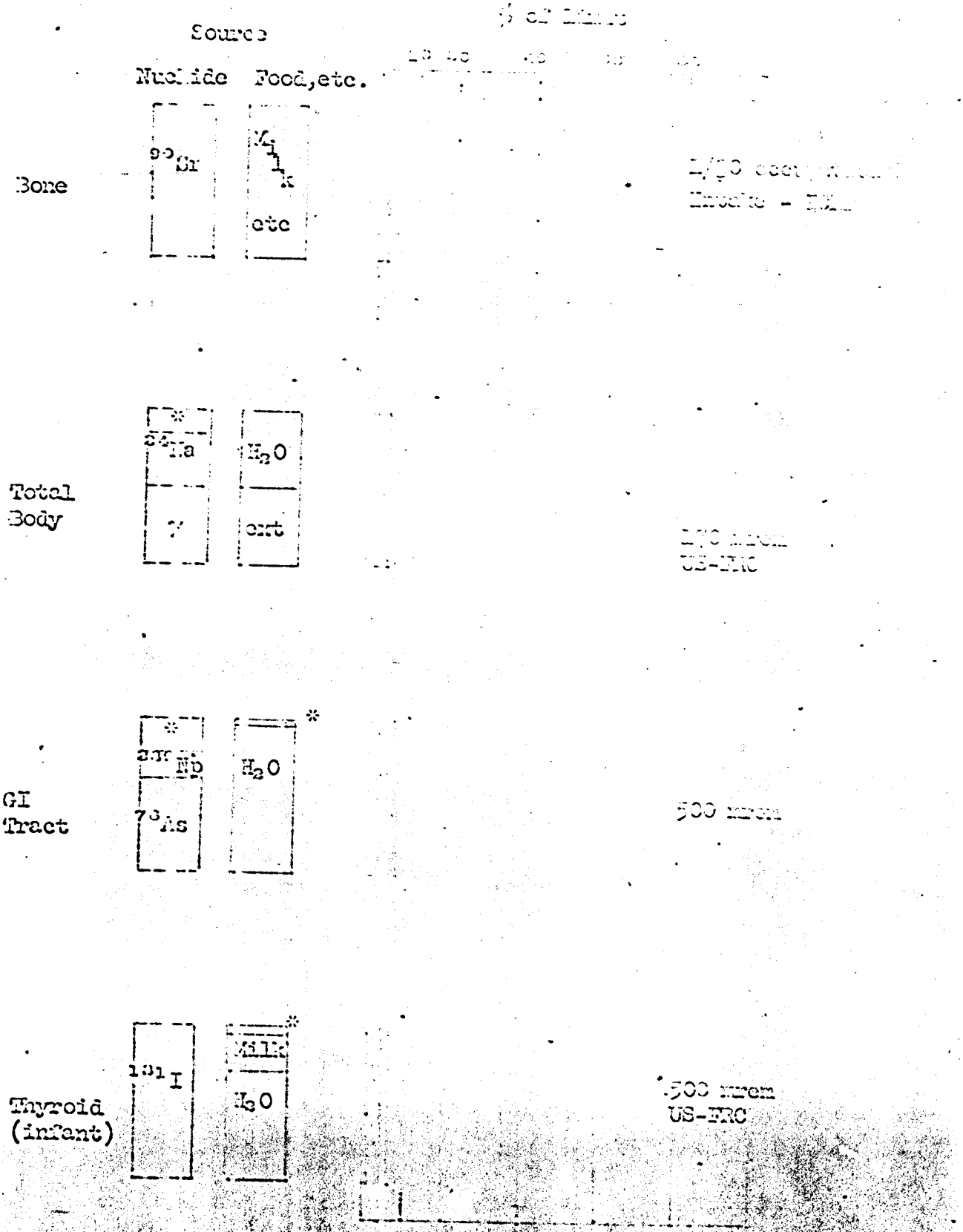
The quantity of ^{32}P consumed with drinking water is so small that it amounts to less than one percent of the limit for bone. In this case, ^{90}Sr from fallout is a much more significant source of exposure. Similarly, the total body dose from the drinking water is very small -- perhaps 2 or 3 mrem in 1965. In recognition of the popularity of water sports in the Tri-City Area, some exposure directly from the river should probably be included in the combined total body dose. For the typical resident, this is taken as 2 mr, although many ardent water skiers would acquire substantially more than this. The estimated combined dose to the total body of 5 mrem in 1965 is about 3 percent of the limit.

The gastro-intestinal tract receives appreciably more exposure than the bone or total body because of the abundance of short-lived and biologically inert nuclides in the drinking water. The annual dose for 1965 is estimated to be about 35 mrem which is equivalent to 7 percent of the limit. This estimate is based on samples taken at the water treatment plant. Since appreciable radioactive decay of the short-lived nuclides occurs during transit through the city's water mains, the actual dose received by Richland residents is lower.

The presence of ^{131}I in the drinking water can provide some exposure to the thyroid gland and this will be greatest in infants because of the small size of the gland in proportion to the quantity of water consumed. The same individual will also take in some ^{131}I with milk and leafy vegetables but, in 1965, drinking water was the dominant source. The total dose for the year from all sources is estimated at 30 mrem for a 2-gram thyroid, which is 6 percent of the FRC limit.

Figure 3

Dose Received by "Typical" Maximum Individual



Conclusion

The radioactive materials that are released from the Hanford Atomic Energy facilities into the Columbia River have been the [illegible] continuous surveillance and have been traced through the [illegible] pathways of potential radiological significance to people that live in the vicinity. Detailed evaluations of the probable dose received by various people have been made through a knowledge of the concentrations of individual nuclides present in water and food, a knowledge of the habits of the people, and through measurements made with whole-body counters. These exposure evaluations confirm that the total dose to members of the public has always been well within appropriate limits and that the radioactive materials generated by the plants have been under sound and continuous control.

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