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100N AREA SHORELINE RADIATION SURVEY AND DOSE EVALUATION

May 1995

Washington State Department of
Health
Environmental Health Programs

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100N AREA SHORELINE RADIATION SURVEY AND DOSE EVALUATION

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May 1995

Washington State Department of Health

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EXECUTIVE SUMMARY

The Washington Department of Health Environmental Radiation staff and members from the Westinghouse Hanford Company Operational Environmental Monitoring Program participated in a joint radiation survey along the 100-N Area shoreline in July of 1994. In February of 1995, a radiation survey of the 100N Area north shoreline (the shoreline opposite of the 100N Area) was performed. The goal of the surveys was to measure "skyshine" as a result of the cobalt-60 and cesium-137 gamma sources located in the 100N area. Skyshine is a phenomena caused by the Compton scattering of gamma rays back to earth. Three sources of external exposure exist in the 100N area. Two of the sources are the 1301-N and 1325-N liquid waste disposal facilities (LWDF), and the third source is the 1304 Emergency Dump Tank located near the 109-N Steam Generator Building.

The results of the measurements along the 100N Area shoreline indicate two areas of elevated exposure. The two areas of exposure correspond to the locations near the Emergency Dump Tank and the Liquid Waste Disposal Facilities. Both areas result in a net maximum dose rate of 19 μrem/hr. This maximum exposure occurs along approximately 800 feet of shoreline.

Dose rates near the 100N Area shoreline will continue to decline due to the decay of their principal constituents, cobalt-60 (half life of 5.27 yr) and cesium-137 (half life of 30.1 yr). Cesium-137, the longer lived radionuclide, will begin to dominate the dose rate beyond the year 2000. As a result, the dose rate will begin to decline at a slower rate after the year 2000. The dose rate is predicted to decline to 30% of the currently observed rate by the year 2015.

Dose estimates based upon the survey results indicated a potential of 5 mrem/yr to the maximally exposed individual fishing along the 100N Area. The dose a typical fisherman could expect to receive would be much less than 1 mrem/yr. The maximally exposed individual scenario is assumed to be conservative enough to apply to Native Americans as well.

Proposed federal regulatory limits require that the combined doses resulting from nuclear waste from the Hanford Site be less than 25 mrem/yr for all pathways. Although the calculated exposure scenarios resulted in estimated doses less than 25 mrem/yr, the Washington Department of Health expects that development of more realistic exposure scenarios through river use surveys should lower this estimate. The exposure scenarios developed for this paper were intentionally conservative in order to ensure that these estimates were an upper bound. Further identification of the exposed population will allow for an accurate population estimate of the number of individuals that are potentially exposed to the 100N Area.

State of Washington ENVIRONMENTAL RADIATION PROGRAM

INTRODUCTION

The Washington Department of Health Environmental Radiation staff and members from the Westinghouse Hanford Company Operation Environmental Program participated in a joint radiation survey along the 100-N Area shoreline in July of 1994. In February of 1995, a radiation survey of the 100N Area north shoreline (the shoreline opposite the 100N area) was performed. The goal of the surveys was to measure "skyshine" as a result of the cobalt-60 and cesium-137 gamma exposure located in the 100N area. Skyshine is a phenomena caused by the Compton scattering of gamma rays back to earth. Three sources of external contributors to exposure exist in the 100N area. Two of the sources are the 1301-N and 1325-N liquid waste disposal facilities (LWDF), and the third is the 1304 Emergency Dump Tank located near the109-N Steam Generator Building.

Skyshine occurs near the LWDFs because of the gamma radiation released from the large inventory of cobalt-60 and cesium-137. This gamma radiation, also known as photons, is projected in all directions around the disposal facilities. The portion of photon energy from the LWDFs directed toward the sky interacts with the atmosphere principally through photoelectric absorption and Compton scattering. Photoelectric absorption involves the absorption of the incident photon with an electron emitted from the orbital shell of the absorbing medium. For skyshine interactions, the absorbing medium is oxygen, nitrogen and other elements of the atmosphere. Compton scattering involves the interaction of an orbital electron with an incident photon and the subsequent scattering of that photon. This scattered photon is akin to billiard balls in that the ball, following collision, may travel in any direction. A portion of the scattered photons, now of lesser energy, will be scattered back toward the ground. This complete Compton interaction with the scattered photon being scattered back toward earth is referred to as skyshine.

A μR meter survey of the 100N area shoreline is conducted annually by staff from the Westinghouse Hanford Company Operation Environmental Monitoring Program. Each year, relative exposure rates are measured along this section of shoreline, starting at N Area outfall and proceeding downstream until radiation levels return to background exposure rates. Environmental exposure rate measurements collected by the Department of Health were used to validate results obtained by Westinghouse Hanford Company.

100N AREA HISTORICAL BACKGROUND

N-Reactor operated from December of 1963 to December of 1986. A map of the Hanford Site with the 100N area identified is shown in Figure 1. The dominant source of skyshine is a result of the effluent discharges from the N reactor to the 1301-N and 1325-N LWDFs. The two trenches were designed to receive wastewater discharge from the operation and decontamination of the reactor coolant system and associated support facilities. Specifically, 1301-N received liquid waste from 1963 until 1985. From 1983 to 1985, both 1325-N and 1301-N received waste from N reactor. 1325-N solely received the wastewater discharge from N reactor since 1986.

The 1301-N Liquid Waste Disposal Facility consists of a crib and extension trench. The crib portion is now covered with 4 feet of fill (Richardson, 1994) and sufficiently attenuates the gamma radiation. The extension trench (the current source of skyshine) has a 4 inch concrete cover to prevent animal intrusion but also serves to attenuate some gamma radiation. As the wastewater from N reactor was diverted entirely to the 1325-N LWDF, the 1301-N LWDF no longer contained a standing column of water to shield the radiation. Skyshine, first observed in 1986, was created as a result. The skyshine from the 1301-N Trench is of primary concern due to its proximity to the river and its receipt of the majority of the wastewater discharge.

The 1325-N LWDF also consists of a crib and extension trench and has a 4 inch concrete cover over the entire length of the disposal facility (Richardson, 1994). The contribution to skyshine from 1325-N was not observed until approximately 1990 when the discharge volume was sufficiently reduced to no longer shield the gamma radiation. Most of the contamination in both trenches is located near the discharge inlet. The dimensions for the 1301-N and the 1325-N Trenches are 49 feet wide x 12 feet deep x 1608 feet long and 56 feet wide x 7 feet deep x 2986 feet long, respectively.

The other source of exposure in the 100N area is the 1304 Emergency Dump Tank located near the 109-N steam generator building. The 1.3 million gallon dump tank was designed to serve as a heat sink and capture steam in the event of a reactor accident. The tank was never used for its original purpose. Instead, primary coolant contaminants continuously settled out in the tank from 1973 until shutdown in 1986. Similar to the liquid waste disposal facilities, the emergency dump tank also contained water that shielded the contamination that had settled on the bottom. Once the N reactor was shutdown, the water in the tank was drained as the need for a heat sink was no longer required.

With the water drained, the contamination was no longer shielded and results in the radiation exposure currently observed. The impacts from these sources are described later in the dose assessment section.

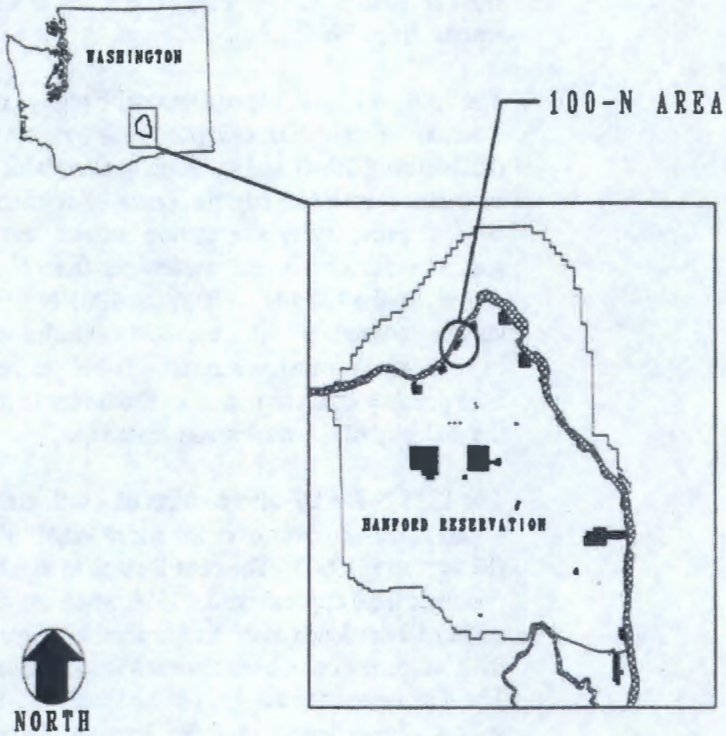


FIGURE 1: HANFORD RESERVATION

RADIONUCLIDE CONTAMINATION SOURCES/ QUANTITIES

Table 1 identifies the inventory of radionuclides which were deposited in the 1301-N Trench following shutdown (Perkins 1987) and the portion remaining in 1995 after accounting for radioactive decay.

Table 1 Radionuclide Inventory Amounts for 1301-N

Nuclide	Half life (years)	Quantity as of 1986 (Curies)	1995 Quantity (Curies)	Radioactive emission mode
Cobalt-60	5.27	3900	1200	β, γ
Strontium-90	29.1	2100	1700	β
Ruthenium-106	1.02	59	0	β, γ
Cesium-134	2.06	44	2	β, γ
Cesium-137	30.1	2800	2300	β, γ
Plutonium-239/240	24,100 /6560	23	23	α, γ

Although N reactor shut down in December of 1986, 1325-N LWDF continued to receive significant quantities of radioactive waste until 1991 (Rokkan 1987, 1988, 1989, Manley 1990, 1991). For example, 1325-N has received approximately 250 curies of cobalt-60 since N reactor ceased operation. Table 2 was created by using the cumulative quantity initially reported by Perkins in 1987 (for the years through 1986), adding the amount discharged for that year, and decaying the previous years amount. The quantity of radionuclides in 1325-N LWDF is significantly less than the amount present in 1301-N. This decreased inventory, combined with a greater distance to the river, implies that the dose contribution at the shoreline from the 1325-N LWDF is significantly less than the contribution from 1301-N.

Table 2	Radionuclide Inventory Amounts for 1325-N			
Nuclide	**Half life (years)**	**Quantity as of 1986 (Curies)**	**1995 Quantity (Curies)**	**Radioactive emission mode**
Cobalt-60	5.27	810	340	β, γ
Strontium-90	29.1	180	230	β
Ruthenium-106	1.02	49	0	β, γ
Cesium-134	2.06	9.5	2	β, γ
Cesium-137	30.1	310	324	β, γ
Plutonium-239/240	24,100/ 6560	2.4	2.4	α, γ

A review of the radionuclide inventory identified in Tables 1 and 2 indicate that only cobalt-60 and cesium-137 are present in sufficient quantity to pose an external radiation hazard. Tritium is not listed in the inventory quantity for either disposal facility because its behavior is similar to water and would not be retained within the confines of the trench. In addition, tritium is a weak, pure beta emitter and as a result does not pose an external risk. Strontium-90 and it's daughter yttrium-90, also a pure beta emitter, can pose an external risk from a direct exposure. The strontium-90 present in the LWDFs and the Emergency Dump Tank is shielded by the existing concrete over the LWDFs and metal lining of the tank. Plutonium is predominately an alpha emitter and generally would only pose a risk if taken internally. For more information on types of radiation and their effects please see Appendix A.

The 1304-N Emergency Dump Tank is located at the edge of the slope of the 100N shoreline. There are no estimates available for the inventory of this tank. The dump tank ceased receiving discharges after the final shutdown of the N reactor. The tank is assumed to have a similar relative fraction of cobalt-60 and cesium-137 as the 1325-N LWDF. The curie content, or inventory amount, should be significantly less since the tank was not an intended, nor ever used as, a primary waste disposal facility.

DOSE MEASUREMENTS \ SURVEY RESULTS

Methods/Instruments Used

Dose rate measurements along the 100N area shoreline were made with a μR meter and a μrem meter. All instruments were calibrated to a Cesium-137 Source. Dose rate measurements along the 100N North shoreline were made with a μR meter, a μrem meter, and a Pressurized Ion Chamber (PIC). In addition to the surveys performed, Westinghouse Hanford Company (WHC), Pacific Northwest Laboratory (PNL), and the Washington Department of Health (WDOH) all have thermoluminescent dosimeters (TLD) located along the N area shoreline near well 199-N-8T. This TLD data will help validate the results of other instruments. A discussion of converting instrument results from exposure to dose, and how well they compare with one another, is located in Appendix B.

Measurements on both shorelines were taken at 3 feet above the surface at 50 foot intervals. Due to the characteristic over-response of the μR meters, the μrem meter was used to obtain a more representative estimate of dose. The PIC, which is a bulky, heavy instrument, was not used on the Hanford side shoreline due to the complexity of the terrain. The 100 Area opposite shoreline allowed for the effective use of the PIC due to a much flatter, grassier terrain. Here, PIC measurements were taken every 100 feet over the entire length of shoreline (using a 15 second average).

100N Area Shoreline Results

The results of the 1994 survey are contained in Figure 2.. This figure displays both the μR and μrem meter results and shows that exposure rates are several times background for the area. Background estimates are discussed in the Exposure from Other Sources section. Two peaks are evident in Figure 2. The first, narrower peak, corresponds to the Emergency Dump Tank. The second, broader peak corresponds to the LWDFs. Field locations 6 through 12, the section of the graph where data is missing, corresponds to the N reactor outfall area. This area was inaccessible by land or water at the time of the survey.

Previous survey results (PNL 1994) are combined with the 1994 survey in Figure 3. The data shows that exposure rates along the shoreline have been naturally declining for several years. The μR meter readings from the 1994 and previous WHC surveys are uncorrected exposure rates.

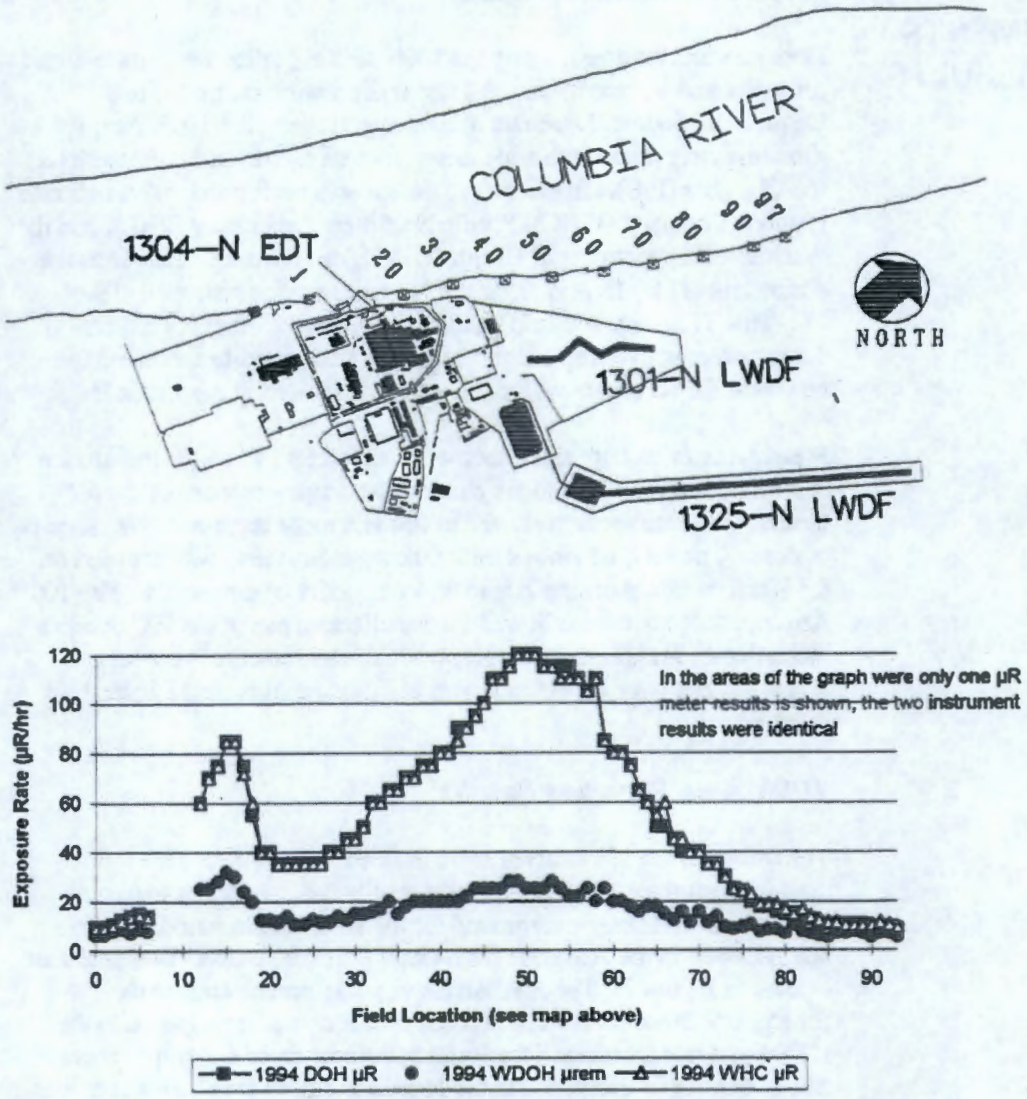
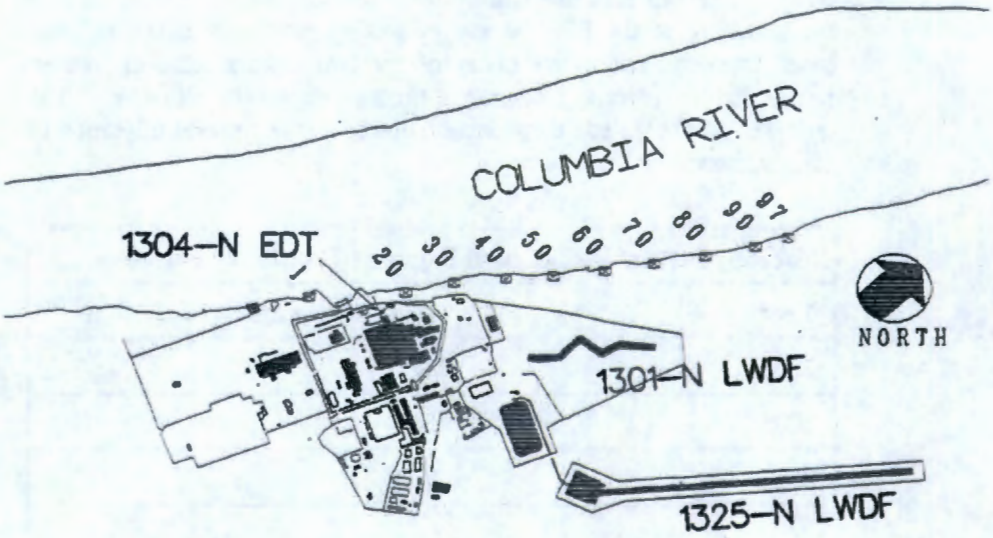


FIGURE 2: 1994 100N SHORELINE RADIATION SURVEY



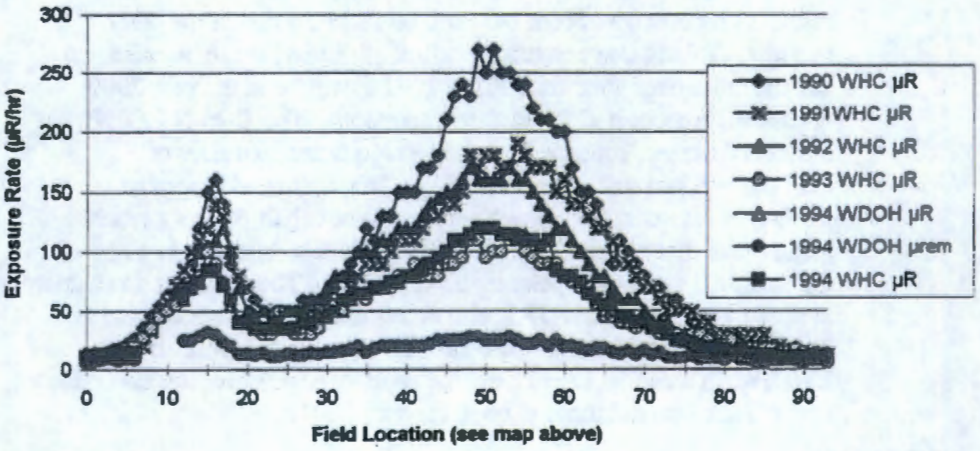


FIGURE 3: SUMMARY OF RADIATION SURVEY MEASUREMENTS ALONG 100N SHORELINE

The skyshine from the LWDFs and the direct shine from the Emergency Dump Tank represent the highest accessible exposure potential to the public. This exposure rate will decrease due to decay over time. Using the inventory of the LWDFs and projecting the future exposure rates based upon the radioactive decay of the two radionuclides of interest results in the percent reduction estimates shown in Table 3. The estimates do not include the reduction due to any downward migration of contaminates.

Table 3 Percent Reduction in Exposure Rate in the Future

Year	100N Shoreline
2000	35%
2005	55%
2015	70%

The reduction in exposure rate over time can also be described by determining at what point cesium-137 becomes the greater contributor to dose. This cross-over point varies for all three exposure sources and is a simple method of explaining how the exposure rate will lower over time. The 1301-N LWDF received its last discharge at the end of 1983. As a result, its percentage of cobalt-60 will be less than that of the other facilities. Taking into account a number of factors, it can be estimated that the cross-over point for 1301-N LWDF will be in the year 2000 (please see Appendix C for further discussion). The 1325-N LWDF, as mentioned earlier, continued to receive significant quantities of radioactive liquid discharge until 1991. This continued receipt of discharges results in the relative percentage of cobalt-60 being much greater than that of the 1301-N LWDF. This results in an extension of the estimated cross-over point to the year 2007. The relative contribution to dose from 1325-N LWDF is also determined in Appendix C and is estimated at 5% of the total exposure rate near the shoreline of the LWDFs. In a similar calculation, the cross-over point for the Emergency Dump Tank was estimated to be in the year 2004.

Ambient gamma dose measurements are also made with thermoluminescent dosimeters which are left in one location for an extended period of time. The dosimeters function by capturing the gamma energy in the thermoluminescent crystal. In the laboratory, the captured gamma energy is emitted as light when the crystal is heated and the corresponding dose is calculated as a function of the light output. TLDs are placed in several locations along the 100N shoreline.

Unfortunately, the number of TLDs located in the field does not permit the continuous tracking of results that survey instruments provide. However, at the 100N shoreline near N-Springs, WHC, PNL, and DOH all have TLDs located in proximity to each other. A comparison of the TLDs can be used to provide a determination of the accuracy of the μrem meter. The results of the comparison, further discussed in Appendix B, are .59 mrem/day compared with the .5 mrem/day result of the μrem meter alone. The 0.09 mrem/day difference between the two results on an hourly basis is roughly 4 μrem/hr. This 18% (.09/.5) difference is the expected accuracy in results and is within the 20% (2 standard deviation) uncertainty of both the TLDs and the μrem meter. Based on the comparison results, the μrem meter can be assumed to be a valid method for estimating dose rates along the shoreline.

100N Area North Shoreline (on the opposite shoreline of the 100N Area)

The Washington Department of Health surveyed the 100N North shoreline on February 9, 1995. A representative of Westinghouse Hanford Company's Environmental Surveillance Program participated in the measurement and collection of data. Three instruments were utilized in order to ascertain relationships between the instruments and to provide reference points for previous surveys.

Data results are divided into two graphs, contained in Figures 4 and 5. Figure 4 displays the results from the two μR meters. Figure 5 displays the results of the μrem meter and the Pressurized Ion Chamber (PIC). All three instruments indicate the variability in results that occur at or near background exposure rates. The PIC results should provide the most accurate record of exposure as an ionization chamber is designed to respond to varying gamma energies and has a relatively flat response curve for the energy range of interest. A review of the PIC data in Figure 5 shows a continuous variation in results with some minor fluctuations. The increased fluctuation in the PIC results can be attributed to the short time average (15 seconds) single data point taken at each location. At field location 18, however, the PIC records a slightly elevated exposure rate directly across from the emergency dump tank. Other areas of elevated exposure occur from field location 80 to approximately 120. These locations corresponds to the area across from the 1301-N and 1325-N Liquid Waste Disposal Facilities.

The μrem meter displayed in Figure 5 does indicate a slight trend in the results. The data of both the PIC and the μrem meters, reviewed in combination, support the conclusion that some impact is observed as

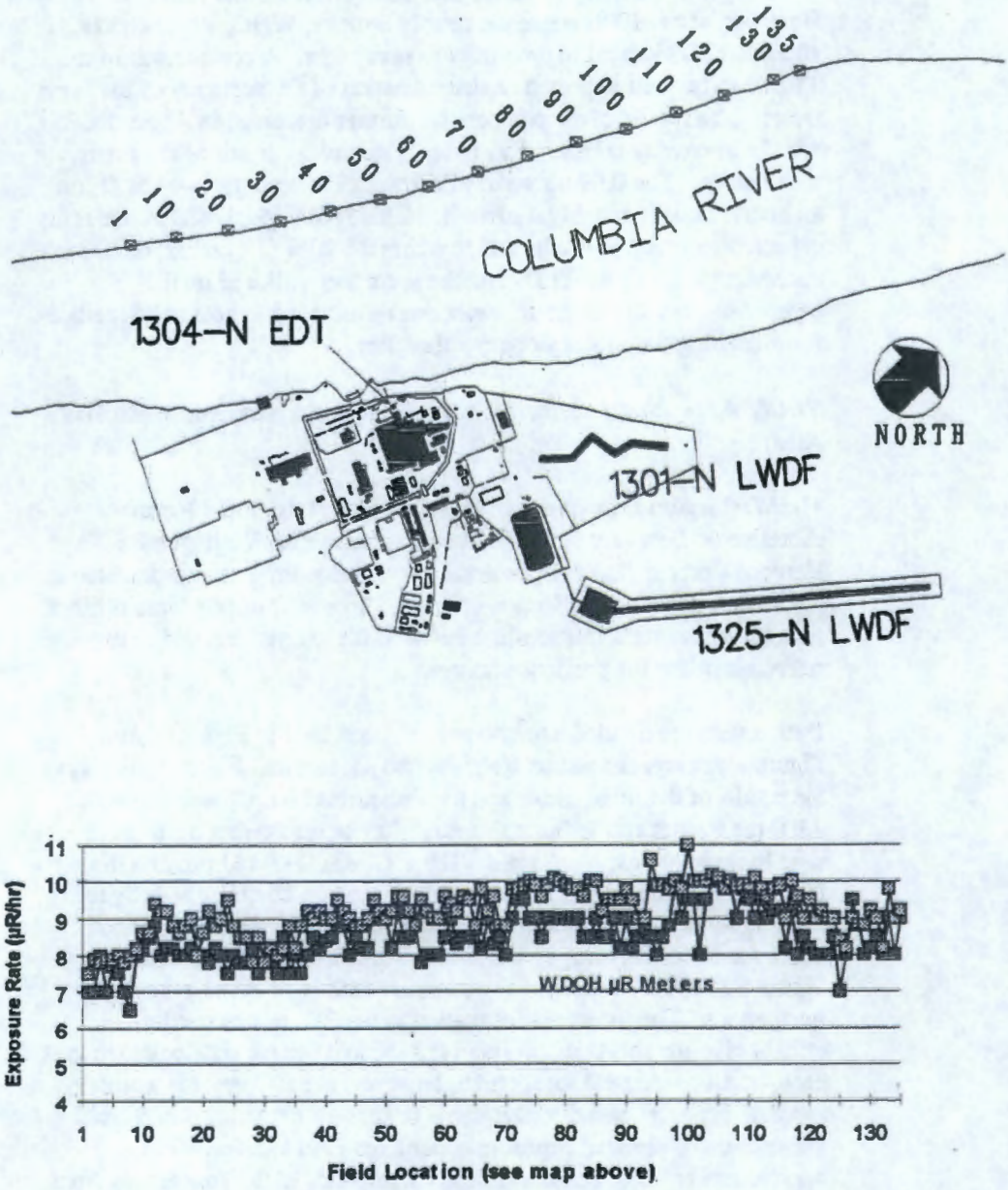


FIGURE 4: 100N AREA NORTH SHORELINE RADIATION SURVEY RESULTS

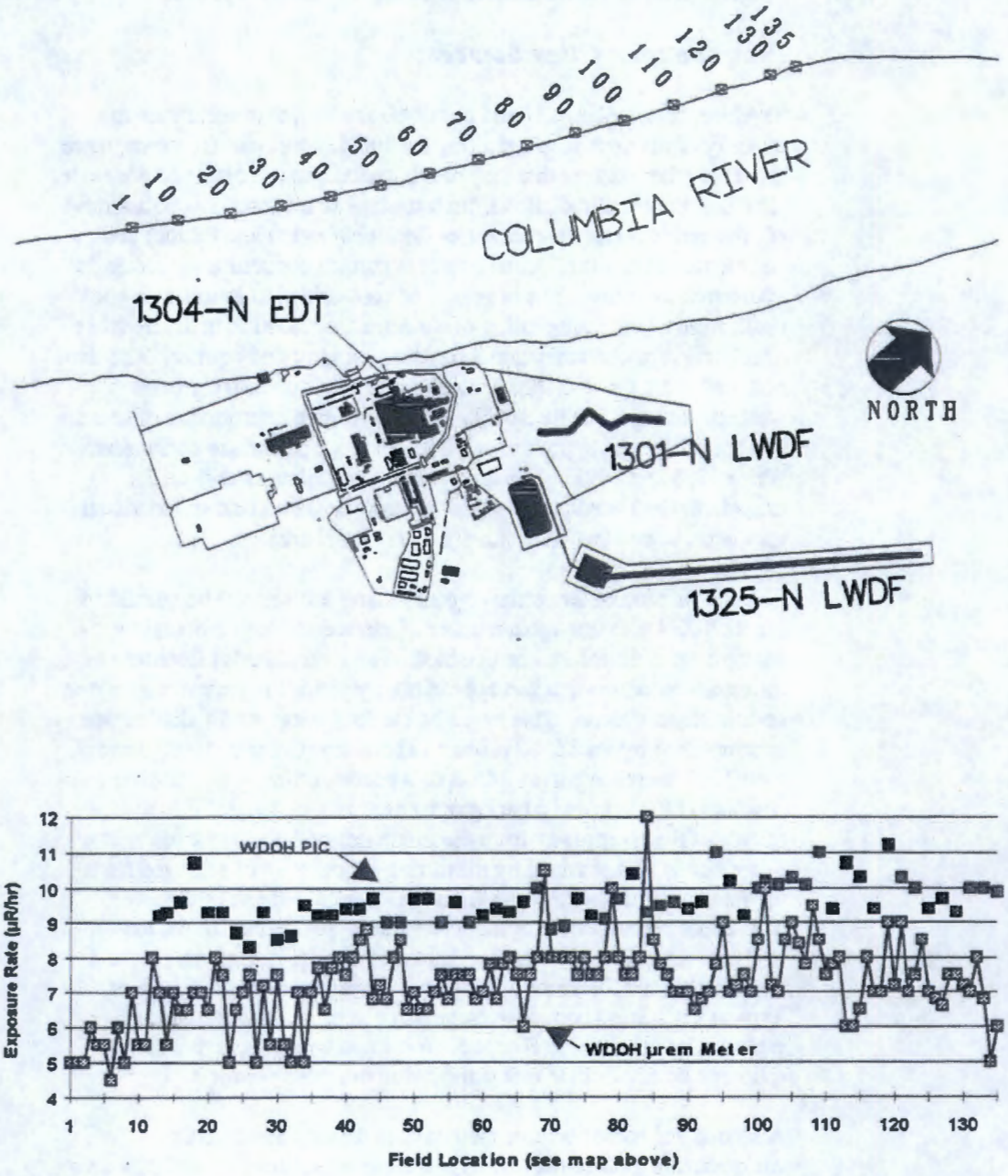


FIGURE 5: 100N AREA NORTH SHORELINE RADIATION SURVEY

a result of skyshine. The difference between the maximum exposure rates peaks and background exposure rates (excluding radon and radon daughter products) are estimated to be approximately 1 μR/hr.

Exposure from Other Sources

Skyshine from cesium-137 and cobalt-60 are known to contribute the majority of the dose received along the 100N shoreline. However, there are three other sources that may also contribute to the observed dose rate. The first is natural radiation from terrestrial sources such as potassium-40, the uranium and thorium series (including radon and thoron) and cosmic radiation. The second source is surface contamination along the 100N area shoreline. The near surface contamination in this area could result from either resuspension of surface contamination in the trenches or migration of contamination through the unsaturated aquifer. The third potential source is atmospheric fallout as a result of above ground weapons testing. For the 100N Area, the relative contribution of cesium-137 from fallout is approximately 20% of the total surface contamination (Price 1988 and 1991). The separation of contributors to dose is important when attempting to quantify the associated risk an individual may experience when in proximity to the 100N area.

The contribution of terrestrial or background sources can be quantified for the 100N area through a number of methods. First, a bound for the background radiation can be obtained. The river shields all sources of terrestrial contamination and approximately yields the exposure rate from cosmic sources alone. This lower bound for background radiation was accomplished by Pacific Northwest Laboratory (Cooper, 1993) during their 1992 shoreline survey. Cooper's results, utilizing a pressurized ion chamber (PIC), yielded a background dose rate of 4μrem/hr in the middle of the river (away from the influences of 100N skyshine). The upper bound was obtained by measuring exposure rates removed from the influences of Hanford and from the shielding effects of the river. This upper bound dose rate is approximately 10-11μrem/hr for the Richland area (PNL 1994). The background dose rate along a river shoreline should therefore be close to the average of the two bounds. Typical variations about an average value at or near background dose rates can be observed in Figure 5. It is important to note that these estimates do not include radon and radon daughter products.

A second and more accurate method is to directly measure the background exposure rate. During the annual surveys of the 100N area shoreline, background radiation levels are attained at the downstream end of the survey. The μrem meter averaged 6.5 μrem/hr

during the 1994 survey at the downstream location. Applying a correction factor to account for under-response at background exposure rates (see μrem/PIC discussion Appendix B) yields approximately 8.5 μrem/hr. The reason for the under-response at low dose rates was not determined.

A separate method utilized in-field gamma spectroscopy (Rathbun 1989) and allowed for the determination of both source term and dose rates along the shoreline. The identified man-made isotopes contributing to dose were cesium-137 and cobalt-60, as expected (see Figure B-2). The skyshine resulting from cesium-137 and cobalt-60 only contributes to the backscatter observed in Figure B-2. The relative contribution of direct exposure as a result of surface contamination from cobalt-60 and cesium-137 was calculated as 14% of the total dose rate for the location closest to the river, and 5% for all other locations. Of that 14%, approximately 1% can be attributed to fallout. The natural contribution was consistently calculated as 8 μrem/hr, or 30% of the dose at the maximum elevated shoreline location. The background or natural components gives us a correction factor which can be applied to dose estimates. Table 4 below summarizes the contribution to dose from other sources.

Table 4	Exposure Breakdown from Other Sources (at Shoreline)	
Contributor	**% of maximum exposure rate (26 μrem/hr)**	**Dose Rate (μrem/hr)**
Natural Background	27% to 30%	7 to 8 μrem/hr
Surface contamination (all sources)	5% to 14%	1 to 4 μrem/hr
Surface contamination from atmospheric fallout	1%	<1 μrem/hr

INDIVIDUAL DOSE ASSESSMENTS FROM AMBIENT GAMMA MEASUREMENTS

Calculation/Development of Exposure Scenarios

The shoreline near the 100N area represents the only area on the Hanford Site where ambient gamma dose rates exist at greater than twice background (Cooper 1995). The scenarios developed for this singly elevated area are intended to provide a dose that the maximally exposed individual could receive. These scenarios have been developed for recreational exposures in the river and along the Hanford shoreline. Exposure scenarios where an individual intentionally gains access to the 100N area (and potentially higher exposures) or areas other than the shoreline are not considered. This type of intentional access, however, could easily result in elevated doses to an individual were it to occur. Willful intent involving individuals exposing themselves to hazards cannot be effectively guarded against in public health programs. As a result, the scenarios developed for this publication are intended to provide a basis for a member of the public to assess exposure risks as a result of pursuing recreational activities near the 100N shoreline. The following exposure scenarios are expected to remain valid for current land use restrictions (public access onto 100 Areas prohibited) .

The first step in developing an exposure scenario is determining the applicable dose rates and areas for exposure. In this scenario, an average maximum dose rate is used because it is reasonable to assume that an individual would not consistently remain in the location of highest exposure over a significant number of days. A review of Figure 2 indicates there are two areas of maximum exposure along the shoreline. The first area, located near the Emergency Dump Tank results in a maximum average dose rate of 26 μrem/hr (see Appendix B for discussion of converting from exposure rate to dose rate). This exposure occurs between survey points 12 and 18, a distance of approximately 300 feet. The second area, located near the LWDFs, also results in an maximum average dose rate of 26 μrem/hr as recorded by a μrem meter. This average maximum dose rate occurs between survey points 44 and 54 and is approximately 500 feet in length.

The average maximum dose rate to an individual fishing in the river near the 100N area shoreline is 16 μrem/hr. This dose rate was determined by PNL using a pressurized ion chamber (Cooper 1993). This location corresponds to the vicinity of the Emergency Dump Tank and is approximately 250 feet in length. The majority of the other river locations near the 100N area varies from one to five μrem/hr above background, depending upon the location.

The next step is to determine and subtract background. As previously discussed, the background for the shoreline area is approximately 7 to 8 μrem/hr. The background for the river is 4 μrem/hr. Subtracting the dose rate as a result of the trenches from natural background in the area results in 19 μrem/hr. For the river, the maximum dose rate would be 12 μrem/hr. The various dose rate conditions are summarized in the Table 5 below:

Table 5 Dose Rates at Various Locations

Location	Observed Dose Rate	Background Dose Rate	Excess Dose Rate
100N Shoreline	26 μrem/hr	7 to 8 μrem/hr	19 μrem/hr
River adjacent to emergency dump tank	16 μrem/hr	4 μrem/hr	12 μrem/hr
Other areas of river near 100N	5 to 9 μrem/hr	4 μrem/hr	1 to 5 μrem/hr

The third step in a dose assessment involving external exposure is to determine the time an individual would spend near the area of highest dose rate. This determination hinges on the type of individuals identified as the most susceptible group. Until lands in the 100 Area are opened to the public, the most likely scenario involves fishing along the Hanford shoreline. Hunting for waterfowl could also present exposure potentials to individuals, but the time spent near the area would be significantly less than that of fishing (habitat not conducive to nesting, prolonged feeding, etc.). A Wild and Scenic Rivers designation would presumably increase both the recreational and fishing traffic on the river. However, this designation should have no effect on the maximally exposed individual who is already well aware of the unique nature of the Hanford Reach (the only free flowing stretch of the Columbia River in the United States).

Once the type of individual is identified, the time spent per day is needed. The public fishing season currently lasts 129 days. A reasonable upper limit on time spent fishing is 12 hours per day. An individual could achieve this 12 hour/day upper limit by camping on the opposite shoreline and fishing near the 100 N shoreline. However,

such an individual would not camp for 1/3 of a year. Another possibility is for an individual to boat to the 100 N area every day to fish. Considering the time involved traveling to the boat launch area, launching the boat and traveling to the 100 N area, an 8 hour fishing day would be a reasonable maximum. Thus, an eight hour day is used for the maximally exposed individual in this report.

The number of days an individual spends fishing along the Hanford reach is a subject for which little data exists. Could an individual realistically fish every day of the season? If an individual does spend an entire day fishing, what fraction of the day would he/she spend near the 100N shoreline? For the purpose of calculating a maximum exposure, the assumption that an individual spends every day of the fishing season out on the river will be used. The fraction of time spent near the 100N shoreline will be conservatively assumed as 50% of the time. Of this 50%, a further conservative assumption that 20% of that time will be spent on the 100N shoreline will also be used.

The maximally exposed individual would therefore spend approximately 520 hours (129 days x 8 hours/day x 50%) near the 100N Area. Of this 520 hours, 100 (20% of 520 hours) would involve actual shoreline exposure conditions. The dose received while on the shoreline is 2 mrem/year (19 μrem/hr x 100 hrs/yr). The river contribution includes 40% of the time spent at 12 μrem/hr with the other 40% spent in an area of 3 μrem/hr, or 3 mrem/yr combined (12 μrem/hr x 210 hr/yr + 3 μrem/hr x 210 hr/yr). The river partitioning assumes that, as one ventures further into the river, the dose rate quickly falls to a few μrem above background. The total dose to the maximally exposed individual is 5 mrem/yr above background.

The calculation for the dose an average fisherman could expect to receive includes an assumption that an individual only fishes once a weekend for the entire fishing season and spends a pro-rated percentage of the time near the 100N shoreline. Of the 40+ miles of shoreline from Vernita Bridge to Richland available for fishing, only 800 feet are in an area of elevated exposure (greater than twice background). This represents only 0.4% of the available shoreline on the Hanford site, and only 0.2% of the total shoreline on both sides of the river. For the time spent fishing on the river, only 250 feet are located in an area of elevated exposure. This area represents 0.12% of the length of the river available for fishing. This 250 foot stretch of elevated exposure is conservative as it assumes that the entire width of the river in that section is elevated. In reality, only the location closest to the Hanford shoreline is significantly elevated. The 19 days spent fishing at 8 hours per day, with .12% of the time near the 100N shoreline, results in a calculated dose of 2 μrem/yr (12 μrem/hr x 150 hr/yr x .12%).

100N North Shoreline Dose Estimates

The dose rate above background was tentatively estimated as 1 μrem/hr. Applying the maximally exposed individual scenario to the north shoreline would result in an estimated dose of less than 1 mrem/yr.

Native American Scenarios

Native Americans remain a segment of the population where exposure scenarios for the general public may not hold true. At the time of the writing of this report, the Columbia River Inter-Tribal Fish Council is in the process of developing fish consumption estimates for the Native American population. More accurate estimates of exposure times may be derived from these consumption values once developed. Until that time, the maximally exposed individual described previously is assumed to be sufficiently conservative to apply to Native Americans as well.

Future Exposure Scenarios

Extrapolations for the future involve a tradeoff between reductions in exposure rates along the 100N area, with increases in uncertainty regarding the time an individual could spend on the 100N shoreline. The total time the typical and maximally exposed individual spends fishing in any given year would be expected to remain the same (assuming current land use restrictions). However, the time spent on the 100N shoreline as opposed to the river will increase to account for uncertainty. Predicted doses are estimated for 5, 10 and 20 years in the future. Calculations are based upon the inventories of the LWDFs and the assumed isotopic mix near the emergency dump tank. Table 3 shows that the reductions over time will be significant for the first 20 years.

Applying the predicted percent reduction (35%) to the maximally exposed individual described above results in a external dose of 3 mrem in the year 2000. In fact, for the maximally exposed individual assumed above, spending 100% of the time on the shoreline of the 100N area would result in a dose of 6 mrem/yr.

Other Contributors to Dose

The scope of recreational drinking water scenarios is generally limited to camping. A camper may or may not be the same maximally exposed individual who fishes along the Hanford Reach. A person who fishes and does not camp would not access seeps or surface water as a source

of drinking water as a clean source can more readily be obtained. This would limit seeps and surface water as a source only during extended camping trips along the river. No attempt to quantify the drinking water pathway is made in this paper. It will be the subject of another Washington Department of Health report.

Data for Population Dose Estimates

Large uncertainties exists when attempting to extrapolate information about individual dose assessments to populations. In order to estimate the percent of the population that could potentially be exposed to the elevated dose rates at the 100N Area, an outer bounds of the potential population must first be defined. As of 1994, there were approximately 169,900 individuals living in Benton and Franklin Counties (Office of Mgt. and Budget, 1994). (Grant Co. was not included in the estimates as the majority of population resides in the northern section of the county. The estimated contribution from Grant Co. was less than 5,000. Individuals living in remote sections of Benton and Franklin Counties were included to offset increases from other areas.) Of those individuals an estimated 13% fish (Dept. of Fisheries & Wildlife, 1991). (Recent data regarding fishing licensees issued for the two counties only exists for 1990 and 1991 . A comparison of fishing licensees issued in those years with the total population indicated approximately 12.5% of the population bought fishing licenses.) A further study of the characteristics of the area shows that approximately 9,500 individuals own recreational boats, or 5.5% of the population (Lince, 1995) (A boating license is required for boats with motors greater than 10 hp. It is assumed that individuals who consistently fish in the Hanford Reach of the Columbia River would have at least a 10 hp motor.)

Once information regarding the subset of the population that both fishes and boats in the Columbia River is obtained, information regarding the distribution of that population must be defined. This involves further determining how many hours the average and maximum individual actually fishes and where they are most likely to fish. For the maximally exposed individual defined in this report, it is unlikely that any individual would fit the characteristics described. Thus, designating a percentage of the boating and fishing population that meets these characteristics would be inappropriate without recent survey information that would support this scenario. The same reasoning may be applied when extrapolating from the average individual to the population as a whole (including the distribution between the average and the maximum). As a result, no estimate of the population dose will be performed by WDOH until a comprehensive survey is completed.

Dose Estimates in Comparison to Other Sources of Exposure

The estimated radiation doses received by an individual may be compared with other radiation doses received annually. For the Benton/Franklin County area, an individual receives about 450 mrem/year from naturally occurring sources, including radon gas (WDOH/EPA, 1993). Man-made consumer products and medical x-rays contribute an additional 60 mrem for a total of approximately 510 mrem received annually by the average individual residing in the Tri-City area. The breakdown of the background doses is summarized in Table 6 (Erickson, 1993). The maximum expected dose as a result of the elevated dose rates from the 100N Area is less than 5% of the total from other sources.

Table 6 Residential Radiation Doses from Other Sources

Radon (Benton and Franklin County)	330 mrem/yr
Background (cosmic, rocks/soil, etc)	80 mrem/yr
Internal Sources (potassium-40, carbon-14, etc)	40 mrem/yr
Medical and Consumer Sources	60 mrem/yr
Total	510 mrem/yr

Dose Estimates in Comparison to Applicable Regulatory Limits

The Department of Energy's current overall regulatory dose limit to members of the public is 100 mrem/yr from all sources and pathways. This 100 mrem/yr limit coincides with the federal limit applied to commercial facilities. This overall limit is further reduced by taking into account the ALARA concept. That is, DOE and it's contractors should conduct operations in such a way as to ensure that doses are As Low As Reasonably Achievable (ALARA). The ALARA concept takes into account social and economic factors when attempting to reduce doses less than their current standard.

DOE is currently in the process of changing their orders into federal law. The proposed regulations in Title 10 of the Code of Federal Regulations

Part 834.109 further state that DOE activities shall be conducted in a manner such that exposure of the public to radiation or radioactive waste from the handling, removal, storage, transport, and packaging of low-level, high-level or transuranic waste, spent nuclear fuel, naturally occurring or elevated radioactive material, and residual radioactive material must comply with ALARA and not exceed a combined dose of 25 mrem/yr from all pathways. The elevated doses from the 100N Area must comply with the 25 mrem limit as the dose is from radioactive waste. The ALARA process must also be applied to this 25 mrem limit. For the 100N Area, considerations such as the cost for reducing the dose rate and the potential dose to workers must be taken into account when attempting to further reduce the allowable limit to less than 25 mrem/yr. The Hanford Site as a whole, existing primarily as a radioactive waste site, must also conform to the 25 mrem/yr limit. Any dose from the 100N Area must also be added to all other projected doses from the Hanford Site when determining the applicable ALARA limit.

CONCLUSION

The recreational fishing population represents approximately 13% of the total population in the Benton/Franklin County Area. The boating population is a further subset representing 5.5% of the estimated 169,900 living in the area. Of this fishing and boating population, the 1995 maximum dose estimate for an individual as a result of external exposure from the 100N Area has been conservatively estimated at 5 mrem/yr. The average or weekend fisherman could expect to receive much less than 1 mrem/yr. The maximum expected dose is expected to be sufficiently conservative so as to apply to Native Americans as well.

In order to reduce the uncertainty surrounding exposure scenarios, WDOH recommends that a survey of the fisherman/recreational users in the area be conducted. This survey would identify the number of individuals, their frequency of use, and locations of interest. Risk assessments for a wide number of restoration projects would benefit from the data gathered. Such a survey should follow the guidelines initially established in a comprehensive survey performed along the Columbia River in the 1960s (Soldat, 1968).

The estimated doses calculated were less than the proposed DOE regulatory limit of 25 mrem/yr. However, more accurate surveys and assessments of the actual use of the Columbia River by individuals should lower these dose estimates.

For the 100N Area, in spite of the significant reduction in dose rates that will occur due to decay over time, free release scenarios involving unrestricted access for the 100N Area could not occur without a remediation of the highly contaminated areas. The scenarios involved in a free release would have to include access to the trenches much closer than the immediate shoreline along the river. The dose rates in close proximity to the LWDFs or the Emergency Dump Tank remain high and could easily result in elevated doses to the public if access were made available.

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APPENDIX A

RADIATION AND HUMAN HEALTH

About Radiation and Radioactivity

Radiation is a natural process to redistribute energy. For example, the hot temperature of the sun causes it to emit visible light, which is a form of radiation. This radiation redistributes energy from the surface of the sun to the earth and fuels all of the life upon the earth. The important aspect of this radiation is that it has just the right energy for plants to build organic molecules and hence grow. In contrast, higher energy radiations, often called ionizing radiation, have too much energy for life to utilize. In fact their collisions with organic molecules can damage or destroy them. This destruction may have negative health effects upon the animal or plant that has been exposed to high doses of radiation. It is ionizing radiation that is cause for concern and which is discussed throughout the rest of this report.

The common forms of ionizing radiation found in the environment are referred to as alpha, beta and gamma. Alpha's are heavy particles that can be characterized by their extremely short range. In fact alpha's are just the nucleus of a helium atom. The range of alpha particles is so short that they can not penetrate human skin, or even a few inches of air. Beta's are much lighter particles that also have a short range, but somewhat longer than alphas. Examples of these particles at an energy too low to qualify as ionizing radiation are electrons circling an atom, or electrons flowing through home-wiring to supply electricity. Gamma rays are massless particles that have a very long range, and often have sufficient energy to penetrate the human body. Their analogue in the low-energy, nonionizing range, is visible light and infrared light.

Radioactivity is the name given to the phenomena of matter emitting ionizing radiation. Similarly, matter that emits radiation is termed radioactive. All matter is made of atoms; which consist of electrons circling around a central core or nucleus. The nucleus is made of protons, which carry charge, and neutrons, which are uncharged. Atoms are all referred to as belonging to the same element if they all have the same number of protons. For example hydrogen has one proton, carbon has six protons and oxygen has eight protons.

The convention we will use is the name of an atom followed by the sum of its number of protons and neutrons. For example carbon-12, which is the most naturally abundant form of carbon, consists of six protons and six neutrons for a total of twelve protons and neutrons. Carbon-13 and carbon-14, which consist of six protons and seven and eight neutrons respectively, are also found in nature. Each of these different forms of carbon are called isotopes of carbon. All isotopes of a particular element have the same chemical properties, but different

isotopes have different nuclear properties. One such property is radioactivity. If an isotope is radioactive it is called a radioisotope. In the example given carbon-12 and carbon-13 are nonradioactive isotopes of carbon. Carbon-14 is radioactive, and therefore a radioisotope of carbon. In this report we use the terms radioisotope and radionuclide interchangeably

All radioisotopes will eventually decay, by emitting radiation, to nonradioactive isotopes. For example carbon-14 decays to nitrogen-14. An important property of any radioisotope is the half-life. The half-life is the amount of time it takes for half of that radioisotope to decay. In the example above carbon-14 has a half-life of 5,730 years. Thus if one had one pound of pure carbon-14, after 5,730 years there would be 1/2 pound of carbon 14 and 1/2 pound of nitrogen-14. After another 5,730 years, for a total of 11,460 years, there would be 1/4 pound of carbon-14 and 3/4 pound of nitrogen-14. This decay process would continue indefinitely until all of the carbon-14 had decayed to nitrogen-14. The physical process of radioactive decay is illustrated in Figure A.1, where the decay of tritium (hydrogen-3) to helium-3 is shown. Tritium is chosen for this illustration because of its relative simplicity.

In contrast to this simple decay scheme, heavier radioisotopes often decay to another radioisotope, which decays to another radioisotope, and so on until this decay process culminates in a nonradioactive isotope. This sequence of decays is called a decay chain. Each of the isotopes produced by these decays are called decay products. For example, uranium-238 decays to thorium-234, which decays to protactinium-234 and so on until the decay chain ends with nonradioactive lead-206.

From the perspective of human health, exposure to radiation is quantified in terms of radiation dose. Radiation dose measures the amount of energy deposited in biological tissues per unit mass of tissue. Thus low energy radiation, such as visible light, yields a negligible radiation dose. Conversely, ionizing radiation, because it is high energy radiation, can deliver large amounts of energy, and hence can cause a significant radiation dose.

Radiation doses are commonly measured in units of rems or milli-rems (mrem). The most significant radiation dose received by the general public is due to radon-222 exposure. Radon-222 is part of the uranium-238 decay chain and is commonly found in homes by the decay of uranium-238 naturally present in the soil below the home. An average individual in the U.S. receives approximately 200 mrem per year (mrem/yr) from radon. Another 160 mrem/yr is received from natural sources and medical procedures, of which 40 mrem/yr comes from

inside the body. The primary pathway into the body for natural radionuclides other than radon is by the consumption of food and water. The average American receives less than 1 mrem/yr from nuclear facilities. The total average effective body nationwide is approximately 360 mrem/yr, or approximately one mrem per day. The components of the average annual radiation dose from various sources is shown in Figure A.2.

The radiation dose that an individual receives from a particular isotope is very sensitive to the type of radiation that the isotope emits and how the individual comes in contact with the radiation. For example, radioisotopes that are alpha emitters will not yield a radiation dose, and therefore are not dangerous, as long as they are external to the body. This is because the short range of alpha's does not allow them to penetrate human skin. Conversely, once inside the body via ingestion, inhalation or absorption through the skin, they can pose a substantial dose. Examples of alpha emitters include radon-222, uranium-238 and plutonium-239. Beta emitters are slightly greater external hazards than alpha emitters, but like alpha's, the short range of beta's implies that beta emitters can yield much greater internal dose than an external dose. An example of a beta emitter is strontium-90. In contrast to beta and alpha emitters, gamma emitters could yield a significant dose, and hence are significant radiological hazards whether, they are internal to the body or not. This is due to the great penetrating power of gammas. An example of a gamma emitter is the decay product of cobalt-60, which is nickel-60.

It is conventional, although incorrect, to refer to cobalt-60 as a gamma-emitter because the gamma decay of nickel-60 occurs very soon after the cobalt-60 nucleus beta-decays to nickel-60. This misuse of language is widely applied to all of the well-known gamma emitters because of its convenience. Other examples of "gamma emitters" that do not directly emit a gamma ray are cesium-137 and europium-152. This report follows this convention.

Health Effects

The ways, or paths, that environmental radioactivity, whether natural or artificial, can lead to a radiation dose are called exposure pathways. One such pathway is called "shine", which is the direct emission of gamma rays from gamma-emitters in soils. Other pathways include inhalation of airborne soils that contain radionuclides, ingestion of soils, water, or food containing radionuclides.

Figure A.1 - A decay-event is shown of a tritium nucleus (hydrogen-3).

THE DECAY OF TRITIUM

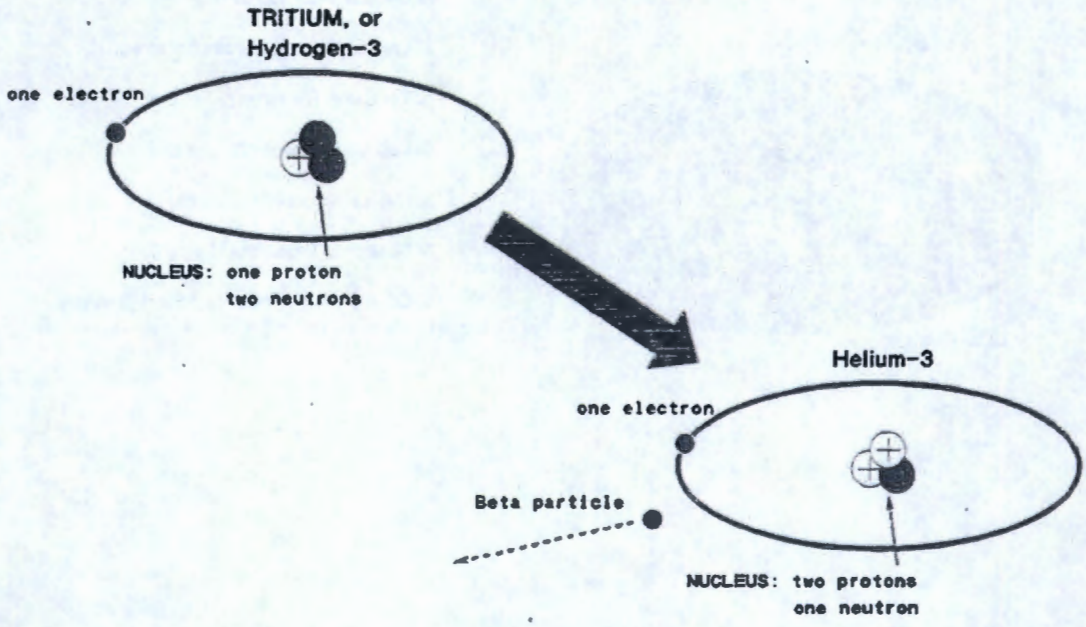
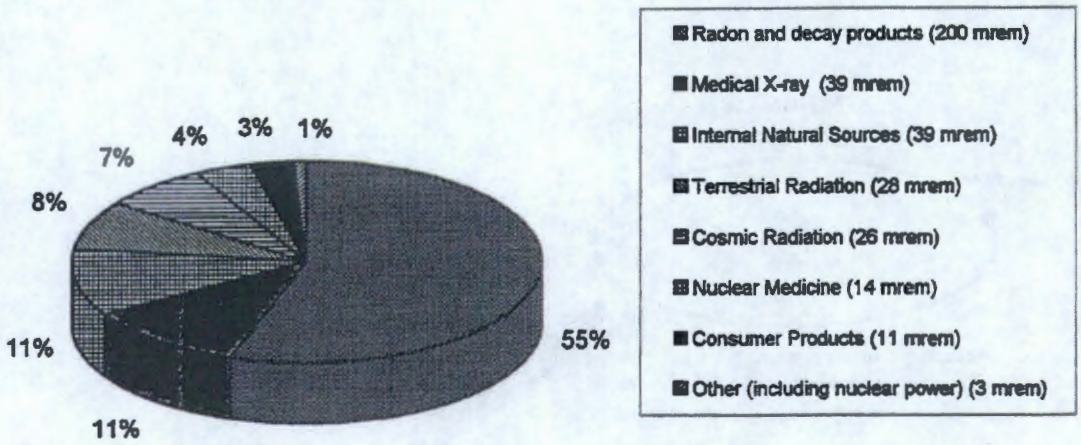


Figure A.2: Sources of radiation dose received by the average American. (Source: NCRP Report No. 93, 1987)



Calculation of radiation dose from a known concentration of radioactivity in the environment is a complex process that is fraught with uncertainty. Nevertheless, there are now a number of computer models and federal and international guidance documents to guide environmental dose assessments. Once these doses have been calculated, the final step is to convert radiation doses to potential human health risks.

The health effects of radiation are substantially better known than are those of most other carcinogens because there is a wealth of human and animal data on the subject. However, like all carcinogenic "agents", when levels of exposure are less than the level where health effects have been observed, scientists must use extrapolations to estimate health effects. For example, it is relatively easy to observe the health effects of smoking two packs of cigarettes per day; but, when an individual only smokes two packs per year it is literally impossible to observe health effects. In this case the risks are estimated from extrapolating from heavy smokers. In radiation protection the relationship between dose and risk is assumed to be linear at normally occurring environmental levels. That is, the risk associated with a dose is directly proportional to that dose.

The risk estimates of this report consider only carcinogenic risks due to radiation dose and do not account for the toxicological characteristics of the radioisotopes in question. Generally, except for uranium, the toxicological effects of radionuclides are much less than the carcinogenic effects from radiation. Estimates of risk are taken from the National Academy of Sciences report BEIR V (National Research Council, 1990). The data from Japanese victims of atomic weapons are the most important data in their analysis. Thus their estimates are extrapolations from persons exposed to doses of 10,000 mrem or more in a very short period of time. BEIR V estimates cancer fatalities per 100,000 individuals for continuous lifetime doses of 100 mrem/year to be 600 for females and 520 for males. Averaging the results of the two sexes, a continuous lifetime radiation exposure of 100 mrem per year results in a excess cancer death rate of 560 deaths per 100,000 persons.

There is much debate over the validity of extrapolating the effects and risks seen at high radiation doses to doses below background levels. Some researchers claim that the risks are significantly higher than the linear response estimates. Others claim that the risks are significantly lower. However, the only claim that can be made with certainty is that the risk of cancer at radiation doses below about 10,000 mrem is so small that no one has been able to unambiguously measure it.

Most radiation protection organizations view the linear response relationship as a conservative, or protective, estimate of risk from radiation (National Council on Radiation Protection Report #39, 1971; National Research Council, 1990). It should be noted that the uncertainty of the linear extrapolation is sufficiently great that the risk of very low levels of radiation may be zero. As stated in BEIR V: "The possibility that there may be no risks from exposures comparable to external natural background radiation cannot be ruled out. At such low doses and dose rates, it must be acknowledged that the lower limit of the range of uncertainty in the risk estimates extends to zero.".

The International Commission on Radiation Protection in 1990 expanded upon the BEIR V statement above and has concluded that there is sufficient evidence to quantify a reduction factor for low doses and low dose rates for radiations of low linear energy transfer (such as beta and gamma rays) (ICRP 60, 1990). The reduction factor is called the dose and dose rate effectiveness factor (DDREF) and reduces the probability estimates by a factor of 2. This reduction factor applies to low doses of less than 20,000 mrem and from higher doses when the dose rate is less than 10,000 mrem/hour. The DDREF can certainly be applied to the elevated environmental radiation levels found at the Hanford Site. This low dose and dose rate is also thought of as a chronic dose rate, or occurring over a long period of time. The background radiation dose received from natural sources can also be thought of as a chronic dose and dose rate. Applying this reduction factor to the BEIR V estimates of 100 mrem/yr continuous exposure would result in a revised excess cancer death rate of 280 persons per 100,000 persons.

APPENDIX B

INSTRUMENT COMPARISONS

The instruments used for the report vary in what they measure. Specifically, the μR meter measures in roentgen, or exposure rate. The PIC measures in units of absorbed dose (rad) or in dose equivalent units (rem). The other instruments, the μrem and the TLD, both measure in dose equivalent units. The rad and the rem equate with the use of a quality factor which factors in the biological effectiveness of a type of radiation. For gamma and x-ray radiation, the quality factor is one. So, for the radiation of interest in this report, the absorbed dose (rad) and the equivalent dose (rem) are the same.

In order to equate a μR meter reading to that of the other instruments, the exposure rate must first be converted to absorbed dose. where one roentgen equals the dose of 0.95 rad in soft tissue (the muscles and organs of the body). To further complicate this conversion, the accuracy of the μR meter diminishes in the presence of low energy gamma rays. For the external dose along the shoreline of the 100N Area, this correction factor can range two to five times higher than the absorbed dose. Due to the larger relative uncertainties (in comparison to the direct readings from the other instruments) in correcting the μR meter to units of equivalent dose, these steps were not performed. For ease of review, the survey section reports all results in terms of exposure rate (as the roentgen is roughly equivalent to a rad (1R=0.95 rad). The dose assessment sections, which contain no μR meter results, are reported and calculated in units of dose.

Instruments can also be segregated based upon the integration time of the result. Both the μR and μrem meters integrate their results over a short time constant (roughly 5-15 seconds). TLDs and PICs, on the other hand, integrate the results over a longer period of time. For the TLD, the time period of integration is generally 3 months. The PIC's integration period can vary from a short time average to fractions of an hour, depending upon the setting. Integrated measurements over longer period of time are more appropriate when the dose rate varies significantly with time. Efforts can be made to improve the accuracy of a μR and μrem meter by taking multiple readings in a single location over a period of time. By taking the average of multiple reading, even if over a short period of time, a simple time-weighted average is developed.

Longer time integrating instruments or devices are not without their own source of errors. TLDs for example: can degrade if subjected to high temperatures; fade to varying degrees over time (Velbeck, 1993); have varying relative responses for each type of TLD depending upon the incident gamma energy (Knoll, 1989); and can have errors introduced during pre and post preparation procedures. Errors for TLDs are nominally 20% of the result (two standard deviations).

Pressurized Ion Chambers are heavy, bulky instruments and are therefore limited in their mobility in rough terrain. When used, however, PICs generally provide an accuracy comparable to the random fluctuations of the source.

Comparison of μR and μrem Meters

The two peaks in Figure 2 aid in the explanation of why a μrem meter is chosen for dose assessments over the μR meter. A rough determination of the photon energy from the sources can also be deduced from Figure 2. The first, narrower peak, corresponds to the Emergency Dump Tank. The height of this peak as recorded on the μR meter, is 85 μR/hr. The height of the second peak, from the LWDFs, is 120 μR/hr. If only the information from the μR meter were available, the logical inference would be that the LWDFs would have a higher exposure rate. However, a review of the μrem meter data plotted beneath the μR results shows that the true exposure rate is much less. The proof of the accuracy of either instrument lies in the relative response curves. Figure B-1 graphs the manufacturer's supplied relative energy responses of both instruments. The closer an instrument's response curve is to 1 on the relative response axis the more accurate that instrument is. The μrem meter's curve is relatively flat, particularly when compared with the μR meter.

The μR meter's response curve is sloped. The μR meter, calibrated to cesium-137 with an energy of 661.6 keV, is more efficient at recording energies less than the calibration energy. The μR meter's relative efficiency can best be explained by understanding how the sodium iodide (NaI) crystal of the μR meter functions with energy. For example, a 1" by 1" NaI crystal is normally 10% to 15% efficient at recording incident energies in the energy range of cesium-137. As the energy of the incident photon is reduced, the NaI crystal is more effective at capturing the photon, thereby improving the efficiency. The NaI crystal, for incident photon energies of 200 keV for example, would now have a 50% to 75% efficiency. Since the μR meter was calibrated to correctly record cesium-137 energies, that same instrument will now read 5 times higher than an instrument designed to correctly respond to 200 keV energies.

With the knowledge of the operation of the μR meter and the difference in the results of the two instruments, a determination of the approximate energy of the incident photons can be made. Near the shoreline of the LWDFs, the readings of the μR meters were almost 5 times higher than the μrem meter. Assuming the μrem meter, a plastic scintillation detector, is recording accurately, the approximate energy of the incident photons is slightly greater than 200 keV. A review of

Figure B-2 (Rathbun, 1989), a gamma distribution on the 100N shoreline, also supports the conclusion that the average Compton energy is approximately 200 keV. This energy range corresponds to the expected Compton scatter energy range from the LWDFs. The difference between the instrument results at the shoreline near the 1304-N tank is approximately 2.5. This corresponds to an energy of approximately 350 keV. This is a higher average energy than expected from skyshine and would indicate a greater direct exposure from the Emergency Dump Tank. As the tank is located directly above the slope of the shoreline, this summation is consistent with the physical geometry.

The results of the μR and μrem meters are positively correlated in elevated radiation fields. Using the exposure rates available during the shoreline survey of the 100N Area (10 μR/hr to 30 μR/hr), a very strong correlation was shown to exist ($r = 0.95$) between the two instruments. Figure B-3 displays the regression line for the data obtained from the 100N area survey. The 1992 PNL shoreline survey found a poor correlation existed for exposure rates between 4 μR/hr and 18 μR/hr for the two instruments ($R = 0.45$). The results of the two instruments along the 1994 DOH opposite shoreline survey also indicated a poor correlation ($r = 0.36$). The exposure rates for the opposite shoreline were less than 12 μR/hr. Inferences made from one instrument to the other should be limited to elevated radiation fields.

Comparison of μrem Meters to TLDs

The Washington Department of Health has placed a TLD along the N area shoreline for the past 4 years. WHC and PNL have both placed TLDs in several locations along the 100N shoreline for numerous years. All three organizations have TLDs located in the immediate vicinity of field location 42-43 of the survey (see Figure 2) (the PNL TLD is located closer to the river than the other TLDs, potentially receiving a greater amount. The third quarter results for the TLDs and the μrem meter are summarized in Table B-1. In order to accurately compare the TLD with the observed dose rate readings, only the μrem meter was used (see discussion above). For the time period in which the survey was performed, the average of the three TLDs was .59 +/- .1 mrem/day. The results for the TLDs and the μrem meter are within the expected accuracy of the, indicating the μrem meter can be relied upon to be an accurate predictor of dose rates.

Figure B-1. Instrument Relative Energy Response

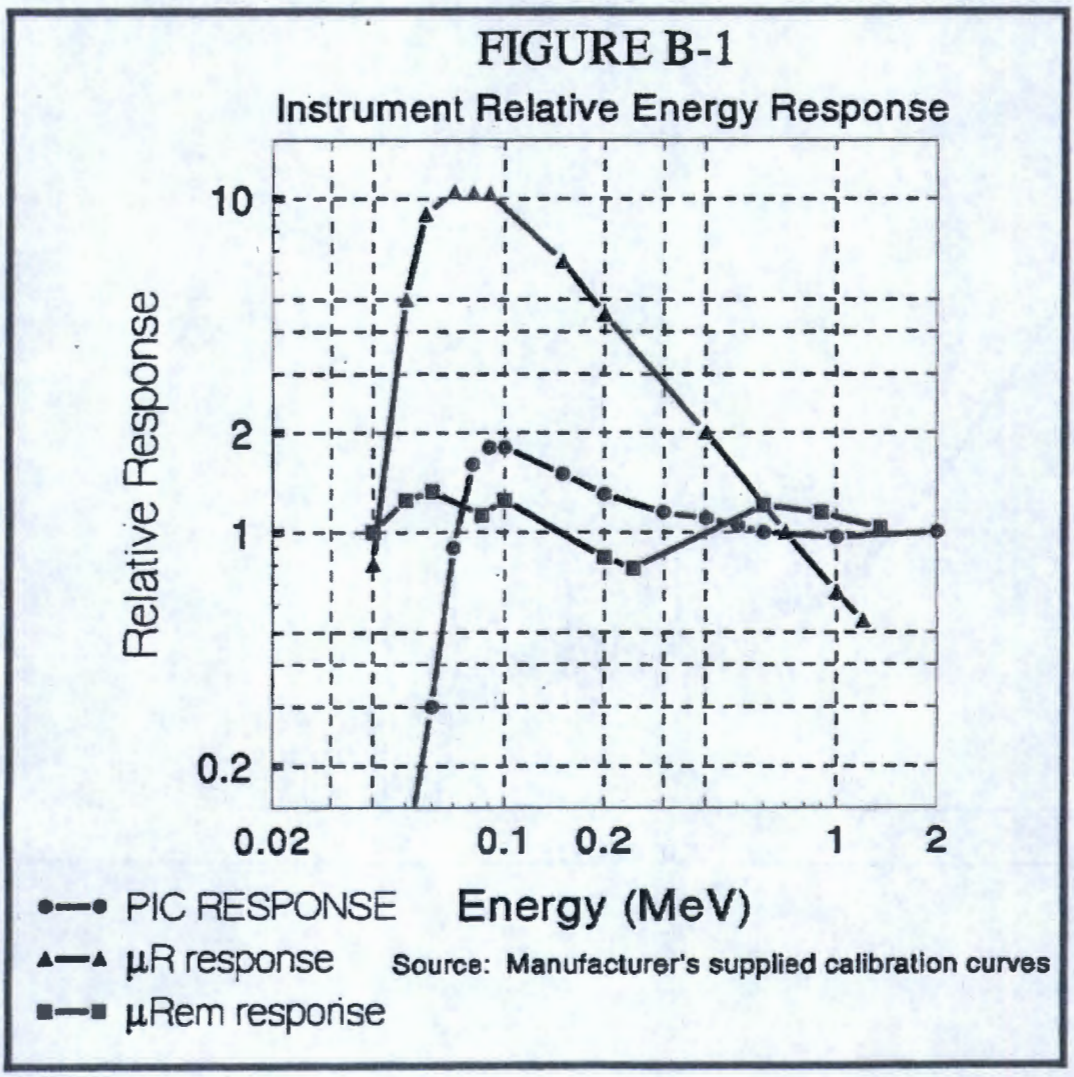


Figure B-2. 100N Area Gamma Spec Distribution (Source: Rathbun, 1989)

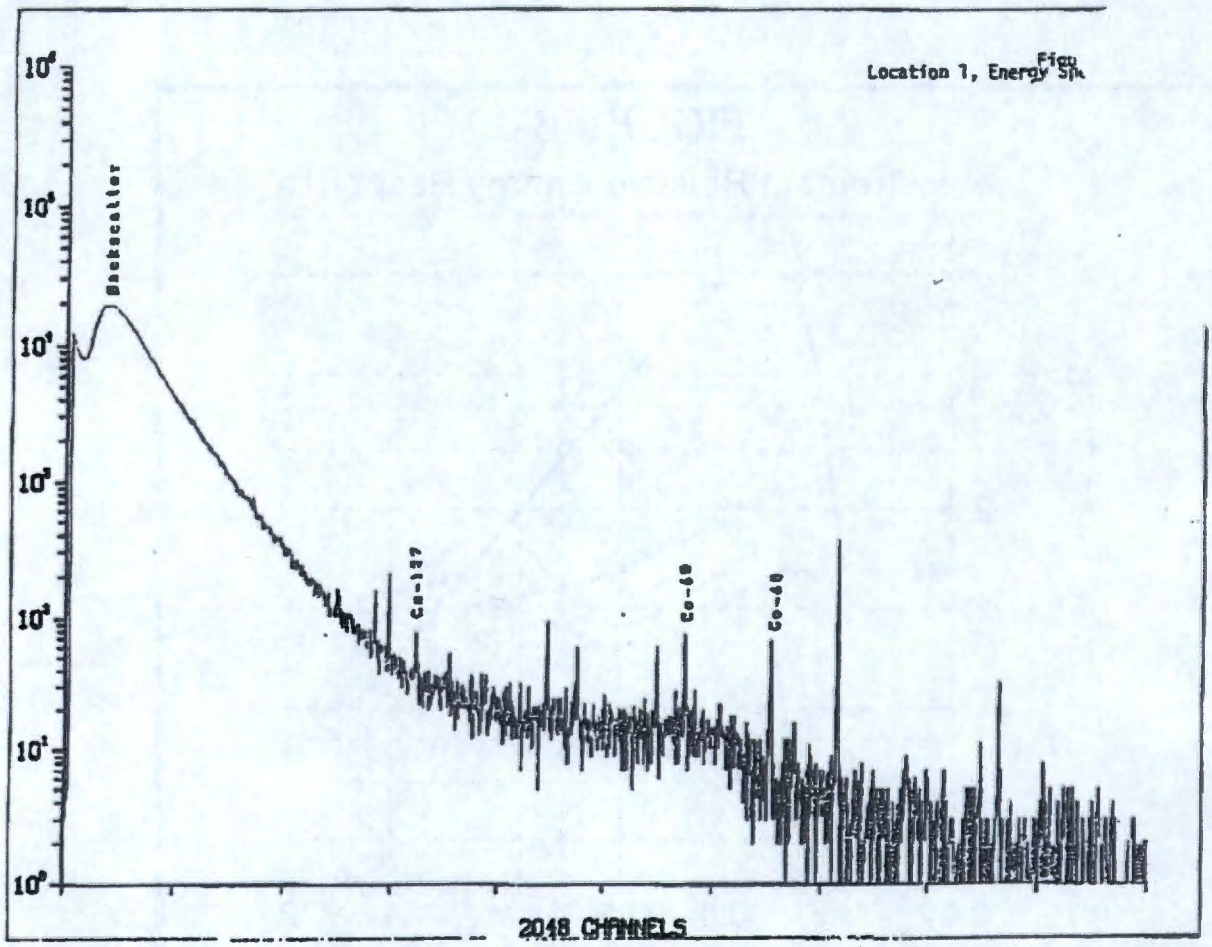


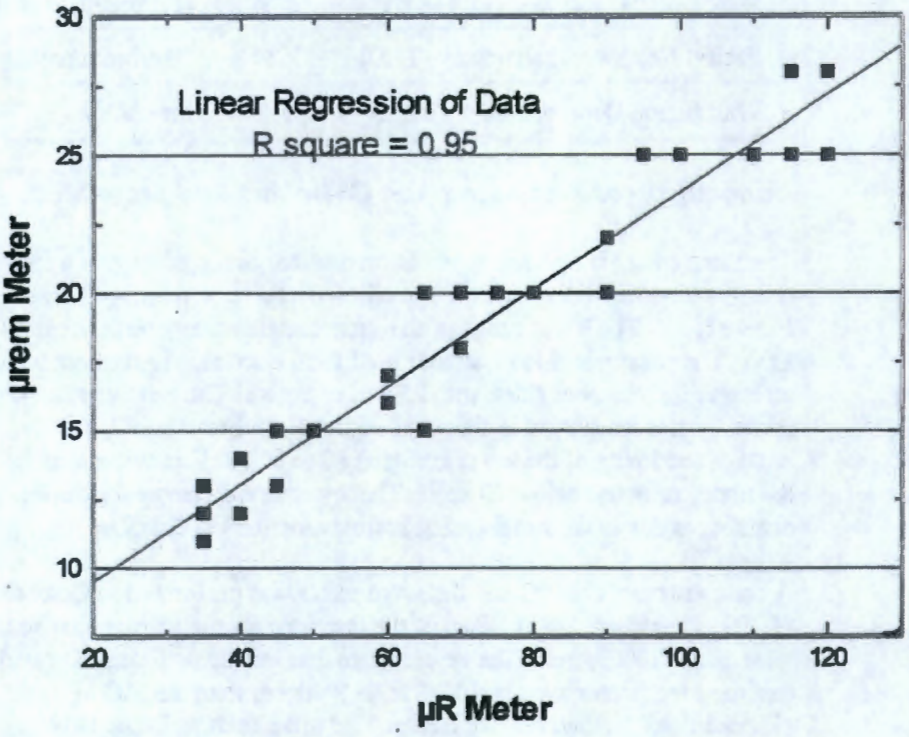
Table B-1 Comparison of TLDs to μrem Meter Results	
Washington Dept. of Health (TLD)	.59 +/- .13 mrem/day
Westinghouse Hanford Co. (TLD)	.576 +/- .1 mrem/day
Pacific Northwest Laboratory (TLD)	.624 +/- .114mrem/day
Washington Dept. of Health (μrem)	.5 +/- .1 mrem/day

Comparison of Pressurized Ion Chambers and μrem Meter

The μrem meter is a plastic scintillation detector designed to give a flat energy response over the range of environmental photon energies (see Figure B-1). The lower range of the μrem meters energy response is 40 keV. The pressurized ion chamber used is an electronic instrument with an ionization chamber filled with 25 atm of argon. The relative response curve for this instrument is shown in Figure B-1. For the PIC, the relative sensitivity of the ion chamber at 80 to 300 keV is evident, as is the under-response below 70 keV. The lower cutoff energy for the ion chamber is due to the metal casing surrounding the ion chamber.

A comparison of the PIC and the μrem meter was performed in October of 1991 (Thatcher, 1992). Two of the locations for the intercomparison were in the 100N Area. The results from that intercomparison indicated that the μrem meter averaged 17% to 29% higher than the PIC in elevated fields. However, for background areas such as Leslie Groves Park in Richland, the μrem meter under-responded to the PIC by approximately 30%. This response difference at background exposure rates was further substantiated by the results obtained in the 1995 survey of the opposite 100N shoreline (see Figure 5).

Figure B-3. 100N Area Survey Data



APPENDIX C

FURTHER DISCUSSION ON ESTIMATED REDUCTIONS IN DOSE RATES

As stated in the test, skyshine from the 100N area represents the highest accessible exposure potential to the public from the Hanford Site. This exposure rate will decrease due to decay over time. A review of the inventory of the 1301-N LWDF indicates that there were approximately 2300 curies of cesium-137 and 1200 curies of cobalt-60 remaining in 1995. Using the shielding of the 4 inches of reinforced concrete and the approximate Compton energies of the scattered photons, the predicted decay curve for the dose from the 1301-N LWDF is shown in Figure C-1. The reduction in dose contribution from cobalt-60 as compared with cesium-137 is due solely to the much shorter half life of cobalt-60. For a discussion of radioactive decay, please refer to Appendix A. The dominance of the cobalt-60 contribution to dose from the 1301-N LWDF can be observed until the year 2000. Using the decay rate from Figure C-1, the estimated dose rate adjacent to the 1301-N LWDF in the year 2000 would be approximately 20 μrem/hr (including background), or about 65% of the currently observed rate. Past the year 2000, cesium-137 becomes the major contributor to dose as the combined decay curve begins to conform with the decay rate of cesium-137. It is important to note that these reduction estimates do not take into account the continued migration of contaminants into the soil column. Any contaminate migration would result in a further reduction of the estimated dose rate.

The 1325-N LWDF also contributes to the observed exposure rate along the 100N shoreline. Figure C-2 shows the predicted combined and individual decay rates for cesium-137 and cobalt-60. This decay rate is based upon the inventory of the 1325-N LWDF, the 4 inches of concrete shielding, the approximate Compton energies of the reflected photons and the increased distance of the 1325-N LWDF in comparison to the 1301-N LWDF from the site borders. The cross-over point of the two radionuclides is estimated to occur in the year 2007. This difference in cross-over points between the two LWDFs can be attributed to the 1325-N LWDF continuing to receive radioactive discharges for several years beyond the closure of 1301-N, resulting in a higher relative percentage of cobalt-60 to cesium-137. The relative contribution of the two disposal facilities can also be obtained from Figures C-1 and C-2. According to the DOH estimates, the 1325-N LWDF contributes approximately 5% of the total exposure rate observed along the 100N shoreline.

As Figure 2 indicates, there are two skyshine peaks located along the 100N shoreline. The dominant peak and its future impact adjacent to the LWDFs was predicted above. For the shoreline near the Emergency Dump Tank, cesium-137 contamination should begin to dominate the observed dose sooner than the year 2004. This difference

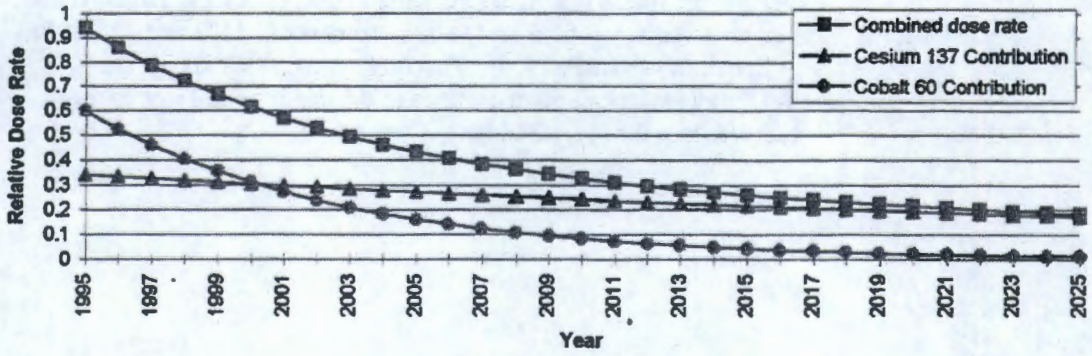


FIGURE C-1: 1301-N LWDF RELATIVE CONTRIBUTION TO DOSE RATE ALONG 100N SHORELINE

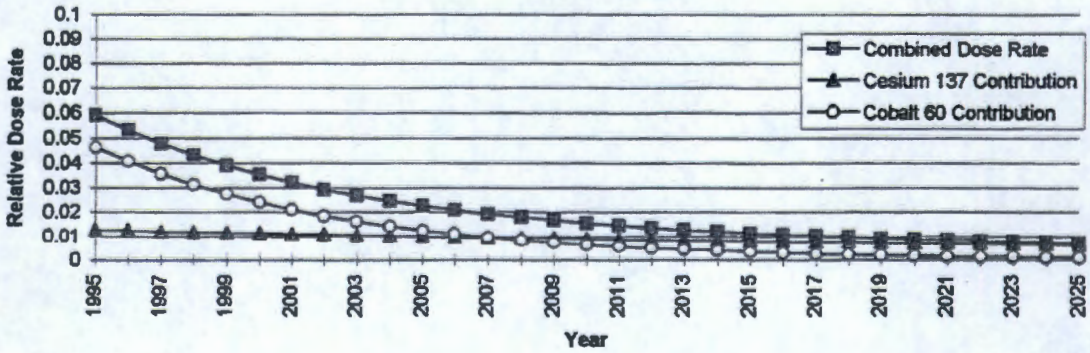


FIGURE C-2: 1325-N LWDF RELATIVE CONTRIBUTION TO DOSE RATE ALONG 100N SHORELINE

in cross-over points is due to the lack of shielding at the source near the Emergency Dump Tank (the metal casing of the tank would provide less than a 10% attenuation factor). For the LWDFs, the 4 inches of concrete shielding provides preferential shielding to the cesium-137 radiation due to its lower energy (661.6 keV versus two peaks of 1171 and 1332.5 keV for Cobalt-60) (NCRP, 1976). This preferential shielding for the LWDFs allows cobalt-60 to continue as the major contributor to the observed dose for several additional years.

GLOSSARY

Compton scattering - The elastic scattering of a photon by an essentially free electron.

Cosmic radiation - High-energy subatomic particles and electromagnetic radiation from outer space that bombard the earth. Cosmic radiation is part of natural background radiation.

Curie (Ci) - A unit of radioactivity equal to 37 billion (3.7×10^{10}) nuclear transformations per second.

Dose Equivalent - A quantity used to express all radiations on a common scale. Dose equivalent is the absorbed dose to a person multiplied by a biological effectiveness factor for the type of radiation, measured in rem.

Exposure - Subjecting a target (usually living tissue) to radiation or chemicals. Also used as a term describing external radiation air ionization (See "Roentgens")

Fallout - radioactive materials that are released into the earth's atmosphere following a nuclear explosion or atmospheric release and that eventually fall to earth.

Half-life - Length of time in which a radioactive substance will lose one-half of its radioactivity by decay. Half-lives range from a fraction of a second to billions of years and each radionuclide has a unique half-life. For example, ^{90}Sr and ^{137}Cs have half-lives of roughly 30 years. Others decay more slowly, such as ^{239}Pu with a half-life of 25,000 years.

Maximally Exposed Individual - a hypothetical member of the public residing near a facility who, by virtue of location and living habits, could receive the highest possible radiation dose from radioactive effluents released from that facility.

Millirem (mrem) - A unit of radiation dose equivalent that is equal to one one-thousandth (1/1000) of a rem.

Radiation - The energy emitted in the form of rays or particles, such as those thrown off by transforming (disintegrating) atoms. For this report, radiation refers to ionizing types of radiation; not radiowaves, microwaves, radiant light or other types of non-ionizing radiation. The ionizing rays or particles typically consist of alpha, beta, or gamma radiation.

- **Alpha radiation** - Least penetrating type of radiation. Alpha radiation can be stopped by a sheet of paper or the outer dead layer of skin, and can cause biological damage only if sufficient quantities are emitted inside the body.

- **Beta radiation** - One form of radiation emitted from a nucleus during radioactive decay. Beta radiation can be stopped by an inch of wood or a thin sheet of aluminum and may cause biological damage if a sufficient amount is internal, or occasionally external, to the body.

- **External radiation** - Radiation originating from a source outside the body.

- **Gamma radiation** - Form of electromagnetic, high-energy radiation emitted from a nucleus. Gamma rays are essentially the same as x-rays. They require heavy shielding, such as lead or steel, to be stopped and may cause biological damage when originating internally or externally to the body in sufficient amounts.

- **Internal radiation** - Radiation originating from a source within the body as a result of the inhalation,

ingestion, skin absorption or implantation of natural or anthropogenic radionuclides in body tissues (e.g., uranium dust in the lungs, radioiodine in the thyroid).

Photoelectric effect - The interaction of a photon with an atom, resulting in the absorption of the incident photon and the release of a bound electron from that atom with energy equal to the photon energy less the electron binding energy.

Radionuclide - Radioactive atomic species or isotope of an element. There are several hundred known radionuclides, both anthropogenic and naturally occurring. Radionuclide and radioisotope are terms that are sometimes used interchangeably, although they are theoretically different terms.

Rem - a unit of dose equivalent (see definition of dose equivalent).

Roentgen - Unit of x-ray or gamma radiation exposure in air, typically used for describing external radiation levels. An exposure of 1 roentgen (R) is approximately equal to 1 rem dose to human tissue.

Thermoluminescent dosimeter (TLD) - A material that, after being exposed to beta and/or gamma radiation, emits light when processed and heated. The amount of light emitted is proportional to the amount of radiation (dose) to which the TLD has been exposed.