ATSDR
AGENCY FOR TOXIC SUBSTANCES AND DISEASE REGISTRY

Public Health Assessment for

THE HANFORD SITE
(a/k/a HANFORD 100-Area (USDOE), HANFORD 200-Area (USDOE), and HANFORD 300-Area (US DOE))
RICHLAND, BENTON COUNTY, WASHINGTON
EPA FACILITY ID: WA3890090076, WA1890090078, WA2890090077
OCTOBER 16, 2006

For Public Comment

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
PUBLIC HEALTH SERVICE
Agency for Toxic Substances and Disease Registry

Comment Period Ends:

NOVEMBER 30, 2006

THE ATSDR PUBLIC HEALTH ASSESSMENT: A NOTE OF EXPLANATION

This Public Health Assessment-Public Comment Release was prepared by ATSDR pursuant to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund) section 104 (i)(6) (42 U.S.C. 9604 (i)(6), and in accordance with our implementing regulations (42 C.F.R. Part 90). In preparing this document, ATSDR has collected relevant health data, environmental data, and community health concerns from the Environmental Protection Agency (EPA), state and local health and environmental agencies, the community, and potentially responsible parties, where appropriate. This document represents the agency's best efforts, based on currently available information, to fulfill the statutory criteria set out in CERCLA section 104 (i)(6) within a limited time frame. To the extent possible, it presents an assessment of potential risks to human health. Actions authorized by CERCLA section 104 (i)(11), or otherwise authorized by CERCLA, may be undertaken to prevent or mitigate human exposure or risks to human health. In addition, ATSDR will utilize this document to determine if follow-up health actions are appropriate at this time.

This document has previously been provided to EPA and the affected state in an initial release, as required by CERCLA section 104 (i) (6) (H) for their information and review. Where necessary, it has been revised in response to comments or additional relevant information provided by them to ATSDR. This revised document has now been released for a 30-day public comment period. Subsequent to the public comment period, ATSDR will address all public comments and revise or append the document as appropriate. The public health assessment will then be reissued. This will conclude the public health assessment process for this site, unless additional information is obtained by ATSDR which, in the agency's opinion, indicates a need to revise or append the conclusions previously issued.

Agency for Toxic Substances and Disease Registry.....Julie L. Gerberding, M.D., M.P.H., Administrator
Howard Frumkin, M.D., Dr.P.H., Director

Division of Health Assessment and Consultation……..William Cibulas, Jr., Ph.D., Director
Sharon Williams-Fleetwood, Ph.D., Deputy Director

Cooperative Agreement and Program Evaluation Branch ..... Richard E. Gillig, M.C.P., Chief

Exposure Investigations and Site Assessment Branch…….……..…..Susan M. Moore, M.S., Chief

Health Promotion and Community Involvement Branch……...Susan J. Robinson, M.S., Chief

Site and Radiological Assessment Branch…….……....Sandra G. Isaacs, B.S., Chief

Use of trade names is for identification only and does not constitute endorsement by the Public Health Service or the U.S. Department of Health and Human Services.

Please address comments regarding this report to:

Agency for Toxic Substances and Disease Registry
Attn: Records Center
1600 Clifton Road, N.E., MS E-60
Atlanta, Georgia 30333

You May Contact ATSDR Toll Free at
1-800-CDC-INFO or
Visit our Home Page at: http://www.atsdr.cdc.gov

PUBLIC HEALTH ASSESSMENT

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Prepared by:

Site and Radiological Assessment Branch
Division of Health Assessment and Consultation
Agency for Toxic Substances and Disease Registry

This information is distributed by the Agency for Toxic Substances and Disease Registry for public comment under applicable information quality guidelines. It does not represent and should not be construed to represent final agency conclusions or recommendations.

Foreword

The Agency for Toxic Substances and Disease Registry (ATSDR) was established by Congress in 1980 under the Comprehensive Environmental Response, Compensation, and Liability Act, also known as the *Superfund* law. This law set up a fund to identify and clean up our country's hazardous waste sites. The US Environmental Protection Agency (EPA) and the individual states regulate the investigation and cleanup of the sites.

Since 1986, ATSDR has been required by law to conduct a public health assessment at each of the sites on the EPA National Priorities List (NPL). The aim of these evaluations is to find out if people are being exposed to hazardous substances and, if so, whether the exposure is harmful and should be stopped or reduced. If appropriate, ATSDR also conducts public health assessments when petitioned by concerned individuals. Public health assessments are carried out by environmental and health scientists from ATSDR and from the states with which ATSDR has cooperative agreements.

Exposure: As the first step in the evaluation, ATSDR scientists review environmental data to see how much contamination is at a site, where it is, and how people might come into contact with it. Generally, ATSDR does not collect its own environmental sampling data. Instead, the agency reviews information provided by EPA, other government agencies, businesses, and the public. When there is not enough environmental information available, the report indicate what further sampling data are needed.

Health Effects: If the review of the environmental data shows that people have or could come into contact with hazardous substances, ATSDR scientists then evaluate whether or not these contacts will result in harmful effects. ATSDR recognizes that children, because of their play activities and their growing bodies, may be more vulnerable to these effects. As a policy, unless data are available to suggest otherwise, ATSDR considers children to be more sensitive and vulnerable to hazardous substances. Thus, the health impact to the children is considered first when evaluating the health threat to a community. The health impacts to other high risk groups within the community (such as the elderly, chronically ill, and people engaging in high risk practices) also receive special attention during the evaluation.

ATSDR uses existing scientific information, which can include the results of medical, toxicological, and epidemiologic studies and the data collected in disease registries to evaluate possible health effects that may result from exposures. The science of environmental health is still developing, and sometimes scientific information on the health effects of certain substances is not available.

Community: ATSDR also needs to learn what people in the area know about the site and what concerns they may have about its impact on their health. Consequently, throughout the evaluation process, ATSDR actively gathers information and comments from the people who live or work near a site, including residents of the area, civic leaders, health professionals and community groups. To ensure that the report responds to the community's health concerns, an

early version is also distributed to the public for its comments. All the public comments that are related to the document are addressed in the final version of the report.

Conclusions: The report presents conclusions about public health threat posed by a site. Ways to stop or reduce exposure will then be recommended in the public health action plan. ATSDR is primarily an advisory agency, so usually these reports identify what actions are appropriate to be undertaken by EPA or other responsible parties. However, if there is an urgent health threat, ATSDR can issue a public health advisory that warns people of the danger. ATSDR can also recommend health education or pilot studies of health effects, full-scale epidemiology studies, the creation of disease registries, surveillance studies, or research on specific hazardous substances.

Comments: If, after reading this report, you have questions or comments, we encourage you to send them to us. Letters should be addressed as follows:

Attention: Manager, ATSDR Records Center
Agency for Toxic Substances and Disease Registry
1600 Clifton Road (E-60)
Atlanta, GA 30333

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1.1 Health Implications

1.1.1 Health Implications from Past Exposures

Although there have been past releases and exposures, substantial controversy remains over the actual doses individuals received and the potential health effects at those doses. Given the uncertainties, ATSDR could not determine conclusively whether exposures to radioactive substances occurred off the Hanford property at levels sufficient to cause harmful health effects.

> ATSDR uses an ***indeterminate public health hazard*** category when a professional judgment about the level of health hazard cannot be made because data critical to such a decision is lacking.

To assess possible health implications of exposure to radioactive materials, primarily radioactive iodine (I-131), ATSDR reviewed the medical, epidemiologic, and radiologic literature. Most recent data include studies in thyroid-induced diseases from the Chernobyl reactor accident in 1986 and other reports describing the cancerous and noncancerous impacts on the thyroid. From these studies, ATSDR found enough evidence to conclude that individuals who were at least 21 years of age during the I-131 releases were probably not exposed to harmful levels of radioactive iodines that would induce thyroid disease or cancer. A review of these studies, however, indicates that younger individuals (under the age of 18) were more sensitive to the potential adverse health effects associated with the uptake of radioactive iodines by the thyroid. Because of the wide range of potential exposures and the uncertainties associated with historical reconstruction of the dose estimates, ATSDR cannot identify specific population groups of younger individuals who may have been impacted by past releases from the site.

ATSDR believes that individuals who were under the age of 18 during the I-131 releases and who also received a thyroid dose in excess of 10 rads (0.1 Gy) should be considered the critical, sensitive population. ATSDR recommends continued health education to inform those who lived in the Hanford region during the period of the I-131 releases — and their health care providers — about the potential health risks of exposure to I-131.

Latency Period

Health effects do not always appear immediately after exposure. A latency period — a time between the exposure and onset of health effects — can be 3 to 30 years or more. The most significant Hanford releases leading to off-site population

exposures occurred during the primary plutonium production era (1944–1972). Again, health effects, if any, from these exposures may not appear for several years or even for decades.

Hanford Environmental Dose Reconstruction Project

The Hanford Environmental Dose Reconstruction Project (HEDR) estimated doses from past off-site radioactive releases. The study indicated that the largest doses of radiation to residents surrounding the site were from iodine-131 released to air and deposited on pastures, and from other radionuclides released to air and deposited on soil or discharged into the Columbia River between December 1944 and December 1957.

The most important human radiation exposure pathway for iodine-131 was drinking milk from those cows and goats that grazed on contaminated pastures. The thyroid usually concentrates about 30% of the iodine taken into the body, with the remainder distributed throughout the body or excreted. By virtue of this concentration in the small thyroid gland, the relative radiation dose from I-131 to the thyroid is greater than that for any other organ of the body. Because the thyroids of children weigh less than adult thyroids, and because they may have consumed more milk than adults, their thyroid concentrations of I-131 may have been greater than those in adults. Thus, the thyroid dose to children may have been greater than doses to adult thyroids.

Infant Mortality

Finalized in November 2000, ATSDR's Infant Mortality and Fetal Death Analysis investigated the association between estimated I-131 exposure and infant mortality, fetal death, and pre-term birth. The study focused on I-131 releases during the years 1940–1952 and included the eight Washington counties in the HEDR project: Adams, Benton, Franklin, Grant, Kittitas, Klickitat, Walla Walla, and Yakima. The study used the HEDR project's 1945 exposure estimates for I-131 and found a 70% higher rate of preterm birth and a 30% higher rate of infant mortality in the areas with the highest estimates of I-131 exposures compared to areas with the lowest estimates of exposure. No association was found for fetal death. The direct mechanism associated with I-131 exposure of the mother and pre-term birth, and the mechanism associated with I-131 exposure of the mother and infant mortality, are not known.

Hanford Thyroid Disease Study (HTDS)

The Hanford Thyroid Disease Study (HTDS) analyzed whether an association could be found between exposure to I-131 and incidence of thyroid disease. The Study reported preliminary findings in January 1999, and released its final report in June 2002. Study participants included off-site populations that may have received the greatest exposures to I-131 as children. This study showed that the

incidence of thyroid diseases among the group studied was about the same as the expected incidence of thyroid disease in a similar group of children who were not exposed to I-131. Study results showed no correlation between the estimated dose to the thyroid from I-131 and the amount of thyroid disease in the study population, and that greater exposures to I-131 did not lead to a greater incidence of thyroid disease.

The findings did not prove healthy people living in the Hanford area during the 1940s and 1950s were not exposed to I-131 and other radionuclides, or that these exposures had no effect on their health. Rather, the study findings showed that if there were an increased risk of thyroid disease from exposure to Hanford's I-131, it was likely too small in number to identify using the best epidemiologic methods available, because thyroid disease occurs at low frequency in all populations, regardless of I-131 exposure. There may be individuals in the overall population who were exposed to Hanford radiation and who did develop thyroid disease because of their exposure.

Migrant Farm Workers

During the period 1942–1947, approximately 16,000 migrant workers harvested crops annually in the six-county area surrounding Hanford. In a study of the migrant workers and their families, Duffie and Willard (1997) concluded that migrant workers may have experienced an increased *daily* exposure to radiation through the air and water pathway as a result of

- time spent out-of-doors,
- exposure to soil and dust in the fields,
- drinking and swimming in local surface waters, and
- consuming locally grown food products.

Migrant workers' *annual* exposure, however, was less than the permanent population because they were only in the area from April 1 to November 1 each year.

Fish Consumption

Radionuclide releases into the Columbia River and subsequent radiation doses to people were greatest from 1956 through 1965, peaking in 1960. Most of the radioactivity was highly diluted by the high volumes of water in the Columbia River. However, some radionuclide concentration occurred in Columbia River fish consumed by local populations. Depending on scenario, this could have led to varing radiation doses to consumers of Columbia River fish. The radiation doses to people during the period 1956 to 1965 may be compared to current recommendations of national and international scientific committees (such as the NCRP and the ICRP), or compared to U.S. federal regulations for limiting exposure of the general public ((10 CFR 20) to 500 mrem for any 5-year period,

or a lifetime average of 100 mrem per year. HEDR project results indicated that consumption of five or more 6-ounce meals of *resident* fish (catfish, bass) per week during the 1950s and 1960s could have resulted in doses greater than 100 mrem per year. However, the consumption of fish that do not remain permanently in the area, such as salmon and steelhead trout that spend most of their time in the ocean, would not result in radiation doses greater than 100 mrem to members of the public consuming the same amounts of fish, because the non-resident fish spent more than 80% of their lives in the oceans and did not concentrate the same amounts of radionuclides.(ICRP 1977, 1990b; NCRP, 1993; TSP 1994).

1.1.2 Health Implications from Current Exposures

People are currently exposed to low-level contaminants from past Hanford Site operations and these exposures are documented in the annual Hanford Site environmental reports. For many of these pathways, ATSDR has determined that these exposures represent no health threat because contact with the contaminants is negligible or infrequent.

Groundwater

The Hanford Site has extensive monitoring of radioactive contaminants in groundwater. The tritium plume that originated from early (1940s) Hanford Site operations and waste disposal in the 200-East Area extends south-easterly to the 600-Area central landfill, parts of the area occupied by Energy Northwest, to the Columbia River and into the 400-Area (Fast Flux Test Facility). On-site groundwater that is used as a drinking water at the Fast Flux Test Facility contains tritium a concentration that exceeds State of Washington standards, but the 400-Area water system, which mixes water from several wells, does meet drinking water standards.

Seeps and Springs

Both DOE and private organizations have documented contamination in seeps and springs along the Columbia River (such as the H-, K- and N-Springs in the 100-Area). Contaminants detected above drinking water standards include chromium, gross beta, strontium-90, and tritium. Uranium concentrations may also exceed a proposed EPA drinking water standard. Some “Danger: Radioactive” signs are present in these area and public access is not permitted. If people drank the water in these seeps and springs, or their skin came in contact with the sediments, they could contact groundwater contaminants above health screening levels. Still, because these areas are isolated and fenced, and public access is controlled, exposure through this pathway is expected to be infrequent and therefore does not represent a public health threat.

Columbia River

Hanford Site discharges or releases to the Columbia River are negligible compared to earlier times when the single-pass cooling systems were used on plutonium-production reactors at the North end of the Site. Therefore, people are not currently being exposed to contaminants in river water — including water used for drinking supplies — at levels expected to cause adverse health effects. The River and all public water supplies are monitored to ensure public safety. People may be occasionally exposed to residual radioactivity along the shoreline and in river- bottom sediments when the sediments are stirred up through boating, dredging or other activities. However, most of the activity released during earlier reactor operations has decayed away or has been collected for safe disposal. Therefore, the Columbia River does not currently represent a source of significant radiation exposure to members of the public.

Plants and Animals

Sr-90 and chromium levels have been identified as possible concerns regarding the health of young salmon redds in the Columbia River near the 100-Area. Although contaminants have also been found above screening comparison levels in tumbleweed, in yarrow, in mulberries, and in mice, current consumption of contaminated plants and animals through subsistence or other uses (e.g., in traditional medicines) is infrequent. Accordingly, such infrequent consumption is not expected to cause adverse health effects.

Soil

A number of contaminants exceeded levels of possible health concern in Hanford soils in the early 1990s. Two of these, Sr-90 and Ce-137, were found at low levels (near detection limits) in on-site soil in 1998. Contaminants in soil in the early 1990s have either since been removed and replaced with clean soil, or the levels of contaminants were of minimal concern for public exposure. Concerns have been expressed about the potential effects of children playing in contaminated soil, but no children have access to these areas. Standards for Hanford Site cleanup determine the actions being taken for Site-wide removal and disposal of contaminated soils. Future access to soils with residual contamination may be restricted.

1.1.3 Health Implications from Future Exposures

ATSDR identified four potential future exposures that could constitute public health hazards. At present, institutional controls limit public access and therefore no exposure takes place. Future exposures could only occur if institutional controls were removed and members of the general public were allowed to be exposed to residual contaminants at the Site.

Groundwater

At some locations, the on-site groundwater levels exceed EPA drinking water standards for many substance, including antimony, arsenic, carbon-14, carbon tetrachloride, cesium-137, chloroform, cobalt-60, and tritium. This highly contaminated groundwater would not be safe to use as a future drinking water source.

Subsistence Land Use

ATSDR identified two substances, lead and silver, that might affect the health of future Hanford Site residents or subsistence food users. The health implications of these substances include

Lead. Future farming and hunting in the contaminated parts of the Hanford Site could results in intakes of lead, which might affect the amount of lead ingested. The scenario considered most important would involve traditional native American preparation of food by wrapping food with contaminated soils. The population most at risk for lead intake is children. Lead levels in wild animals hunted for food are negligible and not considered a source of lead ingestion. Very high levels of lead ingestion would be needed to produce the harmful effects associated with lead ingestion, including neurological impairment, hearing and intelligence quotient (IQ) deficits, and slow growth in children.

Silver. If contaminated parts of Hanford return to tribal use, it is possible that some of the people who eat food prepared by traditional tribal methods involving encasing the food in soil could assimilate silver. The effects of elevated silver ingestion include argyria, which is grey and blue-grey spots on the skin. There is no evidence that argyria interferes with people's health, well being, or other normal functioning.

If land uses or future contamination levels change, the substance-specific health implications would change. ATSDR would then need to review data on contamination levels present at that time.

1.2 Public Health Action Plan

The public health action plan is presented in Chapter 9 and describes actions designed to mitigate and to prevent adverse human health effects resulting from exposure to hazardous substances in the environment.

1.2.1 Health Education

Hanford Community Health Project

The Hanford Community Health Project (HCHP) is an outreach and education initiative sponsored by ATSDR since 1999. The project provided educational information and materials about potential health risks to individuals who were exposed as young children to past releases of I-131 between 1944 and 1951. Through its Web-page, www.hanfordhealth.info, and other outreach efforts, the HCHP worked to make information and educational materials about health risks of exposure to I-131 available to people who lived in the Hanford region during the period of the I-131 releases. The Web site makes available materials that have been developed by several government agencies including, the Agency for Toxic Substances and Disease Registry (ATSDR), the Hanford Health Information Network, Centers for Disease Control and Prevention (CDC), and the National Cancer Institute (NCI).

Radioactive I-131 from Fallout

Hanford was not the only source of I-131 releases that affected populations in Washington State. The largest releases of I-131 in the United States were from the Nevada Test Site. People living downwind of Hanford received radiation doses from both the Hanford Site and the Nevada Test Site. The National Cancer Institute (NCI) has developed a Web site, http://i131.nci.nih.gov/, to provide information on releases from the Nevada Test Site.

1.2.2 Health Studies

Birth Cohort Study

ATSDR conducted the Hanford Birth Cohort study in response to community concerns that autoimmune function and cardiovascular disease health effects may have resulted from exposure to radioactive releases, mainly I-131. The study found that men born near the Hanford site between 1945 and 1951 had a small increased risk of developing thyroid disease – Hashimoto's thyroiditis, a condition that occurs when the thyroid gland makes too little thyroid hormone. The percentage of women reporting Hashimoto's thyroiditis was consistent in all counties surveyed. The study did not find a link between I-131 and autoimmune and cardiovascular diseases in either men or women. Although study participants reported some health problems more often than the general population, other factors such as diet, lifestyle and work history make it difficult to determine if their exposure to radiation is a cause for these findings.

The preliminary study findings were presented at an ATSDR-sponsored public availability session on July 26, 2006 in Richland, Washington. The final report is expected to be released in October 2006. The complete study can be found online at http://www.atsdr.cdc.gov/hanford.

1.2.3 Toxicological Profiles

The radioactive substances released during past Hanford operations for which ATSDR has prepared toxicological profiles includes:

- Iodine (including I-131),
- Cesium (including Cs-134 and Cs-137),
- Strontium (including Sr-89 and Sr-90),
- Cobalt (including Co-57, Co-58, and Co-60),
- Tritium, and
- Thorium.

As funding is provided, ATSDR plans to continue preparing toxicological profiles for substances and their relevant radioactive isotopes. Old (1990) profiles for radium, radon, thorium, and plutonium are available, but these are limited in scope and contain dated material; significant newer material is available. The profile user will benefit when these four documents are updated with current science and enhanced to include sections now contained in current profiles (e.g., child health).

1.2.4 Actions Planned by the U.S. Department of Energy (DOE)

The Department of Energy will continue clean-up of the Hanford Site in accordance with the Hanford Federal Facility Agreement and Consent Order (May 15, 1989) between DOE, the U.S. Environmental Protection Agency (EPA) and the Washington Department of Ecology (WDOE). The Agreement sets forth the Site remedial action provisions and schedule for compliance with the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) and with the Resource Conservation and Recovery Act (RCRA). These provisions define the treatment, storage, and disposal, and other corrective actions for Site remediation. The Tri-Party Agreement defines and ranks the CERCLA and RCRA cleanup commitments, establishes organizational responsibilities, sets the budget, and sets forth enforceable milestones. Annual Tri-Party goals and accomplishments can be found at the Hanford Web site http://www.hanford.gov/

Remediation cleanup levels are set for future use as "industrial," rather than residential. The following institutional controls are planned to ensure industrial use:

- Placement of written notification of the remedial action in the facility land use master plan,
- DOE prohibition of activities that could interfere with remedial activity,
- EPA review of measures necessary to ensure continued restrictions before property transfer or lease,
- Notification to prospective property recipient before transfer or lease, and
- Provision of written verification to EPA that restrictions are in place.

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Introduction

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2.0 Chapter Summary

Site History

On February 9, 1943, the U.S. Undersecretary of War approved a plan to acquire more than 400,000 acres of South-eastern Washington State to the south and west of the Columbia River between today's Vernita Bridge and the Yakima River delta. On February 23, 1943, the U.S. District Court of Washington State, Southern Division, issued an order of possession. The first tract of land was acquired on March 10, 1943. The acquisition of this land, under eminent domain, affected grazing land for 18,000 to 20,000 sheep and 49,000 acres of farmland (Jones, 1985, pp 331–343).

The Hanford Site lies within lands ceded to the U. S. by the Confederated Tribes of the Umatilla Indian Reservation (Umatilla, Cayuse, and Walla Walla) and the Confederated Tribes and Bands of the Yakama Indian Nation. The Wanapums were removed from the Hanford area in 1943 and relocated to an area north of the Site near the current Priest Rapids Dams. Designation of the Hanford Site for the war effort removed it from tribal uses. Native Americans could no longer hunt, fish, or gather herbs in the area (DOE 1997b Section 3). Native Americans want re-access this land in the future.

For approximately 40 years, the 560 (originally 640) square-mile DOE Hanford Site in southeastern Washington was used to produce plutonium for atomic weapons. It also processed spent nuclear fuel and extracted plutonium and uranium for national defense. Because of wartime secrecy, few people knew the purpose of the Hanford Site or knew about its releases of radioactive and nonradioactive materials. These releases contaminated groundwater, the Columbia River, ambient air, and soil (HHIN1997).

Freedom of Information Act Request

In February 1986, the DOE responded to a request under the Freedom of Information Act for detailed information on past Hanford operations. DOE released 19,000 pages of previously classified or unavailable documents. The documents detailed Hanford's operating history and demonstrated its off-site releases of radioactive material, primarily iodine-131 to the atmosphere. The documents revealed that some of the releases of radioactive materials from Hanford were planned as part of scientific study, and that these and other releases had contaminated the Columbia River, ambient air, soil, and groundwater at levels higher than had been previously known by the public (HHIN1997).

Following the release of this information, the states of Washington and Oregon, regional Native American Tribes and the Centers for Disease Control and Prevention (CDC) convened a panel of experts to evaluate the information. The panel, named the Hanford Health Effects Review Panel, found that people in the area were exposed to radioactive materials and recommended dose reconstruction and thyroid health effects feasibility studies (TSP1994).

The Hanford Dose Reconstruction Project began in the late 1980s under the direction of DOE. Public distrust of DOE resulted in the development of a Memorandum of Understanding (MOU) between DOE and the Department of Health and Human Services. This MOU, signed in 1990, transferred responsibility for analytic epidemiologic research at DOE sites to CDC (TSP 1994).

In 1988, the Hanford Thyroid Disease Study was mandated by an act of Congress. The CDC was directed to conduct a study of thyroid morbidity among persons who lived near the Hanford Nuclear Site between 1944 and 1957 (CDC and HTDS 2002).

Hanford Sites Added to the National Priorities List

In 1989, four areas of the Hanford Site (the 100-, 200-, 300-, and 1100-Areas) were added to the National Priority List (NPL). The NPL lists the most seriously contaminated Superfund sites in the country (the 1100-Area has since been removed). Numerous disposal areas were identified, as were plumes of contaminated groundwater and elevated levels of radioactive materials in the Columbia River, in wells, and in springs. Thousands of people obtain drinking water from within 3 miles of the disposal areas (EPA 1989a, b, c, 1992).

ATSDR Involvement

ATSDR conducted a site visit to Hanford in 1989 and issued initial public health assessments. New studies have been conducted since 1989. This document combines information related to Hanford releases and related to public health concerns.

In 1994, ATSDR reviewed the initial findings of the Hanford Environmental Dose Reconstruction (HEDR) project. In a health consultation dated January 1994, ATSDR determined that the major public health risk would most likely be to children downwind of the facility who consumed contaminated milk between 1945–1951 (ATSDR 1994).

In November 2000, ATSDR finalized an Infant Mortality and Fetal Death Analysis. The analysis found a 70% higher rate of pre-term birth and a 30% higher rate of infant mortality in the areas with higher estimated I-131 exposures

(Tatham et al. 2002). ATSDR is currently conducting a Birth Cohort Study on autoimmune disease and cardiovascular diseases. Since 1999, ATSDR has funded the Hanford Community Health Project to inform and educate regarding potential exposures and health effects, and regarding healthcare options.

Community Health Concerns

The community surrounding the Hanford Site show a high level of interest on issues associated with radiation releases. Before it closed in May 2000, the Hanford Health Information Network responded to information requests from approximately 40,000 households. Downwinders expressed concern about health problems possibly resulting from exposure to both past and current Hanford releases of radiation and toxic chemicals. Concerns regarding past exposures include

- exposure as children,
- substances other than I-131,
- cumulative and synergistic effects,
- incorrect dose estimates,
- inadequate knowledge by the medical community,
- need for a government apology, and
- lack of medical monitoring and health care.

Concerns about current conditions include contaminants in sediment, groundwater contamination, and potential accidents or leaks. Some of the health problems most frequently mentioned include thyroid diseases, cancer, cardiovascular diseases, and autoimmune diseases (including allergies and fibromyalgia).

Hanford Contamination

ATSDR has identified contaminants of concern at or near the Hanford Site by comparing the highest concentrations of all contaminants detected at the site to health-based screening comparison values. Comparison values provide a means of selecting contaminants for further evaluation (and are not used to predict adverse health effects). Certain contaminants found at or near Hanford exceeded their comparison values in soil and sediment, groundwater, surface water, and plants, animals, or their products. A total of 35 contaminants exceeded their comparison values, indicating a need for further investigation of these substances.

2.1 Site History

The DOE Hanford Site in southeastern Washington borders the Columbia River and the City of Richland. About 94% of its 560 square miles is vacant sagebrush

land, while about 6% is still actively used and contains buildings and open land (Westinghouse 1995c). The site was used for dryland farming until 1943, when it was acquired by the U.S. War Department to produce plutonium for atomic weapons (Sharpe 1999). Use of the site for nuclear weapons purposes was classified wartime information. Only a small number of people knew about the work carried on at the site until 1945, coinciding with the atomic bombing of Japan at the end of World War II (HHIN 1997).

As a result of that work, many different types of nuclear waste were generated at Hanford, including mixed, high-level radioactive waste, such as cesium-137, strontium-90, and uranium. Since1944 Hanford has periodically released radioactive materials into the environment for various reasons. Gaseous iodine-131 was released from the reprocessing of spent fuel assemblies. Reactor cooling water that contained activation products was cycled back into the Columbia River. Other radioactive and hazardous materials have been released due to inadequate containment. Radionuclide containment is one of the primary functions of the site's current environmental safety program.

Hanford has conducted environmental monitoring since 1943, but much of the information regarding radioactive releases during the 1940s and 1950s was classified as national security information and, consequently, not released to the public. In response to a Freedom of Information Act request, the Department of Energy in 1986 released 19,000 pages of information dating back to 1943. This information revealed that some radioactive releases from Hanford were planned — they were part of a scientific study for military purposes — and that other unplanned releases had contaminated the Columbia River, the ambient air, soil, and groundwater at levels higher than previously known. In particular, off-site populations have been exposed to airborne releases of iodine-131 (HHIN 1997).

2.1.1 Hanford Site Land Acquisition

In March 1943, the urgency of the Manhattan Project to develop atomic weapons required both land and water in relatively remote parts of the country. The Hanford Engineering Works Land Acquisition Office began using the government's power under U.S. statues of eminent domain to acquire more than 400,000 acres of Southeastern Washington State. This acquisition included 40,000 acres of active farm lands. Residents and farmers were forced to move, but were compensated for lost lands and crops.

2.1.2 Tribal Lands

The Hanford Site lies within lands ceded to the United States by the Confederated Tribes of the Umatilla Indian Reservation (Umatilla, Cayuse, and Walla Walla) and the Confederated Tribes and Bands of the Yakama Indian Nation. The Wanapums were removed from the Hanford area in 1943 and relocated to the Priest Dams area north of the Hanford Site. Creation of the Hanford Site eliminated tribal access — Native Americans could no longer hunt, fish, or gather herbs within the boundaries of the Hanford Site (DOE 1997b).

The Hanford Site is now managed by the Department of Energy (DOE). The Site is located about 170 miles southeast of Seattle and 120 miles southwest of Spokane. The Columbia River borders the Site on the north and east. The City of Richland forms the southern border, and the Rattlesnake Hills form the Site's western border. Of the 560 square-mile Hanford Site, much of which contains buildings and open land, about 6% (32 square miles) is in active use (Westinghouse 1995c). The remaining 94% (528 square miles) was acquired as a buffer and security zone. The Hanford Site currently includes portions of Benton, Grant, Franklin, and Adams counties (DOE1990a).

2.1.3 Hanford Mission

In 1943, the Hanford Site was acquired by the U.S. War Department for the Manhattan Project of the Army Corps of Engineers as the location for a highly classified mission: to produce plutonium for atomic weapons as a major component of the nuclear weapons complex. Until recently, the mission of the site was operating reactors for producing plutonium and electricity using the N–Reactor generating station[1], processing spent nuclear fuel, and extracting plutonium and uranium for national defense (DOE, undated).

From the mid-1940s until 1990, the primary mission of the Hanford Site was plutonium production in support of national military defense programs.

[1]During 1965–1966, the PUREX facility processed 664 tons of powered thorium oxide fuel targets that had been irradiated in the K reactors for producing uranium-233. In 1970, 820 kilograms of pelletized thorium targets were processed. Shortly afterward, thorium oxide fuel was ruled out for large scale development at Hanford.

During World War II, the Hanford Project (or "Hanford Engineering Works") employed many thousands of workers recruited to develop the Site infrastructure and facilities. Within a period of months in 1943, workers on the Manhattan Project designed and built nuclear fuel assembly facilities, production reactors, fuel reprocessing plants, and nuclear waste storage tanks. Again, because of wartime secrecy, few people knew the mission and purpose of facilities at the Hanford Site (HHIN 1997).

The Hanford Site was originally divided into areas designated by numbers (see Table 2-1). The production reactors were located on the north side of the Site in the "100-Area" along the banks of the Columbia River. Plutonium and uranium separations and nuclear waste reprocessing and storage were located in the "200-Area" near the northern center of the Site. Uranium fuel assemblies for the reactors were fabricated in the southwestern part of the Site in the "300-Area," just north of Richland. Administrative offices were located in the "700-Area" in the center of Richland. The "1100-Area" near the north end of Richland was the site of construction, transportation, and supply facilities (DOE 1994, [p. 2-2]). Recent additions to the Hanford Site were the construction of the Fast Flux Test Facility (FFTF) and the Fuels and Materials Examination Facility (FMEF) in the Hanford "400-Area," which is about 20 miles south of the 200-Area and about 7 miles northwest of the 300-Area. The FFTF operated for about 10 years and is currently in "decommissioning" mode. The FMEF has not housed any radioactive or chemical materials (DOE 1994 [pp. 2-2, 2-3, 2-6]).

July 16, 1945 — Plutonium from Hanford was first used in the Trinity test detonations at Alamogordo, New Mexico.
August 9, 1945 — Plutonium bomb used in wartime at Nagasaki, Japan.

Additional plutonium is no longer needed for nuclear weapons. Since about 1987, the primary mission at Hanford has been deactivation and decommissioning of production reactors and radiochemical separation facilities, waste management, cleanup of residual radioactive and chemical contamination, and environmental restoration (DOE undated).

Table 2-1. Description of Hanford Areas	
Hanford Area	**Description of Area**
100-Area	North side of the Site along the banks of the Columbia River. Nine production reactors (B, C, KE, KW, N, D, DR, H, F); K-basins 1301-N Trench N-Springs
200-Area	Near the center of the Site. Contains plutonium and uranium separations and nuclear waste reprocessing and storage areas; PUREX plant REDOX plant Tank Farm Plutonium Finishing Plant
300-Area	Southeast part of the Site, just north of Richland. Fuel assembly fabrication areas
400-Area	Southeast part pf the Site, between 200- and 300-Areas. Fast Flux Text Facility (FFTF) Fuels and Materials Examination Facility (FMEF);
700-Area	The Richland Village Contains housing and administrative offices;
1100-Area	North of Richland. Construction, transportation, and supply facilities

Current activities at the Hanford Site focus on environmental management and restoration, including pumping and treating contaminated groundwater, stabilizing underground storage tanks, stabilizing plutonium wastes at the Plutonium Finishing Plant, and treating high-level waste by evaporation. Engineering studies and scientific research and development are also conducted at Hanford in such areas as technology development, environmental management, new materials development, computational systems, and national security (DOE, undated). Additional information about ongoing activities can be found at the DOE Hanford Web site: http://www.hanford.gov/

2.1.4 Radioactive Wastes Released to the Environment

Nine plutonium-producing reactors were built and operated on the Hanford Site near the Columbia River. Eight of these reactors (B, C, D, DR, F, H, KE, and KW) used river water for cooling the reactors; the ninth reactor (N) was a closed-

loop, dual-purpose reactor for both plutonium and electrical power production. Uranium fuel assemblies from the production reactors were reprocessed to separate plutonium from the uranium and from the reactor fission products. The uranium was recycled, re-enriched, and reused in new fuel assemblies. The fission products and other radioactive chemical wastes were stored on-site in large underground storage tanks.

Reactor operations generated several types of nuclear waste. Chemical separations from spent-fuel reprocessing conducted in the B, T, REDOX, and PUREX plants produced mixed, high-level radioactive wastes containing a wide variety of fission and activation products. To minimize the temperatures of the high-level tank wastes, strontium-90 and cesium-137 were separated from these high-level radioactive wastes for storage. Uranium wastes were generated during the manufacture of new fuel assemblies in the 333-building of the Hanford 300-Area.

Since 1944, as the result of Hanford Site operations, radioactive materials have been released into the environment (e.g., water, air, and ground). Reactor cooling water released to the Columbia River contained activation products such as sodium-24, neptunium-239, and zinc-65. Releases to the atmosphere included iodine-131 gases and ruthenium-106 particles from reprocessing of spent fuel assemblies. Single-shell storage tanks have leaked tritium, strontium-90, cesium-137, plutonium-239, and uranium into the ground and into the groundwater. Waste has also leaked from storage basins such as the 100-Area basins and from the K-basin. This waste has entered into the ground, the groundwater, into seeps, and into the Columbia River.

2.2 Hanford Site Added to the National Priorities List

In 1989, four areas (the 100-, 200-, 300-, and 1100-Areas) of the Hanford site were placed on the National Priority List (NPL). The NPL is a list of Superfund sites slated for priority cleanup because they pose the highest potential threat. The threat level is derived from factors such as release or potential release to the environment, amount and toxicity of waste, and number of people and other life forms in the affected environment. Because the “hazard ranking scores” of all of these Hanford areas were relatively high, EPA placed them on the NPL. The areas contained

- numerous waste disposal locations,
- plumes of contaminated groundwater,
- large areas of solid or liquid waste comprised of radioactive, mixed, and hazardous constituents

- elevated radionuclide levels (e.g., strontium-90) in the Columbia River, and were in
- close proximity to the Richland drinking water supply and/or fishing areas.

In the late 1990s, the 1100-Area and parts of the 100-Area were removed from the NPL. The EPA and the State of Washington determined that these areas did not pose a threat to public health or to the environment (EPA1989a, b, c, 1992).

In 1989, ATSDR conducted a site visit to Hanford and released initial public health assessments (PHAs) for the 100-, 200-, 300-, and 1100-Areas. Since that time, additional studies have been conducted and more information has become available, including dose estimates provided by the Hanford Environmental Dose Reconstruction (HEDR) Project.

The Hanford Health Effects Subcommittee, an advisory committee to ATSDR, recommended that the public health assessments for each of the Hanford areas be combined into a single document (i.e., this document) and be made available for public comment. The subcommittee membership considered it more appropriate to address contaminants by pathways, given that contaminants do not stop at the fence line of the various NPL sites. On the contrary, they migrate — often through several NPL sites and into the Columbia River. Also, to enhance credibility of this public health assessment, the subcommittee recommended inclusion of a range of perspectives on public issues.

2.2.1 EPA's Hazard Ranking System

In 1989, because of their "hazard ranking" scores as described below, these four Hanford areas were placed on the NPL. EPA uses a Hazard Ranking System to determine which sites should receive priority attention and, consequently, placement on the NPL (EPA 1990). EPA assigns numerical values to three categories that relate to risk conditions at a site, including:

- The likelihood that a site has released or has the potential to release hazardous substances into the environment.

- The relative amount and toxicity of the waste.

- The number of humans and other life forms in the affected environment.

EPA staff evaluated each of the four Hanford areas proposed for the NPL, which were the 100-Area, the 200-Area, the 300-Area, and the 1100-Area. Each of the four Hanford areas were given hazard ranking scores based on available information on contaminant releases into groundwater, surface water, and air. The scores for each pathway were then combined in a specific equation to calculate the overall Hazard Ranking Score. (At the time that the Hanford Site was ranked, the EPA Hazard Ranking System did not include a score for soil contamination. When the Hazard Ranking System was modified in 1990, sites already on the NPL were not re-scored.) Detailed information on EPA's Hazard Ranking Score System is available on EPA's Superfund Web site, http://www.epa.gov/superfund/action/law/npl_hrs.htm The scores for the four Hanford NPL sites are listed in Table 2-2.

The hazard ranking scores for two Hanford areas, the 200-Area and the 300-Area, were greater than the scores for sites such as Love Canal, New York, and Times Beach, Missouri.

Table 2-2. National Priority List (NPL) Hazard Ranking Scores for Hanford Sites

	100-Area	200 Area	300 Area	1100-Area
Groundwater	06.12	79.59	79.60	62.85
Surface water	80.00	89.09	80.00	00.00
Air	00.00	00.00	00.00	00.00
Cumulative score	46.38	69.05	65.23	36.34

The cutoff point for cumulative scores that mandates a listing on the EPA National Priorities List is 28.5 (EPA, 1990). The maximum score possible for each medium (groundwater, surface water, or air) is 100 (EPA, 1987a, b, c, d).

As Table 2-2 shows, the cumulative scores for each of the four proposed Hanford sites exceeded the minimum for placement on the NPL. On October 4, 1989, the EPA placed the four Hanford sites on the national priorities list.

2.2.2 Major Factors Cited by EPA

EPA cited the following reasons for listing the Hanford 100-Area on the NPL (EPA 1989a):

- Over 110 waste disposal locations have been identified in the 100-Area.

- The disposal locations and plumes of contaminated ground water cover approximately 11 square miles.

- An estimated 4.3 billion cubic yards of solid and dilute liquid waste comprised of radioactive, mixed, and hazardous constituents were disposed in cribs, trenches, and burial grounds in the 100-Area.

- The DOE has detected hexavalent chromium and strontium-90 in ground water beneath the area; ground water is not used within 3 miles of the 100-Area, but it is known to seep into the Columbia River in the 100-Area.

- DOE detected strontium-90 in the Columbia River at levels significantly above background.

- Intakes on the Columbia River within 3 miles of the 100-Area supply drinking water to over 3,000 workers in the 100- and 200 Areas.

EPA cited the following reasons for listing the Hanford 200-Area on the NPL (EPA 1989b):

- Over 230 waste disposal locations have been identified in the 200 Area.

- The disposal locations and plumes of contaminated groundwater cover approximately 215 square miles.

- An estimated 1 billion cubic yards of solid and dilute liquid wastes comprised of radioactive, mixed, and hazardous constituents were disposed of in trenches, ditches, and landfills in the 200-Area.

- DOE has detected tritium, iodine-129, uranium, cyanide, and carbon tetrachloride at levels significantly above background in groundwater beneath the area.

- Over 2,500 persons obtain drinking water from wells within 3 miles of the 200-Area.

- Tritium has been detected in Richland's surface water intakes at levels above background.

- Surface water within 3 miles of [where groundwater from] the 200-Area [discharges into the Columbia River and] provides drinking water to 70,000 people and irrigates over 1,000 acres.

EPA cited the following reasons for listing the Hanford 300-Area on the NPL (EPA 1989c):

- The DOE fabricates nuclear reactor fuel in the 300-Area, which contains 14 disposal locations.
- The disposal locations and plumes of contaminated ground water cover approximately 5 square miles.
- An estimated 27 million cubic yards of solid and dilute liquid wastes comprised of radioactive, mixed, and hazardous constituents were disposed of in ponds, trenches, and landfills in the 300-Area.
- DOE detected uranium in area springs, wells, and the Columbia River at levels above background levels.

EPA cited the following reasons for listing the Hanford 1100-Area on the NPL (EPA 1992):

- On-site wells in the vicinity of the 1100-Area contain volatile organic compounds (VOCs), including TCE.
- Nitrates, sodium, and sulfate are present in Richland's well water.
- On-site soils are contaminated with heavy metals and polychlorinated biphenyls (PCBs).
- Possible exposure routes include direct contact with or accidental ingestion of contaminated groundwater and soil.
- The Yakima River borders the site and is a fishing source for the Yakama Indian Reservation.

Once the DOE sites have been placed on the NPL, DOE—in conjunction with EPA—and the State of Washington develop plans to remediate the sites. After a public comment process, the remediation plans are issued as Records of Decisions (RODs). The RODs for the Hanford sites can be found on EPA's Superfund Web page at http://www.epa.gov/superfund/sites/rodsites/index.htm.

2.2.3 Removal of the 1100-Area from the NPL

In 1996, the EPA removed the Hanford 1100-Area was removed from the NPL. The EPA and the State of Washington determined that this area posed no significant threat to public health or to the environment (EPA 1996). This determination was based on the 1100-Area being limited to non-residential uses. On October 1, 1998, the Port of Benton acquired the Hanford 1100-Area as part of the Horn Rapids Industrial Park. On June 10, 1999, ATSDR wrote to the president of the Port of Benton Commission, to advise that the ATSDR public health assessment for the 1100-Area recommended that, "If portions of the 1100-Area are transferred from DOE to the public, the transfer should include sufficient safeguards (e.g., institutional controls should be considered to protect public health) to protect the public from exposure to unremediated sites and to guard against the breaching of barriers created in the course of remediation (e.g., caps)." Because DOE's remediation was to industrial standards, a less restricted use such as residential or agricultural, may not be protective of public health. ATSDR recommended that future development of the former 1100-Area be limited to industrial or commercial use, and never developed for residential or agricultural purposes.

In 1998, parts of the 100-Area to the north (on the other side of the Columbia River) were removed from the NPL. Clean up activities had removed contaminants from certain waste areas to established residential use levels under the Washington State Model Toxic Control Act (EPA 1998b).

2.3 ATSDR Involvement

The ATSDR conducts public health assessments for each of the sites listed or proposed for listing on the above-referenced NPL. ATSDR is a federal public health agency in the U.S. Department of Health and Human Services. In 1980, Congress established ATSDR in the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as amended, also known as the Superfund Act. Through public health assessments and health consultations, ATSDR can identify follow-up health actions that should be taken at NPL sites.

2.3.1 Purpose of a Public Health Assessment

Public health assessments (PHAs) evaluate available information to determine whether people have been, are, or will be exposed to hazardous substances and, if so, whether such exposure is harmful and should be stopped or reduced. PHAs also serve as mechanisms for determining whether a need exists for additional public health activities.

ATSDR conducted an initial site visit to Hanford on April 17, 1989, and later that year released separate public health assessments for each of the four Hanford NPL sites (the 100-, 200-, 300-, and 1100-Areas, as described above). Since that time, additional information has been made available to ATSDR regarding the levels of radioactive materials released, the radiation dose estimates for members of the off-site general public, and potential health effects. This information includes radiation dose estimates provided by the Hanford Environmental Dose Reconstruction (HEDR) Project, which was sponsored at first by the Department of Energy and later by the Centers for Disease Control and Prevention (CDC).

For the Hanford PHA, most of the scientific information was obtained from DOE or from CDC's HEDR Project. Other sources of information included the State of Washington, the City of Richland, and independent groups, such as the Hanford Environmental Action League.

2.3.2 Recommendations from the 1994 ATSDR Health Consultation

In January 1994 ATSDR drafted a health consultation that considered the initial findings of the HEDR. ATSDR determined that past radionuclides released from the Hanford Site resulted in human exposure and additional public health activities were necessary to address adequately the community health concerns. ATSDR determined that the following actions were needed (ATSDR 1994):

ATSDR determined that the major public health risk is among young children downwind of the facility who consumed contaminated milk during the period, 1945–1951.

- Site-specific surveillance to assess the specific occurrence of defined health conditions.
- A health statistics review of existing health outcome data (e.g., infant mortality and fetal death analysis, and birth cohort study).
- A health education program, coordinated with the Hanford Health Information Network, to assist the community and health care providers in understanding the potential public health implications from known past exposures (e.g., Hanford Community Health Project).

2.3.3 Other ATSDR Activities

Infant Mortality and Fetal Death Analysis

The ATSDR Infant Mortality and Fetal Death Analysis, finalized in November 2000, investigated the association between estimated I-131 exposure and infant mortality, fetal death, and preterm birth. The study focused on the years 1940–1952, and included the eight Washington counties in the HEDR project: Adams, Benton, Franklin, Grant, Kittitas, Klickitat, Walla Walla, and Yakima. The study used the HEDR project's 1945 exposure estimates for I-131, and found a 70% higher rate of pre-term birth and a 30% higher rate of infant mortality in the areas with the highest estimates of I-131 exposures compared with areas having the lowest estimates of exposure. No association was found for fetal death. The study was published in the International Journal of Hygiene and Environmental Health (Tatham et al. 2002).

Birth Cohort Study

ATSDR is currently conducting a birth cohort study. This study of adverse autoimmune function and cardiovascular disease will 1) explore the potential relationship of radioactive releases, mainly I-131, into the environment and the prevalence of autoimmune diseases; 2) explore the potential relationship of radioactive releases, mainly I-131, into the environment and the prevalence of cardiovascular diseases; and 3) conduct a comparative analysis.

Hanford Community Health Project

In the fall of 1999, ATSDR initiated the Hanford Community Health Project (HCHP). Its purpose was to inform and educate individuals exposed to off-site releases of I-131 about associated health effects and healthcare options. By engaging the exposed population and their healthcare providers in an information-sharing dialogue, the HCHP will help them make informed risk-benefit decisions about their healthcare choices. In 2001, the HCHP conducted a survey of exposed individuals to ascertain their level of knowledge and plan an educational campaign.

Hanford Health Effects Subcommittee

In 1998, ATSDR revised the Hanford Public Health Assessments by including information made available since 1989. The Hanford Health Effects Subcommittee, a federally chartered advisory committee to ATSDR, recommended that the public health assessments for the Hanford 100-, 200-, and 300-Areas be combined into a single document, and that the document be made available for public comment. HHES made this recommendation to combine the NPL-site PHAs into one document so as to logically present exposure pathways which crossed NPL sites and which did not stop at site borders. Also, the consensus of the HHES public health assessment working group was to present a

range of opinions on the contentious issues and to present the study in language that was understandable to the public. This document is the product of those efforts.

2.4 Community Health Concerns

In addition to workers, those exposed to Hanford releases included Hanford "Downwinders"; that is, those who now reside or previously resided in areas downstream from the Columbia River or within Hanford's emissions range, which extended through eastern Washington State, northeastern Oregon, Idaho, and western Montana. This section identifies community health concerns expressed by Downwinders.

People in more distant parts of the U. S., as well as other countries, have also expressed concerns about health effects possibly associated with Hanford releases. Other people have said they do not believe that health effects would result from the low-level exposures that occurred to Hanford's radioactive material emissions[2].

The level of concern about existing or future health effects that may be associated with releases of contaminants from Hanford is high among some of the affected populations. As stated earlier, about 40,000 persons requested information from the Hanford Health Information Network, which closed in May 2000, and 10,500 persons asked for Hanford Individual Dose Assessments. In addition, about 2,700 persons donated materials on their Hanford-related experiences to the Hanford Health Information Archives. Over 8,600 persons responded to three surveys regarding health effects from Hanford releases; one survey was conducted by ATSDR and the other two by citizens' groups.

People are concerned that they have been exposed to past releases of radioactive materials and hazardous chemicals from Hanford through breathing contaminated air, drinking contaminated water or milk, eating contaminated local foods, and swimming or boating in the Columbia River. In addition to their own health problems, people have expressed concerns about

- childhood exposures,
- potential effects on future generations,

[2]We know that some Hanford populations were exposed — that is given. The real issues are the uncertainty of dose levels and the health implications of exposure at those dose levels.

- substances in addition to radioiodine (on which research thus far has primarily focused),
- cumulative and synergistic effects,
- the accuracy of dose estimates,
- knowledge of the local health official and the medical community about exposures to Hanford releases, and
- the lack of medical monitoring and health care.

Some have also said that it is important for the federal government to accept responsibility for secretly exposing people to Hanford releases, apologize for its errors, and acknowledge peoples' health problems.

People have also expressed concern about current and potential future involuntary exposures to Hanford releases, including contaminants in Columbia River sediments, possible future accidents or leaks, and groundwater contamination.

The most common health problems reported include thyroid disease, cancer, allergies, cardiovascular disease, and auto-immune diseases. Other health problems have also been suggested as possibly associated with exposure to radiation and to chemicals from Hanford.

2.4.1 Sources Used to Identify Community Concerns

The information in this section is summarized from several sources, including

A survey by the ATSDR Hanford Community Health Project (HCHP)
The HCHP survey was conducted to learn more bout the Hanford community's knowledge of Hanford I-131 releases, about health care utilization, access to care issues related to thyroid disease, health education needs, and any interest in receiving a free medical examination. Interviews were completed with 501 survey participants who were born between 1940 and 1951 in Adams, Benton, and Franklin counties. Notable findings from the survey include

- 54% reported one or more of the seven thyroid dysfunction-related symptoms.
- 18% reported that they had been diagnosed with a thyroid condition.
- 54% felt poorly informed about health problems related to the thyroid.
- 84% would use a free thyroid examination service.

Information published by the Hanford Health Information Network (HHIN) and the Hanford Health Information Archives (HHIA).
The HHIN, which closed in May 2000, was a collaboration among three states (Oregon, Idaho, and Washington) and nine Indian Nations to provide educational

materials concerning the known and potential health effects of radiation. The HHIA was a project of the HHIN and collected and made available health and other information submitted by people who were or may have been exposed to Hanford radioactive and chemical releases.

Approximately 40,000 households requested information from HHIN. These requests came from Oregon, Idaho, and Washington, as well as other areas of the United States and from some international sources. In addition, approximately 10,500 persons asked for Hanford Individual Dose Assessments. Also, about 2,800 persons have donated materials (e.g., medical records, letters, health survey responses) to the Hanford Health Information Archives regarding their Hanford-related experiences.

Telephone conversations with several HHIN members and members of an ATSDR Hanford stakeholders advisory group (the Hanford Health Effects Subcommittee, or HHES) and concerned residents recommended by HHES and HHIN members.

The R-11 Survey

The R-11 Survey was conducted for litigation purposes on behalf of the Hanford Downwinders Coalition to help ascertain the possible full impact of Hanford emissions on the health of the off-site population. The R-11 Survey compared reported illnesses with the prevalence of the illness based on national surveys. Interviews were conducted by telephone, with the goal of obtaining information about the prevalence of selected medical conditions and malignant diseases among graduates of 14 high schools in areas downwind of the Hanford facility. The survey attempted to include all graduates from 1950–1969 from high schools in Washington, Idaho, and Oregon. However, the court ruled that the comparison of surveys was ultimately irrelevant, and that "the R-11 data were so badly tainted because of methodological flaws in the collection process that, as a threshold matter, it was improper to even embark upon the comparison." [Hanford Nuclear Reservation Litigation, LEXIS 15028, E.D.

The *R-11 Survey* concluded that, for high school graduates between 1950–1969 from 14 high schools downwind of Hanford, an excess of thyroid disease, thyroid cancer, and the other types of cancer was apparent (Bird 1997; JSI Center 1995, 1996). However, for litigation purposes, the court rejected the R-11 Survey as flawed science, because "*none of the individuals involved in data collection of study design were epidemiologists or experts in any scientific discipline*." (Merwin et al., 2001)

Wash., 1998; cited by Merwin, et al., "Application of the Supreme Court's *Daubert* Criteria in Radiation Litigation," *Health Phys*. 81(6):670-677; 2001).

Northwest Radiation Health Alliance (NWRHA) Survey

The NWRHA survey was conducted by the Northwest Radiation Health Alliance. The Alliance includes Hanford Downwinders, concerned citizens, and physicians and scientists who are members of the Oregon chapter of Physicians for Social Responsibility (PSR). (NWRHA can be contacted through the PSR-Portland, Oregon office listed later in this section.) The NWRHA survey, which relied primarily on Downwinders' own networks for collecting data, sought to identify suspected patterns of disease, especially those possibly related to radioactive environmental contamination from Hanford.

2.4.2 General Health Concerns

Many people have expressed concerns about whether their current health problems could be associated with Hanford's releases of radioactive materials and hazardous chemicals to the environment, and also about possible future health problems from exposure to Hanford releases. Some people have also expressed concern about their own or their family's health, while others were concerned about their children or their neighbors' children.

Downwinders were concerned about health problems possibly resulting from exposure to both past and current releases of radiation and toxic chemicals from Hanford. Contrary views were expressed by people living in communities near Hanford who believed that no association exists between health problems and Hanford radiation and chemical releases.

2.4.3 Past Releases from Hanford

People have expressed concern about the possible health effects associated with exposure to past releases of radioactive materials and hazardous chemicals through

- breathing contaminated air,
- drinking contaminated water or milk,
- eating contaminated local foods (e.g., vegetables, meat, fish), including food irrigated with contaminated water or grown in/raised on contaminated soil, and
- swimming or boating in the Columbia River.

Other community health concerns regarding past releases from Hanford include

Exposure as children

People have expressed concerns for those individuals who were exposed to Hanford releases as children (in the 1940s, 1950s, and 1960s) because they could be more sensitive to radiation effects later in life that may be related to these exposures. Infants and children are more sensitive to radiation effects because their cellular growth rates are higher and cells are less differentiated.

Substances other than I-131

Most research has focused on exposure to iodine (I-131) and possibly related thyroid effects. For most people, doses of I-131 to the thyroid would have been much higher than doses to other parts of the body. Some people are, however, also concerned about exposure to radionuclides other than radioiodine that were released from Hanford, including cesium-137, plutonium-239, strontium-90, and tritium, as well as hazardous chemicals.

Cumulative and synergistic effects

People within the Hanford exposure area were also exposed to global fallout and fallout from the Nevada Test Site. The cumulative (i.e., additive) dose and risk from these multiple exposures is of great concern to some. To others, possible synergistic (i.e., greater when combined) effects from potentially exposure to both internal radioactivity and hazardous chemicals, such as pesticides, is also a concern.

Incorrect dose estimates

Some people have expressed concern that dose estimates from the Hanford Environmental Dose Reconstruction Project (HEDR) study may underestimate actual radiation doses received because these methods may average over population groups and not fully account for local extremes. Others believe that HEDR overestimated the radiation doses.

Inadequate knowledge by the medical community

Some have said that the medical community does not seem to be well informed about potential adverse health effects from exposure to radiation and other chemical releases from Hanford, the Nevada Test Site and global fallout.

People who reported adverse health effects thought that they occurred prior to 1986, when knowledge of Hanford's radioactive releases became common. In addition to the physical health effects, they may have experienced stress associated with rejection and ridicule by the medical community and healthy neighbors.

Some individuals who might have had hypothyroidism may not have been identified. They may have suffered depression or experienced a variety of other illnesses ranging from musculoskeletal disorders to gastrointestinal and reproductive dysfunction which may have been related to hypothyroidism.

Need for government apology

Some have said that the government should accept responsibility for secretly exposing people to radioactive and chemical releases from Hanford, should apologize for its past errors, and should acknowledge the grief and despair suffered.

Lack of medical monitoring and health care

Many people who believed that they received the highest radiation exposures from Hanford emissions are concerned that funding has not been provided for medical monitoring, and that outreach and education only (without medical testing) is insufficient. In addition, those living in rural areas have expressed a need for vans to come to their areas to perform medical monitoring rather than being required to travel into the cities to receive this service. Others expressed concern that former residents of the Hanford areas who now live outside the Pacific Northwest will need proper screening from trained physicians and other health care professionals no matter where they live.

Those with no health concerns

Others who live in the Hanford area believe no association exists between health problems and Hanford radiation and chemical releases; they believe exposure occurred at doses too low to cause adverse health effects. Some who express these views have lived in the Hanford area for many years, with no health problems themselves or to their families. Some in this group believe that continued government public health studies and medical monitoring associated with Hanford only serve to raise public anxiety and take resources away from other important public health concerns.

2.4.4 Current and Potential Future Releases from Hanford

Several concerns are voiced regarding current or potential future releases of radiation and hazardous chemicals from Hanford, including

Contaminants in sediments

Some people are concerned that sediments in the Columbia River which store contaminants may release these contaminants downriver (e.g., during flooding or if dredging occurred). Some of the radioactive and hazardous chemicals of concern include arsenic, cesium, manganese, and strontium, especially in

sediments behind the McNary Dam. People are also concerned that sediments dredged during past years and deposited on beaches along the Columbia River may affect the health of people who use the beaches for recreation.

Potential accidents or leaks

People are concerned about the potential for accidents (whether occurring naturally or as a result of human activity) at Hanford that would release radioactive and chemical materials into the environment (e.g., from chemical waste tanks, including underground tanks). People are worried that stored chemicals awaiting processing or disposal will leak or be involved in an accident, such as the explosion that occurred at the plutonium finishing area in May 1997. Based in part on past cleanup problems at the Hanford Site, people have expressed concerns about proper management of Hanford wastes. In addition, they have concerns about how the area might be perceived and whether the agricultural crops grown in the area are safe.

Groundwater contamination

People are concerned that contaminated groundwater discharging from the Hanford Site into the Columbia River could expose individuals to radionuclides, hazardous chemicals, and nitrates. Even in communities that obtain drinking water from sources other than the Columbia River, some people are concerned that they could become exposed to contaminated groundwater where the aquifer surfaces off site, such as seeps and springs along the shore, and by eating fish from the river. They are also concerned that a variety of aquatic life could become negatively affected by river contamination.

2.4.5 Specific Illnesses

A number of people have reported a variety of specific health problems, as indicated in Table 2-3, which they believe may be associated with exposure to Hanford radiation and chemical releases. Some of the health problems most commonly of concern to Downwinders include

- Thyroid disease (particularly hypothyroidism)
- Cancer
- Cardiovascular disease
- Autoimmune diseases (including allergies and fibromyalgia)

Other illnesses, such as neurological disorders, immune system problems, gastrointestinal problems, and skin disorders, are also a concern. People expressed concern about the possibility of genetic damage being passed to future

generations, resulting in health problems in the children and grandchildren of individuals who were exposed to radiation and to other chemicals from Hanford.

People have raised the issue of the psychological and emotional effects of involuntarily exposure or potential exposure to Hanford releases. People have reported depression or suicide in their families or communities that they believe may be associated with Hanford emissions and the rejection or ridicule they have encountered by government agencies or by physicians. In some cases, people believed that their symptoms were a result of physical illnesses, but that the symptoms had been incorrectly attributed to psychological or emotional problems. For example, one of the commonly listed symptoms of thyroid disease (hypothyroidism) is clinical depression.

Table 2-3 summarizes some of the illnesses of concern to people who currently live or previously resided in communities in the vicinity or downwind of the Hanford site, and the number of people who reported having a specific health concern. The information in Table 2-3 came from three surveys: the "R-11 Survey," the Northwest Radiation Health Alliance (NWRHA) survey, and an ATSDR survey of community concerns; these surveys are described in the beginning of this section.

Table 2-3. Three Surveys of Community Health Concerns

Health Problem	R-11 Survey*	NWRHA Survey†	ATSDR HCHP Survey
Thyroid disease	6%	56%	18%
Thyroid cancer	0.3%	4%	0%
Other cancers	2%	42%	NA
Immune system	NA	50%	NA
Reproductive and genetic effects	NA	3%	NA
Nervous system	NA	15%	NA
Cardiovascular system	NA	18%	NA
Gastrointestinal system	NA	11%	NA
Psychological/ behavioral	NA	9%	NA

Table 2-3. Three Surveys of Community Health Concerns

Health Problem	R-11 Survey*	NWRHA Survey†	ATSDR HCHP Survey

NA= Not Applicable. The survey did not include this health problem.

*Self-reporting responses from 500 interviews were confirmed by medical records, with 84% confirmed for thyroid disease and close to 100% for various cancers (Bird 1997, JSI Center 1995, 1996). This survey was ruled by the court to lack scientific credibility (Merwin et al., 2001)..

†Respondents reported more than one health problem.

Immune system – includes lupus, multiple sclerosis, autoimmune disease, arthritis, diabetes, allergies and other immune effects.
Reproductive and genetic effects – include endometriosis, fetal wastage, birth defects, genetic damage, SIDS and reduced sperm count.
Nervous system – includes Parkinson's, Alzheimers, Lou Gerig's disease/ALS, narcolepsy, chronic fatigue, fibromyalgia and seizures.
Psychological/behavioral – includes depression and suicide.

2.4.6 Public Interest Groups

Additional reports of health concerns can be found in the *Hanford Health Information Archives (HHIA),* which collected, preserved, and makes available to the public information on the health and personal experiences of individuals who were or may have been exposed to Hanford radioactive and chemical releases. HHIA is located in the Special Collections of the Foley Center Library at Gonzaga University.

More information about community concerns is available from other public interest groups, including

Alliance for Nuclear Accountability (formerly Military Production Network) *Contact:* Susan Gordon, Military Production Network, 1914 N. 34th St., #407, Seattle, WA 98103, (206) 547-3175.

American Nuclear Society

Columbia Riverkeeper http://www.columbiariverkeeper.org/sitemap.htm

Environmental Defense Institute--*Contact:* Chuck Broscious, Environmental Defense Institute, P.O. Box 220, Troy, ID 83871

Government Accountability Project

Hanford Watch

Heart of America Northwest--*Contact:* Heart of America NW, Suite 208, Seattle, WA 98101, (206) 382-1014 (office), e-mail: office@heartofamericanorthwest.org.

Northwest Environmental Advocates (NWEA)--*Contact:* Eugene Rosolie, Northwest Environmental Advocates, 133 SW 2nd Ave., Ste 302, Portland, OR 97204, (503) 295-0490, e-mail: nwea@igc.apc.org

Sierra Club Cascade Chapter 8511- 15th Ave. NE, #201, Seattle, WA 98115-3101 Phone: (206) 523-2147, e-mail: cascade.chapter@sierraclub.org.

Washington Physicians for Social Responsibility (WPSR)--*Contact:* Martin Fleck, WPSR, 4534-12th Ave. NE, Seattle, WA 98105, (206) 547-2630, e-mail: psrwase@igc.apc.org

2.5 Known Contaminants

Contaminants at the Hanford Site include various radioactive materials and non-radioactive chemical wastes. This section summarizes the information that is presently available on the current levels of radioactive and chemical contaminants for the three priority areas at the Hanford Site. The section also explains how ATSDR uses screening values to help determine public health risks from contaminants associated with the Site.

The information provided in this section was obtained from several sources, including the Department of Energy, the City of Richland, and the Washington State Department of Health. DOE provided Hanford Site data and some of the Columbia River data. The Environmental Protection Agency (EPA), the Washington State Department of Ecology, and by the Washington State Department of Health reviewed this information to ensure that it is both accurate and complete.

The highest concentrations of on-site contaminants identified in soil, sediment, water, and plants, animals, or their products in the 100-, 200-, and 300-Areas are shown in Tables 4A to 4D (DOE 1992a, b, 1993a, b, c, 1995b, 1997a; WADOH 1993; Westinghouse 1987, 1992b, 1995a, c). Abbreviations used in these tables are identified in the table footnotes and defined in Appendix A, Glossary. The tables also list current ATSDR “screening comparison values” for each contaminant in each environmental medium.

2.5.1 Comparison Values

ATSDR chose to adopt a practice similar to that of the EPA’s Reference Dose (RfD) and Reference Concentration (RfC) for deriving substance-specific health guidance levels for non-neoplastic endpoints. An MRL is an estimate of the daily

human exposure to a hazardous substance that is likely to be without appreciable risk of adverse noncancer health effects over a specified duration of exposure. These substance-specific estimates, which are intended to serve as screening levels, are used by ATSDR health assessors to identify contaminants and potential health effects. *MRLs are not intended to define clean-up or action levels for ATSDR or for other agencies.*

An ATSDR toxicological profile includes an examination, summary, and interpretation of available toxicological information and epidemiologic evaluations of a hazardous substance. During the development of toxicological profiles, MRLs are derived when ATSDR determines that reliable and sufficient data exist to identify the target organ(s) of effect or the most sensitive health effect(s) for a specific duration for a given route of exposure to the substance.

ATSDR uses the no-observed-adverse-effect-level/uncertainty factor (NOAEL/UF) approach to derive MRLs for hazardous substances. MRLs are set below those levels which, based on current information, might cause adverse health effects in the people most sensitive to such substance-induced effects. MRLs are intended to serve as a screening tool to help public health officials decide where to look more closely.

Because of the lack of precise toxicological information on the people who might be most sensitive (e.g., infants, elderly, and nutritionally or immunologically compromised) to the effects of hazardous substances, MRLs contain some degree of uncertainty. Consequently, ATSDR uses a conservative (i.e., protective) approach to address these uncertainties consistent with the public health principle of prevention.

ATSDR uses “screening comparison values” to help determine whether concentrations of contaminants present at a site indicate a need for further investigation. ATSDR compares the concentrations of contaminants in environmental media (e.g., groundwater, air) with health-based screening comparison values. Such an evaluation is performed if human exposure to a specific chemical occurred or is possible (through ingestion, inhalation, or dermal [skin] contact). Health scientists have determined that chemical concentrations at or below screening comparison values are not likely to cause adverse effects when people are exposed, or, in the case of cancer, pose only a low risk that exposure could result in cancer. Conversely, chemical concentrations above comparison values do not necessarily mean that an adverse health effect will occur; they do, however, indicate that additional investigation is appropriate. If the maximum concentration of a contaminant detected in the environment exceeds its comparison value, the contaminant is considered a possible

contaminant of concern. It is important to note that regardless of a contaminant's concentration, a public health hazard exists only if people are exposed to harmful levels of contaminated media. Health effects associated with exposure to specific contaminants of concern are discussed in Chapter 8, in the section on *Toxicological Evaluation.*

2.5.2 How Screening Comparison Values are Developed

Comparison values contain both 1) a toxicity or cancer component and 2) an exposure component. Chronic exposure is most often evaluated, although acute exposure can be evaluated if more appropriate to site-specific circumstances. ATSDR selects comparison values that are calculated using very conservative exposure assumptions to protect the most sensitive segment of the population.

Examples of comparison values used for the Hanford site include: Cancer Risk Evaluation Guides (CREGs), Reference dose Media Evaluation Guides (RMEGs), Environmental Media Evaluation Guides (EMEGs), and Maximum Contaminant Levels (MCLs). The CREG represents a concentration at which no more than one excess cancer case could develop in a million people exposed over a lifetime. The RMEG and EMEG represent the concentrations at which daily exposure for a lifetime is unlikely to result in adverse noncancerous effects. The MCL represents a concentration in drinking water that is unlikely to be associated with adverse (non-cancer) effects over a lifetime at an assumed water intake rate (e.g., 2 liters per day for an adult).

ATSDR uses the no-observed-adverse-effect-level/uncertainty factor (NOAEL/UF) approach to derive MRLs for hazardous substances. They are set below levels which, based on current information, might cause adverse health effects in the people most sensitive to such substance-induced effects. MRLs are derived for acute (1–14 days), intermediate (>14–364 days), and chronic (365 days and longer) exposure durations, and for the oral and inhalation routes of exposure. Currently MRLs for the dermal route of exposure are not derived because ATSDR has not yet identified a method suitable for this route of exposure. MRLs are generally based on the most sensitive substance-induced end point considered to be of relevance to humans. ATSDR does not use serious health effects (e.g., irreparable damage to the liver or kidneys, or birth defects) as a basis for establishing MRLs. *Again, exposure to a level above the MRL does not mean that adverse health effects will occur.*

MRLs are intended to serve as a screening tool to help public health professionals decide where to look more closely. They may also be viewed as a mechanism to identify those hazardous waste sites that are not expected to cause adverse health

effects. Most MRLs contain some degree of uncertainty because of the lack of precise toxicological information on the people who might be most sensitive (e.g., infants, elderly, and nutritionally or immunologically compromised) to the effects of hazardous substances. ATSDR uses a conservative (i.e., protective) approach to address these uncertainties consistent with the public health principle of prevention. Although human data are preferred, in the absence of human subjects MRLs are often based on animal studies. And in the absence of evidence to the contrary, ATSDR assumes that humans are more sensitive than animals to the effects of hazardous substances to which certain persons or groups may be particularly sensitive. Thus, the resulting MRL may be as much as a hundredfold below levels shown to be nontoxic in laboratory animals. When adequate information is available, physiologically based pharmacokinetic (PBPK) modeling and benchmark dose (BMD) modeling have also been used as an adjunct to the NOAEL/UF approach in deriving MRLs.

ATSDR has derived two MRLs for exposures to ionizing radiation

- An MRL of 0.004 Sv (0.4 rem) above background has been derived for acute-duration external ionizing radiation exposure (14 days or less).

- An MRL of 1.0 mSv/yr (100 mrem/yr) above background has been derived for chronic-duration external ionizing radiation exposure (365 days or more).

When possible, ATSDR considers the combined effect of different contaminants and multiple exposure pathways. While screening comparison values are usually based on exposure to a single chemical, some health assessors estimate the toxicity of chemical mixtures by adding the toxic effects of single chemicals together. Similarly, if exposure to a contaminant occurs by multiple pathways of exposure, health assessors are advised to add together the doses from various exposure pathways to determine the total body dose (ATSDR 1989).

2.5.3 Which Chemicals Have Comparison Values

Comparison values are developed for chemicals for which ATSDR has developed toxicological profiles. Chemicals are selected for profile development because of their toxicity, their frequency-of-occurrence at sites on the NPL, and their potential for human exposure to the substance. All toxicological profiles have been peer reviewed by panels of scientific experts. Comparison values are reviewed regularly and updated as often as every three months if new scientific data (e.g., a new or revised toxicological profile; reviews of relevant toxicological

databases, such as IARC and IRIS) indicate that a change in a comparison value is appropriate. (The EPA IRIS database is updated monthly.)

2.5.4 On-Site Contaminants that Exceeded Screening Comparison Values

A total of 31 substances detected at Hanford exceeded screening comparison values established for these chemicals, as indicated in Tables 4A-4D. As discussed below, comparison values were exceeded in soil and sediment, groundwater, and surface water, as well as in plants, animals, or their products. Some substances exceeded comparison values in more than one environmental medium (in some cases in two or three media).

Soil and Sediment

Of the 35 substances found in soil and sediment onsite at Hanford, 13 were above the established comparison values, including: americium-241, cesium-137, cobalt-60, lead, neptunium-237, plutonium-239 and -240, polychlorinated biphenyls, silver, strontium-90, uranium-234, -235, and -238.

Groundwater

Of the 33 substances found in groundwater onsite at Hanford, 23 were found to be at or above the comparison values, including: antimony, arsenic, carbon-14, carbon tetrachloride, cesium-137, chloroform, cobalt-60, copper, cyanide, europium-154, fluoride, iodine-129, lead, nickel, nitrate, strontium-90, technetium-99, trichloroethylene, tritium, uranium-234 and -238, vanadium, and zinc.

Surface Water

Of the 14 substances found in surface water on site, two (lead and nickel) were found to be above the comparison values.

Plants, Animals, or their Products

Fifteen contaminants were found in fourteen types of plants, animals, or their products. In eight cases, the contaminants were found to be above the comparison values.

Table 2-4. Contaminants in Plants, Animals or Their Products

	Sb	Ba	Cs-137	Co-60	Mn	Pu-239	Sr-90	Ur-238
bird's nest				X				
mice			X					
mulberry	X	X			X		X	
mule deer							X	
rabbit							X	
tumbleweed			X			X	X	
yarrow								X

Sb = antimony
Ba = barium
Cs-137 = cesium-137
Co-60 = cobalt-60
Mn = manganese
Pu-239 = plutonium-139
Sr-90 = strontium-90
Ur-238 = uranium-238

3

Sources of Contamination

Outline

Tables

3.0 Chapter Summary

DOE produced plutonium at the Hanford Site in Eastern Washington State from the 1944 until the late 1980s when the need for plutonium diminished. The Hanford Site comprised fuel fabrication, nuclear production reactors, irradiated fuel reprocessing, and waste disposal activities. The Hanford Site also received radioactive materials from other Department of Energy sites. As the result of incomplete containment, the Site was contaminated by both radioactive materials and chemicals. Released materials have impacted the ,the local soil, groundwater, water, and sediments in the nearby Columbia River. Airborne releases from the Hanford Site have mainly affected residents of Washington, Idaho, and Montana. Until 1986, the DOE did not release details about Hanford operations because they were classified for military and security reasons. Prompted by public interest groups and a Freedom of Information request, DOE in 1986 released thousands of previously classified or unavailable documents. These documents showed that substantial amounts of radioactive material had been released to the environment during prior years of Site operations.

Consequently, the Department of Energy initiated a dose reconstruction project which was later managed by the Centers for Disease Control and Prevention (CDC). In April 1994, CDC released the first estimated doses. Since 1994, CDC researchers have done additional work to more fully characterize public exposures to short-lived radionuclides and to improve on base assumptions used in the Columbia River dose reconstruction model.

Environmental Monitoring

Prior to 1987, DOE and its contractors conducted extensive environmental monitoring of Hanford soils, groundwater, subsurface waters, plant life, animal life, and airborne emissions from its facilities and operations for both radionuclides and chemicals. Since 1987, monitoring programs have expanded. Annual environmental reports, available for public review, document both the extent of Hanford Site contamination and the results of ongoing monitoring efforts. Even though the EPA and state agencies oversee the monitoring program, some public interest groups question the results of the DOE monitoring program.

Four contaminated areas at Hanford (the 100-Area, 200-Area, 300-Area and 1100-Area) are listed on EPA's National Priorities List — a list of the country's most contaminated hazardous waste sites. ATSDR evaluated the 1100-Area in a separate public health assessment (ATSDR 1995a).

100-Area

The 100-Area includes nine former reactors (or their remnants) along the southern shorline of the Columbia River at the north end of the Hanford Site. Water from the Columbia River was cycled through the early production reactors for cooling. The cooling water was then held in retention basins before being discharged back into the river. Contaminants in the cooling water were produced by nuclear interactions with water impurities and by occasional leakage of flission products from cracked or breached fuel elements. Portions of this contamination leached into the ground beneath the basins and then into the deeper groundwaters.

Spent fuel from the reactors was stored in water in the 100-K fuel basins. Some assemblies remained unprocessed when PUREX fuel reprocessing operations were discontinued in 1987. The remaining assemblies corroded and some of their contents leaked into the basins, the ground beneath the basins, groundwater, and eventually into the Columbia River. The fuel basins are therefore sources of strontium-90, technetium-99, and tritium contamination. Groundwater is also contaminated with benzene, chromium, nitrate, and tritium (H-3) from storage tanks in the 100-Area that leaked over time (DOE 1995c).

200-Area

The 200-Area includes the fuel reprocessing plants and facilities used to separate radioactive materials from spent reactor fuels. These fuel reprocessing plants were the major source of air releases. The HEDR project estimated the amount of I-131 released into the atmosphere was about 740,000 curies during 1944–1947. That time period accounts for about 90% of the iodine-131 released (Heeb 1992).

The Purex Plant also recovered U-233 (fissionable) with some thorium in a process called the THOREX operation. There were two runs, one in 1966 and one in 1971.

Reprocessing fuel generated large volumes of water that contained low-levels of radioactive and chemical wastes. These wastes were collected in settling ponds, cribs, and French drains. Contaminants have migrated through the soil into groundwater.

The 200-Area Tank Farms include 177 underground tanks that once contained high-level radioactive wastes. Of the 149 single-shell tanks, 67 of the tanks are suspected of leaking in the past. The leaks have resulted in the release of about one million gallons of radioactive waste to surrounding soils (Anderson 1990). Groundwater beneath the tank farms has been contaminated with radionuclide mixtures including tritium, nitrates, and fluorides (DOE 1995b).

The 200-Area annually discharges almost 100 million gallons of process wastewater, including sanitary sewage, chemical wastes, and laundry wastes. The effluents include measureable levels of Cs-137, Ru-106, Sr-90, tritium, and various uranium radioisotopes (Westinghouse 1992b).

The 200-Area includes several landfills that accept radioactive wastes. Records show that the 200-Area received about 883,000 cubic feet of solid radioactive wastes in a typical year (Anderson and Hagel 1992).

300-Area

The 300-Area was used to fabricate uranium fuel elements for Hanford's production reactors. This process generated uranium-contaminated waste solvents and acids (nitric and sulfuric). Disposal of these wastes has resulted in soil and groundwater contamination. Contaminants in the 300-Area groundwater include arsenic, cadmium, cobalt-60, chromium, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and uranium isotopes. These contaminants are migrating to the Columbia River.

Although the Fast Flux Test Facility is in the 400-Area, it is included in Operable Unit 300. The Fast Flux Test Facility operated for about 10 years as a test reactor for breeder reactor components. The FFTF is currently being decommissioned and dismantled.

3.1 Overview of Contamination and Environmental Monitoring

The Hanford Site is located in southeastern Washington State, about 170 miles southeast of Seattle and 120 miles southwest of Spokane. The Columbia River borders the Hanford Site on the north and east. The City of Richland forms the south border, and the Rattlesnake Hills form the west border of the Site. The total land area of the Hanford Site is presently about 560 square miles. Of this area, about 6 percent (32 square miles) is in active use (Westinghouse 1995c). The remaining 94 percent (528 square miles) is barren, sagebrush-covered desert.

Operational Areas

The Hanford Site is divided into operational areas, including: the 100, 200, 300, 400, 700, 1100, and 300 Areas (see Figure 1). In 1989, EPA added the 100, 200, 300, and 1100 Areas to the National Priorities List (NPL). In 1999, the 1100-Area was removed from the NPL because remediation activities had been completed and the EPA and State of Washington determined that the 1100-Area posed no significant threat to public health or the environment if it continued to be used as an industrial, not residential, area (EPA 1996).

Figures showing the location of the operational areas are in Appendix E.

Figure 1. Location of Hanford Site and Operational Areas
Figure 2. 100-K Area Aerial Photograph
Figure 3. 200-Area
Figure 4. 300-Area Buildings
Figure 5. 300-Area Operable Unit Boundaries
Figure 6. 300-Area Waste Sites

Plutonium production reactors are located in the 100-Area on the north side of the Hanford Site along the Columbia River. Radiochemical separations and waste storage facilities are located in the 200-Area toward the center of the Site. In the 300-Area, fuel assembly and research facilities are located at the southwest part of the Site along the Columbia River.

Administrative offices are located in the 700-Area in the center of the City of Richland. Construction services, transportation, and supply facilities were located in the 1100-Area at the north end of Richland.

A more recent addition at the Hanford Site was the construction of the Fast Flux Test Facility (FFTF) and the Fuels and Materials Examination Facility (FMEF) in the Hanford 400-Area, which is about 25 miles south of the 200-Area and about 10 miles northwest of the 300-Area. The FFTF operated for about 10 years and is currently in "standby" mode. The FMEF is a relatively new facility that has not housed any radioactive or chemical materials.

Classified Information Released

For national security reasons, details about Hanford's operations were not public. Concern about past Hanford operations and a request for documents under the Freedom of Information Act led the DOE to disclose previously classified or unavailable information. In February 1986, DOE provided details about the releases of iodine-131 and other radionuclides.

A series of planned releases of iodine-131 from the chemical separations facilities were conducted as part of a classified military test in 1949 to determine the atmospheric transport of fission products from a nuclear facility.

CDC convened a panel of independent scientists (Hanford Health Effects Review Panel) to evaluate the DOE documents. Two of the panel's most important recommendations were (1) to conduct a study to estimate the radioactive materials released from Hanford and (2) to determine the feasibility of studying the health

effects to the thyroid from that exposure. The panel's recommendations evolved into what are known today as the Hanford Environmental Dose Reconstruction Project (HEDR) and the Hanford Thyroid Disease Study (HTDS).

Hanford Environmental Dose Reconstruction Project (HEDR)

The purpose of the HEDR dose reconstruction project was to develop environmental pathway models for radioactive materials and to calculate estimated doses received by "representative" persons who lived in the surrounding areas and along the Columbia River during Hanford production years. CDC first became involved in the HEDR Project in 1992, when responsibility for the project was transferred from the DOE to the Department of Health and Human Services.

CDC released the first estimated dose results in April 1994. Since then, CDC researchers have been using the mathematical computer model developed during the HEDR project to address remaining community and scientific concerns. The additional work focused on 1) exposures to radioactive particles and short-lived radionuclides, and (2) the doses people may have received from Hanford's radioactive-material releases to the Columbia River.

Hanford Thyroid Disease Study (HTDS)

In 1988, Congress mandated the CDC to evaluate the thyroid morbidity rates among persons who lived near the Hanford Nuclear Site between 1944 and 1957. CDC contracted with the Fred Hutchinson Cancer Research Center in Seattle to conduct the HTDS research. The HTDS thyroid disease study evaluated whether the rates of incidence of thyroid disease were related to different levels of estimated I-131 radiation dose (TSP 1994).

Because health effects resulting from exposure to radioactive iodine would most likely have affected those who were children at the time of exposure, the study focused on those who were children during the time of highest releases. Researchers studies all types of thyroid disease, as well as a disease of the parathyroid glands called hyperparathyroidism.

The study results did not show a link between the estimated I-131 dose and the amount of thyroid disease in the study population. The findings mean that if there is an increased risk of thyroid disease from exposure to Hanford's iodine-131, it is probably too small to observe using the epidemiological methods available. Although no relationship was found, the study does not prove that a link between I-131 and thyroid disease does not exist.

Environmental Monitoring

Environmental monitoring has been conducted at the Hanford Site since 1945. Before 1987, DOE and its contractors measured radionuclides at these locations, but did not sample as extensively for nonradioactive elements and chemical compounds. Federal law under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980, as amended (CERCLA) required DOE and its contractors to obtain comprehensive environmental monitoring data on radionuclides and chemical substances in Hanford soils, groundwater, and Columbia River sediments.

Current monitoring programs evaluate air, soil, surface water, groundwater, and plants, animals, or their products. A network of continuously operating air samplers near the site perimeter, at nine sampling locations in nearby communities, and at six monitoring stations in distant communities provide air data. Environmental monitoring and surveillance activities at the site involve effluent monitoring, radiological dose assessments, and analysis of radionuclide pathways to people, such as through the air, water, soil, and foodstuffs (Westinghouse 1992a, b). The EPA and the State of Washington have monitored the data collection process to ensure that the Hanford Site and contamination levels are thoroughly assessed.

Even though there is oversight, there are public interest groups that question the results of the DOE monitoring program. Independent monitoring has been published by the RadioActivist Campaign (http://www.radioactivist.org/) and the Government Accountability Project (http://www.whistleblower.org/).

CERCLA Evaluation of Sites

DOE identified 1,605 separate waste locations at the Hanford Site. Of these, 1,132 locations, such as landfills, burn pits, burial grounds, underground storage tanks, and engineered structures (see Appendix D), were potentially contaminated with radioactive waste or mixed waste. Ninety-five active and 739 inactive emission sources were identified at the Site, including more than 100 buildings or facilities and 117 stacks and vents (DOE 1995; Westinghouse 1995c).

As of 1995, the radioactive waste stored at Hanford included 254,000 ft^3 of mixed (radioactive and hazardous) waste, 37 decommissioned nuclear submarine reactor compartments (representing 1.1 million ft^3 of mixed wastes), and other low-level wastes received at Hanford from other sites under a permit issued in 1994 (FOCUS 1995a).

Under the CERCLA process, the separate waste locations at the Hanford Site were grouped by locations with similar

characteristics. These groups of locations are known as “operable units”. Each of the 1,605 waste locations and the four groundwater contamination plumes were assigned to one of the 78 designated operable units. In 1989, the 78 operable units were further combined into 17 major groups (DOE 1995c).

Also in 1989, DOE organized “tiger teams” to assess environment, health, and safety at each of its sites in the United States. A tiger team audited the Hanford Site during May to July 1990 (DOE 1990c). Some of the findings of the audit concerned the storage of radioactive wastes in the underground tanks, low-level waste sites, and transuranic waste sites. The audit team found deficiencies in the containment of wastes and was concerned about the contamination of groundwater. The audit team also found deficiencies in several environmental monitoring programs (DOE 1990c).

3.2 100-Area

The 100-Area includes nine plutonium-producing reactors along the shoreline of the Columbia River in the northern part of the Hanford Site. Eight of these reactors were constructed between 1943 and 1955. The ninth (N-Reactor) was constructed during the early 1960s as a dual-purpose reactor (for producing both plutonium for nuclear weapons and steam for electrical power generation). DOE no longer operates the reactors in the 100-Area, which have been decommissioned and are being dismantled or cocooned. The first reactor at Hanford, the B reactor, was listed on the National Register of Historic Places and is now a museum. The B reactor is occasionally open for public tours.

While in operation, the 100-Area reactors contaminated the local environment in the following ways:

River water

Columbia River water was used to cool eight of the nine reactors in operation from 1944–1971. The water was pumped through the reactors, where it came in contact with fuel elements. Some amounts of radioactive material contaminated the cooling water. The cooling water was then held in ponds for decay of short-lived contaminants, and was later released back into the Columbia River. Some amounts of longer-lived contaminants were carried into the Columbia River.

Groundwater

The groundwater under the 100-Area is contaminated by materials that seeped out from retention basins and from spent fuel stored in the K-basins. Groundwater contaminants, including nitrate, chromium, benzene, tritium, and strontium, are seeping into the Columbia River.

Soil

Reactor operations contaminated soil in parts of the 100-Area with products from nuclear operations, including strontium-90. Much of this contamination lies under the retention basins where the reactor cooling water was held.

3.2.1 Reactors Along Columbia River

The reactors along the Columbia River resulted in radioactive contamination of the river, soil, and groundwater. The early reactor design had a single-pass cooling system (rather than a closed-loop) that drew water from the Columbia River, held it in retention ponds, and then discharged the water back into the river. As the water passed reactor water tubes and fuel assemblies, it picked up radioactive materials. Most of the short-lived activation products decayed in the ponds; however, activated corrosion products that did not settle in the ponds were carried back into the river. During periods of increased production, retention times were reduced and the amount of activated material discharged to the river increased.

Later reactor design in the N-Reactor used a closed-loop cooling system with purified water that circulated through the reactor core. Heat from the closed-loop system was used to produce steam that was sold to the Washington Public Power Supply System to generate electricity at the adjacent Hanford Generating Plant.

3.2.2 Fuel Storage Basins

As fresh fuel was inserted into the front face of the reactor's graphite pile, irradiated fuel assemblies were forced out the rear into a pool of water called the fuel storage basin. Fuel assemblies were stored in these water basins to await reprocessing. After several weeks storage in the basin, the irradiated fuel was transported by rail to the 200-Area chemical separation plants for recovery of plutonium. Fuel assemblies were stored in the water basin longer when the reprocessing plants were not in operation.

Some of the irradiated fuel assemblies from the N-Reactor were transported by railcar to the 100-K East and 100-K West fuel basins for "temporary" storage, and these wastes are currently being placed in permanent, long-term storage (DOE 1995c). When the PUREX plant was closed, these fuel assemblies could not be processed. Over time, the spent fuel assemblies corroded and portions of their radioactive contents have leaked.

The main part of the Hanford radioactive waste inventory consists of about 2,300 tons of irradiated N-Reactor fuel stored in the 105-K East and 105-K West Fuel Storage Basins. The fuel storage basins (K-Basins) are located in the reactor buildings to the left of the circular structures, shown in Figure 2, 100-K Area Aerial Photograph (DOE 1995c).

> The unprocessed spent nuclear fuels in storage at the Hanford Site constitute about 80% of the total inventory of defense reactor spent fuels currently stored throughout the DOE complex.

The K-Basins are a potential source of strontium-90, technetium-99, and tritium contamination. As contamination migrates from the basins, it enters the groundwater and then seeps into the Columbia River (DOE 1995c). Sediment samples at the N-Springs had measurably high levels of strontium-90 (Sr-90) (DOE 1997a). Radioactivity has also been measured in groundwater in the 100-Area. The K-Basin remediation and cleanup, with complete removal of radioactivity and associated contamination are scheduled for completion by the year 2009.

Contaminants that leaked from the single-shell, high-level waste tanks in the 200-Area have also reached and contributed to contamination of the 100-Area groundwater. Some of these contaminants include benzene, chromium, nitrate, tritium (H-3), and Sr-90. A waste vitrification plant is being constructed for permanent storage of these wastes.

3.3 200-Area

When the Hanford Site was first developed, the 200-Area was established to separate radioactive materials — including uranium and plutonium — from reactor fuels and to manage liquids, solids, and used equipment waste. On a plateau in the approximate center of the Site, the 200-Area consists of the 200-West and 200-East Areas. The individual components of 200-Area are described in Appendix C and shown in Figure 3.

> The major source of 200-Area contamination is radioactive and chemical waste from reactor fuel reprocessing.

Fuel assemblies were transported to the 200-Area chemical plants, dissolved in acid, and subjected to solvent extraction processes to separate out plutonium, uranium, and waste materials. The recovered plutonium was converted into metal for nuclear weapons. The uranium was recovered for recycling, and mixed

wastes containing fission and activation products were stored on site in underground tanks.

For CERCLA site characterization and remediation activities, the 200-Area was subdivided into 44 operable units. The operable units include four separate types of chemical or radioactive waste contamination: tank farms, process liquid effluents, solid and buried waste, and support service wastes (see Appendix C, Location and Description of 200-Area Plants and 200-Area Operable Unit Groupings). The 200-Area contamination covers about 6,000 surface acres and about 2,000 underground acres (Westinghouse 1995c). The Site is patrolled by a security force, and public access to the 200-Area is restricted (Rinne and Daly 1993).

The 200-Area has two main sources of environmental contamination: the chemical plants that reprocessed reactor fuels and released radionuclides to the atmosphere, and the 177 underground tanks that store high-level radioactive wastes and have released more than one million gallons of radioactive wastes to the surrounding soil and groundwater. Six double-shell tanks remain a concern regarding hydrogen build-up and explosion potential.

Air

Fuel reprocessing routinely resulted in radioactive air releases. Releases between 1944 and 1947 were the most significant, particularly iodine-131 (I-131). Other radionuclides released from the 200-Area include americium, cesium, plutonium, ruthenium, strontium, and tritium. Nonradioactive air releases from the 200-Area include carbon monoxide, hydrocarbons, nitrogen oxides, particulates, and sulfur oxides.

Soil

Radioactive waste from the tank farms contaminating surrounding soils. In addition, mixed chemical and radiological solid wastes from throughout the country were buried in the 200-Area. For example, in 1992, the 200-Area received 883,000 cubic feet of solid radioactive wastes from other sites.

Surface water discharges

Until 1995, over 100 million gallons of waste water were discharged per year to the ground through unlined surface structures (e.g., cribs, ditches, drains, settling ponds). Liquid wastes contained, among other substances, carbon tetrachloride, chromium, nitrate, total organic carbon, and radionuclides, including americium, Ca-137, plutonium, Ru-106, Sr-90, tritium, and uranium.

Groundwater

Groundwater in the 200-Area is contaminated and groundwater flow is towards the Columbia River. On-site groundwater exceeds EPA drinking water standards for chromium, iron, manganese, total organic carbon, and tritium.

3.3.1 Past Radioiodine Air Releases from the 200-Area

Fuel processing at the 200-Area facilities routinely discharged radioactive materials into the atmosphere. Some of these releases were accidental, but others were planned. It is estimated that the time period between 1944 to 1947 accounts for 90% of the iodine-131 released. Current estimates are that from 1944 to 1947, a total of 740,000 curies of I-131 were released (Heeb 1992).

In 1949, a classified test was conducted to determine how radioactive materials were transported through the air (Technical Steering Panel, 1992). During this test, known as "the Green Run," about 7,800 Ci of I-131 and 20,000 Ci of xenon-133 were released to the atmosphere.

3.3.2 Air Releases from the 200-Area

The 200-Area had 69 potential atmospheric discharge points (or stacks) in 1990 for radioactive material. All stacks were equipped with high-efficiency filters to remove particles larger than 0.3 microns (Westinghouse 1992a). Measured air releases during 1990 included 5,700 Ci of krypton-85 (an inert gas) and less than one pCi of U-235.

Under the Clean Air Act, Department of Energy operations may not expose members of the public to a radiation dose greater than 10 millirem per year (40 CFR 61 [1989]). The maximum annual dose to a member of the public since 1990 from Hanford Site airborne releases of radioactive materials has been consistently less than 0.1% of the applicable federal limits.

Table 3-1 shows airborne releases of radionuclides from 200-Area facilities in 1990. Air emissions sampling in 1991 (Table 3-2) showed that tritium (H-3) was the most prevalent of the radionuclides released to the atmosphere. Others included Cs-137 and I-129 (Westinghouse 1992b). Table 3-3 shows radionuclide emissions for 1994.

Table 3-1. 1990 Air Releases from 200-Area		
Radionuclide	**Activity Released* (pCi)**	**Average Concentration† (pCi/L)**
H-3	2.3×10^{10}	0.014
Kr-85	7.81×10^{12}	4.92
Sr-90	7.25×10^{6}	1.0×10^{-6}
Ru-106	2.1×10^{6}	1.18×10^{-6}
I-129	1.5×10^{8}	8.9×10^{-5}
I-131	1.9×10^{6}	1.18×10^{-6}
Cs-137	9.6×10^{5}	1.78×10^{-8}
U-234	0.014	Not detected
U-235	4.8×10^{-4}	Not detected
U-236	0.0011	Not detected
U-238	0.0085	Not detected
Pu-239/240	4.1×10^{5}	2.60×10^{-8}
Pu-241	1.8×10^{6}	1.4×10^{-7}
Am-241	1×10^{5}	3.3×10^{-9}

Data from reference (Westinghouse 1992a).
* Values are in picocuries (pCi).
† Average concentration released from the 291-A-1 stack in the 200 East Area. Values are in pCi per liter.

Table 3-2. 1991 Air Releases from 200-East Area		
Radionuclide	**Activity* (pCi)**	**Average Concentration† (pCi/L)**
H-3	1.4×10^{9}	0.0010
Sr-90	1.1×10^{6}	8.1×10^{-7}
Ru-106	3.85×10^{6}	2.9×10^{-6}
I-129	6.7×10^{7}	4.8×10^{-5}
I-131	ND ‡	$<2.5 \times 10^{-7}$
Cs-137	4.1×10^{6}	3.01×10^{-6}
Pu-239/240	5.2×10^{4}	3.85×10^{-8}
Pu-241	4.1×10^{5}	3.01×10^{-7}
Am-241	4.8×10^{5}	3.56×10^{-7}

Data from reference (Westinghouse 1992b).
* Values are in picocuries (pCi).
† Average concentration released from the 291-A-1 stack in the 200 East Area. Values are in pCi per liter.
‡ Not detected.

Table 3-3. 1994 Air Releases from 200-East Area		
Radionuclide	**Activity* (pCi)**	**Average Concentration† (pCi/L)**
Sr-90	4.8×10^{4}	3.15×10^{-8}
I-129	1.78×10^{7}	1.19×10^{-5}
Cs-137	8.1×10^{4}	5.33×10^{-8}
Pu-239/240	3.85×10^{4}	2.60×10^{-8}
Pu-241	2.5×10^{5}	1.6×10^{-7}
Am-241	1.5×10^{4}	1.0×10^{-8}

Data from reference (Westinghouse 1995b).
* Values are in picocuries (pCi).
† Average concentration released from the 291-A-1 stack in the 200 East Area. Values are in pCi per liter.

The major nonradioactive releases from 200-Area stacks were nitrogen oxides (NO_x) from the PUREX Plant. The maximum release of nitrogen oxides was 32,538 pounds and the highest daily total was 2,772 pounds. All such releases were within EPA limits and within amounts permitted by the Benton-Franklin-Walla Walla County Air Pollution Control Authority. Other nonradiological releases included carbon monoxide, hydrocarbons, particulates, and sulfur oxides, mostly from power plant operations in the 200-Area (Westinghouse 1992a).

Nonradioactive air emissions from the 200-Area powerhouse continued in 1991 (Westinghouse 1992b). In 1994, as in previous years, the 200-Area coal-fired heating plants continued to release nonradioactive pollutants from stacks, including particulates, nitrogen and sulfur oxides, and other compounds (Westinghouse 1995b).

3.3.3 200-Area Tank Farms

High-level radioactive wastes from reactor fuel reprocessing at Hanford are contained in large (up to 1 million gallons), underground tanks. An inventory of the tank farms, number of tanks, type, and capacity is in Appendix C (see Location and Description of the 200-Area Plants). The tanks are of two designs: 1) first-generation, single-shell tanks, and 2) more modern double-shell tanks. The first tanks were constructed of concrete and carbon steel and were covered with at least 7 feet of soil for radiation shielding (Anderson 1990).

Of the 149 single-shell tanks, 67 are suspected of having leaked in the past. The leaks have resulted in the discharge of 1 million gallons of radioactive waste to surrounding soils.

Radioactive wastes have been sent to these tank farms since 1944. A major concern about Hanford has been safe storage of high-level wastes in these tanks. Many of the first-generation tanks corroded and leaked to the surrounding soil. The first leaking tank was identified as early as 1956 (PNNL 1995). Since the 1970s, a major effort has been underway to transfer all waste from single-shell tanks to double-shell tanks to prevent further leakage. The project was completed in August 2004.

Twenty-eight double-shell tanks store high-level radioactive mixed waste. Each of these tanks has a volume of about 1 million gallons. The radioactivity in the contents of the tanks include about 1 million Ci of radioactive cesium and 1,000 Ci of radioactive strontium. These tanks also contain more than

20,000 pounds of nonradioactive salts and chemical sludges (Kaiser 1995). The last fuel reprocessing discharge to the tanks occurred in 1990. The estimated total volume of wastes in the tanks is approximately 37 million gallons of liquid, sludge, and salt cake.

In April 1996, DOE and the Washington State Department of Ecology released an environmental impact statement (EIS). The EIS described nine alternatives for managing the high-level radioactive wastes stored tanks and the more than 1,500 strontium-90 and cesium-137 capsules stored separate from the tank waste. The EIS identified a preferred method for remediating the tank waste and capsules (DOE 1996d). The strontium-90 and cesium-137 capsules have potential commercial value as radiation sources. The plan for stabilizing the tank waste was contained in a 1997 Record of Decision published in the Federal Register, Volume 62, page 8693 (DOE 1997c).

DOE has chemically neutralized and stabilized all of the single-shell tanks, and work continues on pumping radioactive waste from the single-shell tanks to double-shell tanks. The General Accounting Office has conducted audits of spending on waste storage, tank maintenance, and restoration programs (GAO 1994).

Explosion Hazard

Potential explosions from hydrogen gas buildup in several tanks was a hazard, but systems have been added to remove excess heat and hydrogen that accumulate in the tanks. DOE has determined that organic substances in the tanks are of insufficient amounts and concentrations to support explosive chemical reactions. In December 1998, 18 tanks were removed from this category (DOE 1998). Of the 25 tanks in the hydrogen-concern category, the 241-SY-101 tank was of foremost concern for hydrogen build-up. DOE installed a mixing pump to increase the release rate of hydrogen from this tank. Six double-shell tanks are of concern for hydrogen build-up (PNNL 1995).

Monitoring of 54 tanks was conducted for: ferrocyanide, flammable gas, high-heat, organic-containing wastes, and radionuclides. Concerns include radiological contaminants that have leaked from the 200-Area storage tanks, including an estimated 20,000 Ci of radioactive cesium (Anderson 1990).

Tanks containing ferrocyanide can react with nitrate or nitrite under conditions of elevated temperature, and an explosion can result. Of the initial 24 tanks being monitored, six have been downgraded because analyses have verified that the

ferrocyanide concentrations have decreased as a result of either hydrolysis or radiological destruction (PNNL 1995).

The process of radioactive decay releases energy in the form of heat. Although the tanks are equipped with active cooling systems, the heat generated in one tank, the 241-C-106 single-shell tank, exceeds the prescribed engineering limits. Added water and an extra ventilation system provide the necessary cooling (GAP 1996).

Wastes from the single-shell tanks were removed using a low-pressure pumping system. The process effluent passed through an ion exchange system to remove cesium-137 and strontium-90 before going to the Liquid Effluent Retention Facility (LERF) — a surface impoundment. The sludge was piped to double-shell tanks. Volatile organic compounds (VOCs) are also removed and stored at LERF. Metals in the waste included aluminum, barium, boron, cadmium, chromium, magnesium, manganese, and iron. Other inorganic materials included bicarbonate, ammonium, chlorides, fluorides, nitrate, and sulfates (FOCUS 1995b).

Groundwater

The National Research Council of the National Academy of Science has reviewed problems at the tank farm for DOE. Among the concerns is that groundwater monitoring (in the vadose zone) has not adequately defined pathways for cesium and other contaminants that have leaked from the tanks.

The depth to groundwater in the 200-Area varies with location. In the 200-West Area, depth to groundwater is between 200 and 210 feet; in the 200-East Area, the depth to groundwater ranges from 220 to 270 feet. Examples of contaminants detected in groundwater associated with the tank farms and their maximum concentrations in downgradient wells are gross beta emitters (3,000 picocuries per liter [pCi/L]); tritium (380,000 pCi/L); nitrate (510,000 parts per billion [ppb]); and fluoride (5,000 ppb) (DOE 1995b).

The DOE plans to construct a waste vitrification plant to convert the tank waste into solid glass and store the glassified waste logs on site until the permanent off-site storage facility is available, which is scheduled for the year 2028 (PNNL 1995).

3.3.4 200-Area Plants

Several facilities in the 200-Area were used to extract plutonium and uranium (e.g., Plutonium Finishing Plant, REDOX, and PUREX). The 200-Area plants are

described in Appendix C. The PUREX Plant was also used for the THOREX operation in 1966 and again in 1971. THOREX recovered U-233 with thorium.

Separated plutonium from reprocessing was converted into metal at the Plutonium Finishing Plant in the 200-West Area. This facility is no longer used to process plutonium. The area is still used to store plutonium.

A chemical explosion occurred in this area in 1997 in one of the nonradioactive chemical storage tanks. A 400-gallon tank containing hydroxylamine nitrate and nitric acid exploded and eight workers were evaluated for potential radioactive contamination. No workers were injured (Tri-City Herald 1997). A follow-up investigation team determined that the accident did not release radioactive material into the environment or result in the contamination of any of the workers involved (DOE 1997d).

3.3.5 200-Area Liquid Effluents

In 1991, the 200-West Area discharged 67 million gallons of process wastewater and 13.5 million gallons of sanitary sewage to the soils. The 200-East Area discharged 23 million gallons of wastewater and sewage (Westinghouse 1992b).

Effluent discharges in the 200-Area included sanitary sewage, chemical wastes, and laundry wastes. In 1987, the 200-Area discharged about 39,600 lbs of nitrates and about 24,200 lbs of total organic carbon. In 1991, almost 7,700 lbs of nitrates and about 31,460 lbs of total organic carbon were discharged. In 1990, unless radiation monitors reported conditions that might exceed discharge permit levels, liquid effluents from the 200-Area were discharged to the ground by way of unlined subsurface engineered structures such as cribs, ditches, French drains, and reverse wells. Definitions and descriptions of engineered structures are provided in Appendix D.

Radionuclides released in 1990 included Cs-137, Ru-106, Sr-90, tritium, and various uranium radioisotopes. With 20 discharge points reported, the average liquid discharge was 291 million gallons. The average activity of individual radionuclides exceeded the maximum concentration levels (MCLs) for drinking water. This discharge water did not, however, serve as a supply of drinking water in the 200-Area or in any areas outside the Hanford Site that obtain drinking water from the Columbia River (Westinghouse 1992b).

Radionuclides released through effluent discharge in the 200-Area in 1991 continued to included Cs-137, Ru-106, Sr-90, tritium, and uranium isotopes. Fourteen discharge points reported an average of 197 million gallons of liquids discharged. As in 1990, the average activity of the individual radionuclides exceeded the MCLs but again, this water was not a drinking water source (Westinghouse 1992a).

Liquid discharges from the 200-Area during 1994 did not significantly differ from those of other years. Sanitary liquid wastes and process wastes continue to be discharged to engineered ground structures. These discharges will continue until waste stabilization and remediation efforts are completed (Westinghouse 1995b).

For the year 2001, the primary sources of radionuclide emissions were from the Plutonium Finishing Plant, T Plant, 222-S laboratory, underground tanks that were storing high-level radioactive waste, waste evaporators, and the inactive Plutonium-Uranium Extraction Plant. In 2001, there were 49 radioactive emission points were active in the 200-Area (DOE 2002).

3.3.6 200-Area Cribs, Ponds, and French Drains

When fuel was reprocessed, large volumes of water that contained low-levels of radioactive and chemical wastes were generated. These waste waters were collected in settling ponds, cribs, and French drains. At the time, scientists believed that the soil would function as both a filter and an ion exchange medium for many of the radionuclides in the waste water. Other waste liquids were discharged to surface trenches, some of which were more than 2,000 feet long. In addition, mixed chemical and radiological solid wastes were buried in landfills.

The radionuclide inventory of the 200-BP-1 Cribs is shown in Table 3-4. A list of chemicals discharged in 200-BP-1 Cribs in 1987 is shown in Table 3-5.

Table 3-4. Radionuclide Inventory in 200-BP-1 Cribs*

Radionuclide	April 1, 1986 (curies)	April 1, 1995 (curies)
H-3	2,500	1,505
Sr-90	6,054	4,892
Cs-137	2,092	1,700
Co-60	0.449	0.14
Ru-106	0.000090	<0.000001
U-238	0.18	Not substantially reduced†
Pu-239	4.1	Not substantially reduced†
Pu-240	1.09	Not substantially reduced†

Data from reference (DOE 1990b).

* The 1995 values are based on a physical half-life; no adjustment is made for washout or weathering.
† Not substantially decayed: the half-life of these radionuclides is greater than 5,000 years and the change in total decay is less than 0.1% of the initial 1986 concentration in the cribs.

Table 3-5. Chemicals Discharged in 200-BP-1 Cribs in 1987

Chemical	amount (kg)
Sodium	2,650,500
Nitrate	6,501,500
Sulfate	469,000
Phosphate	332,000
Ferrocyanide	18,900
Ammonium nitrate	10,000
Ammonium carbonate	21,000

Data from reference (DOE, 1990b).

In 1994, tritium measured in 9 of 23 downgradient monitoring wells exceeded EPA drinking water standards. Other well contaminants detected above drinking water standards included total organic carbon, chromium, iron, and manganese (DOE 1995b).

The 216-B-3 Pond in the 200-East Area began receiving wastes in 1945 and was closed to new waste in 1994. The pond covered 35 acres and has a maximum depth of 20 feet. Three expansion ponds have been added to the original area. The 1994 discharges to the ponds averaged 4 million gallons per day. The main pond was filled in 1994.

The third expansion pond, 216-B-3C, is still active and continues to recharge the aquifer. Measurements of water quality show that of the contaminants identified in the 200-Area ponds, tritium exceeded the designated maximum concentration level of 20,000 picocuries (pCi/L). The maximum concentration was reported in 1991 at 190,000 pCi/L. As of 1994, the tritium concentration had decreased to 145,000 pCi/L.

The 200-East Area Liquid Effluent Retention Facility (LERF) consists of three lined retention basins with a capacity of 6.5 million gallons each. The facility serves as a temporary storage site for the 242-A evaporator from tank farm volume reduction activities. Liquid wastes stored in the unit include organic materials, metals, and radionuclides (C-137, Ru-106, Sr-90, and tritium). The organic materials are acetone, butanol, and butanone. Of the contaminants detected in monitoring wells associated with this site, only chromium and iron exceeded the recommended EPA standards (DOE 1995b).

In the 200-West Area, the 216-Z-1A Tile Field, the 216-Z-9 Trench, and the 216-Z-18 Crib are disposal sites for carbon tetrachloride (CCl_4). These sites received liquid wastes from 1949 to 1973. The CCl_4 was used in the recovery of plutonium and, to a lesser extent, in the recovery of americium-241 in the Z Plant (the Plutonium Finishing Plant). DOE estimates that as much as 153,000 gallons of CCl_4 was discharged into the 216 crib areas between 1955 and 1973. About 375 pounds of plutonium-239 and about 9 pounds of americium-241 were broadly dispersed into fields, trenches, and cribs as low-level contaminants of carbon tetrachloride waste during this period. The contamination covered an estimated 6.8 square miles in 1991 (DOE 1991).

CCl_4 has been detected in the water table at a depth of 380 feet. Plutonium and americium have also been detected.

The 216-S-10 pond and ditch received liquid wastes from the S-Plant in the 200-West Area, creating a perched water zone. The last discharge occurred in October 1991 and consisted of 50 million gallons and the perched zone is diminishing. Wastes included aluminum nitrate, sodium nitrate, sodium phosphate, sodium hydroxide, sodium fluoride, sodium chloride, and potassium dichromate, as well as associated low-level radioactive wastes. By mid-1994, the concentration of uranium[1] was at or less than the maximum concentration limit of 20 micrograms per liter (μg/L). Volatile organics, tritium, and technetium-99 have not been detected in groundwater beneath the 200-West Area (DOE 1995b).

The 216-U-12 Crib south of the U-Plant in the 200 West Area received wastes from 1960–1988. The average annual volume of liquid discharges was 35 million gallons. Radioactive wastes contained uranium, mixed fission products[2], and plutonium. Nonradioactive contaminants included nitric acid, CCl_4, chromates, and iron. Contamination was detected to depths of 140 feet in 1983. By 1993, the depth of contamination decreased to 64.5 feet because of crib inactivity. Detectable technetium-99, tritium, and other fission products are well below EPA drinking water standards. From 1991 to 1994, the nitrate concentrations in monitoring wells near the crib 216-U-12 Crib ranged from about 100,000 to 500,000 ppb. Carbon tetrachloride exceeded the EPA's drinking water standard (DOE 1995b).

3.3.7 200-Area Solid Waste Disposal

Records show that the 200-Area received about 883,000 cubic feet of solid radioactive wastes from other sites in a typical year (1992).

The 200-Area was designated as the central storage location for solid wastes from the entire Hanford Site. It received mixed wastes, transuranic wastes, contaminated materials, and other types of wastes. These solid wastes contained about 1 million curies (Ci) of uranium, plutonium, strontium-90, cesium-137, ruthenium-106, and other radionuclides. These wastes were placed in the many burial grounds in the 200- East and 200-West areas (Anderson and Hagel 1992).

[1]Natural uranium consists of three radioisotopes: uranium-234 (U-234), uranium-235 (U-235), and uranium-238 (U-238).

[2]Mixed fission products consist of many different radioisotopes produced in uranium fission. The most prominent fission products include isotopes of cesium, strontium, and iodine.

All nonradioactive solid waste generated by DOE activities at the Hanford Site (except coal combustion by-products from the heating plant) is disposed of in a central landfill near the 200-Area (Westinghouse, 1992a). The 200 Area also includes a burial site for decommissioned reactor compartments from the U.S. Navy fleet of nuclear-powered submarines.

A commercial (private business) low-level radioactive waste burial site operated by U.S. Ecology on land leased from DOE is also located in the 200 Area.

3.4 300-Area

Uranium fuel elements for Hanford's production reactors were fabricated in the 300-Area from stock uranium billets, which were then clad with a protective metal. Lubricants and copper coating, which protected the uranium during the rod extrusion process, were removed by treatment with organic solvents, copper sulfate, nitric acid, and sulfuric acid. The smoothed rods were encased in aluminum (early years) or zirconium (later years). These processes generated uranium-contaminated waste solvents and acids, as well as scraps and fines of uranium and other metals (DOE 1994 [p. 2-3]; DOE 1995d [p. 2-1]).

Research and development, covering a broad variety of technologies, was also conducted in the 300-Area. The early research involved materials chemistry in support of fuel fabrication. Later research involved radiochemical separations, reactor technology, and radionuclide metabolism and toxicity. Some of the waste materials generated during research included uranium, fission products, transuranic radionuclides, acids, solvents, metals, and miscellaneous inorganic compounds (DOE 1994 [p. 2-3]; DOE 1995d [p. 2-2]).

The Fast Flux Test Facility (FFTF), which is actually in the nearby 400-Area, is included in one of the 300-Area's operable units. The sodium-cooled FFTF reactor operated for 10 years and is currently being decommissioned. Concerns about proper waste management and transportation of radioactive spent fuels associated with the FFTF have been raised.

The 300-Area includes liquid and solid waste disposal units and active and inactive sewers, including an active radioactive liquid waste sewer. This area also includes contaminated soil, groundwater, and Columbia River water and sediments.

Soil

Environmental contamination resulted from the disposal of liquid and solid wastes, and unplanned releases of materials during production. The waste

disposal trenches were closed when migration of uranium from the soil to area groundwater was observed.

Groundwater

Contaminants in the 300-Area groundwater include arsenic, cadmium, cobalt-60, chromium, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs),, and uranium isotopes. Contaminated groundwater from other areas of the Hanford site has contributed nitrate, trichloroethylene, and tritium contamination to groundwater under the 300-Area.

River water

The 300-Area process ponds, retention basins, and trenches are 300–1,000 feet from the Columbia River. Wastes delivered through the 300-Area sewers to these disposal areas included isotopes of cesium, cobalt, plutonium, and uranium, as well as copper and chromium. These contaminants are migrating to the groundwater and then into the Columbia River.

Air

Between 9145–1962, some solid wastes were burned above ground.

3.4.1 300-Area Operable Units

The 300-Area was consolidated into three operable units (OUs): 300-FF-1, 300-FF-2, and 300-FF-5 (DOE 1995d). The boundaries of the operable units are shown in Figure 5. Waste sites and facilities are shown in Figure 6.

Operable Unit 300-FF-1 includes the major liquid (as well as several solid) waste disposal units of the 300-Area. It includes soil contaminated by waste disposal (DOE, 1995d). Operable Unit 300-FF-5 includes contaminated soil below the water table, groundwater, and Columbia River water and sediment contaminants from the 300-Area (DOE 1995d [p. 1-1]).

Operable Unit 300-FF-2 includes identified waste sources in the 300-Area outside of 300-FF-1 and groundwater contaminant plumes outside of 300-FF-5 (DOE 1994, [p. 2-1]). In addition, Operable Unit 300-FF-2 includes the Fast Flux Test Facility (FFTF) and waste sites in the 600-Area (DOE 1994 [p. 2-1, 2-2]).

3.4.2 Fast Flux Test Facility (FFTF)

Although the Fast Flux Test Facility is in the 400-Area, it is included in Operable Unit 300-FF-2. The FFTF is DOE's relatively new 400-megawatt thermal sodium-cooled nuclear test reactor, located about 15 miles north of the City of

Richland, Washington. The FFTF was deactivated and is being disassembledThe fuel has been removed from the reactor.

The FFTF consists of the reactor and several support buildings and equipment arranged around the central reactor containment building. The reactor is located in a shielded cell at the center of the containment building. Heat was removed from the reactor by low-pressure liquid sodium that was circulated through three primary loops, which include the pumps, piping, and intermediate heat exchangers. The primary loops are connected to secondary loops consisting of pumps, piping, flow meters, and heat exchangers.

The FFTF did not vent measurable levels of radioactivity to the atmosphere or release liquid radioactive wastes to the ground during its 10 years of operations between 1982–1992.

Low-level radioactive wastes (e.g., latex gloves, paper, masking tape) generated while the FFTF was operating were removed to the 200-Area for storage (DeFord et al. 1994 [pp. 4-1–4-36]).

Nonradioactive liquid wastes generated in the 400-Area included solvents stored in tanks, spent fuels stored in secure above-ground fuel storage devices, and aqueous chemical wastes (water solutions of detergents and other nonhazardous substances) (DeFord et al. 1994 [pp. 4-1–4-36]).

In December 1993, DOE ordered shutdown of the FFTF due to a lack of economically viable missions at that time. From 1994–97, fuel was removed from the reactor and stored. In January 1997, DOE put the FFTF on standby status while DOE evaluated the FFTF's potential role for tritium or medical isotope production.

Some expressed concerns about the possible restarting of the FFTF, particularly for producing tritium. The impact to downwinders in the event of a release was questioned, and community members also wanted assurance that the facility would not release harmful materials into the environment, such as into groundwater and into the Columbia River. Community members also questioned whether funding allotted for clean up activities at Hanford should be diverted to maintain and operate the FFTF. In addition, concern was expressed regarding safe transport of radioactive materials that would fuel the FFTF.

In December 2001, DOE ruled out the use of FFTF and reaffirmed their decision for its permanent deactivation. In May 2003, the Tri-Party Agreement agencies

(i.e., DOE, EPA, and Washington State Department of Ecology) signed an agreement defining the deactivation milestones currently underway.

3.4.3 300-Area Contamination Sources

Most of the contamination in the 300-Area occupies about 2.5 square miles. The Columbia River forms the east border of the site, and northern part of the City of Richland lies about 1.5 miles to the south (DOE 1994 [p. 1F-2]; DOE 1995d [p. 2-1]). The 300-Area elevation is 390 feet above mean sea level and about 40 feet above the Columbia River (DOE 1995f [p. 2-8]). Waste sites and facilities in the 300-Area are shown in Figure 6.

Environmental contamination resulted from the disposal of both liquid and solid wastes, as well as from unplanned releases of materials during production, transportation between facilities, and waste management. Liquid wastes were fed from generating facilities through sewer lines into holding tanks for specialized disposal or into trenches and ponds for evaporation and seepage into the soil. Solid wastes were buried in pits and trenches. From 1945–1962, some solid wastes were burned aboveground.

Sources of groundwater contamination include plumes from other waste sites, such as the nitrate and trichloroethylene plumes from the 1100-Area, and the tritium and nitrate plumes from the 200-Area.

Operable Unit 300-FF-2 contains a sanitary sewer, a process sewer, a former radioactive liquid waste sewer, a new active radioactive liquid waste sewer, and a retention process sewer. The currently inactive process and retired waste sewers may have leaked at some of the joints (DOE 1992b [p. 3-2]; DOE 1994 [p. 2-4]). The process sewers delivered most of the liquid wastes from the generating facilities in 300-FF-2 to the process ponds and trenches in 300-FF-1 (DOE 1995d [p. 2-2]). Wastes included isotopes of uranium, cesium, cobalt, plutonium, promethium, and acids and solvents (DOE 1992b [p. 4-4]).

3.4.4 307-Area Retention Basins and Trenches

The 307-Area retention basins and trench system was constructed in 1953 to separate liquid wastes by level of radioactive contamination. Liquid wastes from laboratories in the 300-FF-2 area fed into four concrete retention basins about 350 feet southwest of the South Process Pond. Waste in the basins was monitored for radioactivity. When radioactivity exceeded 5 picocuries per liter (pCi/L), it was diverted into holding tanks below- and above-ground in the 340-building for transport to the 200-Area for disposal.

In 1965, the trenches were retired and soil from the trenches was removed to the 618-10 burial grounds. The trenches were filled with contaminated material dredged from the South Process Pond and with fly ash.

Contaminants in this waste area include radioactive isotopes of uranium and other metals. The area, now covered with gravel, is occupied by several facilities (buildings 3727, 3718E, and 3718G, shown as small boxes north of buildings 308 and 324 in Figure 6) (DeFord et al. 1994 [p. 2-4, 2-14, 3-21–3-26, 3-46–3-50, 3-67–3-68]; DOE 1994 [p. 2-5, plate 2-1b]).

3.4.5 300-Area Process Ponds

The South Process Pond (316-1) was built in 1943 approximately 400-feet from the Columbia River. This pond was used until 1975. It measured 600 by 600 feet, and was 13 to 20 feet deep (DOE 1992b, [p. 3F2]). Dredged material from the pond was used to maintain the dikes until 1969. Contaminants released to the South Process Pond included uranium-238, cobalt-60, copper, and chromium. The pond is now dry and covered with clean soil (Dennison et al. 1981; McCeod 1996 [aerial photographs]; DOE 1995d [pp.2-2–2-3, 2F-19–20]).

The North Process Pond (316-2) was built in 1948 approximately 300 feet west of the Columbia River. It was about 600 feet long, and 13 to 20 feet deep (DOE 1992b [p.3F3]). This pond was active until 1975. The pond was covered with material from the dikes in 1975. Primary contaminants in the pond included copper and uranium isotopes. After 1975, parts of the covered pond were used for fly ash disposal (DOE 1995d [pp. 2–3, 2F-21–22]).

3.4.6 300-Area Process Trenches

Two parallel, unlined trenches were constructed in 1975 about 100 feet west of the North Process Pond and 1,000 feet from the Columbia River. They were originally 1,300 feet long, with a combined width of 90 feet. Liquid wastes from the process sewers were fed to the south end of both trenches by way of a weir box. Contaminants measured in 1991 in two unlined trenches in the 300-Area included arsenic, cadmium, chromium, cobalt-60, copper, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, thorium-228, and uranium isotopes. In 1991, the trenches were closed for remediation.

Closure of the trenches was prompted by observation of soil uranium migration to the 300-Area groundwater.

3.4.7 300-Area Burial Grounds and Landfills

Six solid waste sites (two burial grounds and four landfills) were located in Operational Unit 300-FF-1. These burial grounds contain miscellaneous materials contaminated with uranium. In 1995, the burial grounds contained mostly uranium soil contamination, metal objects, uranium-contaminated materials, solid wastes, and small amounts of the solvents perchloroethylene and trichloroethylene (DOE 1995e [p.6]).

Burial Ground 5 (618-5) was a trash burning pit from 1945 through 1962. Uranium metal on the surface was removed in 1988 (DOE, 1992b [p. 4-7]). Further information on 300 Area burial grounds and trenches is available in Appendix D, Operable Unit 300-FF-2 Burial Grounds (Gerber 1992, 1993; DOE 1995a).

3.4.8 Uranium Fuel Assembly and Research Facilities

The uranium fuel for production reactors was manufactured in the 313-building, the 314-press building, the 306-metal fabrication development building, and the 333-uranium fuels finishing building (DOE 1996c [p. 1-4]). The most important technology and research facilities in the 300-Area included the 321-separations research building, the 3706-building, the 325-radiochemical processing laboratory, the 327- radiometallurgy building, the 329-physical sciences and radioanalytical laboratory, the 309-plutonium recycling test reactor, the 324-chemical engineering laboratory, and the 331-life sciences laboratory (Gerber 1992, 1993; DOE 1996c [p. 1-4]).

4

Past Exposures

Outline

Tables

4.0 Chapter Summary

An exposure pathway is the route by which a contaminant travels from its source of origin, through the environment, to people. To determine Hanford exposure pathways, scientists first estimated the amounts of radioactive materials released from the Hanford Site to the Columbia River (from 1944 to 1971) and to the atmosphere (from 1944 to 1972). Scientists then estimated the amounts of radioactive materials transported from the river or air to soil, plants, animals, animal products, and people. Much of this information was developed during the Hanford Environmental Dose Reconstruction (HEDR) project, which involved the DOE and its contractors, an independent Technical Steering Panel of scientists, the Centers for Disease Control and Prevention (CDC). Congress mandated the HEDR project after the public learned in 1986 of the releases of radioactive materials.

The major exposure pathway through which people received radiation doses involved drinking milk from cows and goats that grazed on grass contaminated with airborne radionuclides. Other exposure pathways included drinking water from cisterns, drinking treated or untreated water from the Columbia River, eating food irrigated with contaminated river water, eating contaminated fish from the river, breathing contaminated air, swimming or boating in the Columbia River, eating contaminated vegetables, eating contaminated waterfowl from the river, contact with contaminated soil, and pica behavior (i.e, children eating contaminated soil). Individual risk factors, such as age at time of exposure and sensitivity to radiation, influence how a person is affected by radiation.

The major sources of air releases were the chemical processing and separation plants of the 200-Area. Persons living in the Columbia Basin and other areas of eastern Washington, northeastern Oregon, and western Idaho, as well as those who ate food products produced in the fallout area, were exposed to radioactive releases, primarily radioiodine (I-131). HEDR estimated the *maximum* radiation dose to an off-site person’s thyroid from airborne I-131 during the period 1944 to 1957 to be between 54 to 850 rads. However, HEDR estimated the *average* thyroid dose to be 2 to 10 rads.

Sources of radioactive releases to the Columbia River included river water used as cooling water for the plutonium reactors, leaks from underground storage facilities, fuel assembly ruptures, and film and corrosion in pipes. Persons in the Tri-Cities area who consumed large amounts of fish or waterfowl from the Columbia River would be among the most exposed. According to HEDR estimates, a person could have received an effective dose of up to 1,500 millirem

(approximately 1.5 rad whole body) from the Columbia River pathway from 1944 to 1971.

4.1 Exposure Pathway Evaluation

An exposure pathway is the route by which chemicals, radioactive materials or both travel from the place where they were released, through the environment, to people (HHIN Undated-b). The most important radionuclide exposure was from I-131 in the milk-ingestion pathway. I-131 released from Hanford chemical processing plants during the late 1940s and early 1950s released into the ambient air and settled on downwind pasture lands. Most of the I-131 decayed away naturally with a half-life of 8 days. The grazing by milk cows transferred I-131 to cows' milk. The I-131 was consumed when nearby populations ingested milk from local farms (HHIN Undated-a). Other potential exposure pathways for other radionuclides released from the Hanford Site may have included direct inhalation of airborne contaminants or ingestion of fish from the Columbia River.

For this public health assessment, ATSDR analyzed the exposure pathways to people by studying five aspects of exposure, including

- the *source* of the radioactive material or chemical contamination,
- the *type* of environmental medium containing the contamination (e.g., air, water, soil, food),
- the *location* of human exposure,
- the *routes* of exposure, such as inhalation, ingestion or skin contact, and
- the target *population* that is potentially exposed.

ATSDR then categorized the exposure pathways as either "completed" or "potential." The presence of "completed" exposure pathways does not always result in health effects. The type and severity of health effects that may occur in an individual from contact with a contaminant depend on the physical properties of the substance, the exposure concentration, the frequency and duration of exposure, and the route of exposure such as breathing, eating, drinking, or skin contact, and the combination of contaminants. Once exposure occurs, characteristics such as age, sex, nutritional status, genetics, life style, and health status of the exposed individual influence how the individual absorbs, distributes, metabolizes, and excretes the contaminant. Together, these

Individual risk factors, such as sex, age at exposure, and individual sensitivity to radiation influence the actual health effect that an exposure to a contaminant may cause.

factors and characteristics determine the health effects that may occur as a result of exposure to a contaminant in the environment.

The most probable exposure pathways were evaluated. For example, if contaminated groundwater was the source of drinking water, it was evaluated for possible human exposure. Similar approaches were taken for ingestion pathways involving wild game and other food.

4.1.1 Estimating Past Releases: The HEDR Project

In September 1986, the Hanford Health Effects Review Panel, representing concerned populations in Washington and Oregon including several Native American tribes, recommended that studies on dosimetry — radiation doses received by people — and thyroid disease studies be initiated to assess the potential impacts of the releases on human health (TSP 1994). The DOE responded by directing one of its contractors, the Pacific Northwest Laboratory in Richland, Washington, to reconstruct the radiation dosimetry for affected populations. This project was called the Hanford Environmental Dose Reconstruction (HEDR) project. The purpose of this project was to determine the amounts of radioactive material that were released, the exposure pathways to people, and the radiation doses that may have been received.

Requests made under the Freedom of Information Action resulted in widespread public knowledge of and concern about radioactive releases.

When members of the public expressed mistrust of the government and its national laboratory in conducting these studies, an independent Technical Steering Panel of scientific experts and representatives of neighboring states was formed to direct the Dose Reconstruction Project (TSP 1994). In 1992, the responsibility for directing this research was transferred from the DOE to the Centers for Disease Control and Prevention (CDC). The Technical Steering Panel provided technical oversight of the HEDR study by evaluating all

Factors Contributing to the Radiation Dose that Persons Received from Hanford Included

- Where a person lived.
- When and how long the person lived there.
- The amount of contact the person had with radioactive substances.

dose reconstruction project data and computer models. The Steering Panelworked for declassification of additional documents that were needed to complete the study (TSP 1994).

The first step in dose reconstruction was to establish technically strong estimates of the types and amounts of radionuclides that were released over time from Hanford Site release points. These are known as the *source term*. This information was assembled by reviewing thousands of technical documents. Ways in which the releases may have traveled through the environment and by which off-site populations may have been exposed were then identified (TSP 1994).

4.1.2 Completed Exposure Pathways

The most important exposures occurred during the plutonium production era — primarily 1944–1972. Notably, I-131 was released into the air. Releases into the Columbia River included sodium-24, phosphorous-32, zinc-65, arsenic-76, neptunium-239, and cobalt-60. Table 4-1 summarizes the major air and water pathways for that time period.

A history of Hanford releases of radioactive materials was published in 1994 (TSP 1994). One purpose of the 1994 report was to estimate the resulting radiation doses to certain populations and to a “maximally exposed individual” from those releases. This public health assessment draws largely from that work.

Table 4-1. Completed Past Exposure Pathways (Primarily from 1944 to 1971)

Pathway Name	EXPOSURE PATHWAY ELEMENTS				
	Contamination Sources	Environmental Media	Points of Exposure	Routes of Exposure	Estimated Exposed Population
Air-Milk 1944–72 (major releases 1944–51)	200-Area separations plants, air, pastureland	Backyard cow and goat milk	Consuming local dairy products (e.g., fresh milk, cheese, ice cream)	Ingestion	Residents of Washington, Oregon, Idaho, neighboring states and provinces
Air - Produce 1944–72 (major releases 1944–51)	200-Area separations plants, air	Backyard produce	Eating home-grown fruits, vegetables	Ingestion	Residents of Washington, Oregon, Idaho, neighboring states, and provinces
Air 1944–72 (major releases 1944–51)	200-Area separations plants	Air	Breathing, immersion in contaminated air, irradiation from air-contaminated surfaces, soil	Inhalation, dermal contact, external irradiation	Residents of Washington, Oregon, Idaho, neighboring states, and provinces
Surface Water – Columbia River 1944–71	100-Area Reactors along the river	Surface water, irrigation water, river sediment	Swimming, boating, fishing, drinking river water	Ingestion, dermal (skin) contact, and/or inhalation	Tri-Cities residents, consumers of locally grown food, occupational and recreational river users
River Plants and Animals 1944–71	100-Area Reactors along the river; river water	Fish, shellfish, waterfowl	Eating anadromous fish and shellfish, their predators, and waterfowl	Ingestion	Recreational and subsistence fishers, sportsmen and their families, Tribal consumers of fish and waterfowl

4.2 Air Releases

One of the most important exposures was I-131 in the milk-ingestion pathway.

Airborne radiation releases were primarily the products of fission and chemical separation processes used to produce plutonium. Some of these products included gases such as radioiodine. Containment, traps, and filters prevented most of these materials from being released, but releases did occur after system failures and by airborne escapes through filters and traps. The addition of better traps and filters greatly decreased airborne radioactive releases.

The Green Run was an intentional release of radioactive materials to the air that used short-cooled fuel — fuel cooled for only 16 days rather than the ususal 90 days at the time. During the Green Run, the filters were also disconnected to increase the amount released. The Green Run was conducted in 1949 as a military experiment to test airborne monitoring equipment and to correlate airborne concentrations with amounts of reactor fuel in process.

The HEDR Project determined that I-131 was the major contributor to radiation dose to members of the off-site general public. The major releases occurred between 1944 and 1951. Iodine-131 was released into the air, then deposited on grass that was eaten by cows and goats; and then people consumed the cows' and goats' milk.

The cumulative amount of I-131 released into the air from 1944 to 1951 was estimated to be 730,000 curies. Scientists also estimated airborne releases of I-131 and other radionuclides between 1944 and 1972, five of which, along with I-131, accounted for about 99% of the doses from Hanford sources that contributed to off-site airborne radiation. The other five radionuclides were strontium-90 (Sr-90), ruthenium-103 (Ru-103), ruthenium-106 (Ru-106), I-131, cerium-144 (Ce-144), and plutonium-239 (Pu-239).

Other exposure pathways included eating contaminated vegetables, breathing contaminated air, skin contact with air containing radiation, and external gamma radiation. Children who ate soil — known as pica behavior — were additionally exposed, as were persons coming into contact with contaminated soil such as sediment in or soil near the Columbia River. Homegrown food has been a particular concern of residents and scientists; this food is usually consumed sooner than store-bought food, reducing the time in which I-131 has a chance to decay, and thus exposing people to higher concentrations.

Persons exposed to airborne releases of radioactive materials from Hanford include those living in the Columbia Basin and other areas of eastern Washington, northeastern Oregon, and western Idaho, and those who ate food products produced in the fallout area. Most airborne radioactive releases from Hanford occurred during the first three years of Hanford operations, 1944 to 1947. Persons living downwind from Hanford also received radiation doses between 1950 to 1957 from Hanford and other sources, including nuclear weapons testing from the Nevada Test Site, which contributed to this population's radiation dose.

Estimating Past Releases

HEDR scientists and the Technical Steering Panel evaluated environmental monitoring and processing records to determine the amounts of radioactive materials that were released into air at the Hanford Site, beginning in 1944. The emissions were estimated from data on production, air filters, stack measurements, and air-monitoring stations at various locations (TSP 1994).

Climate studies at Hanford started before the reactors were operating. These studies included weather measurements, such as wind direction and speed, rainfall, and temperature. Such meteorological data are essential for predicting the behavior and paths of radioactive materials and chemicals that are released into the air (TSP 1994).

Environmental studies at and near the Hanford Site were later expanded to include measurements of radioactive materials in the air, soil, vegetation, food-crops, wildlife, Columbia River water, river sediments, fish, animals, and animal products. However, the exposure pathway of airborne I-131 to persons drinking contaminated milk — involving I-131 in air deposited on grass consumed by cows and goats, and milk from these animals then consumed by people— was not recognized by scientists until about 1957. Therefore, from 1944 to 1957 — the period during which the major I-131 releases took place — pasture grass and cows' milk from farms in Eastern Washington were not monitored for radioiodine (TSP 1994).

Project scientists developed several computer programs to reconstruct the missing information needed to estimate radiation doses and uncertainties. The full set of computer programs (i.e., the Hanford Environmental Dose Reconstruction Integrated Codes, or HEDRIC) consisted of four components including 1) a source-term model, 2) an atmospheric transport model, 3) an environmental pathways model, and 4) a radiation dose model (TSP 1994).

4.2.1 Contamination Sources

The irradiation of uranium fuel assemblies in the Hanford reactors produced plutonium and a large number of fission and activation products. In the 200-Area, irradiated fuel was dissolved in acid to recover plutonium and uranium and to isolate radioactive waste and chemicals for storage. Four chemical separation plants — T Plant, B Plant, REDOX and PUREX plants — operated at various times from 1944 through 1990. Some of the fission products were volatile or inert gases, such as the radioiodines and radioxenons, respectively (TSP 1994).

Dose-reconstruction scientists estimated the types and amounts of radionuclides released — the source-term — from Hanford facilities using the computer programs Reactor Model and Source Term Release Model. Collectively, these programs used information about the operation of Hanford's reactors and processing plants to estimate hourly releases of radioactive materials from the processing plant stacks to the air (TSP, 1994). Iodine-131 was the principal radioactive material released into the air that contributed to the off-site radiation dose. The total amount of I-131 that was released was estimated to be about 735,000 curies during the period from 1944 through 1951. See Table 4-2.

Table 4-2. Estimated Annual I-131 Releases (1944–1951)

Year	Curies per Year
1944 to 1945	557,000
1946	96,000
1947	32,000
1948	1,800
1949	8,700
1950	5,400
1951	34,360

Data from (TSP 1994).

Release events, such as the Green Run test on December 3, 1949, were included in the source-term calculations. The Green Run occurred at the T Plant when a dissolver was loaded with fuel that had been discharged from the reactor after an unusually short holding time. The Green Run was a secret military experiment

that was conducted to test airborne monitoring equipment and to correlate measurements with the amount of spent fuel in process. The regular air filter and containment systems were bypassed to ensure that the release carried enough radioactive material for atmospheric measurements by aircraft. The Green Run accounted for about 7,000 curies of I-131 released to the air. It represented the largest single release of I-131 from Hanford (TSP 1994).

HEDR scientists estimated the airborne releases of strontium-90 (Sr-90), ruthenium-103 (Ru-103), ruthenium-106 (Ru-106), I-131, cerium-144 (Ce-144), and plutonium-239 (Pu-239) for eight locations for the years 1944 through 1972. These radionuclides accounted for more than 99% of the off-site radiation dose from the atmospheric pathways. The major contributor to radiation dose was I-131, most of which was released during the first 3 years of Hanford operations. I-131 releases continued to occur after the first three years, with another peak release in 1951. Lesser contributors to radiation dose were Ru-103 and Ru-106, followed by Ce-144, Sr-90, and Pu-239. Releases of tritium, carbon-14, and argon-41 from reactor stack gas systems and reactor effluent cooling water were negligible contributors to radiation dose.

Additional, Non-Hanford Sources

Radioactivity in the atmosphere has many sources, including naturally occurring cosmic radiation, releases from radionuclides naturally present in all rocks and soils, nuclear weapons testing — including the Nevada Test Site — and releases from nuclear power plants. The U.S. Department of Health and Human Services and the National Cancer Institute have conducted studies to gather air monitoring data from across the U.S. and estimated radiation doses by county from airborne radioactivity. These studies showed that the Hanford Site was not the sole contributor to radiation doses to the thyroids of persons living downwind from the Hanford Site.

A major contributor to public radiation exposure was the atmospheric testing of nuclear weapons between 1945 and 1963. According to the National Cancer Institute studies, the highest thyroid doses from NTS fallout occurred to persons born between January 1950 and December 1963 — when the Limited Test Ban treaty was signed, ending atmospheric testing of nuclear weapons[1]. This was a second major exposure period, in addition to the time period when most of the Hanford releases took place between 1944 and 1947. The dose reconstruction scientists estimated that the theoretical maximum thyroid radiation dose to an

[1]More information about releases from the Nevada Test Site, including individual dose calculations, can be found at the National Cancer Institute's web page: http://i131.nci.nih.gov/.

offsite individual could have ranged from 54 to 850 rads for air releases from December 1944 to December 1957. The average radiation doses to off-site populations in the highest-dose counties downwind of Hanford were much less than the maximum theoretical dose and could have ranged from about 2 to 10 rads.

The Hanford Site air releases were the major contributors to thyroid dose in offsite populations of Eastern Washington. Estimated contributions to thyroid dose from radioiodine released from the NTS are shown in Table 4-3. Figure 13 (HHS 1997, Figure 8.29) shows nationwide estimates of I-131 thyroid doses for persons born on April 1, 1952 with an average diet and average milk consumption.

Table 4-3. Estimated Contribution of I-131 Releases from the Nevada Test Site to the HEDR Study Area *

Date of Birth	Thyroid Dose (rad) for Average Diet, Average Milk Consumption	Thyroid Dose (rad) for Average Diet, High Milk Consumption	Thyroid Dose (rad) for Average Diet, Milk from Backyard Cow
January 1, 1935	0.3 - 3	0.3 - 10	0.3 - 3
January 1, 1940	0.3 - 3	0.3 - 10	0.3 - 10
January 1, 1945	0.3 - 3	1 - 10	0.3 - 10
January 1, 1950	1 - 10	1 - 30	1 - 10
January 1, 1951	1 - 10	1 - 30	1 - 10
January 1, 1952	1 - 10	1 - 30	1 - 10
January 1, 1953	1 - 10	1 - 30	1 - 30
January 1, 1954	0.3 - 10	1 - 10	0.3 - 10
January 1, 1955	0.3 - 10	1 - 10	0.3 - 10
January 1, 1956	0.3 - 10	0.3 - 10	0.3 - 10
January 1, 1957	0.3 - 10	1 - 10	1 - 10
January 1, 1958	0.01 - 3	0.3 - 10	0.3 - 10
January 1, 1959 to 1962†	0.01	0.01	0.01

* Data from reference (HHS 1997).
† Dose for each year

4.2.2 Air Pathway and Transport Modeling

The atmospheric transport of radionuclides released from the Hanford Site were tracked using the computer program RATCHET (Regional Atmospheric Transport Code for Hanford Emission Tracking). This program combined the data on radioactive materials released with the measured meteorological data. Dose-reconstruction project scientists used RATCHET to estimate the daily air concentrations and levels of surface-contamination from fallout in the study region. Calculations were made for over 2,000 locations within the study area on a daily basis. The program accounted for the 8-day physical half-life of I-131 and the cumulative effect of ongoing daily releases (TSP 1994).

4.2.3 Plants and Animals

The third part of the dose-reconstruction program package — DESCARTES or Dynamic Estimates of Concentrations and Radionuclides in Terrestrial Environments — was used to estimate concentrations of radioactive materials in soil and plants in the food chain from airborne releases. The DESCARTES program accounted for weathering and removal of contamination from plant surfaces by wind, rain, and irrigation water (Shindle et al. 1992). During the growing season, dairy cows and goats could have ingested radioiodine deposited on pasture lands. DESCARTES used the daily input values from RATCHET to estimate the concentrations of radioactive materials in several types of vegetation, crops, and animal products. This calculation required data on agricultural production and distribution systems for the affected regions during the period 1944 to 1951 (TSP 1994).

Research on radionuclide migration provided information on the transport of radionuclides from air to vegetables, grains, and fruits eaten by people, and to plants used in animal feed such as grass, alfalfa, silage and grain. Scientists used these concentration factors to estimate radionuclide concentrations in animal products such as beef, venison, poultry, eggs, milk. Radiation doses to people were then estimated using this data. Figure 9 shows the total cumulative deposition of I-131 across the study area for the year 1945 (TSP 1994). Figure 9 also shows that the I-131depositions occurred mainly to the northeast of the Hanford Site, consistent with the prevailing wind directions in the region. On average, an estimated 55% of the I-131 released from Hanford was deposited within the HEDR Project study area. About 10% of the releases decayed during atmospheric transport, 35% was transported beyond the study area, and the remainder decayed during transport beyond the study area (TSP 1994).

4.2.4 Activities Resulting in Exposure

Dose-reconstruction scientists studied four principal exposure pathways for airborne radionuclides, including (TSP 1994)

- ingestion of contaminated farm products (primarily milk) and vegetation,
- external radiation from contaminated surfaces and soils,
- inhalation of airborne radioactivity, and
- submersion in contaminated air.

The routes of exposure for I-131, in order of decreasing importance as contributors to radiation dose, were found to be ingestion of milk, ingestion of vegetables, inhalation of air, skin contact by submersion, and external gamma radiation (TSP 1994). Other activities that could result in exposure include the behavior of pica children who eat soil, and other exposure to contaminated soil such as river sediment along river banks and soil on river islands. The Technical Steering Panel emphasized the importance of radiation dose from home-produced fruits, vegetables, and other farm products because home-grown foods were less subject to market delays that could have reduced I-131 concentrations because of the short half-life of I-131.

Goats' milk was more contaminated than cows' milk (TSP 1994).

4.2.5 Exposed Populations

The populations that were exposed to airborne releases of radioactive material from the Hanford site covered a broad area in the directions of the prevailing winds (TSP 1994). The highest exposures were to residents of eastern Washington, northeastern Oregon, and western Idaho. Persons who ingested food products produced in the fall-out region were also exposed. The HEDR scientists focused on three populations

- Consumers of home-grown food products and locally produced milk,
- Consumers of commercial milk from cows raised on stored feed, and
- Consumers of commercially produced milk and vegetables.

Radiation doses for each of these groups of people, for each location in the study region, and for each year of radionuclide release were estimated using the HEDRIC computer program package developed for the dose-reconstruction project, as discussed in this chapter.

4.3 Releases to the Columbia River

Past Exposures

The Columbia River received contamination from several Hanford areas. Eight of Hanford's nine plutonium production reactors used Columbia River water to cool the reactors. This cooling water, which washed small amounts of radioactive materials from the reactor and which accumulated radioactivity by neutron activation of natural water impurities, was then held in ponds before it was discharged back into the River. Contaminated water was released to the ground from leakages from subsurface storage facilities located near the River, from cracks in failed fuel assemblies, and from films and corrosion in piping.

The HEDR project initially studied 19 radionuclides identified in the Columbia River in the HEDR project, and estimated concentrations in River water of five of these radionuclides considered to be the most important because they contributed about 94 percent of the estimated doses to people

- sodium-24 (Na-24),
- phosphorus-32 (P-32),
- zinc-65 (Zn-65),
- arsenic-76 (As-76), and
- neptunium-239 (Np-239).

CDC funded additional work on the Columbia River dose reconstruction model that evaluated additional radionuclides — including iodine-131, cobalt-60, and strontium-90 — as contributors to the river pathway. The additional work did not support the suggestion that the original HEDR Project should have included dose calculations for I-131 and Sr-90 in the Columbia River (RAC 2002).

HEDR scientists found 0 to 13 pCi/g of radioactivity in Columbia River fish based on measurements of fish caught in the Hanford Reach at the time of the greatest releases to the river. A higher radiation concentration was estimated using a model that assumed all the fish spent their entire life in the Hanford Reach. Using this model, an "upper limit" on the concentrations ranged from about 1 pCi/g to 100 pCi/g.

The HEDR project identified several activities that could have resulted in persons receiving radiation doses from the Columbia River, including

- drinking water from the River,
- using River water for irrigation,
- swimming, boating, or walking along the banks of the River, and
- eating fish, shellfish, or waterfowl from the River.

The HEDR Project estimated the total radiation dose that residents of the Tri-Cities area — Richland, Kennewick and Pasco — from all River exposures for the time period 1944 to 1971. A person could have received as much as 1,500 millirem effective dose (approximately 1.5 rads whole body) from the River pathway during this time (TSP 1994).

4.3.1 Sources of Contamination

The eight original plutonium production reactors along the Columbia River used river water for reactor cooling. Water was drawn in to cool the reactors and then discharged back to the River after being held in a retention basin. The ninth reactor, N Reactor, also used the Columbia River for cooling water, but recirculated its cooling water and did not discharge directly into the river. The N Reactor continued operation until 1987. The use of river water for reactor cooling resulted in releases of radioactive materials into the Columbia River.

The Columbia River was also received contamination from contaminated groundwater. Releases to the ground and groundwater occurred from leakages from subsurface storage facilities that were located near the River (TSP 1994).

Nineteen radionuclides that contributed to people's radiation doses from the Columbia River were initially considered for study by the dose reconstruction project. Five of these radionuclides — arsenic-76 (As-76), neptunium-239 (Np-239), phosphorus-32 (P-32), sodium-24 (Na-24), and zinc-65 (Zn-65) — were included in the Columbia River dose calculations because they contributed about 94% of the estimated dose to people. Five other radionuclides — scandium-46 (Sc-46), chromium-51 (Cr-51), manganese-56 (Mn-56), yttrium-90 (Y-90), and iodine-131 (I-131) — that were not included in the total dose estimate were included in the source term because they could assist in validation of the computer modeling or because some TSP members found them of scientific interest. The HEDR scientists considered that all other radionuclides represented a negligible contribution to dose and potential health effects and were not included in further dosimetry analyses (TSP 1994).

The use of river water for reactor cooling resulted in detectable releases of radioactive materials into the Columbia River. The short-lived radioactive materials decayed while the water remained in the cooling ponds before being released back into the Columbia River. However, detectable levels of longer-lived metals, such as zinc-65, were released into the River (TSP 1994).

A review of the dose reconstruction work by SENES, Oak Ridge, under contract to ATSDR, recommended that three more radionuclides — iodine-131, cobalt-60, and strontium-90 — be evaluated by HEDR for their contribution to dose.

NCEH funded additional work on the Columbia River dose reconstruction model. Native Americans and others whose diets included fish from the Columbia River between 1956 and 1965 were interested in new parameters to estimate radiation doses. The model included the 11 radionuclides for which HEDR had source term estimates, plus others, including cobalt-60 and strontium-90 for which HEDR did not estimate source terms (RAC 2002).

The follow-up NCEH results did not support the suggestion that the HEDR Project should have made dose calculations for I-131 and Sr-90. Although I-131 and Sr-90 were not eliminated in the initial screening, they were identified as low priority contributors to dose in all three exposure scenarios. The scientists accounted for the consumption of whole fish including the bones by Native Americans; however [their] research indicated it was unrealistic to assume whole fish were consumed year round in large quantities. For this reason the dose and risk for Sr-90 and Sr-89 were not significant. Iodine-131 screening values ranked consistently low for the three representative scenarios. On an absolute level, I-131 risk for the local resident (i.e., River user) scenario at Richland was about a factor of 20 less than the estimated risk from the atmospheric releases of I-131 at Ringold. Therefore, I-131 did not appear to warrant further investigation. If further evaluation of risks from radionuclides released into the Columbia River is undertaken, the following four radionuclides are important for the analysis — As-76, Np-239, P-32, and Zn-65; the following four of moderate priority — Na-24, Zr-95, Co-60, and Cs-137. Fallout from atmospheric weapons testing may have exaggerated the significance of Cs-137 in this study. And I-131, I-133, Sr-90, Sr-89, Ga-72, Sc-46, and Y-90 were of low priority and probably could be dismissed. Over the years 1952 to 1964, fish ingestion was the dominant exposure pathway for releases to the Columbia River. The significance of fish ingestion for Native American users of the river was greater than that for non-Native American users by a factor of 10. (RAC 2002).

Radioactive contamination of river water also resulted from fuel assembly failures when ruptures in the fuel cladding occurred. When failures were detected, the reactors were shut down to replace the failed fuel elements. Other contamination resulted from the chemical purges to reduce build-up of films and corrosion products in the piping.

Hanford scientists conducted radiological monitoring of river water. Drinking water was sampled in the nearby towns of Richland, Pasco, and Kennewick.

Several varieties of fish such as whitefish were caught downriver, monitored for radioactivity, and compared with fish caught upriver from the Hanford Site. Whitefish were monitored year-round for contamination of phosphorus-32. Banks of the Columbia River downstream from Hanford were also surveyed for radioactive sediments, such as Co-60 and Zn-65 (TSP 1994).

4.3.2 Estimated Source Terms and Doses

HEDR scientists developed estimates of the types and amounts of radioactivity released to the Columbia River using monthly average releases of radioactivity from each of the reactors for the time period January 1950 through January 1971. For the earlier time period, September 1944 to December 1949, less data were available.

The computer model used accounted for tributary inflows, multiple channels within a river, and the presence of dams and reservoirs.

The exposure models accounted for the physical decay of the radioactive materials (TSP 1994). HEDR estimated the concentrations of the most important radionuclides using this method. HEDR then used the computer model CHARIMA to simulate the flow and transport of radioactive material in the Columbia River from the Priest Rapids Dam, above the Hanford Site, downriver to the Pacific Ocean.

Monthly average water concentrations were reconstructed at 12 river locations for Na-24, P-32, Zn-65, As-76, and Np-239. Concentrations of Cr-51 and other radionuclides were estimated to validate the transport model, but were not found to contribute significantly to the radiation doses.

The results of computer modeling showed that the presence of radionuclides in downriver water was influenced by two factors 1) the physical half-lives of the radionuclides, and 2) the effects of hydroelectric dams — McNary, Dalles, Bonneville and John Day — on river flow-rate (TSP 1994). See Figure 8. The dams altered the flow rate of the Columbia River, and thereby allowed time for shorter-lived radionuclides to decay before reaching downstream locations. Radionuclides with relatively short physical half-lives include Na-24, P-32, As-76, and Np-239. The flow of longer-lived radionuclides such as Co-60, which

The dams slowed the flow of river water and allowed time for short-lived radionuclides to decay.

has a half-life of 5.3 years, and Zn-65, which has a half-life of 245 days, were less influenced by the presence of the Columbia River dams.

4.3.3 Plants and Animals

Some of the contaminants that were released into the Columbia River were first taken up by smaller fish and aquatic organisms such as algae, then larger fish and shellfish. These organisms were then consumed by species higher in the food chain such as waterfowl and humans. The dose-reconstruction project estimated the levels of contaminants in these animals using Hanford monitoring data from samples collected by other scientists, federal agencies, and universities. The correlations between the concentrations of radionuclides in river water, fish, and waterfowl, and concentration factors were used to estimate radiation doses to persons who consumed the fish and waterfowl (TSP 1994) .

The HEDR Project considered fish species that are *anadromous* such as steelhead trout, and chinook, sockeye, and coho salmon. Anadromous means that they live part of their lives in freshwater and part in ocean water and travel up the Columbia River to spawn. Adult sockeye and other Pacific salmon species do not feed once they enter fresh water and head upstream to spawn; instead, they rely on reserves of fat and protein stored up during their ocean feeding to reach their spawning area. Therefore, measured concentrations of radioactive materials in anadromous species were from radioactivity present in ocean waters. Juvenile salmon and steelhead trout, however, feed on river plants and animals during their 3- to 24-month downstream migration to the ocean.

Very little radioactivity was found in Columbia River anadromous fish. Measurements of samples of salmon caught in the Columbia River showed that 37 of 47 samples were below the minimum detection limit, 0.1 pCi/g for Zn-65. The other 10 samples varied from just above the detection limit to a maximum of 13 pCi/g. The median value for Zn-65 was 0.6 pCi/g (TSP 1994).

Based on input from tribal representatives, the Technical Steering Panel recommended that radiation doses to people from ingestion of salmon and steelhead trout be estimated by two different approaches. The first approach used the measurement data discussed above. The second approach used the assumption that fish spent their entire lives in the Columbia River, which would provide an upper limit on the dose estimates. The latter approach yielded Zn-65 concentrations in salmon ranging from about 1 pCi/g to 100 pCi/g (TSP 1994).

Radionuclide concentrations were measured in shellfish in the Pacific Ocean near the mouth of the Columbia River. Data were compiled on P-32 and Zn-65 in

shellfish for Willapa Bay, Astoria, Cannon Beach, Coos Bay, Seaside Beach, Tillamook Bay, and Agate Beach. Scientists found that concentrations of Zn-65 were higher in oysters than in other marine organisms (TSP 1994).

Levels of contamination in the Columbia River decreased as the river flowed away from Hanford to the Pacific Ocean.

Scientists also determined concentration factors for ducks that eat small fish and invertebrates, puddle ducks that eat near-surface water plants and grain crops, and geese, which feed similarly to puddle ducks (TSP 1994).

The dose-reconstruction scientists and the Technical Steering Panel studied 12 segments of the Columbia River from the zones of release near the 100-Area southward to the mouth of the River. The segments and their approximate locations were—see Figure 8 (TSP 1994)

- Ringold — from below reactor areas to north of Richland
- Richland — from north of Richland to above the Yakima River delta
- Kennewick and Pasco — from below the Yakima River delta to above the Snake River delta
- Snake River and Walla Walla River — from below the Snake River to McNary Dam
- Umatilla and Boardman — from below McNary Dam to near Arlington, Oregon
- Arlington — Arlington, Oregon area
- John Day Dam and Biggs — from the John Day River to the Deschutes River
- Deschutes River — the Deschutes River mouth area
- The Dalles and Celilo — the Dalles and Celilo area
- Klickitat River — the Klickitat River mouth area
- White Salmon and Cascade Locks — from White Salmon River to the Bonneville Dam
- Lower River — from Bonneville Dam to the mouth of the Columbia River and including Pacific coastal areas in Washington and Oregon

4.3.4 Activities Resulting in Exposures

The dose-reconstruction scientists and the Technical Steering Panel studied all exposure pathways through which the public may have received radiation doses from Hanford releases into the Columbia River. These pathways included

- drinking water from the Columbia River,
- swimming, boating, or walking along the shoreline,
- showering with water from the river, and
- eating fish, shellfish, and waterfowl from the river (TSP 1994).

In addition to river water, the river sediment also contained contamination. The greatest contribution to radiation dose to people from activities related to the Columbia River was eating fish caught in the river.

4.3.5 Exposed Populations

The communities of Richland, Kennewick, and Pasco — the Tri-Cities — used treated Columbia River water as drinking water (PNNL 1991b). The HEDR scientists and the Technical Steering Panel estimated the total radiation exposures to residents of these communities for the years 1944 through 1971 from drinking river water, eating fish and waterfowl, and from recreational activities such as boating and swimming. They estimated that a hypothetical "maximally exposed individual" could have received an effective radiation dose over this time period of up to 1,500 millirem (approximately 1.5 rad whole body). More than 90% of this dose would have occurred between 1950 and 1970 (TSP 1994). The average population of the Tri-Cities from 1950 to 1970 was 37,741 (Beck et al. 1992). The number of residents who drank treated river water ranged from 27,000 and 68,000. The number of persons who consumed substantial amounts of fish or waterfowl from the River could have been as high as 2,000 persons.

The initial HEDR exposure pathways determined dose for a "representative" person. The estimated doses did not reflect lifestyles and cultural habits of unique populations, such as Native American, Japanese Americans, and Hispanic Americans.

5

Current Exposures

Outline

Tables

5.0 Chapter Summary

Current exposure pathways are the routes by which contaminants travel at the present time — rather than in the past or potentially in the future — from their source of origin, through the environment, to people. Table 5-1 summarizes the current potential pathways, Hanford sources, environmental media, points and routes of exposure, and potentially affected populations.

Groundwater

Nine public water systems on the Hanford Site provide potable water for facilities and workers. Each of these systems is monitored for radioactive contaminants. Very low levels of natural radionuclides — tritium, radium, thorium, uranium — are normally present in all public water systems. The public water systems are monitored for both naturally occurring and man-made radionuclides from Hanford Site operations. All radionuclide concentrations measured in 2004 met the safe drinking water requirements of the Washington State Department of Health and the Safe Drinking Water Act.

Groundwaters at certain locations monitored by test wells showed up to 18 different contaminants that exceeded current drinking water standards. This groundwater, however, is not used for drinking.

Seeps and Springs

The pathway of most concern is exposure to contaminants in seeps and springs along the Columbia River such as the H-, K- and N-Springs in the 100-Area. Warning signs labeled “Danger: Radioactive” are posted in these areas; however, it possible for people to ignore the signs and access the seeps and springs by boat. If people drank the water in these seeps and springs, or their skin touched these sediments, they could be exposed to groundwater contaminants above health screening levels. That said, however, because these areas are isolated, exposure through this pathway is expected to be infrequent.

Columbia River

Levels of contaminants in Columbia River water — including water used for drinking supplies — are below levels expected to cause adverse health effects in the local population. Although it is possible that persons are exposed to shoreline and river bottom sediments when the sediments are stirred up through boating and dredging activities, such exposures would not cause adverse health effects because the amounts of contaminants present are small and exposure times are short.

Plants and Animals

The sampling of deer and elk, which populate the Hanford Site, has shown that deer and elk meet is not contaminated with radioactivity associated with Hanford operations. Hanford elk have been transported to the Blue Mountains of Eastern Washington, to the Washington Cascades, and to Oregon to repopulate elk herds in those regions. Contaminants have been found above screening comparison levels in tumbleweed, yarrow, mulberries, and mice. Consumption of contaminated plants and animals is possible through subsistence or other uses, such as in traditional medicines, is possible; however, consumption is infrequent and not expected to cause adverse health effects. Sr-90 and chromium levels have been identified as possible concerns regarding the health of young salmon in the area.

Soil

A number of contaminants exceeded levels of possible health concern at certain locations in Hanford soils. In 1998, two contaminants, Sr-90 and Ce-137, were found at low levels, near their detection limits, in on-site soil. Contaminated soils have since been removed and replaced with clean soil, or covered with clean soil.

Air

The air pathway, which was the major exposure pathway to off-site populations during reactor operations and chemical facility processing activities — 1945 through 1987 — is not currently a significant pathway. Contaminant levels in air are now consistently below health screening values, and no new releases of airborne contaminants that would result in significant exposures to off-site populations are occurring.

Table 5-1. Current Exposure Pathways

Exposure Pathways	Exposure Pathway Elements				
	Sources	Environ-mental Media	Points of Exposure	Routes of Exposure	Potentially Affected Population
Groundwater	Process wastes, contaminated soil	Groundwater	Nonpotable water sources	Ingestion	None.

Table 5-1. Current Exposure Pathways

Exposure Pathways	Exposure Pathway Elements				
	Sources	Environ-mental Media	Points of Exposure	Routes of Exposure	Potentially Affected Population
Seeps and Springs	Contaminated groundwater	Seeps and springs	Drinking or body contact near shoreline seeps and springs	Ingestion, skin contact	Non expected. Access to contaminated seeps and springs is restricted.
Columbia River Water and Sediments	Contaminated groundwater including seeps and springs, process wastes	Sediments	Found hot particles	Skin contact with hot particles	None known.
Plants and Animals	Process wastes, contaminated soil	Plants, Fish, Other animals, Milk, Wine	Eating game, bone-enriched stews and soups ; burning tumbleweed	Ingestion, inhalation	Subsistence and tribal gatherers who consume contaminated plants and animals or burn tumbleweed as a heat source
Soil	Process wastes	Soil	Handling or moving soil	Skin contact or whole-body exposure	On-site workers having direct contact with waste materials in the soil
Air	Process wastes; fires	Air		Inhalation	Persons working or living near Hanford
External Radiation	Radiation sources	All		External contact	Radiation workers at the Hanford Site.

5.1 Groundwater – Current Exposure Pathways

Since the 1940s, large amounts of contaminated wastes from Hanford were released—either intentionally or accidently—into soil beneath the site. Contaminants migrating in the soil have contaminated area groundwater. Today, contaminants move with the groundwater from their source toward the Columbia River. In 1989, the volume of Hanford wastewater discharges decreased significantly and the spread of contaminants slowed.

Table 5-2 lists the 18 groundwater contaminants that were above drinking water standards. In 1999, tritium and I-129 were the most widespread groundwater contaminants. Of the nonradionuclides, nitrate, carbon tetrachloride, and trichloroethylene covered the largest areas.

The contaminants are mostly from Hanford's waste storage areas: 100-Area reactor cooling water and storage basins; 200-Area storage tanks for high-level wastes and waste cribs; 300-Area waste trenches and ponds. Additional contamination may originate from the private Areva (formerly Siemens Power Corporation) fuel fabrication facility west of the 300-Area (ATSDR 1995a)

Three on-site well systems used groundwater as a source. Two systems are no longer being used. The third system which supplies the FFTF shows trace leves of tritium contamination. The average tritium in the system — 4,173 pCi/L in 1999 and 3,457 pCi/L in 2000 — is below the State of Washington drinking water standard for tritium which is 20,000 pCi/year (PNNL 2001).

Richland's North Wellfield also uses groundwater during winter months as a municipal water supply. Monitoring indicates that concentrations of contaminants reaching municipal well fields or private wells are below drinking water standards, or that the wells are not in the path of contaminant plumes. Table 5-2 lists the substances for which the Richland water supply is tested.

Some of the Hanford Site groundwater is so contaminated that it could not be used as a drinking water source. Access to this contaminated groundwater is limited by institutional controls.

5.1.1 Groundwater Flow

The general direction of groundwater flow at the Hanford Site is northerly, easterly from the highlands, or both through the Site in some areas, and towards and into the Columbia River. In one area which is northeast of Gable Mountain, groundwater flows southwesterly. The Hanford Site groundwaters are recharged by the Yakima River, Rattlesnake Ridge, and Yakima Ridge. Another source of recharge is the North Richland well field, located on property adjacent to the 1100-Area of Hanford, which replenishes the groundwater with Columbia River water. Only a small amount of natural recharge occurs from infiltration by precipitation.

Groundwater generally flows to the north and east toward the Columbia River.

At one time, the Hanford Site groundwater flow was influenced by discharge of contaminated wastes from reactors and chemical reprocessing. Large volumes of contaminated and uncontaminated water seeped into the ground from drainage, water hold-up cribs, trenches, French drains, and leaking storage tanks.

Wastewater discharges from Hanford have accounted for about two to three times the volume of naturally occurring water in the groundwater system under the Hanford Site, causing groundwater levels to rise, most notably in the 200-Area. As a result, groundwater and any contaminants present in the groundwater extended further under a larger portion of the Site, increasing the movement of groundwater and contaminant plumes eastward, toward the Columbia River, and increasing riverbank seepage. This pattern changed in 1989, when wastewater discharges from disposal facilities at Hanford near the N-Reactor were decreased significantly, resulting in a lowering of local groundwater by about 20 feet, and in groundwater contaminants moving in smaller amounts and more slowly toward the Columbia River (PNNL 1999b).

When water discharging ended, groundwater levels over most of the Hanford Site declined. Some the of active monitoring wells went dry. In the eastern portion of the Hanford Site, water levels increased in 1999, presumably because of large-scale, off-site irrigation activities. In part of the 200-East Area, it appeared that groundwater moved upwards rather than in a typically downward movement. The depth of contaminant plumes was not well understood, and was estimated to be between 16.5 and 66 feet in different areas of the site. Carbon tetrachloride and tritium have been detected in the deepest areas.

5.1.2 Contaminants in the Groundwater

Table 5-2 lists some of the contaminants found in Hanford Site groundwater. Table 5-2 lists contaminants whose concentrations were above EPA drinking water standards. At the point where groundwater enters the Columbia River, it carries tritium, iodine-129, uranium, strontium-90, and nitrates (PNNL 1999b).

Table 5-2. Groundwater Contaminants Detected Above EPA Drinking Water Standards

Contaminant	Location
Tritium	100, 200-East, 200-West into the 600-Area, 400 Areas
Iodine-129	200, 600 Areas
Technetium-99	200-East, 200-West, 600 Areas
Uranium	100, 200, 300, 600 Areas
Strontium-90	100, 200, 600 Areas
Cesium-137	200-East
Carbon-14	100-K Area
Plutonium (based on exceeding the standard for gross alpha)	200-East Area
Nitrate	All Areas
Chromium	100, 200-East, 200-West, 300, 600 Areas
Carbon tetrachloride	200-West, 600 Areas
Trichlorethylene	100, 200-West, 300, 600 Areas, Richland North
Chloroform	200-West Area
Cis-1,2-dichloroethylene	300 Area
Fluoride	200-West Area
Cyanide	200-East Area
Tetrachloroethylene	300-Area
Source: (PNNL 1999a, b)	

Radiological Contaminants in Groundwater

In 1999, tritium and iodine-129 represented the most widespread radiological contaminant plumes in groundwater. Tritium was detected at concentrations above the EPA drinking water standard, whereas I-129 was found at concentrations below the drinking water standard.

A tritium groundwater plume extends from the 200-Area to the Columbia River. This plume extends for about 17 miles from the old Hanford Townsite to an area

directly north of Richland. The highest concentrations of tritium, 155,000 pCi/L, were found at the Hanford Townsite area. The drinking water standard for tritium is 20,000 pCi/L. Near the 300-Area, tritium was detected at 6,580 pCi/L. The highest levels of I-129 found in 1999 were 47 pCi/L; the drinking water standard for I-129 is 21,000 pCi/L. Technetium-99 levels have increased in wells near the 200-West area (PNNL 1999b).

Nonradiological Contaminants in Groundwater

Nitrate, carbon tetrachloride, and trichloroethylene were the most notable nonradiological, chemical groundwater contaminants measured at the Hanford Site. Several metals also exceeded standards, but these metals were from natural sources that existed prior to the Hanford operations (PNNL 1999b).

While nitrate was detected above drinking water standards in groundwater at all areas of the Hanford Site, concentrations near the Columbia River at the old Hanford Townsite were below drinking water standards and have not increased in the last ten years.

5.1.3 Sources of Contamination

Most of the groundwater contamination from Hanford resulted from the discharge of liquid wastes into cribs, ponds, and ditches. New areas of groundwater contamination may result if some previously immobile contaminants have begun to move. Also, potential new sources of contamination include additional single-shell tanks, K basins, and disposal facilities.

100-Area Sources

The reactor sites in the 100-Area are the major sources of groundwater contamination along the Columbia River shoreline. The N-reactor hold-up ponds percolated Sr-90, which contaminated nearby groundwater and then entered the Columbia River at the N–Area Spring. Other sources of Sr-90 in the 100-Area included leaks from underground pipelines and retention basins; fuel element ruptures; and Sr-90 in effluent from coolant systems and fuel storage basins (PNNL 1999b).

Tritium leaks at the K-basins have been detected (PNNL 1999b). Also at the K-reactor site, Cs-137 from the K-basins entered the groundwater and was discharged to the river at K-Area Spring. The 100-Area process trenches have contaminated groundwater with cis-1,2-dichloroethylene, trichloroethylene, and uranium at elevated levels. The 100-H-Area basins have contaminated the groundwater with chromium, nitrate, technetium-99, and uranium above regulatory standards.

Sodium dichromate used as a corrosion inhibitor in cooling water for reactors in the 100-Area. The highest chromium levels in the 100-Area were related to operations in the 100-K, 100-D, and 100-H Areas. Chromium was also used for decontamination in the 100, 200, and 300 Areas and for oxidation control in the REDOX plant in the 200-West Area.

Groundwater approaching the 100-H Area from the west is contaminated by chromium and tritium, originating from past disposal in other portions of the 100-Area. Chromium in groundwater in the 100-H Area is a concern because this groundwater eventually discharges to adjacent Columbia River beds used by salmon for spawning (PNNL 1999b).

100-Area Plumes

The boundaries of groundwater plumes in the 100-Area have not been clearly identified. Some researchers suggested that rather than extending in typical groundwater plumes, some of the groundwater contaminants in the 100-Area, such as hexavalent chromium and Sr-90, might be more accurately described as narrow, low-sorption underground stream pathways from a source in the H-reactor area. These underground streams may discharge to narrow shoreline and riverbed seeps when the river is at a low stage, and remain underwater when the river is at higher levels (Buske 1999; Hope and Peterson 1996). This idea may explain why hexavalent chromium levels (up to 130 ug/L) found in the Columbia River are greater than levels (110 ug/L) found in any onshore well (Buske 1999).

200-Area

Single-walled storage tanks in the 200-Area tank farms once contained high-level radioactive waste. Some of the tanks leaked over time and released material into the soil and groundwater. Of the 149 single-shelled tanks, 67 have leaked 1million gallons. The first leaking tank was identified in 1956 (PNNL 1995).

The distance from the tanks to the aquifer groundwater below the tank farms varies from 200 to 1500 feet. Scientist originally believed that the soil would function as a filter trap and ion exchange treatment for the many radionuclides, but boreholes near the tank farms have shown substantial amounts of Cs-137 at least 130 feet below the tanks (DOE 1995b). Nevertheless, Cs-137 was not detected in 1999 in groundwater; this could be because Cs-137 is more likely to attach to solid particles in soil than to appear in groundwater (PNNL 1999b).

Tritium plumes may have originated from the 200-Area, including areas near the PUREX and REDOX plants, as well as from the 100-Area.

Technetium-99 is a fission product present in waste streams associated with fuel processing. High concentrations of technetium-99 in 1999 were found in the 200-

West Area, with the largest plume associated with the U-Plant. Technetium-99 was also found at the single-shell tank farms in the 200-West Area and near cribs in the 200-East Area. Cribs in the 200-West Area were probably the source of uranium concentrations measured in groundwater.

Strontium-90 was present in large amounts in waste streams associated with fuel element processing in the 200-Area. These wastes were then piped to underground tanks or diverted to the soil via cribs, trenches, and ponds. Only a small portion of Sr-90 appears to have reached the groundwater, except for one injection well, and no Sr-90 from the 200-Area is known to have reached the Columbia River via groundwater (Peterson and Poston 2000).

One nitrate plume originated from the PUREX plant in the 200-East Area; two other nitrate plumes began near the U- and T- plants of the 200-West Area (PNNL 1999b). ATSDR believes that the nitrate in the 100-Area monitoring well — and possibly also the tritium and technetium-99 — concentrations were too high to reflect only 100-Area activities.

Carbon tetrachloride contamination in the 200-West Area originated from waste disposal operations associated with the Plutonium Finishing Plant. Carbon tetrachloride has been found in monitoring wells far below the groundwater table; further study is needed to determine its depth.

High levels of trichloroethylene were found near the T- and U- plants in the 200-West Area (PNNL 1999b).

The groundwater concentrations of these substances near the 100-Area facilities and the Columbia River may have resulted from 200-Area leaks, which have migrated toward the River. The number of monitoring wells between the 200-Area sources and the 100-Area monitoring wells may be too few to determine the plume characteristics. Process liquids that were released into the vadose zone beneath cribs, ditches, French drains, ponds, reverse wells, settling tanks, and trenches may have been part of the source.

300-Area

In the 300-Area, sources of groundwater contamination were the liquid process effluents that were discharged to trenches and ponds. See Figures 4, 5, and 6 in Appendix F.

The contaminant most frequently found in 300-Area monitoring wells is uranium-238. Deep-aquifer monitoring in the 300-Area shows the uranium plume resulted from seepage into the soil and groundwater from fuel assembly

manufacturing during Hanford's production years (DOE 1995f). Elevated uranium levels were also found below 300-Area process trenches and ponds, moving toward the southeast (PNNL 1999b).

Also shown in Figure 10 are the extensions of the underground tritium plume from the 200-Area tank farms. A technetium-99 plume may have originated from the Areva (formerly Siemens Power Corporation) fuel fabrication facility west of the 300-Area, and perhaps also from the Horn Rapids Landfill in the 1100-Area (ATSDR 1995a).

600-Area

Tritium levels in a well in the 600-Area near the 618-11 burial ground were as high as 8.1 million pCi/L. A study was undertaken in 2000 to determine the source of these high tritium levels. Monitoring wells were sampled in the vicinity of the 618-11 burial ground including wells upgradient of the burial ground, downgradient wells, Energy Northwest water supply wells, and Energy Northwest monitoring wells. The sampling confirmed elevated tritium levels in a single well downgradient of the burial ground. Other wells contained tritium at lower levels similar to levels in the plume emanating from the 200 East Area (PNNL 2000a). The 618-11 burial ground received a variety of radioactive waste from the 300-Area between 1962 and 1967. Possible source materials include fission products and activation products from nuclear operations. There is a possibility that the tritium is related to tritium production research carried out at the Hanford Site in the 1960s. Although that link has not been established, the hypothesis is consistent with what is known about the research and about burial ground operations.

1100-Area

A technetium-99 plume may have originated from the Horn Rapids Landfill in the 1100-Area, or from Areva, formerly Siemens Power Corporation (ATSDR 1995a). TCE and nitrate groundwater plumes are also believed to have originated from the Siemens Power Corporation (ATSDR 1995a). Chromium in the 1100-Area in the 1990s did not appear to be migrating toward municipal water at levels substantially above comparison values (ATSDR 1995a).

5.1.4 Exposure Routes

Two on-site drinking water supply systems used groundwater until 1999. Well 699-49-100c near the Yakima Barricade is upgradient of the 200-Area. Well 699-S28-E0 supplied the Patrol Training Academy (PTA) until the PTA switched to water supplied by the City of Richland. Monitoring of these two drinking water

systems found the systems to be in compliance with Washington State and EPA drinking water standards (PNNL 1999a).

Tritium in Groundwater Wells

A water system supplies the FFTF. This system draws from three wells, all of which are contaminated with tritium. Well 499-S1-8 (P-16) is the primary supply well and has contamination ranging from 3,990 – 4,150 pCi/L tritium. Well 499-S0-8 (P-14) is a back-up well for the system. Tritium in well P-14 was detected at 33,800 pCi/L. In 1999, well P-14 was used in February, March, April, May, and August for 36 hours. The third well, 499-S0-7 (P-15), is available for emergencies. Its tritium concentration ranged from 15,100 to 20,600 pCi/L (PNNL 2000b). For that year, ATSDR estimated that the average system tritium concentration was 4,173 pCi/L — similar to DOE's estimate of 4,275 pCi/L tritium and well below the state standard for tritium, which is an annual average of 20,000 pCi/year (PNNL 2000b).

Municipal Water Supplies

Municipal groundwater drinking systems and private wells that use groundwater as their water source could potentially be affected by contaminated groundwater flowing from Hanford toward the river. Monitoring thus far has consistently found that concentrations of contaminants reaching municipal well fields or private wells are below drinking water standards and that most of the wells are not in the path of contaminant plumes.

Most of the water used by the City of Richland for its municipal water supply is obtained from a pumping station on the Columbia River south of the Hanford Site (DOE 1993b). Columbia River water is also pumped into an aquifer recharge pond at the North Richland Wellfield, which is 2.5 miles south of the nearest Hanford 300-Area production facilities. The North Richland facility is located less than a mile from the 1100-Area of Hanford. Two other recharge well fields were previously located within Richland City limits.

The recharge of groundwater by the North Richland well field is a potential exposure pathway, although such exposure probably would not occur because 1) groundwater currently flows away from the well field; 2) no private wells are used in the path of contaminant plumes; 3) groundwater contaminants are unlikely to be at levels of possible health concern.

A groundwater plume near the 1100-Area containing TCE and nitrate originating from the Areva (formerly Siemens Power) Corporation and moving toward the Columbia River should be monitored to ensure that it is reduced to levels below possible public health concern before it reaches the Columbia River. TCE is unlikely to persist in surface water until it reaches a water supply intake. Nitrate

levels are high enough to be a possible public health concern, but no drinking water wells tap the plume, and residents drink city water. If in the future the plume reaches the river, nitrate and TCE levels would most likely be below levels of concern and possibly below levels of detection before they reach City water intakes (ATSDR 1995a)

5.2 Seeps and Springs – Current Exposure Pathways

Studies have documented that groundwater contaminants discharge at seeps and springs along the Columbia River shoreline, and that seeps and springs have introduced groundwater contamination into the Columbia River environment. Some of these seeps and springs discharge into the river near salmon spawning grounds (Peterson and Johnson 1992). Contaminants that have been found to exceed comparison values in shoreline seeps and springs include Sr-90, hexavalent chromium, tritium, uranium, gross beta emitters, lead, and nickel. *Gross beta emitter* refers to any beta-emitting radionuclides present from all sources combined.

A number of contaminants in seeps and springs along the shoreline of the Columbia River continued to exceed regulatory health standards in 1998 and 1999, including tritium, Sr-90, chromium, and gross beta emitters.

The interaction between the Columbia River and area groundwater has a significant impact on whether contaminants are present, and at what levels, in the river, groundwater, and along the shoreline in seeps and springs or shoreline sediments. Concentrations of contaminants vary greatly over short periods of time, depending on water levels in the river and the groundwater.

5.2.1 Contamination

The DOE has studied groundwater seepage into the Columbia River. A 1984 DOE study found 115 seeps or springs on the 41-mile stretch of Columbia River shoreline from 1 mile upstream of the Hanford 100-B Area to 1 mile downstream of the 300-Area. This study also found that tritium levels exceeded drinking water standards in samples collected from springs adjacent to Hanford K-, H-, and N-reactors and from riverbank springs believed to be influenced by a tritium groundwater plume coming from the Hanford 200-Area (McCormack and Carlile 1984).

A study in the 1980s sponsored by the Hanford Education Action League (HEAL) identified cobalt-60, ruthenium-106/rhodium-106, cesium-137, and antimony-125

in seeps along the Hanford Reach in the N-Springs area (Buske and Josephson 1988).

A 1990 DOE study (Dirkes 1990) analyzed samples taken from springs, river water up- and downstream of Hanford, and irrigation return water and spring water from the shoreline opposite the Hanford. Table 5-4 lists contaminants found at levels above drinking water standards in seeps adjacent to the Columbia River. Contaminants included chromium, strontium-90, tritium and gross beta.

Sr-90 was detected at levels as much as 1,000 times its drinking water standard. The highest level of Sr-90 (6,680 pCi/L) was detected in the N-Springs seep. The drinking water standard for Sr-90 is 8 pCi/L.

Table 5-3. Contaminants in Seeps and Springs Near the Columbia River

Contaminant	Location	EPA Drinking Water Standard	Variation over Time*
Chromium	100-H, 100-K, 100-D, 100-B	50 ug/L	Slight increase (100-H, 100-K); Significant increase (100-D) NA† (100-B)
Strontium-90	100-N, 100-H, 100-F	8 pCi/L	Highly elevated (100-N); Slightly elevated (100-H, 100-F)
Tritium	100-B, 100-N	20,000 pCi/L	Increase (100-B); Decrease (100-N)
Gross Beta Emitters	100-H, 100-N	50 pCi/L	Moderate increase (100-H); Great increase (100-N)

*A decrease in concentration from earlier times indicates that the source is no longer contributing and/or that the contaminant is not moving with groundwater flow. An increase indicates that slower moving plumes had not reached the sampling locations in earlier times and/or that recent disposal has occurred.
†NA = no data available
Source: (Dirkes 1990)

In 1998, DOE reported that tritium levels (at the old Hanford Townsite and 100-N riverbank springs) and chromium levels (at the 100-B, 100-D, 100-K, and 100-H Area riverbank springs) exceeded Washington State ambient surface water quality criteria. Uranium exceeded a site-specific proposed EPA drinking water standard

in the 300-Area riverbank spring. Arsenic also exceeded state standards, but also at background and other locations. All other radionuclides and nonradiological substances were below the Washington State ambient surface-water quality criteria levels (PNNL 1999a).

5.2.2 Exposure Routes

Contact with contaminated groundwater entering seeps and springs along the Columbia River is a current exposure pathways for Hanford contaminants. Public access to these sites is prohibited. Many of these area are fenced.

5.3 Columbia River – Current Exposure Pathways

Since the single-pass Hanford production reactors were shut down in 1971, the principal source of Columbia River contamination has been groundwater flowing for the Site toward the river. Currently, the levels of all contaminants measured in the river water and in all drinking water supplies in the area are below levels known to cause adverse health effects. Table 5-4 lists substances that the City of Richland tests for in Columbia River water.

Another potential source of exposure is sediments containing activity deposited during reactor operations. Most of the particulate contamination along the shoreline has been detected and removed. It is possible that deep sediments containing residual cobalt-60 particles could be stirred up by boating or dredging activities, although essentially all Co-60 produced during single-pass reactor operations has decayed away — having undergone seven to ten decay half-lives.

Chromium has been measured in riverbed water in some areas, such as near the H-reactor, at levels of concern for young salmon that spawn in these areas. Strontium-90 has also been identified as a possible source for exposure of young salmon. However, follow-up studies by DOE have not confirmed these exposures, and neither chromium VI nor strontium-90 have been detected in young salmon near the Hanford Site.

5.3.1 Sources of Contamination

Releases of radiological and nonradiological contaminants into the Columbia River over the past 50 years from the Hanford Site—both directly into the river and indirectly through groundwater that discharges to the river—have been documented in numerous studies. Radionuclides were dispersed into the river water and sediments, or were consumed as part of the river water.

A total of about 3,000,000 Ci/yr of radionuclides was released from liquid waste discharge lines from Hanford's reactors directly into the Columbia River between 1944 to the mid-1960s.

The last of eight Hanford reactors using once-through cooling systems that discharged to the river was deactivated in 1971. Since that time, releases of radionuclides directly to the river were significantly reduced, and the primary sources of contaminants into the river is contaminated groundwater discharging into riverbank seeps and springs, particularly those adjacent to the 100- and 300-Areas of Hanford. The levels discharged, however, are less than detectable levels in river water samples.

5.3.2 Contaminants Present in Columbia River

A 22-year study by the Oregon Health Division (Toombs et al. 1983) found that radioactivity present in the Columbia River downstream of the Hanford Site has continually decreased, and that at no time during the study were levels in excess of national drinking water standards.

DOE annual Environmental Reports from the early 1990s (PNNL 1991c, 1992a, b, c) indicated that generally

- radionuclides present were not at levels of public health concern,
- concentrations of most radionuclides were essentially the same upstream and downstream of the Hanford Site, indicating they were present naturally, and
- contaminant concentrations were relatively constant or decreasing over time.

According to two studies, regardless of the concentrations of contaminants in sediment of seeps, the concentrations in river water immediately downstream has not been found to exceed drinking water standards (Peterson and Johnson 1992; DOE 1992c).

The 1998 DOE annual Environmental Report (PNNL 1999a) stated that while radionuclides associated with Hanford operations could be detected, such levels remained very low at all locations and were well below safe drinking water standards. In 1998, levels of tritium, iodine-129, and uranium were higher at the Richland Pumphouse downstream from the Site than at Priest Rapids upstream of

the Site, indicating contributions from the Hanford Reach, which includes the Hanford Site (PNNL 1999a).

In 1998, in samples collected across the Columbia River, DOE found tritium levels along the Benton County shoreline near the 100-N Area, the old Hanford Townsite, the 300-Area, and the Richland Pumphouse to be higher than in other areas sampled (but below regulatory health standards). Uranium levels, also found below regulatory health standards, were present from naturally occurring sources. Nitrate concentrations were slightly higher along Benton County shoreline at the old Hanford Townsite and along the Franklin County shoreline of the 300-area and Richland Pumphouse than in other areas; nitrate sources may be from groundwater seepage from irrigation. All metal concentrations in 1998 were less than Washington State ambient surface-water quality criteria; arsenic concentrations exceeded EPA standards, but were similar to concentrations found at background and other locations (PNNL 1999a).

5.3.3 Strontium-90, Chromium and Salmon

Independent studies claimed that strontium-90 (Buske 1999) and hexavalent chromium (Hope and Peterson 1996) from the Hanford H-reactor area may be entering the Columbia River bed at levels of concern for salmon. Hexavalent chromium levels have been measured at up to 130 ug/L in riverbed water near the salmon spawning grounds, which is above the 11 ug/L level identified as a concern for young fall chinook salmon (Hope and Peterson 1996). These findings suggest that high Sr-90 and hexavalent chromium levels may be a concern for health of salmon stock. Other scientists question the findings of the Buske study.

High Sr-90 and hexavalent chromium levels may be a concern for the health of salmon stock.

A DOE contract report stated that while high levels of Sr-90 are present in groundwater at the 100-N Area, wells, riverbank seeps, and other sites near the river, salmon spawning in this area is probably not at serious risk because 1) only 1 of 10 main salmon spawning grounds appear to be within the area influenced by the Sr-90 contamination; and 2) young salmon that are exposed do not accumulate Sr-90, which is taken up by calcified tissue that is formed later in the life of the salmon (Peterson and Poston 2000).

5.3.4 Municipal Drinking Water Intakes

The Columbia River flows eastward and then southward near the northern and eastern borders of the Hanford Site (DOE 1993b). Several cities and towns in the area use the Columbia River as a source of drinking water.

Most of the water used by the City of Richland for its municipal water supply is obtained from a pumping station on the Columbia River south of the Hanford Site (DOE 1993b). Columbia River water is also pumped into an aquifer recharge pond at the North Richland Wellfield, which is 2.5 miles south of the nearest Hanford 300-Area production facilities and about 0.5 miles east of the Columbia River. The North Richland water-intake facility is located less than a mile from the 1100-Area of Hanford. Two other recharge wellfields were previously located within city limits. Table 5-3 lists the substances tested for in the Richland drinking water supply in 1998 through 2001.

Table 5-4. Substances Tested for in the Richland Water Supply

Radionuclides	Nonradionuclides Chemicals	
Alpha emitters (gross)	Ammonia (dissolved, as N)	Nitrate as nitrogen
Antimony-125	Anions	Nitrite + nitrate (dissolved, as N)
Beryllium-7	Calcium	Nitrogen (total Kjeldahl, as N)
Beta/Photon emitters (gross)	Carbon (dissolved organic)	(Dissolved) oxygen
Cesium-134, -137	Chromium (dissolved)	Phosphorus (total)
Cobalt-60	(Total) Coliform bacteria	(Dissolved) solids
Europium-154, -155	Copper	Suspended solids
Gamma emitters	Cryptosporidium	(Total) Trihalomethanes
Iodine-129	Cyanide	Turbidity
Plutonium (238, 239, 240)	Fluoride	
Potassium-40	(Total) hardness ($CaCO_3$)	
Ruthenium-106	Iron (dissolved)	
Strontium-90	Lead	
Technectium-99	Manganese	
Tritium	Metals	
Uranium (234, 235, 238, total)		

Source: (City of Richland 2002; PNNL 1999a; Wiggins et al. 1998)

The City of Pasco draws water from the Columbia River at a location about 12 miles downstream from the Hanford 300-Area. The City of Kennewick obtains municipal water from infiltration wells farther downstream and adjacent to the Columbia River.

Both the Pasco and the Kennewick systems are downriver from the Columbia River's confluence with the Yakima River. See Figure 11. The Yakima River flows 6 miles west and 10 miles south of the 300-Area. Although the Yakima River borders the south end of the Hanford Site at a few places, no part of the Yakima River drainage is downgradient from any Hanford waste-production or storage facility or any groundwater contaminant plumes from the Hanford Site. Figure 11 (DOE 1990a) shows the major surface water features in and near Richland and the Hanford Site.

5.3.5 Contaminants in River Sediment

Shoreline Sediment

A 1980 study of onshore sediment on 26 islands looked at the residual concentrations of long-lived radionuclides from reactor cooling water. Some of these islands were as far as 40 miles downstream of the Hanford Site. The study determined that a constant level of contamination was observed uniformly over the entire study area. Densely vegetated areas had relatively higher levels of cobalt-60, cesium-137, and europium-152. Areas with the highest concentrations included White Bluff Slough, old Hanford Townsite, and Island 344 near the Hanford 300-Area. Average exposure rates were slightly above natural background, ranging from 38 to 45 uR/hr. According to study authors, a member of the public spending 500 hours per year at the location of the highest measured contamination would receive a whole body dose of 220 mrem. This compares to a local naturally occurring whole body dose of 300 mrem per year from natural contributors to background (Sula 1980).

During the study, 188 discrete particles of cobalt-60 were detected and removed from the shoreline. These metallic flake particles were thought to be fragments of valves, lines, or pump components from Hanford reactor cooling systems (Sula 1980). Direct dermal contact and the effect of beta and gamma radiation is a possible health concern of exposure to these particles. Residual cobalt-60 will have mostly decayed away by now.

In 1998, strontium-90 levels in surface sediments downstream from the Hanford Site, but north of McNary Dam, were higher than upstream locations or riverbank springs along the Hanford Reach. All other radionuclides were found at the similar levels at all locations. The highest chromium concentrations were found in riverbank springs sediment (PNNL 1999a).

River Bottom Sediments

Some of the contaminants from Hanford adhered to sediment at the bottom of the Columbia River and remain there today. Smaller amounts of contaminants are also present in Columbia River sediments as the result of fallout from nuclear testing in various locations around the world, including the Nevada Test Site. Generally, levels of radiological contaminants in offshore sediments are low, and have been covered with increasingly less contaminated sediment over time. Contaminants in offshore sediments/seeps in the Columbia River determined to be greater than comparison values in the 1970s and 1980s included cobalt-60 (Co-60), neptunium-237 (Np-237), and strontium-90 (Sr-90).

> Stirring up of Columbia River sediments through activities such as boating or dredging could expose people to contaminated sediments.

Generally, Columbia River flow rates and flow volumes are high enough that no major sedimentation of fine-sized material was expected or observed upstream of the McNary Dam pool. Plutonium and americium-241 were found at lower concentrations in the area of the Hanford Ferry (near the old Hanford Townsite) than in the McNary Dam pool. Samples from downstream showed decreasing concentrations from those measured at the McNary Reservoir (Robertson and Fix 1977).

One study of plutonium, americum-241, cesium-137, and cobalt-60 in sediment samples from the lower Columbia River suggested that these substances were not transported in significant amounts to the lower portion of the river or estuary (Robertson and Fix 1977). Another study found the amount of residual radioactivity to be “vanishingly small” and that measurements showed that natural radioactivity of the sediments containing isotopes of K, Th, U, and Ra exceeded that of the artificial radioactivity by nearly an order of magnitude (Beasley and Jennings 1984).

Another study found that, except for plutonium-239, radionuclides in the sediment were consistent with levels expected from global fallout estimates. Hanford-derived plutonium-239 appeared to account for 20 to 25% of the total plutonium found in the McNary sediments. This study also stated that most of the radionuclides that have been transported downstream to the McNary Reservoir were trapped behind the dam and subsequently buried by sedimentation (Beasley et al. 1981).

5.3.6 Exposure Routes

The Columbia River is used for recreation, power, and irrigation water. The Columbia River is the region's major source of water for drinking, industrial processes, crop irrigation, boating, swimming, fishing, and both subsistence and recreational hunting. The Columbia River does not currently represent a significant exposure route for members of the off-site general public.

5.4 Plants and Animals – Current Exposure Pathways

Contaminants that have exceeded levels of possible health concern in plants in the Hanford area. Tumbleweeds contain Sr-90; mulberries contain antimony, barium, cadmium, manganese, and zinc. Under current institutional controls, people do not come into contact with these plants often enough to be exposed at levels that would cause adverse health effects. If Native Americans were to exercise their rights in the future to use resources in the vicinity, their use of certain vegetation as traditional foods and medicines would warrant the reevaluation of exposures to area vegetation and animals.

One estimate of Sr-90 levels in fish calculated that a person near Hanford would receive 9% of their maximum dose of Sr-90 through eating area fish. Estimates in 1991 of radiological doses to clams, carp, crayfish, ducks, deer, rabbits, and vegetation in the N-Springs area did not exceed a 1 rad/day DOE guideline. In 1998, radionuclide levels in carp and in wildlife were similar near and further away from the Hanford Site.

In 1998, iodine-129, strontium-90, and tritium detected in milk were found to be higher in locations downwind of Hanford than upwind, but the levels were not present at high enough concentration to represent a concern for public (PNNL 1999a).

5.4.1 Plants

Radionuclides that have exceeded comparison values in on-site plants include strontium-90 in tumbleweed and uranium-238 in yarrow. Nonradioactive contaminants that have exceeded comparison values have included antimony, barium, cadmium, manganese, and zinc in mulberries.

Radiological samples taken in 1998 for vegetation on- and off-site were similar to samples taken from 1992 to 1994. Cobalt-60, strontium-90, cesium-137, plutonium-239 and -240, and uranium were consistently detectable. Uptake of contaminants, particularly of strontium-90 and cesium-137, by plants from soil

was found in reed canary grass samples in the 100-N shoreline area near N Springs (PNNL 1999a).

100 N-Springs Area

Vegetation in the 100 N-Springs area (e.g., such as such as mulberry, chicory, and water plants) might be an important food source to local animals species; however, humans are not currently using the vegetation for subsistence. Sampling results from 1990 to 1992 indicated that maximum concentrations of tritium (97,000 pCi/L), strontium-90 (440 pCi/g), cobalt (0.34 pCi/g), and possibly uranium-238 in mulberry foliage were elevated compared to sampled from upstream locations. The researchers then calculated possible doses to people from eating the edible portions of the vegetation. The highest dose was three orders of magnitude less than the 100-mrem dose limit set by the DOE. The most significant contribution to dose (0.2 mrem for 50 years) resulted from Sr-90 in mulberries (Antonio et al. 1993). One study also reported that levels of strontium-90 in a mulberry leaf sample from a tree at the N-Springs were much higher (202,000 pCi/kg(dry)) than Sr-90 found in a nearby groundwater monitoring well (average of 5,900 pCi/L) (Buske 1999).

Tumbleweeds and Thistle

Contaminated tumbleweed was found, mainly in the 200-Area, when the DOE began to remediate the most contaminated parts of the Hanford Site in 1979 (McKinney and Markes 1994). Investigations also showed that Russian thistle growing in trenches and in other engineered waste-storage structures in 200-East Area contained Sr-90. Thistle and tumbleweed from other parts of the 200-Area, such as the ponds and ditches of the 200-West Area, were less contaminated (Johnson et al. 1994). Russian thistle continues to grow in the less contaminated areas (United Press International 1998).

Radionuclide samples in tumbleweed are reported each year.

When the contamination was identified, tumbleweed was removed from the 100-Area, 200-Area, and other treatment, storage, and disposal areas (Hayward 1997). Public interest groups have expressed concern about the tumbleweeds that blow off-site.

In 1998, strontium-90 levels as high as 7,360,000 pCi/g (or 272,320 Bq/g, compared to the comparison value of 108 Bq/g) and cesium-137 levels as high as 1,410,000 pCi/g (or 52,170 Bq/g, compared to the comparison value of 422 Bq/g) were recorded in tumbleweed (PNNL 1999a).

Plutonium

Little, if any, plutonium is taken up into roots of plants; soils and sediments are the major environmental repositories for plutonium. Plant uptake of plutonium that does occur does not take place in relevant food exposure pathways to people (Stannard and edited by Baalman 1988). Plutonium contamination of plant and animal life was not found above comparison values.

5.4.2 Fish

A 1992 DOE report stated that Sr-90 was found in fish bone samples, but not consistently in muscle. This is consistent with the fact that Sr-90 is a bone seeking radioisotope. The report estimated that Sr-90 in fish would contribute 9% of the 0.02 mrem of the maximally exposed individual dose to a person (PNNL 1992b).

The Department of Energy found that concentrations of cobalt-60 and Sr-90 in sturgeon collected in the Hanford area were not significantly different from concentrations in those collected up- or downstream, and also that no evidence of bioaccumulation in older/larger sturgeon existed (Dauble et al. 1992). A 1998 DOE report stated that no life stage of salmon or steelhead fish was found to be at risk from Sr-90 in groundwater, seeps, or sediment, although the 100-N springs area was identified as a potential location for measureable concentrations (DOE 1997a). In 1998, radionuclide levels in carp were similar upstream and downstream of the Hanford Site. Radionuclides in wildlife were at similar levels at the Hanford Site and at background locations (PNNL 1999a).

Other DOE contract researchers have stated that high levels of Sr-90 in groundwater at the 100-N Area, wells, riverbank seeps, and other sites near the river are unlikely to be a concern for salmon spawning in this area because only 1 of 10 salmon spawning grounds was in the areas affected by the Sr-90 contamination, and also because young salmon eggs and fry do not accumulate Sr-90 which is taken up by calcified tissue formed later in the life of the salmon. (Peterson and Poston 2000).

5.4.3 Other Animals

A 1991 DOE study, conducted at the request of the Washington State Department of Ecology, estimated radiation doses to clams, carp, crayfish, fish-eating ducks, deer, rabbits, and aquatic and terrestrial vegetation in the N-Springs area. None of the dose estimates exceeded the 1 rad/day DOE guideline for aquatic animals (Poston and Soldat 1992).

5.4.4 Milk and Wine

Sampling of farm products in 1998 found that milk contained iodine-129 at slightly elevated levels in locations downwind of Hanford compared to upwind locations; iodine-129 levels have decreased in milk collected over the past five years and are close to levels at upwind locations. The maximum level of I-129 in milk in 1998 was 0.0007 pCi/L; there is no regulatory standard for I-129 in milk, but the drinking water standard for I-129 is 1 pCi/L.

Strontium-90 was found in milk at the same levels upwind and downwind of the Hanford Site. The maximum level of Sr-90 found in milk in 1998 was 0.95 pCi/L, compared to the drinking water standard for Sr-90 in water is 8 pCi/L. There is no standard for Sr-90 in milk. Sr-90 was also detected in two leafy vegetable samples at a maximum level of 0.021 pCi/L, and in one grape sample at 0.005 pCi/g.

Tritium is a naturally existing radionuclide in all plants. Tritium was found in Columbia Basin wine samples, at a maximum of approximately 86 pCi/L. Tritium was also found in milk samples in 1998, but results have not yet been reported due to sampling analysis problems; additional sampling in 1999 found a maximum concentration of approximately 92 pCi/L of tritium in milk; the drinking water standard for tritium is 20,000 pCi/L. No standard exists for tritium in milk or wine. (PNNL 1999a, 2000b).

5.4.5 Exposure Routes

Off-site hunters could hunt game that could have grazed on Hanford lands; however, monitoring studies have confirmed that levels of radioactivity in elk, deer, and other game on the Hanford Site are the same as levels in game from elsewhere in the Pacific Northwest.

Tumbleweed is not known as a food source. Persons who gather dried brush and tumbleweed for disposal could receive an effective dose of less than 1 mrem from beta exposure to their skin.

Other than the activities discussed above, people who eat or otherwise regularly use plants and animals from the Hanford area are unlikely to be exposed to levels of contaminants at levels of possible public health concern because of the current restricted access to Hanford land and because contaminant levels in farm or animal products in the area appear to be either non-detectable or well below levels that would cause adverse health effects. Potential exposures if land use changes in the future are discussed in Chapter 7.

5.5 Soil – Current Exposure Pathways

Several radionuclides exceeded comparison values in on-site Hanford soils in the early 1990s, including cesium-137, plutonium-239 and -240, strontium-90, and uranium-238. The cesium, plutonium, and strontium have since been removed or covered with several feet of uncontaminated soil and thus are not current exposure pathways to people.

A number of nonradionuclides also exceeded comparison values for children including antimony, arsenic, barium, beryllium, cadmium, manganese, mercury, lead, nickel, silver, vanadium, zinc, and PCBs. With current institutional controls, children do not come into contact with these on-site soils.

5.5.1 Soil Contamination

Radionuclides consistently found in soil onsite at Hanford included cobalt-60, strontium-90, cesium-137, plutonium-239 and -240, and uranium. Sr-90 and Ce-137 levels were low, near their detection limits. Maximum Sr-90 concentrations were 0.38 pCi/g; maximum Ce-137 levels were 1.8 pCi/g; and maximum plutonium 239 and 240 levels were 0.53 pCi/g, dry weight (PNNL 1999a).

100-Area

In the 100-Area, cobalt-60, strontium-90, and plutonium-238 and -240 levels were higher near the 1301-N facility than other locations in the 100-Area and in the 200, 300, and 400 Areas (PNNL 1999a).

200-Area

Surface soil samples from the 200-Area were generally less contaminated, except for cesium-137, which was higher in the 200-Area than in the 100, 300, and 400 Areas. Soils beneath the waste storage cribs are contaminated with Cs-137, plutonium-239, Pu-40, and Sr-90, all of which exceeded comparison values. Soils under the waste cribs are now covered with several feet of uncontaminated soil, and thus are not a current exposure pathway to people, by either ingestion or inhalation. Levels of Cs-137, Pu-239, Pu-240, and Sr-90 in other 200-Area soils (other than the cribs, including surface soils) were found to be below comparison values in the 1990s, and thus not expected to cause adverse health effects.

300-Areas

Uranium levels in the 300-Area were higher than those in the 100 and 200 Areas (PNNL 1999a). For subsurface soils in the 300-Area, levels of antimony, arsenic, barium, beryllium, cadmium, manganese, mercury, lead, nickel, silver, vanadium,

zinc, polychlorinated biphenyls (PCBs), and uranium-238 (U-238) exceeded comparison values.

5.5.2 Sources of Contamination

The sources of current soil contamination primary involve past releases from the production reactor operations. Releases included cesium-139 (Cs-137), europium-152 (Eu-152), europium-154 (Eu-154), strontium-90 (Sr-90), and technetium-99 (Tc-99). Soil contaminants in Hanford's 200-Area originated from leaking tanks, cribs, ditches, French drains, process ponds and trenches, and unplanned releases. Soil contaminants in the 100- and 300-Areas originated from cooling water and process wastes discharged to ponds and trenches, or from leaking sewer lines.

5.5.3 Exposure Routes

Comparison values for child ingestion of surface soil were exceeded by arsenic, barium, lead, manganese, mercury, nickel, PCBs, silver, vanadium, and zinc concentrations in on-site soils in the early. However, children would are not ingesting soil and being exposed to these contaminants. The elimination of the soil exposure pathway depends on both the maintenance of present institutional control over Hanford Site and on the public respecting that control. No current examples of the exposure of children to Hanford Site soils is known.

5.6 Air – Current Exposure Pathways

There are not as many air releases as there were in the past and doses to the public are less than 1% of the allowed limit. There is a potential for unplanned releases, such as the brush fire that occurred in 2000. During the fire, levels of plutonium were detectable, but not a health hazard.

5.6.1 Contaminants

In 1998, strontium-90, cesium-137, plutonium-239, 240, and uranium were detected in the air in the 100-K, 100 N, and 200 Areas. Cobalt-60 was detected in the 100 N Area. These radionuclides were detected within about 1,500 feet, primarily downwind, of sites or facilities having the potential for, or a history of, environmental releases. Radiological doses to people through the air pathway were calculated to be 0.13% of the EPA limit of 10 mrem/yr. Gross alpha air concentration in 1998 at the site perimeter was slightly higher than concentrations at a distant community location. Gross beta air concentrations were the same at the Hanford Site perimeter as at distant community locations. Iodine-129 levels

were higher at the Hanford Site perimeter compared to distant locations, indicating a measurable Hanford source (PNNL 1999a).

5.6.2 2000 Hanford Brush Fire

On June 27, 2000, an automobile accident started a wildfire that swept through portions of the Hanford Site. It burned 192,000 acres or 256 square miles of sagebrush and grass-covered land, mostly on the Hanford Reservation, and destroyed 11 homes in nearby Benton City and West Richland. The fire was reported to have been the fastest-spreading fire in the United States during the prior ten years. The fire swept over two dried-out ponds just south of the 200 West Area where contaminated water was dumped from the 1950s to 1970s. The fire also burned around part of the B/C Cribs Area just south of the 200 East Area.

The wildfires at Hanford and Benton City were primarily sagebrush and grass fires that spread quickly and completely consumed areas in minutes. Grass and sagebrush fires, like the one at Hanford, move quickly and burn all available organic material in minutes and do not last long enough to draw significant radon out of the ground.

The typical historical plutonium concentration in air at Hanford's perimeter is 0.0003 picocuries per cubic meter, with the federal limit for plutonium being 2 picocuries/cubic meter of air and the concentrations found during the fire were not a threat to public health.

- Air samples were analyzed at the state laboratory according to emergency protocols, and no radioactive contamination was initially detected. Follow-up environmental level analyses of the emergency response samples have been analyzed and plutonium was slightly elevated at five on-site and five off-site locations. There are two locations next to the 200 East Area, two next to the 200 West Area—both in central Hanford—plus one in the 300 Area near Richland.

- U.S. Environmental Protection Agency test results from samples taken off-site showed increased plutonium concentrations at three Richland sites, one West Richland site, and one western Pasco site. The EPA's elevated off-site readings were reported to range from 0.12 to 0.42 picocuries per cubic meter.

- DOE's elevated on-site plutonium contamination readings ranged from 18 to 200 attocuries of plutonium per cubic meter of air.

Only plutonium concentrations increased, while uranium and other radionuclide concentrations were unchanged. Elevated plutonium concentrations were found at similar levels both on and off site, leading to speculation that it was due to resuspension of global fallout.

The fire included parts of the newly designated Hanford Reach National Monument. With monument status comes the policy to use a "light hand on the land". Therefore, local fire districts were restricted in their ability to bring in and use heavy equipment to fight the fire. The Fish and Wildlife Service is now stating that an incident commander is given full discretion to use heavy equipment when it is essential to protect life and property (FWS 2000).

Hanford Site Contingency Plan

Members of the Hanford Health Effects Subcommittee requested that the public health assessment address the Hanford contingency plan. The Hanford Site Emergency Plan is written and updated in coordination with the States of Oregon and Washington. Specifically the Oregon Department of Energy and the Washington Departments of Health, Environmental Health, Nuclear Planning, Agriculture and Washington State Emergency Management Division review the emergency plans. DOE also receives assistance from the U.S. Nuclear Regulatory Commission, because Energy Northwest's Columbia Generating Station (formerly Washington Public Power Supply System Unit-2 or WPPSS WNP-2) located on land leased from the U.S. Department of Energy (USDOE) on the Hanford Site. The complete plan can be found at the following URL

http://www.hanford.gov/docs/rl-94-02/rl94-02contents.html

5.7 External Radiation Doses

Measurements of external radiation include cosmic radiation, naturally occurring radioactivity in air and soil, and fallout from nuclear weapons tests, as well as any contributions from Hanford Site activities. Generally, DOE 1998 average dose rates at various 100-Area Hanford locations were comparable to off-site ambient background levels. At some 100-Area locations, on-site or nearby doses were somewhat higher (e.g., 4% and 9%) than 1997 doses rates, while at other locations 1998 doses had decreased substantially (e.g, 17% and 61%) from 1997 doses. In the 200-, 300-, and 400-Areas, annual dose rates were either comparable to or slightly lower or higher than 1997 measurements.

N-Springs

Dose rates at the N-Springs shoreline were elevated above the 100 mrem/yr DOE annual external dose limit to members of the public, reportedly because of a

"skyshine" effect — radiation reflected by the atmosphere back to the earth's surface; N-Springs dose reduction measures are being studied. Because it is unlikely that either a member of the public or a Hanford worker would spend an entire year at the N-Springs which the dose estimate assumes, people will probably not have this level of exposure (PNNL 1999a).

Estimated Off-Site Dose

DOE estimated the potential dose to the maximally exposed individual from Hanford Site operations was 0.02 mrem in 1998 and was 0.01 mrem in 1997. The radiological dose to the population within 50 miles of the site, estimated to number 380,000 people, from 1998 site operations was 0.2 person-rem, which was the same as for 1997. These numbers can be compared to 1) the national average dose from background sources, which according to the National Council on Radiation Protection is about 300 mrem/yr; and 2) the current DOE radiological dose limit for a member of the public, which is 100 mrem/yr. Thus, the average person potentially received 0.002% of the national average background and 0.0005% of the DOE limit. (PNNL 1999a).

6

Future Pathways

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Land Use

Future use plans indicate that after the year 2020, part of the current Hanford Site will be transferred to non-DOE owners. Future uses include tribal, scientific, agricultural, and industrial activities. Some of the residual chemical and radiological contamination will remain. As land use changes, it is conceivable that future populations could be exposed in some places to remaining radionuclide or chemical contamination. For most persons living in the area, future exposure will be limited—most Hanford areas will be used for industrial purposes. Persons could, however, be exposed to contaminants at levels of health concern. For example, certain traditional Native American tribal practices, if resumed in the future at the Hanford Site, could expose persons to radionuclides and chemicals present in the area, as described below.

Native American Activities

Soil

The tribal practice of wrapping food in soil before cooking could expose persons to soil contaminants. The exposure could cause adverse health effects if persons use traditional tribal food preparation methods exclusively, use soil from the most contaminated Hanford lands, and if some of the soil adheres to the food that is consumed. Persons could also be exposed to contaminants in game if these foods are cooked prior to deboning them, or if bones or antlers are added to soups or stews for thickening. Using these deboning or thickening food preparation practices could result in an increase of the amounts of Hanford contaminants such as strontium, uranium, and lead to which persons could be exposed.

Plants and Animals

Persons who in the future rely on the most contaminated parts of the Hanford Site for their food or water—through activities such as hunting, food or medicine gathering—could be exposed to contaminants at levels that could result in harmful health effects. Examples include exposure to cadmium in wild plants (e.g., berries) and lead in wild game and plants.

Land and Buildings, New Activities, and Catastrophic Events

Other possible pathways through which persons could potentially be exposed to contaminants originating from the Hanford Site include 1) the use of Hanford lands and buildings, if residual contaminants are present at levels that could be health hazards; for example, children could be exposed to lead in soil if the land is used for non-industrial use; 2) potential releases of wastes from new activities

involving Hanford facilities; and 3) through catastrophic events such as fires, earthquakes, floods, or terrorism that unearthed residual contamination.

Drinking Water

If persons in the future use the seeps or springs along the banks of the Columbia River or install private wells on land that was previously part of the Hanford Site, persons could be exposed to contaminants in the water. Persons could also be exposed in the future to 1) tritium in the Columbia River, if tritium recently found in groundwater reaches the River in the future; 2) possible future contaminants in the North Richland well field groundwater, if groundwater flow is redirected into this well field; 3) TCE and nitrate in groundwater, if the groundwater plume containing these substances reaches the Columbia River; and 4) previously immobile contaminants that may begin to move into soil and water from single-shell tanks, K basins, and disposal facilities at the Hanford Site. The physical half-life of tritium (12.3 years) naturally reduced the concentration of tritium in soil and groundwaters by one-half every 12 years. It is not likely that future concentrations of radionuclides and chemicals in groundwater will exceed the levels currently known from monitoring. Further, it is unlikely that future drinking water sources would draw from contaminated groundwaters.

Future Health Effects

The appearance of future health effects in persons previously exposed to Hanford contaminants is possible because health effects sometimes appear long after exposure to a contaminant occurs. For example, persons who were exposed to I-131 as children may not see the health effect until they are adults.

6.1 Land Use

In the future, exposure of the general public to contamination remaining on the Hanford Site will be limited because most of the land will be used for industrial purposes. New drinking water wells will not be drilled into the contaminated groundwater. Most current drinking water sources are not in the path of contamination or are not expected to be at levels that could cause harmful human health effects. Persons who might hunt or gather food from the Hanford Site will not rely on the Hanford Site as their sole source of food. This is true for the general population, and does not pertain to uniquely sensitive or susceptible individuals. If, however, it were possible that someone relied exclusively on the Hanford Site for their food or water, they could be exposed to contaminants at levels of potential

The transfer of Hanford land from federal to private control will eventually take place.

health detriment, as described below.

While the Hanford Site is under federal ownership—as it is currently— public access is not permitted to many areas of the site, including all contaminated areas, without escort. Additionally, the land cannot be used for private residential or agricultural purposes. This situation is unlikely to change substantially before the year 2020. Nevertheless, in anticipation of expected changes in land ownership from federal to private after that time, this chapter explores the potential for persons to be exposed in the future to residual contaminants on lands formerly part of the Hanford Site.

Parts of the 300-Area have been decontaminated for eventual release and future public industrial use. The Department of Energy (DOE) plans to remediate the 300-FF-1 area soil and all 300-Area groundwater to levels suitable for industrial use (DOE 1995e). Other areas of the Hanford Site will also likely be decontaminated for scientific, agricultural, or industrial uses, rather than residential use. Some more heavily contaminated areas, such as waste disposal sites in the 200 Area, will not be remediated to levels that allow public use in the future. Also, because groundwater moving under the 100-Area toward the Columbia River is contaminated by 200-Area tank farm leaks, much of the Hanford Site to the north and east of the 200 Area may not be suitable for future agricultural development.

6.2 Native American Activities

Once Native American tribes reclaim access to parts of the Hanford Site—as they are planning to do—tribal people could be exposed to Hanford contaminants from hunting, cooking, gathering foods and medicines, and pasturing livestock on former Hanford lands. One way that persons could be exposed is through the use of food-wrapping, a traditional tribal cooking method that involves encasing food, such as fish or game, in soil before cooking it in a fire. Any contaminants in the soil, such as cadmium or copper, being used to wrap the food could be ingested by persons who consume some of the soil remaining on the food. Another exposure pathway could be through consuming contaminants, such as strontium, uranium, lead, or cadmium, in local game and in wild plants used as food or medicine.

Table 6-1 summarizes the future exposure pathways that could introduce contaminants into the diets of persons who consume food from the Hanford Site. Persons could be exposed to contaminants through more than one of the pathways listed in Table 6-1. The contaminants of possible concern are discussed further in Chapter 7, and the potential health effects associated with these contaminants are discussed in Chapter 8.

Table 6-1. Future Diet-Related Exposure Pathways					
Pathway	**Source**	**Environ-mental Media**	**Points of Exposure**	**Routes of Exposure**	**Exposed Population**
Soil	process wastes	soil	soil consumed by children; food wrapped in soil	ingestion	pica children eating soil; tribal members
Plants and Animals	process wastes	fish, game, plants	food, medicines	ingestion	subsistence fishers, hunters and their families
Drinking Water	process wastes	surface water, groundwater	drinking water wells, seeps	ingestion inhalation dermal contact	future residents

6.2.1 Future Access

Native Americans in the vicinity of Hanford plan to reclaim access to parts of the Hanford Site. Tribal treaties involving Hanford lands, signed in the nineteenth and twentieth centuries, reserved the rights of tribal members to hunt, fish, gather foods and medicines, and pasture livestock on Hanford lands. In addition, DOE is required to allow access to sacred sites, including ceremonial sites and grave sites, within Hanford boundaries. While tribal leaders look forward to exercising these rights, they and other tribal members express concerns about radiation and chemical exposures that might occur as a result of hunting, fishing, and gathering activities.

The Native American tribes involved in these treaties include what is now known as the Confederated Tribes of the Umatilla Indian Reservation and the Yakama Indian Nation. The Hanford Site is 60 miles northwest of Umatilla's reservation and 20 miles east of Yakama's reservation. Other tribes interested in the future disposition of the site include the present-day reservations of the Coeur d'Alene Tribe, Colville Confederated Tribes, Confederated Tribes of the Umatilla Indian Reservation, Confederated Tribes of the Warm Springs Reservation of Oregon,

Kalispel Tribe, Kootenai Tribe of Idaho, Nez Perce Tribe, Spokane Tribe, and Yakima Indian Nation.

Federal law requires DOE to restrict public access to areas that could pose hazards to human health (McLeod 1995; DOE 1995e). Although DOE is committed to maintaining controls that will limit future use of the Hanford Site to industrial users, the Agency for Toxic Substances and Disease Registry (ATSDR) considered the possibility that the land along the Columbia River currently being held in trust for one or more of the tribes could one day revert to traditional tribal use. The following paragraphs address tribal activities and potential for exposure if Hanford lands are eventually released for tribal use.

6.2.2 Soil Pathway

When tribes reoccupy Hanford Site lands in the future, exposures to radiation and chemical contaminants at concentrations of possible health concern could occur for persons who adhere exclusively to traditional food preparation. For example, food-wrapping (i.e., encasing food in soil), as discussed below, could increase the amount of contaminated soil ingested inadvertently (CTUIR 1995). Also, fish and game might be cooked before being deboned, or soups and stews could have bones or antlers added for thickening, which could increase the amounts of certain radionuclides such as strontium and uranium, and nonradionuclides such as lead that may be ingested with the fish and game.

In some traditional tribal food preparation practices, food items may be encased in soil prior to cooking to control the heat from the cooking fire (CTUIR 1995). The rate of soil consumption by a 154-pound adult from eating soil-encased food could amount to 5 grams (one teaspoonful) of soil daily over a lifetime. If the soil came from the most contaminated areas of Hanford, possible health effects from eating food encased in soil could occur from consuming cadmium or copper if these substances are present at high enough levels in the food-encased soil. Possible health effects for sensitive individuals from eating food encased in soil prior to cooking from the most contaminated areas of Hanford include kidney damage from eating cadmium in the soil. Consuming copper present in the food-encased soil could lead to stomach and intestinal irritation, especially for persons who already have liver damage or certain metabolic problems. In addition, some persons could develop skin spots from ingesting silver in soil-encased food; these

When food is wrapped in soil, as is done in some traditional tribal food preparation practices, some of the soil may adhere to the food and may be ingested, along with any contaminants present in the soil.

skin spots are not considered to be a concern to health. The health effects from consuming contaminants in soil-encased food are discussed in more detail in Chapter 8.

6.2.3 Plants and Animals

The return of Hanford land to unrestricted or traditional tribal use would increase the likelihood that residents might subsist on local wild vegetation and animals from the Hanford Site. Also, local medicinal herbs could be collected and used in traditional ways to treat persons for illnesses. Persons who used plants and animals from the most contaminated areas of the Hanford Site could be exposed to levels of radionuclides and chemicals that might cause harmful health effects or could affect some persons' susceptibility to certain illnesses. While unlikely, kidney impairment could result from consuming trace levels of uranium in yarrow used as medicine; kidney impairment could occur in sensitive individuals who consumed cadmium in wild plants. Children could experience lead poisoning (e.g., reduced growth and IQ) from ingesting lead in wild game and plants. The possible health effects that might result from consumption or other uses of local wild plants and animals are discussed in more detail in Chapter 8.

6.3 Land and Buildings Released for Industrial Use

In the future, buildings and lands formerly part of the Hanford Site may still contain contamination; persons working in or visiting those buildings or lands may not know that contamination remains. An example is Building 313, which was previously used for testing uranium fuel rods for leaks and was later used as a commercial aluminum extrusion plant.

Limiting former Hanford lands only to industrial uses cannot be assured. For example, persons are concerned that parts of the Hanford Site might be used for agricultural, residential, or other purposes, such as a day-care center. Lead has been found in the soil. In the future, children might be exposed to this lead contamination.

6.3.1 Buildings with Residual Contamination

Most of the former DOE buildings on the Hanford Site will be removed. Some have expressed concern that the user of remaining DOE buildings or lands may not be aware of the remaining contamination and the potential health hazards.

For example, the Washington Department of Health (WDOH) investigated the 313-Building in response to concerns raised by a citizens group, the Government

Accountability Project (GAP). GAP expressed concern that workers and others were exposed to elevated levels of radiation at the Richland Specialty Extrusions factory which, at that time, leased part of the Hanford 313-building to produce aluminum objects. These concerns were based on testing done by GAP. The WDOH found that the site had unrestricted access despite signs, chain-link fences, and shield blocks identifying radiological areas and attempting to prevent unintentional entry. One "hot spot" was identified by the WDOH in an inaccessible area; the WDOH stated that this area did not expose anyone to doses above 100 mrem, which is the annual DOE dose limit to members of the public. The DOE and ATSDR concluded that no public health risk existed from external exposure to radiation at the site. See Appendix K for a more detailed discussion of the aluminum factory and Building 313 radiation testing results.

6.3.2 Clean-up Standards based on Industrial Use

There is public concern that clean-up standards based on industrial use are not adequate because limiting land use to industrial activities cannot be ensured. For example, if future users create a day-care center for workers in the area, the persons operating and using the day-care center would not necessarily be aware that they could be exposing children to lead in soil. This potential exists because the area was remediated to industrial, not residential, standards; some parts of this area were not remediated and still contain lead in the soil. Also, barriers to contamination that do exist (e.g., caps) could be breached. The health effects of children exposed to lead in soil include reduced growth and IQ; the health effects associated with children ingesting lead in soil are discussed in more detail in Chapter 8.

ATSDR advised the Port of Benton that properties formerly part of the 1100-Area of Hanford should be limited to industrial or commercial use, rather than residential use.

In 1998 a portion of the 1100-Area was acquired by the Port of Benton, with the intention that it would become part of the Horn Rapids Industrial Park. ATSDR notified the Port of Benton that this transfer should include sufficient safeguards to protect public health from exposure to unremediated areas and to guard against the breaching of barriers created in the course of remediation (e.g., caps). Because DOE's remediation was to industrial standards, less restricted use such as residential or agricultural use may not be protective of public health.
If the Fast Flux Test Facility (FFTF) is restarted a major community concern is the potential for the release of tritium. On December 19, 2001, DOE announced that the FFTE would not be restarted and that its deactivation would proceed.

Currently, the FFTE is being deactivated. Additional information on the FFTE and its current status can be found at http://www.hanford.gov/fftf/

6.4 Catastrophic Events

Persons are concerned that radioactive contamination may be released by future fires. On June 27, 2000, a 5-day fire occurred at the Hanford Reach National Monument that burned almost 164,000 acres of land. While this fire did not reach areas of high contamination, levels of plutonium measured in air were slightly elevated during the fire, The fire approached some nuclear waste disposal areas. There is also concern about possible exposure to contamination if earthquakes, floods, or terrorist acts occur in the future.

6.4.1 Fires

The June 27–July 1, 2000, the Hanford Reach National Monument Fire burned nearly 164,000 acres of federal, state, and private land, including 11 homes. A review of the response to the Hanford fire identified key areas that need improvement (FWS 2000).

In 1997, the U.S. Fish and Wildlife Service, under contract with the DOE, assumed management of the Arid Lands Ecology Reserve, which is part of the newly designated Hanford Reach National Monument. In June 2000, the Fish and Wildlife Service assumed management responsibility of the entire monument—with one fire management officer with no staff or equipment.

With monument status comes the policy to use a “light hand on the land”. Therefore, local fire districts were restricted in their ability to bring in and use heavy equipment to fight the fire. The Fish and Wildlife Service, however, stated that an incident commander is given full discretion to use heavy equipment when it is essential to protect life and property. It was not clear who was to have made the decision that life and property were threatened.

Although this fire did not go through areas with levels of high contamination, there were elevated plutonium readings during the fire. At one point, the fire reached a point within 400 yards from 330 50-gallon barrels containing uranium packed in combustible oil residues stored near the Columbia River. The blaze also passed through an area of known contamination near nuclear waste dump sites.

During the Hanford fire in the summer of 2000, flames burned close to areas of nuclear wastes that could have exploded and caused an emergency.

6.4.2 Earthquakes, Floods, and Terrorist Acts

In addition to fires, there is the potential for earthquakes, floods, and terrorist acts. The potential for adverse health effects depends on the intensity of the event. Review of contingency plans is the responsibility of the Federal Emergency Management Agency (FEMA).

6.5 Drinking Water

Several contaminants, such as radioactive tritium in on-site groundwater, are above drinking water standards. ATSDR does not expect to drill new wells in the contaminated groundwater. Still, as groundwater flows toward the Columbia River, higher levels of contamination could reach seeps and springs, the North Richland well field, and the river.

Radioactive tritium in Hanford groundwater could reach the Columbia River in the future. Concentrations are currently being reduced by one-half every 12 years due to natural decay. Persons would not be expected to be exposed to harmful levels of other contaminants in the River because detected levels of groundwater contaminants are low, in part due to dilution with clean river water, and because most levels of contaminants are expected to decay naturally to less than the levels of concern before they reach municipal water supplies.

Other sources of possible future contamination of groundwater or Columbia River water include offshore river sediments—if stirred or dredged—currently immobile contaminants that might be released in the future from sources such as single-shell tanks, K basins or disposal facilities, and radiological particles along the shoreline of the Columbia River.

6.5.1 Increased Water Usage

The return of Hanford lands to unrestricted public use could increase the possibility that some residents would use local river water or groundwater (e.g., private wells, springs, seeps) as a source of drinking water. A number of contaminants have been found in on-site groundwater at levels that are above drinking water standards. Also, some groundwater-related exposure pathways could transport contaminants to persons who drink water from these sources. All wells in Benton County require permits, and it is unlikely that permits would be granted for wells on lands with contaminated groundwaters.

Most persons will continue to drink water from uncontaminated municipal water supplies (e.g., the City of Richland) and these water supplies could be extended in

the future to newly developed areas. It is possible, however, that persons might use contaminated sources of drinking water, such as seeps and springs along the banks of the Columbia River.

If the City of Richland significantly increased pumping capacity for the North Richland well field, the groundwater flow direction could be influenced. The flow direction is currently influenced by injection of Columbia River water using large ponds overlying the North Richland well field. However, a change in groundwater flow could result in contamination being drawn into the North well field. Persons would then be exposed to groundwater contaminants in the city water system through ingestion of the water, foods irrigated with contaminated water, inhalation, or skin exposure. Local groundwater flow is monitored to ensure that the flow is not redirected into the well field and that contaminated water is not supplied to City residents.

6.5.2 Tritium

According to an Associated Press (AP) article, the concentration of tritium found in Hanford groundwater in January, 2000 at one location measured 8,000,000 picocuries per liter of water, whereas the federal drinking water standard is less than 20,000 picocuries per liter. The source of this tritium contamination may be an area where drums and caissons (large metal pipes) are buried. This burial area is located 3½ miles from the Columbia River. The Department of Energy stated that some portion of this tritium could reach the Columbia River in the future.

In January, 2000, levels of radioactive tritium were found in groundwater at the Hanford Site at levels above the federal drinking water standard.

In May 2000, DOE published the results of a preliminary investigation of this tritium plume near the 618-11 burial ground. Tritium in one well down-grade of the burial ground was detected at levels up to 8,140,000 pCi/L. The 618-11 burial ground received a variety of radioactive waste from the 300 Area between 1962 and 1967. The Energy Northwest reactor complex was constructed immediately east of the burial ground (PNNL 2000a). The investigation did not define the extent of the elevated tritium levels in groundwater. The available data suggested the tritium plume is narrow and confined. Data on vertical extent of the contamination are sparse. No tritium was detected in the confined aquifer samples (PNNL 2000a).

6.5.3 Trichloroethylene and Nitrate

If trichloroethylene (TCE) and nitrate currently in the groundwater plume near the 1100-Area from the Siemens Power Corporation were to reach the Columbia River, persons might be exposed to these chemicals. Levels of these contaminants would most likely be below levels of health concern before reaching Richland City water intakes.

6.5.4 Potential new sources of contamination

It is possible that some previously immobile contaminants may begin to move in the future and that new contamination may be released to soil and water from sources such as additional single-shell tanks, K basins, and disposal facilities. Also, if offshore river sediments are stirred (e.g., by boating) or dredged in the future, exposure could occur through skin contact with or ingestion of contaminants in the sediments. Another source of potential future exposure might be contact with radiological particles along the Columbia River shoreline.

6.6 Air

Contaminants in air releases from the Hanford Site in the future are not expected to pose a health concern to persons. Current levels are consistently below regulatory health limits, and no new releases of airborne contaminants above these limits are anticipated to be released in the future.

6.7 Health Effects from Past Exposures

Certain health effects associated with particular radionuclides or chemicals might not appear until quite some time after a person was exposed to the substance. This time lag between exposure to a substance and the onset of disease related to that exposure is known as a “latency period”. For example, persons who were exposed to I-131 as children may not see a health effect until they are adults.

Some persons may have been exposed in the past to radiation and chemicals from Hanford, but health effects from that exposure may not appear until sometime in the future.

The developing body systems of children can sustain permanent damage if toxic exposures occur during critical growth stages. Children are more vulnerable to the effects of iodine in milk for several reasons

- they drink more milk than adults,
- their thyroids glands, where iodine concentrates, are smaller, and
- children tend to be more sensitive to contaminants than adults.

Children are also smaller, so they receive higher doses of exposure proportional to their body weight.

7

Contaminant Screening

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Exposure Evaluation Process

For environmental contamination to pose a health concern, three conditions must be met 1) the contaminants must be present in the environmental media (e.g., air, water, soil, etc.), 2) persons must come in contact with the environmental media containing the contamination, and 3) the level of contamination must be high enough to affect human health.

Each environmental medium was evaluated to determine whether persons would come into contact with the contaminants through ingestion, dermal (skin) absorption, inhalation or whole body exposure. Target populations, which have factors that could influence their extent or duration of exposure, were also identified (e.g., children and tribal members).

Once a potential for exposure was identified, the ATSDR determined whether the levels of contamination were high enough to produce adverse health effects. This was done by first comparing the contaminant concentration against a *screening value*. The screening values are media-specific concentrations of a substance that are not expected to cause adverse health effects.

The ATSDR uses two sets of screening values, one set for carcinogens and one for non-carcinogens. Provisional consumption rates are generated to help determine if people's ingestion of contaminated foods exceed the screening values for those contaminants.

Contaminants Eliminated

Some contaminants were eliminated because ATSDR determined that the contamination was not a human health concern. The list of contaminants eliminated can be found in tables at the end of this chapter. Table 7-1 lists contaminants not in an exposure pathway. Table 7-2 lists chemicals below ATSDR's screening values. The tables list the contaminant, the maximum concentration found, where the contaminant was on the Hanford Site, and the screening value used by ATSDR.

Contaminants Selected for Further Evaluation

For each medium, contaminants for further evaluation were identified. The substances were selected because they were above our screening value or there was a community concern.

Air. The primary contaminant released in the air was iodine-131 during the 1945–1951 period. Plutonium is also found in the air monitored at the 200-Area stacks, but it is found at very low concentrations.

Seeps and Springs. Strontium-90, tritium, lead, and uranium were selected for further evaluation because they were found above screening values in springs and seeps along the Columbia River. They were below screening values at the Richland drinking water intake.

Columbia River. Five radionuclides were identified as Columbia River contaminants: arsenic-76, neptunium-239, phosphate-32, sodium-24, and zinc-65. Their historical average concentrations were below drinking water screening values. The concentrations and doses of these radionuclides were greatest in the Columbia River from 1950–1971. Because of community concern, this health assessment will further evaluate these substances.

Game. For game animals, such as deer, elk, and rabbits, concentrations of most radionuclides were below ATSDR screening values. Strontium-90 was found above selection criteria in the bones and antlers of rabbits and mule deer. The animal parts could be potentially used to make meat stock by future subsistence dwellers. This exposure pathway will be further evaluated.

Fish. No fish-borne contaminants are currently found above background levels. In a reconstruction of historic doses, the HEDR project investigated the five radionuclides identified above in the Columbia River between 1950 and 1971 for their doses to fish consumers by. This reconstruction was further refined by the Risk Assessment Corporation. Both reconstructions are reviewed in Chapter 8.

Plants. Vegetation contaminated with antimony, barium, and manganese will be further evaluated. The use of yarrow and other medicinal plants is further evaluated because of uranium-238 uptake (bioconcentration). Plutonium-239/240, cesium-137, and cobalt-60 were found in bird nests and tumbleweed, but not in a complete pathway to man. Nevertheless, because of the communities' concern these radioisotopes are discussed in Chapter 8. Strontium-90 was found in mulberries above screening values and will be evaluated further.

Soil and Sediment. Soil contamination in the 300-Area could be a potential source of exposure. Because of traditional cultural practices Native Americans are the groups considered most likely to come in contact with soil contamination among the persons who could use the 300-Area land in the future. Specific substances selected for further evaluation because of their concentration in soil include arsenic, lead, and silver. In 1991 uranium isotopes in the 300-Area were

remediated to below their screening values. Cesium-137, cobalt-60, neptunium-237, strontium-90, and plutonium-239/240 were found in soil or sediment in completed soil exposure pathways, but not above their screening values. Because of the communities' concerns these radioisotopes are discussed in Chapter 8.

Table 7-0. Contaminants Selected for Further Evaluation

Substance	Air	Columbia River	Plants and Animals	Soil and Sediment
Antimony			√	○
Arsenic		√		○
Barium			√	○
Cesium-137*		○	○	np
Cobalt-60		○	np	np
Iodine-131	√			
Ionizing Radiation*		○		
Lead		√	○	√
Manganese			√	○
Plutonium*	○		np	np
Silver				√
Strontium-90		√	√	np
Tritium		√		
Uranium		√	√	○

√ = above screening value in an exposure pathway
○ = below screening value in an exposure pathway
np = not found in an exposure pathway (i.e., no pathway)
* Cesium-137, ionizing radiation (As-76, P-32, Np-239, Na-24, Zn-65), and plutonium were selected for further evaluation even though they did not exceed screening values.

7.1 Exposure Evaluation Process

ATSDR's exposure evaluation process considers three factors, 1) are the environmental media contaminated, 2) are persons exposed to the contaminants, and 3) for each exposure pathway, will the contamination affect public health.

ATSDR's Exposure Evaluation Process

For a public health concern to exist, the following three conditions must all be met

1. Contaminants must exist in the environmental media.
2. Persons must come in contact with areas that have potential contamination.
3. The amount of contamination must be sufficient to affect a person's health.

Are contaminants present in the environmental media?	**Are persons in contact with areas that have potential contamination?**	**Is the amount of contamination sufficient to affect a person's health?**
ATSDR considers soil, groundwater, surface water, sediment, air, food sources	For exposure to occur, contaminants must be in locations where persons can contact them. Persons may contact contaminants by any of the following three exposure routes: inhalation, ingestion, and dDermal absorption.	ATSDR evaluates existing data on contaminant concentration and exposure duration and frequency. ATSDR also considers individual characteristics, such as age, gender, and life style, of the exposed population that may influence the public health effects of contamination.

7.1.1 Contaminated Environmental Media

Chapter 3, *Sources of Contamination,* describes how contamination occurred at Hanford, which local areas are contaminated, and what kinds of and how much contamination is present. Since the Hanford Nuclear Reservation began operating in the 1940s, the Site's production and waste disposal operations and contaminated the environment — including the local soil, groundwater, surface water, sediment, and air. The tables at the end of Chapter 4 list the contaminants found in each environmental media.

Much of the data reviewed by ATSDR was provided by the U.S. Department of Energy (DOE), the City of Richland, and the Washington State Department of Health (WADOH). The DOE data were obtained from documents that were previously reviewed by the U.S. Environmental Protection Agency (EPA), the Washington State Department of Ecology (WADOE), and (in some cases), by the WADOH to ensure reliability of the information sources. Another major source of information, estimated source terms and doses, was the Hanford Environmental Dose Reconstruction (HEDR) Project.

The Agency requested data from each of these sources. All requested data were provided, and no data or document requests were refused by DOE, by the City of Richland, or by the State of Washington. The availability of DOE data was greatly facilitated by the HEDR project and by the public's Freedom of Information Act requests that resulted in the declassification of thousands of documents.

Data from private organizations, such as the Hanford Education Action League, was also considered whenever such organizations felt individual privacy would not be violated.

7.1.2 Exposure Pathways

ATSDR considered the potential for past, current, and future exposures to the environmental contamination. Chapters 4, 5, and 6 discuss the pathways and the target exposure populations for each time period.

Each environmental medium (e.g., air, surface water, groundwater, etc.) was evaluated to determine if people would come in contact with the contaminants through ingestion, dermal absorption, inhalation, or whole body exposure. Table 7-1 lists the contaminants in the environment, but that ATSDR believes will not result in human exposure.

Target populations for each exposure were then identified. Unique factors that would influence extent or duration of exposure were also identified. For example, Native American Indians would have more exposure to contaminants associated with the Columbia River. Another example is children who drank goat's milk during 1945–1952, when the most of air releases occurred which contained higher doses of iodine-131.

7.1.3 Potential for Health Effects

If the potential for exposure exists, ATSDR then considers whether the contaminants are at levels that might affect public health. ATSDR does this by comparing contaminant concentrations against screening values. The screening values are concentrations not expected to cause adverse health effects, regardless of the extent or duration of exposure. Table 7-2 lists contaminants that are below their screening value and therefore not expected to cause adverse health effects.

Contaminant concentrations above their screening values are further evaluated in Chapter 8, *Health Implications*. Factors other than the screening value, such as multi-media exposures, interaction effects, or community health concerns, may be considered. Therefore, some chemicals with concentrations below their screening values are discussed in Chapter 8.

7.1.4 Determining Screening Values

The agency recognizes that not all scientists agree on screening levels. Some would prefer higher levels, other scientists would prefer lower or no screening levels. The Hanford Health Effects Subcommittee requested that the public health assessment describe how ATSDR determined its screening values. The HHES thought that readers would want to know the science from which ATSDR's screening values were based on.

Screening values are media-specific chemical concentrations used to select contaminants for further evaluation in a public health assessment.

Because contaminants can cause both cancerous and non-cancerous effects, ATSDR has developed two sets of screening values.

For carcinogens, an ATSDR screening value known as a cancer risk evaluation guide (CREG) is derived from EPA's cancer slope factors. The CREG corresponds to the dose, over a 70-year lifetime, that would result in a 1 in a million increased risk of cancer.

For non-carcinogenic effects, ATSDR has developed environmental media evaluation guidelines (EMEGs). ATSDR EMEGs are based on the minimal risk levels (MRLs) presented in the ATSDR toxicological profiles. EMEGs have been developed for inhalation and ingestion, for both adults and children, and for chronic, intermediate and acute exposures.

When a toxicological profile (and therefore an MRL) is not available for a chemical, ATSDR uses EPA's reference doses (RfD) and reference

concentrations (RfC) to determine reference dose media evaluation guides (RMEG). RfD's are for inhalation and RfC's are for ingestion.

Besides its own screening values, ATSDR uses health guidelines established by other agencies and organizations. For example, ATSDR considers EPA's drinking water standards' maximum contaminant level (MCL), maximum contaminant level goal (MCLG), proposed maximum contaminant level goal (PMCG), and life-time health advisory (LTHA). For essential nutrients, ATSDR uses the published upper tolerable limit, taken, for example, from <http://books.nap.edu/books/0309071836/html/116.html#pagetop> for phosphate, and <http://books.nap.edu/books/0309072794/html/224.html#pagetop> for copper. ATSDR's media evaluation guidelines make conservative assumptions about intake, e.g., the child UTL-MEG for water is calculated from the UTL by assuming a 10-kg child consumes 1 liter of water daily and the oral soil UTL-MEG for children by assuming the child ingests 200 mg of soil daily.

ATSDR also uses guidelines developed by EPA for its Superfund program, including action levels and soil screening values. For example, the action level for lead in water is that concentration which, if exceeded in more than 10% of homes, triggers treatment of a water supply. For lead in soil, EPA relies on its integrated uptake/biokinetic (IU/BC) model for the relationship between soil and blood-lead concentrations to protect children under 6 years old.

7.1.5 Provisional Consumption Rates

The Agency has no standard consumption rates for fish, game, or vegetation. Therefore, provisional consumption rates are generated for each site.

Estimated daily consumption rates

Category	Surrogate	Adult	Child
fish	fish	6 ounces	1.5 ounces
meat	mouse	8 ounces	1 ounce
vegetation	mulberry	16 ounces	2 ounces
herbs	yarrow	2 ounces	0.5 ounce

For the Hanford Site, ATSDR assumed that adults would ingest no more than ½ pound of meat, fish, or poultry daily from the Site (see box). We assumed a 10-kg (1- year old) child might eat as much as 1½ ounces of fish taken from the Hanford Reach of the Columbia River and up to 1 ounce of game meat taken from the Site.

Some data show that tribal members 18 years and older in the Columbia Basin ingest an average of 2 ounces of fish daily. This value can be compared to the

¼ ounce daily fish consumption rate for the average American adult (CRITFC 1994). Tribal children under 5 years of age consume an average of about 2/3 ounce per day (CRITFC 1994).

The Agency assumed that 1 pound of local vegetation could be consumed daily by adults, and that ¼ cup could be consumed daily by 1-year-old children. For yarrow, a sampled medicinal herb, the Agency assumed that the daily intake prepared from 2 ounces of the fresh plant was 1 tablespoon dried yarrow for hot water extracts or up to 4 teaspoons of yarrow juice (Lust 1974). A year-old child's dosage, prepared from ½ ounce of the fresh plant, would be about a teaspoon dried yarrow in hot water or up to 1 teaspoon of yarrow juice.

For non-radioactive substances and for uranium, whose principal health effects are from its chemical properties, screening values are estimated from site-specific intake parameters. Mulberry parts were considered representative of fruit and vegetables, mouse carcasses could be a surrogate for game consumption, and yarrow daily might typify medicinal herbs.

7.1.6 Screening Values for Radionuclides

Toxicological profiles, reference concentrations, and reference doses are not available for many radionuclides. Therefore, ATSDR based screening values for radionuclides on information from other sources, including EPA, DOE and the National Research Council (NRC).

ATSDR also used recommendations from the National Council on Radiation Protection and Measurements (NCRP), the International Commission on Radiological Protection (ICRP), and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). The potential for increased biological response of some population groups to radiation was also considered.

For radioactive substances in this public health assessment, ATSDR screened soil contamination using the National Council on Radiological Protection and Measurement's (NCRP) Report No. 129 (1999), for contamination levels associated with a dose equivalent of 25 mrem per year under conditions of commercial or industrial use. We screened water contamination using EPA MCLs based on an annual whole-body dose equivalent of 4 mrem. For radioisotopes without listed MCLs, we calculated the concentrations in water associated with an annual whole-body dose equivalent of 4 mrem. For potentially ingested biota, we screened contamination using Federal Guidance Report 13 (EPA 402R-99-001). Intakes were based on a potential whole-body dose equivalent of 25 mrem estimated for a 10-kg, one-year-old child consuming one quarter cup (55 grams)

of each fruit or vegetables per day (e.g., mulberry parts or asparagus), ¼ pound (119 grams) dried birdnest or tumbleweed per week in soups, 1 ounce (30 grams) per day of subsistence game (rabbit muscle), 48 grams per day of subsistence fish, 10 grams bones or antlers daily as soup or stew thickeners, 1 gram dried algae daily as a food supplement, and 100 milligram (mg) incidental ingestion of rodent or rabbit feces scattered on surface soil.

7.2 Contaminants Eliminated

Tables 7-1 and 7-2 list the substances that were present in each environmental media that ATSDR determined are not a health concern. The tables identify the contaminant, the maximum concentration where the maximum concentration was found, and the screening value that ATSDR used. If the reason a substance was determined to not be a health hazard was the absence of an exposure pathway to man, the substance is listed in Table 7-1. If the substance was found in an exposure pathway but not above its selection value in any medium, it was listed in Table 7-2.

Many 100-Area contaminants were eliminated from the report because 100-Area groundwater contamination is not a current or future public drinking-water source.

Although radioactive materials and chemicals will continue to be stored in the 200-Area, public access is restricted; therefore, many 200-Area contaminants were eliminated from the report.

DOE's Remedial Investigation Report summarized the measured concentrations in mulberry leaves and twigs for stable elements (aluminum, antimony, barium, beryllium, cadmium, chromium-III and -VI, copper, iron, manganese, nickel, silver, and zinc) and for the radioactive species uranium and strontium-90 (DOE 1993b). Analyses of perennial vegetation and milfoil for cesium-137 (Cs-137), cobalt-60 (Co-60, europium-154 (Eu-154), technetium-99 (Tc-99), strontium-90 (Sr-90), uranium-234 (U-234), and uranium-238 (U-238) were compiled during review of the Screening Assessment for the Columbia River Comprehensive Impact Assessment (DOE 1997a).

The Columbia River Comprehensive Impact Assessment contained data for clams, carp, suckers, rainbow trout, and whitefish. The fish were analyzed for Cs-137, Co-60, Eu-154, Tc-99, U-234, and U-238 (DOE 1997a). Nonradioactive substances that were analyzed included barium, cadmium, chromium, copper, lead, manganese, nickel, zinc, 1,1-dichloro-2,2'-bis(p-chloro-phenyl)ethylene

(DDE, a metabolite of DDT), and Aroclors. All these analytes were found to be below detection limits.

7.3 Contaminants Selected for Further Evaluation

This section describes concentration levels for radioactive and chemical contaminants that exceeded ATSDR's screening values. Contaminants exceeding these screening values were further evaluated to determine their potential to reach humans and become a potential concern to human health.

Table 7-3 lists contaminants present at the Hanford Site that exceeded their screening value. The tables also show the maximum concentration detected, as well as background concentrations.

7.3.1 Air

The HEDR project identified contaminants released to the environment during the early years of Hanford operations. The primary contaminant released to the air was iodine-131 (I-131) from the 200-Area during the period 1945 through 1951.

Community members have expressed concern that Hanford is not the only source of I-131. Residents were exposed to radionuclides released from other nuclear weapons production facilities and to fallout from the Nevada Test Site, the Marshall Islands and from world-wide fallout from nuclear weapons testing. At this time there is no a mechanism for individuals to estimate their approximate lifetime dose equivalent from all possible sources of I-131.

In recent sampling, plutonium-239/240 was detected (0.000281 pCi/L) in 200-Area stacks. Although this is below its screening value of 81 pCi/L, plutonium is evaluated in this public health assessment because of community health concerns.

7.3.2 Columbia River

The HEDR project identified the five most important contaminants released to the Columbia River that contribute to human dose as arsenic-76, neptunium-239, phosphorus-32, sodium-24, and zinc-65 (TSP 1994). These radionuclides have been included in the list of contaminants in the Columbia River selected for further evaluation.

HEDR's dose estimates incorporated specific measurement data for the Columbia River during the period when the greatest Hanford releases took place (primarily 1950–1971). HEDR estimated annual radiation doses from drinking Columbia

River water to be a few millirem (TSP 1994 [p. 47]). This reconstruction was further refined by the Risk Assessment Corporation, which took additional substances, such as iodine-131 and strontium-90, into consideration (Risk Assessment Corporation 2002). The two reconstructions and health implications are discussed Chapter 8 of this public health assessment.

Seeps and Springs

In the 100-Area, contaminated groundwater near the reactors seeps into the Columbia River. Lead concentrations in one seep was above drinking water standards.

Because lead seeps into the Columbia River and the City of Richland draws its drinking water from the River, water is sampled at the nearest Columbia River intake point. Lead was below detection limit at that point.

Activity levels of strontium-90 in groundwater are over 80 million pCi/L; seeps in the N-Springs area were 11,000 pCi/L, and strontium-90 was not detected a few yards downstream in the Columbia River (DOE 1997a).

The activity levels of tritium are similar to levels of strontium-90. The maximum level—more than three billion pCi/L—was reported for a groundwater sample taken near the 100-K reactor. The most tritium-contaminated seep was 173,000 pCi/L at the oldHanford Townsite; tritium at the Richland Pump-house intake was below 200 pCi/L (McBaugh 1996).

7.3.3 Fish and Game

The HEDR project concluded that radiation doses from releases to the Columbia River were highest from 1956 through 1965, peaking in 1960. The most important fish pathway was the consumption of nonmigratory fish from the Columbia River during the years of releases, a particular concern to Native Americans. The HEDR scientists identified five radionuclides (sodium-24, phosphorus-32, zinc-65, arsenic-76, and neptunium-239) that together contributed 94% of the total estimated dose to people by the river pathway.

ATSDR funded a review of HEDR data by SENES, Inc. (Oak Ridge, Tennessee) to determine whether the Columbia River data could be used to establish eligibility for a medical monitoring program. SENES, Inc. estimated radiation doses from eating contaminated fish and waterfowl along the Columbia River during the period of peak releases. The SENES, Inc. analysis found that additional study would be needed before doses could be calculated for Native American dietary lifestyles. Specifically, the report recommended that three other

radionuclides should be considered: 1) iodine-131 because dose is age-dependent, with children being more sensitive, 2) cobalt-60 because it accumulates in soil and sediment, and 3) strontium-90 because it accumulates in fish skeleton (assuming persons only ate filleted fish did not account for exposure if they also ingested the fish bones).

NCEH funded a contract to complete additional work on the Columbia River dose reconstruction model. The contractor, Risk Assessment Corporation, submitted a final report, entitled *A Risked-based Screening Analysis for Radionuclides Released to the Columbia River from Past Activities at the U.S. Department of Energy Nuclear Weapons Site in Hanford Washington*, to CDC. The CDC published this report in November, 2002. Native Americans and others whose diets included fish from the Columbia River between 1956 and 1965 were interested in the new model parameters used to estimate radiation doses. The model included the 11 radionuclides for which HEDR had source term estimates, plus others, including cobalt-60 and strontium-90 for which HEDR did not provide source term estimates. In all, the study examined 23 radionuclides in two levels of screening and estimated risks based on scenarios involving three types of Columbia River users: Native American, local resident, and migrant worker.

The NCEH study results did not support the SENES, Inc. claim that the HEDR Project should have made dose calculations for iodine-131 and strontium-90. If further evaluation of risks from radionuclides released to the Columbia River is to be undertaken, the following four radionuclides will be the most important for dosimetric analysis: arsenic-76, neptunium-239, phosphorus-32, and zinc-65; the following four radionuclides will be of moderate priority: sodium-24, zirconium-95, cobalt-60, and cesium-137. Iodine-131, iodine-133, strontium-90, strontium-89, gallium-72, scandium-46, and yttrium-90 will continue to be of low priority because they contribute only a negligible component to the whole-body radiation dose equivalent.

Because some Hanford lands along the Columbia River could be returned to traditional tribal use in the future, the Agency considered current contamination in meat and fish that might be consumed by people. Agency scientists reviewed published summaries of contaminants in game at the Hanford Site.

Typical game animals at the Hanford Site would include deer, elk, and rabbits. Measurements of radionuclide concentrations in meat from these game animals were found to be below ATSDR screening values and less than the comparison values reported in the Remediation Investigation Report and the Columbia River Comprehensive Impact Assessment (DOE 1993b, 1997a).

The Department of Energy provided measurement data for tissue samples obtained from mice and other rodents (DOE 1993b). Lead was selected for further evaluation.

7.3.4 Plants

Under current practice and probable future industrial or agricultural use at the Hanford Site, persons are not expected to ingest Hanford Site vegetation. The Agency, however, evaluated plant data from the standpoint that land areas would return to Native Americans for traditional tribal use. The Agency further assumed that tribal members would return to ancient practices — and perhaps also subsist to some degree on the local plants, fruits, and vegetables — and that wild herbs, such as yarrow, would be used for medicinal purposes.

Three nonradioactive substances reported in mulberry plants were selected for further evaluation. They are antimony, barium, and manganese. One radioactive substance, uranium, was selected for further evaluation based on its content in yarrow.

7.3.5 Soil and Sediment

The 300-FF-1 Operable Unit was a waste disposal site for the 300-Area research complex. The nonradioactive substances in Table 7-3 were reported in the Phase I Remedial Investigation Report for Operable Unit 300-FF-1 (DOE 1992b, [Appendix B]).

ATSDR's exposure analyses for the 300-Area assumed that the Area would be used for current industrial activities and future access by Native American tribes. Industrial workers were assumed to be indoors 30 hours and outdoors 10 hours each workweek (McLeod 1995; DOE 1995e; DOE et al. 1996).

Contaminated soil in the 300-Area, if not completely remediated, could represent a source of exposure to future inhabitants of the Hanford Site.

Because Native Americans could use these lands for subsistence, values for elements such as barium, manganese, and silver are included in Table 7-3. Comparison values for children are included.

Arsenic (listed in Table 7-3) is not a product or byproduct of Hanford or other activities of man; rather, it occurs naturally in regional soils (Dragun and Chiasson 1991). Copper was found in at a higher level than background but below

its screening value (Dragun and Chiasson 1991). Lead was selected for further evaluation even though its concentration is similar to that naturally present in regional soils (Dragun and Chiasson 1991).

The principal radioactive material found in the 300-Area soils was uranium (DOE 1992b, [Appendix B]) (Wolbarst et al. 1996). Even though the uranium in 300-Area soils consisted mainly of uranium in insoluble oxide forms, the screening values for uranium were based on the assumption that the uranium present existed in a soluble, rather than insoluble form, and that the chemical toxicity of soluble uranium was limiting over the potential radiological toxicity. These assumptions hold because processed uranium is typically a mixture of soluble and insoluble compounds, and prior studies have shown that chemical toxicity is more limiting for mixtures than is the radiological toxicity. The toxicological significance of the solubility of uranium is discussed in Chapter 8.

ATSDR screened soil for radioactive contaminants using the National Council on Radiation Protection and Measurement's (NCRP) Report No. 129 (1999) for contamination levels associated with a whole-body radiation dose equivalent of 25 mrem per year under conditions of commercial or industrial use.

7.3.6 Abbreviations

In the data tables that follow, a large number of different chemical and radioactive contaminants are listed. The data tables include the following abbreviations and acronyms.

pCi/g	picocuries per gram, or 0.037 Bq/g
pCi/L	picocuries per liter, or 0.037 Bq/L
ppb	parts per billion
ppm	parts per million

Abbreviations for screening values sources

CREG	cancer risk evaluation guide
EMEG	environmental media evaluation guide
MCL	maximum contaminant level
mrem/y	millirem per year. We set a limiting dose equivalent and used media- and site-specific tools to estimate a concentration in a medium associated with that dose equivalent based on site-specific conditions and usage. For screening tools, conditions,

	and limiting doses used for radioactive substances in this public health assessment, see Section 7.1.6.
RMEG	reference dose (or concentration) media evaluation guide
UTL	upper tolerable limit (for an essential nutrient)
UTL-MEG	upper tolerable limit media evaluation guide

Table 7-1. Contaminants Eliminated — May be above screening values, but not in exposure pathway						
Contaminant	**Maximum Concentration**	**Units**	**Screening Value**	**Screening Value Source**	**Location**	**Description**
Air — All contaminants considered in a potential exposure pathway.						
Surface water — All contaminants considered in a potential exposure pathway.						
Groundwater* All groundwater contaminants considered in an incomplete exposure pathway						
Carbon-14	23,000,000	pCi/L	2,550	MCL (4 mrem/year)	100K-Area	monitoring well
Cesium-137	10,500	pCi/L	109	MCL (4 mrem/year)	100N-Area	monitoring well
Cesium-137	18	pCi/L	109	MCL (4 mrem/year)	200-Area upper aquifer	monitoring well
Cobalt-60	34,600	pCi/L	435	MCL (4 mrem/year)	Hanford town site	monitoring well
Europium-154	12,000	pCi/L	720	MCL (4 mrem/year)	Hanford town site	monitoring well
Iodine-129	50	pCi/L	14	MCL (4 mrem/year)	200-Area, upper aquifer	monitoring well
Iodine-129	911	pCi/L	14	MCL (4 mrem/year)	300-Area	monitoring well
Strontium-90	83,500,000	pCi/L	53.7	MCL (4 mrem/year)	100N-Area	monitoring well
Technetium-99	2,750,000	pCi/L	2,310	MCL (4 mrem/year)	100H-Area	monitoring well
Tritium	3,324,000,000	pCi/L	77,200	MCL (4 mrem/year)	100K-Area	monitoring well
Tritium	378,000	pCi/L	77,200	MCL (4 mrem/year)	200-Area upper aquifer	monitoring well
Uranium-234	90,400	pCi/L	20	MCL (4 mrem/year)	300-Area	monitoring well
Uranium-238	210,000	pCi/L	33	MCL (4 mrem/year)	300-Area	monitoring well
Ammonia	1,520	ppb	3,000	Intermediate Child EMEG	100D-Area	monitoring well
Antimony	47	ppb	4	child RMEG	300-Area	monitoring well
Arsenic	15	ppb	10	MCL	300-Area	monitoring well
Benzene	31	ppb	40	Child RMEG	300-Area	monitoring well
Chromium	2,500	ppb	20,000	Child RMEG, chromium-III	100K- Area	monitoring well

Table 7-1. Contaminants Eliminated—May be above Screening Values, But Not in Exposure Pathway *(Continued)*

Contaminant	Maximum Concentration	Units	Screening Value	Screening Value Source	Location	Description
cis + *trans* 1,2-Dichloroethene	180	ppb	3,000 *(cis)* 2,000 *(trans)*	Intermediate Child EMEG	300-Area	monitoring well
Cyanide	21.1	ppb	200	Chronic Child EMEG	300-Area	monitoring well
Carbon tetrachloride	6,000	ppb	5	MCL	200-Area, T&Z plants	monitoring well
Chloroform	1,595	ppb	100	Child EMEG	200-Area, T&Z plants	monitoring well
Copper	2,900	ppb	1,000	Child UTL-MEG	100K-Area	monitoring well
Cyanide	1,690	ppb	200	Child RMEG	200-Area, BP-1	monitoring well
Fluoride	5,000	ppb	4,000	MCL	200-Area, tank farms	monitoring well
Lead	280	ppb	15	EPA Action Level	100N-Area	monitoring well
Manganese	333	ppb	1,500	Child RMEG	300-Area	monitoring well
Mercury	0.62	ppb	3	Child RMEG	100K- Area	monitoring well
Nickel	206	ppb	200	Child RMEG	300-Area	monitoring well
Nickel	3,300	ppb	200	Child RMEG	100K-Area	monitoring well
Nitrate	559,000	ppb	20,000	Child RMEG	200-Area, BP-1	monitoring well
Nitrate	1,160,000	ppb	20,000	Child RMEG	100H-Area	monitoring well
Phosphate	11,000	ppb	5,000,000	Child UTL-MEG	100N- Area	monitoring well
Selenium	27	ppb	50	Child EMEG	200-Area, BP-1	monitoring well
Trichloroethylene	24.3	ppb	5	MCL	200-Area, T&Z plants	monitoring well
Trichloroethylene	16	ppb	5	MCL	300-Area	monitoring well
Vanadium	38	ppb	30	Child RMEG	200-Area, BP-1	monitoring well
Xylenes (total)	10	ppb	2,000	Intermediate child EMEG	100B–C-Area	monitoring well
Zinc	21,000	ppb	3,000	Chronic child EMEG	100F-Area	monitoring well

Table 7-1. Contaminants Eliminated—May be above Screening Values, But Not in Exposure Pathway *(Continued)*

Contaminant	Maximum Concentration	Units	Screening Value	Screening Value Source	Location	Description
Surface Water (Columbia River) — All contaminants considered in a potential exposure pathway.						
Fish, Game, and Vegetation †						
Cesium-137	760,000	pCi/g	15,000	25 mrem/year	200-Area near semi-works	dry mouse feces, 1987
Cesium-137	3,240	pCi/g	88	25 mrem/year	200-Area West, basin 207-T	tumbleweed, 1986
Cesium-137	22	pCi/g	88	25 mrem/year	200-Area West, pond 216U-10	tumbleweed, 1991
Cobalt-60	85	pCi/g	41	25 mrem/year	202-A railroad cut	bird nest, 1987
Europium-154	3,110	pCi/g	15,000	25 mrem/year	200-Area near semi-works	dry mouse feces, 1987
Europium-155	3,890	pCi/g	84,500	25 mrem/year	200-Area near semi-works	dry mouse feces, 1987
Plutonium-239	1.0	pCi/g	2.58	25 mrem/year	200-Area near semi-works	bird nest, 1987
Plutonium-239	15	pCi/g	2.58	25 mrem/year	200-Area east northeast	tumbleweed, 1990
Strontium-90	22	pCi/g	15	25 mrem/year	200-Area West, pond 216U-10	tumbleweed, 1991
Strontium-90	55,700	pCi/g	2,500	25 mrem/year	231-Z fence line	dry rabbit feces, 1987
Strontium-90	3,243,000	pCi/g	15	25 mrem/yr	200-Area West, 216-BC crib	tumbleweed, 1981
Soil and Sediment ‡						
Americium-241	2,500,000	pCi/g	12.7	25 mrem/y	200-Area under 216-Z-1A Crib	Subsurface soil:
Cesium-137	6,378,000	pCi/g	12	25 mrem/yr	200-Area, By Crib	subsurface soil
Cesium-137	140	pCi/g	12	25 mrem/year	200-Area West	surface soil
Cesium-137	4,600	pCi/g	12	25 mrem/year	Columbia River	sediment
Cobalt-60	4,970	pCi/g	2.68	25 mrem/yr	Seep 091-2	sediment
Europium-152	1,800	pCi/g	8,000	25 mrem/year	Columbia River	sediment
Europium-154	265	pCi/g	8,000	25 mrem/year	Columbia River	sediment
Neptunium-237	605	pCi/g	0.087	25 mrem/yr	Columbia River	sediment
Plutonium-239/240	40,000,000	pCi/g	12.7	25 mrem/yr	200-Area, 216-Z1A crib	subsurface soil

Table 7-1. Contaminants Eliminated—May be above Screening Values, But Not in Exposure Pathway *(Continued)*

Contaminant	Maximum Concentration	Units	Screening Value	Screening Value Source	Location	Description
Plutonium-239/240	3.2	pCi/g	12.7	25 mrem/year	200-Area West	surface soil
Strontium-90	6.5	pCi/g	838	25 mrem/year	200-Area West	surface soil
Strontium-90	730,000	pCi/g	838	25 mrem/yr	200-Area, BY crib	subsurface soil
Strontium-90	207,000	pCi/g	838	25 mrem/yr	Seep 090-1	sediment
Technetium-99	500	pCi/g	35,100	25 mrem/year	Columbia River, Richland	sediment
Uranium-234	2,570	pCi/g	105	25 mrem/year	Seep 110-1	sediment
Uranium-238	8,810	pCi/g	105	25 mrem/year	Columbia River	sediment
Antimony	15	ppm	20	Child RMEG	300-Area, S. Process Pond	subsurface soil
Benzene	0.000224	ppm	10	Oral CREG	Columbia River, west channel	sediment
Cyanide	248.5	ppm	1,000	Oral RMEG child	300-Area, BY crib	subsurface soil
Nickel	52.4	ppm	1,000	Oral RMEG child	100-F slough	sediment
Nitrate	2.76	ppm	80,000	Oral child RMEG	Columbia River, downstream of Strawberry Island	sediment
PCBs	16.3	ppm	0.4	Oral CREG	300-Area, N. Process Pond	subsurface soil
Phosphate	8	ppm	5,000,000	UTL-MEG	Lake Wallula	sediment
Xylenes (total)	0.00143	ppm	10,000	Interim child EMEG	100-F Slough	sediment

* Groundwater. Volume II: Appendices, DOE (1997a), and Westinghouse (1992b, 1995a, 1995c), and DOE (1992a, 1993a, 1995b).

† Fish, game, vegetation. Bird nest, mouse, rabbit feces, Westinghouse (1987), tumbleweed, Appendix A, Johnson (1994), mulberry, DOE (1993b), fish, DOE (2002); all others, Volume II, Appendices, DOE (1997a). For intake assumptions, see footnotes c and d of Table 4D.

‡ Soil and Sediment. 100-Area from Volume II, Appendices DOE (1997a), 200-Area data from DOE (1993c), 300-Area data from DOE (1992b).

Table 7-2. Contaminants Eliminated — Below Screening Values						
Contaminant	**Maximum Concentration**	**Units**	**Screening Value**	**Screening Value Source**	**Location**	**Description**
Air — All contaminants eliminated, other than iodine-131 released between 1945 and 1972.						
Surface Water *						
Technetium-99	330	pCi/L	2,310	MCL (4 mrem/year)	North of 300-Area	
Mercury	0.22	ppb	3	Child RMEG	100H-Area seep	not at Richland intake
Nitrate	5.5	ppb	20,000	Child RMEG	100-H, Seep 110-1	not at Richland intake
Zinc	261	ppb	3,000	EMEG	100H-Area, Seep 149-1	not detected at intakes
Groundwater † All groundwater contaminants are considered to be in an incomplete exposure pathway						
Game, Fish, and Vegetation ‡						
Europium-152	13	pCi/g	2,500	25 mrem/year	Hanford town site	dry algae, 6/24/1992
Cadmium	0.60	ppm	1.76	provisional	300-Area	mulberry leaves & stems
Chromium	15	ppm	176	provisional	300-Area	mulberry, 1992
Zinc	32	ppm	52	provisional	300-Area	mulberry leaves & stems
Soil and Sediment §						
Beryllium	1.9	ppm	100.0	Chronic Child EMEG	300-Area, process trenches	surface soil
Cadmium	23	ppm	50	Oral Child RMEG	300-Area, sanitary trenches	surface soil
Chromium	177	ppm	80,000	Child RMEG chromium-III	300-Area, process trench	surface soil
cis + *trans* 1,2-Dichloroethene	1	ppm	20,000 (*cis*) 10,000 (*trans*)	Intermediate child EMEG	300-Area, process trench	surface soil
Mercury	4.1	ppm	20.0	Oral child RMEG	300-Area, sanitary trenches	surface soil
PCBs	0.323	ppm	0.40	Oral CREG	300-Area, north process pond	surface soil

Table 7-2. Contaminants Eliminated — Below Screening Values *(Continued)*

Contaminant	Maximum Concentration	Units	Screening Value	Screening Value Source	Location	Description
Trichloroethylene	0.15	ppm	60	Oral CREG	300-Area, process trenches	surface soil
Vanadium	176	ppm	200	Intermediate child EMEG	300-Area, process trenches	surface soil
Vinyl chloride	0.031	ppm	0.50	Oral CREG	300-Area, process trenches	surface soil
Zinc	3,830	ppm	20,000	Chronic oral child EMEG	300-Area, sanitary trenches	surface soil

* Volume II: Appendices of DOE (1997a), WADOH (1993), DOE (1993b), and CRITFC (1994).
† Surface water. Groundwater. Volume II: Appendices from DOE (1997a), Westinghouse (1992b, 1995a, 1995c), and DOE (1992a, 1993a, 1995b).
‡ Game, fish, vegetation. Bird nest, mouse, rabbit feces, Westinghouse (1987), tumbleweed, Appendix A, Johnson (1994), mulberry, DOE (1993b), fish, DOE (2002); all others, Volume II, Appendices, DOE (1997a). For intake assumptions, see footnotes c and d of Table 4D.
§ Soil and sediment. 100-Area from Volume II, Appendices from DOE(1997a), 200-Area data from DOE (1993c), 300-Area data from DOE (1992b).

Table 7-3 Contaminants Selected for Further Evaluation						
Contaminant	**Maximum Concentration**	**Units**	**Screening Value**	**Screening Value Source**	**Location**	**Description**
Air *						
Iodine-131	approximately 740,000 curies (Ci) released 1945–1972; 0.0014 Ci 1990					
Plutonium239/240	0.0000281	pCi/L	81	EPA FGR13 & EPA EFH	200-East Area, 291 A stack	average concentration 1991
Surface Water (Columbia River) †						
Arsenic-76	736	pCi/L	923	MCL (4 mrem/year)	near Richland	average 1944–1971
Cesium-137	3.2	pCi/L	109	MCL (4 mrem/year)	100-K Spring	found only in springs
Cobalt-60	92	pCi/L	435	MCL (4 mrem/year)	100-N Spring 8-13	found only in springs
Europium-154	13	pCi/L	720	MCL (4 mrem/year)	100-N Spring 8-13	only at springs
Neptunium-239	1,800	pCi/L	1,860	MCL (4 mrem/year)	near Richland	average 1944–1971
Phosphorous-32	130	pCi/L	616	MCL (4 mrem/year)	near Richland	average 1944–1971
Sodium-24	22.2	pCi/L	3,400	MCL (4 mrem/year)	near Richland	average 1944–1971
Strontium-90	10,900	pCi/L	53.7	MCL (4 mrem/year)	Seep 8-13 near 100-N Spring	now found only in seeps, springs
Strontium-90	1.27	pCi/L	53.7	MCL (4 mrem/year)	Richland	average 1944–1971
Tritium	173,000	pCi/L	77,200	MCL (4 mrem/year)	Old Hanford town site, Spring 28-2	above MCL only at springs/seeps
Tritium	< 200	pCi/L	77,200	MCL (4 mrem/year)	Columbia River	split sample with DOE & WADOE
Uranium-234	65	pCi/L	20	MCL (4 mrem/year)	300-Area Spring 42-2	Only detected at springs
Uranium-238	58	pCi/L	33	MCL (4 mrem/year)	300-Area Spring 42-2	Only detected at springs
Gross alpha	<4	pCi/L	20	MCL (4 mrem/year)	Richland Pump-house intake	Surrogate for total uranium
Zinc-65	213	pCi/L	375	MCL (4 mrem/year)	near Richland	average 1944–1971
Arsenic	3	ppb	10	MCL	300-Area spring	only detected in springs

Table 7-3 Contaminants Selected for Further Evaluation *(Continued)*

Contaminant	Maximum Concentration	Units	Screening Value	Screening Value Source	Location	Description
Lead	17.2	ppb	15	EPA action level	100H-Area, seep 146-1	only detected in seeps
Lead	<2	ppb	15	EPA action level	Richland water intake	below detection limits
Nickel	130	ppb	200	Child RMEG	100BC-Area, seep 037-1	not detected at intakes
Nickel	<2	ppb	200	Child RMEG	Richland water intake	below detection limits
Groundwater[‡] All groundwater contaminants considered in an incomplete exposure pathway						
Game, Fish, and Vegetation[§]						
Cesium-137	20	pCi/g	24.6	25 mrem/year, provisional	Hanford town site	dry asparagus, 5/14/1990
Cesium-137	10	pCi/g	1,500	25 mrem/year, provisional	Hanford town site	dry algae, 6/24/1992
Cesium-137	0.04	pCi/g	31	25 mrem/year, provisional	Columbia River, Hanford reach	fish
Cobalt-60	14	pCi/g	23.1	25 mrem/year	100N-Area	cottontail rabbit muscle, 7/11/1991
Cobalt-60	12	pCi/g	690	25 mrem/year	Hanford town site	dry algae, 6/24/1992
Strontium-90	88	pCi/g	4.52	25 mrem/year	100N-Area	white mulberry fruit, 10/29/1992
Strontium-90	81	pCi/g	25.6	25 mrem/year	100N-Area	cottontail rabbit bone, 7/11/1991
Strontium-90	58	pCi/g	25.6	25 mrem/year	100N-Area	mule deer antler, 9/14/1990
Strontium-90	0.02	pCi	5.3	25 mrem/year	Columbia River Hanford reach	fish
Uranium-238	23	ppm	2.4	provisional	300-Area	yarrow, whole plant
Antimony	10.1	ppm	0.08	provisional	300-Area	mulberry leaves & stems
Barium	94	ppm	12	provisional	300-Area	mulberry leaves & stems
Barium	23	ppm	12	provisional	300-Area	mulberry leaves & stems
Lead	2.4	ppm	2.6	provisional	300-Area	mouse carcass
Manganese	53	ppm	24.8	provisional	300-Area	mulberry leaves and stems

Table 7-3 Contaminants Selected for Further Evaluation *(Continued)*

Contaminant	Maximum Concentration	Units	Screening Value	Screening Value Source	Location	Description
Soil and Sediment[¶]						
Uranium-235	1,570	pCi/g	17.6	25 mrem/year	300-Area, process trenches	surface soil, before '91 removal
Uranium-235	>8	pCi/g	17.6	25 mrem/year	300-Area, process trenches	surface soil, after '91 removal
Uranium-235	0.0054	pCi/g	105	25 mrem/year	background	subsurface soil
Uranium-238	9,140	pCi/g	105	25 mrem/year	300-Area, process trenches	surface soil, before '91 removal
Uranium-238	43.3	pCi/g	105	25 mrem/year	300-Area, process trenches	surface soil, after '91 removal
Uranium-238	0.190	pCi/g	105	25 mrem/year	background	subsurface soil
Antimony	<10.4	ppm	20.0	Child RMEG	300-Area, south process pond	surface soil
Arsenic	5.2	ppm	20.0	Chronic Child EMEG	300-Area, fly ash pit	surface soil
Barium	424	ppm	4,000	Oral Child RMEG	300-Area, fly ash pit	surface soil
Copper	3,560	ppm	5,000	Child UTL-MEG	300-Area, process trenches	surface soil
Lead	500	ppm	400	EPA soil screening value	300-Area, sanitary trenches	surface soil
Lead	11.3	ppm	400	EPA soil screening value	background	subsurface soil
Manganese	2,480	ppm	3,000	Oral child RMEG	300-Area, process trenches	surface soil
Nickel	959	ppm	1,000	Oral child RMEG	300-Area, process trenches	surface soil
Silver	320	ppm	300	Chronic oral child EMEG	300-Area, sanitary trenches	surface soil

* Air. Historical data from TSP (1994). Recent data from Westinghouse (1992b).

† Surface Water (Columbia River). Recent data taken from: Volume II: Appendices from DOE (1997a), WADOH (1993), DOE (1993b), Duncan (1994), and McBaugh (1996). Strontium-90 and other recent radioisotope data from DOE (1997a). Historical radioisotope data from RAC (2002).

‡ Groundwater. Data taken from Volume II: Appendices of DOE (1997a), Westinghouse (1992b, 1995a, 1995c), and DOE (1992a, 1993a, 1995b).

§ Game, Fish, Vegetation. Bird nest, mouse, rabbit feces, Westinghouse (1987), tumbleweed, Appendix A, Johnson(1994), mulberry, DOE (1993b), fish, DOE (2002); all others, Volume II, Appendices, DOE (1997a). For intake assumptions, see footnotes c and d of Table 4D.

¶ Soil and Sediment. 100-Area from Volume II, Appendices of DOE (1997a), 200-Area data from DOE (1993c), 300-Area data from DOE (1992b).

8

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8.0 Chapter Summary

General Principles of Toxicology

Toxicology is the study of how chemical or physical agents can adversely effect living organisms. For adverse health effects to occur, a person must be exposed to a toxic dose. The dose or amount of a substance the person is exposed to is one key in determining what types of adverse health effects may occur.

Some toxic substances, including many non-cancer causing substances, only become harmful when the dose exceeds a threshold limit. Other substances, such as cancer-causing substances, are considered to have no threshold limit and can be harmful at any dose.

The health concerns at the Hanford Site have focused on radionuclide releases. The toxicity of radiological substances differs from non-radiological substances. With radionuclides, the health effects are related to the radiation absorbed dose received by the body tissues, the dose rate, the sensitivity of the body tissue that was exposed, and the types of radiation involved.

Health Effects from More than One Contaminant

Exposure is not limited to one chemical substance or radionuclide. Hanford contamination includes many substances—both radioactive and non-radioactive. When considering how toxic substances found in the environment affect human health, an additive effect is the most expected interaction. With an additive effect, the combined effects of the substances is equal to the effects of each substances added together.

Exposure to radioactive and non-radioactive substances can also cause synergistic or multiplicative effects; that is, the effects of the combined substances are greater than the additive effect of either substance alone.

Women, Infants, and Children

Women, because their physiology is different from that of men, could experience more adverse effects from a toxic substance. In addition, if a woman is exposed to a toxic substance that enters her breast milk, her infant may experience a larger dose of the substance.

Because of their smaller body size, higher rates of metabolism, and their rapid growth rate, infants and children receive a larger dose of toxic substances in proportion to their body size than an adult would receive and are more sensitive to the effects of radiation. Studies of Marshall Islanders who were exposed to I-131 during atomic weapons testing in the Pacific suggest that children are about twice

as susceptible to non-cancer thyroid conditions from exposure to I-131 as are adults.

Unique Populations

Sub-groups within a population are sometimes at greater risk for adverse health effects because their ethic, cultural, or lifestyle practices increase their exposure to toxic substances. For the Hanford Site, the Hanford Health Effects Subcommittee requested that ATSDR consider specific unique populations including migrant farm workers, prisoner-of-war detainees, Hanford construction laborers, Japanese internment camp detainees, and subsistence fish eaters.

During the period 1942–1947, approximately 16,000 migrant workers for short periods and harvested crops in the six-county area surrounding Hanford. A study of the migrant workers and their families concluded that they had increased daily exposure to radiation through the air and water pathway as a result of time spent out-of-doors, exposure to mud and dust in the fields, drinking and swimming in local surface waters, and consumption of local vegetables (Duffie and Willard 1997). That said, however, their *annual* exposure was less than the permanent population because they were only in the area for short time periods from April through November each year.

In 1944, a prisoner-of-war camp in Pasco housed 300 men. Their exposure would have been similar to the resident population.

Hanford construction laborers included military personnel and 1200 African-American workers. Most of the construction was completed between 1943–1945.

ATSDR identified 10 Japanese-American Relocation Centers operating after 1943, with one in south central Idaho (out of the primary area of I-131 releases) and none in Washington or Oregon (Yu 1997). The two nearest Assembly Camps (in Puyallup, Washington and Portland, Oregon) closed in 1942, before Hanford began operating (Yu 1997).

Some community members were concerned that traditional Japanese dietary preferences might have put Japanese-Americans at elevated risk during the period 1950 through 1971 from exposures associated with the Columbia River, because the traditional Japanese diet is rich in fish products. Columbia River Basin tribes also consume more fish than does the general population (CRITFC 1994).

National and international scientific advisory bodies recommend that radiation dose to members of the general public be limited to 500 mrem per year for any 5-year period and a lifetime average of 100 mrem per year. HEDR project results

indicated that consumption of five or more 6-ounce meals of *resident* fish (catfish or bass) per week during the 1950s and 1960s may have resulted in intakes of radionuclides that may have led to radiation doses that could have exceeded the recommended dose limits for members of the general public. These radiation exposure limits are relatively conservative, and the limits for radiation workers are five to ten times greater than the limits for members of the general public.

Eating non-resident fish, such as salmon and steelhead trout—which spend some time in the ocean—would not result in radiation doses to the public to the same degree as eating resident fish. Current recommendations on dose to members of the public would not be exceeded for non-resident species that feed in the ocean more than 80% of their life spans (ICRP 1977, 1990b, NCRP 1993, TSP 1994).

Health Implications of Exposure to Hanford Contaminants

The Hanford Environmental Dose Reconstruction Project (HEDR) estimated radiation doses to persons from prior-era radioactive materials releases from the Hanford Site. The HEDRstudy indicated that the largest doses of radiation to residents surrounding the site were from iodine-131 released to air and deposited on pasture lands and from other radionuclides released into the Columbia River between December 1944 and December 1957. The most important radiation exposure pathway for iodine-131 was the consumption of contaminated milk produced by cows and goats that the residents kept on their properties. Children received the highest estimated thyroid doses. Radiation doses from releases to the Columbia River were highest from 1956 through 1965, peaking in 1960. Health implications associated with past exposures depend on the dose received.

ATSDR's Infant Mortality and Fetal Death Analysis, finalized in November 2000, investigated the association between estimated I-131 exposure and infant mortality, fetal death, and pre-term birth. The study focused on the years 1940–1952, and included the eight Washington counties in the HEDR project (Adams, Benton, Franklin, Grant, Kittitas, Klickitat, Walla Walla, and Yakima). The study used the HEDR project's 1945 exposure estimates for I-131, and found a 70% higher rate of pre-term birth and a 30% higher rate of infant mortality in the areas with the highest estimates of I-131 exposures compared to areas with the lowest estimates of exposure. No association was found for fetal death.

The Hanford Thyroid Disease Study (HTDS) reported preliminary findings in January 1999. While thyroid diseases were observed among the participants, the prevalence of thyroid disease among the study population was approximately the natural background incidence, that is, the same as might be expected in a comparison populations not exposed to I-131. The study results did not show a link between the estimated dose to the thyroid from I-131 and the amount of thyroid

disease in the study population and did not show an increased risk with higher radiation doses from I-131. These results do not mean that persons living in the Hanford area during the 1940s and 1950s were not exposed to I-131 and other radionuclides, or that these exposures had no effect on their health. In the final release of their report (June 21, 2002) the HTDS authors said "that if there is an increased risk of thyroid disease from exposure to Hanford's iodine-131, it is probably too small to observe using the best epidemiologic methods available."

Health Implications of Specific Substances

ATSDR identified three substances (lead, silver, and uranium) that might affect the health of future Hanford residents or subsistence food users. The health implications of these substances include

Lead. Young children could develop elevated blood-lead levels if all their food is prepared by encasing it in soil taken from the most contaminated parts of Hanford. This scenario is highly unlikely in a modern society.

Silver. Persons who eat food prepared by encasing it in soil could experience grey and blue-grey spots on their skin, known as argyria.

Uranium. If medicinal herbs from the Hanford Site (e.g., yarrow) are contaminated with uranium and are used to treat persons for blood in their urine—a possible sign of kidney injury or disease—it is possible that kidney condition could worsen.

8.1 General Principles of Toxicology

Exposure does not always result in health effects. The type and severity of health effects that occur in an individual from contact with a contaminant depend on the properties of the chemical, the exposure concentration (how much), the frequency and duration of exposure (how long), the route or pathway of exposure (breathing, drinking, or skin contact), and the multiplicity of exposure (combination of contaminants). Once exposure occurs, characteristics such as age, sex, nutritional status, genetics, life style, and health status of the exposed individual influences how the individual absorbs, distributes, metabolizes, and excretes the contaminant. Together, many factors and characteristics determine the health effects that could occur as a result of exposure to a contaminant in the environment.

Some substances, including many non-cancer causing chemicals, only become harmful when the dose a person receives exceeds a threshold limit. Other substances, such as cancer-causing chemicals, are considered to have no threshold and can be harmful at any dose.

The toxicology of radiological substances differs somewhat from non-radiological substances. The health effects of radiation are related to several important factors including absorbed dose received by the exposed body tissues, the body tissues sensitivity to radiation, and the type of radiation involved.

8.1.1 Non-radiological Substances

Toxicology is the study of the adverse effects of chemicals or physical agents on living organisms (NLM 2001). Even when exposure occurs, this does not mean that a person automatically experiences a health effect. Persons can be exposed to a toxic substance primarily through three *routes of exposure*:

- Inhalation (breathing),
- Ingestion (eating or drinking),
- Dermal contact (with skin or mucous membranes).

A substance can enter the body by one of these routes more readily than by another. The amount of the substance entering the body also depends on 1) the concentration of the substance received (the *dose*), 2) how long (duration) a person was exposed, and 3) how often (frequency) that person was exposed. Additional factors that affect toxicity include the form of a substance (e.g., mercury vapor vs. methyl mercury), the species exposed (e.g., a person or a fish), the age, the sex, the presence of other chemicals, and the ability of the substance to be absorbed, metabolized, distributed, and excreted by the body (NLM 2001).

Even when exposure occurs, this does not mean that a person automatically experiences a health effect.

Once in the body, a toxic substance could have 1) *a local toxic effect*, which means that it affects only specific organs or tissues (e.g., the skin, the respiratory tract) it immediately contacts, or 2) *systemic effects*, which mean that the entire body or several organs or tissues are affected. A combination of local and systemic effects can occur.

ATSDR distinguishes three different exposure durations. *Acute* durations of exposure last up to 14 days. *Intermediate* durations of exposure last from 15 days to 1 year. *Chronic* exposures persist for more than 1 year.

Different types of toxic effects include carcinogenicity (cancer), neurological (nervous system) effects, reproductive effects (on male or female reproductive

systems), developmental effects on fetuses or children, and mutagenic effects, which affect genes.

For non-carcinogenic (non-cancer) substances, generally as the dose increases, the severity of the toxic response increases. Through review of studies of toxic effects on animals and accidental exposures of humans, ATSDR identifies the lowest dose at which adverse effects are known to occur (i.e., the Lowest Observed Adverse Effect Level or LOAEL). ATSDR also established the dose at which no effect is observed (i.e., the No Observed Adverse Effect Levels, NOAELs). The threshold dose is between the dose at which no effect occurs and the dose at which an effect is known to occur.

For carcinogenic substances, some scientists do not think threshold levels exist; that is, some scientists believe effects could occur at any dose. Cancer data is generally not available for doses persons experience from environmental exposure. Most government agencies use the assumption that no threshold exists (i.e., linear-no-threshold models) to set regulatory or advisory levels. Part of such an model is a “cancer slope factor” (CSF). The CSF is used to estimate the high end of a modeled, or theoretical, range of probabilities that persons could get cancer if exposed at a particular low dose for a lifetime, if no threshold exists.

Agencies such as ATSDR and EPA develop exposure standards or guidelines to protect public health. For noncancerous effects, guidelines such as ATSDR’s Minimal Risk Level (MRL) and EPA’s Reference Dose (RfD) are estimates of human exposure to a substance that is likely to be without appreciable risk of adverse noncancer effects. ATSDR uses MRLs and cancer slope factors to develop screening values, such as those used throughout this public health assessment. MRLs and RfDs are derived from observed thresholds for toxicity by dividing the threshold dose by uncertainty factors to include margins of safety to protect against various considerations that might increase the possibility of harm to some persons. Thus, although doses less than MRLs and RfDs will probably not make persons sick, doses above these values do not necessarily mean they will become sick. In other words, doses higher than MRLs or RfDs are indicators that further study is needed.

8.1.2 Radiological Substances

The adverse health effects of radiation are related to the *radiation absorbed dose* received by tissue, the dose rate, the type of radiation, and the relative radiosensitivity of the target tissue involved. In some cases, the severity of the effect increases proportionately to the dose received. In other cases, the probability of a radiation-induced change, such as a mutation, chromosome aberration, or transformation leading to carcinogenesis is proportional to the absorbed dose.

These linear relationships do not apply exactly at very high or very low levels of radiation exposure.

The lowest radiation dose at which an adverse effect occurs is the *threshold* absorbed dose level, but no threshold is assumed for probabilistic effects. For non-cancer health effects, values have been determined for levels of radiation exposure or intake for which "no observed adverse effects levels" (NOAELs), and for "lowest observed adverse effects" (LOAELs). The most sensitive toxic effect likely to occur in humans is used to determine the NOAEL or the LOAEL.

The LOAELS have been further classified into "less serious" or "serious" effects. "Serious effects" are those effects which evoke failure in a biological system and can lead to disease and death—such as acute radiation sickness followed by death. "Less serious" effects are those effects not expected to cause significant dysfunction or death, or those effects the significance of which the individual is unaware.

Carcinogenic effects may occur at low, intermediate, or high levels of radiation exposure. This means that the dose-response relationship may not exhibit a threshold, and cancer may occur at any level of dose received. The probability of cancer can be proportionate to the level of exposure. In that case, a *cancer slope factor* can be determined to estimate the likelihood that an individual, exposed continuously over a lifetime of 70 years, will develop a form of cancer.

8.2 Exposure to More than One Contaminant

The Hanford Health Effects Subcommittee (HHES) requested that the Hanford public health assessment include a discussion of synergism in general, synergism between chemicals and radionuclides, and the potential for adverse health effects that might arise from combined exposures to radiological and nonradiological substances released from Hanford. This discussion is in response to that request.

Studies have indicated that synergism occurs only when the doses of the individual substances present are high enough to cause an effect on their own and when the substances interact with the body in the same way as each other. Because the levels of the individual substances released at these sites are usually much lower than levels known to produce adverse effects, interactions among substances released from hazardous waste sites might not result in synergism. Nevertheless, ATSDR continues to evaluate the possibility of synergistic interactions between hazardous substances, especially when substances target the same organs or tissues in the body and when mechanisms of toxicity overlap, creating the potential for synergistic or antagonistic effects.

8.2.1 Synergism, Antagonism, and Additive Effects

Synergism occurs when the combined effect of two or more substances is greater than that which would be predicted by adding the effects of the individual substances. *Antagonism*, the opposite of synergism, occurs when the combined effect of two or more substances is less than the that which would be predicted by adding the effects of the individual substances. In most environmental exposures, rather than synergism or antagonism, *additive effects* occur, which is when the combined effect of two or more substances equals that which would be predicted by adding up the effects of the individual substances (Klaassen 1996, Seed et al. 1995).

Persons most frequently encounter the potential for synergism or antagonism in their use of medications. Doctors and pharmacists discuss with patients any other medications they are already taking to avoid the possibility of synergistic (higher) or antagonistic (lower) interactions that might change the effects of the medications.

Synergism is known to occur at high levels of exposure to toxic substances, such as those found in certain occupations or certain lifestyle habits (e.g., cigarette smoking). Some ATSDR scientists believe that synergistic effects probably occur at low doses as well as at high doses, although studies conducted thus far have not shown synergistic effects at low doses.

For synergism to occur, the substances involved must use the same (or overlapping) "mechanism of action" within the body (i.e., interact with the body in the same way), which places greater demands on the body and can increase harmful effects of contaminants (Freedman and Mumtaz 1995, EPA 1986). With antagonism, the opposite occurs; the two or more substances compete with each other for the same mechanism of action within the body, thus reducing harmful effects (Cassee et al. 1996). In most cases of environmental exposure, substances do not use the same mechanism of action. When contaminants in the environment do share the same mechanism of action, the results are usually additive and the amounts of the substances to which persons are exposed are, generally, substantially less than the amounts that would produce synergism or antagonism (Coleman 1990a, b, 1991, Colman 1990a, b, Freedman 1990a, b, 1991a, b, c, Hughes 1991, Ingerman 1990, Llados et al. 1991, McClure 1990a, b, c, d, e, McClure and Coleman 1990, Odin 1990a, b, 1991, Odin and Llados 1990).

8.2.2 Exposure to Chemical Mixtures

For noncarcinogenic substances, exposure to a mixture of chemicals has not been known to result in synergistic, adverse effects when the individual components of

the mixture are all present at levels below their thresholds (levels below which no harmful effects have been observed upon exposure) (Groten et al. 1991, Jonker et al. 1990). One study did initially report substantial synergism when endocrine disrupters (substances that either mimic or inhibit hormonal activities in the body) were below their thresholds; but after many investigators (including the study authors) were unable to confirm the results, this study was withdrawn (Arnold et al. 1996, Ashby et al. 1997, Gaido et al. 1997a, Gaido et al. 1997b, McLachlan 1997, Ramamoorthy et al. 1997a, Ramamoorthy et al. 1997b, 1997c). Additional research into the potential effects of chemical mixtures and endocrine disrupters continues to be conducted.

8.2.3 Combined Exposure to Radiological and Non-Radiological Substances

For carcinogenic substances, evidence has been found of synergism between cigarette smoking and plutonium in studies of lung cancer resulting from combined exposures to plutonium and cigarette smoke (Finch et al. 1997, 1998, 1995, 1996, Hobbs et al. 1994, Talbot et al. 1987, Tokarskaya et al. 1995, 1997, Voelz et al. 1997). It is possible, however, that cigarette smoke is the main substance of concern because 1) lung cancer incidence did not necessarily increase as the plutonium dose increased, and 2) low doses of plutonium did not result in increased lung cancer (Tokarskaya et al. 1997, Voelz et al. 1997). In animal studies, rats exposed to both plutonium-239 dioxide and cigarette smoke had higher lung cancer incidence than predicted by adding the cancers incidence observed in rats exposed to each substance alone (Finch et al. 1995, Hobbs et al. 1994).

Pending available funding, ATSDR plans to solicit relevant research proposals from the scientific community to determine how radiation affects toxicity during co-exposure to other chemicals. Data from DOE sites would be reviewed to identify candidate radioactive and non-radioactive substances to which individuals might be co-exposed and that could impact common target organs, such as the kidney or liver. Relevant literature searches would be conducted to compile known information, if any, on combined toxicity of the substances in mixtures. Based on these findings, experiment(s) would be designed and conducted to answer specific questions concerning the role radiation might play in increasing or decreasing the adverse effects of the chemical mixture on health.

8.2.4 Multiple Chemical Sensitivity (MCS)

Some persons have reported health symptoms that they have associated with exposure to many different substances in the environment, including colognes and perfumes, aerosol air fresheners, laundry detergents, gasoline exhaust, cleaners,

insecticide sprays, and cigarette smoke. Reported symptoms include fatigue, headaches, nausea, mucous membrane irritation, breathing difficulty, dizziness, depression, difficulty concentrating, loss of memory, and others. Such reactions to substances commonly found in the environment are called multiple chemical sensitivity (MCS), also referred to by other names, including environmental illness, ecological illness, idiopathic environmental intolerances, and others.

The scientific literature currently does not adequately indicate whether an association exists between human exposure to chemicals in the environment and the development or worsening of MCS. Nor can specific tests identify MCS. Several theories and definitions of MCS exist. One researcher defines MCS as "an acquired disorder characterized by recurrent symptoms, referable to multiple organ systems, occurring in response to . . . exposure to many chemically unrelated compounds at doses far below those established in the general population to cause harmful effects" (Cullen 1987). Different theories propose immunologic, neurologic, and psychologic factors as possible causes of MCS. Physician-diagnosed MCS range from 0.2% (of college student participants in a study) to 4.0% (of elderly persons participating in a study) (Bell et al. 1996, 1994). Fully controlled epidemiological studies, as well as laboratory methods with sound study design and appropriate quality assurance, are needed to verify suggested mechanisms, lab tests, effects, and treatments reported to be associated with MCS.

While thus far no conclusive evidence of multiple chemical sensitivity exists, ATSDR acknowledges that in the past, other types of suspected health effects from environmental exposures were later verified through scientific research. Monitoring of such possible diseases and disabilities is appropriate in a public health context to help prevent and alleviate illnesses, even when such illnesses are not fully explainable. Thus ATSDR has held or sponsored a number of workshops on MCS, including a 1991 AOEC meeting on the clinical aspects of MCS, a 1991 National Academy of Science conference, and a 1993 expert panel on chemical sensitivity and low-level environmental exposures—as well as a 1994 meeting to consider neurological/biological aspects of chemical sensitivity, based on a 1992 Congressional mandate. In 1994 ATSDR also provided a grant to the California Department of Health Services to develop a scientifically acceptable research design for identifying MCS. In addition, ATSDR has published proceedings of its sponsored conferences, served as an information resource on MCS, and encouraged clinical and other research on MCS.

Workshops and research continues by several federal and state agencies on various aspects of MCS or related issues, including the validity of immune and lymphocyte tests, the use of biomarkers to indicate MCS, the illnesses suffered by Persian Gulf War veterans, indoor air pollutants, and MCS test protocol development and pilot studies.

8.3 Women, Infants, and Children

Women and children can be affected differently by environmental contaminants. They are smaller than the average male, and thus affected slightly more by smaller quantities than in adult males. The effect of hormonal variations, pregnancy, and lactation changes the way a woman's body responds to some substances.

Exposure during pregnancy and lactation can expose the woman's fetus or infant to the substances if they cross her placenta or get into her breast milk. Depending on the stage of her pregnancy, exposure of her fetus could result in miscarriage, stillbirth, or impaired development (birth defects). If the woman is exposed during lactation, her milk may concentrate certain contaminants, especially fat-soluble substances such as DDT and PCBs, and increasing the exposure of her infant (Klaassen 1996).

ATSDR recognizes that unique vulnerabilities are inherent in a developing fetus, an infant, or a child. Public health assessments include evaluations of potential effects on the young in light of these unique exposures. Children are not just "small adults." Exposures affect children more because of their reduced body weight and higher ingestion rate, resulting in an increased dose (amount taken into the body) compared to their body weight. For example, infants at Hanford received higher doses from Hanford's iodine-131 releases than did adults.

Children's shorter stature results in a breathing zone closer to the ground and thus closer to soil and dust contaminants. Behavioral characteristics different from adults, for example hand-to-mouth behavior, increases a child's ingestion of toxicants in soil or dust. Their play activities close to the ground increases their exposure to any contaminants in the soil.

Children undergo rapid growth and development in the first months and years of life. Some organ systems, especially the nervous and respiratory systems, may experience permanent dysfunction if exposed to high concentrations of certain contaminants during this period. In addition, because of more rapid growth and development, a child's DNA is more likely to be exposed than later in life, rendering this period of life more vulnerable to genotoxic effects.

Children have more future years than adults, so exposure during early years leaves more time for development of chronic diseases. This is especially true for multistage diseases (e.g., cancer) which may require many years to progress from initiation to actual manifestation of illness.

Finally, children have less ability to avoid hazards because they are dependent on adults to make decisions. Adults may not recognize circumstances hazardous to children, especially those not hazardous to adults.

8.4 Unique Populations

The HHES recommended that ATSDR include a discussion on special populations whose ethnicity, cultural practices, or lifestyles could have affected their past, current, or future susceptibility to Hanford's environmental releases. Native Americans practicing traditional food and medicine gathering at Hanford in the future with unrestricted public access is one example of such a special population. Another example is the many groups who seasonally assisted Washington State crop growers in harvesting their crops during the latter stages of World War II and the immediate postwar years. A report on these migrant farm workers was developed for the Washington State Department of Health in 1997 (Duffie and Willard 1997).

8.4.1 Migrant Farm Workers

From 1942 to 1947, wartime and postwar labor shortages created an emergency need to mobilize large numbers of farm workers for harvesting. The Emergency Farm Labor Program brought in Mexican Nationals (Braceros), Japanese evacuees, prisoners of war, state and local prisoners, and women and youth volunteers to meet the manual labor shortages. In addition, Canadian, Plateau and Blackfeet Indian groups, and Mexican-American families came to the area from Montana and Wyoming. During 1942–1947, between April 1 and November 1, some 16,000 seasonal workers annually participated in this effort in the Washington counties of Benton, Franklin, Grant, Kittitas, Walla Walla, and Yakima . Many workers came back year after year, often to the same growers. After the war, Mexican immigrants, and migrant families from Southeastern states supplemented the continued harvesting efforts (Duffie and Willard 1997).

Workers lived in camps in Kittitas (90 miles northwest), Walla Walla (75 miles east southeast), Dixie (85 miles east southeast), near Moses Lake (30 miles north) and, for 51 days in 1946, near Kennewick (25 miles south southeast). Camps along the Yakima River included Ahtanum, Tortilla Flats, Del Monte Golden Farms (at Toppenish), Yakama Chiefs #1 (near Mabton), and Yakama Chiefs #2 (near Satus). Additional farm camps were west of the river near White Swan and Harrah (Duffie and Willard 1997).

These families drank milk from both commercial and farm sources. Reports did not specify where the dairy cattle on these farms grazed, or how much of their feed

was stored pasturage. Native American workers consumed little milk, and most of it was canned. Drinking water came from wells, city reservoirs, and irrigation ditches. Farm food (asparagus, corn, potatoes, and peas) was purchased at roadside stands or prepared traditionally (e.g., fresh and dried roots and dried corn) by Native American workers. Workers and their families spent much of their time outdoors. Reports concluded that this population was primarily "vulnerable to radiation exposure through the air and water pathway . . . due to the extended . . . time spent out-of-doors, exposure to mud and dust in the fields, and drinking and swimming in local surface waters."—as well as from the consumption of local vegetables (Duffie and Willard, 1997).

A number of factors may have reduced migrant workers' radiation exposures. The migrant worker camps were primarily upgradient, upwind, and upstream from Hanford radioiodine sources. The seasonal nature of migrant work also limited exposure time. Because inhaled I-131 was not first bioconcentrated (as it was in milk from backyard cows fed fresh pasturage), direct inhalation of this isotope contributed no more than 10% of the total dose to persons maximally exposed during the peak releases. External exposure (e.g., swimming in surface water) supplied 5% of the dose. Fresh non-leafy vegetables supplied 5% (corn is protected from direct iodine deposition by husks, peas by pods, and potatoes and other roots by soil). Soil ingestion supplied 0.02% of the dose.

ATSDR could find no evidence that the migrant worker group is a high-risk population from radiation exposure. Still, their use of irrigation water for drinking, swimming, and bathing could have exposed them to pesticides.

Some Hanford Downwinders received much higher doses than the farm workers because of their location or the quantity of fresh-pastured backyard cow's milk they consumed (TSP 1994). A previous study of 35,000 persons given I-131 for medical reasons failed to find any association between dose and thyroid cancer among adults, but did find a statistically non-significant trend among children (this trend was at a much lower than that expected from the same dose from external radiation) (Hall et al. 1996). ATSDR could find no evidence that the migrant worker group is a high risk population because of radiation exposure, but their use of irrigation water for drinking, swimming, and bathing could have exposed them to pesticides. Their hazard from pesticide exposure would depend on the kinds of pesticides in use at the time and on the concentrations of these substances in the irrigation water.

ATSDR responded to HHES advice to research independently the issue of historically special populations. From the Franklin County Historical Society, the ATSDR learned that the greatest immigration of Mexican-Americans into the

region began in the 1950s during the "Green Giant" expansion that enabled large agri-businesses to form and grow (Sonderman and Guynn 1996). Thus, most of the Hispanic-American population influx postdates the time of the greatest Hanford air releases (December 1944 through 1947). Some of the Hispanic migrants of the 1950s became successful Pasco businessmen in the 1960s and 1970s (Moser 1992, Williams 1989). Many of those who came to work on the farms as transients later stayed and integrated into permanent communities near Hanford. By 1970 the Hispanic community in Franklin County numbered 1,303, or 5% of the population. By 1980, they were 5,403, or 15%, and by 1990, 11,317, or 30%, of the Franklin County population were of Hispanic origin (ATSDR 1997, Franklin County Historical Society 1990, Bureau of the Census 1991). Thus, most of the county's Hispanic population arrived later than the greatest Hanford river releases (1950–1971).

8.4.2 Prisoner-of-War Camps

The HHES also inquired about prisoner-of-war (POW) camps that might have contributed to the Hanford workforce near the end of World War II. During that war, resident aliens and citizens of Japanese, Italian, and German descent were temporarily interred in camps around the United States. A POW camp populated by the 255th Italian Quartermaster Salvage and Repair Unit, opened in the Pasco, Washington area in 1944. The camp housed as many as 300 men, 150 in each of two administrative units. They were selected for technical skills to perform essential jobs that could not otherwise be undertaken because of regional wartime labor shortages. ATSDR found no indication that the men worked at Hanford (Van Arsdol 1984a, b).

8.4.3 Hanford Construction Laborers

In early 1943, when Hanford was selected for the Manhattan Engineering District, nearby towns were evacuated. By mid-1945, Hanford had produced enough plutonium to abruptly end the war in Japan with the world's first and only wartime explosions of nuclear devices. During and after that interval, Hanford facilities were constructed by labor imported from throughout the country. Military personnel were housed in barracks called "Camp Hanford" in the southern part of the newly evacuated Hanford Site. Some 1200 African-American workers arrived in the early 1940s to live near Hanford and accept employment in such construction projects as the Pasco Reconsignment Depot, the Naval Air Station, and the Hanford Works (Van Arsdol 1984b). ATSDR found no information about cultural practices that might have put African Americans at higher risk than any other population groups in the Tri-Cities area. Some of these workers stayed, others worked for the railroad. The 1990 Census reported 5.6% of the Pasco population was African-American (Bureau of the Census 1991).

8.4.4 Japanese Internment Camps

HHES advised ATSDR to find information on Japanese-American internment camps in the region during the Hanford releases. HHES also asked whether Japanese-Americans were a high risk population. A search of Franklin County Historical Society records yielded no information about Japanese-American internment camps in the immediate Hanford vicinity (Sonderman and Guynn 1996). Japanese-American internees were not listed among the ethnic groups who helped bring in south central Washington crops during the war years (Duffie and Willard 1997).

A search of the World Wide Web for internment camps found 10 Japanese-American Relocation Centers, with one in south central Idaho (out of the primary area of I-131 releases) and none in Washington or Oregon (Yu 1997). The two nearest Assembly Camps (in Puyallup, Washington and Portland, Oregon) closed in 1942, before Hanford began operating (Yu 1997).

The Kooskia Internment Camp was a Justice Department Internment camp 30 miles from Kooskia, Idaho, near Lowell, Idaho (Wegars 1999, Yu 1997). The camp operated until May, 1945 and housed 256 non-U.S. citizens of Japanese ancestry from at least 16 states and three South American countries (Wegars 1999). Six Justice Department Internment Camps in five states housed 2,260 Kibei (Japanese-Americans born in the U.S. who returned to the U.S. after being educated in Japan), Buddhist ministers, former newspaper employees, community leaders and others of Japanese ancestry from throughout the U.S. and 12 Latin American countries (Yu 1997). It was not clear that any children were included among this group of internees.

Internees in the camps were fed a predominantly non-traditional diet, including Vienna sausages, stewed tomatoes, and bread—initially with no fresh vegetables, fruit, or fresh meat, but plenty of canned food (Mudrock et al. 1997). The U.S. Army contracted with farmers in Oregon for milk to supply these camps (Mudrock et al. 1997).

ATSDR estimated a maximum dose of 4 rads (thyroid) to infants that may have been in the Kooskia camp. In its calculations ATSDR used the fraction (15.2%) of the cumulative total releases that occurred between December, 1944, when Hanford operations began, and May, 1945, when Kooskia closed, and also used the maximum dose that could have been received by an infant exclusively drinking fresh milk from fresh pasturage-fed backyard cows in northwestern Umatilla County and northeastern Morrow County, the parts of Oregon with the greatest I-131 deposition (TSP 1994). This thyroid dose is below the threshold for hypothyroidism and presents a risk of thyroid cancer too low to expect that it may

have caused any cases among the 256 internees (NCRP 1977b). Thus Japanese-American internees, as a group, were not at greater risk than other Downwinders from Hanford air releases.

8.4.5 Subsistence Fish Eaters (Japanese-Americans, Native Americans, Hispanics)

Some HHES members were concerned that traditional Japanese dietary preferences might have put Japanese-Americans at risk during 1950 through 1971 from exposures associated with the Columbia River. Traditional Japanese food is rich is seafood, some of it uncooked.

During Hanford's production years (especially 1950 through 1971), neutron-irradiation of elemental substances naturally present in the Columbia River resulted in radioactivity in the water and associated plants, animals (including fish and shellfish), and their products. Scientists of the HEDR project estimated that five radionuclides (Na-24, P-32, Zn-65, As-76, and Np-239) contributed 94% of the estimated whole-body dose to persons exposed to the river and its fish. Cooking would not be expected to increase or decrease the concentrations of Na-24, P-32, Zn-65, As-76, and Np-239 in the fish.

HEDR scientists estimated combined doses from ingestion of drinking water, resident fish, shellfish, waterfowl, and salmon, as well as from external exposure by swimming and proximity to the shoreline. They did this for three types of representative individuals: 1) the person who consumed the highest rate of local fish and spent much time in or near the river, 2) the average person who lived near the river but ate little or no fish, and 3) the occupationally exposed person who was employed on the river (e.g., a barge worker) but who consumed little or no fish.

The assumption that a heavy fish consumer ate all local fish is conservative. Like the traditional Japanese diet, Columbia River Basin tribes consumed more fish than the general population (CRITFC 1994), but they prefered salmon and steelhead that spend some time in the ocean (anadromous fish). Traditional Japanese fish preference also leans towards ocean-going fish and shellfish, such as tuna, octopus, and shrimp.

The HEDR used bioconcentration factors to estimate the dose resident fish, such as bass and catfish, could have delivered to persons with various fish consumption rates. For the maximum user assumptions, scientists applied these factors to salmon and steelhead. Monitoring data for salmon during this period showed that most specimens had undetectable levels of radioactivity. Where radioactivity was

detectable, levels were 6-10 times lower than those assumed for the maximum dose calculations (TSP [p. 44]).

Modeling based on bioconcentration factors was more relevant to fish that spend their entire lifespans feeding in the river, as distinct from the ocean-going species favored by a traditional Japanese diet or the anadromous species favored by the tribes. Using the maximum dose estimates and a three-meal-a-day (440 pounds per year, 6 ounces of fish per meal) rate of local fish consumption, HEDR project results did not indicate that the regulations in effect at the time for public whole-body exposure were exceeded. No 5-consecutive-year period produced a mean annual estimated dose exceeding 500 mrem and the lifetime (70 years including the maximum release years) annual mean was not shown to exceed 100 mrem per year (10 CFR 20). Persons eating fifteen 6-ounce servings per day would not have exceed regulations in effect at that time if their dietary fish sources were primarily anadromous species that feed in the ocean more than 80% of their lifespans, or if 80% of the fish and shellfish they consumed were ocean-dwellers (e.g., tuna, octopus, and shrimp).

HEDR project results indicated that consumption of five or more 6-ounce meals of local fish per week during the 1950s and 1960s could have resulted in radiation doses that might have exceeded the recommended dose limits for members of the general public. This estimate applied only to local fish, not salmon or steelhead, which migrate back and forth from the ocean.

Current ICRP and NCRP recommendations as adopted in federal regulations (10 CFR 20) limit the public's exposure to less than 500 mrem for any 5-year period and a lifetime average of 100 mrem per year. HEDR project results indicated that consumption of five or more 6-ounce meals of resident fish per week during the 1950s and 1960s could have exceeded the regulations and recommendations in effect in the 1990s. Persons eating three 6-ounce servings per day would not exceed current regulations and recommendations if their dietary fish sources were primarily anadromous species that feed in the ocean more than 80% of their life spans, or if 80% of the fish and shellfish they consumed were ocean-dwellers (e.g., tuna, octopus, and shrimp) (ICRP 1977, 1990b, NCRP 1993, TSP 1994).

Oothers have challenged HEDR dose modeling for the river pathway. Hoffman et al (1997) reported that the bioconcentration factors used by HEDR (which yielded up to 10 times higher radioactivity in the fish meat than was measured in samples) were lower than the highest available published factors, and because HEDR assumed filets, rather than whole fish (including bony parts), would be eaten (Hoffman et al. 1997).

The National Center for Environmental Health funded a contract to complete additional work on the Columbia River dose reconstruction model (Risk Assessment Corporation 2002). The model included the 11 radionuclides for which HEDR had source term estimates, plus others—including cobalt and strontium—for which HEDR did not have source term estimates. In all, the study examined 23 radionuclides in two levels of screening and estimated risks based on scenarios involving three types of Columbia River users: Native American, local resident, and migrant worker. The additional work (Risk Assessment Corporation 2002) reported the following.

> The "results did not support the suggestion that the HEDR Project should have made dose calculations for [iodine-131 and strontium-90]. Although they were not eliminated in the initial screening, they were identified as low priority in all three exposure scenarios (ranked 10 out of 15). [The scientists] accounted for the consumption of whole fish including the bones by Native Americans; however [their] research indicated it was unrealistic to assume whole fish were consumed year round in large quantities. For this reason the dose and risk for [strontium-90 (and strontium-89)] was not increased significantly. Iodine-131 screening values were ranked consistently low for the three representative scenarios. On an absolute level, [iodine-131] risk for the local resident [River user] scenario at Richland was about a factor of 20 less than the estimated risk from the atmospheric releases of [iodine-131] at Ringold. Therefore, [iodine-131] did not appear to warrant further investigation.
>
> If further evaluation of risks from radionuclides released to the Columbia River is undertaken, the following four radionuclides are considered most important for the analysis: [arsenic-76, neptunium-239, phosphorus-32, and zinc-65]; the following four of moderate priority: [sodium-24, zirconium-95, cobalt-60, and cesium-137] . . . (fallout from atmospheric weapons testing may have exaggerated the significance of [cesium-137] in this study) . . . , and that [iodine-131, iodine-133, strontium-90, strontium-89, gallium-72, scandium-46, and yttrium-90] were of low priority and probably could be dismissed. . . . [F]ish ingestion was the dominant exposure pathway for releases to the Columbia River . . . over the years 1952 to 1964. . . The significance of fish ingestion for Native American users of the river was greater than that for non-Native American users by a factor of 10."

8.5 Health Implications

Releases of radionuclides and chemicals substances from the Hanford Site is well documented. The resulting contamination has potential for both historical and future health effects.

The iodine-131 released to air between December 1944 and December 1957 resulted in exposure through milk consumption. Iodine concentrates in the thyroid and is known to cause thyroid diseases, such as hypothyroidism. Health effects associated with past exposures depend on the radiation dose received by the subject.

The Hanford Thyroid Disease Study (HTDS) reported preliminary findings in January 1999. CDC and the Fred Hutchinson Cancer Research Center released the final report in June 2002. While thyroid diseases were observed among the participants, the study results did not show an increased prevalence above natural background rates of thyroid disease, and no increases in disease were observed with increasing iodine-131 exposures.

ATSDR's Infant Mortality and Fetal Death Analysis, finalized in November 2000, found a 70% higher rate of pre-term birth and a 30% higher rate of infant mortality in the areas with the highest estimates of iodine-131 exposures compared to areas with the lowest estimates of exposure. No association was found for fetal death, and no direct mechanisms were found to associate iodine-131 exposures with pre-term birth or infant mortality.

Iodine-131 and air releases were the major sources of radiation from Hanford Site releases, but were not the only potential sources for exposures. Radiation doses associated with the Columbia River were highest from 1956 through 1965, peaking in 1960. Current on-site soil contamination might result in health problems if the contaminated dirt was used as part of traditional tribal food preparation practices.

8.5.1 Health Implications of Past Exposures

The Hanford Environmental Dose Reconstruction Project evaluated past off-site radioactive releases from Hanford to the surrounding communities. The study indicated that the largest doses of radiation to residents surrounding the site were from iodine-131 released to air and deposited on soil and into the Columbia River between December 1944 and December 1957. The most important radiation exposure pathway for iodine-131 was the consumption of contaminated milk produced by cows and goats that the residents kept on their properties. Children received the highest estimated thyroid doses. Radiation doses from releases to the Columbia River were highest from 1956 through 1965, peaking in 1960. Potential health effects from childhood milk consumption could be associated with radiation dose to the thyroid.

ATSDR conducted an analysis of infant and fetal deaths and birth records for eight counties in southeastern Washington State during the period 1940–1952. The study focused on rates of infant and fetal deaths, and pre-term birth, especially during 1945 when the highest air emissions of iodine-131 (I-131) occurred. Because birth weight was not recorded on the birth certificate until 1949, it could not be evaluated in this study. The project reviewed over 70,000 live births, almost 2,000 infant deaths, and about 1,000 fetal deaths. Radiation doses estimated by the Hanford Environmental Dose Reconstruction (HEDR) project were used to characterize geographic areas of exposure to I-131 air releases. The health outcomes were analyzed by geographic areas of exposure and time periods.

Study findings suggested that residence of the mother in a geographic area with relatively high estimated I-131 exposure in 1945 may have had an effect on the fetus or the mother which resulted in pre-term birth (adjusted odds ratio = 1.6, 95% confidence interval = 1.0–2.6). High estimated I-131 exposure in the latter part of pregnancy was also associated with pre-term birth (adjusted odds ratio = 1.9, 95% confidence interval = 1.2–3.0) and was somewhat associated with infant mortality (adjusted odds ratio = 1.3, 95% confidence interval = 0.8–2.1). The rates of fetal deaths were similar in the high and low exposure areas.

The Hanford Thyroid Disease Study (HTDS) evaluated whether the occurrence of thyroid disease was related to different levels of estimated radiation dose in a group of 3,441 persons who were exposed as children to radioactive iodine (I-131) from the Hanford Nuclear Site during the 1940s and 1950s.

While thyroid diseases were observed among the HTDS participants, the study results did not show an excess of thyroid cancers above the background level in populations not exposed to I-131. The study also found no association between dose to the thyroid from I-131 and the rates of thyroid disease in the study population. Those who had higher estimated radiation doses were not more likely to have thyroid diseases than those who had very low doses. In the final release of their report (June 21, 2002), the HTDS authors said “that if there is an increased risk of thyroid disease from exposure to Hanford’s iodine-131, it is probably too small to observe using the best epidemiologic methods available.”The final report added the results of a review of other studies and stated, “[T]he rates of thyroid disease in the HTDS population were

Despite the fact that no association was found between estimated I-131 radiation dose and cases of thyroid disease identified by the HTDS in the study population, the study results did not prove the absence of a link between I-131 and thyroid disease.

generally consistent with the rates of disease detected in other [non-exposed] populations."

Although no correlation was found between estimated I-131 radiation dose and the amount of thyroid disease identified by the HTDS in the study population, the study results do not prove the absence of a link between I-131 and thyroid disease. Although some individuals in the overall population who were exposed to Hanford radiation could have developed thyroid disease because of their exposure, the absolute numbers of thyroid disease found was consistent with the expected or natural background rates in an unexposed population..

Hanford Downwinders anectdotally reported numerous health effects that were believe to be associated with radionuclides, as discussed in Chapter 2. Health effects associated generally with radionuclides to which Hanford Downwinders and other have been exposed include: DNA damage, adverse endocrine gland (e.g., thyroid) effects, and tumors (benign and cancerous).

Iodine-131, has been associated in other studies, at higher dose levels, with thyroid diseases such as thyroiditis, hypothyroidism, and thyroid nodularity.. Health effects from acute (immediate or short-term) exposures to ionizing radiation include various types of cancers.

Health effects from low-level, chronic exposure to ionizing radiation are unclear.

Exposures to ionizing radiation from Hanford through the Columbia River were chronic (long-term) rather than acute and at lower levels.

In the past, the public has not had access to areas at Hanford contaminated with plutonium. Moreover, U.S. epidemiological studies have not shown clear associations between plutonium and human disease.[1] The public also did not have past access to uranium from Hanford.

8.5.2 Health Implications from Current or Future Exposures

Groundwater

[1]The 1995 and 1997 Tokarskaya epidemiological studies did find lung cancer, but at doses much higher than reported in American epidemiological studies. By contrast, both the Tokarskaya human studies and the Sanders 1988 animal studies show a decrease in lung cancer in the dose ranges used in the U.S. epidemiological studies.

On-site groundwater exceeds EPA drinking water standards for many substances, including antimony, arsenic, carbon-14, carbon tetrachloride, cesium-137, chloroform, cobalt-60, and tritium. On-site groundwater would not be safe to use as a drinking water source.

Soil and Sediment

The Hanford Site includes lands that were previously tribal lands in the nineteenth and twentieth centuries. Treaties reserve the rights for tribal members to hunt, fish, gather foods and medicines, and pasture livestock on Hanford lands (Jim 1997). Traditional tribal dietary and food preparation practices could result in harmful exposures if food were prepared by wrapping in contaminated soils. Exposures would occur to those who adhere to such practices at the most contaminated of the Hanford locations.

ATSDR identified three substances that might affect the health of future Hanford residents or subsistence food users. The three substances are lead, silver, and uranium; health implications of exposure to these substances are discussed later in this chapter.

Except for tribal land uses, subsistence on food sources from the Hanford site is unlikely, given DOE's commitment to restrict access and use institutional controls to limit future use to industrial use (McLeod 1995, DOE 1996a, c, DOE et al. 1996). Hanford Site deer and elk meat does not show contamination. For most of the contaminants now on site at Hanford, the public is not likely to be exposed—most persons do not have access to contaminated soil or plants on the Hanford site. Adult on-site workers in the future are not likely to experience harmful effects from exposure to such substances because under commercial and industrial use, the opportunity for contact or ingestion is limited.

Columbia River

Although the Columbia River is contaminated from past operations and from groundwater seeps, ATSDR believes that the concentrations at the drinking water intakes are too low to cause human health effects. Contaminants include lead, strontium-90, and tritium.

8.6 Effects on Specific Organs

The radiation dose to and effects on different parts of the body may vary depending on several factors, including the amount absorbed into the body, the distribution within organs or tissues, the mass of each of the organs or tissues, the half life of a particular radionuclide, and the physical and chemical nature of a radionuclide.

For example, strontium-90 (Sr-90) is chemically similar to calcium, so the body uses strontium in bones in much the same way it uses calcium. Sr-90 concentrates in the bone, and thus the organ (in this case the bone) receives a larger dose from this radioisotope than do other organs or tissues in the body.

Another example is I-131. The thyroid is thought to concentrate about 30% of the iodine taken into the body, with the remainder distributed throughout the body or excreted; the iodine dose to the thyroid is much more than the dose to the remainder of the body.

Other radioactive substances (e.g., tritium), do not concentrate in one organ, but are distributed uniformly throughout the body. Table 8-1 lists 11 major radioactive materials released from Hanford activities, the most vulnerable organs, and the physical half-lives of the radioactive material.

Table 8-1. Specific Organs and Half-Lives for 11 Radionuclides

Substance	Main Routes of Exposure	Specific Organs *	Physical Half-life †
Air Contaminants			
Iodine-131	ingestion	thyroid	8.04 days
Ruthenium-103	external inhalation	whole body lungs	39.27 days
Ruthenium-106	inhalation ingestion	lungs GI tract	1.02 years
Strontium-90	ingestion	bone	29.1 years
Plutonium-239	inhalation ingestion	lungs bone	24,100 years
Cerium-144	inhalation ingestion	lungs GI tract	284.6 days
Columbia River Contaminants			
Phosphorus-32	ingestion	bone	14.28 days
Zinc-65	ingestion	whole body	243.8 days
Arsenic-76	ingestion	GI tract stomach for infants	26.3 hours
Sodium-24	ingestion	stomach	14.96 hours
Neptunium-239	ingestion	GI tract	2.355 days

* International Commission on Radiological Protection: Various references.
† Reference (General Electric Company 1989).

8.7 Health Implications of Specific Substances

The substances listed in Table 8-2 were identified in Chapter 7 for further evaluation because they were detected in a completed exposure pathway at levels above comparison values, or they were further evaluated to address specific community concerns. ATSDR concluded that the substances in bold (iodine-131, lead, silver and uranium) were potential health hazards.

Table 8-2. Substances Selected for Further Evaluation

Substances	Air	Surface Water (Columbia River)	Game, Fish, or Vegetation	Soil and Sediment
Antimony			√	
Arsenic		√		
Barium			√	
Cesium-137*				
Cobalt-60*				
Iodine-131	√			
Ionizing Radiation (As-76, P-32, Np-239, Na-24, Zn-65)*				
Lead		√		√
Manganese			√	
Plutonium*				
Silver				√
Strontium-90		√	√	
Tritium		√		
Uranium			√	√

* Substances were not above screening criteria in a completed exposure pathway, but were evaluated to address community health concerns.

Past Exposure

Past exposure to iodine-131 can result in thyroid diseases including hypothyroidism, nodules, and thyroid cancer. The occurrence of hypothyroidism is 20 times greater than thyroid nodules and 80 times greater than thyroid cancer.

Very early stage hypothyroidism may be without symptoms. The earliest symptoms may make persons feel chronically tired and overly sensitive to cold. Muscle and joint aches often develop. Weight gain is common even though appetite diminishes. Constipation can be a problem, and premenopausal women may experience heavy periods or, in rare cases, a milky discharge from the breasts. As the activity of the thyroid gland diminishes over the following months, the skin becomes rough and dry, hair coarsens, and mental activity, including concentration and memory, become impaired.

Most health physicists concur that exposure to iodine-131 affects the thyroid, but there is disagreement about the dose levels above which effects may occur. Although the HTDS found no link between estimated I-131 radiation dose and the incidence of thyroid disease in the study population, the study results do not prove the absence of a link between I-131 and thyroid disease. Although persons in the overall population who were exposed to I-131 released from the Hanford Site could have developed thyroid disease, the actual incidence in the population was not greater than the expected background incidence from all natural causes.

Future Exposure

ATSDR identified three substances as having potential health implications for *future* Hanford residents or subsistence food users: lead, silver, and uranium. The health implications of these substances include:

Lead. Young children and fetuses could develop elevated blood-lead levels from future hunting and gathering in contaminated areas of the Hanford site—if the food is traditionally prepared by encasing the it in soil. Elevated blood-lead levels have been associated with neurological impairment, including hearing and intelligence quotient (IQ) deficits and slow growth in children.

Silver. If Hanford land returns to tribal use, some persons who eat food prepared by encasing it in soil could experience grey and blue-grey spots on their skin, known as argyria. Argyria is not known to cause any health problems or interfere with normal functioning.

Uranium. If medicinal herbs from the Hanford site (e.g., yarrow) are contaminated with uranium and are used to treat persons for blood in their urine, which is a possible sign of kidney injury or disease, it is possible that their kidney condition could worsen.

If land uses or future contamination levels change, the substance-specific health implications would change. ATSDR would then need to review data on contamination levels present at that time.

8.7.1 Antimony

ATSDR scientists found that antimony levels in plants was insufficient to cause harm via potential hunting and gathering exposure pathways, even if the most contaminated Hanford land is returned to traditional tribal use.

Surface water — Antimony was not detected in the Columbia River water (Duncan 1994, DOE 1993b).

Plants —ATSDR considered consumption of mulberry leaves and stems (DOE 1993b) in its evaluation of future subsistence food practices—including traditional tribal practices—on the most contaminated of Hanford land now held in trust for the tribes. ATSDR evaluated whether harmful effects could occur if the 1.3 to 10.1 micrograms (µg) of antimony per gram of mulberry leaves and stems (DOE 1993b) found represents the antimony concentration in edible wild fruits and vegetables. ATSDR assumed that 70-kilogram adult subsistence residents might consume a pound of wild fruit and vegetables daily from contaminated land, for a total of 0.6 to 4.6 mg antimony daily, or 0.008 to 0.066 mg/kg/day (ATSDR 1992b). A 10-kilogram child might consume ¼ cup (55 grams) of each fruit or vegetable per day, for a total of 0.07 to 0.6 mg antimony daily, or 0.007 to 0.06 mg/kg/day.

The EPA derived a RfD of 0.0004 mg/kg/day for chronic oral exposure, based on shortening of rats' lifespans as well as effects on their blood glucose levels when they ingested 0.35 mg antimony per kg/day (EPA 1998b). EPA lowered the observed-effect level by a factor of 1000 to allow for the possibility of greater sensitivity in humans, variation in human sensitivity, and the absence of an experimental level of exposure of the rats at which no harm was seen.

Other studies in which rodents swallowed antimony also reported effects on life span and glucose and cholesterol metabolism. Anyone who eats a pound of local wild mulberries daily would ingest 5 to 40 times less antimony than the amount in drinking water that harmed rats. Thus even if a pound of fruits and vegetables were ingested daily, all the fruits and vegetables were collected in the wild, and all were collected from the most contaminated Hanford land, antimony ingestion still would not result in adverse health effects.

Soil — There are no completed exposure pathways at Hanford by which the public could be exposed to antimony at levels that might lead to illness. Currently,

the public does not have access to contaminated soil at Hanford, plants growing in that soil, or groundwater under the soil (this groundwater is not used for drinking water).

Food Preparation — Food prepared in a traditional tribal manner might include encasing fish or game in moist, local soil before exposing it to the cooking fire. After cooking, the food is then pulled from the soil casing and consumed, possibly along with adhering soil particles (CTUIR 1995 March). If the most contaminated parts of the land held in trust for the tribes is released without use restrictions, antimony in the soil could be ingested by adults at doses up to those of small children with frequent hand-to-mouth (pica) behavior.

If these traditional practices are followed a 10-kg child might ingest a teaspoon (5 grams [g]) of soil per day and a 70-kg adult might ingest 2 tablespoons (30 g) each day. On-site surface soil was all below its detection limit. On-site subsurface soil antimony, which was not readily accessible to children with pica behavior or to adults gathering soil for traditional food preparation, varied from below its detection limit (1.5-10.4 mg/kg) to as much as 15.4 mg/kg (DOE 1992b). Because surface soil samples were below the detection limit and subsurface soil was poorly accessible, the daily consumption rate for either use would be well under 0.05 mg/kg/day. This is less than one-seventh of the amount that is harmful to rats.

If the same persons consumed wild plants and well water, they would not ingest enough antimony to harm them.

8.7.2 Arsenic

ATSDR determined that neither ingestion of arsenic-contaminated drinking water nor lifetime ingestion from foods prepared by traditional tribal cooking methods are expected to result in adverse health effects (cancer or non-cancer).

Arsenic is not a product or byproduct of any human activities known to have occurred at Hanford. The concentration of arsenic at the Hanford Site is similar to that expected naturally in regional soil and water, and its occurrence at reported concentrations is probably a natural phenomenon. The health effrects of arsenic were evaluated because reported arsenic concentrations are above ATSDR’s screening values.

Arsenic occurs in the environment in both inorganic and organic forms. In the absence of specific information about the form of arsenic present at Hanford, ATSDR made the worst-case assumption that all arsenic found on site in surface water and soil is in the much more toxic inorganic form.

Surface Water — Because Richland will probably supply drinking water to Hanford land when it is developed, any future residents are unlikely to drink groundwater. Arsenic in groundwater was found at 15 parts per billion (ppb) (DOE 1992b, 1993b, 1995f). Arsenic was found at 3 ppb in a some samples from springs that feed Hanford groundwater into the Columbia River but not elsewhere in the river, including samples from Richland's Columbia River intake (Duncan 1994, DOE 1993b). If a person drank 2 liters of river water at the maximum detected arsenic concentration (3 ppb) in the springs feeding groundwater to the river every day, their estimated lifetime exposure dose would be 0.00009 mg/kg/day (or 0.006 mg of arsenic daily).

Studies have not shown an increase in skin and other cancers in U.S. populations exposed to arsenic in drinking water (ATSDR 2000). A study of over 4,000 persons in Utah (Lewis et al. 1999) reported that an association did not exist between internal cancers (lung and bladder) and arsenic exposures in groundwater—but there were some study limitations. Several studies, however, have been conducted in non-U.S. populations.

Two recent studies on persons in Taiwan (Chiou et al. 2001) and Chile (Ferreccio et al. 2000), have shown associations with urinary and lung cancers, respectively. The authors reported that specific exposure levels (approximately 40 ppb for Ferreccio et al. (2000), and 50–100 ppb for Chiou et al. (2001) showed moderate to strong associations between arsenic exposure from groundwater and cancer. Based on this epidemiological evidence, one might expect to see an increased incidence of lung cancer at doses above 0.0011 mg/kg/day (approximately 40 ppb) and for urinary and bladder cancers at doses at or above 0.0014-0.0029 mg/kg/day (about 50-100 ppb).

Although the applicability of of cancer occurrence in non-U.S. populations to the U.S. is uncertain, these studies may be used to evaluate the likelihood of adverse effects in the Hanford population. EPA has stated that analysis of non-U.S. population studies for their new arsenic drinking water standard may overstate the risk to the U.S. population when the total consumption of inorganic arsenic (from food, food preparation, and drinking water) is considered (EPA 2000). The estimated exposure doses in the Hanford population and water concentrations are much lower than those reported to cause cancer in the Taiwanese and Chilean populations. As such, exposure to arsenic in drinking water is not expected to result in cancer.

Several studies have reported non-cancer effects from chronic human oral exposure to inorganic arsenic including effects on the liver, G.I. system, nervous system and skin at levels around 350 ppb or at doses ranging from 0.01 to 0.1 mg/kg/d (ATSDR 2000). ATSDR uses a No Observed Adverse Effect Level

(NOAEL) of 0.0008 mg/kg/d (approximately 28 ppb) from a Taiwanese population as the basis for the chronic oral minimal risk level. That said, however, this study did not account for contributions from food or food preparation. Schoof et al. (1998) estimated that dietary contributions from rice and yams would result in an approximate doubling of the NOAEL to 0.0016 mg/kg/d (approximately 56 ppb). The maximum detected arsenic concentration and estimated exposure doses are much lower then those reported to cause non-cancer effects. Therefore, exposure to arsenic in drinking water is not expected to result in non-cancer effects.

Using the studies of skin and of internal cancers developed by persons drinking water in Taiwanese villages with water wells containing different arsenic concentrations, EPA has derived a unit risk in water of 0.05/mg/liter (EPA 1998b). Because EPA assumes chemical carcinogenesis has no threshold, this value suggests that lifetime exposure to drinking water containing as little as 0.0002 milligrams per liter (mg/L or ppm) or soil containing as little as 4 mg/kg or ppm of inorganic arsenic might result in a slightly increased cancer rate in persons exposed in the United States.

Two bio-chemical mechanisms support existence of a threshold for arsenic. First, a growing body of evidence suggests that arsenic carcinogenicity may result from mechanisms other than by direct attack on genetic material, which would be consistent with a threshold (Stohrer 1991). A second reason to consider a threshold for arsenic is that humans and other animals change inorganic arsenic to a much less toxic, methylated organic form, which is readily eliminated from the body. This methylation is effective as long as the inorganic arsenic intake remains below a threshold of 0.2–1 mg/day (ATSDR 1993 [p. 56]).

Ingestion of less than 0.250 mg/day (0.004 mg/kg/day) does not affect blood arsenic concentration. Studies of non-Taiwan populations find an absence of arsenical cancers in areas where intake from drinking water is less than 0.400 mg/day (ATSDR 1993, Valentine et al. 1984). To consume 0.400 mg/day of arsenic, persons would need to drink at least 35 gallons per day, every day. Because this level of water consumption is not realistic, ATSDR believes that ingestion of arsenic from the most contaminated springs entering the Columbia River is not a potential health hazard.

Game — Hanford wild plants or animal carcasses were not tested for arsenic (DOE 1993b).

Soil — Although arsenic was estimated in Hanford surface soil at concentrations as high as 12.5 ppm, it was not verified at concentrations above 5.2 ppm (ATSDR 1997).

Food Preparation — ATSDR estimated that someone who prepared food in a traditional tribal manner might ingest as much as 2 tablespoons (30 g) of soil daily, containing up to 0.156 mg of arsenic (0.0022 mg/kg/day) for a lifetime.

ATSDR estimated that someone who cooked food in a traditional tribal manner might ingest as much as 0.156 mg arsenic (0.0022 mg/kg/day) daily for a lifetime at Hanford. We do not know if the human digestive tract can absorb arsenic from basaltic soil, and if so, to what degree. It is prudent to assume some absorption does occur. Yet even in the unlikely event that absorption is 100% and some persons ingest double this conservative estimate of soil, their arsenic intake would still be less than the amount seen worldwide that does not cause arsenical cancers.

8.7.3 Barium

There are no completed exposure pathways at Hanford by which the public could be exposed to barium levels that could cause harm.

The public does not have access to Hanford soil or plants, and levels of barium sufficient to cause illness in adults or children were not found in groundwater or river water. Should the most contaminated of Hanford land held in trust for the tribes be returned to traditional tribal use, ATSDR could find no evidence that barium in plants or surface soil was sufficient to cause harm when we considered exposure via the potential hunting and gathering pathway.

Vegetation — ATSDR considered whether traditional tribal members who subsisted on food sources from Hanford land in the *future* could be adversely impacted by ingesting contaminated fruits and vegetables. ATSDR assumed that the 23–94 µg barium per gram of mulberry leaves and stems represented the barium concentration in edible wild fruits and vegetables and that future 70-kilogram adult residents could consumed 1 pound of wild fruit and vegetables daily from the most contaminated areas. This would result in adult barium consumption of 10.4 to 43 mg daily, or 0.15 to 0.6 mg barium/kg body weight/day. A 10-kilogram child might consume ¼ cup (55 grams) of each fruit or vegetable per day, for a total of 1.2 to 5.2 mg barium daily, or 0.12 to 0.52 mg/kg/day.

EPA derived a reference dose (RfD) of 0.07 mg/kg/day for chronic oral exposure based on the absence of hypertension in persons drinking water containing barium at 7 to 10 mg/liter, a dose of 0.2 mg/kg/day (EPA 1998b). Because this population included adult males, who are the most likely to develop hypertension, EPA divided the known dose (0.2 mg/k/day) by an uncertainty factor of 3 rather than the usual 10 or 100 to establish the RfD (0.007 mg/kg/day).

ATSDR often derives a minimal risk level (MRL); that is, an estimate of daily human exposure to a substance that is likely to be without an appreciable risk of adverse, noncancer effects over a specified *duration* of exposure. ATSDR has not derived an MRL for barium because human studies did not report a chronic or subchronic barium intake level that did cause hypertension. Moreover, animal studies, with an uncertainty factor to account for possible different sensitivities to barium in animals and humans, would have led to an MRL lower than the estimated average adult barium intake from food, air, and water of 1.77 mg/day (0.025 mg/kg/day) (ATSDR 1992c, [pp. 34, 85]).

For this public health assessment, ATSDR searched the literature for information about the amount of barium needed to produce hypertension or other harmful effects in persons. Data from identified studies contained possible confounding variables: Brenniman et al. (1985) failed to find differences in blood pressure between persons drinking water with low (averaging 0.1 ppm) and high (averaging 7.3 ppm) barium concentrations (Brenniman, et al. 1981, Brenniman and Levy 1985). ATSDR could find no clear evidence of any adverse effects from chronic exposure of persons to barium.

Acute toxicity, which included high blood pressure, salivation, turning blue, diarrhea, and an irregular heartbeat, was identified from exposure to high doses of barium. These acute exposures were much higher than persons could receive from Hanford soil or vegetation (Schorn et al. 1991). To reproduce these acute effects, an adult would have to swallow, all at once, 18 to 128 pounds of the most contaminated surface soil, or eat 82 to 670 pounds of local wild fruits and vegetables. Because this level of consumption is not sustainable, ATSDR concluded that barium in soil or food from the Hanford site is not a health hazard.

8.7.4 Cesium-137

Cesium-137 was selected because of community health concerns, rather than for the magnitude of its dose to the public. Cesium-137, one of several radioisotopes of the element cesium, is produced inside nuclear reactors by uranium fission. Cesium-137 has a half-life of 30 years. Cesium-137 emits a beta particle spectrum with a maximum energy of 0.514 MeV and gamma rays with an energy of 0.662 MeV. It decays to stable barium.

Cesium shares similar metabolic pathways with potassium and sodium, being distributed throughout the soft tissues such as muscle. Absorption of cesium from the gut is considered 100% for radiation protection, but age-dependent excretion rates may occur (ICRP 1990a). Although long-term animal studies of the biological effects of cesium-137 have been conducted, they were high-dose studies to evaluate radiation-induced health effects. The doses in these studies were more

than 1,000 rads, much higher than even the highest doses received from fallout from atmospheric testing. The animal studies showing bone marrow destruction, cancers, and death involved radiation doses greater than 400 rads (NCRP 1977a).

Current guidelines and federal regulations limit the public's exposure to ionizing radiation to 100 millirem per year excluding medical exposures. The same guidelines apply for the public who visit DOE facilities such as Hanford. To protect against higher radiation doses known to cause harmful effects the DOE limits the whole body exposure of workers to 5,000 millerem per year (10 CFR 835.202), which includes both external and internal exposures (10 CFR 835.203).

For the purpose of conservative screening, ATSDR calculated the concentration of cesium-137 in biota, soil, or drinking water that could result in a 25 mrem dose to a 10-kilogram child ingesting as much as possible from the most contaminated samples found in each of these media. The selection criteria are conservative because the 100 mrem standard is protective of sensitive individuals and because children would consume some of their food taken from areas with less than the maximum level of contamination. As seen in Chapter 4 and 7 tables, cesium-137 was not present in the most contaminated samples at sufficient levels to generate a dose of 25 mrem in accessible soil, drinking water, or any biota. Because the Hanford site is and has been restricted in the past, childhood access to on-site Hanford contaminants is more plausible in the future. There is no Hanford exposure pathway for cesium-137 in drinking water, soil, or biota sufficient to cause illness in persons who might someday subsist on the Hanford Nuclear Reservation.

8.7.5 Cobalt-60

Cobalt-60 was selected because of community health concerns, rather than for the magnitude of its dose to the public. Cobalt-60 is the most important radioisotope of cobalt. It was produced in the Hanford nuclear reactors by neutron activation of natural cobalt metal, cobalt-59, with neutrons. Cobalt-60 decays by giving off a beta ray (or electron) with a half-life of 5.27 years, transforming into a stable isotope of nickel (atomic number 28). The decay is accompanied by the emission of two high energy (1.1 MeV) photons (gamma rays). Photon radiation is electromagnetic energy released during radioactive decay. Its energy is similar to visible light but is *hundreds of thousands of times* more energetic than visible light.

When we speak of exposure to cobalt-60, we are interested in exposure to the radiation given off by this isotope—primarily the gamma rays. Gamma rays, or photon radiation, are more penetrating and travel farther than other types of radiation such as alpha and beta particles. Current guidelines and federal

regulations limit the public's exposure to ionizing radiation to 100 millirem per year, excluding medical exposures. The same guidelines apply for the public who visit DOE facilities such as Hanford. To protect against radiation doses known to cause harmful effects the DOE limits the whole body exposure of health workers to 5,000 millerem per year (10 CFR 835.202), which includes both external and internal exposures (10 CFR 835.203). Because gamma rays lose energy rapidly with distance, the most injurious type of exposure is usually from within the body, or internal radiation.

To be conservative and pick up even the smallest risks, as with cesium-137 (see above), we screened soil, biota, and drinking water for concentrations of cobalt-60 that could result in a dose of 25 mrem to a 10-kilogram child ingesting as much as possible from the most contaminated samples found in each of these media. The selection criteria are conservative because the 100 mrem standard is protective of sensitive individuals and because children would consume some of their food taken from areas with less than the maximum level of contamination. As can be seen in tables from Chapters 4 and 7, no media sampled in any completed pathway contained sufficient cobalt-60 to cause illness in persons who might someday subsist on the Hanford Nuclear Reservation.

8.7.6 Iodine-131

Most of the iodine isotopes of interest at the Hanford site were produced by uranium fission in the plutonium-production reactors. The primary radioiodines of interest are I-131 and iodine-129 (I-129). The amount of I-131 released into the atmosphere from Hanford was about 740,000 curies. The half-life of I-131 is about 8 days. Therefore, releases from Hanford mainly involved mainly the processing of freshly irradiated fuels.

Iodine is an essential element that is required by the thyroid gland for production of thyroxin, a hormone that regulates metabolism, body weight, and the use of energy by cells. Because the thyroid gland accumulates the iodine it needs, this gland is the most susceptible organ to uptake of iodine-131 (I-131).

The decay of I-131 irradiates the thyroid tissue. At very high doses of radiation (1,000 rads), the thyroid gland is known to lose tissue and experience a decreased ability to produce thyroid hormones. Radiation can also induce thyroid cancer or benign growths.

The acute effects of I-131 exposure may include thyroiditis, hypothyroidism and thyroid nodularity (NCRP 1977b). An increased incidence of these diseases has been associated with radioiodines in fallout from atmospheric nuclear testing and some nuclear accidents. The incidence of benign thyroid disease is more common

than malignant thyroid cancer. Groups studied include Marshall Islanders, residents downwind from the Nevada test site, and residents near the Windscale reactor in the United Kingdom. Other studies have documented an increase in thyroid disease after exposure to radioiodine released during the Chernobyl reactor accident in Ukraine. Studies of Marshall Islanders who were exposed to I-131 during atomic weapons testing in the Pacific suggest that children are about twice as susceptible to noncancer thyroid conditions from exposure to I-131 as are adults.

Following the Chernobyl reactor accident, I-131 was measured in thyroids of children living in three areas in Ukraine. The highest estimated thyroid doses were 330 rads in infants and 50 rad in adults (Likhtarev et al. 1994). The Belarus Ministry of Health and the U.S. government are conducting a 15–30 year cohort study of Chernobyl-area populations to determine whether the exposure to I-131 will produce an increased incidence of thyroid cancer in children (Brill and Hull 1994). More recently, a combined study investigated exposures to over 100,000 exposed individuals in which 700 thyroid cancers had been observed. The results suggested that the incidence of thyroid disease may be proportionate to thyroid dose if exposure occurred before the age of 15.

Relative to their total body weight, newborn infants have larger thyroid glands than do older children and adults (NCRP 1977b). Therefore, the dose to (and any resulting adverse effects in) an infant's thyroid would be greater than to an adult ingesting or inhaling several times as much I-131. Also, the tissues of a child's developing thyroid gland are more sensitive to radiation exposure that are the tissues of an adult (NCRP 1977b).

Thyroiditis, or inflammation of the thyroid, has been associated with individuals with large intakes (more than 20 millicuries, or 20 million pCi per person) of I-131 for medical treatments.

Scientists who were part of the Hanford Environmental Dose Reconstruction (HEDR) project developed models for radioiodine exposure pathways and calculated doses to human thyroids from I-131 releases from Hanford. These dosimetry models and methods are being refined and updated as new information becomes available to the researchers. The HEDR dose estimates were used by epidemiologists at the Fred Hutchinson Cancer Research Center (Seattle, Washington) for an extensive follow-up study to determine the incidence of thyroid disease in persons who received the greatest exposure as children to iodine-131 from the Hanford Site.

Up to 1,400 children (including infants) living near Hanford during 1945 to 1955 could have been part of the group who received the highest exposure. The average

thyroid dose to this group could have been about 100 rads (PNL 1991). Of the off-site general public population, the person who would have been the most exposed to I-131 would have been a child born in January, 1945, in the Ringold area directly east of the Hanford site, along the Columbia River, who also drank milk only from backyard cows that were fed entirely on fresh pasturage from birth through the end of 1951. The HEDR scientists estimated that such a person could have received as much as 54 to 840 rads to the thyroid gland during the time of maximum I-131 release, 1945–1951 (TSP 1994). In contrast, the maximum dose to the thyroid from iodine-129, because of its long physical half-life and relative small amounts in the atmosphere, would have been about 1 rad (Robkin and Schleien, 1995).

Recommended Exposure Limits — The Nuclear Regulatory Commission regulates iodine releases from nuclear power plants (10 CFR 20), and DOE limits exposures to workers in DOE facilities (10 CFR 835). The EPA's maximum concentration limit for iodine-131 in public drinking water sources is 100 pCi/L. The International Commission on Radiological Protection's annual limit on intake (ALI) for ingestion is 21.6 million pCi, and the ALI inhalation is 27 million pCi (ICRP 1991).

The probability of cancer induction is very low but increases with dose over the range of about 1 Gy (100 rads) to about 100 Gy (10,000 rads). Radiation doses in the range of 150 Gy to 300 Gy (15,000 to 30,000 rads) are required to treat successfully thyroid cancer using iodine-131 (NCRP 1977b). Iodine-131 is the most common treatment for patients with hyperthyroidism, a condition of overactive hormone production. Radiation from I-131 is used to destroy some of the tissue and reduce the production of thyroid hormones.

8.7.7 Ionizing Radiation (including As-76, P-32, Np-239, Na-24, and Zn-65)

Ionizing radiation includes charged particles (alpha and beta), gamma rays, and neutrons from both radioactive materials and radiation-generating devices. The health effects of ionizing radiation have been studied extensively and are known for high doses. The health effects at low doses however, such as those found in the environment, are not known.

For radiation protection, national and international scientific organizations have set safety limits for radiation exposure of workers and members of the general public. These limits do not apply to medical treatments or diagnostic procedures involving radiation sources. The regulatory limits are currently 100 mrem for members of the general public and 5,000 mrem for radiation workers (10 CFR 835.202). These limits apply to workers at, and members of the public who visit, DOE nuclear

facilities. They include exposure to both external gamma sources and radionuclides that may be taken into the body. For comparison, a typical natural background exposure rate in the U.S. from cosmic radiation and terrestrial sources is about 200 to 300 mrem per year.

Because the public does not have access to the most contaminated parts of the Hanford site, they are not currently exposed externally to on-site ionizing radiation. At the administrative areas on the site radiation levels are below the limits for the general public.

The health effects resulting from exposure to ionizing radiation have been studied for radium dial painters, uranium miners, the atomic bomb survivors of Hiroshima and Nagasaki and, more recently, the populations affected by the Chernobyl accident. The health effects associated with external exposure to ionizing radiation received during the atomic bombings include various types of cancers, such as multiple myeloma and cancers of the esophagus, stomach, bone, liver, and colon. Noncancerous radiation-related effects include mental retardation and brain dysfunctions, benign (noncancerous) tumors of the parathyroid gland, and ocular damage. Evidence of cancer in offspring of atomic bomb survivors suggests that although the rates of childhood cancer were not significantly elevated, rates of adult cancers might be increasing (Schull 1995).

The acute, short-term radiation doses atomic bomb survivors received were much higher than the highest environmental levels detected at the 200-Area tank farms or other locations at Hanford. The exposures at Hanford are considered chronic, long-term exposures. Over most of the 200-Area, especially the tank farms, the exposures are elevated above background levels but less than 1 rem/year. Elsewhere at Hanford, exposures were lower.

In the past, Hanford's releases exposed persons off-site to radiation. Scientists of the HEDR project estimated that five isotopes (Na-24, P-32, Zn-65, As-76, and Np-239) contributed 94% of the estimated whole-body dose, which combines doses from ingestion of drinking water, resident fish, shellfish, waterfowl, and salmon, as well as from external exposure by swimming and proximity to the shoreline. Doses were estimated for three types of representative individuals: 1) the representative person who consumed the highest rate of resident fish and spent much time in or near the river, 2) the average representative person who lived near the river but ate little or no fish, and 3) the occupationally exposed person who was employed on the river (e.g., a barge worker), but also consumed little or no fish.

The Columbia River Basin tribes consume considerably more fish than does the general population (CRITFC 1994), but they tend to prefer fish that spend some

time in the ocean, such as salmon and steelhead. The HEDR used bioconcentration factors to estimate the dose that local fish could have imparted when ingested by persons having varying fish consumption rates. For the maximum user assumptions, scientists applied these bioconcentration factors to salmon and steelhead, but monitoring data for salmon during this period showed most specimens had undetectable radioactivity. Where radioactivity was detectable, contamination levels were 6-10 times lower than those calculated from bioconcentration factors for the maximum dose estimates (TSP 1994 [p. 44]).

Using the maximum dose estimates and a three-meal-a-day rate of fish consumption, HEDR project results did not indicate that the recommendations for public whole-body exposure were exceeded. No 5-consecutive-year period produced a mean annual estimated dose that exceeded 500 mrem, and the lifetime (70 years including the maximum release years) annual mean was not shown to exceed 100 mrem per year (ICRP 1977, 1990b, NCRP 1993, TSP 1994).

Using these assumptions, HEDR scientists calculated that a maximum exposed person living in Richland, Washington could have received a whole-body dose of 1,500 mrem during 1944 through 1992 (a mean of 30 mrem per year). This compares to a cumulative thyroid dose of 54 to 870 rad to infants in Ringold consuming milk from backyard cows fed on fresh pasturage 1945 to 1951 (a mean of 9,000 to 145,000 millirad per year) that failed to produce a measurable increase in disease rate.

Under certain conditions when exposures exceed at least 10 rad to any one organ following an acute exposure, the health effects of ionizing radiation exposure are clearly defined. When low radiation exposures or doses spread diffusely throughout the body and have occurred over a long period (chronic exposure), as is the case at Hanford, the effects are not detectable.

8.7.8 Lead

There are no completed exposure pathways by which the public *currently* could be exposed to lead at Hanford at levels sufficient to harm health. The public does not have access to Hanford soil or plants.

Future hunting and gathering in the contaminated parts of Hanford might elevate blood-lead levels in young children if the food is consistently prepared by traditional tribal methods involving encasing the food in soil. Elevated blood-lead levels have been associated with neurological impairment.

Should Hanford land revert to traditional tribal use, persons subsisting on the land would get most of their fruits, vegetables, fish, and meat from that land locally by

hunting, fishing, and gathering. Lead contamination was not analyzed in local plants.

Game — Market meat, fish, and poultry contain lead at 0.002 to 0.159 micrograms per gram (μg/g), which adds about 4.54 μg to the typical U.S. diet (ATSDR 1990a). In Hanford mouse carcasses, lead ranged from 1.2 to 2.4 μg/g (DOE 1993b), which can serve as a conservative surrogate for game.

Lead is a bone-seeking contaminant, which may explain the difference between market meats and wild animal carcasses; the wild carcass includes the bone. If the servings (with bones) are marinated in acidic seasonings (e.g., with lemon, vinegar, or semi-sour berries), partial solution of bone calcium could disrupt the bone matrix enough to allow some leaching of lead into the meat, blurring the distinction between bone-lead and meat-lead. Similar leaching could occur in the making of soups or if the game (with bone) is stewed.

Vegetation — Because lead is not biomagnified in terrestrial food chains (ATSDR 1990a), ATSDR assumed this range (1.2 to 2.4 μg/g) for local edible plants. ATSDR estimated that adults consume 454 g local wild fruits and vegetables along with 170 g of meat from land animals, and that children might consume 55 g of each fruit and vegetable and 30 g meat from land animals. The lead content of these diets could range from 0.75 to 1.5 mg lead/day (0.011 to 0.021 mg/kg/day) for adults and from 0.10 to 0.20 mg lead/day (0.01 to 0.02 mg/kg/day) for children.

If future Hanford land use is unrestricted, an adult subsisting entirely on wild plants and animals might have blood-lead levels increased by as much as 2.4 μg/dl, and children's blood levels could increase by as much as 1.6 μg/dl. These blood-lead concentrations would not be expected to result in lead toxicity in adults, including pregnant women, or in young children.

Soil — Most of the Hanford surface soil sampled since remediation contains lead within the expected range of concentrations in the state of Washington (Dragun and Chiasson 1991, DOE, 1990a). Elevated concentrations of lead were only found at the Hanford sanitary sewer trenches. Surface soil contained lead at 400 to 500 ppm in two out of three samples, compared to background levels of about 11 ppm (DOE 1990a, 1992b).

The bioavailability of lead in soil can vary considerably, depending on particle size, chemical composition, and other factors. In the absence of information about bioavailability of the lead contamination above the sewers, ATSDR made the assumption of 100% bioavailability.

Food-wrapping with dirt would lead to a soil lead intake of up to 0.21 mg/kg/day (Xintaras 1992). ATSDR calculated that cooking food wrapped in this soil could increase blood-lead levels by 10 μg/dl (Xintaras 1992). If food were prepared with soil from a sanitary sewer area, pregnant women could have sufficiently elevated blood-lead levels to affect the development of their fetuses, and children could have neurological impairment (Xintaras 1992 [p. 17]).

In the event of future unrestricted access to Hanford land, strict adherence to traditional tribal food preparation (eating soil-encased food) could elevate blood-lead levels in children sufficiently to put them at risk for neurological impairment.

Monitoring of blood levels is warranted when increases of this magnitude are suspected. Nevertheless these implications apply only in the future, only if land use becomes unrestricted, and only to those who subsist entirely on Hanford plants and animals and adhere to the traditional tribal practices (e.g., hunting and gathering of wild plants and animals and soil-encased food preparation).

Surface water — The highest lead concentration (17.5 ppb; comparison value 15 ppb) was found at a 100-Area seep. This seep is not used as a public or private drinking water source. The cross-sectional flow of the Columbia River averages 3.4 million liters per second (120,000 cubic feet per second [ft3/sec] or 54 million gallons per minute) (DOE 1992c). At the nearest public water supply intake downriver from this seep, at Richland, lead is below its 2 ppb level of detection. Thus, no adverse health effects are anticipated from drinking Columbia River water.

8.7.9 Manganese

There is no completed exposure pathway by which the public could *currently* be exposed to manganese at Hanford at levels that could make them ill because the public does not have access to manganese-contaminated parts of the site, including contaminated surface soil, plants, animals, or groundwater. If the land reverts to traditional tribal use in future decades, persons who subsist on Hanford lands would not experience manganese toxicity.

Manganese is an essential trace element (NAS 1989, EPA 1998b). The estimated safe and adequate daily dietary intake for an adult has been variously estimated at 3.5–7, 2–3, and 8–9 mg/day (NAS 1989, EPA 1998b). Persons who have a vegetarian diet or eat an abundance of fruits and vegetables and relatively little meat absorb manganese poorly and may require quite a bit more (EPA 1998b).

ATSDR's estimated provisional EMEGs (of 6.6 μg manganese per gram of wild fruits and vegetables for children and 22 μg for adults) assuming that a 70-kg adult

required 10 mg/day. If persons are subsisting on a diet with little meat, then manganese would be absorbed poorly and persons would need to eat wild plants with manganese concentrations much higher than the provisional EMEGs to reach dietary needs.

Inadequate *dietary* intake of manganese has been associated with epilepsy, multiple sclerosis, cataracts, and osteoporosis (EPA 1998b). Although *inhaled* manganese has been demonstrated to cause neurotoxicity, chronic *oral* toxicity has been difficult to establish (EPA 1998b).

Soil — Manganese content in surface soil is well within the range normally found in western U.S. soils (Dragun and Chiasson 1991, DOE 1992b).

Vegetation — The manganese content of local plants is not likely to produce toxicity in persons who might subsist in the area in the decades to come.

Food Preparation — Preparation of food using traditional tribal methods that could result in ingestion of local surface soil is not more likely to result in manganese toxicity than elsewhere in the western U.S.

8.7.10 Plutonium

Plutonium is a man-made element. Reactors were established at the Hanford Site to produce plutonium, an element in nuclear weapons. Plutonium production, chemical processing, separations, packaging, and waste-handling activities resulted in plutonium contamination of buildings and soils. The most common plutonium isotopes found at Hanford are plutonium-238, plutonium-239, plutonium-240, and plutonium-241.

The general public is not *currentl*y exposed to plutonium at the Hanford site or to off-site releases that could cause illness or health effects of concern. Some soils at the Hanford Site are contaminated with plutonium, but public access to these contaminated areas is restricted. Most of the contaminated soils are in the 200-Area. The major source of public exposure to plutonium at other locations is fallout from nuclear weapons testing.

If taken into the body by inhalation or ingestion, the metabolic behavior of plutonium depends on its chemical solubility. Soluble forms of inhaled plutonium dissolve in blood and may be transported to the liver or bone surfaces, where plutonium is retained for a long time. Insoluble forms of inhaled plutonium are retained for long periods in the lungs and associated lymph nodes. Ingested plutonium is poorly absorbed from the gastrointestinal tract (NRC 1988) and is almost totally excreted.

Alpha particle radiation from plutonium in the lungs, liver, and skeleton are associated with cancer. No clear evidence of cancer has been established in long-term epidemiological studies of U.S. workers who have inhaled or ingested plutonium (Boice Jr. 1992, NRC 1988), but a dose-response has been shown in beagle dogs exposed to moderate levels by inhalation or direct injection.

Regulations limit plutonium releases from nuclear power plants (10 CFR 20) and plutonium exposures to workers at DOE facilities (10 CFR 835). Annual limits on intake recommended for workers by the International Commission on Radiological Protection vary from 1 to 54 million pCi, depending on isotope and solubility (ICRP 1991).

The EPA drinking water standards for plutonium-239, -240, -241, and 243, based on a dose of 4 mrem/year, range from 5.9 to 17,400 picocuries per liter [pCi/L].

8.7.11 Silver

A completed exposure pathway for silver did not exist in the past and does not currently exist at Hanford because the public has not had access to silver-contaminated parts of the site. If planned institutional controls are successful and contaminated parts of Hanford remain industrial, the public will not experience adverse health effects from silver in Hanford surface soil in the future. If, however, contaminated parts of Hanford return to tribal use, it is possible that some of the persons who eat food prepared by traditional tribal methods involving encasing the food in soil may experience argyria, which is grey and blue-grey spots on the skin. There is no evidence that argyria interferes with persons's health, well being, or other normal functioning (ATSDR 1990b).

When persons handle products or media containing silver-bearing chemicals, the chemicals can deposit on and in their skin. The silver is then changed to silver metal by light, forming grey or blue-grey patches on the skin (argyria). Around the turn of the century, many oral medicines contained chemically combined silver, and argyria was common. Argyria is not often seen now as a result of oral intake of silver.

If contaminated parts of Hanford return to tribal use, some persons who eat food encased in soil that contains high enough levels of silver may experience grey and blue-grey spots on the skin (argyria), which are not known to cause any health problems.

EPA derived an oral RfD of 0.005 mg/kg/day for argyria based on injected silver solutions and assumptions about human ability to absorb ingested silver compounds; the estimated lowest oral dose that could cause argyria was 0.014

mg/kg/day, which was then divided by 3 to protect sensitive individuals (EPA 1998b).

Soil — In the past, silver concentrations in Hanford surface soil have been as high as 320 ppm at the sanitary trenches. Since the trenches have been remediated the highest silver concentration is 35.8 ppm (DOE 1992b). Should the contaminated parts of Hanford be released to unrestricted use, the amount of soil normally ingested by children and adults would not result in argyria.

Food Preparation — That said, if future land use at Hanford becomes unrestricted and if persons spending most of their time at Hanford use traditional tribal practices (e.g., hunting and gathering; encasing food in soil prior to cooking) exclusively at the most contaminated Hanford areas, they could ingest sufficient soil that they might, over many years, develop argyria.

8.7.12 Strontium

Strontium-90, a radioactive form of strontium, is a fission product produced by nuclear reactors. Strontium-90 has a half-life of 29.1 years. During its decay it emits a beta particle spectrum with a maximum energy of 0.546 MeV. Strontium-90 decays into yttrium-90 (Y-90), which is also radioactive, has a half-life of 2.67 days, and emits an energetic beta particle spectrum (maximum energy of 2.2 MeV) and a 2.3 MeV photon.

Early studies recognized strontium-90 as a possible health hazard because it is chemically similar to calcium and has a relatively long physical half-life. Internal strontium-90 accumulates in bone. The primary health effect observed in animals was induction of bone cancers. After ingestion by an adult, 20–30% of the strontium is absorbed and deposited in bones and the remainder circulates in the blood or is excreted in urine and feces. Following ingestion of an equal amount of strontium-90 an infant or child could receive a higher effective dose than an adult (ICRP 1994).

Many radiation studies on the effects of Sr-90 uptake were animal studies (e.g., dogs, monkeys, swine, and mice). They showed that very high levels of radiation were necessary to produce adverse health effects, such as bone cancers, leukemia, and death. Lower doses, such as 100 rads, did not produce these observable adverse effects. No direct studies exist for human exposure to strontium-90; however, strontium has biological properties similar to radium. Using this relationship, researchers have sought to correlate radium exposure to strontium exposure. According to NCRP (1991) these studies suggest that it would require a strontium-90 radiation dose of 1,000,000 rads (one billion millirads) to induce one bone cancer or three cases of leukemia.

The Nuclear Regulatory Commission regulates the release of Sr-90 from nuclear power-generating plants (10 CFR 20). DOE also limits exposures to occupational workers (10 CFR 835) in its facilities. The EPA MCL for strontium-90 in public drinking water is 57.3 pCi/L, based on a dose of 4 mrem/year. For surface soil, ATSDR has adopted NCRP 129 (1999), using as screening values contamination levels associated with a dose of 25 mrem per year under the conditions of commercial or industrial use likely at Hanford in the future. Strontium-90 was not found above this comparison value in soil in a completed exposure pathway at Hanford. For biota, we screened for concentrations of strontium-90 that could result in a dose of 25 mrem to a 10-kilogram child ingesting as much as possible from the most contaminated samples found. The selection criteria are conservative because the screening thresholds are very much below the one billion millirad dose (approximately 1 billion millirem to the body) estimated to result in a blood or bone cancer, and because persons who might subsist on the site in the future are unlikely to take all their meat, fruit, vegetables, and water from the most contaminated of those found at the site.

Surface water — Strontium-90 does not enter the public's drinking water in significant amounts. It was found in monitoring wells near N-reactor as high as 83.5 million pCi/L by DOE (1997a), Westinghouse (1992b, 1995a, 1995c), and DOE (1992a, 1993a, 1995b). By the time it reached the Columbia River at N-Springs, DOE (1997a) reported that its highest concentration was 10,900 pCi/L. In the mainstream of the Columbia River during Hanford's active years 1944–1971, strontium-90 averaged 1.27 pCi/L (Risk Assessment Corporation 2002), and it is no longer detectable at the Richland pump-house intake (McBaugh 1996). The dose associated with a drinking water concentration of 1.27 pCi/L is 0.09 mrem per year, which is considerably less than the one billion millirad estimated to cause a case of bone or blood cancer.

Vegetation — ATSDR considered whether traditional tribal members who subsisted on food sources from Hanford land in the *future* could be adversely impacted by ingesting contaminated fruits and vegetables. For screening, ATSDR assumed that a 10-killogram (1-year old) child could average as much as a quarter cup (55 grams) of white mulberries every day of the year. At 88 pCi/g, this would result in a dose of 487 mrem per year. This is considerably less than the one billion millirad estimated to cause a case of bone or blood cancer. To receive a billion millirad from eating mulberries, the child would need to eat 123 tons of berries daily. In reality, the berries would not be available from contaminated sources out of season. In season, they would be supplemented with berries from less contaminated sources; and ATSDR site visits found that the most contaminated plants near the river have been cleared from the shoreline. Thus, blood or bone cancer from strontium in Hanford vegetation is unlikely.

Fish and Game — Fish contamination is currently below screening values. As for past fish consumption, a recent refinement of HEDR river dose estimations by RAC (2002) reported that "results did not support the suggestion that the HEDR Project should have made dose calculations for [iodine-131 and strontium-90]. Although they were not eliminated in the initial screening, they were identified as low priority in all three exposure scenarios (ranked 10 out of 15). [RAC scientists] accounted for the consumption of whole fish including the bones by Native Americans; however [their] research indicated it was unrealistic to assume whole fish were consumed year round in large quantities. For this reason the dose and risk for strontium-90 (and strontium-89) was not increased significantly from the HEDR estimates."

Strontium concentrates in the bony parts of game species. The most contaminated samples reported were from mule deer antlers and rabbit bones. If future families subsisted entirely on Hanford land, they might prepare meat stocks by boiling these bones and antlers and using the concentrated stock to thicken stews. We estimated a 10-kilogram child could eat the extract from as much as 10 grams of bones in one day. If this ingestion rate were followed consistently, a dose of 79 millirad per year could settle in the child's bones. This is less than the one billion millirad needed to cause bone or blood cancer. For such a dose, the child would need to ingest the extract from 139 tons of rabbit bones per day contaminated at the maximum reported levels. In reality, most rabbit bones or deer antlers would be less contaminated than these samples (the most contaminated that were found). Thus illness from ingesting Hanford-contaminated fish or game is unlikely.

8.7.13 Tritium

Tritium (H-3) is the only radioactive form of hydrogen, the lightest and simplest element. Tritium decays by releasing a beta particle, identical to an electron, with a maximum energy of 18,600 electron volts [2]. The half-life of H-3 is 12.26 years, which means that half the initial amount present is gone after 12.26 years. The decay product is helium-3, a nonradioactive form of helium. The ionizing radiation energy of H-3 is very weak and presents no external radiation hazard. The internal radiation dose resulting from ingestion or inhalation is quite small per unit intake. Tritiated water is believed to be rapidly and uniformly distributed among all soft tissues following its intake. According to ICRP (1979, 1990a) retention in body water is assumed to have a half-life of 10 days, and longer if the H-3 is incorporated into organic materials such as carbohydrates, fats, and proteins.

[2]An electron volt is a unit energy used to describe extremely small amounts of energy. In 10 hours a 100-watt light bulb consumes about 2,200,000,000,000,000,000,000,000 (2.2×10^{25}) electron volts.

Cosmic ray interactions in the atmosphere and in nuclear reactors produce tritium. Several federal agencies have developed environmental regulations for H-3. The Nuclear Regulatory Commission limits the release of tritium from nuclear power plants to water and air (10 CFR 20), and DOE limits H-3 exposures in air to occupational workers at its facilities (10 CFR 835). The EPA bases its MCL of 77,200 pCi/L on the current regulatory limits for H-3 in drinking water for public consumption (4 mrem).

Surface water — Tritium does not enter the public's drinking water in significant amounts. Although it was found in a monitoring wells near the 100 K reactor at more than 3 billion pCi/L, its highest concentration upon entering the Columbia River was 173,000 pCi/L in an Old Hanford Townsite spring, which is not a drinking water intake. At the Richland Pump-house intake, its concentration generally runs below 200 pCi/L, for a dose to the public of 0.01 mrem.

No current completed exposure pathways in Hanford exist that would result in exposures to tritium higher than this. Using current knowledge of low dose health effects, such exposures as these to tritium are unlikely to result in any resultant measurable or detectable health effects.

8.7.14 Uranium

The general public is not exposed to uranium at the Hanford site or to off-site releases that could cause illness. Some soils at Hanford were contaminated with uranium, but public access to these contaminated areas has been restricted. They are not part of a current or past pathway. Soils contaminated with uranium in the process trenches have been remediated and cannot be part of a future pathway. The levels of uranium contamination in Hanford soils are not sufficiently high to cause harmful health effects in healthy persons, even with unrestricted use. If, however, uranium-contaminated medicinal herbs from Hanford are used to treat persons whose kidneys are impaired for other reasons, it is possible that their condition could worsen if the uranium is at high enough concentrations.

The health effects of high-level exposures to uranium are well known and include kidney toxicity in humans and animals (EPA 1998b). The EPA-recommended limit on intake of uranium is 3 μg/kg/day for soluble uranium (EPA 1998b). The RfD is equivalent to a drinking water concentration of 100 parts per billion for a 70-kg adult drinking 2 liters daily.

If medicinal herbs, such as yarrow, contaminated with uranium are used to treat persons whose kidneys are impaired for other reasons, it is possible that their condition could worsen.

The International Commission on Radiological Protection has also recommended 100 parts per billion as a drinking water standard protective against kidney toxicity when limiting the kidney-uranium concentration to 3-μg per gram kidney (Wrenn et al. 1985).

Gastrointestinal absorption of insoluble uranium, which is the form present in past contaminated parts of Hanford because of soil and soil and groundwater pH, has been estimated at 0.2% (Kocher 1989). Higher concentrations of insoluble forms of uranium (compared to soluble forms) may be needed to cause kidney injury (Leggett 1989).

Food Preparation — The amount of insoluble uranium in surface soil that might cling to ingested food prepared by traditional methods would not be likely to cause kidney toxicity in healthy persons who might subsist in the area in future decades.

Vegetation — (Lust 1974) states, however, that if yarrow contaminated with up to 24 μg uranium-238 per gram of plant tissue is used to treat persons for blood in their urine, —a possible indication of kidney injury or disease— a possibility of harm could arise.

The appearance of uranium in the plant tissues may indicate that the uranium has become solubilized. A 10-kilogram child's daily dose of uranium from 15 g yarrow could be as high as 0.36 mg (3.6 mg/kg/day), which is almost twice the dose that caused moderate injury in healthy rabbits (EPA 1998b). A 70-kilogram adult's daily dose of uranium from 60 g yarrow could reach 1.4 μg, or 20 μg/kg/day to a 70-kg adult), about 1% of the dose that caused moderate injury in healthy rabbits (EPA 1998b). It is possible, but unlikely that this much soluble uranium would exacerbate a kidney problem being treated with the yarrow (DOE 1992b).

9

Public Health Action Plan

Outline

This Public Health Action Plan (PHAP) for the Hanford Site in general, and the 100-, 200-, and 300-Areas in particular, describes actions taken and those to be taken by ATSDR and other agencies.

9.1 Completed Actions

National Iodine-131 Education Project

Through a cooperative agreement with ATSDR, the American College of Preventive Medicine (ACPM) has provided education to health care professions. Activities included distribution of educational materials, such as the *Iodine-131 Case Study in Environmental Medicine* developed by ATSDR. The ACPM also developed an entire web page, http://www.iodine131.org/, devoted to educating health care professions about I-131.

Health Studies

Appendix B, Hanford Health Studies, provides a description of the study purpose, results, study completion dates, methodology, principal investigators and funding sources. The studies are divided into three categories: community health effects, studies of Hanford workers, and research data sources.

9.1.1 Community Health Effects

Studies that focused on the health of people living near Hanford include:

- Hanford Infant Mortality and Fetal Death Analysis, 1940–1952
- Epidemiologic Evaluation of Childhood Leukemia and Paternal Exposure to Ionizing Radiation
- Hanford Thyroid Disease Study (HTDS)
- The R-11 Survey
- Northwest Radiation Health Alliance Survey
- Hypothyroidism and Spontaneous Abortion
- Hypothyroidism in Children Living Near Hanford and Chernobyl

9.1.2 Studies of Hanford Workers

Studies that looked at the health of Hanford workers include:

- Hanford Mortality Study
- Re-analysis of Hanford Data
- Relationships Between Age at Exposure and Cancer Risk

- Multiple Myeloma Among Nuclear Workers
- Mortality Among Female Nuclear Weapons Workers
- Multi-site Study of Heat Stress among Carpenters
- Surveillance Methods for Solvent-Related Hepatotoxicity
- Exposure History for the Construction Trades
- Comprehensive Occupational Health Surveillance

9.1.3 Research Data Sources

Several data sources have been established to provide public access to health and exposure data collected during studies of Hanford facilities. They include:

- The Comprehensive Epidemiologic Data Resource (CEDR)
- Hanford Health Information Archives (HHIA)
- The United States Transuranium and Uranium Registries (USTUR)

9.2 Actions Planned by ATSDR

9.2.1 Hanford Community Health Project

In the fall of 1999, ATSDR initiated the Hanford Community Health Project (HCHP). The project seeks to provide educational information and materials about potential health risks to individuals who were exposed as young children to past releases of I-131 between1944 and 1951. The project's goal is to assist individuals and their health care providers in making informed health care choices concerning these exposures.

Information about the HCHP can be found at the ATSDR Web site http://www.atsdr.cdc.gov/hanford/. This Web site makes available materials that have been developed by several government agencies including ATSDR, CDC, and the National Cancer Institute. On the HCHC Web site you can read and print fact sheets about Hanford and how I-131 can affect the health of those who were exposed to Hanford releases of I-131; print an order form to request materials be mailed to you; and see other Web sites that contain useful information about Hanford and I-131.

HCHP developed a physician's treatment guideline to aid in addressing thyroid disease concerns of patients who consider themselves at risk from Hanford I-131 releases. The guideline was distributed to over 26,000 physicians in the California and the Pacific Northwest.

9.2.2 Ongoing Health Studies

Birth Cohort Study

ATSDR conducted the Hanford Birth Cohort study in response to community concerns that autoimmune function and cardiovascular disease health effects may have resulted from exposure to radioactive releases, mainly I-131. The study found that men born near the Hanford site between 1945 and 1951 had a small increased risk of developing thyroid disease – Hashimoto's thyroiditis, a condition that occurs when the thyroid gland makes too little thyroid hormone. The percentage of women reporting Hashimoto's thyroiditis was consistent in all counties surveyed. The study did not find a link between I-131 and autoimmune and cardiovascular diseases in either men or women. Although study participants reported some health problems more often than the general population, other factors such as diet, lifestyle and work history make it difficult to determine if their exposure to radiation is a cause for these findings.

The preliminary study findings were presented at an ATSDR-sponsored public availability session on July 26, 2006 in Richland, Washington. The final report is expected to be released in October 2006. The complete study can be found online at http://www.atsdr.cdc.gov/hanford.

9.2.3 Toxicological Profiles

Toxicological profiles identify the full range of health effects, by duration and route of exposure, observed in animals and humans from exposure to particular substances. They also identify relevant chemical, physical, and radiological information, the production, import, export, use, and disposal of those substances, their potential for human exposure; analytical methods; regulations and advisories, and toxicological data gaps for which additional research is needed. The principal audiences for the toxicological profiles are government health professionals, interested private sector organizations and groups, and members of the public.

As funding is provided, ATSDR plans to continue preparing toxicological profiles for substances and their relevant radioactive isotopes. The radioactive substances released during past Hanford operations for which ATSDR has prepared toxicological profiles includes:

- Iodine (including I-131),
- Cesium (including Cs-134 and Cs-137),
- Strontium (including Sr-89 and Sr-90),
- Cobalt (including Co-57, Co-58, and Co-60),

- Tritium, and
- Thorium.

ATSDR has published toxicological profiles for uranium and ionizing radiation. . New profiles for americium, cesium, cobalt, iodine, and strontium were published in 2004. Old (1990) profiles for radium, radon, thorium, and plutonium are available, but these are limited in scope and contain dated material; significant newer material is available. The profile user will benefit when these four documents are updated with current science and enhanced to include sections now contained in current profiles (e.g., child health).

9.3 Actions Planned by DOE

100-Area

For the 100-Area, DOE plans eventually to dismantle and decontaminate the reactor facilities and spent fuel facilities along the Columbia River. In general, the bulk of the 100-Area is likely to remain a wildlife refuge.

200- and 300-Areas

DOE plans institutional controls to maintain industrial use of the 200- and 300-Areas. The following institutional controls are planned:

- Placement of written notification of remedial action in the facility land use master plan,
- DOE prohibition of activities that could interfere with remedial activity,
- Prior to property transfer or lease, Environmental Protection Agency (EPA) review of measures necessary to ensure continued restrictions,
- Notification to prospective property recipient before transfer or lease, and
- Provision of written verification to EPA that restrictions are in place. Please see, for example, DOE, EPA, WADOE, 1996, page 62.

For the 300-Area, DOE plans to excavate soil above its cleanup level of 15 millirem/year assuming industrial land use. DOE equates this level with a total uranium concentration of 350 picocuries per gram (DOE, EPA, WADOE 1996, [pp.45, 52-54, 61]).

Until contaminants are below health levels, DOE selected an interim remedial action for 300-Area groundwater. Final remedial action will await determination of peak levels of contaminants in-migrating from other groundwater sources (DOE, EPA, WADOE 1996, [p. ii]).

10

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11

Contributors

Outline

The Hanford Public Health Assessment was prepared with input from many individuals. Contributors have diverse backgrounds and viewpoints. The four main sources of input were ATSDR staff, the Hanford Health Effects Subcommittee (HHES), a focus group, and the Inter-tribal Council on Hanford Health Projects (ICHHP).

11.1 ATSDR Staff

Although the Division of Health Assessment and Consultation (DHAC) has primary lead for preparing public health assessments, many ATSDR divisions contributed to the Hanford public health assessment. Functional units include:

Division of Health Studies (DHS)
Division of Toxicology (DT)
Office of Assistant Administrator (OAA)
Office of Policy and External Affairs (OPEA).

Individual staff that contributed to the public health assessment include:

Frank Bove, Sc.D.
Epidemiologist, DHS

Michael Brooks, CHP
Senior Health Physicist, DHAC

Paul Charp, Ph.D.
Senior Health Physicist, DHAC

Caroline Cusack, MPH
Epidemiologist, DHS

Rita Ford, MBA
Supervisory Engineer, DHAC

Jo Ann Freedman, Ph.D.
Toxicologist, DHAC

Ginger Gist, Ph.D.
Supervisory Epidemiologist, DHS

Sandra Isaacs
Supervisory Health Scientist, DHAC

Sam Keith, CHP
Senior Health Physicist, DT

Jeff Kellam
Geologist, DHAC

Wallace K. Sagendorph
Writer-Editor, OPEA

Robert Spengler, Sc.D.
Epidemiologist, OAA

Greg Thomas
Health Scientist, DHS

11.2 Members of the HHES

Members of the HHES provided extensive comments on the initial public health assessments released in July 1997. Their main concern was that portions of the site (i.e., 100-, 200-, and 300-Areas) were addressed in different documents. The HHES recommended that ATSDR issue a single document addressing issues on a site-wide basis.

In 1999, the HHES provided comments on the draft consolidated public health assessment. In addition, a Public Health Assessment Work Group was formed to review the individual chapters as they were revised. This resulted in a dramatically revised document, reflecting enormous constructive input from subcommittee members working in close collaboration with ATSDR staff scientists.

The review time donated by HHES members was beyond hours reasonably associated with participation on an advisory committee. The agency recognizes and appreciates the many hours that the work group provided. Members of the HHES include:

Henry A. Anderson, III, M.D.
Madison, Wisconsin

Delbert S. Barth, Ph.D.
Henderson, Nevada

Glyn G. Caldwell, M.D.
Frankfort, Kentucky

Herman Cember, Ph.D.
Lafayette, Indiana

Dale H. Denham
Richland, Washington

Darrell R. Fisher, Ph.D.
Richland, Washington

Ricardo R. Garcia
Granger, Washington

Michele S. Gerber, Ph.D.
Richland, Washington

Henry C. Hartley, III
Pasco, Washington

Linda Keir
Gualala, California

Martha Jane McNeely
Gilroy, California

Trisha T. Pritikin, J.D.
Berkeley, California

Wilber J. Slockish, Jr.
The Dalles, Oregon

John W. Stanfill
Lapwai, Idaho

Beverly J. Walker
Gresham, Oregon

11.3 Focus Group

After drafting a consolidated public health assessment, ATSDR used a focus group to address the following four questions:

1. Chapter Summary - is it readable to the public?
2. Section summaries - are the important ideas included?
3. Text boxes - should something from the main text be highlighted in a text box?
4. Are there other perspectives that should be included?

Focus group members were selected for their knowledge of Hanford activities. Members of the focus group that provided comments included:

Jim Thomas
Seattle, Washington

Norm Buske
Belfair, Washington

Marilyn Jio, R.N.
Pendleton, Oregon

Louise Kaplan, Ph.D.
Tacoma, Washington

Marlene Nesary
(retired HHES member)

Rudi Nussbaum, Ph.D.
Portland, OR

Laura Chenet-Leonard
Portland, Oregon

11.4 Inter-tribal Council on Hanford Health Projects (ICHHP)

ATSDR also received valuable input from the tribal representatives attending meetings of the Inter-tribal Council on Hanford Health Projects (ICHHP). The ICHHP included nine tribes near the Hanford Site: the Coeur D'Alene Tribe, the Colville Confederated Tribes, the Confederated Tribes of the Umatilla Indian Reservation, the Confederated Tribes and Bands of the Warm Springs Indian Reservation, the Kalispel Tribe, the Kootenai Tribe of Idaho, the Nez Perce Tribe, the Spokane Tribe, and the Yakama Indian Nation.

Appendix A

Glossary

[*Note*: Phrases in italics are defined in this glossary.]

Absorption - The process of taking in. Fluids or other substances can be taken up by the skin, mucous surfaces, or vessels.

Absorbed dose - The fundamental quantity in radiation dosimetry; the amount of energy deposited in a material by ionizing radiation per unit mass of the material. The S.I. unit of *absorbed dose*, in gray (Gy), is a measure of energy absorbed (in joules) per kilogram of material. The traditional unit of absorbed dose is rad, where 1 rad equals 0.01 Gy. See also *dose*, *effective dose*, and *equivalent dose*.

Acute exposure - Exposure to radiation or chemicals occurring over a short time, less than or equal to about 14 days, and usually a few minutes or hours. Depending on magnitude, an *acute* exposure can result in short-term or long-term health effects.

Acute effect - An *acute* effect of exposure to radiation or chemicals is one that is manifest a short time (up to 1 year) after exposure.

Additive Effect - The effects of two or more insults are said to be additive when their combined effect is approximately equal to the sum of the individual effects that would be produced by each insult independently of the others.

Adverse Health Effect - A change in body function or in the structures of cells that can lead to disease or health problems. (Also see *Health Effect*.)

Antagonistic Effect - Less response from exposure to a mixture of substances than would be predicted by adding together the effects from exposures, one at a time, to the same amounts of each substance in the mixture.

Agency for Toxic Substances and Disease Registry (ATSDR) - *ATSDR* is a federal health agency in Atlanta, Georgia that addresses issues regarding hazardous substances and waste sites. ATSDR provides information about harmful chemicals in the environment. The agency also evaluates whether persons are exposed to hazardous substance, and if so, whether that exposure is harmful and should be stopped or reduced. The agency may also recommend appropriate *public health actions* to address community *concerns* and exposures.

Alpha particle or alpha radiation - Alpha particles are positively charged particles made up of two protons and two neutrons (helium atoms), released from some elements during radioactive decay. Their energy is deposited in the absorbing medium. They travel only a few inches (centimeters) in air, and only a few micrometers in water or body tissue. Therefore, they do not penetrate the skin surface if exposure is external. Atoms that emit alpha particle radiation may enter the body through a cut in the skin, by ingestion, or inhalation. Examples of alpha-emitters are radium-226 and plutonium-239.

Ambient - Surrounding; for example, *ambient* outdoor air is the air immediately surrounding a person outdoors.

Animal study - Laboratory experiments are conducted using animals to provide scientific information that may be useful in estimating how humans might respond to similar exposures or conditions.

Atomic veteran - Refers in this document to U.S. military personnel exposed to radiation from the atmospheric testing of nuclear weapons during the period 1945 to 1963. An estimated 300,000 persons are considered atomic veterans, including U.S. military personnel exposed at Hiroshima and Nagasaki during the American occupation of Japan following the detonation of the atomic bombs.

Autoimmune disease - A disease resulting from the immune system attacking the cells of one's own body rather than attacking foreign cells, such as germs.

Autoimmune hypothyroidism - An autoimmune disease that prevents the thyroid from producing enough thyroid hormone for normal hormonal balance.

Background level - The natural or expected normal levels of a chemical substance or radiation in the environment from natural sources and without human intervention. *Background* radiation includes radiation from terrestrial and cosmic sources.

Becquerel (Bq) - The *SI* unit used in the measure of radioactivity. One Bq is that quantity of a radioactive material characterized by exactly one transformation (decay) per second. One *curie* is the traditional unit of radioactivity equal to 37 billion Bq.

BEIR V Report - The 1990 report of the National Research Council's Committee on Biological Effects of Ionizing Radiations entitled, “Health Effects of Exposure to Low Levels of Ionizing Radiation.”

Beta particles - Negatively charged electrons released from atoms during radioactive decay. Electrons may travel up to about six feet in air or half an inch in water or tissue. Examples of beta-emitting radionuclides include iodine-131, phosphorus-32, and strontium-90.

Bioaccumulation - The progressive increase in the amount of a substance in an organism that occurs because the rate of intake exceeds the organism's ability to remove the substance from the body.

Biological clearance half-time - The amount of time it takes for exactly one half of a radioactive substance or non-radioactive material to be removed by an organ or tissue (or from the whole body) due to natural biological processes (metabolism, urination, defecation, exhalation, and perspiration).

Biological uptake - The transfer to and assimilation of radioactive or chemical substances from the environment to plants, animals, and humans.

Body burden - The total amount of a radioactive material or chemical substances in the body as the result of biological uptake.

Cancer - A class of diseases characterized by uncontrolled cell division that occurs when cells in the body become abnormal and grow, or multiply, out of control; a malignant growth capable of invading surrounding tissue or spreading to other parts of the body.

Carcinogen - Any substance that may induce cancer.

Case-control study - A common type of epidemiologic (human) study involving two groups that are compared. Individuals in one group may have been subjected to a treatment or insult, whereas individuals in the control group are not exposed or treated. Information is collected in the same way from individuals in both groups regarding specific exposures or treatments. Characteristics of the individuals that may have increased or decreased susceptibility to the treatment or exposure are also compared. The two groups are compared to determine the degree to which the exposures, characteristics, or other factors may be related to an association between insult, treatment, or exposure, and the prevalence of an observed effect or disease.

Central nervous system - The parts of the nervous system that includes the brain and the spinal cord.

Chromosome - Thread-like bodies consisting of chromatin that are found in the human cell nucleus that carry genes, which transmit and determine inherited characteristics; human cells have 46 chromosomes.

CERCLA - The Comprehensive Environmental Response, Compensation, and Liability Act of 1980, also known as "Superfund." This is the legislation that created the Agency for Toxic Substances and Disease Registry (ATSDR).

Chronic - Effects from an exposure or treatment that occur over a long period of exposure (usually more than 1 year).

Cohort study - A study of a group of persons sharing a common experience, such as exposure to a substance, within a defined time period; used to determine whether an increased risk of a health effect may be associated with that exposure.

Comparison values - The amounts of substances in air, water, food, and soil that are unlikely, upon exposure, to cause adverse health effects. ATSDR uses *comparison values* as screening levels to exclude contaminants from further evaluation because they are unlikely to cause ill health, given a standard daily intake rate and standard body weight. *Comparison values* are derived by applying conservative assumptions and safety factors to values from the scientific literature on exposure and health effects. Because of the conservatism of the assumptions and safety factors, contaminant concentrations exceeding comparison values do not necessarily indicate a health hazard.

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) - CERCLA, also known as "Superfund," was established in 1980. This act concerns releases of hazardous substances into the environment and the cleanup of these substances and hazardous waste sites. ATSDR was created by this act and is responsible for looking into health issues related to hazardous waste sites.

Concentration - The amount of a substance contained per unit mass of another substance. For example, sea water contains a higher *concentration* of salt than does fresh water. *Concentration* may refer to the amount of a substance present in a certain amount of soil, water, air, or food.

Confounding factors - Sources of harm or protection from harm, in addition to a particular exposure and disease being studied, that may also affect the risk of developing a disease. Confounding factors can mask or contribute to a health

effect so that the relationship of the effect and the exposure is not recognized, or make it appear as though there is a relationship to an effect when, in fact, none exists.

Contaminant - Any substance or material in a system (the environment, human body, food, etc.) in larger amounts than it is normally found, that renders it impure or unsuitable.

Cancer Risk Evaluation Guide (CREG) - The contaminant *concentration* estimated to result in one excess cancer case in a million persons exposed over a 70-year lifetime.

Cumulative effect - Effects that can result from repeated or chronic exposure to a substance. The cumulative effect occurs (or increases) with an increase in the total amount of the substance delivered to a particular tissue.

Curie - A unit used to quantify the amount of *radioactive* material. (It was originally based on the number of atoms that decay each second from one gram of radium). One curie is equal to 37 billion atoms undergoing radioactive decay per second. A "nanocurie" is one billionth of a curie. A "picocurie" is one trillionth of a curie.

Delayed effect - A health effect after exposure to a substance that does not become apparent for days, months, or years after the exposure.

Derived concentration guide (DCG) - An *effective dose equivalent* to members of the general public defined as exactly 1 mSv/year (100 mrem/year) from a specific radionuclide in air or water. *Derived Concentration Guides* serve as reference values for comparisons to environmental levels, and do not represent exposure limits.

Dermal - Referring to the skin (for example, *dermal* absorption means absorption through the skin).

Disease rate - The prevalence or occurrence of a disease in a population during a given year, often expressed as the number of cases per 100,000 persons per year.

Disease registry - A structured record-keeping system for collecting and maintaining information on the occurrence of disease in a population.

Deoxyribonucleic acid (DNA) - Nucleic acid chains of deoxyribose found mainly in the nucleus of cells, encoded with the protein construction instructions and responsible for carrying hereditary characteristics from one cell generation to another.

Department of Energy (DOE) - The U.S. department of the federal government that sets forth and maintains the national energy policies, including nuclear energy, nuclear defense programs, high-energy physics, and environmental management of agency properties; an outgrowth of the former Atomic Energy Commission, later the Energy Research and Development Administration. The Department is responsible for the development of nuclear weapons and materials, and also for cleaning up nuclear and chemical wastes that were generated by U.S. nuclear weapons programs, including the management of the Hanford Site.

Dose - The quantity administered, as in the amount of medicine prescribed to a patient. In physics, radiation absorbed dose is the amount of energy absorbed by a given mass of absorber, such as living tissue. See also *absorbed dose, effective dose, dose equivalent,* and *equivalent dose.*

Dose equivalent - A term used in radiation dosimetry now superseded by effective dose; the product of the absorbed dose from ionizing radiation in tissue or organ and factors that account for differences in biological effectiveness due to the type of radiation and its distribution in the body, given in units of rem or sievert (Sv).

Dose reconstruction - A retrospective scientific study based on historical records of radiation exposure or release of radioactive materials that are use to estimate radiation doses to individuals or population groups.

Dose-response - The association between the dose of a substance and the effects that it produces in a living organism.

Downwinder - A term commonly used to refer to persons living in the weather pattern pathway of radioactive emissions from a nuclear facility or atomic bomb test site.

Duration - The length of time (days, months, years) during which something continues; such as the time during which a person is exposed to a substance.

Effective dose - A measure of radiation risk or detriment to an individual, that takes into account the human as the receptor, organ sensitivity, and radiation

quality; it is the sum of equivalent doses to organs and tissues, each multiplied by the appropriate tissue weighting factors.

Effective half-life - The time required to reduce the radioactivity in a tissue or organ by 50 percent, taking both physical and *biological retention half-time* into account.

Environmental media evaluation guide (EMEG) - The *concentration* of a radioactive contaminant calculated from ATSDR's minimum risk level (MRL), which is an estimate of the daily exposure, usually for a lifetime, to a contaminant that is unlikely to cause adverse health effects, given conservative uncertainty factors to allow for differences between laboratory conditions and environmental exposure scenarios. An EMEG value is usually derived for chronic exposure (over two years to a natural lifespan), but EMEGs can also be derived for intermediate periods (six months to two years) and short-term (two weeks or less) exposures.

Environmental contaminant - A substance present in a system (person, animal, or the environment) in amounts higher than that normally found at *background or expected levels as the result of activities of man*.

Environmental contamination - The presence of hazardous substances in the soil, water, or air from the activities of man. From a public health perspective, *environmental contamination* is addressed when it potentially affects the health and quality of life of persons living and working near the contaminated *environmental media*.

Environmental exposure - Exposure to substances through the environment.

Environmental media - Usually refers to the air, water, and soil in which chemicals of interest are found; sometimes refers to the plants and animals that are eaten by humans. (Also see *exposure pathway*.)

Environmental Protection Agency (EPA) - A federal agency that develops regulations and enforces environmental laws to protect the environment and the public's health.

Equivalent Dose - In radiation dosimetry, a measure of radiation risk or detriment to an organ or tissue; the sum of the contributions of dose from different radiation types, each multiplied by its appropriate radiation weighting factor.

Exposure - Coming into contact with a substance, by swallowing, breathing, or direct contact (such as through the skin or eyes); e*xposure* may be short term (acute) or long term (chronic).

Exposure Pathway - A description of the way that a chemical moves from its source to where and how persons come into contact with (or become exposed to) the chemical. ATSDR defines an exposure pathway as having five parts: the source of contamination; the environmental medium in which contaminants may be present or through which they may migrate; a point of exposure (such as a private well); the route of exposure (ingestion, inhalation, or dermal contact); and a receptor population (persons who are exposed or potentially exposed). When all five parts of an exposure pathway are present, it is called a *completed exposure pathway*. An incomplete pathway is one in which at least one of the five elements is missing; a potential pathway is currently incomplete, but the missing elements could exist if conditions change. A pathway is eliminated if at least one element cannot be present.

Exposure registry - A system for collecting and maintaining, in a structured record, information on persons with documented environmental exposures. The *exposure registry* evolved from the need for fundamental information about the potential impact on human health of long-term exposure to low and moderate levels of hazardous substances.

External radiation - Exposure to *radioactive* substances or X-rays outside the body, where the radiation may be gamma rays, cosmic rays, and X-rays that penetrate human skin and impart energy to the skin, internal organs and tissues, or the whole body.

Fine needle aspiration (FNA) - Drawing out a small tissue sample from the body through a thin needle; a test often used when a *thyroid nodule* is found on the *thyroid* gland. Cells are collected from the nodule to see if they are malignant.

Freedom of Information Act (FOIA) - A law of the United States intended to assure government openness and accountability. It establishes that citizens have the right of access to federal agency records. Enacted in 1966, the Act also defines specific kinds of information that the government can exempt from disclosure.

Frequency - How often something (for example, exposure to a substance) happens over time (for example, every day, once a week, twice a month).

Gamma rays - Photons (electromagnetic waves) that are emitted from the atomic nuclei of radioactive materials. *Gamma rays* carry no charge and pass through the human body at the speed of light. As *gamma rays* pass through the body, they impart energy, which may damage cells. Cesium-137 is an example of a radioactive material that emits gamma radiation.

Graves' Disease - A disease characterized by an enlarged thyroid, a rapid pulse, and an increased basal metabolism due to excessive thyroid secretion; a form of hyperthyroidism (over-active thyroid).

Gray - The *SI* unit for *absorbed dose*. One Joule of energy deposited in one kilogram of matter. One gray (1 Gy) is equivalent to 100 rads.

Green Run - An intentional release of iodine-131 into the air from a fuel processing facility at the Hanford Site on December 2–3, 1949, to determine the characteristics of I-131 transport through the atmosphere.

Half-life - The amount of time it takes for any given amount of a radioactive substance to decay to one half of its value. Half-lives for different substances vary from millionths of a second to billions of years. Iodine-131 (I-131) has a half-life of approximately 8 days. At the end of 8 days, half of any given amount of I-131 becomes stable xenon-131. After another eight days, half of the remaining I-131 will decay into stable xenon-131, and so on.

Hashimoto's thyroiditis - An autoimmune disease of the thyroid caused by lymphocytes entering and spreading throughout the thyroid. The disease results in goiter, tissue damage, and *hypothyroidism*.

Hazard - A danger or risk of harm.

Hazardous Waste - Substances that are no longer in use, that may have been released or thrown away into the environment and, under certain conditions, could be harmful to persons who come into contact with them.

Health consultation - A response to a specific question or request for information pertaining to a hazardous substance or facility (which includes waste sites). It often contains a time-critical element that necessitates a rapid response; therefore, it is a more limited response than a public health assessment.

Health education - A program of activities to promote health and provide information and training about hazardous substances or practices, to reduce exposure, illness, or disease. The program may include diagnosis and treatment information for health care providers and community activities to promote prevention or mitigation of health effects from exposure to hazardous substances.

(Adverse) health effect - Injury or illness that may be the result of exposure to biological, physical, or chemical agents (such as germs, radiation, or chemicals) that are harmful to a person's health; may include disease, cancer, birth defects, genetic effects, and death.

Health professional education - Any activity directed toward public health professionals and the local health care community. The purpose is to improve their knowledge, skill, and behavior regarding medical surveillance, screening, and methods of diagnosing, treating, and preventing injury or disease related to exposure to hazardous substances. These activities may include immediately disseminating written materials or making database information available, presenting workshops and short courses, or, where appropriate, long-term follow-up activities.

Health statistics review - Evaluation of information and relevant health outcome data for a population, including reports of injury, disease, or death in the community. Databases may be local, state, or national; information from private health care providers and organizations may also be used. Databases may include morbidity and mortality data, tumor and disease registries, birth statistics, and surveillance data.

Health surveillance - The periodic medical screening of a defined population for a specific disease or for biological markers of disease for which the population is, or is thought to be, at significantly increased *risk*. The program should include a mechanism to refer for treatment persons who test positive for disease (also called *medical monitoring*).

Healthy-worker effect – Lower rates of disease observed in a working population than observed in the general population due to the higher standards of living, levels of education, and wages generally earned by workers than are characteristic of the population as a whole.

Hibakusha - The Japanese word for World War II victims of the atomic bombs dropped on the cities of Hiroshima and Nagasaki.

Hormesis - Beneficial health effects from low doses of *ionizing radiation* or hazardous chemicals due to adaptive response or other radiobiological mechanism.

Hot spot - A term used to describe an area where the *concentration* of contaminants is much greater than that in the surrounding area.

Hyperparathyrodism - A condition caused by too much parathyroid hormone in the body, resulting from not being able to properly regulate the levels of calcium and phosphorus.

Hyperthyroidism - A condition caused by enlarged or overactive thyroid and greater-than-normal amounts of *thyroid* hormones produced, causing an elevated basal metabolic rate and symptoms such as nervousness, constant hunger, weight loss and tremors.

Hypothyroidism - A thyroid deficiency of too little hormone production causing symptoms such as fatigue, weight gain, and skin and hair changes.

Immune system disorders - Abnormalities that include *autoimmune diseases* and other disruptions of the immune surveillance system. The primary function of the normal immune system is to detect and eliminate foreign substances, including foreign matter, germs, and proteins.

Ingestion - Swallowing (such as eating or drinking), one *route of exposure* by which substances can enter a person's body. Chemicals can get in or on food, drink, utensils, cigarettes, or hands, where they can be swallowed. After *ingestion*, chemicals may either be eliminated or be absorbed into the blood and distributed throughout the body.

Inhalation - Breathing. A *route of exposure*. Exposure may occur from breathing contaminants in if they can be deposited in the lungs, taken into the blood, or both. Some, but not all, substances that are taken into the lungs can diffuse across the walls of the lung capillaries (tiny blood vessels) into the bloodstream.

Internal radiation - Exposure to a *radioactive* substance that is inside the body after ingestion, inhalation, or absorption.

In utero - In the uterus or womb.

Iodine - A nonmetallic halogen element that sublimes into a vapor; an essential element in the diet for proper thyroid function. *Thyroid* hormone contains *iodin*e.

Ionizing radiation - The type of radiation that has sufficient energy to remove one or more electrons from atoms it encounters, leaving positively charged ions. It may have a variety of forms, either particles such as alpha and beta, or non-particulate forms such as X-rays and gamma radiation.

Isotopes - Different forms of the same chemical element. The forms, have different numbers of neutrons but the same number of protons in the nuclei of their atoms. A single element may have many *isotopes*. An *isotope* is characterized by the sum of its neutrons and protons. For example, stable iodine is iodine-127 (74 neutrons and 53 protons). Its radioactive *isotopes* include iodine-129 (76 neutrons and 53 protons) and iodine-131 (78 neutrons and 53 protons).

Latent period - The time between an exposure and the observation of disease development (e.g., *cancer*). The *latent period* for *cancer* induction may be 3 to 20 or more years, depending on type of cancer.

Leukemia - A family of blood cell cancers. The diseases affect different types of white blood cells, making them abnormal in shape or number.

Linear effect model - A model of the *dose-response* relationship between radiation or cancer-causing chemicals and health effects; based on the theory that the damage per unit dose of radiation or cancer-causing chemical is proportional to the observed effect or probability of occurrence. The theory predicts that the number of induced cancers will be directly proportional to the dose delivered, down to the lowest possible dose.

Linear-quadratic effect model - A model of the *dose-response* relationship between radiation or cancer-causing chemicals and health effects; this model assumes that relatively less damage occurs per unit dose of radiation or cancer-causing chemical at low doses than at high doses, and that risk of detriment is not strictly linear with level of exposure.

Lowest observed adverse effect level (LOAEL) - The lowest dose of a chemical or radiation exposure in a study, or group of studies, observed to have caused harmful health effects in persons or animals.

Lymphocyte - A type of white blood cell primarily formed in lymphoid tissue such as lymph nodes, tonsils, the spleen, and the thymus. Lymphocytes provide protection against some kinds of infections.

Lymphopoietic neoplasm - A tumor consisting of *lymphocytes* that can be either benign or *cancer*ous.

Malignancy - See *Cancer*.

The Manhattan Project - The name of the U.S. Government scientific/military project, begun in 1939, that developed the world's first uranium reactor and the first atomic bomb. Hanford was part of the Manhattan Project, producing plutonium used in the atomic bomb dropped on Nagasaki, Japan.

Maximum contaminant level (MCL) - A regulatory value for the maximum contaminant *concentration* in public drinking water systems that EPA deems safe to public health over an individual's normal (70-year) lifetime.

Media - Soil, water, air, plants, animals, or other parts of the environment that can contain contaminants.

Medical monitoring - Periodic medical testing to screen persons at significant increased threat of disease.

Metabolism - All the chemical reactions that are caused by living things and that change a substance from its original chemical form. For example, food is *metabolized* (chemically changed) to supply the body with energy. Chemicals can be *metabolized* and made either more or less harmful by the body. Some chemicals can be *metabolized* by organisms in the environment. This is called "environmental *metabolism*". Persons may then be exposed to the changed chemicals, which may be either more or less harmful to their bodies then the original chemicals.

Metabolite - Any product of *metabolism*.

Metastasis - The spread of *cancer* from the original site of the disease to another part of the body.

Millirem (mrem) - A millirem (mrem) is one-thousandth of a rem.

Minimal risk level (MRL) - An estimate of daily human exposure to a substance that is likely to be without an appreciable risk of adverse, noncancer effects over a specified *duration* of exposure. *MRLs* are derived when reliable and sufficient data exist to identify the target organ(s) of effect or the most sensitive health effect(s) for a specific *duration* via a given *route of exposure*. *MRLs* can be derived for acute, intermediate, and *chronic duration* exposures by the inhalation and oral routes. MRLs can be derived for dermal exposures, but none are currently available.

Morbidity - Illness or disease. Morbidity rate is the number of illnesses or cases of disease in a population.

Morbidity rate - The incidence of a population affected by a disease during a given year, often expressed as the number of cases per 100,000 persons per year.

Mortality rate - The incidence of a population that die from a disease, such as a specific type of cancer. It is usually expressed as the number of deaths from the disease per 100,000 deaths per year.

Multiple myeloma - A rare disease that is characterized by anemia, bleeding, recurrent infections and weakness. It is a form of *cancer* in which the plasma cell in the bone marrow has been transformed and is malignant. It occurs more frequently in men than women.

Mutation - A genetic change in a cell's DNA that can be passed on to daughter cells during cell division.

Nanocurie - One billionth of a curie, abbreviated as *nCi*. The curie is a measurement of radioactive decay. One curie equals 37 billion atoms decaying per second; one *nanocurie* therefore equals 37 atoms decaying per second.

National exposure registry - A listing, divided into chemical-specific subregistries, of persons exposed to hazardous substances. The primary purpose of the registry program is to create a large database of similarly exposed persons. This database is used to facilitate epidemiologic research in ascertaining adverse health effects of persons exposed to low levels of chemicals over a long period.

National Priorities List (NPL) - The Environmental Protection Agency's (EPA) listing of Superfund hazardous waste sites that are most in need of cleanup. These sites have undergone preliminary assessment and site inspection to determine which locations pose threats to the environment or to persons living or working

near the releases. Populations near the sites may have had prior exposure to radiation or chemicals.

National Toxicology Program (NTP) – The *National Toxicology Program* conducts toxicological testing on substances most often found at sites on the EPA National Priorities List, for which there is the greatest potential for human exposure. NTP also assigns substances to cancer classes such as "Known *Carcinogen*" or "Reasonably Assumed a *Carcinogen*".

Neoplasm - An abnormal growth of tissue that can be *cancer*ous or non-*cancer*ous.

Neural tube defects - The neural tube develops into the spinal cord and brain. Defects occur when the neural tube fails to close completely during the early stages of pregnancy.

No Observed Adverse Effect Level (NOAEL) - The highest dose of a chemical or radiation (below the lowest *LOAEL*) in a study, or group of studies, that did not cause harmful health effects in persons or animals.

Non-ionizing radiation - *Radiation* which does not have enough energy to cause atoms to lose electrons and become ions. This includes visible, ultraviolet, and infrared light, as well as radio waves. Also see *ionizing radiation.*

No apparent public health hazard - Category assigned to sites where human exposure to contaminated *media* is occurring or has occurred in the past, but having contaminant levels below those that are expected to cause adverse health effects.

No public health hazard - Category assigned to sites for which data indicate no current or past exposure or no potential for exposure and, therefore, no health *hazard.*

No threshold - The premise that there is no level below which exposure to radiation or chemicals does not increase the risk of disease; for cancer from chemical or radiation exposure, the hypothesis that any dose of ionizing radiation or a specific chemical carcinogen may increase the risk of developing cancer in organs or tissues of the body.

Nuclear fallout - The descent of airborne particles of dust, debris, and radioactive substances. About 200 different radionuclides of many different elements are

formed from a nuclear bomb explosion; most have very short half-lives. Millions of curies of radioactivity in the form of dust and debris get carried into the upper atmosphere by the mushroom cloud. Jet stream winds can carry fallout from bomb blasts around the world within a few weeks.

Nuclear fission - The splitting of an atom which releases energy.

Nucleus - The center of an atom consisting of protons and neutrons. Also refers to the main heredity-carrying part of cells in living organisms.

Occupational exposure - Exposure to radioactive or chemicalsubstances at the workplace.

Organ dose - The amount of energy from radiation delivered to a particular organ. Usually expressed in rad or Gy. Among the factors to consider in measuring radiation dose is whether a person received a radiation dose to a single organ or to the whole body. For example, when iodine-131 enters the body, it mainly concentrates in the thyroid gland and gives a dose to this organ.

Parathyroid glands - Glands near the *thyroid* that help control the calcium level in the body.

Pathway - See *exposure pathway.*

Pica behavior - An abnormal psychological behavior characterized by the consumption of non-nutritive substances such as soil.

Pica child - A child who consumes non-nutritive substances such as soil.

Plume - An area of contaminants in a particular medium, such as air or groundwater, moving away from its source in a long band or column. A *plume* can be a column of smoke from a chimney or chemicals moving with groundwater or surface water.

Proposed maximum contaminant level goal (PMCLG) - A non-enforceable drinking water contaminant *concentration* that EPA proposes, based upon levels at which no known or anticipated adverse effects on human health are known to occur, with an additional safety margin.

Point of exposure - The place where someone can come into contact with a contaminated *environmental medium* (air, water, food or soil) .Examples include:

the area of a playground that has contaminated dirt; a contaminated spring used for drinking water; fruits or vegetables containing contamination from contaminated soil; or the backyard area where someone might breathe contaminated air.

Potential/indeterminate public health hazard - Category assigned to sites for which no conclusions about public health hazard can be made because data are lacking.

Potentially exposed - Condition in which valid information (usually analytical environmental data) indicate the presence of contaminant(s) of public health concern in one or more environmental media (i.e., air, drinking water, soil, food chain, surface water), with evidence that some of those persons have an identified route(s) of exposure (e.g., drinking contaminated water, breathing contaminated air, having contact with contaminated soil, or eating contaminated food).

Public comment - An opportunity for the general public to comment on agency findings or proposed activities. The public health assessment process, for example, includes the opportunity for public comment.

Public health action - Designed to prevent exposures and mitigate or prevent adverse health effects in populations living near hazardous waste sites or releases. Public health actions are identified from information developed in public health advisories, public health assessments, and health consultations. These actions include recommending dissociation (separation) of individuals from exposures (for example, by providing an alternative water supply), conducting studies on biologic indicators of exposure to assess exposure, and providing health education for health care providers and community members.

Public health hazard - Sites that could put people's health at *risk* as the result of exposures to harmful substances.

Rad - A unit used to express the amount of energy absorbed by matter. Equal to 100 ergs energy deposited per gram of matter.

Radiation - Energy radiated in the form of energetic particles or waves (photons).

Radiation standards - Recommendations for limiting the exposure of persons (workers and members of the general public) to radiation or radionuclides in air and water, to maximum permissible levels established by highly reputable scientific groups such as the National Council on Radiation Protection and

Measurements (NCRP) in the U.S., or the International Commission on Radiological Protection (ICRP).

Radioactive - A substance which has an unstable nucleus which becomes more stable by changing, usually emitting energy in the form of charged particles, gamma rays, fission fragments, neutrinos, or other types of radiation in the process.

Radioactive decay - Transformation of the nucleus of an atom with the release of energy or particles. *Radioactive decay* produces a new isotope, of the same or different element, which may itself be radioactive or stable.

Radioactivity - The state of nuclear instability characterized by spontaneous release of *radiation* from the nucleus of an atom.

Radioisotope - The *radioactive* form of an element that has all the chemical properties of the stable form of the element is a radioisotope. R*adioisotopes* undergoes radioactive decay. Usually synonymous with *radionuclide*.

Radionuclide - An unstable form of an element that can decay and give off *radiation* is a *radionuclide*. Usually synonymous with *radioisotope.*

Radiosensitivity - Relative vulnerability of specific cells, tissues, organs and other organisms to harm by radiation.

Reference Dose (RfD) - An estimate, with *uncertainty factors* included, of the daily exposure of human populations, averaged over a lifetime, to a possible hazard that is not likely to cause harm to a person.

Reference dose (RfD) Media Evaluation Guide (RMEG) - A contaminant *concentration* based on *EPA*'s health guideline, the *RfD,* which is similar to *ATSDR*'s *MRL*. An estimate of the lifetime daily exposure, averaged over a lifetime, to a contaminant unlikely to cause *adverse health effects;* includes conservative uncertainty factors to allow for differences between laboratory and environmental exposure conditions.

Registry - A system for collecting and maintaining, in a structured record, information on specific persons from a defined population.

Rem - A unit of dose equivalent that is used in the regulatory, administrative and engineering design aspects of radiation safety practice. One rem is equal to 0.01 sievert, and a millirem (mrem) is one thousandth of a rem.

Representative dose estimate - An approximation of the amount of substance taken in by a typical individual who represents a larger group of people; often is based on lifestyle factors.

Risk - The estimated probability that a *hazard* (e.g., an environmental contaminant shown to harm animals at higher than environmental doses) will cause harm (e.g., disease, injury, or death to persons) under specific exposure conditions.

Risk Assessment - A process used to estimate the likelihood of *adverse health effects,* or evaluation of levels, exposure or dose, and biological effects; to determine likely risk of such exposure in human populations..

Route of exposure - The way a substance gets on or into the body. Three primary *routes of exposure are*: *inhalation* (breathing), *ingestion* (eating or drinking), and *dermal* (skin) contact (e.g., through bathing or other skin contact with a substance).

Safety factor - See *uncertainty factors.*

Sievert - The *SI* unit for *dose equivalent*. One sievert equals 100 rem; the abbreviation is Sv.

Significant health risk - Circumstances in which persons are or could be exposed to hazardous substances at levels that pose an *urgent public health hazard* or a *public health hazard*; public health advisories are generally issued when *urgent public health hazards* have been identified.

Somatic effects or injury - The harm from radiation or chemical exposure that results from damage to non-reproductive cells. The harm may become clinically observable if the body does not spontaneously repair the damage. *Somatic effects* are not passed on to succeeding generations.

Source (of contamination) - The place where a substance comes from (such as a landfill, pond, creek, incinerator, tank, or drum). *Contaminant source* is the first part of an *exposure pathway.*

Source term - Refers to the amount and type of chemical or *radioactive* material released into the environment; one of the modeling elements used to estimate doses that could have received as a result of the release.

Special populations - People who may be more sensitive to chemical exposures because of certain factors such as age, inherited characteristics, cultural practices, a disease they already have, occupation, sex, or certain behaviors (like cigarette smoking). Children, pregnant women, American Indian or Alaskan native tribes, and older persons are often considered special populations.

Spontaneous abortion - A miscarriage.

Superfund - Another name for the *Comprehensive Environmental Response, Compensation, and Liability Act* of 1980 (*CERCLA*), which created *ATSDR*.

Superfund Amendments and Reauthorization Act (SARA) - The 1986 legislation that broadened ATSDR's responsibilities in the areas of public health assessments, establishment and maintenance of toxicological databases, information dissemination, and medical education.

Superfund site - See *National Priorities List (NPL)*.

Supralinear effect model - A dose-response model of *radiation health effects* which proposes that more damage is caused per unit radiation exposure at low doses than at higher doses. The theory behind this model is that high doses of radiation kill cells outright, while lower doses of radiation weaken and damage cells which may then live on in an altered state.

Synergistic effect - A more severe response, or sometimes a different kind of response, from exposure to a mixture of substances than would be predicted by adding together the effects from exposures, one at a time, to the same amounts of each substance in the mixture. The combined effect of the agents acting together is greater than the sum of the effects of the agents acting by themselves.

Threshold hypothesis - The assumption that no *adverse health effects* occur from radiation or chemicals at or below an observed dose level.

Thyroid - A two-lobed gland lying at the base of the throat that produces hormones to regulate the rates of a variety of metabolic processes in the body. When iodine is ingested, much of it goes to the *thyroid* gland.

Thyroid function tests - There are two standard blood tests commonly used to evaluate *thyroid* function: 1) the measurement of *thyroid* hormones, referred to as T3 and T4, and 2) the measurement of thyrotrophin or *thyroid-stimulating hormone (TSH)*. The TSH test is usually performed before tests for T3 and T4.

Thyroid nodules - Lumps in the *thyroid* gland which may be benign or cancerous. "Cold *nodules*" are non-functioning lumps in the *thyroid* gland. "Hot *nodules*" refer to overactive *thyroid* lumps.

Thyroid nuclear scan - A test that measures the uptake of radioiodine by the *thyroid* gland. The *thyroid nuclear scan* can help evaluate a *thyroid nodule* and can provide additional information about how the *thyroid* is functioning, whether it is hyperactive or underactive, or whether it is cancerous.

Thyroid palpation - The most common procedure for checking the *thyroid* gland; a simple physical examination which consists of feeling the gland in the neck with the fingers, often as the patient swallows water. Palpation can determine the size and texture of the gland and can also detect larger nodules.

Thyroid stimulating hormone (TSH) - A hormone released by the pituitary gland near the brain that controls *thyroid* hormone production. When the *thyroid* gland is not working properly, the pituitary releases large amounts of *TSH* to try to stimulate the *thyroid* gland into producing *thyroid* hormone. The *TSH* circulating in the blood stream thus indicates *thyroid* failure.

Thyroid ultrasound scan – An image of the *thyroid* gland created by reflected sound waves. The ultrasound scan can detect abnormal small lumps in the gland.

Toxic - Harmful. Almost any substance, even pure water, can be *toxic* at a certain *dose* (amount). The *dose* is what determines the potential harm of a substance and whether it would cause someone to get sick.

Toxicological profile - A document about a specific substance in which *ATSDR* scientists interpret known information on the substance and specify levels below which people are unlikely to be harmed if exposed for various periods of time. A *toxicological profile* also identifies significant knowledge gaps, and serves to initiate further research when needed.

Tracheoesophageal fistula - A birth defect that is an abnormal connection between the trachea (the windpipe) and the esophagus (the part of the digestive tract that connects the mouth to the stomach).

Tumor - Abnormal growth of tissue or cells that have formed a lump or mass.

Uncertainty factor - One of several factors applied to the *Lowest Observed Adverse Effect Level (LOAEL)* or the *No Observed Adverse Effect Level (NOAEL)* to derive a *Minimal Risk Level* (*MRL). Uncertainty factors* are used to account for variations in the individual sensitivities in people to certain substances; extrapolations of animal data to humans; and other reasons. Scientists use *uncertainty factors* when they have some, but not all, the information to determine if an exposure will harm people, to allow for the possibility that what is not known might lead to greater harm. These factors add confidence to an estimate of a chemical dose that is not likely to harm anyone. Called an *safety factor* by some agencies.

Urgent public health hazard - Category assigned to sites that pose a serious risk to the public health as the result of short-term exposures to hazardous substances.

Volatile organic compounds (VOCs) - Substances that easily become vapors or gases and that contain carbon and other elements such as hydrogen, oxygen, fluorine, chlorine, bromine, sulfur, or nitrogen. A number of the volatile organic compounds are commonly used as solvents (paint thinners, lacquer thinners, degreasers, and dry-cleaning fluids).

Voluntary residents tracking system - A collection of people who are contacted periodically, for a limited time, for the purpose of disseminating information or of coordinating other health-related services.

White blood cell count - The number of white blood cells in a specific amount of blood. An abnormal *white blood cell count* can be an indication of an adverse drug reaction, infection, or other disease.

Whole body dose - Radiation dose to the whole body from internal or external sources of radiation; the total amount of energy deposited in the body divided by the person’s weight.

X-rays - X-rays are photons of a characteristic wavelength and energy, similar to *gamma rays* but are produced by the interaction of electrons from a cathode with

atomic nuclei of a dense target anode, rather from the decay of an unstable atomic nucleus.

Appendix B

Hanford Health Studies

Outline

Summary of Hanford Health Studies

Over the years various investigators and organizations have completed, or are in the process of completing, scientific studies to assess the potential health effects from radioactive materials released from Hanford. This appendix provides a brief summary of some of these studies compiled by the Hanford Health Information Network (HHIN) and Agency for Toxic Substances and Disease Registry (ATSDR). The HHIN closed in May 2000, but the Washington Department of Health maintains a database of HHIN publications on an internet website at http://www.doh.wa.gov/Hanford/default.htm

The summaries provided in this appendix include a description of the studies' purpose, results, study completion dates, methods, principal investigators, and funding sources. If available, a name or contact for further information is also provided. In 1993, the Hanford Education Action League also compiled a list of public health studies, beyond radiation effects, related to the Hanford Site. A list of these studies, principal investigators, and publication journals and dates are listed at the end of this appendix.

B.1 Community Health Effects

B.1.1 Hanford Infant Mortality and Fetal Death Analysis, 1940–1952

Focusing on the years 1940–1952, ATSDR conducted a study to investigate the potential association between I-131 exposure of the mother and infant mortality, fetal death, and preterm birth. The study used the HEDR project's estimates for I-131 release, distribution, and uptake by persons in affected downwind counties.. The eight Washington counties included in the HEDR project were Adams, Benton, Franklin, Grant, Kittitas, Klickitat, Walla Walla, and Yakima.

Results of this study provided contradictory findings, suggesting for some years that an expecting woman who lived in an area with relatively high iodine-131 exposures may have experienced lower risk of preterm (premature) birth. However, the opposite results were observed for other years. For example, infant mortality rates in low-exposures areas with low I-131 exposures were higher than rates in areas with high I-131 exposures for nearly every year from 1940 to 1952, except for 1945 and 1946. For 1945 and 1946, the study found a 70% higher rate of preterm birth and a 30% higher rate of infant mortality in the areas with the highest estimates of I-131 exposures compared to areas with the lowest estimates of exposure. No association with I-131 exposure of the mother was found for fetal

death. The study was not conclusive with respect to the association between I-131 exposure and infant mortality rates, perhaps because socioeconomic or factors may have been more important rather than I-131 exposure. The higher mortality rates in the high exposure area during1945 and 1946, the years of highest I-131 releases, may indicate that the I-131 release were more important than socioeconomic factors in infant mortality during those years. Overall, the study concluded that I-131 exposure may have been associated with preterm births. The initial results of this study were released in a draft final report in July 1999 and finalized in November 2000.

This study was performed by comparing the locations of the mothers' homes, infant mortality rates, and estimated I-131 doses to mothers. Investigators established geographic exposure areas, ranging from low to high I-131 exposure doses, using data from the HEDR project. Birth and death records from 1940 to 1952 for eight counties surrounding Hanford were reviewed, and each record was assigned to one of the geographic exposure areas based on the mother's residence a the time of birth. Infant mortality rates were calculated and the data were reviewed to evaluate any connection between the infant mortality rates and I-131 doses.

The Division of Health Studies at ATSDR completed and released the results of this study. Funding was provided by ATSDR. Contact for further information: Frank J. Bove, ATSDR; toll free 1-800-CDC-INFO; or email Fbove@cdc.gov.

B.1.2 Epidemiologic Evaluation of Childhood Leukemia and Paternal Exposure to Ionizing Radiation

The focus of this study was to evaluate where childhood leukemia was associated with exposure of the father to radiation before the conception of the child, as previously reported in a British study by Gardner (1990) at the Sellafield Nuclear Plant in West Cumbria, England. 1 Contrary to Gardner's results, this study found no link between childhood cancer risk and the father's exposure to radiation from work at the Hanford Site. Althouth the investigators found a small

1 Gardner MJ, Snee MP, Hall AJ, et al. Results of Case-control Study of Leukemia and Lymphoma among Young People Near Sellafield Nuclear Plant, West Cumbria. British Medical Journal. 1990; 300:423-429.

increase in central nervous system cancers among children whose fathers worked at Hanford, as compared to the controls, this increase was not statistically significant. This study was the fourth attempt to replicate Gardner's findings. The final study report underwent a peer review process and was released in October 1998.

To complete this study, researchers identified children under 15 years of age who were diagnosed with cancers between 1957 and 1991 and who lived in counties near three DOE sites (Hanford, Idaho National Engineering and Environmental Laboratory, and Oak Ridge). These children were compared to children from the same counties who did not have cancer. Researchers conducted a statistical analysis to evaluate whether children with cancer were more likely to have fathers who were exposed to radiation.

This study was funded by the National Institute of Occupational Safety and Health (NIOSH). The principal investigator was epidemiologist L. Sever from the University of Texas-Houston School of Public Health. For more information, contact: NIOSH, Health-Related Energy Research Branch, 4676 Columbia Parkway, MS-R44, Cincinnati, OH 45226-1998; 513-841-4400 or toll free 1-800-356-4674.

B.1.3 Hanford Thyroid Disease Study (HTDS)

The Hanford Thyroid Disease Study (HTDS) evaluated whether the occurrence of thyroid disease was related to exposure to iodine-131 released from the Hanford Nuclear Site during the 1940s and 1950s, and whether the prevalence of thyroid disease was related to the estimated radiation dose to the thyroid. The study focused on a group of 3,441 downwind residents, exposed as children, who were expected to have received the highest I-131 uptakes.

The study looked for increases in thyroid disease greater than the expected natural incidence rate in the general public from all causes. Persons who had higher estimated radiation doses appeared no more likely to have thyroid diseases than those who had very low doses. The study findings did not prove that Hanford radiation had no effect on the health of the area population. However, it did show that any potential effects were too few in number to be distinguished statistically from the natural or expected occurrence of thyroid disease in unexposed populations. The study findings show that if there is an increased risk of thyroid disease from exposure to Hanford's I-131 releases during the 1940s and 1950s, it is probably too small to observe using available epidemiological methods.

Investigators identified 3,441 persons who were born in one of seven counties near Hanford between 1940 and 1946 with the highest downwind exposures to I-131 and who were children in the 1940s and 1950s. For each study participant, investigators estimated a radiation dose to the thyroid from I-131. Participants were then given a medical examination to identify any thyroid disease or abnormalities. Instances of disease or abnormality were compared to I-131 doses.

The HTDS was authorized in 1988 by an act of Congress and funded by CDC. The principal investigators were affiliated with the Fred Hutchinson Cancer Research Center in Seattle, Washington.

For more information: 1-800-638-4837 (638-HTDS). Both a summary and the full HTDS Technical Report are available on the CDC web site: http://www.cdc.gov/nceh/radiation/default.htm

Information is also available on the HTDS Web site: http://www.fhcrc.org/science/phs/htds.

B.1.4 The R-11 Survey

The R-11 Survey was conducted to help determine the potential effects of Hanford emissions on the health of off-site populations.

Results from this survey are currently unavailable. Investigators completed data collection in 1995; however, release of the results was delayed pending the completion of legal proceedings. During those proceeding, a federal judge ruled that the R-11 study was scientifically flawed (Merwin et al., Health Phys. 81(6):670-677; 2001).

The R-11 survey compiled health histories and medical records of high school seniors who graduated during relevant exposure time periods. Records were collected from 15 representative towns downwind and downriver from Hanford, as well as from control-group towns. Data collected in the health histories and medical records will be analyzed to assess possible health effects of Hanford emissions on downwind populations.

Epidemiologist R. Clapp of the John Snow International Center for Environmental Health Studies in Boston, Massachusetts, in collaboration with S. Wing of the Department of Epidemiology at the University of North Carolina are the lead investigators who will analyzed the collected data. The R-11 Survey has been funded by private sources.

For more information: No contact information is available.

B.1.5 Northwest Radiation Health Alliance Survey

The Northwest Radiation Health Alliance conducted a survey to investigate health problems among Hanford Site downwinders.

The survey investigated the prevalence of thyroid diseases and miscarriages and other adverse birth outcomes related to hypothyroidism, a thyroid disease. To complete this survey, investigators distributed approximately 2,000 questionnaires to Hanford downwinders. The questionnaire asked for information about radiation exposure, health problems, and personal information. Follow-up phone calls were placed to a sample of the respondents.

The Northwest Radiation Health Alliance, an independent group of Hanford downwinders, physicians, and scientists, completed this survey with funding from grants through the McKenzie River Gathering Foundation and Oregon Community Foundation.

For more information: Northwest Radiation Health Alliance, PSR/Oregon, 921 S.W. Morrison, Suite 500 (The Galleria). Portland, OR 97205; 503-274-2720

B.1.6 Hypothyroidism and Spontaneous Abortion

This study was completed to investigate the prevalence of spontaneous abortions among female downwinders with hypothyroidism.

Investigators concluded that spontaneous abortions occurred more frequently in women who had hypothyroidism and who were exposed to radioactive releases from Hanford when compared to women who did not have hypothyroidism. Data gathered during the Northwest Radiation Health Alliance Survey, described elsewhere in this appendix, were analyzed. Investigators noted two data concerns: 1) the available data did not include thyroid doses, and 2) the data were self-reported, which is not the scientific standard required for epidemiologic study. Nonetheless, the investigators determined that the percentage of persons reporting

hypothyroidism seemed to be unusually high compared to an unexposed population, and that the frequency of spontaneous abortions in women with and without hypothyroidism suggests an association between hypothyroidism and spontaneous abortion.

Funding for this study was provided by a grant from the McKenzie River Gathering Foundation with assistance from the Portland, OR Chapter of Physicians for Social Responsibility. C. Grossman and R. Nussbaum served as the principal investigators.

For more information see Grossman C. and Nussbaum R. 1996. Hypothyroidism and spontaneous abortion among Hanford, Washington downwinders. Arch Environ Health. 51(3): 175-176.

B.1.7 Hypothyroidism in Children Living Near Hanford and Chernobyl

Investigators conducted this study to examine the potential relationships between hypothyroidism in children and exposure to releases of radioiodine from Hanford (starting in 1944) and Chernobyl (after the 1986 accident).

Hypothyroidism in a "self-defined group of downwinders" under the age of 20 was found to be associated with exposure to I-131 releases from Hanford and exposure to cesium-137 releases from Chernobyl. At Hanford, the onset of the disease was associated with radioiodine releases for the years 1944 through 1949. However, the group of juvenile (less than age 20 at time of exposure) downwinders was not considered to be a representative sampling of the total population living near the Hanford Site (Goldsmith et al., 1999).

Self-reported data on juvenile hypothyroidism was collected during the Northwest Radiation Health Alliance Survey and exposure information was developed during the HEDR project. Both are described previously in this appendix, and both were analyzed by study investigators to reach conclusions about Hanford. Conclusions about Chernobyl were based on an analysis of thyroid screening data for children living near Chernobyl during the accident.

The McKenzie River Gathering Foundation and Oregon Community Foundation provided grants to the Northwest Radiation Health Alliance for completion of this study. Some funding was also provided by CDC. J. Goldsmith and C. Grossman were the principal investigators in this study.

For more information: Goldsmith J, Grossman C. et. al. 1999. "Juvenile hypothyroidism among two populations exposed to radioiodine." Environ Health Perspect. 107(4): 303-308.

B.1.8 Other Studies

In spring 1993 the Hanford Education Action League compiled a list of other articles by

1. The Prevalence at Birth of Congenital Malformations in Communities near the Hanford Site
   - Authors: Lowell E. Sever, Nancy A. Hessol, Ethel S. Gilbert and James M. McIntyre
   - Years covered by study: 1968-1980
   - Journal: American Journal of Epidemiology 127:243-254; 1988

2. Childhood Leukemia Mortality Before 1970 Among Populations near Two U.S. Nuclear Installations
   - Author: J. R. Goldsmith
   - Years covered by study: 1950–1979
   - Journal: Lancet l:793; 1989; and Lancet 2:1443-1444; 1989

3. Childhood Leukemia Before 1970 Among Populations near Two U.S. Nuclear Installations
   - Author: S. Milham
   - Years covered by study: 1950–1979
   - Journal: Lancet l: 1443; 1989

4. The Feasibility of an Epidemiologic Study of Thyroid Disease in Persons Exposed to Environmental Releases of Radioiodine from the Hanford Nuclear Facility
   - Authors: S. Cate, A.J. Ruttenber and A.W. Conklin
   - Years covered by study: not applicable
   - Journal: Health Physics 59:169-178; 1990.

5. Statistical Aspects of the Hanford Environmental Dose Reconstruction Project and the Hanford Thyroid Disease Study
   - Authors: R.O. Gilbert, J.C. Simpson, B.A. Napier, H.A. Haerer, A.M. Libetrau, A.J. Ruttenber and S. Davis
   - Years covered by study: not applicable
   - Journal: Radiation Research 124:336-372; 1990.

6. Cancer Populations Living Near Nuclear Facilities: A Survey of Mortality Nationwide and Incidence in Two States
   - Authors: Seymour Jablon, Zdenek Hrubec, John D. Boice, Jr.,
   - Years covered by study: 1950–1984
   - Journal: Journal of the American Medical Association (JAMA) 265:11; 1403-1408; March 20, 1991.

7. Oregon Malignancy Pattern Physiologically Related to Hanford Washington Radioisotope Storage
   - Author: R.C. Fadely
   - Years covered by study: 1959–1964
   - Journal: Journal of Environmental Health, 27:883-897; 1965.

8. Oregon Malignancy Pattern and Radioisotope Storage
   - Author: J.C. Bailar and J.L. Young
   - Years covered by study: 1935–1960
   - Journal: Public Health Report 81:311-317; 1966.

B.2 Studies of Hanford Workers

B.2.1 Hanford Mortality Study

In 1964, the U.S. Atomic Energy Commission initiated a scientific study of the potential lifetime health and mortality experience of its contractors working at the Hanford, Oak Ridge, and Los Alamos sites. This study looked at all radiation exposures and causes of death. The Hanford Mortality Study was part of this effort to determine the possibility of adverse health effects associated with employment at the Hanford Site. Several reports were published by different scientists. This study was most recently updated in 1993.

Early studies found a possible association between radiation exposure and multiple myeloma, but the most recent update did not find this association. In fact, the most recent update found little evidence of a correlation between the cumulative radiation dose and death from cancer. Cancer of the pancreas and Hodgkin's disease (a cancer of the lymphatic system) were correlated with radiation dose. Study investigators, however, did not attribute this finding to radiation at Hanford because neither of these cancers is normally associated with radiation exposures. Overall, death rates in Hanford workers for all causes were much lower than those of the general population. These low death rates are

attributed to the "healthy worker effect," or the selective bias that results because workers must have a certain level of health to be employed. Results from the most recent update of the Hanford Mortality Study were published in the journal *Health Physics* in June 1993.

To complete this study, researchers collected information for over 44,000 workers who were employed at Hanford for at least 6 months between 1944 and 1978. Information gathered included death certificates from public records and external radiation exposure data from personal dosimeters. The study compared causes of death and death rates to radiation dose.

The Hanford Mortality Study began in 1965 under direction of T. Mancuso of the University of Pittsburgh. Battelle's Pacific Northwest Laboratory and the Hanford Environmental Health Foundation assumed responsibility for the study in 1977 and published updated results in September 1993.

For more information see the early report by Mancuso TF, Stewart A, and Kneale GW., 1977, "Radiation exposures of Hanford workers dying from cancer and other causes," Health Phys 33: 369–85; as well as the updated analysis by Gilbert E Omohundro E, Buchanan J, Holter N, 1993, "Mortality of workers at the Hanford site: 1945-1986," Health Phys 64(6): 577-90.

B.2.2 Re-analysis of Hanford Data

This study was conducted as the first non-DOE study of the health records of 35,000 Hanford workers and covered the years from 1944 to 1986. The intent of the study was to confirm 1989 findings of no correlation between radiation exposure and cancer deaths.

The researchers concluded that 1) small doses of radiation are 4 to 8 times more likely to cause cancer than previously believed, 2) persons are far more vulnerable to radiation-induced cancer if the exposure comes later in life, possibly due to aging persons' immune systems' declining ability to repair radiation damaged and mutated cells, and 3) radiation delivered in small doses over time could carry a higher risk of cancer than radiation delivered in a single dose. The study was published in March 1993 by the *American Journal of Industrial Medicine*.

Investigators used DOE Hanford Worker Mortality Data, which reports 1944–1986 data about Hanford workers and the badges they wore to monitor for external radiation. Dose estimates were obtained from these records and causes of

death were obtained from public records. Statistical methods were used to correlate dose and cause of death. Other factors considered included age at exposure, year of exposure, and time between exposure and death. Sex, race, birth year, year of hire, years at Hanford, and socioeconomics were also considered.

A. Stewart, a British epidemiologist at Birmingham University, and G. Kneale co-authored the study. The study was financed by the Three Mile Island Public Health Fund, a private foundation.

For more information see Kneale G and Stewart A. 1993. "Re-analysis of Hanford data: 1944–1986 deaths." Am J Ind Med. 23: 371–89.

B.2.3 Relationships Between Age at Exposure and Cancer Risk

Kneale and Stewart (1996) analyzed the influence of age at time of radiation exposure and subsequent cancer risk using data from a variety of nuclear worker populations, including Hanford Site workers.

This study found evidence that the risk of cancer increased with radiation dose received, with increasing risk for workers of ages 55 to 65. The relative frequency of specific cancer types were similar for those assumed to be caused by radiation and those occurring naturally in the general population unexposed to radiation.

For more information see Kneale G and Stewart A., 1996, "Relations between age at occupational exposure to ionizing radiation and cancer risk," Occup Environ Med 53(4):225-230.

B.2.4 Multiple Myeloma Among Nuclear Workers

The purpose of this study was to investigate a possible link between multiple myeloma, a cancer of the blood-forming tissues, and exposure to radiation by workers at four DOE sites (Hanford, Los Alamos, Oak Ridge, and Savannah River).

In this age-matched, case-control study, researchers found an increased risk of multiple myeloma for workers who received radiation doses at age 45 or older. The relative risk was found to be 6.9% per rem (0.01 Sv) whole-body exposure, with risk increasing with age at time of radiation exposure. However, the workers' lifetime cumulative whole-body dose was not associated with risk of multiple myeloma.

NIOSH provided funding for this study at the University of North Carolina (see Wing S, Richardson D, Wolf S, Mihlan G, Crawford-Brown D, and Wood J., 2000, "A Case Control Study of Multiple Myeloma at Four Nuclear Facilities," Ann Epidemiol 10(3):144-153.).

For more information contact NIOSH, Health-Related Energy Research Branch, NIOSH, 4676 Columbia Parkway, MS-R44, Cincinnati, OH 45226-1998; 513-841-4400 or toll free 1-800-356-4674.

B.2.5 Mortality Among Female Nuclear Weapons Workers

This study was the first multi-site mortality study of female workers at 12 Department of Energy nuclear facilities, including the Hanford Site. The purpose of this study was to determine the potential relationships between exposure to radiation or chemical hazards and mortality. Risk estimates were developed for exposure to ionizing radiation or to chemicals. NIOSH provided the study funding.

A strong healthy worker effect was found for all causes of death among these workers. For the entire pooled cohort, mortality from mental disorders, diseases of the genitourinary system, and from ill-defined conditions was higher than expected. External ionizing radiation exposure in these workers appeared to be associated with increased relative risk for leukemia and, to a lesser degree, was associated with increased relative risks for all cancers combined and for breast cancer (Wilkinson GS, Trieff N, and Graham R., 2000, "Study of Mortality Among Female Nuclear Weapons Workers," Final report to NIOSH, University of Buffalo, State University of New York, Buffalo, NY.

For more information contact Health-Related Energy Research Branch, NIOSH, 4676 Columbia Parkway, MS-R44, Cincinnati, OH 45226-1998; 513-841-4400 or toll free 1-800-356-4674.

B.2.6 Surveillance Methods for Solvent-Related Hepatotoxicity

The University of Washington, sponsored by a NIOSH grant, conducted a cross-sectional study at the Hanford site to establish a scientific basis for surveillance of hepatic effects in solvent exposed workers. One hundred industrial painters exposed subacutely and chronically to a variety of solvent mixtures over their working careers were compared with a reference group of 100 non-exposed carpenters matched by age, sex, and race. The study examined the hypothesis that solvent-related hepatic injury is characterized by parenchymal changes of

steatosis and fibrosis without associated necrotic changes, which are detected by elevated hepatic transaminases in blood. To obtain a copy of the final technical report visit the NIOSH Web site http://www.cdc.gov/niosh/2001-133.html or call 513-841-4400.
For more information contactDr. Carl A. Brodkin, University of Washington, werd@u.washington.edu or 206-341-4458.

B.2.7 Exposure History for the Construction Trades

The University of Cincinnati, under a NIOSH grant, created an exposure history for the construction trades at Hanford, based on earlier work at Oak Ridge. This project aimed to improve worker recall of complex occupational exposures across a large number of short-term workplace assignments. New techniques were used to establish guidelines and formats for personal work histories. To obtain a copy of the final technical report visit the NIOSH Web site http://www.cdc.gov/niosh/2001-133.html

For more information contact Dr. Eula Bingham, University of Cincinnati, 513-558-5728; eula.bingham@uc.edu.

B.2.8 Comprehensive Occupational Health Surveillance

Under a NIOSH grant the University of Washington, designed and implemented a model occupational safety and health surveillance system at Hanford. This study gathered appropriate occupational medicine and industrial hygiene data to identify hazardous exposures and adverse health outcomes. An Employee Job Task Analysis process supports the objective evaluation of occupational health interventions through worker involvement in prevention efforts. To obtain a copy of the final technical report visit the NIOSH Web site http://www.cdc.gov/niosh/2001-133.html or the University of Washington Web site http://depts.washington.edu/fmrwrkr/EJTA

For more information contact Dr. Tim Takaro by e-mail ttakaro@u.washington.edu or 412-624-1074.

B.3 Research Data Sources

B.3.1 The Comprehensive Epidemiologic Data Resource (CEDR)

The CEDR was created to provide public access to health and exposure data collected during studies of DOE facilities. The public may access study summaries at CEDR's Web site; researchers may apply for a permit from DOE to access the data.

The CEDR is a compilation of DOE-supported environmental and health related studies completed over the past 30 years. DOE worker health and mortality studies, which began in the 1960s to determine possible health effects from working in DOE facilities, form the core of the database. Data in the CEDR consist of numerous files that pertain to more than 150,000 workers. In addition, studies of Japanese atomic bomb survivors, studies of radium dial painters, and the dose reconstruction project for the Nevada Test Site are included in the CEDR. Specific to Hanford, the database includes the Hanford Worker Mortality Study begun in 1965, a study of lung cancer among workers, birth defect studies of workers' children, and epidemiological surveillance annual reports which began in 1992. Also included is an inventory of the records at Hanford relating to worker or community health studies.

Studies summarized in the CEDR were completed by various investigators. DOE has served as the primary funding source. For more information contact Barbara Brooks, Office of Epidemiologic Studies, EH-62/270CC, U.S. Department of Energy, 19901 Germantown Road, Germantown, Maryland 20874-1290; (301) 903-4674; Web site: http://cedr.lbl.gov.

B.3.2 Hanford Health Information Archives (HHIA)

The HHIA is a collection of personal experiences and health histories of persons who actually were or who could have been exposed to Hanford's radioactive material releases. The archive is available to the public at the Foley Center Library at Gonzaga University in Spokane, Washington or at the Web site: http://www.hhia.org.

The HHIA contains material donated by persons who were or could have been exposed to Hanford's releases between 1944 and 1972. The collection includes health information questionnaires, medical records, oral histories, letters, photographs, drawings, newspaper clippings, and other similar material. The

Health Information Database provides access to the health questionnaires and can be searched by body system, disease, town, exposure pathway, or donor's name.

The HHIA was a project of the HHIN and is operated by Gonzaga University.

For more information contact Foley Center Library Gonzaga University, 502 E. Boone Ave., Spokane, WA 99258-0095; 509-323-5932 or toll free 1-800-799-4442 (799-HHIA). Search for HHIA at http://www.gonzaga.edu/Academics/Libraries/Foley+Library/default.htm

B.3.3 The United States Transuranium and Uranium Registries (USTUR)

The USTUR is a human tissue research program whose primary purpose is to assure the adequacy of radiation protection standards for elements such as uranium, plutonium and americium. Two data collections are available: 1) the National Human Radiobiology Tissue Repository (NHRTR) is a collection of more than 20,000 human tissue samples, solutions, pathology slides and other biological materials from individuals with known exposure to radioactivity; 2) the National Radiobiology Archives (NRA) contain research data and biological materials from animal studies of radiation exposures. These materials are available to researchers for collaborative or individual studies of radiation effects.

The USTUR is built on donations of tissue obtained postmortem from individuals with a known history of exposure to uranium, plutonium, and americium. Tissues are analyzed to determine the amount of radionuclides of these elements remaining. These data are used along with the exposure history and medical data to evaluate the distribution and movement of radionuclides in the body and to assess doses to various tissues and organs. This information is used to improve the scientific methods for estimating internal doses from long-lived radioactive materials.

The registries program is carried out by the College of Pharmacy at Washington State University at the Tri-Cities campus. Dr. Anthony James serves as the USTUR Director. Funding for the program is provided by a grant from DOE.

For more information: Dr. Anthony C. James, USTUR, College of Pharmacy, Washington State University at TriCities, 2710 University Drive, Richland, Washington 99352; 509-372-7317 or toll free 1-800-375-9317; Web site: http://www.ustur.wsu.edu

B.4 Ongoing Studies Involving the Hanford Site

B.4.1 Birth Cohort Study

ATSDR conducted the Hanford Birth Cohort study in response to community concerns that autoimmune function and cardiovascular disease health effects may have resulted from exposure to radioactive releases, mainly I-131. The study found that men born near the Hanford site between 1945 and 1951 had a small increased risk of developing thyroid disease – Hashimoto's thyroiditis, a condition that occurs when the thyroid gland makes too little thyroid hormone. The percentage of women reporting Hashimoto's thyroiditis was consistent in all counties surveyed. The study did not find a link between I-131 and autoimmune and cardiovascular diseases in either men or women. Although study participants reported some health problems more often than the general population, other factors such as diet, lifestyle and work history make it difficult to determine if their exposure to radiation is a cause for these findings.

The preliminary study findings were presented at an ATSDR-sponsored public availability session on July 26, 2006 in Richland, Washington. The final report is expected to be released in October 2006. The complete study can be found online at http://www.atsdr.cdc.gov/hanford.

The study population consisted of 2,000 persons randomly selected from six Washington state counties. The "high exposed" group included persons who were born in Adams, Benton, or Franklin Counties between January 1, 1945 and December 31, 1951. The "low exposed" control group included persons who were born in San Juan, Whatcom, or Mason Counties during the same period and did not live in any of the high exposure counties.

For more information see Caroline Cusack, ATSDR; toll free 1-800-CDC-INFO; or email CCusack@cdc.gov.

B.4.2 Ionizing Radiation and Mortality among Hanford Workers

Under a NIOSH grant, the University of North Carolina is updating a mortality study of Hanford workers. The study will re-analyze cancer and noncancer mortality from chronic, low-level external radiation exposure. New methods will be used to estimate doses previously assumed to be zero and to account for the effects of internal dose.

NIOSH is providing the funding for Steve Wing, University of North Carolina, to complete this study.

For more information contact NIOSH, Health-Related Energy Research Branch, 4676 Columbia Parkway, MS-R44, Cincinnati, OH 45226-1998; 513-841-4400 or toll free 1-800-356-4674.

B.4.3 Multi-site Case-control Study of Lung Cancer and External Ionizing Radiation

This ongoing NIOSH case-control study combines worker information from multiple sites, including Hanford, to clarify the relationship between lung cancer and external radiation exposure.

For more information contact NIOSH, Health-Related Energy Research Branch, 4676 Columbia Parkway, MS-R44, Cincinnati, OH 45226-1998; 513-841-4400 or toll free 1-800-356-4674.

B.4.4 Lung Cancer Case-Control Study

This study investigates the association between mortality from lung cancer and exposure to external ionizing radiation among workers at four DOE sites, including Hanford. NIOSH scientists, using NIOSH funding, are a using multi-site, case-control method to complete the investigation.

For more information contact NIOSH, Health-Related Energy Research Branch, 4676 Columbia Parkway, MS-R44, Cincinnati, OH 45226-1998; 513-841-4400 or toll free 1-800-356-4674.

B.4.5 Multi-site Leukemia Case-control Study

This ongoing NIOSH case-control study combines worker information from multiple sites, including Hanford, to explore the relationship between external radiation and leukemia risk among 250 workers with leukemia, as compared to similar workers who do not have leukemia.

For more information contact NIOSH, Health-Related Energy Research Branch, 4676 Columbia Parkway, MS-R44, Cincinnati, OH 45226-1998; 513-841-4400 or toll free 1-800-356-4674.

Appendix C

200-Area Facilities

Outline

Tables

C.1 Processing Plants

Figure 3 in Appendix F shows the locations of the facilities within the 200-Area. The following descriptions of the 200-Area facilities are taken from USDOE (1987): Disposal of Hanford Defense High-Level, Transuranic and Tank Wastes (DOE/EIS-0113). Washington, DC: Department of Energy, December 1987.

Z Plant (Plutonium Finishing)

Also called the Plutonium Finishing Plant, the Z plant converted plutonium nitrate to plutonium oxide or plutonium metal. Building 231-Z began plutonium finishing in 1945 using the bismuth phosphate procedure. The plutonium recovery and finishing plant operation began in late 1949 using tributyl phosphate and carbon tetrachloride. The liquid process wastes were sent to cribs. Low levels of transuranic wastes in the liquid process wastes precipitated near the discharge point.

T and B Plants

The T Plant, one of the original fuel reprocessing plants, operated from 1944 to 1956. B Plant operated from 1945 to 1952, and again from 1967 to 1985. Both T Plant and B Plant used bismuth phosphate to separate uranium and plutonium by co-precipitation from reactor fuel. The plutonium was removed with lanthanum fluoride and bismuth phosphate. The 221 Canyon Buildings were the site of the bismuth phosphate process. The 224 Buildings were used in the lanthanum fluoride procedure. The neutralized wastes from these processes were stored in single-shell, carbon steel underground tanks. The T Plant was converted to an equipment decontamination and repair facility in 1957, and continues to serve in that capacity. The B plant was converted to a cesium and strontium recovery facility from 1967 to 1985. The B plant is adjacent to the Waste Encapsulation and Storage Facility.

U Plant

The U Plant operated from 1952–1958. Tributyl phosphate and kerosene were used as solvents to extract and recover uranium for recycle from bismuth phosphate processes. The U Plant extracted uranium but not plutonium. The uranium was converted to uranium trioxide ($UO_{3)}$. Other structures associated with the U Plant such as 224-U Building were operational until the early 1960s.

S Plant (REDOX)

The REDOX facility was built in 1951 and operated until July 1967. The reduction-oxidation process recovered both uranium and plutonium using hexone solvents. The hexone solvents removed aqueous dissolved uranium and

plutonium, which were then extracted using a slightly acidic aqueous solution. The waste stream, which also included aluminum nitrate, was neutralized and stored in single-shell, carbon steel underground tanks.

A Plant (PUREX)

The A Plant operated from 1955 until 1972 and is known as the PUREX Plant. Tributyl phosphate and kerosene were used to extract plutonium and other special materials from nitric acid solution. The process was similar to the S Plant operation. Acid wastes were neutralized and stored in single-shell tanks but double shell tanks were used for newer wastes. A process run began in 1983 to process N Reactor fuel. The PUREX Plant also recovered U-233 (fissionable) from irradiated thorium fuels in a process called the THOREX operation.

SO-1 E Plant

The SO-1 E plant was a large scale test facility that served as the pilot basis for the REDOX, PUREX, and cesium and strontium recovery processes. The test facility processes were then scaled up for use at the respective plants.

NO-1 N Plant

The NO-1 Plant consisted of three large storage facilities (the 212 buildings). Fuel rods from the 100-Area were stored prior to transfer to the bismuth phosphate process facilities. The storage allowed the shorter half-life isotopes to decay. These facilities operated from 1945 to 1952.

C.2 Tank Farms

Large-volume, underground storage facilities for radioactive chemical wastes are tank farms associated with each of the processing plants. A general description of the tank farms is given below and in Table D-1.

A Six single-shell storage tanks with maximum operating capacities of 1,000,000 gallons per tank. These tanks were constructed between 1954 and 1955.

AN Seven double-shell storage tanks with maximum operating capacities of 1,140,000 gallons each. These tanks were constructed between 1980 and 1981.

AP Eight double-shell storage tanks, each with a maximum operating capacity of 1,140,000 gallons. These tanks were constructed between 1983 and 1986.

AW Six double-shell storage tanks with maximum operating capacities of 1,140,000 gallons. These tanks were constructed between 1978 and 1980.

AX Four single-shell storage tanks with maximum operating capacities of 1,000,000 gallons per tank. These tanks were constructed between 1963 and 1964.

AY Two double-shell storage tanks with maximum operating capacities of 980,000 gallons each. These tanks were constructed between 1968 and 1970.

AZ Two double-shell storage tanks, each with a maximum operating capacity of 980,000 gal. These tanks were constructed between 1971 and 1977.

B Twelve single-shell storage tanks with maximum operating capacities of 500,000 gallons per tank, and four tanks with maximum operating capacities of 55,000 gallons per tank. These tanks were constructed between 1943 and 1944.

BX Twelve single-shell storage tanks, each with a maximum operating capacity of 500,000 gallons. These tanks were constructed between 1946 and 1947.

BY Twelve single-shell storage tanks with maximum operating capacities of 750,000 gallons. These tanks were constructed between 1948 and 1949.

C Twelve single-shell storage tanks with maximum operating capacities of 500,000 gallons and four single-shell tanks with maximum operating capacities of 55,000 gallons. These tanks were constructed between 1943 and 1944.

S Twelve single-shell storage tanks with maximum operating capacities of 750,000 gallons each. These tanks were constructed between 1950 and 1951.

SX Fifteen single-shell storage tanks with maximum operating capacities of 1,000,000 gallons per tank. These tanks were constructed between 1953 and 1954.

SY Three double-shell storage tanks with maximum operating capacities of 1,140,000 gallons per tank. These were constructed between 1974 and 1976.

T Twelve single-shell storage tanks with maximum operating capacities of 500,000 gallons each and four single-shell storage tanks with maximum operating capacities of 55,000 gallons per tank. These tanks were constructed between 1943 and 1944.

TX Eighteen 18 single-shell storage tanks with maximum operating capacities of 750,000 gallons per tank. These tanks were constructed between 1947 and 1948.

TY Six single-shell storage tanks with maximum operating capacities of 750,000 gallons each. These were constructed between 1951 and 1952.

U Twelve single-shell storage tanks with maximum operating capacities of 500,000 gallons each and four single-shell tanks with maximum operating capacities of 55,000 gallons each. These tanks were constructed between 1943 and 1944.

Table C-1. 200-Area Tank Farms

Tank Farm	Single (S) or Double (D) Shell	Number of Tanks	Individual Tank Capacity (m^3)	Tank Farm Total Volume (gal)
A	S	6	3,800	6,023,304
AN	D	7	4,300	7,951,818
AP	D	8	4,300	9,087,792
AW	D	6	4,300	6,815,844
AX	S	4	3,800	4,015,536
AY	D	2	3,800	2,007,768
AZ	D	2	3,800	2,007,768
B	S	12	2,000	6,340,320
B	S	4	210	221,911
BX	S	12	2,000	6,340,320
BY	S	12	2,800	8,876,448
C	S	12	2,000	6,340,320
C	S	4	210	221,911
S	S	12	2,800	8,876,448
SX	S	15	3,800	15,058,260
SY	D	3	4,300	3,407,922
T	S	12	2,000	6,340,320
T	S	4	210	221,911
TX	S	18	2,800	13,314,672
TY	S	6	2,800	4,438,224
U	S	12	2,000	6,340,320
U	S	4	210	221,911
Totals		177	58,243	124,471,049

Reference: US Department of Energy. 1987. Disposal of Hanford defense high-level, transuranic and tank wastes. Washington, DC: DOE/EIS-0113.

C.3 Disposal Structures

Hanford designed several different types of facilities for storage and disposal of waste streams. The following descriptions of those structures are from the Department of Energy's 1987 report on "Disposal of Hanford defense high-level, transuranic and tank wastes" (Washington, DC: DOE/EIS-0113).

Cribs

The cribs are buried structures initially constructed of either wood or concrete construction for hold-up of waste materials. Cribs provided an open underground space to discharge and percolate waste or contaminated liquids. Later crib construction was similar to sanitary drain fields (excavated trench with piping covered by a gravel fill).

Ditches

Ditches were unlined long narrow excavations used to transport or detain liquids. Ditches allowed for connection of pipelines to ponds. Although some liquid wastes percolated into the soils of the ditch, the major part of the liquids were transported to the ponds.

French Drains

French drains were large-diameter pipes buried vertically to depths normally less than 14 meters. The French drains were filled with rocks to allow percolation of small intermittent flows of liquid wastes into soils.

Ponds

Ponds were the primary structures to percolate waste or contaminated liquids into the underlying soils. Generally, the liquids discharged to ponds was less contaminated that the liquids discharged to cribs.

Reverse Wells

Reverse wells were pipe casings extending deep into the ground.

Settling Tanks

Settling tanks consisted of single-shell tanks or sumps constructed of concrete to contain liquids. The solids settled out in the settling tanks and the liquids flowed into either French drains or cribs.

Trenches

Trenches were open, long, narrow excavations for burial of contaminated objects and small amounts of liquid waste.

C.4 Operable Unit Groupings

Waste streams in the 200 Area were grouped into operable units. The following descriptions of the operable units were taken from Stenner RD, Cramer KH, Higley, KA et al., 1988, "Hazard Ranking System evaluation of CERCLA inactive waste sites at Hanford," PNL-6456, Richland, Washington: Pacific Northwest Laboratory.

Process Liquids Units

Process liquids units were areas that received and discharged wastes to the soils, that is, no tanks were in the process stream. Examples of the discharge areas include cribs, French drains, trenches, ditches, and basins. Over 50 such discharge sites were identified in the 200-Area. Sufficient liquid wastes were discharged to affect both the water table and contaminate the groundwater beneath the sites.

Tank Farm Units

The tank farm units included the single-shell and double-shell underground storage tanks. In 1994, the tanks were thought to contain more than 61 million gallons of liquids, salts, and sludges from the process streams (GAO 1994). Additional information on the tank farms is given in this appendix.

Solid and Buried Waste Units

The solid and buried waste units were pits and burial grounds. The burial sites contained various types of wastes, including drums, equipment, boxes, and tools.

Support Services Units

The support services units included coal plant steam (heating) operations, laundry facilities, and equipment maintenance areas.

Appendix D

Operable Unit 300-FF-2
Burial Grounds

Bechtel-Hanford compiled documents on 13 burial grounds and three other burial grounds and trenches within Operating Unit 300-FF-2 (70). The Department of Energy posted information on the Internet about solid waste interred in burial grounds (75). The posted material was derived from from two Westinghouse-Hanford documents (76; 77). Information from these sources is summarized if the following table.

Burial Ground	Dates Used	Waste	Description
618-1	1944–1951	Uranium (U), putonium (Pu), fission products	See Figure 6. NE corner operable unit (OU) near bldg 333. 2 north-south trenches 200' long, 16' wide, 8' deep. 15' east-west pits 20' deep. 16 tons U, some Pu, fission products, additional laboratory wastes. Now covered with buildings and tank farms. Nitric acid spill from tanks in bldg 334 dissolved much of U and iron, which migrated to groundwater.
618-2	1951–1954	U, fission products, tin, lead, auto batteries	See Figure 6. NE of bldg 333. 4 east-west trenches 150' X 51' X 15' for disposal of U-contaminated oxides from cuttings for fuel fabrication, Pu, fission products, tin, lead, auto batteries. Fire '54. Surface readings of 35 R/hr '55.
618-3	1954–1955	U	W of 618-2. 1 trench or several pits. U-contaminated building materials from building 313.
618-6	1944–1946	solid U	See Figure 6. 1944-1946 near bldg 325 (about 700' SW of SW corner South Proc. Pond), exhumed, moved twice and relocated to bldg 324 (about 700 ft east of first site) 1951-1962, then relocated to 618-10, see below).
618-7	1955–1956 or 1960–1973	U-contaminated solvents, beryllium-contaminated zircaloy chips, low-level U- and thorium-contaminated matter	½ mile west of North Process Pond. 2 drive-in E-W trenches 160'X100'X12' and 1 V-shaped pit 140'X20' used for thorium disposal, low-level U- and thorium from fuel fabrication. Drummed U-contam. solvent and hundreds 30 gallon drums with beryllium-contaminated flammable zircaloy chips packed in water. Drums leaked water; chips potentiall an explosion hazard.
618-8	1943–1944	Solid U wastes from uranium fuel fabrication	Under parking lot about ¼ mile SW of North Process Pond. Several burial trenches. Radiation markers lost when parking lot built. Contamination found outside burial ground borders.

Appendix D – Operable Unit 300-FF-2 Burial Grounds

Burial Ground	Dates Used	Waste	Description
618-9	1950–1956	U-contaminated solvents, including kerosene, methyl-isobutyl ketone, tributyl phosphate, ammonium nitrate fertilizer	200' NE of 600-22 (see Figure 4), the 300 west burial ground was open trench backfilled in 1956. U-contaminated solvent from REDOX experiments, used and unused ammonium nitrate, agitators from bismuth phosphate process tests. Exhumed 1991, removed solvents and debris to low-level burial ground. Soil has traces kerosene; no methyl isobutyl ketone.
618-10	1954–1963	Fission products, Pu, low- to high-level dry wastes, petroleum liquids.	See Figure 4. Called 300 north burial ground. 12 trenches 50–300' long, 25–40' wide, 25' deep with low-level wastes. 94 pipe facilities made of 22" pipe in 15' lengths from 55 gallon drums with medium to HLW. In 1994, up to 5 R/hr; fire 1995 spread particles 1500 feet NE up to 4.5 R/hr; fire 1961 in trench contaminated area to more than 100,000 cpm; now backfilled and topped with concrete, no rads 1990.
618-11	1962–1967	Fission products, Pu, low- to high-level radioact. waste, solvents, eutectic wastes.	See Figure 4. Called Wye burial ground. 3 trenches 900' by 50', 25'deep, 50 pipe facilities (see 618-10), and 4 caissons made of 8' diameter, 10' long metal pipe, some up to 100 R/hr; accidents spread airborne contamination. Surface stabilized '83, no surface rads 1990.
618-13	1950–1974	Various radionuclides contamination	Just south of 618-9. Probably storage area prior to burial of solvents in 618-9.
Undocumented solid waste site	1943–1944	Solid U, construction debris.	Possibly part of 618-8 (see below). Just west of northern part of 618-8.
Early burial ground, undocumented	1943–1944	Fuel fabrication U, U-contaminated shavings, unknown materials	1000 feet west of northern part of North process pond, north of rail tracks (see Figure 5). Formerly used for staging U-contaminated aluminum shavings. Site now posted.
Undocumented burial trench	1950s	Unknown	Just west of southern part of 316-5 Process Trenches (see Figure 5 and Figure 6). Now posted.
Buried construction waste area #1	1977–1979	Construction waste	NW corner of 400-Area (see Figure 4).

Appendix D – Operable Unit 300-FF-2 Burial Grounds

Burial Ground	Dates Used	Waste	Description
Buried construction waste area #2	1972–1974	Construction waste	Near north-central border of 400-Area (see Figure 4).
Suspected burial ground	Unknown, believed inactive	Unknown	¾ mile NE of 400-Area (see Figure 4). Now covered with soil mounded 15' above ground level.
Undocumented construction waste area #1	1977–1979	Construction waste	Just east of "buried construction waste area #1" (see above).
Undocumented construction waste area #2	1972–1974	Construction waste	Just west of "buried construction waste area #2" (see above).

Appendix E

Building 313

Outline

Hanford 313-Building: Investigation of Potential Radiation Exposure at an Aluminum Products Factory

E.1 Background

In January 2000, members of the Government Accountability Project (GAP), a citizens watchdog group, raised concerns that workers and members of the public might be exposed to elevated levels of gamma radiation at the Richland Specialty Extrusions Facility, a subsidiary of Kaiser Aluminum. This facility had leased the northern end of the Hanford 313-building and a nearby parking area, located south of the gate at the northern end of Hanford's 300-Area. While it operated at that site from 1994 to 2002, Richland Specialty Extrusions made aluminum parts aircraft, automobiles, and sporting goods, such as baseball bats, using a 4,000-ton Sutton extrusion press..

As discussed in Chapter 2, DOE previously used the extrusion plant in the 300-Area to manufacture uranium fuel for the Hanford Site's plutonium production reactors.. In the 1940s through the early 1970s protective metal coverings were placed over the fuel elements, and the fuel elements and coatings were tested for leaks in the 313-building. When the building was remodeled in 1954, radioactive wastes were removed for burial. After 1983, DOE used the south end of the 313 Building to test N-reactor fuel elements. The 313 Building and extrusion press were leased to Richland Speciality Extrusions in 1994. In 2002, the company and extrusion press later relocated to a leased facility on Steven Drive in North Richland, where it operates as a division of Kaiser Aluminum.

E.2 Governmental Accountability Project (GAP) Investigation

Members of GAP visited the 313-building site in January, 2000. In a letter to the Washington Department of Health (WDOH) they reported that access to the 313-Building area was unchecked (uncontrolled beyond signs stating that badges are required for entry). They also reported that radiation count-rates using a Rad Alert Geiger-Muller radiation counter outside the building were high. They further expressed concerns about potentially contaminated discharges of liquid onto soils near the factory.

GAP members took measurements from atop and behind a 6-foot high wall of concrete shielding blocks. From their readings of up to 1,520 counts per minute (cpm) on the wall and up to 2,000 cpm behind the wall, GAP calculated that at 2

mrem per hour, a worker in the aluminum factory could receive up to 700 times EPA's 25 mrem per year limit on whole-body dose equivalent outside of controlled areas. Although GM counters are not the appropriate instrument for determining whole-body exposure rates, and counts per minute from a GM counter cannot be directly translated to exposure rate in mrem (without identity of the radiation sources, emission energies, and other information), an approximate translation of 1,520 counts per minute would be about 0.4 mrem per hour at 1 m above ground level. GAP investigators also measured the GM count rate close to soil where liquid discharged from the 313 Building. The GAP investigators reported a high GM measurement of 200 counts per minute.

E.3 Washington Department of Health Findings

In response to GAP's concerns the Washington State Department of Health (WDOH) investigated the 313-Building site, and found that the site had unrestricted access, although it was gated and all entrances to radiologically controlled areas were posted with the required signs. One sign on top of the 6-foot high wall of blocks that GAP tested stated that the block itself was radioactive. WDOH also found that 1) engineered barriers such as shield blocks and chain-link fences were used to designate the boundaries of radiological areas and to prevent unintentional entry by workers; 2) doses from external sources within unrestricted areas did not exceed 2 mrem per hour; and 3) factory workers received basic radiological and emergency response training annually from DOE, as required for site radiation safety.

Except for one "hot spot," measured dose rates at other areas were less than the equivalent of 25 mrem per year—the EPA limit for public exposure outside of controlled radiation areas. WDOH reported that the building "hot spot" could expose someone to up to 100 mrem dose per year if a worker remained at that location for 2000 hours, but that the "hot spot" was in an inaccessible area, and therefore was in full compliance with limits in DOE's Hanford Radiological Control Manual (DOE/RL-96-109), similar to WDOH licensee requirements in WAC 246-221-060(1)(a).

WDOH readings on top of the 6-foot block shield-wall ranged from 200 to 500 uR/hour; readings behind the wall ranged from 35 to 50 microRoentgens per hour (roughly equivalent to 0.03 to 0.05 mrem per hour). If one were to remain on top of the wall continuously (24 hours/day) for 365 days a year, they could receive a whole-body dose of 3,000 mrem, which exceeds the DOE exposure limit of 100 mrem whole-body to members of the general public on DOE property. A more realistic scenario would involve a few minutes of exposure per week or negligible exposure for one year.

Appendix E – Building 313

Radiation levels were at background levels near the building perimeter. WDOH soil samples near the 313-building found higher levels of uranium-234 and uranium-238 than at off-site locations.

WDOH concluded that the 313 Building location fully complied with applicable DOE and WDOH radiation safety regulations, adding that "there is no public health risk from external exposure or residual radioactive contaminants" at the property leased to Richland Specialty Extrusions in the 313 Building (Danielson 2000).

Appendix F

Figures

Appendix F – Figures

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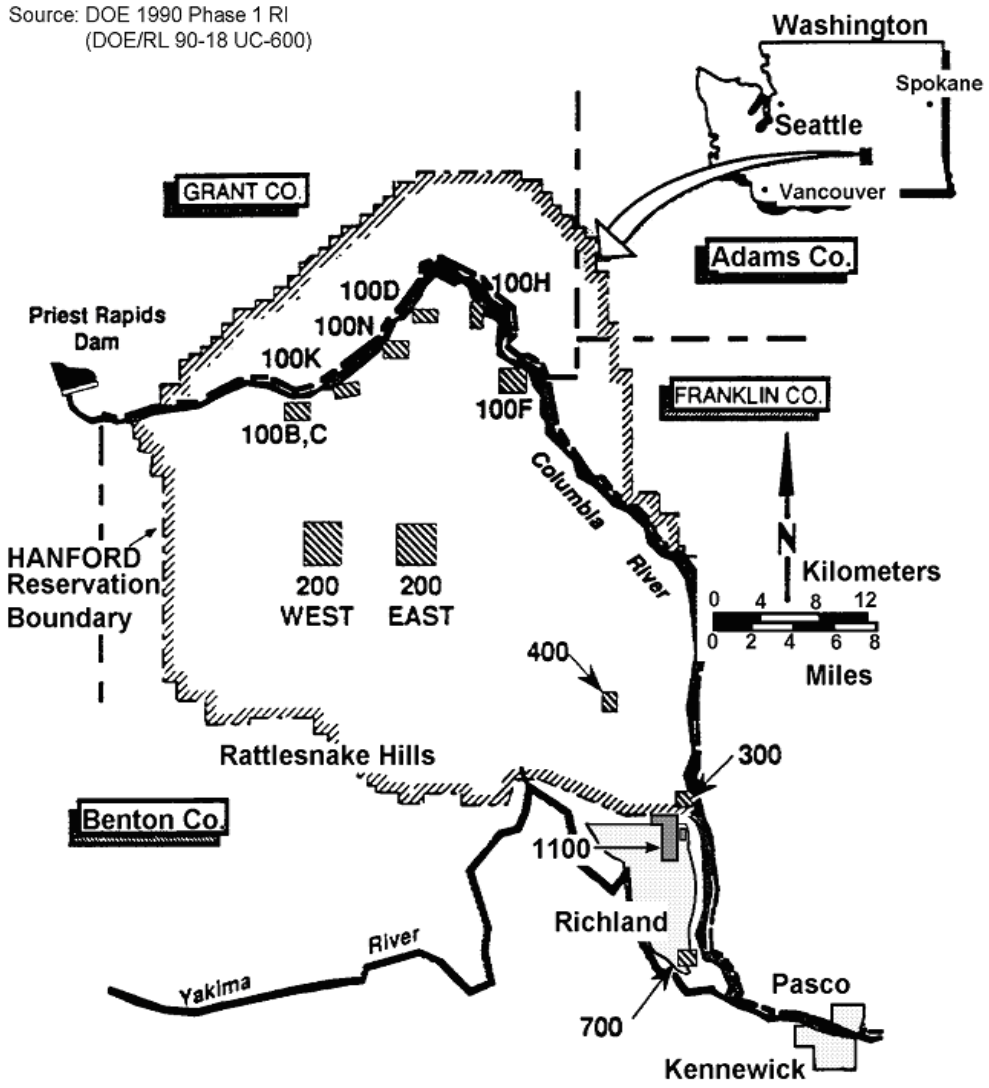

Figure 1. Location of Hanford Site and Operational Areas

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Figure 2. 100-K Aerial Photograph

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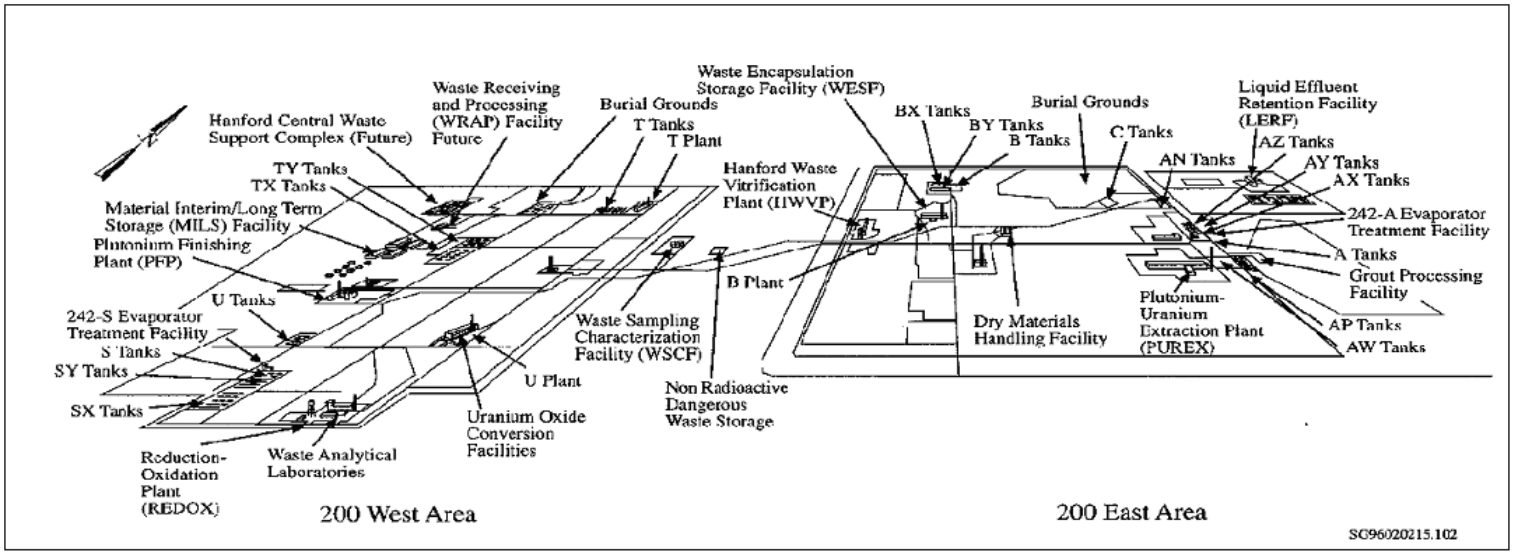

Figure 3. 200-Area

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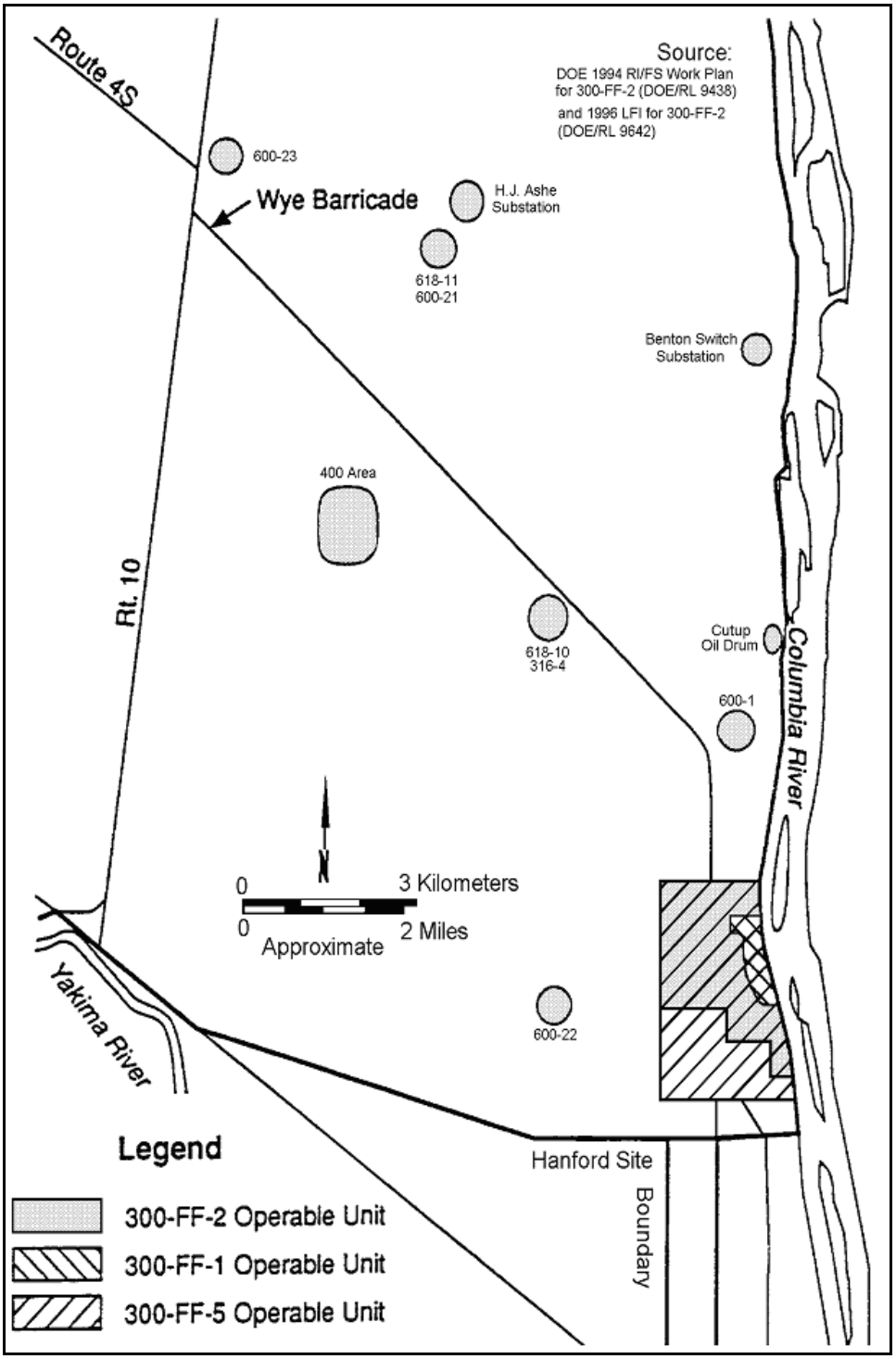

Figure 4 300-Area, Showing Outlying Features

Appendix F – Figures

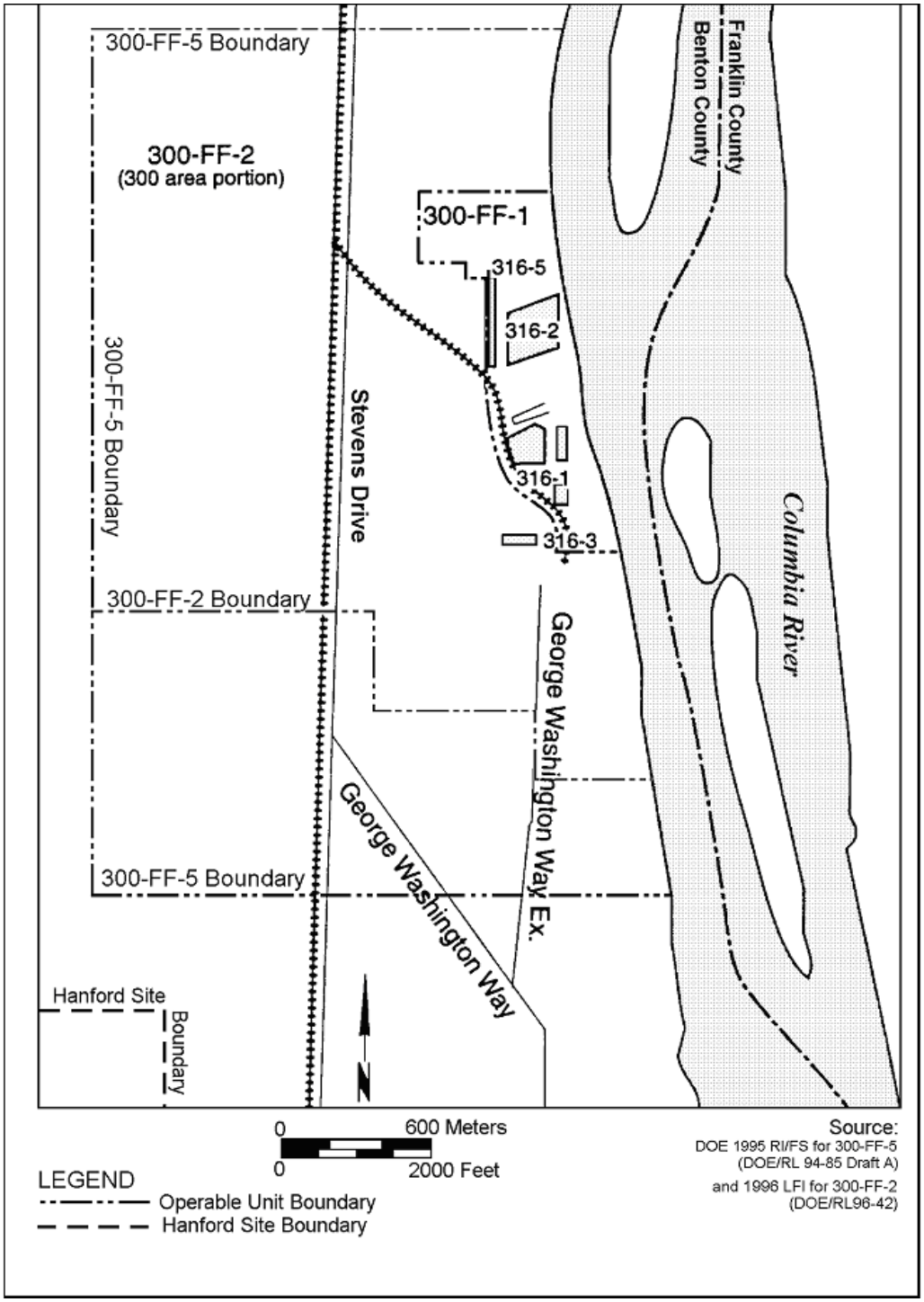

Figure 5. 300-Area Operable Unit Boundaries

Appendix F – Figures

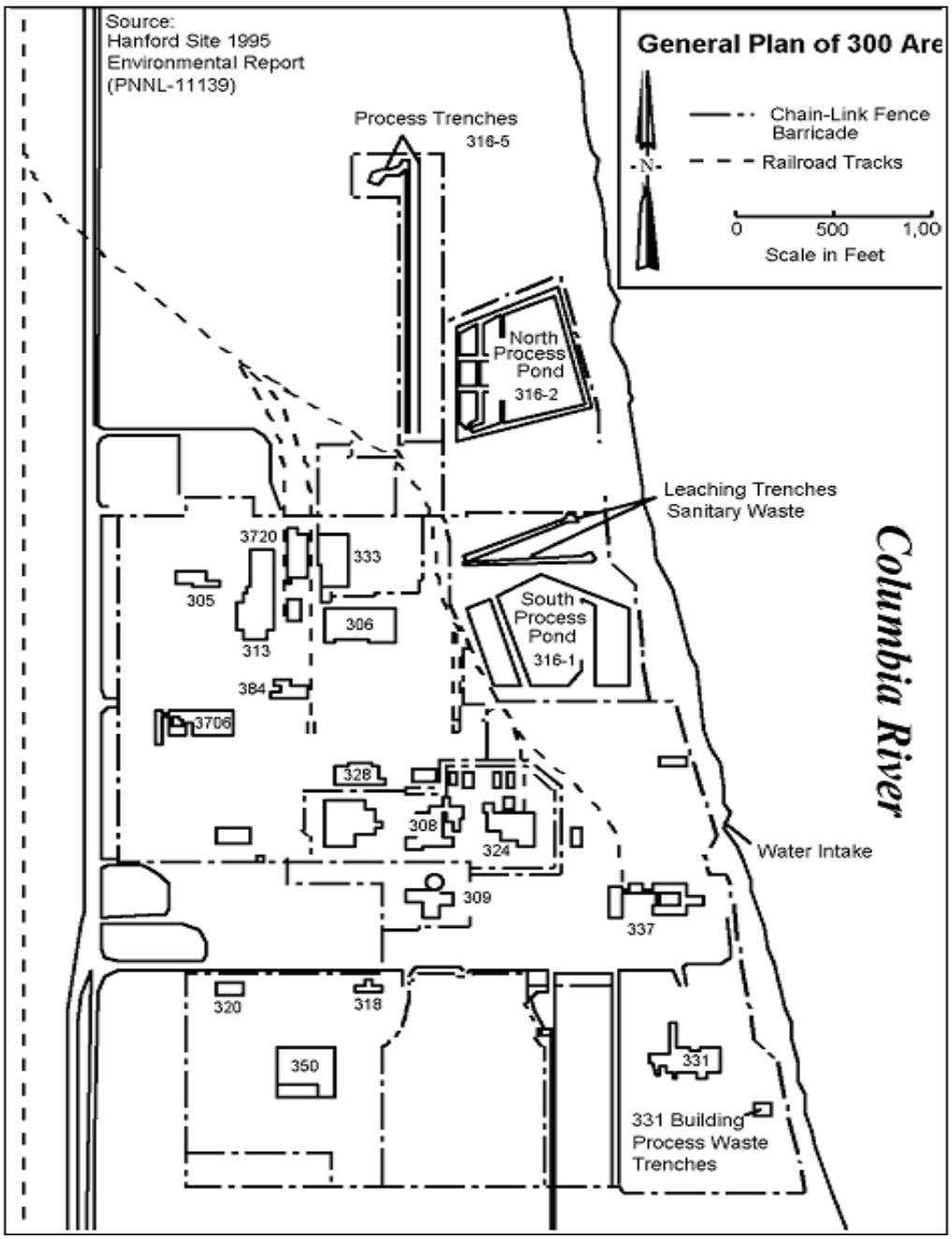

Figure 6. 300-Area Waste Sites and Facilities

Appendix F – Figures

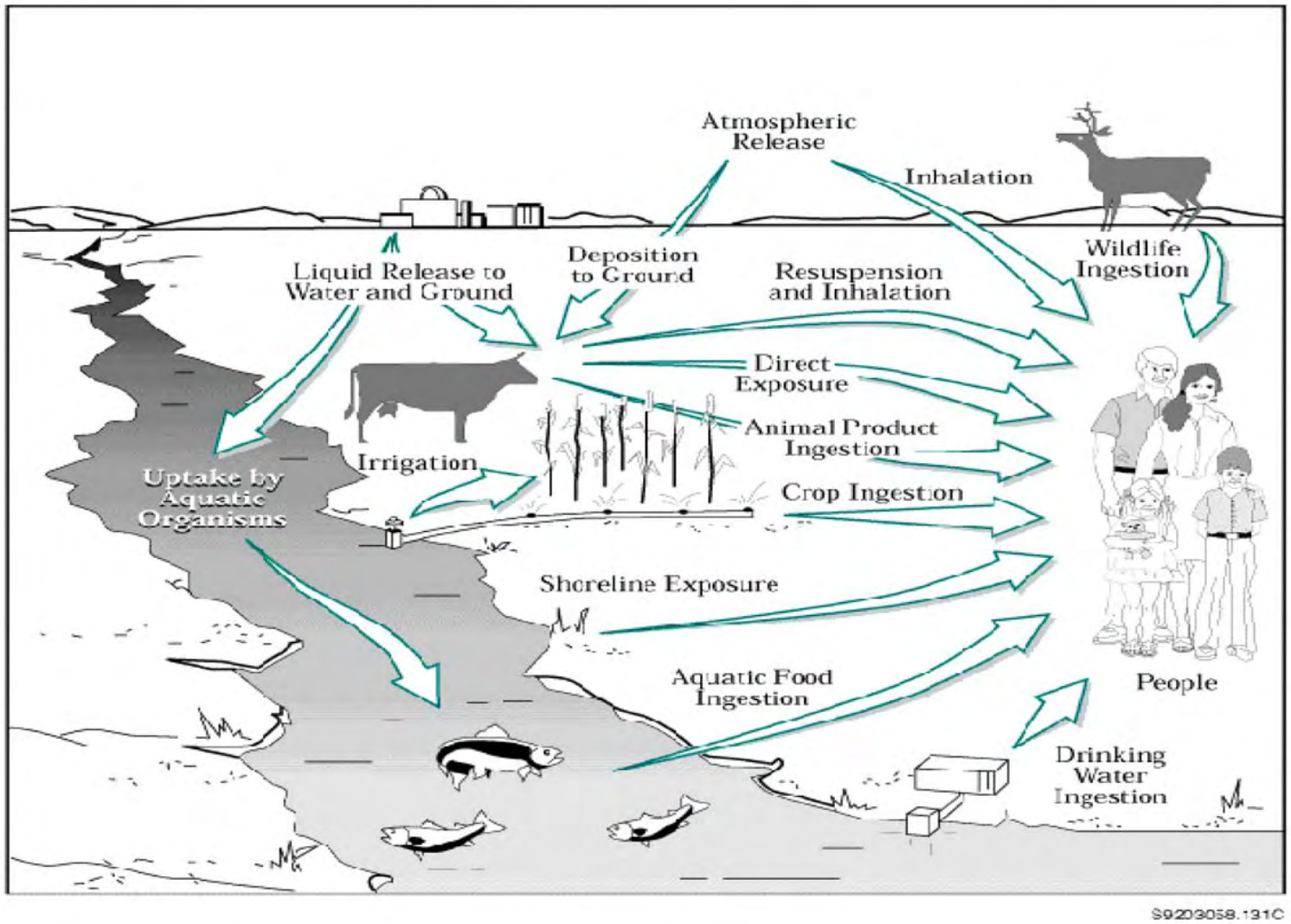

Figure 7. Potential Pathways

Appendix F – Figures

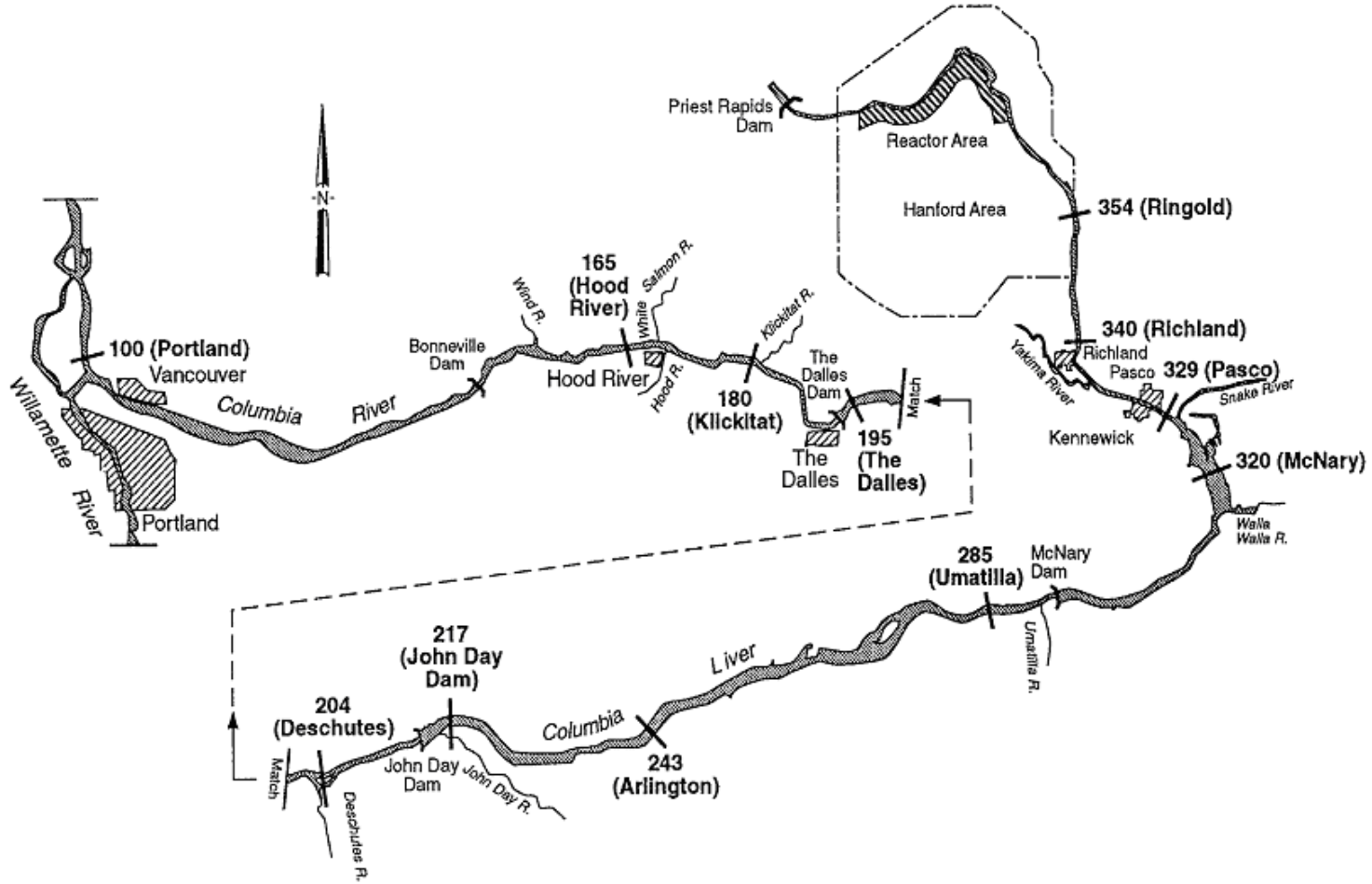

Figure 8. Columbia River

Appendix F – Figures

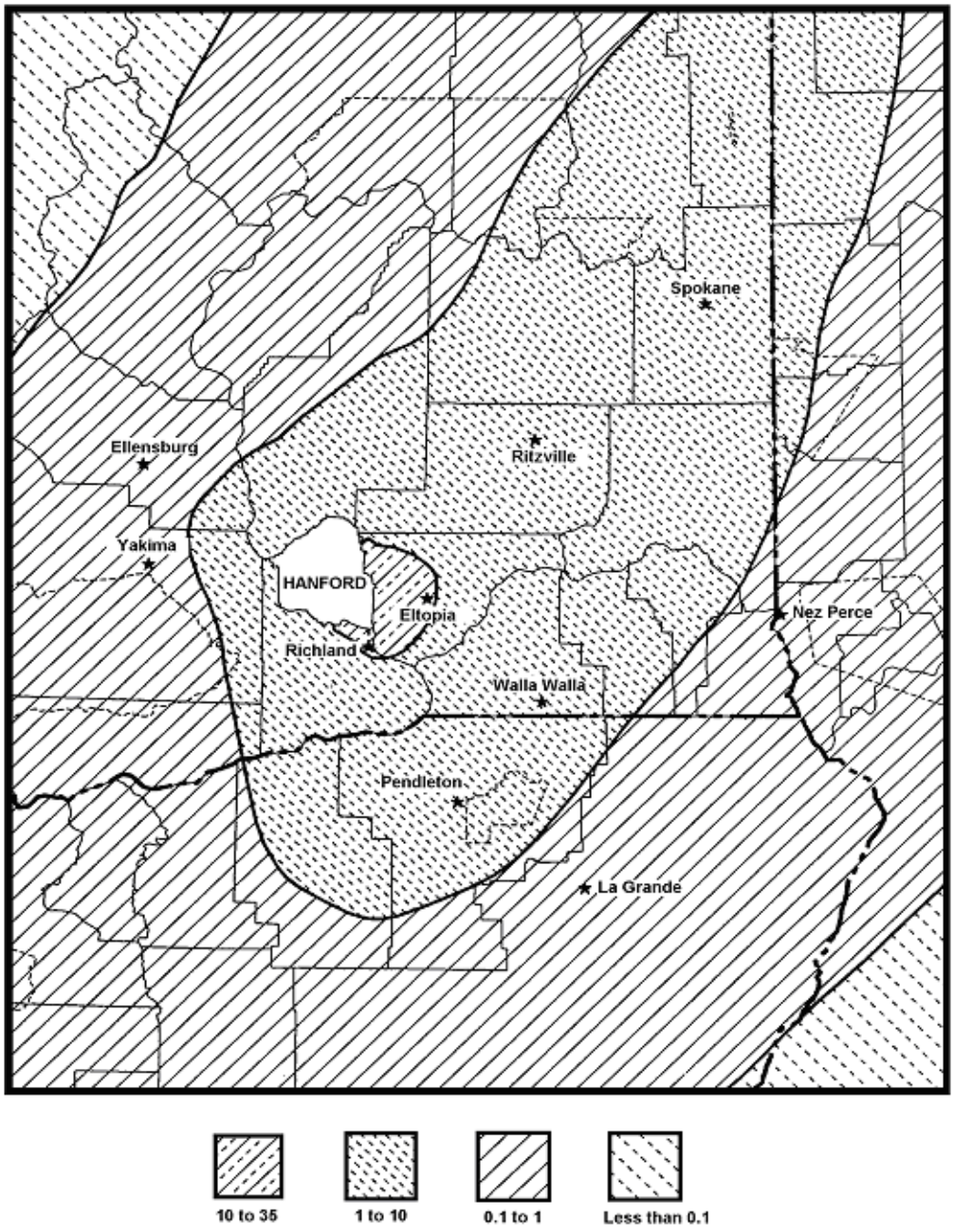

Figure 9. Cumulative Iodine-131 Deposition

Appendix F – Figures

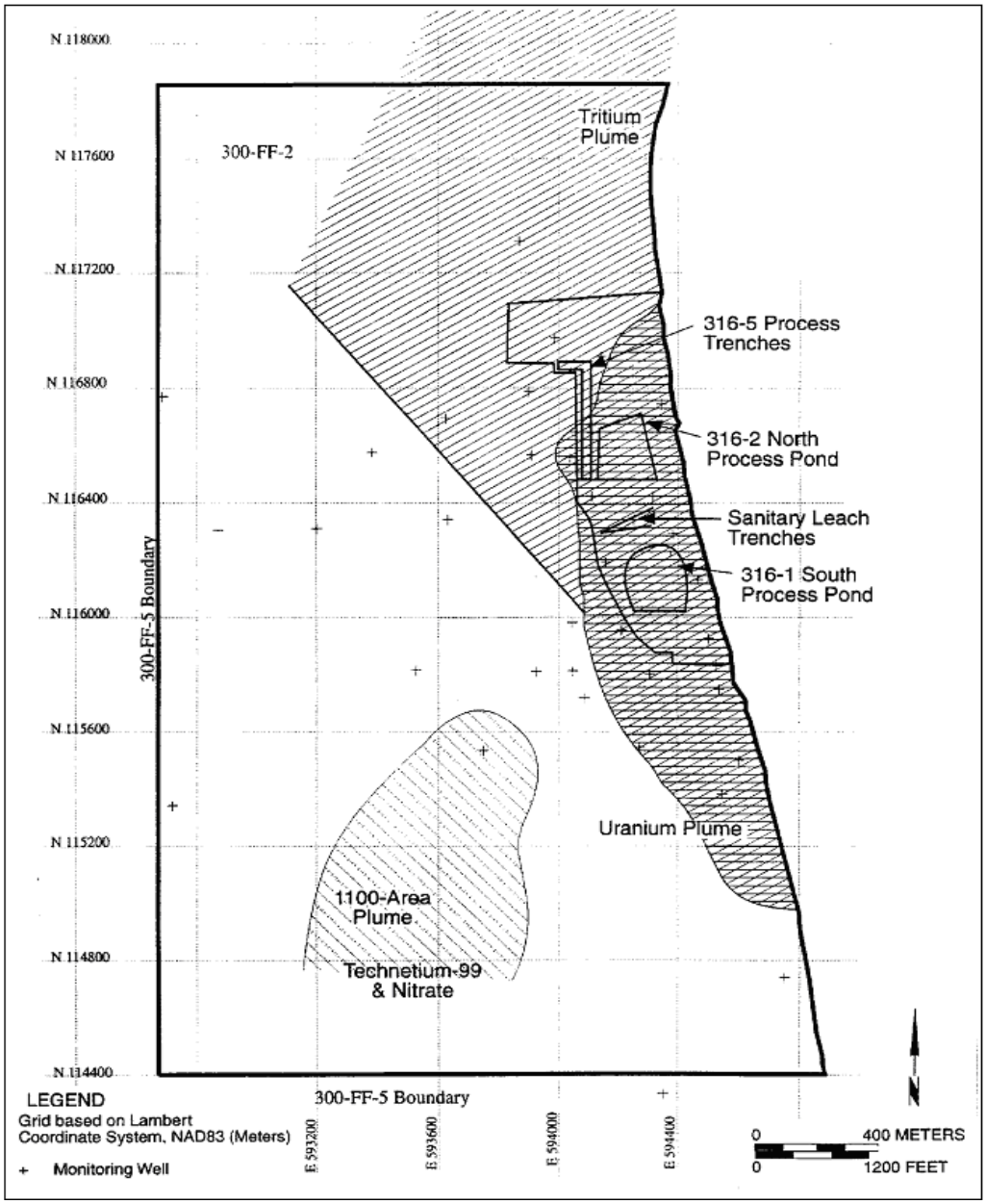

Figure 10. Groundwater Plumes in the 300-Area

Appendix F – Figures

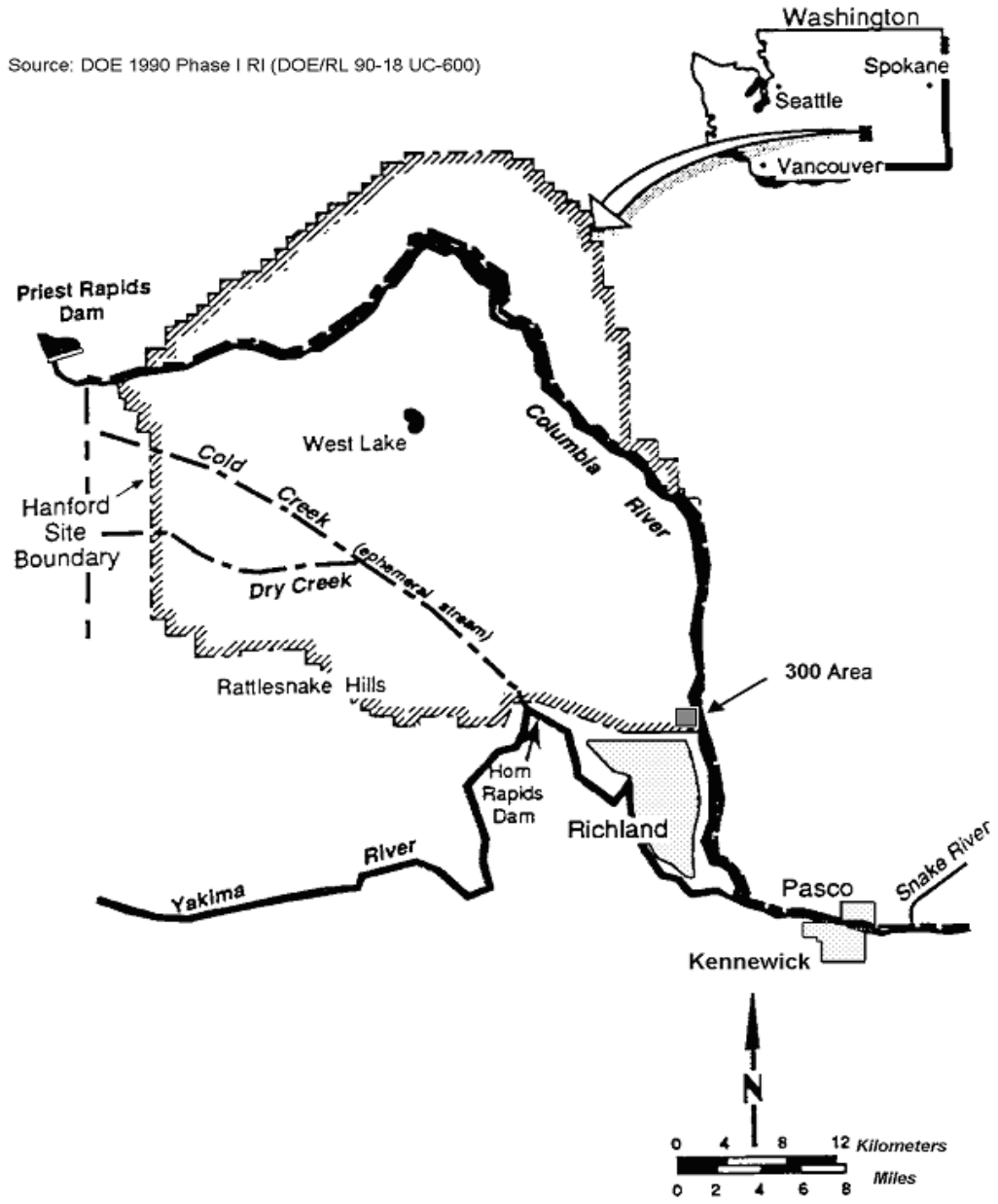

Figure 11. Major Surface Water Features

Appendix F – Figures

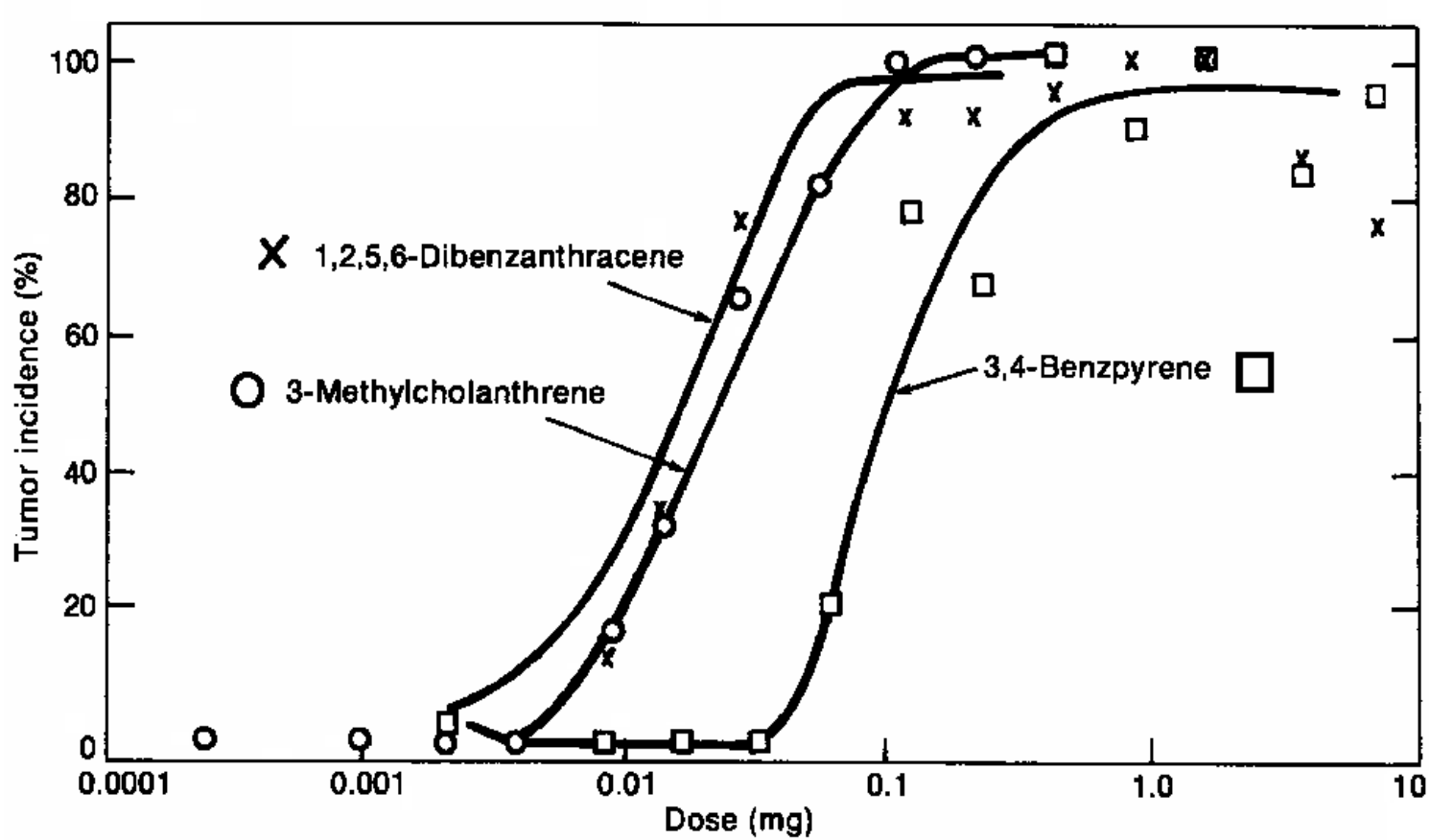

Figure 12. Sigmoid Dose-Response Curves for three Carcinogens

Appendix F – Figures

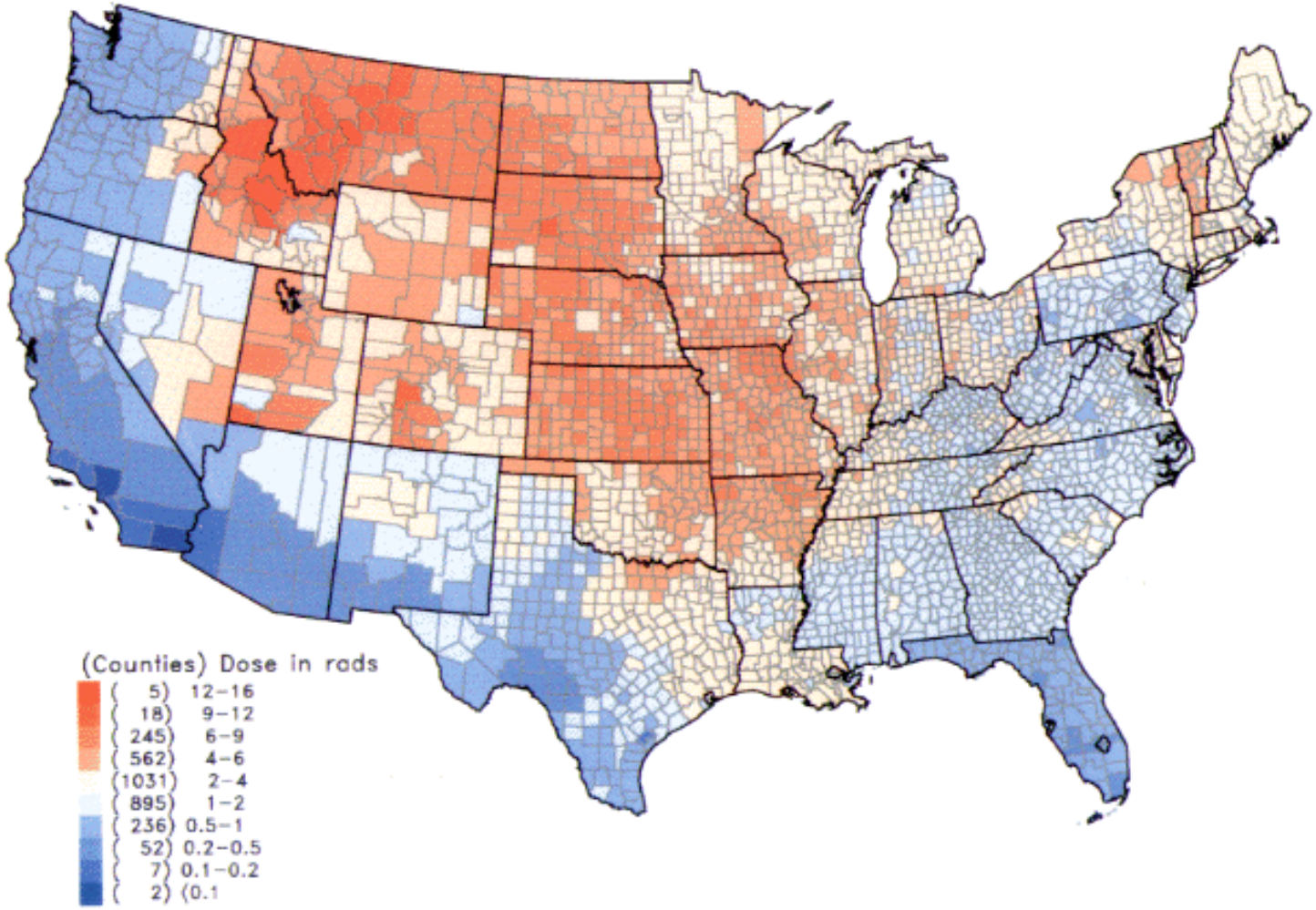

Figure 13. Overall I-131 per Capita Dose from Nevada Test Site Fallout (from reference HHS 1997)