II.F.2. TDOH

Oak Ridge Health Studies. In 1991, DOE and the state of Tennessee entered into the Tennessee Oversight Agreement, which allowed the TDOH to undertake a two-phase independent state research project to determine whether past environmental releases from ORR operations harmed people who lived nearby (ORHASP 1999). All of the technical reports produced for the TDOH Oak Ridge Health Studies are accessible in portable document format (PDF) at http://cedr.lbl.gov.

- *Phase I.* Phase I of the Oak Ridge Health Study is a Dose Reconstruction Feasibility Study. This feasibility study evaluated all past releases of hazardous substances and operations at the ORR. The objective of the study was to determine the quantity, quality, and potential usefulness of the available information and data on these past releases and subsequent exposure pathways. Phase I of the health studies began in May 1992 and was completed in September 1993 (ATSDR et al. 2000). A brief summary of the Phase I Feasibility Study is provided in Appendix D.

  During this process, the state reviewed thousands of documents and interviewed knowledgeable parties to assess the possibility of creating a dose reconstruction, and to examine historical releases from the ORR that posed the greatest threat to public health. The state reviewed documents related to four major facilities, X-10 (now ORNL), Y-12, K-25, and the former S-50, and for several off-site areas associated with ORR contamination (ChemRisk 1999a). In the feasibility study, the state 1) evaluated historical activities at each facility on the ORR, 2) compiled an inventory of environmental sampling and research data for use in the dose reconstruction, 3) identified activities with the highest potential to release substantial quantities of contaminants to off-site populations, 4) determined the potential that the contaminants released could affect public health, 5) identified important environmental media and exposure pathways through which off-site populations could be exposed, 6) compiled a list of contaminants that needed further evaluation, 7) examined if a completed exposure pathway existed, and 8) assessed which pathways contributed significantly to the potential health risks for off-site populations. Through this extensive process, ChemRisk was able to identify the contaminants and pathways with the greatest likelihood for causing adverse health effects. *For information on other activities conducted during the feasibility study, please see ChemRisk's 1993 Oak Ridge Health Studies.*

  The findings of the Phase I Dose Reconstruction Feasibility Study indicated that a significant amount of information was available to reconstruct the past releases and potential off-site exposure doses for four hazardous substances that had the largest potential risk for adverse health effects. These four substances include 1) radioactive iodine releases associated with radioactive lanthanum processing at X-10 from 1944 through 1956; 2) mercury releases associated with lithium separation and enrichment operations at the Y-12 plant from 1955 through 1963; 3) PCBs in fish from East Fork Poplar Creek (EFPC), the Clinch River, and the Watts Bar Reservoir; and 4) radionuclides from White Oak Creek associated with various chemical separation activities at X-10 from 1943 through the 1960s (ATSDR et al. 2000).

- *Phase II (also referred to as the Oak Ridge Dose Reconstruction).* Phase II of the health studies conducted at Oak Ridge began in mid-1994 and was completed in early 1999. Phase II primarily consisted of a dose reconstruction study focusing on past releases of radioactive iodine, radionuclides from White Oak Creek, mercury, and PCBs. In addition to the full dose reconstruction analyses, the Phase II effort also included additional detailed screening analyses for releases of uranium and several other toxic materials that had not been fully characterized in Phase I (a brief in Appendix D summarizes the *Screening-Level Evaluation of Additional Potential Materials of Concern, Task 7*). The significant findings for each of the substances evaluated, as well as the significant findings of the additional screening analyses in the Task 7 report, are presented in the following paragraphs.

Radioactive iodine releases were associated with radioactive lanthanum processing at X-10 from 1944 through 1956. Results indicate that children who were born in the area in the early 1950s and who drank milk produced by cows or goats living in their yards had the highest theoretical increased risk of developing thyroid cancer. The results suggest that a female born in 1952 at Bradbury, TN would have the highest risk of developing thyroid cancer from the radioactive iodine releases.

> EPA's reference dose is an estimate of the largest amount of a substance that a person can take in on a daily basis over their lifetime without experiencing a significant increase in risk of adverse health effects.

The study evaluated mercury releases associated with lithium separation and enrichment operations at the Y-12 plant from 1955 through 1963. Results indicate that during the mid-1950s farm families living along the East Fork Poplar Creek and children playing in the creek could have received annual average doses of mercury exceeding the EPA reference dose. The results also suggest that fetuses of pregnant women who ate significant quantities of fish from the Clinch River or Poplar Creek in the late 1950s and early 1960 are at the highest risk of methylmercury exposure.

Additional studies were conducted on PCBs in fish from EFPC, the Clinch River, and the Watts Bar Reservoir. Preliminary results indicated that individuals who consumed a large amount of fish from these waters might have received doses that exceeded the EPA reference dose for PCBs.

Radionuclides associated with various chemical separation activities at the X-10 site from 1943 through the 1960s were released into White Oak Creek. Eight radionuclides were studied: cesium 137, ruthenium 106, strontium 90, cobalt 60, cerium 144, zirconium 95, niobium 95, and iodine 131; those deemed more likely to carry significant risks. The results indicate that the releases caused small increases in the radiation dose over background for individuals who consumed fish from the Clinch River near the mouth of White Oak Creek. The dose reconstruction scientists estimated that an adult male who ate up to 130 meals of fish from the mouth of White Oak Creek every year for 50 years (worst-case scenario) had the highest theoretical increase risk of developing cancer. The risk from eating fish goes down proportionately for people who eat fewer fish and for people who eat fish caught farther downstream. A brief summary of the Task 4 report is provided in Appendix D.

Uranium was released from various large-scale uranium operations, primarily uranium processing and machining operations at the Y-12 plant and uranium enrichment operations at the K-25 and S-50 plants. Because uranium was not initially given high priority as a contaminant of concern, a Level II screening assessment for all uranium releases was performed. Preliminary screening indices for Y-12 and K-25 were below the Oak Ridge Health Agreement Steering Panel (ORHASP) decision guide of one chance in 10,000. A brief summary of the Task 6 report is provided in Appendix D.

The *Screening-Level Evaluation of Additional Potential Materials of Concern* was conducted to determine if contaminants other than those identified in the *Oak Ridge Dose Reconstruction Feasibility Study* warranted further evaluation to assess their potential to cause health effects to off-site populations. Three methods—a qualitative screening, a quantitative screening, and a threshold quantity approach—were used to evaluate the potential for 25 materials or groups of materials to cause off-site health effects. Based on the screening results, 5 materials used at the K-25 plant and 14 materials used at the Y-12 plant warranted no further study. Three materials used at the K-25 plant (copper powder, nickel, and technetium 99), three materials used at the Y-12 plant (beryllium compounds, lithium compounds, and technetium 99), and one material used at the ORR (chromium VI) were determined to be potential candidates for further study. High priority candidates for further study included one material used at the K-25 plant (arsenic) and two materials used at the Y-12 plant (arsenic and lead). A brief summary of the Task 7 report is provided in Appendix D.

The Oak Ridge Health Agreement Steering Panel (ORHASP)—a panel of experts and local citizens—was appointed to direct and oversee the Oak Ridge Health Studies and provide liaison with the community. Given the findings of the Oak Ridge Health Studies and what is generally known about the health risks posed by exposures to various toxic chemicals and radioactive substances, ORHASP concluded that, "past releases from the Oak Ridge Reservation were likely to have harmed some people." Two groups most likely to have been harmed were 1) local children who drank milk produced by a "backyard" cow or goat in the early 1950s and 2) fetuses of women who routinely ate fish from contaminated creeks and rivers downstream of the ORR in the 1950s and early 1960s. For additional information on the ORHASP findings, please see the final report of the ORHASP titled *Releases of Contaminants from Oak Ridge Facilities and Risks to Public Health*.

II.F.3. Tennessee Department of Environment and Conservation (TDEC)

Sampling of Public Drinking Water Systems in the Tennessee. For 30 years, under the Safe Drinking Water Act of 1974 (summary available at http://www.epa.gov/safewater/index.html), the EPA has set health-based standards and specified treatments for substances in public drinking water systems. In 1977, EPA gave the state of Tennessee authority to operate its own Public Water System Supervision Program under the Tennessee Safe Drinking Water Act. Through this program, TDEC's Division of Water Supply regulates drinking water at all public water systems. As a requirement of this program, all public water systems in Tennessee individually monitor their water supply for EPA-regulated contaminants and report their monitoring results to TDEC. The public water supplies for Kingston, Spring City, and other supplies in Tennessee are monitored for substances that include 15 inorganic contaminants, 51 synthetic and volatile organic contaminants, and 4 radionuclides (EPA 2004a). According to EPA's Safe Drinking Water Information System (SDWIS), the Kingston and Spring City public water supply systems have not had any significant violations (U.S. EPA 2004b). For EPA's monitoring schedules for each contaminant, go to http://www.epa.gov/safewater/pws/pdfs/qrg_smonitoringframework.pdf. On a quarterly basis, TDEC submits the individual water supply data to EPA's Safe Drinking Water Information System (SDWIS) (TDEC 2003c). To look up information and sampling results for public water supplies in Tennessee, go to EPA's Local Drinking Water Information Web site at http://www.epa.gov/safewater/dwinfo/tn.htm.

In addition, in 1996 TDEC's DOE Oversight Division began participation in EPA's Environmental Radiation Ambient Monitoring System (ERAMS). As part of the Oak Ridge ERAMS program, TDEC collects samples from five facilities on the ORR and in its vicinity. These public water suppliers include the Kingston Water Treatment Plant (TRM 568.4), DOE Water Treatment Plant at K-25 (CRM 14.5), West Knox Utility (CRM 36.6), DOE Water Treatment Plant at Y-12 (CRM 41.6), and Anderson County Utility District (CRM 52.5) (TDEC 2003b). Under the Oak Ridge ERAMS, TDEC collects finished drinking water samples from the Kingston Water Treatment Plant on a quarterly basis and then

> EPA's ERAMS program was established to provide radiological monitoring for public water supplies located close to U.S. nuclear facilities.

submits the samples to EPA for radiological analyses. The schedule and contaminants sampled at the Kingston Water Treatment Plant are available at http://www.state.tn.us/environment/doeo/99empdw.pdf. TDEC has also conducted filter backwash sludge sampling at Spring City—radioactive contaminants from the reservation could potentially move downstream into community drinking water supplies. TDEC analyzed Spring City samples for gross alpha, gross beta, and gross gamma emissions (TDEC 2002, 2003a, 2003b). To ask specific questions related to your drinking water, contact TDEC's Environmental Assistance Center in Knoxville, Tennessee at 865-594-6035. To find additional information related to your water supply or other water supplies in the area, please call EPA's Safe Drinking Water Hotline at 800-426-4791 or visit EPA's Safe Drinking Water Web site at http://www.epa.gov/safewater.

Watts Bar Reservoir and Clinch River Turtle Sampling Survey, May 1997. TDEC conducted this survey to assess the body burdens of contaminants in snapping turtles in the Clinch River and in the Watts Bar Reservoir. Because of PCB contamination, fish advisories had been in effect for several years, and TDEC was concerned that people who consumed turtles from these water sources could also be exposed to PCBs. TDEC concluded that PCBs and additional contaminants accumulate in turtles from the Clinch River and the Watts Bar Reservoir. Using data used to formulate the fish advisories, the PCB concentrations in turtle tissue were detected at levels of concern for human consumption. The majority of PCB contamination was however detected in the fat tissue of the turtles, which is also seen in fish. Thus food preparation techniques, particularly tissue selection, can significantly influence the quantities of PCBs consumed with turtle meat (ATSDR et al. 2000). A brief summary of this survey is in Appendix D.

II.F.4. DOE

Watts Bar Interagency Agreement, February 1991. DOE, EPA, TVA, TDEC, and USACE comprise the Watts Bar Reservoir Interagency Working Group (WBRIWG), which works collaboratively through the Watts Bar Interagency Agreement—an agreement that established guidelines related to any dredging in Watts Bar Reservoir. Through this agreement, these agencies review permitting and all other activities that could possibly disturb the sediment of Watts Bar Reservoir, such as erecting a pier or building a dock (ATSDR 1996; Jacobs EM Team 1997b; U.S. DOE 2003a). The agreement also establishes guidelines for reviewing potential sediment-disturbing activities in the Clinch River below Melton Hill Dam, including Poplar Creek (Jacobs EM Team 1997b). According to the interagency agreement, DOE is required to take action if an institutional control is ineffective or if a sediment-disturbing activity could cause harm (U.S. DOE 2003a).

Permit coordination under the Watts Bar Interagency Agreement was established to allow TVA, USACE, and TDEC (the agencies with permit authority over actions taken in Watts Bar Reservoir) to discuss proposed sediment-disturbing activities with DOE and EPA before conducting the normal permit review process to determine if there any DOE contaminants in the sediments. The coordination follows a series of defined processes as outlined in the agreement.

The basic process of obtaining a permit, which is detailed in Section III.B.3, is the same for any organization or individual (Jacobs EM Team 1997b). If dredging is necessary in an area with contaminated sediments, DOE will assume the financial and waste management responsibility that is over and above the costs that would normally be incurred (Jacobs EM Team 1997b). For more details, please see the Clinch River/Poplar Creek OU ROD at http://www.epa.gov/superfund/sites/rods/fulltext/r0497075.pdf and page 3–5 of the Lower Watts Bar Reservoir ROD at http://www.epa.gov/superfund/sites/rods/fulltext/r0495249.pdf (Jacobs EM Team 1997b; U.S. DOE 1995a).

Oak Ridge Environmental Information System (OREIS), April 1999. Because an abundance of environmental data exists for the ORR, DOE created an electronic data management system to integrate all of the data into a single database. This database was developed to facilitate public and governmental access to environmental data related to ORR operations, while also maintaining data quality. DOE's objective was to ensure that the database had long-term retention of the environmental data and useful methods to access the information. OREIS contains data related to compliance, environmental restoration, and surveillance activities. Information from all key surveillance activities and environmental monitoring efforts is entered into OREIS. These include but are not limited to studies of the Clinch River embayment and the Lower Watts Bar, as well as annual site summary reports. As new studies are completed, the environmental data are entered as well. The public can access the database at the Information Resource Center, which has a computer linked to OREIS. In addition, all of the OREIS files were stored onto CD-ROMs, which were then used to make all of the data accessible to the public via the Internet (ATSDR et al. 2000).

Comprehensive Epidemiologic Data Resource (CEDR). CEDR is a public-use database that contains information pertinent to health-related studies performed at the Oak Ridge Reservation and at other DOE sites. DOE provides this easily accessible, public-use repository of data (without personal identifiers) collected during occupational and environmental health studies of workers at DOE facilities and nearby community residents. This large resource organizes the electronic files of data and documentation collected during these studies and makes them accessible on the Internet at http://cedr.lbl.gov. Most of CEDR's large data collection pertains to about 50 epidemiologic studies of workers at various DOE sites. Of particular interest to Tennessee residents is an additional feature of CEDR (at http://cedr.lbl.gov/DR/ordr.html) that provides searchable text for about 1,800 original government documents (now declassified) used by the TDOH scientists for the Oak Ridge Dose Reconstruction. Also available through CEDR at http://cedr.lbl.gov are all of the technical and summary reports produced by this study. Later in fiscal year 2004, CEDR will provide images in slideshow format that give estimated concentrations, doses, and risk values for the contaminants at all locations studied in TDOH's Dose Reconstruction. For the first time, this complex information will be easily accessible in a concise, uncluttered, and easily comprehended manner.

III. Evaluation of Environmental Contamination and Potential Exposure Pathways

III.A. Introduction

In 2001, ATSDR scientists conducted a review and analysis of the Phase I and Phase II screening evaluation of TDOH's Oak Ridge Health Studies to identify contaminants that require further public health evaluation. In the Phase I and Phase II screening evaluation, TDOH conducted extensive reviews of available information and conducted qualitative and quantitative analyses of past (1944–1990) releases and off-site exposures to hazardous substances from the entire ORR. Having reviewed and analyzed Phase I and Phase II screening evaluations, ATSDR scientists determined that past releases of uranium, mercury, iodine 131, fluorides, radionuclides from White Oak Creek, and PCBs require further public health evaluation. The public health assessment is the primary public health process ATSDR is using to evaluate these contaminants further.

ATSDR scientists previously prepared a public health assessment on uranium releases from Y-12 and addressed current public health issues related to the East Fork Poplar Creek and the Lower Watts Bar Reservoir (LWBR). ATSDR is conducting public health assessments on the following releases: Y-12 mercury releases, X-10 iodine 131 releases, K-25 uranium and fluoride releases, and PCB releases from X-10, Y-12, and K-25. Public health assessments will also be conducted on other issues of concern, such as the Toxic Substances Control Act (TSCA) incinerator and off-site groundwater. In addition, ATSDR is screening current (1990 to 2003) environmental data to identify any other chemicals that will require further evaluation.

This public health assessment focuses on exposures to X-10 radionuclide releases to the Clinch River and the Lower Watts Bar Reservoir via White Oak Creek. More specifically, it evaluates 1) the data and findings of previous studies and investigations of X-10 radionuclide releases to the LWBR and the Clinch River via White Oak Creek; 2) assesses whether people who previously used the river, people who continue to use the river, or neighboring residents have been or could be exposed to radionuclides or radiation; and 3) determines the health implications of past, current, and future radiation exposure.

III.A.1. Exposure Evaluation Process

A release of a contaminant from a site does not always mean that the substance will have a negative impact on a member of the off-site community. For a substance to pose a potential health problem, exposure must first occur. Human exposure to a substance depends on whether a person comes in contact with the contaminant, for example by breathing, eating, drinking, or touching a substance containing it. If no one comes into contact with a contaminant, then no exposure occurs—and thus no health effects can occur. Even if the site is inaccessible to the public, contaminants can move through the environment to locations where people could come into contact with them. In the case of radiological contamination, exposure can occur without direct contact because of the emission of radiation, which is a form of energy.

> The five elements of an exposure pathway are (1) source of contamination, (2) environmental media, (3) point of exposure, (4) route of human exposure, and (5) receptor population. The source of contamination is where the chemical or radioactive material was released. The environmental media (e.g., groundwater, soil, surface water, air) transport the contaminants. The point of exposure is where people come in contact with the contaminated media. The route of exposure (e.g., ingestion, inhalation, dermal contact) is how the contaminant enters the body. The people actually exposed are the receptor population.

ATSDR evaluates site conditions to determine if people could have been or could be exposed to site-related contaminants. When evaluating exposure pathways, ATSDR identifies whether exposure to contaminated media (soil, water, air, waste, or biota) has occurred, is occurring, or will occur through ingestion, dermal (skin) contact, or inhalation. ATSDR also identifies an exposure pathway as *completed* or *potential,* or *eliminates the pathway from further evaluation*. Completed exposure pathways exist if all elements of a human exposure are present. (See “Exposure Pathway” in Appendix A for a description of the elements of a completed exposure pathway.) A potential pathway is one that ATSDR cannot rule out because one or more of the pathway elements cannot be definitely proved or disproved. A pathway is eliminated if one or more of the elements are definitely absent.

Identifying the Types of Radiation Exposure

There are two broad classes of radiation exposure: internal radiation and external radiation. Internal exposures result from radioactive sources taken into the body through the inhalation of radioactive particles or the ingestion of contaminated food. External exposure results from radiation sources originating outside the body, such as radiation emitted from contaminated sediment. These external sources can sometimes penetrate the human skin. Whether an exposure contributed to an individual's internal or external exposure depends primarily on the type of radiation—that is, alpha and beta particles or gamma rays—to which a person was exposed. Most radionuclides associated with White Oak Creek releases are beta or gamma emitters. Through its scientific evaluation, ATSDR eliminated internal radiation exposure from alpha particles associated with X-10 releases as a concern (see the text box).

> **Beta particles** can penetrate human skin and tissues and deliver a dose both internally and externally. **Gamma rays** can travel long distances and easily penetrate body tissues, and are therefore the primary type of radiation that results in external radiation exposures. Most radionuclides from X-10 were beta or gamma emitters. **Alpha particles** cannot penetrate skin, so they pose a minimal external exposure concern. Alpha particles can inflict biological damage if the body takes them in, for example by breathing or swallowing radioactive material in air or food. However, alpha particles were not associated with the majority of radionuclides released to White Oak Creek.
>
> Source: ATSDR 1999b

Deriving Radiation Doses

ATSDR scientists calculate the radiation dose by using the concentration of the radionuclide in the environment and, if available, site-specific exposure factors such as time spent outdoors and amount of water ingested. If these site-specific factors are unavailable, ATSDR either uses default values or derives region-specific values. Once these inputs are derived, the dose coefficient that converts the radiation concentration to the radiation dose is applied. ATSDR scientists might use worst-case exposure factors as the basis for determining whether adverse health effects are *possible*. Because of this approach, the estimated radiation doses are usually much higher—that is, more conservative—than the levels to which people are really exposed. Note that the concept of radiation dose is not as simple as related here; a number of other factors (for example, how radionuclides decay, the critical organ concept, particle size distribution, and the chemical form) might affect "dose" and therefore need to be factored into the dose derivation.

> The radiation dose is the amount of energy from radiation that is actually absorbed by the body.

> ATSDR uses the term "conservative" to refer to values that are protective of public health in essentially all situations. Values that are overestimated are considered to be conservative.

Internal radiation exposure from a radionuclide continues after the initial radioactive material has been taken into the body, even if no additional radionuclides are ingested or inhaled. That is, internal exposure of radiation from radioactive material commits the exposed person to receiving a radiation dose for a period of time that typically depends on the radionuclide's half-life and rate of elimination from the body. (See *III.A.2.a.* for a discussion on half-life.) This dose is called the *committed equivalent dose* for an organ-specific dose and the *committed effective dose* for a whole-body dose. Exposure to external radiation sources, however, stops when the source is removed or when a person moves away from the source. A dose associated with external radiation is called an *effective dose*. The doses are further defined as follows:

Committed Equivalent Dose

> The International Commission of Radiological Protection's (ICRP's) term (starting with ICRP Publication 60) for the dose to organs and tissues of reference that an individual will receive from an intake of radioactive material over a 50-year period following the intake for workers or adults and over a 70-year period following the intake for children.

Committed Effective Dose

> ICRP's term for the sum of the products of 1) the weighting factors applicable to each body organ or tissue that is irradiated and 2) the committed equivalent dose to the appropriate organ or tissue integrated over time (in years) following the intake, with the assumption that the entire dose is delivered in the first year following the intake. The integrated time for an adult is 50 years; for children, it is from the time of intake to 70 years. The committed effective dose is used in radiation safety because it implicitly includes the relative carcinogenic sensitivity of the various tissues.

Effective Dose

> ICRP's term (starting with ICRP Publication 60) for the sum of the products of 1) the weighting factors applicable to each body organ or tissue that is irradiated and 2) the mean equivalent dose in the tissue or organ following exposure to external radiation.

The organ dose (equivalent, H_T) and the whole-body dose (effective, *E*) can be defined mathematically using the equations below. *W* and *D* are the weighting factor and dose, respectively. The subscripts *R* and *T* represent the type of radiation and the tissue of concern.

$$H_T = \sum_R W_R D_{R,T} \text{ (organ, equivalent dose)}$$

$$E = \sum_T W_T H_T \text{ (whole body, effective dose)}$$

The sum of the equivalent dose is theoretically equal to the effective dose (*E*). By rearranging the equations, one can solve for the equivalent dose from the whole-body (effective) dose:

$$H_T = \frac{E}{\sum_T W_T}$$

Weighting factors (W_T) are modifying factors selected for the type of radiation and its energy as it impacts matter to convert organ or tissue dose equivalents to committed effective dose equivalents for the whole body. They are used because the same radiation exposure to different parts of the body can have very different results. That is, if the entire body were irradiated, some parts of the body would react more dramatically than other parts. To take this effect into account, the ICRP developed weighting factors for a number of organs and tissues that most significantly contribute to the overall biological damage to the body (ICRP 1991).

The tissue weighting factors are based on both cancer fatality risk and the relative effect of an exposure to a single organ or tissue.[3] The grouping of tissues is complex, and substantial rounding of the values takes place. When summed for the entire body, the values of WT are normalized to give a total of one. Table 6 gives the currently adopted tissue weighting factors.

Table 6. Tissue Weighting Factors

Tissue	w_T	$\sum w_T$
Bone marrow (red), Colon, Lung, Stomach	0.12	0.48
Bladder, Breast, Esophagus, Liver, Thyroid	0.05	0.25
Bone surface, Skin	0.01	0.02
Gonads	0.20	0.20
Remainder Tissues–Adrenals, brain, intestinal tract, kidneys, muscle, pancreas, spleen, thymus, and uterus	0.05	0.05
Total		1.0

Assessing Health Effects

Exposure does not always result in harmful health effects. The type and severity of health effects a person can experience depend on the dose, which is based on age at exposure, the exposure rate (how much), the frequency or duration of exposure (how long), the route or pathway of exposure (breathing, eating, drinking, or skin contact), and the multiplicity of exposure (combination of contaminants). Once a person is exposed, characteristics such as age, gender, nutritional status, genetics, lifestyle, and health status influence how that person absorbs, distributes, metabolizes, and excretes the contaminant. The likelihood that adverse health outcomes will actually occur depends on site-specific conditions, individual lifestyle, and genetic factors that affect the route, magnitude, and duration of actual exposure—an environmental concentration alone will not cause an adverse health outcome.

As a first step in evaluating radiation exposures, ATSDR health assessors screened the radiation doses against comparison values. ATSDR develops comparison values from available scientific literature concerning exposure, dose, and health effects.

> ATSDR uses comparison values to identify hazardous substances that are not considered a health hazard at the site and hazardous substances that require an additional follow-up evaluation.

Comparison values represent radiation doses that are lower than levels at which no effects were observed in studies on experimental animals or in human epidemiologic studies. They are not thresholds for harmful health effects; instead, they reflect an estimated dose that is not expected to cause harmful health effects. Estimated doses below these comparison values are not considered a health hazard, so doses at or below the relevant comparison value can reasonably be considered safe. Doses above the comparison values, meanwhile, will not necessarily produce adverse health effects. This screening process enables ATSDR to safely eliminate contaminants that are not of health concern and to evaluate potentially harmful contaminants further.

If the estimated radiation doses at a site are above comparison values, ATSDR proceeds with a more in-depth health effects evaluation to determine if the doses are sufficient enough to trigger public health action to limit, eliminate, or further study any potential harmful exposures. ATSDR scientists conduct a health effects evaluation by carefully examining site-specific exposure conditions about actual or likely exposures; conducting a critical review of medical, radiologic, medical, and epidemiologic information in the scientific literature to ascertain the levels of significant human exposure; and comparing an estimate of the radiation doses that people might frequently encounter at a site to situations that have been associated with disease and injury. This health effects evaluation involves a balanced review and integration of site-related environmental

3 For 2005, the ICRP is proposing a new system that uses cancer incidence and considers lethality rate, years of life lost, and weighted contribution from the nonfatal cancers and hereditary disorders.

data, site-specific exposure factors, and toxicologic, radiologic, epidemiologic, medical, and health outcome data to help determine whether exposure to contaminant levels might result in harmful effects. The goal of the health effects evaluation is to decide whether harmful effects might be observed in the exposed population by weighing the scientific evidence and keeping site-specific doses in perspective. See Figure 19 for ATSDR's health-based determination of radiological doses.

More information about the ATSDR evaluation process can be found in ATSDR's Public Health Assessment Guidance Manual at http://www.atsdr.cdc.gov/HAC/HAGM/ or by contacting ATSDR at 1-888-42-ATSDR. An interactive program that provides an overview of the process ATSDR uses to evaluate whether people will be harmed by hazardous materials is available at http://www.atsdr.cdc.gov/training/public-health-assessment-overview/html/index.html.

III.A.2. Radiation-Related Terms

Half-Life

The half-life of a radionuclide is the time that it takes for the activity of radioactive material (or radioactivity) to decrease by one-half. This is known as the physical half-life. Radionuclides that are taken into the body will also decay by biological processes, such as excretion. The measure of time it takes to eliminate half of a material taken into the body by biological processes is called the biological half-life. The measure of the combined influences of these physical and biological half-lives is called the effective half-life. For example, as shown in Table 7, the physical half-life of strontium 90 is about 29 years and the biological half-life is about 49.2 years (18,000 days) for bone. Therefore, the effective half-life of strontium 90 deposited in the bone is 17.5 years (6,400 days). That is, half the radioactivity of strontium 90 taken into the body will be gone after 6,400 days, another half of the remaining radioactivity will be depleted after an additional 6,400 days, and this process will continue as the radioactivity is depleted from the body. The effective half-life is always less than either its physical or biological half-life.

Figure 19. ATSDR Health-Based Determination of Radiological Doses

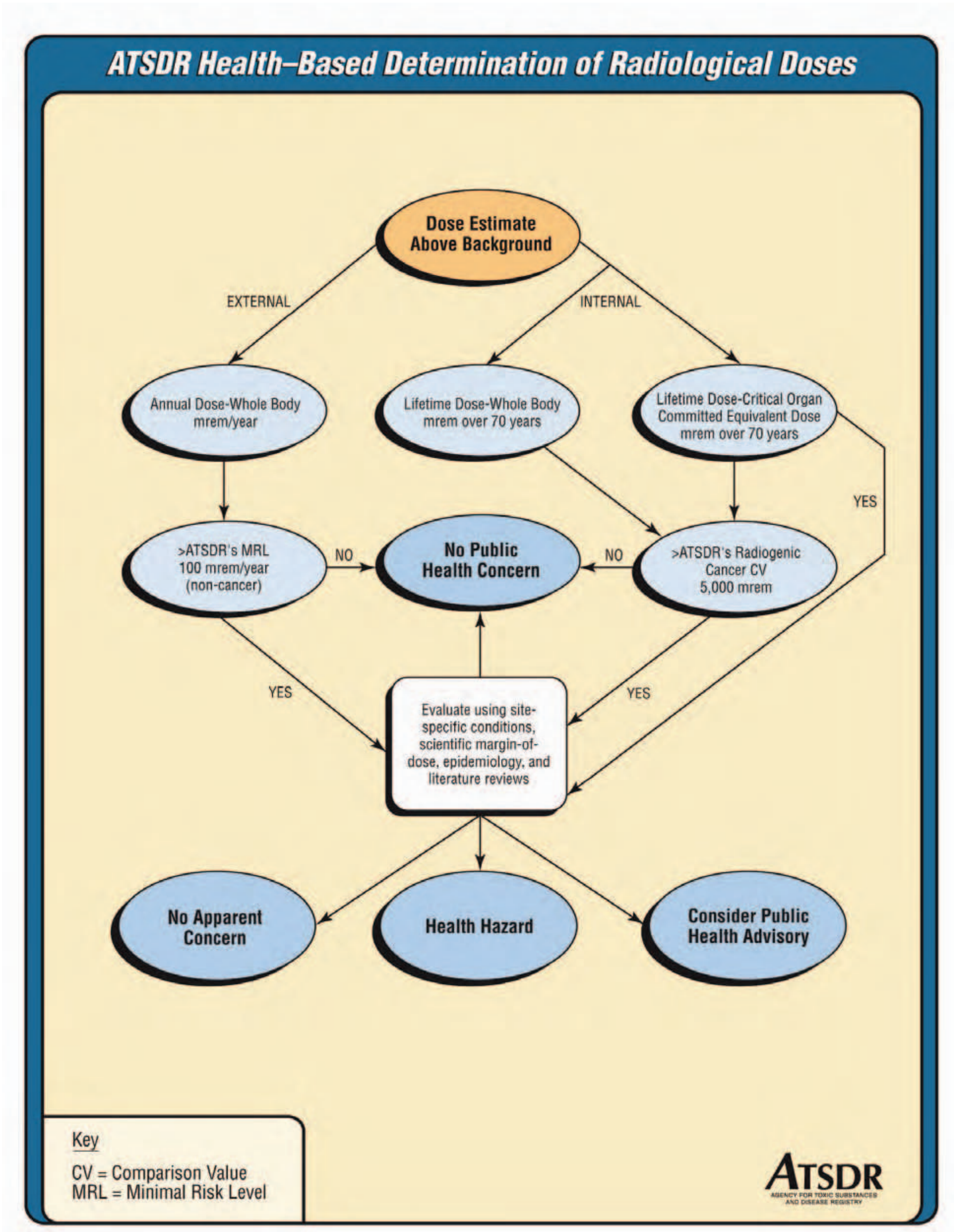


Table 7. Half-Lives of Selected Radionuclides in the WOC Public Health Assessment

Radionuclide	*Physical Half-Life*	*Biological Half-Life*	*Effective Half-Life**
Tritium	12.3 years	12 days (whole body)	12 days (whole body)
Cesium 137	30.2 years	70 days (whole body)	70 days (whole body)
Strontium 90	28.6 years	18,000 days (bone)	6,400 days (bone)
Cobalt 60	5.3 years	9.5 days (whole body)	9.5 days (whole body)
Yttrium 90	64.2 hours	14,000 days (bone)	64 hours (bone)

* Effective half-life is the time required for the radioactivity of a radionuclide to be diminished 50 percent through the combined action of radioactive physical decay and biological elimination.

Radiological Measurements

This PHA uses two systems for radiological measurements and doses: the Conventional System and the Systeme International. The key in Table 8 describes these units and lists their abbreviations.

Table 8. Units for Radiological Measurements

System	*Unit*	*Parameter/Description*
Conventional System	picocurie, pCi	The curie (Ci) is the basic unit of radioactivity. The pCi is 1,000,000,000,000 (one trillion) times smaller than one Ci.
	millirem, mrem	Dose is given in units "roentgens equivalent man," or rem. One mrem is 1,000 times smaller than one rem. This is the unit for both the equivalent dose and the effective dose.
Systeme International	becquerel, Bq	The basic unit of activity is the becquerel (Bq). The number of curies must be multiplied by 3.7×10^{10} to obtain an equivalent number of Bq.
	millisievert, mSv	The sievert (Sv) is the unit of equivalent dose and the effective dose. One mSv is 1,000 times smaller than one Sv. The number of millisieverts (mSv) must be multiplied by 100 to convert to millirem.

III.B. Exposure Evaluation of the Clinch River and Lower Watts Bar Reservoir

ATSDR evaluated past (Clinch River) and current exposures (Clinch River and LWBR) to radioactive contamination (based on environmental samples) that was released from X-10 via White Oak Creek. ATSDR evaluated future exposures to the Clinch River and the LWBR based on the current estimated exposure doses and the institutional controls that are in place for both of these watersheds. The highest exposure doses were estimated for people who frequently ate fish (1 to 2.5 fish meals a week) caught from the Clinch River near the mouth of White Oak Creek from 1944 to 1953. Doses were much lower for people who ate fewer fish or fished further downstream and for the other past and current exposure pathways evaluated in this public health assessment.

This section presents an overview of past, current, and future exposures to radioactive contaminants released to the Clinch River, and current and future exposure to radioactive contaminants released to the LWBR. An evaluation of potential public health hazards from likely exposures to White Oak Creek releases is presented in Section IV. Public Health Implications.

ATSDR used the following time periods and information in its evaluation.

- Past exposure: "Past" refers to the period from 1944 to 1991. For its evaluation of past exposures, ATSDR reviewed the Task 4 report and documents associated with the report. The Task 4 report is entitled Radionuclide Releases to the Clinch River From White Oak Creek on the Oak Ridge Reservation—an Assessment of Historical Quantities Released, Off-Site Radiation Doses, and Health Risks. The complete project can be accessed through TDOH's Web site at www2.state.tn.us/health/CEDS/OakRidge/ORidge.html and a brief summary of the Task 4 report is provided in Appendix D.

- Current exposure: "Current" refers to the period from 1988 to the present. In evaluating current exposures and doses related to releases from White Oak Creek, ATSDR relied on data collected from 1988 to 1994 (as presented in its 1996 health consultation entitled Health Consultation for U.S. DOE Oak Ridge Reservation: Lower Watts Bar Reservoir Operable Unit, Oak Ridge, Anderson County, Tennessee) and on data collected from 1989 to the present from the Oak Ridge Environmental Information System (OREIS). A brief summary of the 1996 ATSDR health consultation on Lower Watts Bar Reservoir is provided in Appendix D.

- Future exposure: "Future" refers to exposures that occur after the present time period. ATSDR based its evaluation of future exposures on current doses and exposures related to releases from White Oak Creek, data on current contaminant levels in the LWBR and the Clinch River, consideration of the possibility that remedial activities could release radionuclides to White Oak Creek, and institutional controls that are in place to monitor contaminants in the LWBR and the Clinch River. These controls consist of the following: 1) prevention of sediment-disturbing activities in the Clinch River and LWBR; 2) DOE's annual monitoring of Clinch River and LWBR surface water, sediment, and biota; 3) DOE's monitoring of White Oak Creek releases; 4) TDEC's monitoring of public drinking water supplies in Tennessee under the Safe Drinking Water Act for EPA-regulated contaminants; and 5) TDEC DOE Oversight Division's quarterly radiological monitoring of five public water supplies on the ORR and in its vicinity under the EPA's Environmental Radiation Ambient Monitoring System (ERAMS) program.

III.B.1. Possible Exposure Situations in the Clinch River and Lower Watts Bar Reservoir Areas

People could come in contact with contaminants along the Clinch River and the Lower Watts Bar Reservoir via several different pathways. ATSDR analyzed radioactive contaminant data for surface water, sediment, and biota (aquatic and terrestrial) to determine whether the levels detected in these media might pose a past or current public health hazard. This evaluation looked at the level of contamination present, the extent to which individuals contact the contamination, and estimated doses to individuals coming in contact with the media under different exposure scenarios. ATSDR identified several exposure situations for the Clinch River and LWBR areas that required further evaluation. This PHA evaluates the following situations for exposures at the Clinch River, LWBR, or at both locations:

- Ingestion of drinking water
- External exposure from contact with water and sediment during recreational activities
- External contact with dredged sediment used as topsoil in home gardens
- Ingestion of locally produced milk and meats
- Ingestion of fish or local game animals
- Incidental ingestion of surface water during recreational activities

Exposure situations associated with radioactive contaminants released from White Oak Creek are evaluated in detail in the following discussion and depicted in Figure 20. To acquaint the reader with terminology and methods used in this PHA, Appendix A provides a glossary of environmental and health terms presented in the discussion. Additional background information is provided in appendices as follows: Appendix B summarizes detailed remedial activities related to the study area; Appendix C summarizes other public health activities at the ORR; Appendix D contains summaries of ATSDR, TDEC, and TDOH studies or investigations; and Appendix E provides a table on Task 4 conservative screening indices for radionuclides in the Clinch River.

III.B.2. Past Exposure (1944–1991)

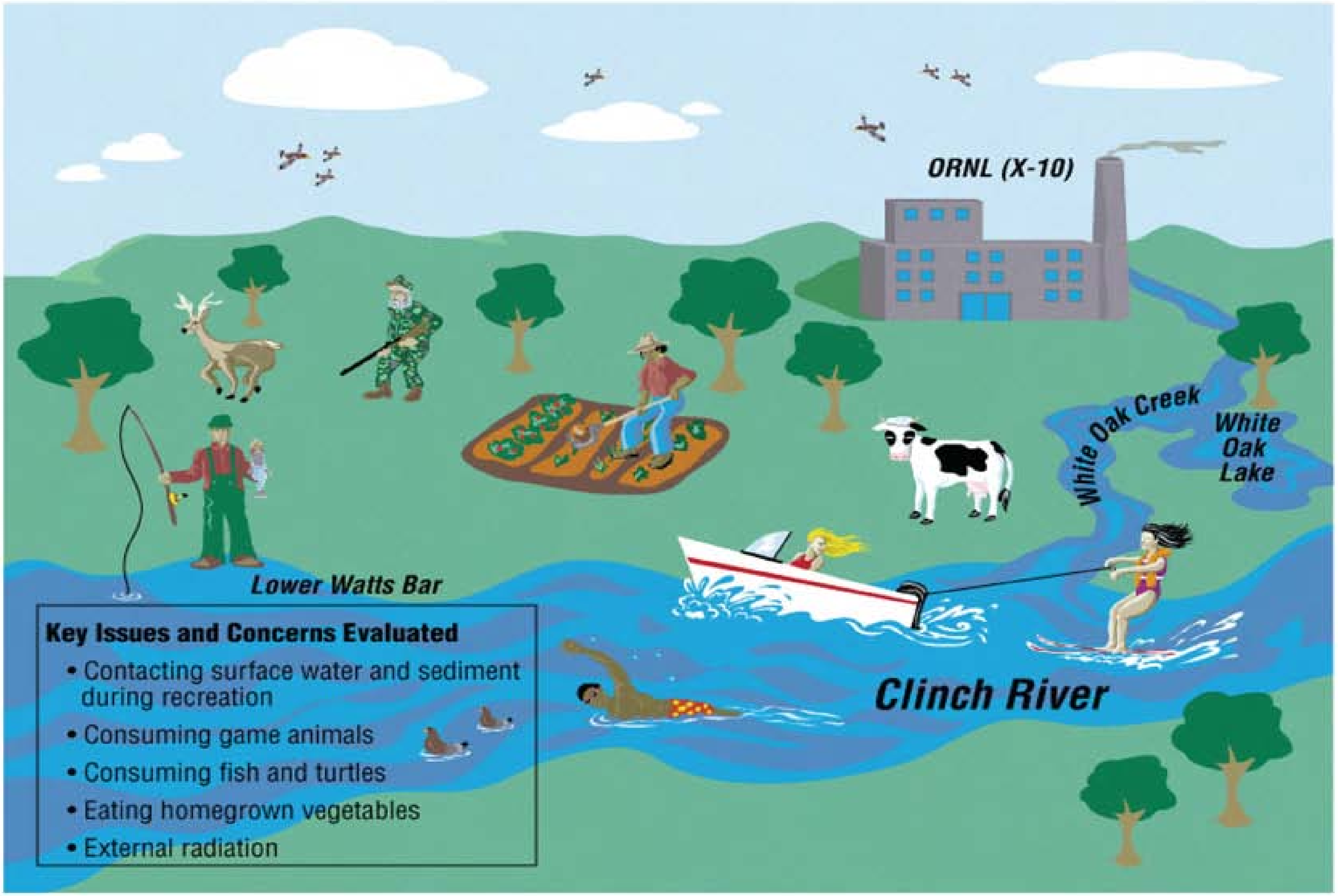
TDOH's Task 4 Study

Wastes from historical X-10 operations were released to White Oak Creek, which travels south along the eastern border of the X-10 site, flows into White Oak Lake, over White Oak Dam, and into the White Oak Creek Embayment before meeting the Clinch River at Clinch River Mile (CRM) 20.8 (see Figure 3 and Figure 4). Radionuclides were released when creek flow eroded the contaminated bottom sediment of White Oak Lake and carried them into the Clinch River. Some of the upstream river sediment containing radionuclides was scoured and the transport of the suspended contaminated sediment contributed to the buildup of radionuclides in sediment further downstream. Prior to the impoundment of Melton Hill Dam in 1963, the particulate in the water column was usually deposited near CRM 14 (close to the mouth of Grassy Creek). This is an area where the river is wider and is influenced by the Watts Bar Reservoir. After 1963, however, the pattern of particulate deposition in sediment changed because of the controlled releases from Melton Hill Dam (Blaylock 2004).

In 1996–1999, TDOH's Task 4 team prepared the TDOH's Reports of the Oak Ridge Dose Reconstruction, Radionuclide Releases to the Clinch River From White Oak Creek on the Oak Ridge Reservation—An Assessment of Historical Quantities Released, Off-Site Radiation Doses, and Health Risks (referred to as the "Task 4 report") to assess whether individuals visiting or living along the Clinch River area might have come in contact with harmful levels of radioactive materials in the past. Wastes generated at X-10 from 1944 to 1991 (the time frame covered in the Task 4 report) included radionuclides in various chemical forms (solids and liquids). Specifically, the purpose of the Task 4 effort was to:

- Estimate the historical releases of radioactive materials from the X-10 processes to White Oak Creek.
- Review and evaluate the possible exposure pathways for the public who lived downstream from White Oak Creek along the Clinch River and the Tennessee River.
- From these potential exposure pathways, calculate both the radiation doses and risks associated with these exposures. Because historical records were not maintained to today's standards, the Task 4 team performed independent reviews of environmental monitoring reports and existing data on releases and also used mathematical models to estimate the radiation doses and the associated risks (ChemRisk 1999a).

Figure 20. Possible Exposure Situations Along the Clinch River



Task 4 Screening Assessment

As an initial evaluation in 1996, the Task 4 team identified 24 radionuclides—americium 241, barium 140, cerium 144, cobalt 60, cesium137, europium 154, hydrogen 3, iodine 131, lanthanum 140, niobium 95, neodymium 147, phosphorus 32, promethium 147, praseodynium 143, plutonium 239/240, ruthenium 106, samarium 151, strontium 89, strontium 90, thorium 232, uranium 235, uranium 238, yttrium 91, and zirconium 95—that were released to the Clinch River via White Oak Creek from 1944 to 1991 (ORHASP 1999). The Task 4 team determined that a screening analysis would help focus its efforts on the most important radionuclides and on the ways that people could have been exposed to radionuclides in White Oak Creek releases via the Clinch River. The Task 4 team used a risk-based screening process to calculate conservative human health risk estimates for reference individuals and target organs, assuming that exposure occurred between 1944 and 1991 (a period of up to 48 years, except where noted).[4] These risk estimates represented exposed individuals' increased likelihood of developing cancer—known as "excess lifetime cancer risk estimates." Because of the conservative assumptions used in calculating the estimates, the risk level would likely overestimate the public health hazard for people who actually lived in the community. For comparison, the Task 4 team used an upper bound of 1 in 100,000 (1×10^{-5}) as the decision point, or minimal level of concern. This value was one-tenth of the ORHASP-recommended value of 1 in 10,000 (1×10^{-4}); thus, the value used by the Task 4 team was *more conservative* than the ORHASP-recommended value.

Task 4 Phases

<u>Initial Assessment</u>
Radionuclides released to White Oak Creek
24
⇓
<u>Screening Analysis</u>
Radionuclides identified for further evaluation
8
⇓
<u>Supplemental Analysis</u>
Radionuclides identified as the important contributors to dose and health hazards
4

The same value can be presented in different ways:

0.0001
1.0E-04
$\times 10^{-4}$
1/10,000
one in ten thousand

Through this screening process, the Task 4 team eliminated 16 out of 24 radionuclides released to the Clinch River from White Oak Creek because the estimated screening indices were below

[4] For the purposes of the Task 4 study, a reference individual is a hypothetical or real unidentified person who resides in the area or who consumes contaminated foodstuffs from the area.

the minimal level of concern (1 x 10^{-5}). The eight radionuclides for which additional analysis would be necessary were cobalt 60 (Co 60), strontium 90 (Sr 90), niobium 95 (Nb 95), ruthenium 106 (Ru 106), zirconium 95 (Zr 95), iodine 131 (I 131), cesium 137 (Cs 137), and cerium 144 (Ce 144) (ChemRisk 1999a). Because the screening risk estimates for the swimming and irrigation pathways were below the minimal screening level for all 24 radionuclides, the team was able to eliminate these two exposure pathways (and therefore, consumption of locally grown crops) from further analysis. The exposure pathways that required further evaluation were ingestion of fish, surface water, and meat and milk from cattle that grazed near the river, and external radiation from walking on shoreline sediment. Following this screening, the TDOH conducted a supplemental screening that included developing annual release amounts for the eight radionuclides and conducting a more comprehensive analysis of various exposure pathways.

Using its supplemental screening, the Task 4 team determined that four radionuclides (Cs 137, Co 60, Ru 106, and Sr 90) were more likely than the other four (Nb 95, Zr 95, Ce 144, and I 131) to cause adverse health effects to exposed off-site populations (ChemRisk 1999a). For more information on the screening process, see the brief summarizing the Task 4 report in Appendix D. For additional details and calculations used in the screening and supplemental screening processes in the Task 4 report, see Appendices 3A, 3B, and 4A of the document online at http://www2.state.tn.us/health/CEDS/OakRidge/WOak1.pdf.

Estimated Quantities of Radionuclides Released into White Oak Creek

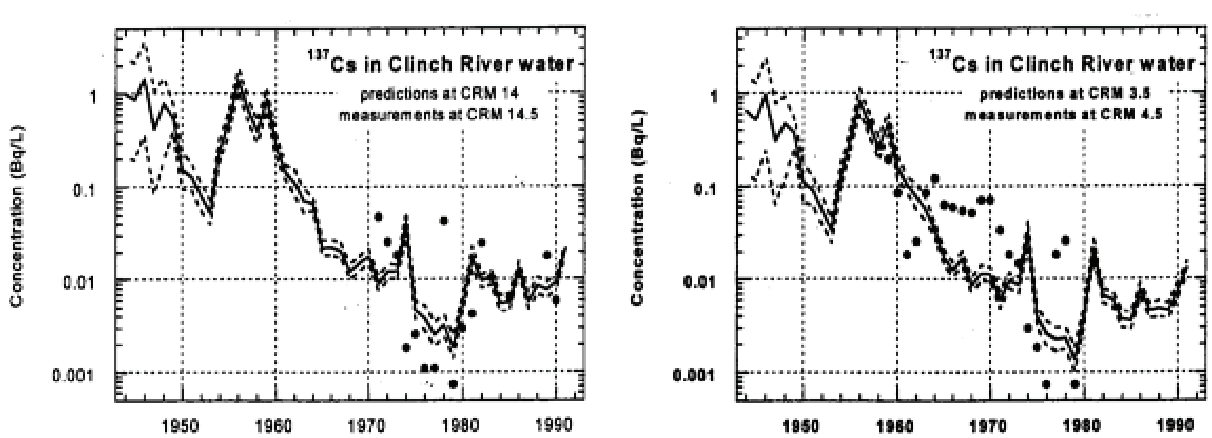
Because accurate environmental monitoring and sampling data were not available, the Task 4 team performed an in-depth evaluation to estimate the amount of radionuclides that flowed from X-10, over White Oak Dam, and to the Clinch River. Through this evaluation, the team derived annual estimates for the eight radionuclides of interest: Co 60, Sr 90, Nb 95, Ru 106, Zr 95, I 131, Cs 137, and Ce 144. In total, about 200,000 curies of radioactive material were released from White Oak Creek into the Clinch River between 1944 and 1991 (ChemRisk 1999a). Using this information, the team then performed mathematical modeling to estimate the annual average concentrations of the eight radionuclides in water and sediment at specified locations downstream of White Oak Creek. Limited available monitoring data were used to calibrate the results of the team's modeling efforts.

Of the radionuclides released to White Oak Creek, the greatest health hazards were believed to be associated with Cs 137. Cs 137 releases along White Oak Creek were highest from 1955 to 1959. The high Cs 137 releases during those years resulted when the creek flow eroded the contaminated bottom sediment of White Oak Lake after the lake was drained in 1955. This was particularly true during the heavy rains in the winter and early spring of 1956. Currently, the elevated levels of Cs 137 are limited to the subsurface sediment buried in the deep channels of the LWBR.

> Releases of radionuclides to White Oak Creek from 1955 to 1959 were believed to account for the highest concentrations of Cs 137 that reached the Clinch River.
>
> Concentrations of radionuclides in the Clinch River have decreased over time.

Because of remedial actions and preventive measures at X-10, physical movement of sediments from the area, and radiological decay, the radionuclide releases from White Oak Creek have decreased over time and the concentrations of radionuclides in the water and along the shoreline have decreased as well. For example, Cs 137 in the Clinch River water near CRM 14 and CRM 3 has decreased by about a factor of 100 (see Figure 21). Though, because Clinch River sediments are not as actively exchanged as the river itself, the Cs 137 in sediment at CRM 14 has decreased as a function of its half-life (see Figure 22) (ChemRisk 1999a).

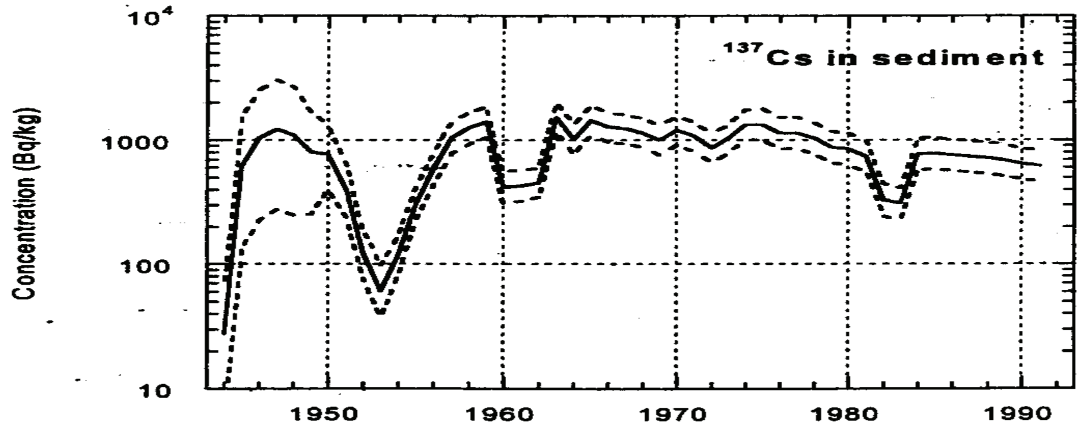
Figure 21. Comparison of Predicted Annual Average Concentrations of Cs 137



Comparison of predicted annual average concentrations of Cs 137 in water with measured annual average concentrations. Comparisons are shown for predictions at CRM 14 with measurements at CRM 14.5 (left) and for predictions at CRM 3.5 with measurements at CRM 4.5 (right). Solid lines indicate the central values of the predictions; dashed lines indicate predicted 95% confidence bounds based only on uncertainty in release estimates. Dark circles indicate measured values.

Source: ChemRisk 1999a

Figure 22. Annual Average Cs 137 Concentrations in Shoreline Sediment



Example of predicted annual average concentrations of Cs 137 in shoreline sediment for CRM 14. The solid line indicates the central values of the predictions; dashed lines indicate predicted 95% confidence bounds based only on the uncertainty in the release estimates.
Source: ChemRisk 1999a

Task 4 Exposure Pathways Evaluation

> The greatest exposures to White Oak Creek releases occurred between 1944 and 1963.

For the eight radionuclides (Cs 137, Co 60, Ru 106, Sr 90, Nb 95, Zr 95, Ce 144, and I 131) requiring additional analysis, the Task 4 team conducted an in-depth exposure pathway evaluation of ingestion of fish, surface water, and meat and milk from cattle that grazed near the river, and external radiation from walking on shoreline sediment. Table 9 presents the past exposure pathways, the reference populations, and the radionuclides studied in the pathway exposure evaluation. Individuals were exposed over the entire 48-year study period, except for certain years pertaining to drinking water, external exposures, and meat and milk ingestion (excluded years are noted below in the table). For the fish consumption pathway, the Task 4 team considered three categories of fish consumers to account for differences in the amount of fish that individuals consume (Category I: 1 to 2.5 fish meals/week, Category II: 0.25 to 1.3 fish meals/week, and Category III: 0.04 to 0.33 fish meals/week)[5] (ChemRisk 1999a).

[5] A meal was defined as 0.1 to 0.3 kilograms (roughly 3.5 to 10.5 ounces) per meal for males and 0.08 to 0.25 kilograms (roughly 2.8 to 8.8 ounces) per meal for females.

Table 9. Past Exposure Pathways Evaluated in the Task 4 Report

Exposure Pathway	*Reference Individuals*	*Radionuclide*
Fish ingestion	Adults eating fish from the Clinch River that were caught near Jones Island, K-25/Grassy Creek, Kingston Steam Plant, and the city of Kingston	Cs 137, Ru 106, Sr 90, Co 60
Drinking water ingestion*	Adult visitors to K-25 and the Kingston Steam Plant Adults and children in the city of Kingston	Cs 137, Ru 106, Sr 90, I 131
Meat ingestion*	Adults eating meat from cattle that had access to the Clinch River	Cs 137, Ru 106, Sr 90, Co 60
Milk ingestion*	Adults and children drinking milk from cows that had access to the Clinch River	Cs 137, Ru 106, Co 60, I 131
External exposure*	Adults walking along the shoreline on Jones Island, K-25/Grassy Creek, Kingston Steam Plant, and the city of Kingston	Cs 137, Ru 106, Sr 90, Co 60, Ce 144, Zr 95, Nb 95

* Drinking water exposures occurred from 1944 to 1991, except at the city of Kingston (1955–1991) and the Kingston Steam Plant (1954–1989). External exposures occurred from 1944 to 1991, except at Jones Island (1963–1991). Meat and milk ingestion exposures occurred from 1944 to 1991, except at Jones Island (1963–1991).

The Task 4 study covered a broad area along the Clinch River, from the mouth of White Oak Creek to the confluence of the Clinch and Tennessee Rivers. Because exposure situations might vary with the differences in topography and land uses at various sections of the river, the Task 4 team divided the area of study into four segments. Table 10 gives the CRM range, location, and exposure situations evaluated for each segment.

Table 10. Locations and Exposure Scenarios Considered in the Task 4 Study

Clinch River Mile*	Location	Exposure Scenarios	
		Pathway†	**Years of Exposure**
21 to 17	Jones Island	— Ingestion of fish — Ingestion of meat and milk — External exposures to shoreline sediment	1944 to 1991 1963 to 1991 1963 to 1991
17 to 5	K-25/Grassy Creek	— Ingestion of fish — Ingestion of drinking water — Ingestion of meat and milk — External exposures to shoreline sediment	1944 to 1991 1944 to 1991 1944 to 1991 1944 to 1991
5 to 2	Kingston Steam Plant	— Ingestion of fish — Ingestion of drinking water — Ingestion of meat and milk — External exposures to shoreline sediment	1944 to 1991 1954 to 1989 1944 to 1991 1944 to 1991
2 to 0	City of Kingston	— Ingestion of fish — Ingestion of drinking water — Ingestion of meat and milk — External exposures to shoreline sediment	1944 to 1991 1955 to 1991 1944 to 1991 1944 to 1991

* The river mile is the distance from the mouth of the river. That is, Clinch River Mile 0 is where the Clinch River empties into the Tennessee River. White Oak Creek enters the Clinch River at Clinch River Mile 20.8.

† The Task 4 report originally included produce ingestion and swimming pathways in its screening analysis. Based on low conservative screening indices, however, the Task 4 team eliminated these two pathways from further evaluation.

The Grassy Creek area includes portions of the Clinch River from Clinch River Mile (CRM) 17 to CRM 14. The mouth of Grassy Creek empties into the river at CRM 14.5; a tenth of a mile below that (CRM 14.4) is the potable water intake for the K-25 Gaseous Diffusion Plant. Associated with the intake was a combined filtration plant (using sand as the filter) and water storage facility that supplied potable water to the K-25 facility. Any radiological contaminants in the water intake for K-25 originated from the releases from White Oak Creek, approximately 7 miles upstream from the K-25 intake area. ATSDR learned about issues related to the K-25 intake from members of the public at meetings held by the Exposure Evaluation Work Group (EEWG), formerly known as the Public Health Assessment Work Group (PHAWG), as well as the community concerns database maintained by ATSDR and discussions with DOE. ATSDR also learned from a community member that the K-25 intake was used at the J.A. Jones Construction Camp, which is locally referred to as the Happy Valley Settlement. The Happy Valley settlement was first occupied in 1943 and 1944, primarily by construction workers, some family members, and a few concessionaires. At its peak in 1945, Happy Valley had more than 8,700 residents, including an estimated 5,600 workers and 3,100 dependents (Keith and Baker 1946; Prince 2003). Most people began leaving the settlement between the spring and fall of 1945, as construction of gaseous diffusion facilities was completed or permanent housing became available. Even so, anecdotal reports by an Oak Ridge community member suggest that the settlement might have been occupied as late as 1948. Because of possible exposure to contaminants in drinking water at Happy Valley, ATSDR conducted a separate evaluation for the Happy Valley community for the years the community was in existence.

Task 4 and ATSDR Estimated Radiation Doses

> Radionuclides along the Clinch River could have contributed to an individual's internal or external dose of radiation. *Internal exposures* were due to internally-deposited radionuclides from ingestion of radionuclides in fish, meat, milk, and surface water. The main source of *external exposure* to the Clinch River was through exposure to shoreline sediment along the river.

The Task 4 team derived radiation doses for each pathway of interest to estimate the amount of radiation that a potentially exposed individual might have received.[6] In deriving the doses, the team used the International Commission on Radiological Protection's (ICRP) critical organ concept of dose limitation. ICRP's method limits dose (and long-term effects) to the critical organ—the organ most sensitive to or receiving the highest radiation dose following an intake of radioactive material. Using this approach, the cumulative dose to an organ from internally-deposited radionuclides is estimated separately from the dose attributed to external exposure (*see text box*).

The Task 4 team calculated the 95% confidence intervals for the cumulative organ dose equivalents. The 95th confidence interval is defined as the range of values centered about the mean, where the expected "true" (population) mean is located.[7] The distributions from which the upper and lower confidence limits for each variable are obtained are based on the individual sets of measured data. For internal doses from ingestion, the Task 4 team considered exposure to Cs 137, Sr 90, Co 60, and Ru 106 and estimated dose factors for 22 organs for an adult; the team assessed exposure to I 131 and estimated thyroid doses for a child. The Task 4 team used different methods for estimating dose factors depending on the amount and quality of

[6] The Task 4 team's estimated organ doses, estimated cancer risk coefficients, and associated uncertainties and sensitivities of variables are reported in chapters 13 and 14 of the Task 4 study (ChemRisk 1999a).

information available for each radionuclide (ChemRisk 1999a). For external exposures, the team evaluated the following seven radionuclides for external exposure: Cs 137, Co 60, Ru 106, Zr 95, Nb 95, Sr 90, and Ce 144. The Task 4 team assumed that people were exposed for the entire study period of 48 years (1944 to 1991), except (as noted in Table 10) for a 29-year exposure duration associated with external exposure and ingestion of meat and milk at Jones Island, a 36-year exposure duration for drinking water at Kingston Steam Plant, and a 37-year exposure duration for drinking water at the city of Kingston.

ATSDR summarized the Task 4 organ doses for the bone, lower large intestine, red bone marrow, breast, and skin locations using the 50th percentile value of the 95% confidence interval. The 50^{th} percentile (central) values represent the medians of organ doses. ATSDR selected these organs because the contaminants of concern, particularly Sr 90 and Cs 137, tend to concentrate in these organs. ATSDR focused its evaluation on two potential exposure locations—Jones Island and the city of Kingston (see Table 11). ATSDR narrowed it evaluation to these two locations because Jones Island is the closest land mass to the mouth of White Oak Creek and the city of Kingston is the closest large city downstream of the creek before the confluence of the Clinch River and Tennessee River. (For certain pathways, doses at K-25/Grassy Creek are presented as the location of maximum exposure.)

Weighting factors are used to convert an organ dose equivalent to a committed effective dose for the whole body that is lower than the organ dose. The committed effective dose is obtained by multiplying the organ dose by the weighting factor. For example, a 5 mrem dose to the thyroid would be multiplied by the weighting factor 0.05 to yield 0.25 mrem whole-body dose. For its evaluation, ATSDR applied weighting factors to the Task 4 organ doses and summed the adjusted organ doses across pathways to derive the annual and whole-body doses for each pathway. Then, ATSDR summed the annual and whole-body dose for each pathway to derive the total annual dose to the whole body and the *committed effective dose* to the whole body over 70 years. ATSDR also summed the organ doses to derive a *committed equivalent dose* to an organ over a 70-year (lifetime) exposure. When deriving the committed equivalent dose to an organ, ATSDR adjusted the Task 4 organ doses from a 48-year exposure (except in cases noted in Table

[7] The confidence intervals are based on the assumption that the variable is normally distributed in the population under consideration.

10) to a 70-year exposure so that ATSDR could compare these doses to health guidelines for radiation exposures to the public.

Table 11 presents the organ-specific and whole-body doses for all pathways of interest. As shown in Table 11, the maximum annual whole-body dose from all exposure pathways of interest is 4 mrem. This dose is about 2% of the 360 mrem that the average U.S. citizen receives from *background radiation* (levels typically found in the environment) and sources from medical radiological procedures. Background radiation is the amount of radiation to which a member of the general population is exposed from natural sources, such as terrestrial radiation from naturally occurring radionuclides in the soil, cosmic radiation originating from space, and naturally occurring radionuclides deposited in the human body. About 300 mrem comes from natural sources and the remaining 60 mrem results from human activities and products (e.g., dental and medical x-rays) (Nuclear Energy Institute 2004). Of the 22 organs evaluated, the Task 4 authors predicted that the bone surface received the highest dose of radiation from any of the exposure pathways. The higher doses to the bone reflect the additional contribution from Sr 90.

After its review of Task 4 organ-specific doses and ATSDR-derived lifetime and whole-body doses, ATSDR determined that exposures to radionuclides by way of fish ingestion, water ingestion, and external radiation were more likely than the other pathways to result in higher radiation exposures in off-site populations. For comparison, doses from ingesting meat and milk were more than 1,000 times less than doses from eating fish (see Table 12.) ATSDR discusses the fish ingestion, water ingestion, and external radiation exposure pathways below.

Table 11. Summary of Estimated Organ-Specific Doses and Whole-Body Doses for Each Past Radiation Exposure Pathway and the Estimated Lifetime Organ-Specific Doses and Lifetime Whole-Body Doses From All Past Radiation Exposure Pathways

Exposure Pathway	*Location*[‡]	*Organ-Specific Radiation Dose (mrem over 48 years)**					*Whole-Body Dose*[†]	
		Bone	*Lower Large Intestine*	*Red Bone Marrow*	*Breast*	*Skin*	*Annual (mrem per year)*	*Lifetime (mrem over 70 years)*
Fish ingestion	Jones Island	810	570	600	240[§]	310	3.4	238.6
	Kingston	96	64	65	30[§]	35	0.4	27
Drinking water ingestion	K-25/ Grassy Creek	110	81	46	2.1	2.4	0.3	24
	Kingston	3.5	6.2	1.7	0.12	0.14	<0.01	1.4
Meat ingestion	K-25/ Grassy Creek	1.4	2.1	0.81	0.31	0.31	<0.01	0.6
Milk ingestion	K-25/ Grassy Creek	0.84	0.13	0.42	0.046	0.048	<0.01	0.1
External radiation (walking on sediment) ¶	Jones Island	12	7.1	7.7	9.0	10	0.1	3.6
	Kingston	50	29	32	37	47	0.2	14.8
Estimated Committed Equivalent Doses (over 70 years) **		Less than 1,200 mrem	Less than 1,100 mrem	Less than 1,100 mrem	Less than 500 mrem	Less than 400 mrem	4[††]	278[‡‡]

* Data were derived from ChemRisk 1999a—Tables 13.3, 13.4, and 13.5. The organ-specific radiation doses are the 50th percentile (central estimate) as reported by the Task 4 authors for individuals exposed during the entire study period (48 years), except for specific years that were not included for certain areas (see Table 10).

† ATSDR approximated the annual (1-year) whole-body dose for each pathway by applying weighting factors to Task 4's estimated 50th percentile organ-specific doses, adjusting for a 1-year exposure, and summing the adjusted organ doses across each pathway. ATSDR approximated the lifetime (70-year) whole-body dose for each pathway by adjusting the doses for a 70-year exposure and summing the adjusted doses for each pathway.

‡ The location represents the locations along the Clinch River of maximum exposure for each exposure pathway.

§ Doses are for females only; doses were too low to be significant in males.

¶ The doses are based on exposure to shoreline sediments.

** ATSDR divided the Task 4 dose—based on up to 48 years of exposure—by 48, multiplied by 70 years, and rounded up to approximate a committed equivalent dose to an organ over 70 years.

†† ATSDR derived the total annual whole-body dose over a lifetime by summing the annual whole-body doses for each pathway.

‡‡ ATSDR derived the committed effective dose to the whole body by summing the equivalent doses for eachorgan using ICRP methodology.

Fish Ingestion

The highest radiation doses were associated with eating fish taken from the Clinch River near Jones Island between 1944 and 1991. Doses were much lower for all other pathways (see Table 11 and Table 12). The Task 4 report's estimated organ doses to the bone, lower large intestine, red bone marrow, breast, and skin from eating fish were at least 7 times greater than the radiation doses to these organs from eating meat and milk and via external radiation (Table 12). Likewise, ATSDR's derived annual whole-body and committed equivalent doses from eating fish were at least 10 times more than any of the other exposure pathways (Table 10).

The highest radiation dose associated with radionuclide releases to the Clinch River was from **frequent consumption of fish** (1 to 2.5 meals per week) caught near the mouth of White Oak Creek. The doses were much lower for other pathways and for individuals who ate fewer fish or caught fish further downstream.

Table 12. Ratio of Adult Organ-Specific Radiation Doses Relative to Ingestion of Fish Caught Near Jones Island

Pathway†	Location‡	Ratio of Radiation Dose*				
		Bone	Lower Large Intestine	Red Bone Marrow	Breast	Skin
Fish ingestion	Jones Island	1.0	1.0	1.0	1.0§	1.0
	Kingston	0.12	0.11	0.11	0.13	0.11
Drinking water ingestion	K-25/ Grassy Creek	0.14	0.14	0.08	0.01	0.01
	Kingston	<0.01	0.01	<0.01	<0.01	<0.01
Meat ingestion	K-25/ Grassy Creek	<0.01	<0.01	<0.01	<0.01	<0.01
Milk ingestion	K-25/ Grassy Creek	<0.01	<0.01	<0.01	<0.01	<0.01
External radiation (walking on sediment)¶	Jones Island	0.01	0.01	0.01	0.04	0.03
	Kingston	0.06	0.05	0.05	0.15	0.15

* The fish consumption dose used to calculate the ratio was the 50th percentile dose received by the maximally exposed individuals who consumed fish caught near Jones Island over the 48-year exposure.
† The pathway presented represents the maximally exposed category.
‡ When doses for two areas are given for the same pathway, ATSDR compared the highest dose to fish doses.
§ Doses are for females only; doses were too low to be significant in males.
¶ The doses are based on exposures from walking along the shoreline.

The highest organ doses of radiation from fish consumption were estimated for the bone surface (810 mrem for males and 600 mrem for females, central values), and the lowest organ doses were estimated for the skin (310 mrem for males and 230 mrem for females, central values).

Despite these differences, the organ doses varied by a factor of only 2 to 3 for males and 3 to 4 for females. This similarity between doses reflects the contribution of Cs 137 to organ doses. Cs 137 distributes rather uniformly throughout the body of the person eating the fish, and therefore, there was little difference among the various organ doses. It should be noted that because different organs are believed to have different sensitivities to radiation-induced cancer, the organ with the highest dose is not necessarily the organ with the highest probability of developing cancer.[8]

The dose for fish consumption depended on how often people ate fish and the area of the Clinch River where the fish were taken. The highest doses were received by individuals who consumed 1 to 2.5 fish meals per week and caught their fish near Jones Island, close to the mouth of White Oak Creek. The estimated annual whole-body dose of 3.4 mrem from eating frequent meals of fish caught near Jones Island was less than 1% of the average annual background dose of 360 mrem for a U.S. citizen. Doses were much lower for individuals who ate fewer fish or caught their fish further downstream from White Oak Creek and Jones Island. For example, organ-specific and whole-body doses for people who ate fish caught near Kingston were 8 times lower than doses from eating fish caught near Jones Island (see Table 12). People who ate fish caught near Kingston received an estimated annual whole-body dose of 0.4 mrem, which is 900 times less than the average annual background dose of 360 mrem for a U.S. citizen.

Drinking Water Ingestion

In Table 11, ATSDR summarizes radiation doses for drinking water at K-25/Grassy Creek (CRM 17 to 5) and the city of Kingston (CRM 0), located downstream from the mouth of White Oak Creek. The estimated organ-specific and whole-body radiation doses received from drinking water from the Clinch River were much lower than the radiation doses received from eating Clinch River fish. For example, the doses to the bone, lower large intestine, red bone marrow, breast, and skin from drinking Clinch River water were at least 7 times lower than the doses to those same organs from eating Clinch River fish. The highest annual whole-body dose from drinking water of 0.3 mrem was estimated for K-25/Grassy Creek. This annual whole-body dose is more than 1,000 times less than the background dose of 360 mrem that the average U.S. citizen receives each year. Lower doses were associated with drinking water further downstream at the city of Kingston. Organ-specific doses from drinking city of Kingston water were at least 13 times less than the doses estimated for K-25/Grassy Creek drinking water.

In addition to the Task 4 team's analysis of exposure to X-10 contaminants via the K-25 water intake, ATSDR conducted a separate analysis of exposure of residents living in the Happy Valley settlement. In its evaluation, ATSDR derived whole-body doses for hypothetical residents of Happy Valley who drank water from the K-25 intake. Most information about Happy Valley indicates that workers and their families occupied the settlement between late 1943 and 1946. Anecdotal reports suggest, however, that some workers stayed on through 1948. Given the uncertainty about the actual time frame in which Happy Valley was occupied—and the duration of possible exposure—ATSDR overestimated the likely exposure period by conservatively assuming that Happy Valley residents could have been exposed over a 7-year period, from 1944 to 1950. Conservative assumptions such as this create a protective estimate of exposure, which allows ATSDR to evaluate the likelihood, if any, that the K-25 drinking water containing radionuclides could cause harm to Happy Valley residents.

ATSDR did not identify any Clinch River monitoring data for radionuclides covering the period when Happy Valley was used as a housing area. In the absence of historical monitoring data, ATSDR used the 50th percentile of the modeled radioactivity concentrations in the Grassy Creek area of Clinch River as reported in the Task 4 report. ATSDR's highest annual radiological dose estimate at the K-25 water intake was about 14 mrem/year. ATSDR predicted that Happy Valley residents who lived at the settlement between 1944 and 1950 would have received a dose of 98 mrem over the 7-year period. The whole body dose for drinking water at Happy Valley (from the K-25 intake) was about 2.5 times less than the doses estimated for fish consumption.

[8] Because the risk level associated with iodine was below the screening level and none of the other radionuclides are associated with effects on this organ, the Task 4 team did not further evaluate the effects on the thyroid (ChemRisk 1999a).

External Radiation (Walking on Sediment)

Radionuclides that had accumulated in the sediment deposited along the Clinch River were found in the top layer (averaging about 6 to 7 centimeters [cm], but varying between 2 and 15 cm) of sediment. The Task 4 derived organ doses for people who might have incurred external exposure to radionuclides while walking on Clinch River shoreline sediment. When estimating doses from external exposure, the team used dose-rate factors (dose per unit intake) as reported by the ICRP and modified these factors to consider the thickness of the contaminated sediment layer and the width of the Clinch River shoreline. The Task 4 team obtained the external doses by combining the concentrations of radionuclides in sediment with the dose-rate factors and the exposure parameters.

ATSDR focused its evaluation on those exposures occurring near Jones Island and the city of Kingston. Overall, the Task 4 organ doses from walking on sediments were at least 6 times lower than doses received from eating Clinch River fish caught at or near Jones Island. Individuals walking on sediment in the Kingston area were predicted to receive slightly higher doses than individuals at Jones Island. Upstream sediment containing radionuclides was likely dislodged by the water flow and contributed to the buildup of sediment farther downstream. Even so, the maximum annual whole-body dose from external radiation by walking on sediments in Kingston is more than 1,000 times less than the radiation dose of 360 mrem that the average U.S. citizen receives from background radiation each year (see Table 11).

ATSDR's Review of the Task 4 Dose Reconstruction Report

As part of its involvement at the ORR, ATSDR convened a panel of technical experts to evaluate the study design, the scientific approaches, the methodologies, and the conclusions of the Task 4 report. ATSDR had the report reviewed to determine if it would provide a foundation for follow-up public health actions or studies, particularly ATSDR's congressionally mandated public health assessment of the ORR. The reviewers agreed that the overall design and scientific approach were appropriate. One reviewer commented that the methods and analysis plan "break new and important ground in the use of uncertainty analysis in environmental assessment." The reviewers also commented that the results were generally quite valid and consistent with earlier studies, and were applicable to public health decision-making as long as careful attention was given to the assumptions behind the estimates. Some issues with the team's report raised some concern among the reviewers; in their opinion, however, the report was well written and advanced the science of dose reconstruction.

III.B.3. Current and Future Exposure (Years After 1987)

Lower Watts Bar Reservoir (1988–Present and Future)

Background

The LWBR extends from the convergence of the Clinch River and the Tennessee River (about 22 river miles downstream of White Oak Dam) to the Watts Bar Dam (see Figures 4 and 11). Community members use the reservoir for recreational activities, such as boating and swimming. The LWBR is also a popular recreational fishing spot for area anglers—an estimated 10,000 to 30,000 anglers fish at the Lower Watts Bar Reservoir each year (ORHASP 1999). In addition, Kingston and Spring City obtain drinking water from surface water potentially influenced by Watts Bar Reservoir. Since 1995, Kingston has maintained a water intake that would potentially be impacted by ORR contaminants. The water intake, on Watts Bar Lake, is upstream from the Clinch River confluence on the Tennessee River at Tennessee River Mile (TRM) 568.4 (Hutson and Morris 1992; G. Mize, Tennessee Department of Environment and Conservation, Drinking water program, personal communication re: Kingston public water supply, 2004). Although the intake is slightly upstream, flow direction in this area is impacted by the Tellico and Fort Loudon Dams and releases through the Watts Bar Dam. Spring City obtains its water from an intake on the Piney River branch of Watts Bar Lake (Hutson and Morris 1992).

In March 1995, the U.S. Department of Energy (DOE) released a proposed plan that called for leaving the contaminated deep sediment in place at the reservoir; deep sediment is generally considered inaccessible to the public, and the LWBR sediment—if left undisturbed—is not expected to pose a concern for public exposure (U.S. DOE 1995c). Because the reservoir was used so widely, some community members expressed concern to ATSDR about possible exposure to contaminants in the water and sediment. The community questioned whether DOE's proposed actions were sufficient to protect people who use the river from exposure to these contaminants. Subsequently, these residents asked ATSDR to evaluate the potential health risks from exposure to the LWBR contamination and provide an independent opinion on whether

DOE's selected remedial actions were adequate to protect public health. ATSDR prepared a health consultation in 1996 to respond to community concerns about potential hazards associated with contaminants in the water and deep sediments of the LWBR (ATSDR 1996). See Section II.F.1. in this document and the brief in Appendix D for more details on ATSDR's health consultation.

Since February 1991, the Watts Bar Interagency Agreement has set guidelines related to any dredging in Watts Bar Reservoir and for reviewing potential sediment-disturbing activities in the Clinch River below Melton Hill Dam, including Poplar Creek (Jacobs EM Team 1997b). Under this agreement, the Watts Bar Reservoir Interagency Working Group (WBRIWG) reviews permitting and other activities, either public or private, that could possibly disturb sediment, such as erecting a pier or building a dock (ATSDR 1996; Jacobs EM Team 1997b; U.S. DOE 2003a). The WBRIWG consists of DOE, EPA, USACE, TDEC, and TVA because of their permit authority or their knowledge of the sediment contamination and how that contamination could impact the public if disturbed (Jacobs EM Team 1997b).

Permit coordination under the Watts Bar Interagency Agreement was established to allow TVA, USACE, and TDEC (the agencies with permit authority over actions taken in Watts Bar Reservoir) to discuss proposed sediment-disturbing activities with DOE and EPA before conducting the normal permit review process to determine if there were any DOE contaminants in the sediments. The coordination follows a series of defined processes as outlined in the agreement.

The basic process of obtaining a permit is the same for any organization or individual:

1. an application is completed and submitted to TVA/USACE/TDEC (depending on scope of activity);
2. if the proposed activity would occur within the Watts Bar Reservoir and its tributaries, the application is forwarded to the WBRIWG for review;
3. the WBRIWG reviews available data for the location involved or DOE collects any necessary existing data on sediment contamination;
4. if the location is considered to be uncontaminated or clean enough to pose no significant health risks, then the application is forwarded back to TVA/COE/TDEC for their standard review process; and

5. if the location is considered to be contaminated and sediments may pose a health risk, DOE works with the applicant to determine how best to conduct the requested activity (assuming TVA/COE/TDEC permit the action based on their own statutory program of review). The interagency agreement covers any potential sediment-disturbing activity (other than locations predetermined to be free of DOE-related contaminants) (Jacobs EM Team 1997b).

If dredging is necessary in an area with contaminated sediments, DOE will assume the financial and waste management responsibility that is over and above the costs that would normally be incurred. Dredging and subsequent disposal of sediments will take place in accordance with best management practices and in compliance with all state and federal laws regarding downstream impacts and disposal of hazardous or radioactive materials (Jacobs EM Team 1997b).

Environmental Monitoring Data for the Lower Watts Bar Reservoir

To address the community concerns, ATSDR evaluated environmental monitoring data for surface and deep channel sediment, surface water, and local biota collected from the LWBR by DOE and the TVA during the 1980s and 1990s (Olsen 1992; U.S. DOE 1994b).[9] In addition to these data, ATSDR evaluated the institutional controls in place to monitor contaminants in the LWBR. These controls, which include measures to keep sediment in place and ongoing water monitoring, have helped to minimize the potential for human exposure to contaminants in sediment and water. Data on radionuclides that were transported downstream from the ORR by the LWBR in sediment, surface water, and fish are discussed below.

<u>Sediment</u>

Radionuclides were detected in the *surface* and deep *subsurface* layers of sediment in the LWBR (see Table 13). The surface samples were collected from shallow areas of the reservoir and the subsurface samples were collected from the deep river channels—beneath several meters of water and 40 to 80 centimeters of sediment. Samples collected from the surface layer contained Cs 137, Sr 89/90, and Co 60. Other radionuclides were also detected, but at much lower frequencies and concentrations. The highest concentration of Cs 137 in surface sediment was below 15 pCi/g, the screening value adopted by the Interagency Working Group. This value is also below the soil screening value for Cs 137 used by ATSDR as adopted from NCRP's Report

129 (NCRP 1999). Historical documents suggest that 2 to 5 times more strontium than cesium was released to the Clinch River between 1982 and 1992; however, higher concentrations of Cs 137 were detected in the top layers of sediment (Martin Marietta Energy Systems, Inc.1992). Both cesium and strontium tend to bind to sediment; although, cesium binds more strongly to sediment, while strontium is released from sediment more readily under certain conditions.

Table 13. Maximum Radionuclide Concentrations in Lower Watts Bar Reservoir Sediment

Radionuclide	***Activity pCi/g (Bq/g)***	
	Surface Sediment	***Subsurface Sediment***
Americium 241	0.168 (0.006)	0.30 (0.011)
Beryllium 7	0.417 (0.015)	Not reported
Cesium 137	10.31 (0.382)	151.2 (5.6)
Cobalt 60	0.34 (0.013)	1.21 (0.045)
Curium 242	0.021 (0.001)	Not reported
Curium 243/244	0.040 (0.001)	0.04 (0.001)
Curium 245/246	Not reported	0.06 (0.002)
Curium 248	Not reported	0.06 (0.002)
Europium 152	0.241 (0.009)	Not reported
Europium 154	0.072 (0.003)	Not reported
Potassium 40	30.36 (1.124)	Not reported
Plutonium 238	0.230 (0.009)	0.23 (0.009)
Plutonium 239/240	0.072 (0.003)	0.45 (0.017)
Plutonium 241	20.00 (0.741)	Not reported
Plutonium 242	0.07 (0.003)	Not reported
Strontium 89	2.30 (0.085)	Not reported
Strontium 90	0.90 (0.33)	3.30 (0.122)
Uranium 234	0.096 (0.004)	3.08 (0.114)
Uranium 235	0.08 (0.003)	0.37 (0.014)
Uranium 238	0.07 (0.003)	2.45 (0.091)

[9] Additional sources used by ATSDR's evaluation of the Lower Watts Bar Reservoir included a 1992 Clinch River Scoping Report and the data summary for the 1994 near-sediment characterization task for the Clinch River environmental restoration program.

Cs 137, Co 60, and Sr 90 are the most common radionuclides detected in the *subsurface* sediment. The depth of the peak concentrations appears to vary with the location in the reservoir, the rate of sediment accumulation, and the type of sediment. In general, radionuclide concentrations were higher in the subsurface sediment than in the surface sediment (see Figure 23), and increased with depth within the subsurface sediment. The highest concentration of Cs 137 (151.2 pCi/g, or 5.6 Bq/g) was found in the deep river channel subsurface sediment at a depth of 15 to 33 inches (Olsen et al.1992).

The vertical distribution of Cs 137 was strongly correlated to mercury (Hg) concentrations, with both exhibiting large subsurface maximum concentrations that coincided with their peak discharge histories. Sr 90 and Co 60 also existed in the subsurface sediment, but they were generally found at concentrations lower than Cs 137. Peak concentrations of Sr 90 and Co 60 do not strongly relate to peak concentrations of Cs 137 and they do not show a similar dramatic change in concentration with depth of sediment. Uranium concentrations were slightly higher than background concentrations for the region.

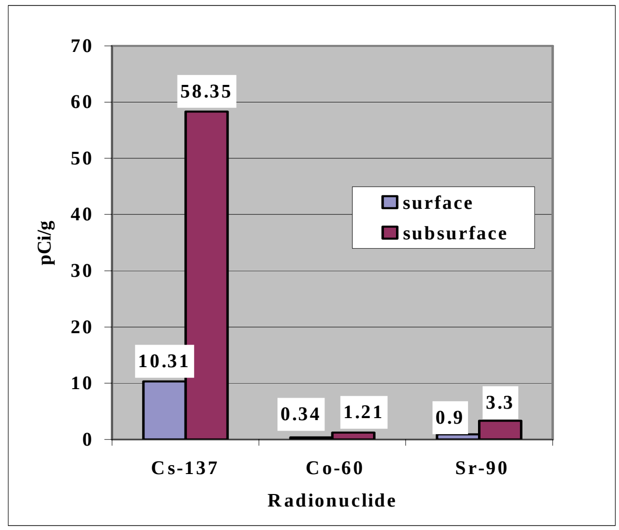


Figure 23. Radionuclide Concentrations in Surface

Surface Water

Some of the radionuclides released to White Oak Creek were suspended in the water. These radionuclides would be expected to decrease in concentration as they mixed with the surface water of the Clinch River before reaching the LWBR. To evaluate surface water sampling data for the reservoir, ATSDR reviewed TVA's 1991 sediment sampling report (TVA 1991) near major water intakes along the Tennessee River system reservoirs of the Watts Bar, Melton Hill, and Norris Dams; the *Phase 1 Data Summary Report for the Clinch River Remedial Investigation: Health Risk and Ecological Risk Screening Assessment* (Cook et al. 1992); and the *ORR 1992 Environmental Report* (Martin Marietta Energy Systems, Inc. 1993). Samples were collected from 29 locations at the reservoir and were analyzed for 11 radionuclides. ATSDR also reviewed water samples collected by TVA from the water intakes for the city of Kingston and Spring City (TVA 1991). Water sampling data consisted of both grab and composite samples. Composite samples were collected weekly, mixed in one container, and analyzed quarterly. Table 14 summarizes the surface water monitoring data for the Lower Watts Bar Reservoir.

Table 14. Maximum Radionuclide Concentrations in Lower Watts Bar Reservoir Surface Water

Radionuclide	*Maximum Concentration pCi/L (Bq/L)*
Cesium 137	0.51 (0.019)
Cobalt 60	0.54 (0.020)
Hydrogen 3	853 (31.59)
Plutonium 238	0.0081 (0.0003)
Plutonium 239	0.0049 (0.0002)
Strontium 90	0.7 (0.026)
Uranium—total	0.13 (0.005)

Of the seven radionuclides detected, hydrogen 3 (H 3, also known as tritium) reached the highest concentration (853 pCi/L) in the collected surface water samples. According to the Task 4 report, over 90% of the total radioactivity released from White Oak Creek was in the form of H 3. Concentrations of the other radionuclides were less than 1 pCi/L. The likelihood of adverse health effects from H 3 is extremely low; H 3 is a very weak emitter of radiation and the concentrations were well below the EPA's current maximum contaminant level (MCL) of 20,000 pCi/L of H 3, an amount that would produce a radiation dose of 4 mrem/year if ingested at 2 liters of water per day for a year.

The MCL is the level of a contaminant that is allowed in drinking water.

Drinking Water

The city of Kingston and Spring City have public drinking water supplies that draw water from the Tennessee River system. EPA's Safe Drinking Water Act (SDWA) requires all public water suppliers in Tennessee to monitor their water to ensure that it meets safe drinking water standards, or MCLs. The public water supplies for Kingston and Spring City are monitored for substances that include 15 inorganic contaminants, 51 synthetic and volatile organic contaminants, and 4 radionuclides (EPA 2004a). According to EPA's Safe Drinking Water Information System (SDWIS), the Kingston and Spring City public water systems meet safe drinking water standards (U.S. EPA 2004b). In 1996, TDEC's DOE Oversight Division started to participate in EPA's Environmental Radiation Ambient Monitoring System. Under this program, TDEC collects water samples from the Tennessee River system around Kingston and Spring City and analyzes them for radiological content. The public water supply monitoring and ERAMS results lead ATSDR to consider this water safe for consumption and other potable uses.

Fish

LWBR sediment and water quality have been affected by radioactive contaminants released from White Oak Creek to the Clinch River and the LWBR. Some of the radiological materials have long half-lives, and thus might remain in the environment for many years after being released. Even though radionuclide levels in surface water or surface sediment of the reservoir might be relatively low, certain contaminants can persist and accumulate in fish tissue. Fish are exposed to contaminants when they eat smaller fish or consume sediment that contains contaminants. Because of this process, larger and older fish can build up high levels of contaminants (TVA 1994).[10]

Limited data describing radionuclide concentrations in fish from the LWBR were available for ATSDR's review in 1995. The available data came from three sites along or downstream of the LWBR: Mid Watts Bar Reservoir (Tennessee River Mile 557.0), the LWBR north of the Watts Bar Dam (Tennessee River Mile 530.5), and the Upper Chickamaugua Reservoir (Tennessee River Mile 518.0 and below Watts Bar Dam). A combined total of 42 fish specimens were collected, coming from three different species—channel catfish, bluegill, and largemouth bass. All of the fish fillet samples were analyzed for Cs 137 and Co 60. Channel catfish samples with bones were also analyzed for Sr 90, since strontium is a bone-seeking radionuclide. As shown in Table 15, the radionuclides Cs 137, Co 60, and Sr 90 were detected at 0.16 pCi/g (0.006 Bq/g), 0.24 pCi/g (0.009 Bq/g), and 1.0 pCi/g (0.037 Bq/g), respectively.

[10] Available (though limited) sampling data of other biota (for example, turtles) were considered. No contaminants of concern were identified in these other biota samples collected at or near the Lower Watts Bar Reservoir.

Table 15. Maximum Radionuclide Concentrations in Lower Watts Bar Reservoir Area Fish

Radionuclide	***Maximum Concentration pCi/g (Bq/g)***
Cesium 137	0.16 (0.006)
Cobalt 60	0.24 (0.009)
Strontium 90 (with bone)	1.00 (0.037)

Lower Watts Bar Reservoir Exposure Pathways and Estimated Radiation Doses

In its evaluation of exposures at the LWBR, ATSDR derived whole-body (committed effective) doses for hypothetical people who came in contact with radionuclides while walking on surface and dredged subsurface, swimming in surface water, or consuming fish. When deriving the doses, ATSDR used *worst-case* exposure scenarios that relied on literature-based conservative assumptions for fish ingestion. The worst-case scenarios assumed that the most sensitive population—that is, young children and older adults—were exposed to the highest concentration of radionuclides in sediment, surface water, or fish by the most likely exposure control routes—inhalation, dermal contact, and external radiation exposure. Using these assumptions when estimating the hypothetical exposure doses likely overestimates the actual magnitude of exposure. These conservative assumptions create a protective estimate of exposure, which allows ATSDR to evaluate the likelihood, if any, that environmental media containing radionuclides could cause harm. ATSDR's estimated doses are summarized in Table 16 and in the discussion that follows.

Table 16. Estimated Whole-Body Doses for Current Lower Watts Bar Reservoir Exposure Pathways

Exposure Pathway		***Individual***	***Whole-Body Dose****	
			Annual (mrem per year)	***Estimated Committed Effective Dose (mrem over 70 years)***
Fish ingestion		Adult and child	6.0	420
Water ingestion		Child	0.25	17.5
External radiation	Contact with surface sediment	Child	15	1,050
	Contact with dredged channel sediment†		20	1,400
	Swimming or showering		0.05	3.5

* ATSDR's conservative assumptions used to estimate radiation doses likely created overestimates of the magnitude of the true exposure.

† ATSDR's evaluation of exposure to dredged sediment along LWBR also considered inhalation of, ingestion of, and dermal contact with contaminated dredged sediment.

<u>Fish Ingestion</u>

To determine if the consumption of contaminated fish could be detrimental to human health, ATSDR estimated doses for individuals who eat fish from the LWBR. Because uncertainty exists regarding how often people consume fish from the river and how large a portion might be eaten, ATSDR used worst-case scenarios that assumed an adult and child eat two 8-ounce meals of LWBR fish each week. ATSDR also assumed that the fish consumed contained the highest probable level of each of the primary radionuclides. For example, when evaluating the likelihood of health effects from strontium, ATSDR assumed that the fish fillet meal could include some bone because strontium is a bone-seeking radionuclide. For both an adult and a child, the dose estimated for the primary radionuclides were 6 mrem per year, or less than 420 mrem over 70 years for the committed effective dose. The annual whole-body dose of 6 mrem per year is more than 60 times less than the background dose of 360 mrem that the average U.S. citizen receives each year.

<u>Water Ingestion</u>

ATSDR examined the possibility that harmful health effects could result from exposure to the radionuclides detected in LWBR surface water. Local residents might be exposed to contaminants in surface water through incidental ingestion of water when they use the reservoir for recreational activities, such as swimming. Residents of Kingston or Spring City who are supplied with municipal water from the reservoir could also contact contaminants when they drink water from their taps or use it for other household purposes. Even so, potential exposures to harmful levels of radionuclides in the home from municipal water use are expected to be limited—monitoring data indicate that the drinking water has met safe drinking water standards for radionuclides.

ATSDR evaluated exposure to surface water contaminants for a 10-year-old child who lives near the LWBR. ATSDR focused its evaluation on the child to consider the potential likelihood that this sensitive population might be exposed to surface water contaminants. ATSDR used conservative assumptions to examine how a child could be exposed to contaminants and how much contaminated water that child might ingest each day. In its evaluation, ATSDR assumed that the child drank unfiltered water. ATSDR's estimated dose to a child from drinking unfiltered water obtained from the LWBR is 0.25 mrem per year, or less than 17.5 mrem over 70 years for the committed effective dose. The annual whole-body dose of 0.25 mrem per year is about 1,440 times less than the background dose of 360 mrem that the average U.S. citizen receives each year.

External Radiation Contact With Shoreline Sediment or Dredged Sediment

Relatively low levels of radioactive contaminants have been detected in the *surface* sediment of the LWBR (see Figure 23). People could be exposed to external radiation released from radionuclides in shallow areas of the reservoir or along the shore while swimming, fishing, or boating. The highest concentrations of radioactive contaminants are in subsurface sediment located in the deep river channels and are shielded by several meters of surface water and 15 inches or more of sediment on the river bottom—thus these areas with the highest concentrations are generally inaccessible to the public. In the unlikely event that these subsurface sediments might in the future be dredged from the river channel, ATSDR examined the potential exposure for a hypothetical individual who might come in contact with contaminants when walking on or handling sediment that was dredged from the deep river channel and deposited on the shoreline. ATSDR's committed effective doses to the whole body for individuals hypothetically exposed to external radiation from surface sediment or subsurface sediment over a 70-year period were less than 1,050 mrem over 70 years and 1,400 mrem over 70 years, respectively.[11] These committed effective doses were based on annual doses of 15 mrem per year and 20 mrem per year for external radiation from surface sediment and subsurface sediment, respectively. These annual whole-body doses are more than 18 times less than the background dose of 360 mrem that the average U.S. citizen receives each year.

External Radiation: Swimming or Showering

Local residents might be exposed to contaminants in surface water through physical contact with water when they use the reservoir for recreational activities, such as swimming and boating. Residents of Kingston and Spring City who are supplied with municipal water from the reservoir could also contact contaminants when showering or bathing. As previously noted, potential exposures to harmful levels of radionuclides in the home from municipal water use are expected to be limited—monitoring data indicate that the drinking water has met safe drinking water standards for radionuclides.

ATSDR used conservative assumptions to examine how a 10-year-old child could be exposed to contaminants and how much contaminated water that child might contact each day. In its evaluation, ATSDR assumed that the child showered, or that the child swam in the reservoir, for up to 8 hours a day. In all likelihood, a child would spend far less time in either situation. Still, these assumptions enable ATSDR to calculate a conservative estimate of exposure that it uses to confidently evaluate the likelihood, if any, that contaminants in surface water could cause harm. Potential exposure was also evaluated for a person under similar circumstances who might live near the Watts Bar Lake for a lifetime (70 years). The dose to the whole body from external radiation via bathing or swimming is 0.05 mrem per year, or less than 3.5 mrem over 70 years for the committed effective dose. The annual whole-body dose is more than 7,200 times less than the background dose of 360 mrem that the average U.S. citizen receives each year.

ATSDR combined the annual doses for the two surface water exposures from incidental ingestion and contact (0.25 mrem and 0.05) to obtain the total dose from waterborne radioactive

[11] ATSDR determined that dredging might pose greater harm to human health from resuspension of sediment, which would subsequently increase the waterborne concentration of radionuclides in the Lower Watts Bar Reservoir and increase any potential exposure for employees involved in the dredging.

contaminants, which was below 1 mrem over 70 years—less than 1% of the typical background radiation dose that a U.S. citizen receives each year.

Clinch River (1989–Present and Future)

Environmental Data

To evaluate the current exposures and doses related to releases from White Oak Creek, ATSDR obtained data in electronic format from the Oak Ridge Environmental Information System (OREIS), detailed in Section II.F.4 of this document. The data received and analyzed by ATSDR covered the time period from 1989 to the present. Samples included surface waters collected from the LWBR and sediments from the associated shorelines. ATSDR also evaluated biota data that included fish, geese, and turtle samples. ATSDR analyzed samples for rivers in the watershed that included the Clinch River below Melton Hill Dam and the Tennessee River below the mouth of the Clinch River. For comparison, ATSDR reviewed data collected from background locations (Emory River, streams that feed into the Clinch River, the Clinch River above the Melton Hill Dam, and the Tennessee River upstream of the Clinch River.

For the initial data sorting, ATSDR included the radionuclides associated with the Task 4 report, as well as the radionuclides reported in the OREIS data. The purpose of the data sorting was to collate data by the following parameters: river location, species (for biota), radionuclide, or a combination of one or more of these parameters. As a result of this sorting, ATSDR performed its evaluation on the radionuclides presented in Table 17.

Table 17. Summary of Radionuclides Evaluated for the Clinch River Area

Radionuclide	***Half-Life****	***Mode(s) of Decay†***	***Critical organ (ingestion) ‡***	***Decay Product§***
Cesium 137	30.2 years	Beta/gamma	Lower large intestine	Barium 137
Cobalt 60	5.3 years	Beta/gamma	Lower large intestine	Nickel 60
Strontium 90	28.6 years	Beta	Bone surface	Yttrium 90
Yttrium 90	64 hours	Beta/gamma	Lower large intestine	Zirconium 90
Americium 241	432 years	Alpha	Bone surface	Neptunium 237
Hydrogen 3	12.2 years	Beta	Whole body	Helium 3

* The half-life is the amount of time required for 50% of the initial amount present to physically decay.
† The mode of decay is the principal method whereby the isotope decays or releases energy. In those instances where a gamma mode is listed, this indicates that the decay product releases a gamma ray (photon) as a method of nuclear rearrangement.
‡ The critical organ, as defined by the International Commission on Radiological Protection, is the organ receiving the highest radiation dose following an intake of radioactive material.
§ The decay product is the first isotope produced during the decay of the parent radioisotope.

Exposure Pathways and Estimated Radiation Doses

ATSDR sorted the environmental monitoring data by pathway: ingestion of fish, geese, and turtle), ingestion of water, and external radiation via walking on shoreline sediment or contacting water while swimming) (see Table 18). Exposure scenarios were evaluated by using specific values from the EPA Exposure Factors Handbook, other federal guidance manuals, and/or interviews performed during ATSDR's 1998 exposure investigation that evaluated serum PCB and blood mercury levels in consumers of fish and turtles from the Watts Bar Reservoir. See Section II.F.1. in this public health assessment for additional details and Appendix D for a brief summary of the exposure investigation. In the discussion that follows, ATSDR evaluates these exposure situations and derives estimated radiation doses.

Table 18. Current Exposure Pathways Evaluated for the Clinch River Area

Exposure Pathway		***Individual***	***Description of Exposure Situation***
Biota ingestion	Fish	Adult, teenager, and child	Eating one 8-ounce fish meal each week for an adult and one 4-ounce fish meal each week for a child (ATSDR assumed lifetime exposure—until 70 years of age—for a 10-year-old child, a 15-year-old teenager, and a 20-year-old adult)
	Geese and turtle	Adult, teenager, and child	Eating about 1 pound of goose liver, 22 pounds of goose muscle, and 3.5 ounces of turtle each year (ATSDR assumed lifetime exposure—until 70 years of age—for a 10-year-old child, a 15-year-old teenager, and a 20-year-old adult)
Water ingestion (incidental ingestion of surface water)		Adult	Incidental ingestion while swimming: ingesting 0.1 liters per hour for 1 hour per day for 150 days per year
External radiation	Walking on sediment	Teenager	Contact during recreational activities: 5 hours each day for 150 days per year
	Swimming	Adult	Contact while swimming: 1 hour per day for 150 days per year

ATSDR reviewed biota (fish, geese, and turtle), surface water, and sediment data for the presence of radionuclides. The samples were collected from the Clinch River below the Melton Hill Dam and from the Tennessee River below its confluence with the Clinch River. For comparison, ATSDR reviewed data collected from background locations (Emory River, streams that feed into the Clinch River, the Clinch River above the Melton Hill Dam, and the Tennessee River upstream of the Clinch River.

For the dose assessment, ATSDR looked at the critical organ and the radiation dose delivered to the whole body. For the time period of the dose assessment (1989 to the present), ATSDR set the age of an adult at 20 years and estimated the dose received until that person was 70 years of age; that is, ATSDR assumed exposure for a 50-year period. For a teenager and child, ATSDR also estimated the dose to age 70, but modified the years of exposure as appropriate for a 15-year-old (55 years) and a 10-year-old (60 years).

Biota Ingestion

ATSDR reviewed biota data for the presence of radionuclides. The biota samples included various species of fish, turtles, and geese that were collected from the Clinch River below the

Melton Hill Dam and from the Tennessee River below its confluence with the Clinch River. For comparison, ATSDR reviewed data for background locations.

<u>Fish</u>

In deriving radiation doses from the consumption of fish, ATSDR considered only fillet portions and muscle. ATSDR assumed that a child eating fish from the river consumes 113.4 grams (4 ounces) per week and that an adult consumes 227 grams (8 ounces) per week. These ingestion rates are based on a survey of fish consumption patterns conducted as part of the 1998 ATSDR Watts Bar Reservoir exposure investigation. Table 19 presents the estimated radiation doses by fish species consumed and the river where the samples were collected for an adult, teenager, and child (until age 70 years).

ATSDR's analysis of fish consumption indicates that the doses to the critical organ and to the whole body are very similar for the 10-year-old, the 15-year-old, and the 20-year-old. Some of the highest doses were associated with eating catfish or largemouth bass caught from the Clinch River below Melton Hill Dam. Even so, the estimated whole-body doses, or committed effective doses, over 70 years were less than 125 mrem. ATSDR derived the committed effective dose from fish ingestion by multiplying the dose of 89.3 mrem to an adult over 50 years by 70 years/50 years to approximate a 70-year exposure. The highest committed equivalent dose of 114 mrem to the bone surface was estimated for a 15-year-old, based on a 55-year exposure. Because Sr 90 is a bone seeker and because much bone growth occurs during the teenage years, a 15-year-old could conceivably have a higher dose than either a 20-year-old adult or a 10-year-old child (see Table 19).

At one time, the Clinch River had many species of mussels and dredging for mussels took place in the lower Clinch River on a large scale. The mussel population declined rapidly after the impoundment of Norris and Melton Hill Dams.

Table 19. Estimated Radiation Doses From Current Ingestion of Fish

			Radiation Dose to Age 70		
			Adult (50 years of intake)	***15-Year-Old (55 years of intake)***	***10-Year-Old (60 years of intake)***
Tennessee River below the confluence with the Clinch River	Channel catfish	Lower large intestine	2.13	2.65	4.07
		Whole body	0.99	0.818	1.01
	Largemouth bass	Lower large intestine	1.20	1.38	1.89
		Whole body	0.71	0.48	0.506
	Striped bass	Lower large intestine	0.74	0.769	0.839
		Whole body	0.56	0.31	0.26
Clinch River below Melton Hill Dam	Catfish	Lower large intestine	98.4	52.2	60.3
		Whole body	89.3	68.5	58.8
	Channel catfish	Lower large intestine	55.5	29.2	33.2
		Whole body	41.0	23.2	20.1
	Largemouth bass	Lower large intestine	109	57.2	63.8
		Whole body	82.1	45.8	39.2
	Striped bass	Lower large intestine	1.64	1.03	1.59
		Whole body	0.75	0.62	0.78
	Sunfish‡	Bone surface	4.65	114	71.7
		Whole body	3.15	4.94	4.08

* The doses are expressed in mrem calculated from age of intake to 70 years. For example, the intake for an adult occurs at age 20 and continues for 50 years.

† Doses are presented for the organ receiving the highest radiation dose and for the whole-body dose (the dose delivered to the entire body).

‡ The doses for sunfish are based on dry weight samples; all other doses are based on wet weight samples.

Many unconfirmed reports suggest that people consumed mussels from the Clinch River (usually on a very limited basis); however, there are no records of mussels being consumed on a regular basis and the Clinch River mussels were generally considered to be a poor source of food. Therefore, the likelihood is low that people consumed mussels from the Clinch River (Blaylock 2004).

Turtle and Geese

Canadian geese were introduced into the X-10 area about 20 years ago. Turtles also inhabit the Clinch River environment. Contaminated geese and turtles have been identified in the radioactive ponds at X-10. Geese are grazers that only feed at the ponds in late winter and early spring. For several years, the ORR had a program to control access of waterfowl to radioactive waste ponds, mainly at X-10. These ponds were monitored, and geese that continued to use the ponds were collected. A few geese collected from 3504 waste disposal ponds at X-10 were found to have high concentrations of radionuclides, primarily Cs 137 in their tissues; however, the quantity of geese found with high radionuclide concentrations was extremely small. Further, the possibility of obtaining more than one goose or one turtle with high radioactive concentrations is "highly unlikely" (Blaylock 2004).

For hunters consuming geese, ATSDR assumed that not all portions of the animal would be consumed. Therefore, only the goose liver and the goose muscle were chosen for this analysis. ATSDR selected a consumption value of 500 grams of liver per year (approximately 1 pound) and 10 kilograms (approximately 22 pounds) of goose muscle per year. For the ingestion of turtles, only the muscle was estimated at a value of 100 grams (about 3.5 ounces) per year. For the critical organs, ATSDR used bone surface (Sr 90) and lower large intestine (Cs 137 and Co 60).

Estimated doses for the consumption of geese and turtles are shown in Table 20. As noted in the table, the estimated dose from ingestion of goose muscle was generally greater than the estimated dose from ingestion of turtle, with most of the dose going to the bone surface. The highest committed effective dose to the whole body was 16 mrem over a 70- year lifetime exposure (based on a dose of 14 mrem to a 10-year old child over 60 years) for goose consumption.[12] The highest committed equivalent dose to the bone surface was associated with eating geese.

[12] ATSDR multiplied a dose of 14.0 mrem over 60 years by 70 years/60 years to approximate a 70-year dose.

Table 20. Estimated Radiation Doses From Current Ingestion of Geese and Turtles

Food	Organ†	Radiation Dose to Age 70 (mrem)*		
		Adult (50 years of intake)	***15-Year-Old (55 years of intake)***	***10-Year-Old (60 years of intake)***
Geese (muscle and liver)	Bone surface	154	230	190
	Lower large intestine	1.3	1.8	0.083
	Whole body	7.6	9.5	14
Turtle	Lower large intestine	0.029	0.03	0.033
	Whole body	0.022	0.025	0.021

* For radionuclides with similar critical organs, the doses from each radionuclide were added together. In the case of data reported as strontium 89/90, the doses were calculated as if the reported values were entirely strontium 90. Furthermore, the dose includes the presence of yttrium 90, which is the decay product of strontium 90.

† Doses are presented for the organ receiving the highest radiation dose and the whole-body dose (the dose delivered to the entire body).

<u>Water Ingestion</u>

A person swimming in the river might be exposed to radiation from incidental ingestion of radionuclides in the surface water. To evaluate potential hazards from contact with radionuclides, ATSDR estimated radiation doses for persons swimming in the river. In deriving these doses, ATSDR used exposure values published by the EPA in its *Federal Guidance Report 13*; these values are conservative and typically overestimate true exposure (EPA 2002c). ATSDR assumed that a swimmer might incidentally ingest surface water at a rate of 0.1 liters per hour (Stenge et al. 1995). For swimming frequency, ATSDR assumed an exposure of 1 hour per day for 150 days per year (as noted in the EPA Exposure Factors Handbook). Table 21 provides the results of this evaluation.

The analyses indicated that committed effective dose received by the whole body in the study area of 0.13 mrem is about 3 times higher than the dose for background locations (0.4 mrem). The critical organ for exposure from incidental ingestion of surface water depended on the radionuclide that was ingested. As would be expected, however, the doses to the bone surface of up to 2.8 mrem were higher (by about two orders of magnitude) than those for skin (up to 0.006 mrem).

Table 21. Estimated Radiation Doses From Current Shoreline Recreational Activities for the Clinch River

Exposure Pathway		***Location***	***Radiation Dose (mrem)****		
			Bone Surface	***Skin***	***Whole Body***
Water ingestion (incidental ingestion of surface water)		Background†	0.41	0.01	0.04
		Clinch River	2.8	0.006‡	0.13
		Lower Watts Bar Reservoir	0.072	<0.0001§	0.003
External radiation	Walking on shoreline sediment	Background†	1.57	0.18	0.14
		Clinch River	13	1.6	9.4
		Lower Watts Bar Reservoir	0.16	0.026	0.11
	Swimming	Background†	5.83	0.62	1.15
		Clinch River	1.2	3.9	0.82
		Lower Watts Bar Reservoir	0.048	0.1	0.033

* Doses are presented for the organ receiving the highest radiation dose and the whole-body dose (the dose delivered to the entire body). ATSDR estimated the committed equivalent dose to the organs receiving the highest doses and the committed effective dose to the whole body over a lifetime (70-year) exposure. For the radionuclides with similar critical organs, the doses from each isotope were added together. In the case of data reported as strontium 89/90, the doses were calculated as if the reported values were entirely strontium 90.

† Background locations include areas above Melton Hill Dam, above the confluence of the Tennessee River and the Clinch River, Emory River, and streams that feed into the Clinch River. The background dose represents the average radiation dose at these background locations.

‡ The critical organ for incidental ingestion of Clinch River water is the lower large intestinal wall.

§ The dose is too low to be significant.

External Radiation: Contact With Sediment and Surface Water

To evaluate potential hazards from contact with radionuclides in sediment and surface water, ATSDR estimated radiation doses for persons who might walk along the shoreline and swim in the river. In deriving these doses, ATSDR used exposure values published by the EPA in its *Federal Guidance Report 13*; these values are conservative and typically overestimate true exposure (EPA 2002c). ATSDR presumed that the average recreational users of the Clinch River would be in their mid-teens and that they would be exposed to a 2-square-meter area of shoreline for 5 hours per day and for 150 days per year. For swimming frequency, ATSDR assumed an exposure of 1 hour per day for 150 days per year (as noted in the EPA Exposure Factors Handbook). Table 21 provides the results of this evaluation.

The analyses included the doses received by the entire body, as well as the estimated radiation doses to the organs that are receiving the highest radiation doses. (The exposures from the shoreline, both from walking and swimming, basically impacted the skin.) The highest estimated dose to the whole body within the study area of 9.4 mrem is associated with walking on sediment along the Clinch River below Melton Hill Dam. Walking on sediment at this location was also associated with the highest committed equivalent dose of 13 mrem to the bone surface.

The data indicate that the dose from walking along the sediment is higher in the study area along the Clinch River (below Melton Hill Dam) and Lower Watts Bar Reservoir than at the background locations. For example, the resulting committed effective dose to the whole body from walking on the sediment in the study area is about 60 times higher than for background locations. Similarly, the dose to the bone is about 9 times higher in the study area. As one would expect from the amount of skin exposure, swimming in the Clinch River resulted in the highest doses to the skin out of all pathways evaluated. The estimated dose for swimming at background locations (based on average for all background locations) was, however, actually higher than in the study area.

IV. Public Health Implications

IV.A. Introduction

When evaluating the public health impact associated with exposures to hazardous substances, CERCLA, as amended by SARA §104 [i][6][f], requires that ATSDR consider such factors as

- the nature and extent of contamination,
- the existence of potential pathways of human exposure (including ground or surface water contamination, air emissions, and food chain contamination),
- the size and potential susceptibility of the community within the likely pathways of exposure,
- the comparison of expected human exposure levels to the short-term and long-term health effects associated with identified hazardous substances and any available recommended exposure or tolerance limits for such hazardous substances, and
- the comparison of existing morbidity and mortality data on diseases that could be associated with the observed levels of exposure.

To evaluate health effects from radiation doses received by individuals exposed to radionuclides released into the Clinch River from White Oak Creek, ATSDR used a “weight-of-dose approach.” The weight-of-dose approach involves conducting a critical review of available radiological, medical, and epidemiologic information to ascertain levels of significant human exposure, and then comparing the estimated radiation doses that individuals might have encountered at the Clinch River and LWBR to situations that have been associated with disease and injury. This approach is used to determine whether or not harmful health effects might be possible and observable, and to determine if the doses require a public health action to limit, eliminate, or further study any potential harmful exposures.

The exposure pathways analysis in Section III of this public health assessment indicates that radioactive materials were released from X-10 via White Oak Creek. These radioactive contaminants have migrated off site to the Clinch River and the Lower Watts Bar Reservoir (LWBR), where people have or could come in contact with these contaminants. In this section, ATSDR assesses the health implications of past and current exposures to radioactive contaminants released from White Oak Creek for people who used or lived—and or currently do so—near the Clinch River and LWBR. In assessing exposure, ATSDR evaluated radiation doses presented in the Task 4 report or derived radiation doses using available environmental data.

When calculating doses, ATSDR made conservative assumptions about the frequency, duration, and magnitude of radiation exposures. These conservative estimates allow ATSDR to evaluate the likelihood, if any, that exposure to radionuclides is associated with adverse health effects. Because cancer is the most recognized adverse health outcome resulting from radiation exposure (though studies are beginning to show cardiovascular effects in atomic bomb survivors), ATSDR will discuss this disease in the public health implications section.

The public health implications of past exposures at the Clinch River and current exposures associated with the Clinch River and the LWBR are presented in Tables 22 and Table 23, respectively, and in the discussion that follows.

Table 22. Past (1944 to 1991) Radiation Doses for the Area Along the Clinch River

Organ	*Dose Type*	*Estimated Dose*[†]	*Comparison Value*	*Is the Estimated Dose Above or Below the Comparison Value?*	*Conclusion*
Whole body	Annual[*]	4 mrem	100 mrem/year ATSDR MRL, ICRP, NCRP, and NRC[‡]	Below (25 times less)	The radiation doses received by people in the past are not likely to cause adverse health effects. Past releases of radioactive material from White Oak Creek are not a public health hazard for people who used or lived near the Clinch River and LWBR.
	Committed effective dose or lifetime	278 mrem	5,000 mrem[§]	Below (18 times less)	
Bone surface	Committed equivalent dose or lifetime	Less than 1,200 mrem	390,000–620,000 mrem[¶]	Below (at least 325 times less)	
Lower large intestine	Committed equivalent dose or lifetime	Less than 1,100 mrem	5,000 mrem[§]	Below (4 times less)	
Red bone marrow	Committed equivalent dose or lifetime	Less than 1,100 mrem	390,000–620,000 mrem[¶]	Below (at least 350 times less)	
Breast	Committed equivalent dose or lifetime	Less than 500 mrem	10,000 mrem**	Below (20 times less)	
Skin	Committed equivalent dose or lifetime	Less than 400 mrem	9,000 mrem[††]	Below (22 times less)	

* Annual dose considers a 1-year exposure. Committed effective doses and committed equivalent doses consider a 70-year exposure duration.

† The estimated doses were taken from Table 11. Please see the discussion related to Table 11 for an explanation on the derivations of the past radiation doses.

‡ ATSDR's MRL for ionizing radiation is based on noncancer health effects only; it is not based on a consideration of cancer effects. MRLs are estimates of daily human exposures to substances that are unlikely to result in noncancer health effects over a specified duration (ATSDR 1999b). The ICRP, NCRP, and NRC recommended value of 100 mrem/year for the public considers both noncancer and cancer health effects (Health Physics Society 2003; ICRP 1991; Nuclear Energy Institute 2004).

§ Based on studies of atomic bomb survivors (NRC 1988).

¶ A review of human radium dial workers suggests that a threshold for bone cancers induced by radium should be between 390,000 and 620,000 mrem (Rowland 1994).

** Based on atomic bomb data (Schull 1995).

†† Based on studies of patients irridated for the treatment of ringworm (NRC 1990).

Table 23. Current Radiation Doses for the Lower Watts Bar Reservoir and Clinch River

Area and Time Frame	*Organ*	*Dose Type*	*Estimated Dose*[†]	*Comparison Value*	*Is the Estimated Dose Above or Below the Comparison Value?*	*Conclusion*
Lower Watts Bar Reservoir (1988–present)	Whole body	Annual[*]	Less than 30 mrem/year	100 mrem/year ATSDR MRL, ICRP, NCRP, and NRC[‡]	Below (3 times less)	The current radiation doses received by people are not likely to cause adverse health effects. Current releases of radioactive material from White Oak Creek are not a public health hazard for people who currently use or live on the Clinch River and LWBR. [‡‡]
		Committed effective dose or lifetime	Less than 1,900 mrem	5,000 mrem[§]	Below (2.5 times less)	
Clinch River *(1989–present)*	Whole body	Annual[*]	3.4 mrem/year	100 mrem/year[‡]	Below (29 times less)	
		Committed effective dose or lifetime	235 mrem	5,000 mrem[§]	Below (21 times less)	
	Bone	Committed equivalent dose or lifetime	Less than 5 mrem	390,000–620,000 mrem[¶]	Below (78,000 times less)	
	Lower large intestine	Committed equivalent dose or lifetime	Less than 12 mrem	5,000 mrem[§]	Below (416 times less)	
	Skin	Committed equivalent dose or lifetime	Less than 6 mrem	9,000 mrem[††]	Below (1,500 times less)	

[*] Annual dose considers a 1-year exposure. Committed effective doses and committed equivalent doses consider a 70-year exposure duration.

[†] The annual and committed doses are based on all exposures pathway combined. The dose for a pathway was adjusted for a 70-year exposure to derive the committed effective dose and the committed equivalent dose.

[‡] ATSDR's MRL for ionizing radiation is based on noncancer health effects only; it is not based on a consideration of cancer effects. MRLs are estimates of daily human exposures to substances that are unlikely to result in noncancer health effects over a specified duration (ATSDR 1999b). The ICRP, NCRP, and NRC recommended value of 100 mrem/year for the public considers both noncancer and cancer health effects (Health Physics Society 2003; ICRP 1991; Nuclear Energy Institute 2004).

[§] Based on studies of atomic bomb survivors (NRC 1988).

[¶] A review of human radium dial workers suggests that a threshold for radium-induced bone cancers is between 390,000 and 620,000 mrem (Rowland 1994).

[††] Based on studies of patients irridated for the treatment of ringworm (NRC 1990).

[‡‡] ATSDR assessed the estimated current doses in its evaluation of future exposures. See the discussion of future exposures in Section IV.C.

IV.B. Past Radiation Exposure (1944–1991)

ATSDR determined that levels of radioactive contaminants from X-10 that entered the Clinch River via White Oak Creek are not a public health hazard for individuals who, in the past, used or lived near the Clinch River. Past exposure to these radioactive contaminants is not expected to cause adverse health effects.

For *past exposures,* which for the purposes of this PHA occurred between 1944 and 1991, ATSDR evaluated the health implications of the radiation dose estimates presented in Task 4 of the TDOH's Reports of the Oak Ridge Dose Reconstruction, *Radionuclide Releases to the Clinch River From White Oak Creek on the Oak Ridge Reservation—an Assessment of Historical Quantities Released, Off-Site Radiation Doses, and Health Risks* (referred to as the "Task 4 report"). As discussed in Section III, ATSDR evaluated the 50^{th} percentile of the 95% confidence level for doses reported by the Task 4 team. The doses considered past exposures (over a maximum 48-year exposure period) to radionuclides (Cs 137, Ru 106, Sr 90, Co 60, I 131, Ce 144, Zr 95, and Nb 95) via consumption of fish, meat, milk, and water, and external radiation exposures from walking on shoreline sediment (see Table 11) (see Appendix E). ATSDR focused its evaluation on three locations: Jones Island (CRM 20.5), the K-25/Grassy Creek area (CRM 14), and the confluence of the Clinch River with the Tennessee River (CRM 0) near the city of Kingston. ATSDR then used the organ-specific doses derived by the Task 4 team to estimate both the whole-body dose (annual and committed effective dose over 70 years) and total lifetime organ doses for the bone, lower large intestine, red bone marrow, skin, and female breast.

Table 22 presents ATSDR's estimated whole-body dose (annual dose and committed effective dose over 70 years) and the committed equivalents dose to organs (bone, lower large intestine, red bone marrow, breast, and skin) for *past exposures* along the Clinch River. An individual exposed to the primary radionuclides in Clinch River water, fish, shoreline sediment, meat, and milk was expected to receive a committed effective dose to the whole body of less than 300 mrem over 70 years and an annual whole-body dose from combining the organ doses of 4 mrem/year. This whole-body dose is well below (18 times less than) ATSDR's radiogenic comparison value of 5,000 mrem over 70 years and the annual whole-body dose is well below (25 times less than) ATSDR's radiogenic minimal risk level (MRL) of 100 mrem/year, which is also the maximum dose constraint for members of the public as recommended by the

International Commission on Radiological Protection (ICRP), the U.S. Nuclear Regulatory Commission (NRC), and the National Council on Radiation Protection and Measurements (NCRP). ATSDR also evaluated potential exposures to radionuclides in drinking water (from the K-25 intake) for residents who lived in the Happy Valley settlement camp between 1944 and 1950. ATSDR's estimates suggest that residents of the camp would have received an annual dose of 14 mrem to the whole body, which is at least 7 times less than the ATSDR radiogenic MRL of 100 mrem/year and the ICRP, NRC, and NCRP recommended maximum dose for the public of 100 mrem/year. ATSDR's evaluation of radiological, epidemiological, and medical literature shows that the estimated whole-body radiation doses were well below levels likely to cause observable or detectable health effects.

ATSDR derived the *radiogenic comparison value* of 5,000 mrem over 70 years after reviewing the peer-reviewed literature and other documents developed to review the health effects of ionizing radiation. Doses below this value were not expected to result in observable health effects. ATSDR's *external exposure MRL for ionizing radiation* is based on noncancer health effects only; it is not based on a consideration of cancer effects. MRLs are estimates of daily human exposures to substances unlikely to result in noncancer effects over a specified duration (ATSDR 1999b). The ICRP, NRC, and NCRP maximum dose constraint for the public of 100 mrem/year considers both noncancer and cancer health effects (Health Physics Society 2003; ICRP 1991; Nuclear Energy Institute 2004).

The doses from past exposure to radionuclides in and along the Clinch River varied by the critical organ. ATSDR further evaluation of the organ doses is in the discussion that follows.

- The bone received the highest estimated total committed equivalent dose over a lifetime (70 years) of exposure to the primary radionuclides along the Clinch River. ATSDR's estimates, however, suggest that the dose to the bone was less than 1,200 mrem over 70 years—at least 325 times lower than the doses of 390,000 to 620,000 mrem shown to cause bone cancers in radium dial workers. Eating many fish meals from the Jones Island area resulted in the highest estimated organ dose to the bone (810 mrem) (see Table 11). Doses to the bone were much lower for people who ate fewer fish or fished further downstream and for all other pathways. Strontium most likely contributed to the higher levels in the bone because it seeks out and accumulates in bone.

- Radiation effects on individual organs have not been studied extensively. Most of the available studies on the effects of radiation involve exposures associated with luminous dial painting, the atomic bombing of Japan, medical treatments, and uranium mining. ATSDR's comparison value for the dose to the bone comes from studies that evaluated exposures of radium dial painters to levels of radium known to cause adverse health effects following acute intakes of radium. Workers in these studies were exposed to larger doses and for longer periods of time than exposures associated with White Oak Creek releases. Bone cancers induced by radium exposure were evident in dial workers at doses ranging between 390,000 and 620,000 mrem (Rowland 1994). More recent studies have included workers at nuclear plants and other nuclear industries. For example, studies of nuclear workers at the Mayak facility in Russia suggest that chronic radiation exposure resulting in "chronic radiation syndrome" is associated with cumulative exposures to radiation above 100,000 mrem (U.S. DOE, Office of International Health Programs 2001).[13] In 1999, the Airlie Conference concluded that 10,000 mrem was the lowest dose at which a statistically significant radiation risk has been shown, and that the effects of low-level radiation below 100 mrem/year above background are currently indistinguishable from those of everyday natural health hazards (Mossman et al. 2000).[14] The doses received by individuals in these studies are in substantial excess of the estimated doses from past exposures to White Oak Creek radionuclide releases.

- The committed equivalent dose to the *lower large intestine* was less than 1,100 mrem over 70 years. This estimated dose is 4 times lower than ATSDR's radiogenic comparison value of 5,000 mrem over 70 years.

- The committed equivalent dose to the *red bone marrow* was less than 1,100 mrem over 70 years. Exposure from eating fish, drinking Clinch River water, and walking along the shoreline (external exposures) resulted in the highest doses to the red bone marrow. The highest committed equivalent dose, however, is more than 350 times lower than the lowest doses between 390,000 and 620,000 mrem, which is where bone cancers were first observed in radium dial workers with measured amounts of radium in their bodies (Rowland 1994). ATSDR's estimated committed equivalent dose to the red bone marrow for past exposure is also below the levels that epidemiological studies can detect, and below 25,000 mrem, which is the level generally related to blood disorders associated with acute exposures. Doses on the order of 25,000 mrem are believed to affect the formation of blood cells and may induce leukemia. Studies in the atomic bomb survivors indicated that leukemia was observed with acute doses as low as 50,000 millirads (assumed 50,000 mrem), with most of the leukemia occurring within the first 20 years following the bombings (Radiation Effects Research Foundation 2003).

- The committed equivalent dose to the *breast in females* was less than 500 mrem over a 70-year lifetime. Exposure to radionuclides from eating fish and walking on shoreline sediment contributed the highest doses to the breast. For comparison, the committed equivalent dose is 20 times less than doses shown to cause effects in atomic bomb survivors (Schull 1995).

- The committed equivalent dose to the *skin* over a 70-year lifetime of exposure to external radiation was less than 400 mrem. Organ doses to skin from eating fish and walking along the shoreline exceeded dose estimates for all other pathways. Even so, the committed

[13] Please see http://www.utah.edu/radiobiology/mayak/index.html#toc for additional information.
[14] Please see http://www.inea.org.br/bridradia.htm for more details.

equivalent dose is 22 times below the value of 9,000 mrem, which is based on the BEIR V report of patients irradiated for treatment of ringworm (NRC 1990).

Organ doses for people who ate fish from the Clinch River exceeded dose estimates for all other exposure pathways (drinking water, meat ingestion, milk ingestion, and external radiation) by at least a factor of 7 (see Table 12). Primarily, the organ dose depended on how often people ate fish and the area of the Clinch River where the fish were collected. The highest cumulative organ doses (1944–1991) were for individuals who consumed fish frequently (1 to 2.5 fish meals per week) and caught their fish near Jones Island, close to the mouth of White Oak Creek. For individuals who frequently ate fish caught near Jones Island and received maximum exposure to radionuclides released from White Oak Creek (see Table 11), ATSDR determined that the estimated doses to each organ were well below ATSDR's comparison values and levels associated with the development of disease or cancer.

Organ doses for people walking along the shore and ingesting milk, water, and meat were much lower than the doses received by people consuming fish (see Tables 10 and 12). For an individual with no exposures other than to shoreline contaminants, the bone and skin were the organs that received the greatest dose. The estimated doses to the bone and skin from walking along the shoreline are well below ATSDR's comparison values and levels associated with the development of disease or cancer. Also, individuals exposed to radionuclides in the past from walking along the shoreline or ingesting milk, water, meat, or fish (further downstream from Jones Island) were not expected to develop adverse health effects or cancer.

Lifetime inhabitants of Grassy Creek (CRM 14) who ingested meat, milk, and water received the highest radiation dose to the bone. ATSDR used the tissue weighting factors to convert each organ dose to the corresponding whole-body dose, and summed the values to achieve a whole-body dose less than 20 mrem. ATSDR does not expect these exposures to have resulted in any observable adverse health effects.

All the estimated doses for past exposure to radionuclides in the Clinch River released from White Oak Creek are lower than ATSDR's comparison values and doses reported in radiological and epidemiological studies on the effects of radiation exposure. Therefore, ATSDR does not expect carcinogenic health effects to have occurred from past exposure to radionuclides in the Clinch River.

IV.C. Current and Future Radiation Exposure (1988–Present and Future)

ATSDR determined that current and future exposure to radioactive materials is not a public health hazard for individuals who use or live near the Clinch River and the Lower Watts Bar Reservoir. Radiation doses for individuals who might contact even the highest current concentrations of radionuclides in Lower Watts Bar Reservoir or Clinch River fish, turtles, geese, surface water, and sediment are too low to be a health hazard now or in the future.

Current Exposure

For *current exposures* (1988–present), ATSDR estimated radiation doses for conservative hypothetical scenarios that considered likely pathways of exposure for people who use the LWBR and the Clinch River. ATSDR evaluated current users' exposures to LWBR sediment, surface water, and fish (see Tables 13, 14, 15 for the maximum detected concentrations). ATSDR also evaluated current users' exposures to Clinch River biota (fish, turtles, and geese), external radiation (walking on sediment and swimming), and incidental ingestion of surface water (see Table 17 for the radionuclides evaluated and Table 18 for the exposure pathways evaluated). ATSDR's evaluation shows that current exposures to even the highest detected concentrations of radionuclides in the Clinch River or LWBR biota, sediment, and surface water are not likely to cause health effects for current users of these waterways. In addition, ATSDR analyzed drinking water samples collected around the cities of Kingston and Spring City from 1990 to the present. ATSDR evaluated these samples for radiological content, and determined that all water samples were below U.S. Environmental Protection Agency's (EPA) maximum contaminant levels (MCLs), and therefore, ATSDR considers this water safe for consumption and other potable uses now and in the future.

Lower Watts Bar Reservoir (1988–present)

ATSDR's estimated committed effective dose to the whole body for all pathways combined is less than 1,900 mrem—2.5 times below ATSDR's radiogenic CV of 5,000 mrem. The estimated annual whole-body dose is less than 30 mrem, and below ATSDR's screening comparison value and ICRP's, NCRP's, and NRC's recommended values for the public of 100 mrem/year.

Therefore, the estimated exposures for the LWBR are not expected to result in adverse health effects.

Clinch River (1989–present)

ATSDR's estimated committed effective dose to the whole body for all pathways along the Clinch River combined is less than 240 mrem—more than 20 times below ATSDR's radiogenic CV of 5,000 mrem. The estimated annual whole-body dose is less than 3.4 mrem, and about 30 times below the dose of 100 mrem per year recommended for the public by ATSDR, ICRP, NCRP, and NRC. Therefore, the estimated exposures for the Clinch River are not expected to result in adverse health effects.

The current radiation doses from exposure to radionuclides along the Clinch River varied by organ as summarized below.

- ATSDR estimated that the *bone* receives the highest total committed equivalent dose over a lifetime (70 years) of exposure to the primary radionuclides detected along the Clinch River. Estimates suggest that the dose to the bone is less than 5 mrem over 70 years—at least 78,000 times lower than the doses of 390,000 to 620,000 mrem associated with bone cancers in radium dial workers. The highest committed equivalent doses to the bone resulted from ingestion of geese muscle or liver (230 mrem) and fish (114 mrem). ATSDR's estimates indicate that the teenager would receive the highest dose because of the age-weighted dose coefficients associated with accelerated bone growth in this age group. Much lower doses were associated with ingestion of Clinch River water (2.8 mrem) and external exposures from walking on sediment (13 mrem) and swimming (1.2 mrem) in the study area. Note that the dose for swimming at background locations (expressed as the average of all background locations under study) of 5.83 mrem exceeds the dose incurred from swimming in the study area.

- The committed equivalent dose to the *lower large intestine* is 12 mrem over 70 years. This estimated dose is about 415 times lower than ATSDR's radiogenic comparison value of 5,000 mrem over 70 years, which is based on studies of atomic bomb survivors, radiation workers, and radiation workers' children. Exposure to radionuclides from eating fish (particularly catfish) contributed to the highest committed equivalent dose to the lower large intestine of 99.4 mrem over 70 years. Doses to the lower large intestine from eating fish exceeded doses for the other pathways.

- The committed equivalent dose to the *skin* over a 70-year lifetime of exposure is less than 6 mrem, which is 1,500 times below the value of 9,000 mrem that is based on a review of the BEIR V report (NRC 1990). As one would expect from the amount of skin exposure, swimming in the Clinch River resulted in the highest doses to the skin out of all pathways evaluated.

Estimated doses for current exposure to radionuclides in the LWBR and Clinch River released from White Oak Creek in the present are lower than ATSDR's screening comparison values and doses reported in radiological and epidemiological studies on the effects of radiation exposure. ATSDR does not expect these current exposures to result in any adverse health effects.

Future Exposure

For *future exposures* (exposures occurring after the "current" time period), ATSDR evaluated current doses and exposures related to releases from White Oak Creek, data on current contaminant levels in the LWBR and the Clinch River, consideration of the possibility that radionuclides could be released to White Oak Creek during remedial activities, and institutional controls that are in place to monitor contaminants in the LWBR and the Clinch River. These controls consist of the following: 1) prevention of sediment-disturbing activities in the Clinch River and LWBR; 2) the Department of Energy's (DOE) annual monitoring of Clinch River and LWBR surface water, sediment, and biota; 3) DOE's monitoring of White Oak Creek releases; 4) the Tennessee Department of Environment and Conservation's (TDEC) monitoring of public drinking water supplies in Tennessee under the Safe Drinking Water Act for EPA-regulated contaminants; and 5) TDEC DOE Oversight Division's quarterly radiological monitoring of five public water supplies on the ORR and in its vicinity under the EPA's Environmental Radiation Ambient Monitoring System program.

Lower Watts Bar Reservoir and Clinch River

Because the current radionuclide levels in the Clinch River and LWBR are not expected to result in adverse health effects and institutional controls reduce and monitor contaminants released from White Oak Creek, ATSDR believes that future contaminant levels in the Clinch River and LWBR will not increase as a result of White Oak Creek releases. Though a slight potential remains that radionuclides could be released to White Oak Creek due to remedial activities taking place at the ORR, these releases are expected to be minimal, and as noted previously, would be monitored by DOE. Therefore, as current exposures are not expected to result in adverse health effects, ATSDR does not expect adverse health effects to result from future concentrations of radionuclides in the Clinch River or Lower Watts Bar Reservoir fish, geese, sediment, surface water, or turtles.

V. Health Outcome Data Evaluation

Health outcome data are measures of disease occurrence in a population. Common sources of health outcome data are existing databases (cancer registries, birth defects registries, death certificates) that measure morbidity (disease) or mortality (death). Health outcome data can provide information on the general health status of a community—where, when, and what types of diseases occur and to whom they occur. Public health officials use health outcome data to look for unusual patterns or trends in disease occurrence by comparing disease occurrences in different populations over periods of years. These health outcome data evaluations are descriptive epidemiologic analyses. They are exploratory as they could provide additional information about human health effects and they are useful to help identify the need for public health intervention activities (for example, community health education). That said, however, health outcome data cannot—and are not meant to—establish cause and effect between environmental exposures to hazardous materials and adverse health effects in a community.

ATSDR scientists generally consider health outcome data evaluation when there is a plausible, reasonable expectation of adverse health effects associated with the observed levels of exposure to contaminants. In this public health assessment on X-10 radionuclide releases to the Clinch River from White Oak Creek, ATSDR scientists determined that people using the Clinch River and the Lower Watts Bar Reservoir for food, water, and recreation were exposed to radionuclides released via White Oak Creek from the 1940s to 2003.

Criteria for Conducting a Health Outcome Data Evaluation

To determine how to use or analyze health outcome data in the public health assessment process, or even whether to use it at all, ATSDR scientists receive input from epidemiologists, toxicologists, environmental scientists, and community involvement specialists. These scientists consider the following criteria, based only on site-specific exposure considerations, to determine whether a health outcome data evaluation should be included in the public health assessment.

1. Is there at least one current (or past) potential or completed exposure pathway at the site?
2. Can the time period of exposure be determined?
3. Can the population that was or is being exposed be quantified?

4. Are the estimated exposure doses(s) and the duration(s) of exposure sufficient for a plausible, reasonable expectation of health effects?

5. Are health outcome data available at a geographic level or with enough specificity to be correlated to the exposed population?

6. Do the validated data sources or databases have information on the specific health outcome(s) or disease(s) of interest—for example, are the outcome(s) or disease(s) likely to occur from exposure to the site contaminants—and are those data accessible?

Using the findings of the exposure evaluation in this public health assessment, ATSDR sufficiently documented completed exposure pathways to radionuclides via the surface water, sediment, and biota pathways from the mid-1940s to the late 1990s for people using the Clinch River and the Lower Watts Bar Reservoir. In this public health assessment, the documented evidence of off-site exposure to radionuclides indicates that estimates of past and current radiation doses are below doses associated with health effects (see Section IV. Public Health Implications).

The estimated radiation doses for people using the Clinch River and the Lower Watts Bar Reservoir for food, water, and recreation are less than the 1) average U.S. background radiation dose, 2) ATSDR’s screening values for ionizing radiation, 3) the NCRP’s, ICRP’s, and NRC’s allowable limits of exposure to the public, and 4) organ-specific doses shown to cause adverse health effects. Therefore, residents using the river and reservoir have not been exposed to harmful levels of radionuclides from White Oak Creek, and they are not currently being exposed to harmful levels of radionuclides released to White Oak Creek from the X-10 site. Because the estimated radiation doses are not expected to cause health effects, no further analysis of health outcome data is appropriate. Analysis of site-related health outcome data is not scientifically reasonable unless the level of estimated exposure is likely to result in an observable number of health effects. And because such an estimate of exposure cannot be made, the requirement to consider analysis of site-related health outcome data on the basis of exposure is complete.

Responding to Community Concerns

Responding to community health concerns is an essential part of ATSDR’s overall mission and commitment to public health. Concerns of all community members are important and must be addressed during the public health assessment process. The individual community health concerns addressed in the Community Health Concerns section (Section VI) of this public health assessment are concerns from the ATSDR Community Health Concerns Database that are related to issues associated with radionuclides released from White Oak Creek.

Area residents have also voiced concerns about cancer. Citizens living in the communities surrounding the ORR have expressed many concerns to the ORRHES about a perceived increase in cancer in areas surrounding the ORR. A 1993 TDOH survey of eight counties surrounding the ORR indicated that cancer was mentioned as a health problem more than twice as much as any other health problem. The survey also showed that 83% of the surveyed population in the surrounding counties believed it was very important to examine the actual occurrence of disease among residents in the Oak Ridge area.

To address these concerns, ORRHES requested that ATSDR conduct an assessment of health outcome data (cancer incidence) in the eight counties surrounding the ORR. Therefore, ATSDR is currently conducting a cancer incidence review using data already collected by the Tennessee Cancer Registry. This cancer incidence review is a descriptive epidemiologic analysis that will provide a general picture of the occurrence of cancer in each of the eight counties. The purpose of conducting this evaluation is to provide citizens living in the Oak Ridge Reservation area with information regarding cancer rates in their county compared to the state of Tennessee. This evaluation will only examine cancer rates at the population level and not at the individual level. It is not designed to evaluate specific associations between adverse health outcomes and documented human exposures, and it will not—and cannot—establish cause and effect.

"Cancer incidence" refers to newly diagnosed cases of cancer that are reported to the Tennessee Cancer Registry.

In addition, over the last 20 years, local, state, and federal health agencies have conducted public health activities to address and evaluate public health issues and concerns related to chemical and radioactive substances released from the Oak Ridge Reservation. For more information, please see the Compendium of Public Health Activities at http://www.atsdr.cdc.gov/HAC/oakridge/phact/c_toc.html.