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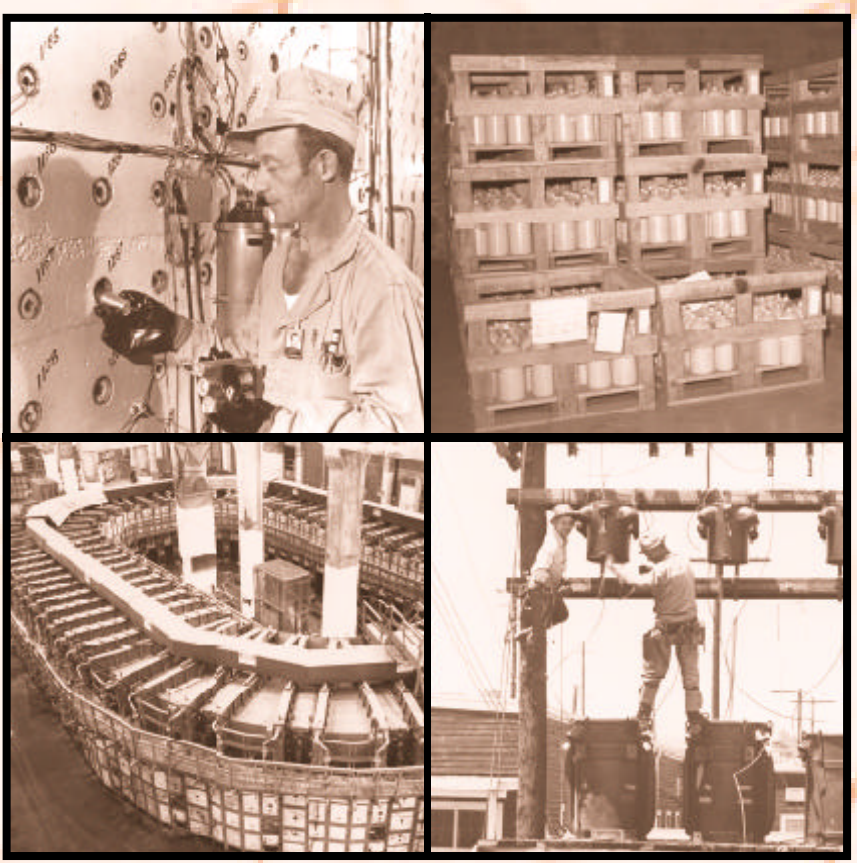
Oak Ridge Dose Reconstruction
Project Summary Report



Submitted to the Tennessee Department of Health by

ChemRisk
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Oak Ridge Dose Reconstruction PROJECT SUMMARY REPORT

A summary of retrospective evaluations of potential health effects due to releases of radionuclides and toxic chemicals from the U.S. government complexes in Oak Ridge, Tennessee since 1943. These evaluations were performed from 1994 to 1999 by the following scientists and engineers:

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Completed in March 2000 for the Tennessee Department of Health by project manager Tom Widner, based largely on the technical reports prepared by the above project team and completed in July 1999.

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THE OAK RIDGE DOSE RECONSTRUCTION

This document presents a summary of various investigations performed within Phase II of the Oak Ridge Health Agreement Studies, in a project that became known as the Oak Ridge Dose Reconstruction. From late 1994 to early 1999, a team of scientists and engineers performed detailed dose reconstruction analyses focused on past releases of radioactive iodine, mercury, and polychlorinated biphenyls (PCBs) released from the U.S. government complexes on the Oak Ridge Reservation (the ORR) and radionuclides released from White Oak Creek to the Clinch River. This report summarizes the methods and results of these dose reconstructions. In addition, this report describes the systematic searching of classified and unclassified historical records that was a vital component of the project, and summarizes the less detailed, screening-level assessments that were performed to evaluate the potential off-site health significance of a number of other materials, most notably uranium.

1. INTRODUCTION

Several characteristics make evaluation of the potential off-site health effects from the ORR very complex and very challenging. In terms of variety and complexity of past operations and materials used (radionuclides and chemicals), the ORR is among the most complex sites in the world. The settings of the three main ORR complexes (the plant sites code-named K-25, X-10, and Y-12), in complex ridge-and-valley terrain, lead to some particularly complex effluent transport patterns and pathways for public exposure. The potential importance of Oak Ridge releases is heightened by the fact that there are communities closer to key production areas than at any other U.S. Department of Energy (DOE) site in the country.

A late-1940s view of the central portion of the X-10 Site, now called Oak Ridge National Laboratory. The graphite reactor is in the large building on the right, and the radioactive lanthanum processing building is at lower left.

The Oak Ridge Health Agreement Studies used a preliminary screening phase, an iterative assessment approach with predetermined decision guides, and exposure assessment methods that emphasized the use of environmental measurements wherever possible. The investigations of the Oak Ridge Dose Reconstruction used these methods to focus on operations, releases, exposure pathways, locations, and groups of people that are representative of 1) maximum and 2) more typical doses and health risks to people who have lived near the ORR.

The Oak Ridge Health Studies Agreement

In 1991, DOE and the State of Tennessee entered into a Health Studies Agreement. One of the goals of the agreement was to assemble a panel to design a study to evaluate the feasibility of doing a dose reconstruction of releases from ORR facilities, in effect an independent

investigation of the potential for adverse heath effects from past operations. The Oak Ridge Dose Reconstruction Feasibility Study was conducted from 1992 to 1993. In it, investigators from McLaren/Hart-ChemRisk took an intense and comprehensive, but relatively quick, "look through the key hole" at past Oak Ridge operations and performed screening evaluations to identify those operations and materials that warranted detailed investigation.

At the close of the Feasibility Study, the Tennessee Department of Health (TDH) and the Oak Ridge Health Agreement Steering Panel (ORHASP) recommended that a dose reconstruction be conducted for radioactive iodine releases from X-10 radioactive lanthanum processing, mercury releases from Y-12 lithium enrichment, polychlorinated biphenyls (PCBs) in the environment near Oak Ridge, and radionuclides released from X-10 to the Clinch River via White Oak Creek. They also called for the study to include systematic searching of historical records, an evaluation of the quality of historical uranium effluent monitoring data, and additional screening of some materials that could not be fully evaluated during the Feasibility Study.

The Oak Ridge Dose Reconstruction began in late 1994. The methods, accomplishments, and findings of the project are the subjects of this summary report. The project was designed to develop estimates of past doses and health risks from the selected contaminants potentially received by people who have lived in off-site areas near the Reservation. The Dose Reconstruction was not designed to include reconstruction of exposures received by workers in the course of their duties at the Oak Ridge plants. And while some projection was done of the potential for health effects to be experienced in the future due to releases up to the current time, this project did not include projection of releases or doses from potential future activities.

Why do we do dose reconstruction?

Dose reconstruction provides important details about historical doses and health risks–

- What contaminants people were likely exposed to;
- Who was most likely to have been harmed (sensitive genders, cultural or age groups);
- Where exposures were likely highest and where they were much lower; and
- When exposures were highest and how they varied over the years.

A dose reconstruction project involves assembly of an independent and comprehensive historical record of operations at a particular facility. This goes a long way in pulling away the "cloak of secrecy" that has hidden past operations and releases at DOE sites and led to public distrust. With public involvement, dose reconstruction can be an avenue for providing a thorough public accounting of past practices and releases.

A 1945 view of a portion of the Y-12 Plant. The large buildings in the center housed devices called calutrons for electromagnetic enrichment of uranium during World War II. These same buildings were sites of lithium enrichment processing in the 1950s and 1960s that used large quantities of mercury.

Dose reconstructions have also been effective avenues for public release of records that are relevant to off-site health risks. Armed with the access and "need-to-know" afforded to dose reconstruction project team members with appropriate security clearances, thousands of historical records relevant to off-site releases and health effects are typically released to the public for the first time. Examples of important information that was released during this study include:

- A listing of the contents of the Y-12 "Mercury Files,"
- A new version of the Mercury Task Force report, reflecting updated classification guidelines from DOE,
- A detailed accounting of the X-10 radioactive lanthanum processing runs,
- A detailed accounting of unmonitored uranium release events at the K-25 site, and
- Names of materials that were formerly classified by their mere presence on the ORR.

Epidemiologic studies that have the benefit of dose reconstruction are much more likely to produce meaningful results. Quantitative estimates of past doses are necessary if a study is to assess cause and effect relationships between exposure and outcome or to describe incidences of health effects at varying levels of dose. It is typically not possible to measure individual exposure levels from past releases.

An early aerial photo of the K-25 Site, which has also been called the Oak Ridge Gaseous Diffusion Plant. K-25 enriched uranium in its U-235 component for approximately 40 years.

In situations where off-site exposures lead to incidences of health effects that are below the limits of epidemiologic detection (for example due to low doses or small population sizes), dose reconstruction can give us an idea of what the health risks might have been. It is important to remember, however, that these risks are estimated probabilities of additional health effects, not measured frequencies or necessarily what will be seen in a given group of people that have been exposed to a contaminant.

At sites that are also Superfund sites, dose reconstruction can play a significant role. Knowledge of past operations and practices and how current contamination came about and has changed over the years can be important in selecting and prioritizing future corrective or protective actions. Dose reconstruction can provide data and methodological information that can be used to better assess potential future exposures from activities such as site clean up.

On the other hand, some would prefer that the time and money spent on dose reconstruction be devoted to health clinics or other initiatives that appear to more directly or more immediately address health concerns of individuals. Some people also believe that there is too much emphasis on "studying the poisons, rather than the people." There are often considerable uncertainties associated with the results from a dose reconstruction, and no individual will ever be able to know if any health effects they are experiencing are actually caused by the exposures that were estimated. After considering the pros and cons of dose reconstruction and epidemiologic studies, the ORHASP and TDH decided that it would be appropriate to perform dose reconstruction for a number of materials that were used at the Oak Ridge plants.

Why don't we just measure contaminants in people today?

Measurements of biological markers of past exposures can be useful for some contaminants, and should be considered whenever feasible. For example, information regarding past exposures can be obtained from measurements of:

- Lead in teeth, bone, or blood;
- Mercury in hair, blood, or urine; and
- PCBs and some pesticides in adipose tissue (fat).

However, the usefulness of current-day measurements of contaminants in people's bodies can be limited by the following considerations:

- Many contaminants are no longer present in our bodies, and offer no measurable "tracers." For example, ^{131}I has decayed away, and there are too many other sources of ^{129}I from X-10 activities, nuclear weapons fallout, and nuclear processing elsewhere to make it a good indicator of past exposures to ^{131}I from lanthanum processing.
- Without knowledge of an individual's exposure history, it is difficult to say anything about the sources of contaminants that may be found in the body, or to clarify the role of the local facility in contributing to exposure.
- Biological indicators of the exposure a person received are generally not reliable when levels of exposure are comparable to those normally found in the environment.
- A significant degree of inter-individual variability in biology and personal behaviors can limit the applicability of results from selected individuals to others.
- Measurements of contaminants in individuals can be invasive and very expensive.

The Oak Ridge Dose Reconstruction

The Oak Ridge Dose Reconstruction involved seven main components that were conducted concurrently and called project tasks. They were described in the project's contract as follows:

Task 1:	Investigate Radioactive Lanthanum (RaLa) Processing and Doses from Radioiodines at X-10
Task 2:	Investigate Lithium Enrichment Processing and Mercury Releases at Y-12 and Estimate Exposures to Mercury
Task 3:	Investigate the Releases of PCBs from Transformers at K-25 and from Y-12 Uranium Machining Operations and Estimate Exposures to PCBs
Task 4:	Investigate Releases of Cesium-137 and Other Radionuclides from White Oak Creek (WOC) to the Clinch River and Estimate Radiation Doses
Task 5:	Perform Systematic Search of Document Repositories
Task 6:	Investigate the Quality of Airborne and Waterborne Uranium Effluent Monitoring at Y-12, K-25, and X-10 Complexes
Task 7:	Perform Additional Screening Calculations for Materials Not Evaluated in Phase 1 for Further Health Studies

Although these components were conducted concurrently, the assessments of the individual contaminants were to a certain extent conducted separately. Because people who lived near Oak Ridge may have been exposed to several contaminants at the same time, it is important to look at how the important operations did or did not coincide within the overall time frame of Oak Ridge operations from 1943 through 1994. A map depicting the reference locations used for dose reconstruction and screening on the Oak Ridge project is presented as Figure 1-1. The identification of the potential time periods and locations of exposure to several (multiple) contaminants is one of the goals of this summary report. Results of the study are discussed in this context in a later section of this report, and general timelines of key operations relevant to project tasks are depicted in Figure 1-2. A summary of how responsibilities were divided among project team members for the dose reconstruction, document searching, and screening tasks is presented in Table 1-1.

Workers disassemble the main process building of the S-50 Plant in the 1940s. The S-50 liquid thermal diffusion process for enrichment of uranium was abandoned after about one year.

Decision Making Processes Used on the Project

Investigators in environmental dose reconstruction projects are being asked to perform increasingly comprehensive investigations of complex sites. In many cases, a wide variety of contaminants, release sources, and exposure pathways must be evaluated for their potential significance. The Oak Ridge project was likely the most complex of any conducted to date in this regard. To achieve the goals of the project in light of this complexity, a number of decision making processes were applied to assist in focusing project attention and resources.

The Use of Predetermined Decision Guides

More and more commonly, decision guides or "stopping rules" are being considered in the early stages of dose reconstruction projects to guide decisions that will likely be faced later in the studies. Decision guides support compromises between the desire for complete investigation of potential hazards of materials that could have been released and the need to control costs of health studies. They can be used to guiding decisions in screening contaminants or exposure pathways, in setting geographic domains of studies, and in determining when certain portions of an assessment should not continue. Possibly useful bases for decision guides include:

- Exposure or dose guidelines or regulations,
- Levels of epidemiologic detectability of health effects,
- Government dose standards,
- Minimal risk levels, and
- Background contaminant concentrations or exposure levels.

For this project, a lifetime risk of one in ten thousand (0.0001 or 10^{-4}) of developing cancer for cancer-causing agents, and a hazard index of 1 for noncarcinogenic chemicals were adopted as guidelines to support decisions as to whether or not to do dose reconstruction for particular materials. A hazard index is the ratio of the estimated dose that an exposed person has received to the reference dose for the chemical. Published by the USEPA, reference doses (RfD's) are estimates of the largest amounts that an individual can take in, per unit body weight, on a daily basis over a lifetime without adverse health effects (even for people who are unusually sensitive). RfDs are generally well below No Observed Adverse Effect Levels (NOAELs).

In early phases of investigation, materials or exposure pathways that yielded estimates of risk above these decision guides were given higher priority for further screening or dose reconstruction. These decision guides are not viewed as inflexible, because most risk assessments are complex and uncertain, and there may be health effects caused by exposure to multiple contaminants that are not predicted by analyses that address the contaminants one at a time. However, in general a Hazard Index of 1 is a conservative guideline, since it is well below the NOAEL, which is in turn well below the Lowest Observed Adverse Effect Level (the LOAEL). The project team took seriously any risks that approached but did not quite meet guide values.

Screening Calculations

In complex investigations, it is wise to focus on those areas that warrant detailed investigation. An effective method toward this end is the use of a combination of conservative and nonconservative screening calculations. Conservative screening calculations are designed so that exposures are not underestimated. They typically are based on maximum reported environmental concentrations and the use of models to estimate concentrations where contaminants were not sampled or were sampled but not positively detected. Conservative screening calculations use reasonable maximum parameter values in a deliberate effort to err on the side of safety. Conservative screening calculations yield upper bounds on estimated health risks, and are used (with predetermined decision guides) to identify low priority contaminants.

In contrast, nonconservative screening calculations are designed so that exposures are not overestimated. Nonconservative calculations typically use means or geometric means of concentrations that were measured. In general, margins of safety or conservative biases are removed. In some cases, it is advisable to retain some conservatism in areas with particularly high uncertainty. Nonconservative (or reduced conservatism) screening calculations yield estimates of more typical risks, and (used with predetermined decision guides) identify high priority contaminants that warrant immediate consideration. Use of conservative and nonconservative screening allows investigators to separate contaminants into three classes: those of low importance, those warranting immediate attention, and those requiring further investigation to determine their true significance.

The Iterative Assessment Process

Performance of assessments in an iterative fashion can be an effective tool in guiding allocation of resources among different sites, contaminants, exposure routes, or elements of an analysis. In the iterative assessment approach, initial risk calculations are based on information that is readily at hand. The dominant sources of uncertainty in results are identified (typically through Monte Carlo simulation and sensitivity analysis), and further research targets these areas in order to reduce uncertainty. Revised calculations are performed with the new data, with results being more specific and less uncertain. The process is repeated until the uncertainty of results is either acceptable or cannot be further reduced. The iterative assessment process was used in the dose reconstruction to guide allocation of resources between and within the main project tasks that focused on radioiodine, mercury, PCBs, and radionuclides released from X-10 via White Oak Creek.

Figure 1-1:
Area Surrounding the Oak Ridge Reservation, with Locations of Interest for Dose Reconstruction and Screening Calculations

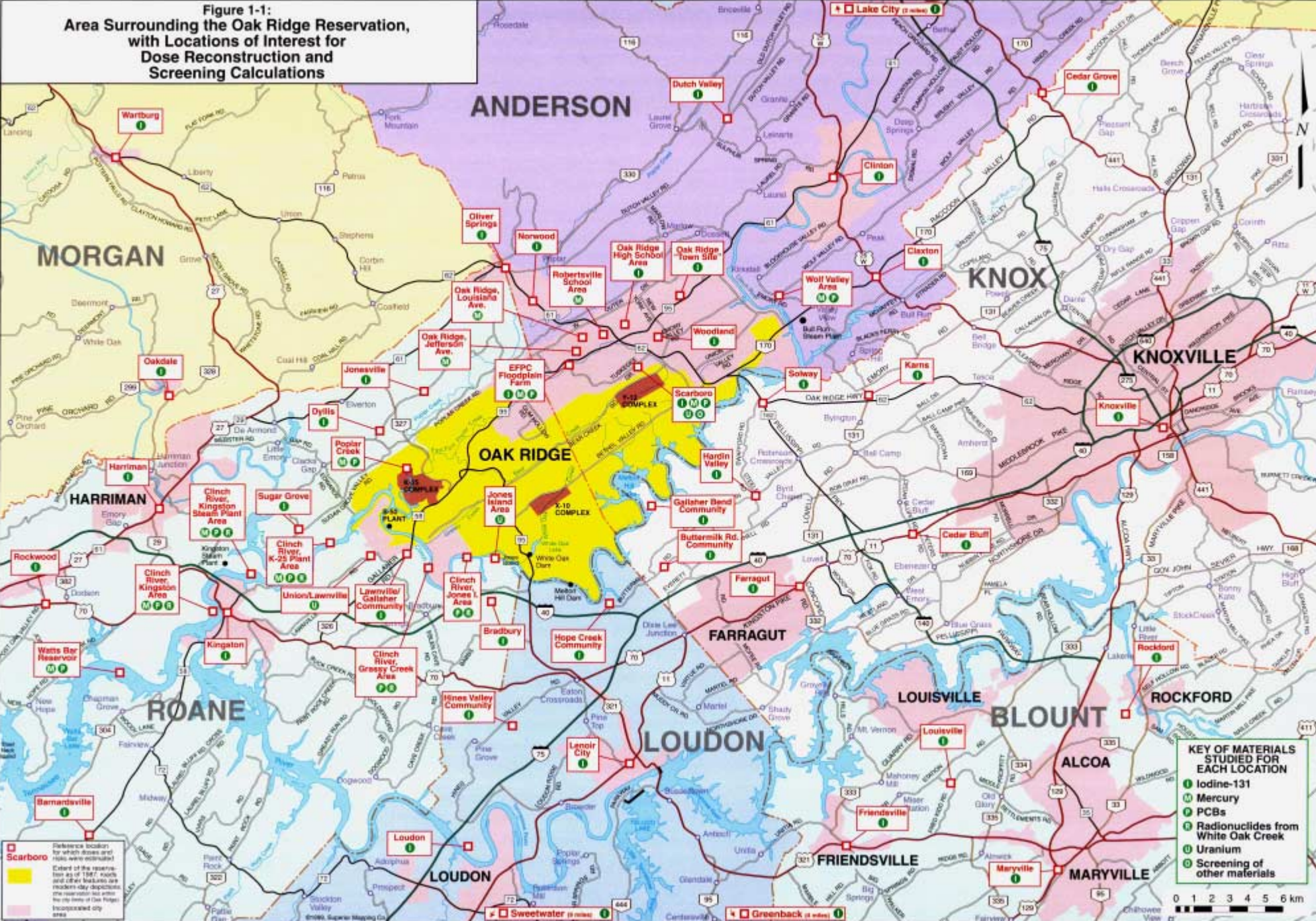

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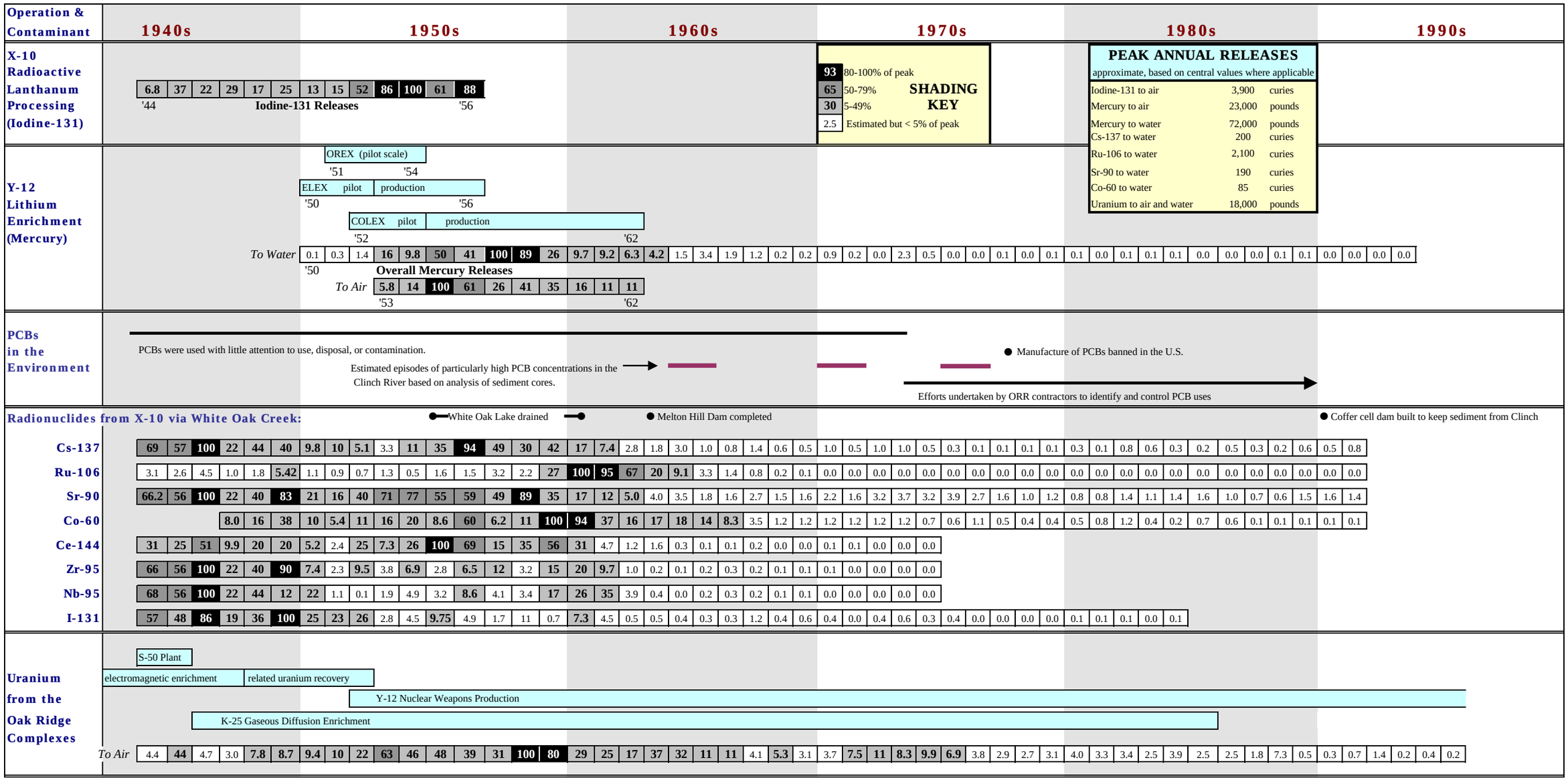
Figure 1-2: Overall Timeline of Operations and Releases Important to the Oak Ridge Dose Reconstruction

(numbers given for each year indicate percentages of the highest annual release of that contaminant)



"Who Did What" on the Project Team

L = Led this part of the work; **C** = Contributed to this activity

Table 1-1

	Iodine-131 from X-10									Mercury from Y-12								PCBs near Oak Ridge										Radionuclides from X-10 via White Oak Creek												Systematic Document Searches								Additional Screening						Screening Evaluation of Uranium Releases					
	Directed document search	Fuel inventory calculations	Source term assessment	Air dispersion modeling	Demography/land use	Dosimetry and risk per unit dose	Assessment of pathways, exposures, doses, risks	Estimation of excess cancers	Analysis and interpretation of results	Directed document search	Source term assessment	Air dispersion modeling	Concentrations in water, soil, foods	Demography/land use	Dose assessment	Toxicologic assessment / analysis of results	Directed document search	History of uses and releases of PCBs	Exposure pathway analysis	Exposure point concentrations	Demography/land use	Preliminary screening (level I)	Dose assessment (level II)	Estimation of population threshold	Two-dimensional analysis (Level III)	Directed document search	Source term assessment	Preliminary screening	Aquatic transport modeling	Concentrations in water, sediments	Demography/land use	Internal/external dosimetry, risk per unit dose	Assessment of pathways, exposures, doses, risks	Analysis and interpretation of results	Systematic search at K-25	Systematic search at X-10	Systematic search at Y-12	Systematic search of off-site repositories	Database management	General interviews	Quality Assurance/Quality Control	Development of two-level methodology	Development of other screening methods	Directed document searching	Performance of screening evaluations	Directed document search	Source term assessment	Air transport modeling	Concentrations in the environment	Screening-level exposure assessment	Evaluation of heavy metal toxicity
Joanne Avantaggio															C										C																														
Nancy Bonnevie															C	L	C	L	L	C	C		C																																	
Gretchen Bruce	C									C	C	C	L	C	L	L	C								C			C					C	L	C			C			C	C	C												
Jack Buddenbaum	C		C							C	C	C					C									C								C	C	C			C				C	C			C	C	L	L	C	C	L	L
Brian Caldwell																									L	L		C	C																									
Jennifer Cockroft	C														C																				L	C	C			C				L	L	L		C	C						
Catherine DaMassa					C									L					C										C																									
Ellen Ebert																					C		C																															
Samer El Sururi												L																																										
Shih-Shing Feng																											L																											
Susan Flack	C									L	L	C	C	C	C	L	C								C	C		C					C	C	L			C				C	C	C										
Patrick Gwinn																		C																																				
Jane Hamblen															L	C	L	C	C	L	L	C	C																															
Talaat Ijaz			C																																																		
Christopher Kirman																																		C	C	C								C	C											
James Knight																											C	C																									
Rajendra Menon																																																				
Thomas Mongan											C	C			C	C																																				
Paul Price															C	C	C	C	C	C	C	L	L																														
Julie Rothrock															C								C																														
Charles Schmidt																				C																																
Thomas Widner	L	C	L	C								C													C	C		C	C				C	C	C			C		C	C	C	C	C		C	C	C				
Iulian Apostoaei				C		L	L	L	C																						L	C																					
Gordon Blaylock																										C	C		C			C	C																			
Douglas Chambers																																																				C
Jana Gouge																										C	L					C	C								C										
Owen Hoffman				C	C	C	C	C	L																	C					C	C	C								C										
Cathy Lewis					L		C	C																					L		C								C										
Shyam Nair			C	L			C																			C		C	C																					
Willow Reed					C																									C																					
Kathleen Thiessen																												L			L	L								L			C								
Brian Thomas																										C	C	C	C																					
Ivan White																																									C										
Timothy Bennett																																		C									C	C						
Regan Burmeister																																		C									C	C						
Robert Burns, Jr.	C	L	C																															C																
Young Moon										C																								C	L	C	L		C	C									
Deborah Shonka																																						L		C										
Joseph Shonka		C	C																						C	C								C			C	C	L										

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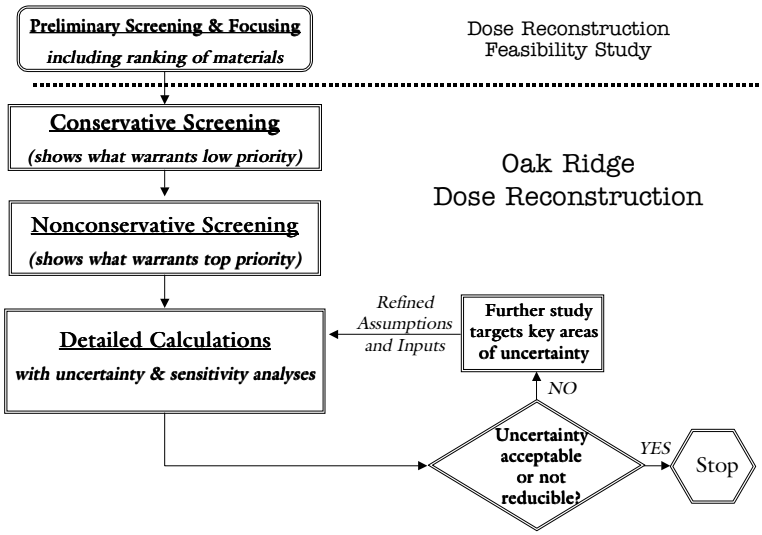
Uncertainty Analysis and Subjective Confidence Intervals

Although efforts were made to minimize uncertainties in the dose reconstruction, the project team had imperfect knowledge about most of the inputs to the equations used to reconstruct historical doses. For example, there is uncertainty about the true value of some parameters because exposures occurred in the past, and precise measurements of exposure concentrations or intake rates were not made. In addition, many parameters in the dose equations also exhibit natural variability. For example, within any population, variability in body weights and rates of food and water consumption is expected. Each parameter in the dose equations was characterized by a range of values, called a probability density function (PDF), describing what is known about the uncertainty and variability of that parameter for the population of interest. PDFs were subjectively defined, allowing confidence intervals to be derived within which there is a high probability of including the true but unknown value of the parameter.



Flow Chart of Screening Approaches and Decision-Making Processes Used in the Oak Ridge Dose Reconstruction and the Feasibility Study that Preceded It

When inputs to an equation are defined using distributions, each equation has many possible answers and is solved repeatedly using different values selected from the distributions of input parameters. This process used a computer program and Monte Carlo simulation. Results of the calculations are themselves probability distributions. Dose estimates in this report are usually stated as central estimates with 95% subjective confidence intervals. The confidence intervals indicate that the investigators are 95% confident that the true values are no lower than the lower confidence limit and no higher than the upper confidence limit, and the central estimates are median (50th percentile) values that represent a more likely region of doses.

Technical Highlights of the Oak Ridge Dose Reconstruction

The project team selected the following aspects of the technical investigations that were undertaken as the highlights of the dose reconstruction project:

- The estimated upper bound of the total ^{131}I release from Oak Ridge lanthanum processing is about 5-6 times the Hanford "Green Run" release, over double the Windscale release, and about 4,000 times the 1979 release from Three Mile Island. While the average annual airborne ^{131}I release from Hanford was about 8 times the value for X-10, members of the Oak Ridge public lived considerably closer to the release points than at Hanford. Releases from RaLa processing were estimated based on original records located by the project team that documented irradiation of fuel slugs at X-10 and Hanford and conduct of 731 dissolving batches. These data allowed estimation of iodine inventories in groups of the fuel slugs and quantities of ^{131}I in three physicochemical forms likely released past a caustic scrubber.
- The modeling of dispersion of airborne ^{131}I: a) explicitly included uncertainties in airborne transport of iodine and chemical transformation during transport; b) accounted for simultaneous dry and wet deposition during wet periods; and c) accounted for deposition onto trees when leaves were present, distinguishing this from deposition onto pasture grass

and adjusting plume depletion accordingly. Data from experiments conducted near Oak Ridge and from the scientific literature were used in specifying feed-to-milk transfer coefficients for ^{131}I, with separate values used for family cows and commercial milk.

- Calculations of thyroid doses reflected recent ultrasound measurements of thyroid mass, accounting for inter-individual variability and uncertainty. The estimation of expected rates of cancer induction included evaluation of: a) age and gender dependency; b) differences in background rates of thyroid cancer depending on age, gender, and ethnicity; and c) a biological effectiveness factor for induction of cancer after ^{131}I intake compared to acute, external exposure to X or gamma rays.
- The number of excess thyroid cancers within 200 km of Oak Ridge was estimated. Estimated health impacts at 41 locations were stated as excess lifetime risks, relative risks, probabilities of causation, and total numbers of cancers. Excess risk of nonneoplastic disease was identified as a potential concern for those who as children drank milk produced near Oak Ridge or were exposed to ^{131}I from both X-10 and fallout from nuclear weapons testing at the Nevada Test Site. Doses and risks from combined exposure to ^{131}I from X-10 RaLa releases and NTS fallout were estimated for five areas near Oak Ridge.
- With about 280,000 pounds entering East Fork Poplar Creek (EFPC), the releases of mercury from the Y-12 Plant represent a unique case of long-term releases to the environment, with an extensive record of routine effluent measurements. EFPC travels through residential and commercial areas that were fairly well populated. The Y-12 releases were independently estimated based on detailed original records of EFPC concentrations and flow rates that were assembled and analyzed by the project team.
- The 73,000 pounds of mercury estimated released to the air from Y-12 lithium processing is about 1.8 times the estimated total annual release of anthropogenic mercury to the air from non-combustion sources in the U.S. in recent years. The Y-12 releases were estimated based on records of indoor air concentrations and ventilation rates of key process buildings. Review of measurements of mercury in tree rings during this project pointed out the apparent importance of evasion of mercury from EFPC to the air as an additional avenue for historical public exposure. This study accounted for releases from Y-12 buildings and from the creek.
- The assessment of Y-12 mercury releases was one of the first major assessments of public exposures to mercury completed after the USEPA issued its Mercury Study Report to Congress. The dose reconstruction for mercury included evaluation of exposures to three species of mercury for adults and children in 17 reference populations, by 16 exposure pathways, for up to 41 individual years of exposure.
- In the dose reconstruction for PCBs near Oak Ridge, the population threshold for noncancer effects was characterized in an uncertainty analysis of the USEPA reference dose and associated safety factors.
- A two-dimensional analysis of PCB exposures allowed the project team to determine: a) the distribution of "true" hazard quotients across the population (doses divided by the threshold dose), 2) the fraction of the population receiving doses above the threshold, and 3) the incremental contribution of Oak Ridge releases to risks from other sources of PCBs.
- An evaluation of the sustainable fish harvest in EFPC showed that rates of fish consumption from EFPC were very low. PCB and mercury doses from the fish were likely relatively low.
- Radioactive effluents from X-10 to the Clinch River via White Oak Creek also represent a unique case of long-term releases with extensive monitoring records. Concentration and flow rate measurements were studied in this project, and an assessment of associated uncertainties and biases yielded annual release estimates for eight radionuclides for 1944 through 1991.

- Concentrations of radionuclides in the Clinch River were estimated using a combination of aquatic transport modeling and environmental measurements, both adjusted for sources of bias and uncertainty, in a single analysis. Site-specific bioconcentration factors for fish were developed using environmental measurements and the scientific literature.
- Uncertainty in internal and external dosimetry was expressed explicitly in the calculations for radionuclides in the Clinch River, and a dose-response relationship of cancer incidence was expressed for each of 27 organs and for total cancers. Extending to risk accounted for differing radiosensitivity among organs and identified the most important organs.
- A critical component of this project was the systematic searching of historical records of past Oak Ridge operations and releases. Forty-four document collections in Oak Ridge and at remote locations were targeted in over 15,000 hours of document review. Relevant records were copied, and summary information placed in a database that is now available.
- Knowledge about past releases of uranium from the Oak Ridge complexes was significantly advanced by the monitoring data review and screening conducted in this project. Airborne releases from Y-12 were independently estimated to have been over seven times those reported by DOE, and releases from K-25/S-50 were 50% higher than reported. Screening evaluations were also performed for technetium-99 and neptunium-237, two radionuclides that were contaminants in recycled uranium that was processed at Y-12 and K-25.
- To evaluate public exposures at Scarboro, which likely lies closer to a DOE weapons facility than any other community in the country, monitoring data were used to estimate transport of contaminants over Pine Ridge. Airborne uranium measurements in Scarboro from 1986-1995 were coupled with estimates of Y-12 uranium releases during the same periods to derive an empirical dispersion factor. This factor was used to estimate airborne uranium and mercury levels in Scarboro for each year for which releases to the air were estimated.
- Hundreds of materials were evaluated using 1) qualitative screening, 2) a threshold quantity approach, or 3) a two-level combination of conservative and nonconservative screening. Quantitative screening was conducted for 10 materials or classes of materials and less detailed evaluations completed for 18 others. The two-level screening separated materials into those that warrant immediate attention, those of low importance, and those requiring more investigation to determine their true significance. The screening was supported by use of predetermined "decision guides."
- Some of the materials subjected to screening were formerly classified at Oak Ridge by their mere presence. All materials can now be named, but special approaches were taken in this public study to evaluate some materials that still have classified aspects of use.

The Remainder of this Report

The remainder of this report contains summaries of the work that was done within the Oak Ridge Dose Reconstruction project. Following the discussions of the detailed dose reconstructions that were performed for I-131, mercury, PCBs, and radionuclides released via White Oak Creek, there is a description of the systematic document search effort that provided much information that was useful in the dose reconstructions, and built confidence among the project team, TDH, and ORHASP that the appropriate operations and contaminants were being studied.

This report then describes the less detailed, screening-level assessments that were performed. These focused on uranium and some other materials that were not fully evaluated during the Feasibility Study. At the close of this report, there is an overall summary of project results across all materials for which dose reconstruction was performed. This summary discusses eight example scenarios that illustrate some situations under which people who lived in or near Oak Ridge could have been exposed to multiple contaminants concurrently or during different periods of time.

2. IODINE-131 RELEASES FROM X-10 RADIOACTIVE LANTHANUM PROCESSING

Oak Ridge National Laboratory (ORNL), originally known by the code name X-10, released radioactive iodine (^{131}I) to the air from 1944 through 1956 as it processed freshly irradiated nuclear reactor fuel. The process recovered radioactive lanthanum (RaLa) to support weapons development at Los Alamos, for atmospheric radiation tracking, and for radiation warfare experiments. Iodine concentrates in the thyroid gland. Therefore, the health concerns stemming from exposure to ^{131}I include various diseases of the thyroid such as thyroid cancer and non-neoplastic abnormalities such as autoimmune hypothyroidism and Graves disease.

This study investigated the possible risks of thyroid cancer from the releases of ^{131}I between 1944 and 1956 at 41 representative locations within 38 kilometers of ORNL. Communities within this region include Oak Ridge, Clinton, Oliver Springs, Kingston, Harriman, Lenoir City, Sweetwater, Maryville, and Knoxville. At each of these locations, the risks of developing thyroid cancer, the relative risk with respect to an unexposed population, and the probability of causation for diagnosed cases of thyroid cancer were determined for individuals of both genders and of various age groups at the time of exposure. The numbers of cancers that could have resulted from exposure to the Oak Ridge ^{131}I releases within 38-km, 100-km, and 200-km radii of the X-10 facility were also estimated. The overall impact of ^{131}I exposure from the combined contributions of X-10 releases and fallout from atmospheric testing of nuclear weapons at the Nevada Test Site was also evaluated. The results of this study were found to be comparable to those from similar studies conducted at other U.S. sites. The probability of occurrence of non-neoplastic thyroid disease within 38-km of X-10 is discussed in the Task 1 report based on new evidence on the doses of radiation required to induce such diseases.

Uranium fuel slugs, such as these being loaded into the Clinton Pile, were used as the source of barium for RaLa production.

Some recommendations are made in the Task 1 report that can be used in any follow-up work to reduce the uncertainty in doses and risks and to identify and eliminate any remaining sources of bias. Important components of the study and the processes addressed within each component are summarized below, followed by a discussion of the estimated health effects.

Describing the I-131 Releases

Over the 13-year period of the RaLa operations at X-10, approximately 30,000 reactor fuel slugs were dissolved in about 731 batches during the process of separating over 19,000 TBq (1 TBq = 10^{12} Bq; approximately 500,000 Ci) of radioactive barium as a source of ^{140}La for shipment to Los Alamos. Development of the source term (the amount of ^{131}I released to the atmosphere) involved estimation of quantities of radioiodine released from vents and openings in process buildings and from X-10 stacks during routine and off-normal conditions. For an accident that occurred in April 1954, releases were estimated for five half-hour periods.

The most important source of radioiodine releases from RaLa processing was exhaust (off gas) from the slug dissolver. Volatile gases, which included radioiodine, were drawn from the dissolver under negative pressure, through a condenser and a chemical scrubber, and then through piping to reach a 200-foot tall stack. After March 1950, exhausts from the chemical scrubber were routed to a central treatment facility in which contaminated air was passed through an electrostatic precipitator and particulate filters prior to release up a 250-foot brick stack.

The iodine and barium contents of the irradiated fuel slugs from the X-10 Clinton Pile (Graphite Reactor) and the reactors at Hanford were estimated. For each of the 731 dissolving batches, the potential for "direct" releases of untreated exhaust to the atmosphere through building vents, windows, and other openings was evaluated. Because of the absence of monitoring data, expert opinion was used to quantify the ^{131}I collection efficiency of the condenser and caustic scrubber for routine operations. Expert opinion was also used to quantify the potential degradation of collection efficiencies during the April 1954 accident.

A Los Alamos apparatus that used RaLa to test the implosion process in early atomic weapons. A lanthanum radiation source was placed inside the sphere shown in the center of this photo.

Approximately 8,800 to 42,000 Ci (0.3 to 1.6 PBq; 1 PBq = 10^{15} Bq) of ^{131}I was released between 1944 and 1956, of which 6,300 to 36,000 Ci (0.23 to 1.3 PBq) was in the elemental (most environmentally reactive) form of iodine; most of the remainder was in the nonreactive volatile organic form. As shown in Tables 2-1 and 2-2, the largest releases occurred between 1952 and 1956, when the irradiated uranium fuel slugs came from Hanford reactors. The April 29, 1954, accident released 105 to 500 Ci (3.9 to 21 TBq) over 2.5 hours[1], accounting for about 6.5% of the total releases for 1954.

Atmospheric Dispersion

After being released into the atmosphere, ^{131}I was transported by the prevailing winds. A fraction of the iodine released in the elemental (reactive) form was chemically transformed during transport to particulate and organic (nonreactive) forms within a few kilometers of the RaLa processing facility. The ground-level concentration of ^{131}I in air is affected by several factors including the distance of the location of interest from the RaLa processing facility, the dilution of the concentrations in the air during atmospheric dispersion or mixing, the depletion of iodine from air by the processes of wet and dry deposition, and the chemical form in which iodine is present.

Annual average ground-level concentrations of ^{131}I for routine releases and time-integrated ground-level concentrations of ^{131}I for the 1954 accident were estimated using a mathematical model (SORAMI) that accounts for the processes that are important during transport of ^{131}I in the atmosphere. The model was benchmarked using another public-domain model. The model was validated using site-specific release and monitoring data, and the validation results indicated that model predictions were within a factor of two of the annual average measurements.

[1] While the period of direct release from the RaLa dissolver appears to have lasted 30 minutes, it took some time for the building ventilation to clear out this airborne contamination. Releases were estimated for five half-hour periods, resulting in a total release duration of 2.5 hours.

Table 2-1: Annual Iodine Releases from RaLa Processing via the X-10 Stack

	Elemental Iodine-131 (Ci)			Organic Iodine-131 (Ci)			Partculate Iodine-131 (Ci)		
	2.5%-ile	Central Value	97.5%-ile	2.5%-ile	Central Value	97.5%-ile	2.5%-ile	Central Value	97.5%-ile
1944	75	250	660	2.9	12	60	0.015	0.082	0.56
1945	510	1,200	2,400	43	170	810	0.44	1.4	5.6
1946	260	670	1,600	41	160	760	0.0076	0.13	2.0
1947	330	870	2,200	56	220	990	0.0032	0.066	1.0
1948	150	510	1,200	34	130	610	0.22	0.89	4.3
1949	270	790	1,700	41	160	780	0.40	3.1	27
1950	140	400	890	26	100	410	0.025	0.081	0.28
1951	200	500	890	18	71	290	0.0070	0.037	0.18
1952	550	1,600	4,100	110	410	1,700	0.11	0.32	0.83
1953	910	2,700	5,500	150	590	2,400	0.10	0.37	1.6
1954*	1,200	2,900	6,500	160	630	2,400	0.082	0.32	1.3
1955	690	1,900	4,400	110	430	1,600	0.055	0.19	0.61
1956	840	2,700	5,700	160	670	2,400	0.10	0.33	1.2
Totals	5,600	15,000	36,000	940	3,600	17,000	3.6	6.5	14

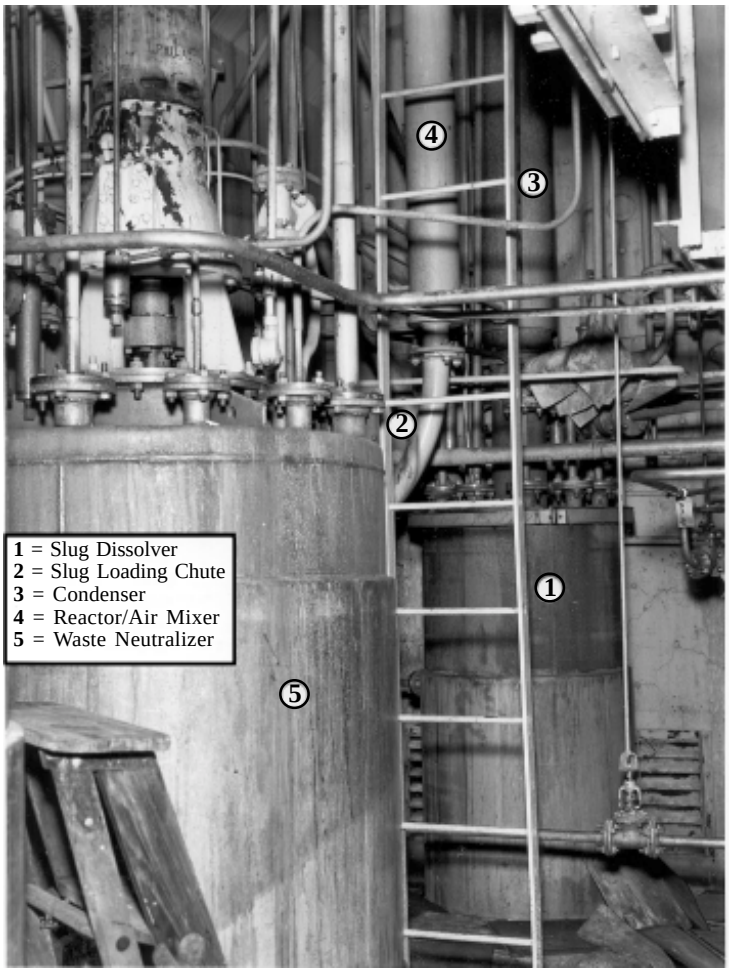
Table 2-2: Annual Iodine Releases from the RaLa Processing Building

	Elemental Iodine-131 (Ci)			Organic Iodine-131 (Ci)			Partculate Iodine-131 (Ci)		
	2.5%-ile	Central Value	97.5%-ile	2.5%-ile	Central Value	97.5%-ile	2.5%-ile	Central Value	97.5%-ile
1944	0.27	0.52	0.94	0.00064	0.0027	0.015	0.000044	0.00016	0.00061
1945	34	62	100	0.084	0.36	1.8	0.006	0.020	0.070
1946	9.2	16	40	0.018	0.10	0.58	0.0015	0.005	0.024
1947	11	19	38	0.028	0.11	0.57	0.0017	0.006	0.026
1948	4.8	16	57	0.015	0.091	0.82	0.00085	0.0048	0.036
1949	5.5	12	27	0.014	0.071	0.43	0.00085	0.0039	0.019
1950	2.2	5.3	13	0.006	0.030	0.15	0.00033	0.0017	0.006
1951	0.75	2.6	5.8	0.0024	0.015	0.066	0.00013	0.00088	0.0032
1952	10	17	25	0.023	0.092	0.37	0.0014	0.0053	0.018
1953	17	40	98	0.051	0.23	1.2	0.0026	0.013	0.057
1954*	22	52	99	0.059	0.28	1.3	0.0036	0.016	0.063
1955	12	28	71	0.034	0.18	0.71	0.0020	0.0094	0.038
1956	14	26	43	0.030	0.14	0.56	0.0022	0.0081	0.027
Totals*	320	500	780	0.70	2.8	14	0.046	0.15	0.54
Totals* Both Sources:	**6,300**	**16,000**	**36,000**	**940**	**3,600**	**17,000**	**3.8**	**6.7**	**14**

Total* Iodine-131 Released, all Sources and all Forms: 95% confidence interval is 8,800 to 42,000 Ci, with central value of 21,000 Ci.

*** Note:** The 1954 totals do not include releases from the Run 56 accident, but the grand totals do. See the Task 1 report for details concerning that accident.

For the analysis of routine releases between 1944 and 1956, observation data in electronic form collected at X-10 from 1987 to 1996 were analyzed statistically to generate surrogate hourly meteorological data. For the April 1954 accident, the dispersion model was supplied with half-hourly meteorological data obtained from records of the specific meteorology prevailing at the time of the accident. Uncertainties in all input parameters to the model were quantified before the concentrations were estimated for each of the 41 locations of interest. A plot of upper-bound estimates of time-integrated, ground-level ^{131}I concentrations following the April 1954 accident is shown in Figure 2-1.



The Building 706-D slug dissolver and associated components.

Transfer from Air to Vegetation

Consumption of contaminated milk and meat from cattle grazing on pastureland contaminated by the deposition of ^{131}I from air is one of the most important pathways by which ^{131}I enters the human body. Once ^{131}I is transported to a given location, it is transferred from the atmosphere to vegetation and the ground surface by precipitation scavenging of the plume and by dry deposition processes. The rates of transfer from the atmosphere to vegetation surfaces depend on the chemical form of iodine in air; therefore, the total amount of ^{131}I transferred was estimated by accounting for all three forms of iodine (elemental, particulate, and organic).

For routine releases, annual average concentrations of ^{131}I on vegetation were estimated using a constant rate of deposition of ^{131}I from the air for a given year and the assumption that the annual average concentrations of ^{131}I in vegetation and in air were in equilibrium with each other. For the 1954 accident, deposition of ^{131}I onto vegetation lasted for a period of 2.5 hours, but the ^{131}I remained on the vegetation until the processes of removal from vegetation and natural radioactive decay eliminated it completely. A time-integrated concentration of ^{131}I on the vegetation was estimated to account for the longer-term availability of contaminated feed to cattle.

Transfer from Pasture to Food Products

Once ^{131}I is transferred to the surfaces of vegetation, it is available for ingestion by grazing animals. Once ingested, it is further transferred into milk, meat, cheese, and eggs. Estimates of the transfer of ^{131}I from pasture to milk and beef were based on information from literature and on unpublished measurements of the transfer of ^{131}I into the milk of various breeds of dairy cattle used on farms in East Tennessee during the 1950s and 60s. No significant difference was observed among the various breeds of cows; however, an inverse relationship was observed

Iodine-131
from X-10 RaLa processing

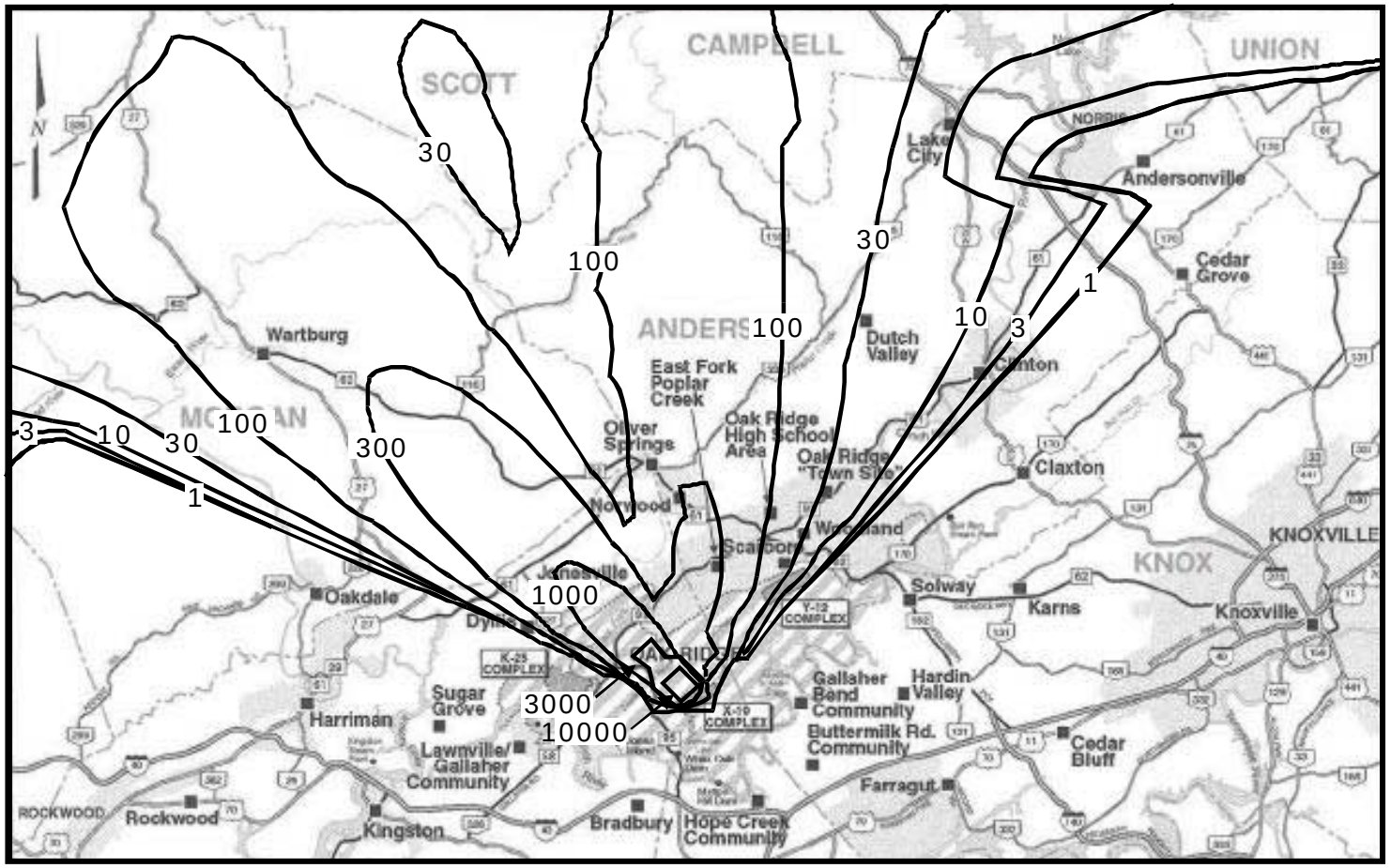


Figure 2-1: Upper bound estimates of the 95% subjective confidence intervals of time-integrated, ground-level concentrations of total iodine-131 in air following the April 1954 accident . Actual concentrations at a given location were highly likely to be less than the value for that location presented in this figure. Lower bound estimates do not exceed 30 Bq h m^{-3} off the Reservation.

LEGEND:

300 ^{131}I Concentration contour (Bq h m^{-3})

between ^{131}I transfer to milk and milk yield for those animals producing less than 10 L d^{-1}. For this reason, a distinction was made between the transfer of ^{131}I into the milk for low-producing "backyard" cows and the higher-producing cows belonging to commercial dairies. Concentrations of ^{131}I were also estimated for goats' milk, human breast milk, cottage cheese, eggs, and beef.

The modeling approach used in this study for estimating concentrations of ^{131}I in milk was validated. Average concentrations of ^{131}I measured in raw milk collected from locations around X-10 in 1962 and 1964 were found to lie well within the 95% subjective confidence intervals of average values predicted by the model for eight locations near the sampling sites. Radioiodine releases from ORNL during this period were from reactor operations and radioisotope production.

Concentrations of ^{131}I in animal food products were estimated using mathematical models. The annual average concentration on pasture was related directly to the annual average concentration in animal food products. For the 1954 accident, time-integrated concentrations of ^{131}I in milk and meat were estimated based on the concentrations of ^{131}I in pasture grass.

Distribution of Contaminated Food Products

The distribution of food products from various producers to a potential consumer is a complex process that is difficult to reproduce with high accuracy. Contaminated foodstuffs produced in an affected area may be distributed to other areas not directly exposed by the radioactive plume. Conversely, individuals in the affected area may consume uncontaminated products imported from unaffected areas. In this analysis, food products produced at a given farm were generally assumed to be consumed locally or distributed to the local population for consumption. Milk was often exchanged between counties to cover consumption needs in milk-deficient areas. The effects of the distribution system for a given food type were considered by accounting for radioactive decay between the time of milking or harvest and the time of human consumption of the food product, for the fraction of the food consumed that originated from uncontaminated areas, and for the amount of radioiodine lost during food preparation. Eggs and cottage cheese were assumed to be produced and consumed locally, with the reduction of contamination due to radioactive decay between production and consumption considered.

Intake of ^{131}I via Inhalation and Food Consumption

Human exposure to ^{131}I is dependent on the concentration of ^{131}I in air and in food at a given location and on the rates of inhalation and food consumption. This study included a detailed investigation of inhalation and ingestion rates by gender and age. Different rates of inhalation and ingestion were considered for estimating exposures from the routine releases of ^{131}I and from the 1954 accident. Because of the importance of human exposure via the consumption of contaminated milk, this study focused heavily on the estimation of consumption rates of fresh milk for infants and children under the age of 10. These estimates included differences in the consumption of locally produced milk and milk obtained at school. The estimated rates for inhalation of contaminated air for infants, children, teenagers, and adults accounted for the amount of time spent indoors and the differences between the concentration of ^{131}I in air between the indoor and outdoor environments.

Consumption of meat, leafy vegetables, eggs, and cheese was also considered in addition to the ingestion of milk. In all, doses and risks were estimated for 11 individual exposure pathways: ingestion of backyard cows' milk, commercial milk, regionally mixed commercial milk, goats' milk, meat, leafy vegetables, eggs, cottage cheese, inhalation of contaminated air, prenatal exposure from ^{131}I ingested by mothers, and ingestion of contaminated mother's milk.

Individuals living near X-10 may have been exposed via more than one exposure pathway at a time. Three special exposure scenarios are designed to match the most likely dietary habits and lifestyles in the vicinity of the ORR. The first exposure scenario (called "diet 1") refers to individuals living in a rural farm setting. The intake for this exposure scenario is obtained from

ingestion of backyard cows' milk, beef, leafy vegetables, eggs, and cheese and from inhalation. The second exposure scenario ("diet 2") refers to individuals in a rural area who buy milk from a local dairy farm. They are also exposed to contaminated beef, leafy vegetables, eggs, cottage cheese, and air. The third scenario ("diet 3") refers to individuals in a more urban setting, who buy milk and food from the grocery store. The intake for this exposure scenario is obtained from ingestion of regionally averaged commercial milk and from inhalation. Given that the doses and risks from ingestion of goat milk are substantially larger than the doses and risks from any other exposure pathway, it is addressed separately under the "diet 4" scenario.

Estimation of Thyroid Doses from ^{131}I Intake

After it is inhaled or ingested, ^{131}I is absorbed into the bloodstream and then metabolized in a manner that is identical to the absorption and metabolism of stable iodine in the human body. The thyroid gland preferentially absorbs iodine from the extracellular fluid into the thyroid cells and follicles. Iodine is then used in the production of hormones essential for human metabolism. In this analysis, the absorbed thyroid dose per unit intake of ^{131}I was estimated as a function of age. Since the uncertainty in the dose per unit intake is largely affected by the interindividual variability in the thyroid mass, this investigation employed the most recent information on thyroid volume as determined by ultrasonography. It was found that the mass of the thyroid was somewhat smaller than assumed in past studies. However, this finding was offset by the finding of a more rapid biological clearance rate from the thyroid, which resulted in a central estimate of the dose per unit intake that was similar to values recommended by the International Commission on Radiological Protection for children from birth up to age 15.

Excess Lifetime Risk per Unit Absorbed Dose

It is well established that X and gamma irradiation of the thyroid at absorbed doses approaching 10 centigray (1 cGy = 1 rad) will result in increased incidences of thyroid carcinomas and adenomas in children exposed before the age of 15. At higher doses, radiation might also induce non-neoplastic thyroid conditions such as autoimmune hypothyroidism and Graves disease. The thyroid gland in children has one of the highest radiogenic risk coefficients of any organ. Fortunately, fatal thyroid cancers are rare; the 5-year survival rate is 95%. The effectiveness of ^{131}I in producing thyroid cancers is a subject that is still under investigation with ongoing epidemiological studies at numerous other locations. The most convincing evidence of the link between ^{131}I exposure and thyroid cancer is still emerging from the follow-up of children exposed to ^{131}I from the 1986 Chernobyl accident. Additional supporting evidence exists from animal studies and from epidemiologic investigations of Utah school children exposed to ^{131}I from atmospheric weapons testing at the Nevada Test Site.

In this study, a relative risk model was used to estimate the chance of acquiring a thyroid cancer from an absorbed dose of ^{131}I. This model calculates the excess lifetime risk of thyroid cancer per unit dose as the product of the excess relative risk per unit absorbed dose and the background lifetime risk for an unexposed individual, including a series of modifying factors to account for differences in radiosensitivity by gender and age at time of exposure and for the effectiveness of ^{131}I in producing thyroid cancer compared with that of X rays and gamma rays. The background lifetime risk of thyroid cancer was obtained from incidence data for Tennessee, excluding Anderson, Roane, Loudon, and Knox counties, which were affected by X-10 releases.

The excess lifetime risk of thyroid cancer per cGy changes markedly depending on the gender of the individual and the age at time of exposure. For females exposed to 1 cGy before the age of 5 years, the excess lifetime risk per cGy ranged from about five chances in one hundred thousand to sixteen chances in ten thousand, with a central value of three chances in ten thousand. At the same dose, the risk to males in this age group would be about four times

less than that for females. Females who were over the age of 20 at time of exposure to 1 cGy would have had risks almost 80 times less, while males over the age of 20 would have had risks about 300 times less than females who were under the age of 5 years.

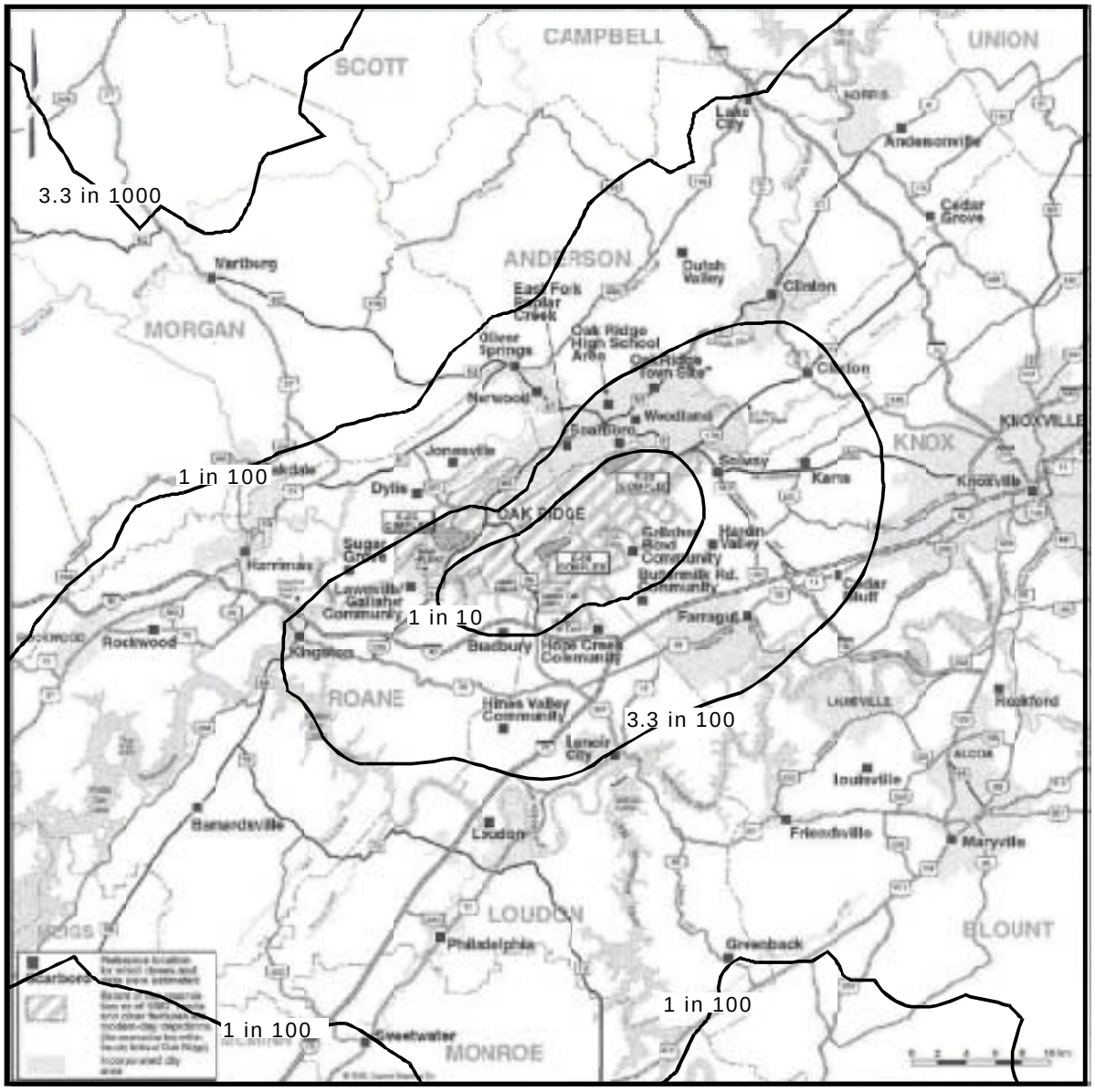
Results of the Iodine-131 Assessment

Females born in 1952 who consumed milk from goats (diet 4) that grazed areas adjacent to the ORR received the highest doses and have the highest risks of contacting thyroid cancer during their lifetime. The next highest dose resulted from the consumption of milk from a backyard cow, followed by milk from a local commercial dairy and milk that was regionally mixed. Since the concentration of ^{131}I in regionally mixed retail milk is about the same regardless of location within the 38-km domain, its importance with respect to the consumption of local produce or to inhalation varies from location to location. A sample contour plot of upper bound estimates of excess lifetime risk of developing thyroid cancer for a female born in 1952 on a diet including local produce and backyard cows' milk is shown in Figure 2-2. Other contour plots are presented in the Task 1 report.

Lower doses are obtained from inhalation or from the consumption of locally produced beef, cottage cheese, mother's milk (with the mother assumed to be on diet 1), or leafy vegetables. The doses from inhalation or from the consumption of one of these food types for a child under the age of 5 at the time of exposure are several hundred to more than 1000 times less important than the dose from the consumption of backyard cows' milk. The thyroid dose from prenatal exposure during the first part of 1952 (assuming the mother to be on diet 1) is about equal to the 5-year total thyroid dose obtained from the consumption of beef or cottage cheese. Risks were estimated specifically for the four diets, each of which consists of a combination of pathways.

Among those 41 reference locations addressed in the dose reconstruction for ^{131}I, the highest doses occurred at Gallaher Bend, located a little more than 6 km to the east of X-10, while the lowest doses occurred at Wartburg, located 27 km northwest of X-10. For example, at Gallaher Bend, thyroid doses ranged from about 4 to 250 cGy for individuals of each gender born between 1940 and 1952 who consumed milk from a backyard cow (between one and five 8-ounce glasses each day) and who consumed food products from a local garden or farm. A similar group of individuals residing in Wartburg would have received doses ranging from about 0.08 to 6 cGy. Doses from the consumption of regionally mixed commercial retail milk ranged from about 0.3 to 10 cGy for individuals born from 1940 to 1952 and did not vary by location.

Detailed summaries of calculated doses and risks at each of the 41 selected locations within 38 km of the X-10 facility are presented in Appendix 11C to the Task 1 report. Doses were calculated for males and females born in 1920, 1930, 1935, 1940, 1944, 1950, 1952, 1954, and 1956 who lived near X-10 during the period of radioactive lanthanum processing (1944-1956). These years of birth were chosen to allow comparison of doses and risks from ^{131}I intake by individuals of different ages at time of exposure. It was assumed that all members of the reference populations received no ^{131}I exposure other than that from the X-10 RaLa releases that occurred from 1944 to 1956. This being the case, it is not important where a person was born or where they lived before 1944 or after 1956. It is very important, however, where in the Oak Ridge area the person lived from 1944 through 1956. Assuming the same dietary sources for ingestion of ^{131}I at a specific location, differences in gender account for only minor differences in the estimation of the thyroid doses. More significant differences are determined by the year of birth, with the lowest doses being for individuals born in 1920, 1930, and 1956. These doses are about one-fourth to one-fifth of the largest doses received by individuals born between the years of 1944 and 1952. Individuals born in 1954 have about the same doses as those born in 1940, which are about 65% of the doses for those born between 1944 and 1952.



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3.3 in 100 Risk contour

Figure 2-2: Upper bound estimates of the 95% subjective confidence interval of excess lifetime risks of developing thyroid cancer for a female born in 1952 on a diet including local produce and backyard cows' milk (diet 1). It is highly unlikely that the actual risk at a given location exceeds the value shown for that location on this figure. Lower bound values are about a factor of 200 lower than the values shown here. Backyard cows were not present in all areas shown on this map.

The highest excess risk of developing thyroid cancer for a female born in 1952 on diet 1 occur at the agricultural communities of Bradbury and Gallaher Bend. For these locations, based on the assumed quantities of backyard cows' milk, beef, vegetables, eggs, and cheese consumed each day, the risk estimates are confidently above one chance in one thousand (1×10^{-3}) but less than 1 chance in ten (1×10^{-1}). In addition, at these locations, the central estimate of the probability of causation approaches or exceeds 50% for females born in 1952 on diets 1, 2, and 4, meaning that a diagnosed thyroid cancer has more than an even chance of being due to exposure to ^{131}I released from X-10. The central estimate of risk for a female born in 1952 on diet 1 is likely to exceed 1 chance in 1,000 (1×10^{-3}) up to distances of 35 km to the southwest and more than 38 km to the northeast of X-10. A risk of more than one chance in ten thousand (1×10^{-4}) is likely with a subjective confidence of over 50% at all locations in the 38-km vicinity of X-10.

Depending on the year of birth, the excess lifetime risk to females is 3 to 4 times larger than the risk to males. At a location such as Bradbury or Gallaher Bend, the lowest risk is for a male born in 1920, who has an excess lifetime risk of thyroid cancer almost 1000 times less than the highest risk for females born in 1952. A female born in 1920 has a risk about 350 times lower than that for a female born in 1952. Individuals of the same gender born in 1944 have about 50-60% of the risk than those born in 1952 have, while individuals born in 1940 or 1956 have risks about 5 times lower than those for individuals born in 1952. However, a male born in 1940 or 1956 has a risk almost 20 times less than that of a female born in 1952.

The primary locations affected by the April 1954 accident are those to the north and northwest of X-10, such as Jonesville, Norwood, the East Fork Poplar Creek (EFPC) area in Oak Ridge, Oliver Springs, and Wartburg. The excess lifetime risk of thyroid cancer to females on diet 1, exposed in their early childhood at either Jonesville, Norwood, EFPC, or Oliver Springs ranged from 3 or 4 chances in 10 million to nearly 1 chance 1,000. In general, total doses and risks from the 1954 accident are much lower than those from routine emissions.

Most of the uncertainty in the estimates of risk is associated with uncertainty in the estimates of dose (55%), followed by uncertainty in the dose response for groups exposed to external radiation. Uncertainty in the dose estimates is dominated by uncertainty in the concentrations of ^{131}I in milk (45%), followed by the uncertainty in the internal dose conversion factor (40%). The uncertainty in milk concentrations is dominated by the uncertainty in the transfer of ^{131}I from air to pasture (71%). The uncertainty in the internal dose conversion factor is dominated by the uncertainty in the mass of the thyroid in individuals of a given gender and age.

Fallout from atmospheric testing of nuclear weapons at the Nevada Test Site (NTS) during 1952, 1953, 1955, and 1957 was a significant contributor to the total ^{131}I exposure for people within 38 km of X-10. Beyond 38 km, ^{131}I from NTS fallout was the dominant source of exposure. For a female born in 1952 who drank backyard cows' milk, central estimates of thyroid dose from exposures from both X-10 releases and NTS fallout within 15 km of X-10 ranged from 25 to 30 cGy, with the 95% upper confidence limit exceeding 200 cGy. At all locations within 15 km of X-10, risks to females born in 1952 on rural diet 1 exceeds 1 chance in 1,000. The 95% upper confidence limit of the excess lifetime risk of thyroid cancer is 6-9 chances in 100 up to over 1 chance in 10 at Bradbury and Gallaher Bend. The doses from the combined exposure to ^{131}I from X-10 and NTS fallout are high enough to have possibly manifested excess cases of non-neoplastic disease, namely autoimmune thyroiditis. Available information is not sufficient to support quantitative estimation of the rates of such health effects.

Number of Excess Cancers Expected within Given Distances

Within 38 km of X-10, the 95% subjective confidence interval of the number of excess thyroid cancers from consumption of cows' milk (commercial and backyard, combined), contaminated by ^{131}I from RaLa processing between 1944 and 1956, range from 6 to 84, with a central estimate of 21. For the consumption of backyard cows' milk alone, the confidence interval ranged from 1 to 33 excess cases, with a central estimate of 7. Commercial cows' milk contributed more to the excess cancers because more individuals were exposed via its consumption.

The 95% confidence interval of the number of excess thyroid cancers from drinking of cow's milk contaminated by X-10 ^{131}I releases (commercial and backyard milk, combined) range from 14 to 103 (central estimate of 35) within 100 km of X-10, and from 25 to 149 (central estimate of 58) within 200 km. These cancers are expected to manifest between 1950 and 2020, with most occurring after 1970. These calculations of possible numbers of excess thyroid cancers are based on the linear, no threshold hypothesis. Under that hypothesis, added cancer risk is assumed to be proportional to the collective radiation dose received. This holds whether one has large doses received by a few people or low doses received by a much larger population. Available data cannot exclude the possibility that there is a low-level threshold for causation of cancer. If this is the case, then the values presented above are likely overestimates of true incidence rates.

These estimates were made using a baseline of thyroid cancer diagnoses within the region, with the assumption that the individuals in this population were unexposed. Only about 28% of the total thyroid cancers in a population are diagnosed and reported. Therefore, it is likely that the total number of diagnosed and occult cases of thyroid cancer is about 3 to 4 times greater than the total estimates given in this study which are based on the incidence of thyroid cancer reported only through clinical diagnosis. The clinical significance of an excess incidence of benign nodules is not evaluated in this study, but it is noted that about 9% of benign nodules diagnosed through palpation and about 28% of those diagnosed through ultrasound will be surgically removed.

In January 1999, the Centers for Disease Control and Prevention (CDC) released a draft final report from the Hanford Thyroid Disease Study, which was conducted by the Fred Hutchinson Cancer Research Center. This nine-year study evaluated whether the occurrence of thyroid disease was associated with radiation dose to the thyroid in a group of 3,441 people who were exposed to ^{131}I as children due to releases from the Hanford Nuclear Reservation in the 1940s and 1950s. The draft study results, which are still under review, show that thyroid disease was observed among study participants, but that there was no relationship seen between estimated doses to the thyroid from ^{131}I and the level of thyroid disease in that population.

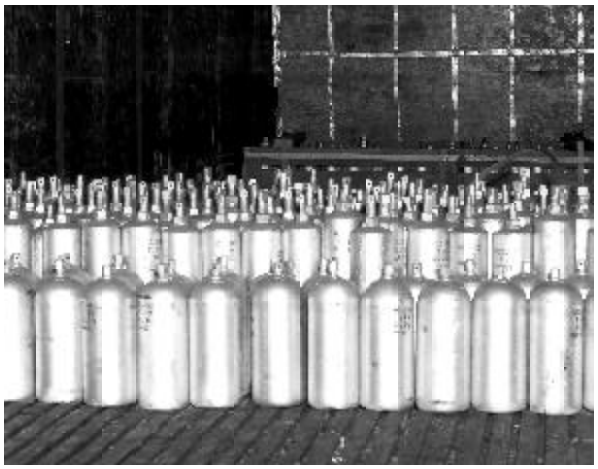
Other recent studies involving people exposed to ^{131}I in the environment have yielded different results. A study of almost 2,500 residents of Utah, Nevada, and Arizona who were exposed to NTS fallout as children reported an association between ^{131}I dose to the thyroid gland and the occurrence of thyroid cancer or nodules (*Kerber et al., JAMA, 270:2076-2082, 1993*). The recent Institute of Medicine/National Research Council report "Exposure of the American People to Iodine-131 from Nevada Nuclear-Bomb Tests" (*National Academy Press, 1999*) states that "there is now strong evidence from Chernobyl that children exposed to I-131 develop thyroid cancer at higher than usual rates." It is important to note that the epidemiologic studies discussed here neither prove nor disprove that a relationship exists between ^{131}I exposure to the thyroid gland and the occurrence of thyroid disease.

3. MERCURY RELEASES FROM Y-12 LITHIUM ENRICHMENT

Between 1950 and 1963, while lithium was being enriched in its lithium-6 component for use in thermonuclear weapons, many tons of mercury were released to the air and surface waters from the Y-12 Plant on the ORR. Preliminary investigations in the Oak Ridge Dose Reconstruction Feasibility Study indicated that mercury releases from operations at the Y-12 Plant likely resulted in the highest potential non-cancer health risks of any material used in historical activities on the Oak Ridge Reservation. Because of that finding, Task 2 of the Oak Ridge Dose Reconstruction was initiated by TDH and ORHASP to bring about a detailed, independent investigation of potential off-site doses and health risks from historical releases of mercury from the Y-12 Plant. The objectives of this detailed investigation were to:

- Describe (and independently quantify) past releases of mercury from the Reservation;
- Characterize historical environmental concentrations of mercury from those releases;
- Define potential pathways of human exposure to mercury;
- Describe potentially exposed populations;
- Estimate historical human exposures; and
- Estimate human health hazards, to put the dose estimates in perspective.

The Oak Ridge processes that used the most mercury were the lithium enrichment operations conducted at the Y-12 Plant in the 1950s and 1960s. Lithium enrichment operations included three production facilities, requiring over 24 million pounds of mercury. Facilities at Y-12 involved in the Colex (column-based exchange) process for lithium enrichment released the most significant quantities of mercury. Other processes that used much lower quantities of mercury included facilities built to test or demonstrate other processes for lithium enrichment, production of some nuclear weapon components, processes for chemical recovery or decontamination of nuclear materials, burning of coal in steam plants, and instrumentation.



Flasks of mercury as received at the Y-12 Plant. About 24 million pounds of mercury were used.

The project team's review of lithium enrichment operations and mercury releases included close examination of records assembled by members of a 1983 Task Force appointed to investigate and quantify mercury releases from Y-12. The investigation included interviews with members of the 1983 Task Force, review of thousands of Task Force files and documents archived in the Y-12 Records Center, and review of classified and unclassified versions of the Task Force's report. However, this investigation differed from the 1983 Mercury Task Force study in that:

- The Task 2 team identified the references that support the 1983 Mercury Task Force's release estimates and had them made available to the public.

- This project included a more thorough records review, including an extensive search of boxes of inactive records.
- The Task 2 team took additional steps to verify the data used to estimate historical mercury releases, through review of additional historical drawings and documents.
- Mercury release estimates were revised where more complete information was assembled.
- The Task 2 team estimated that about 62,000 pounds more mercury was released to the air and water than estimated historically.

Releases of Mercury to the Air

Mercury was released from Y-12 to air largely as a result of building ventilation systems installed to lower the concentration of mercury vapor inhaled by workers in the lithium enrichment facilities. However, airborne mercury in Y-12 exhaust was not routinely monitored. To quantify mercury releases to the air, the Task 2 team located thousands of measurements of mercury in indoor air and used historical engineering drawings to estimate building ventilation rates. The team estimated that about 73,000 more pounds of mercury was released to air from lithium enrichment buildings, a mercury recovery facility, and Y-12 steam plants– about 22,000 pounds more than estimated by the Mercury Task Force (Figure 3-1). This increase was largely due to corrections to calculated average concentrations and estimated building ventilation rates, and inclusion of additional mercury sources.

Workers at the Y-12 mercury dumping shed. Pipelines carried mercury to the buildings that housed Colex operations.

Releases of Mercury to Surface Waters

Mercury was also released from Y-12 to EFPC. The largest releases to water were the result of an early process in which mercury was washed with nitric acid to remove impurities prior to use for lithium enrichment– the washing process increased the solubility of the mercury and led to an increase in off-site releases as $HgNO_3$. The waters of EFPC near Y-12 have been routinely monitored for mercury since 1953. To quantify waterborne mercury releases, the Task 2 team cross-checked measurements for 1953 through 1993 from several sources and made corrections where mathematical errors had been made. Team members also collected EFPC flow rate measurements from numerous sources and assembled a more complete data set than the 1983 Mercury Task Force used. The Task 2 team estimated that about 280,000 pounds[1] of mercury was released to EFPC from 1950 to 1993– about 40,000 more than officially reported (Figure 3-2). This increase was largely due to use of more complete mercury concentration and flow rate records.

[1]A volume of about 12 cubic yards (a cubic yard of mercury weighs about 22,800 pounds).

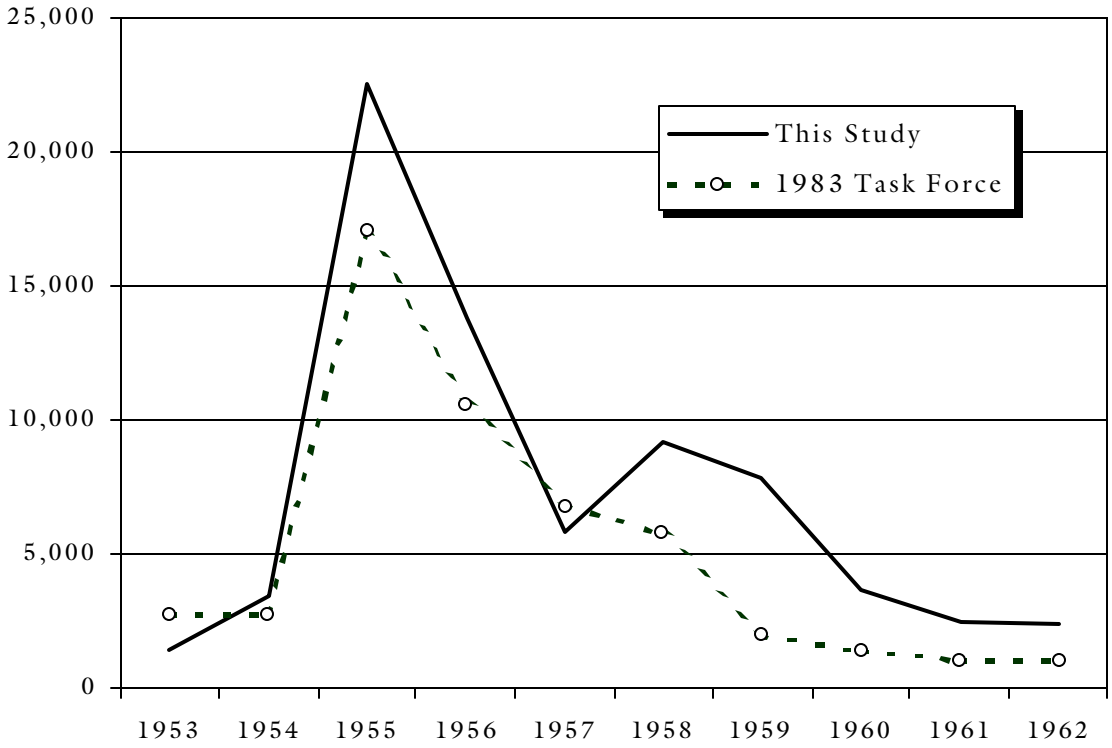


Figure 3-1: Annual Airborne Mercury Release Estimates by the Project Team and the 1983 Mercury Task Force (pounds)

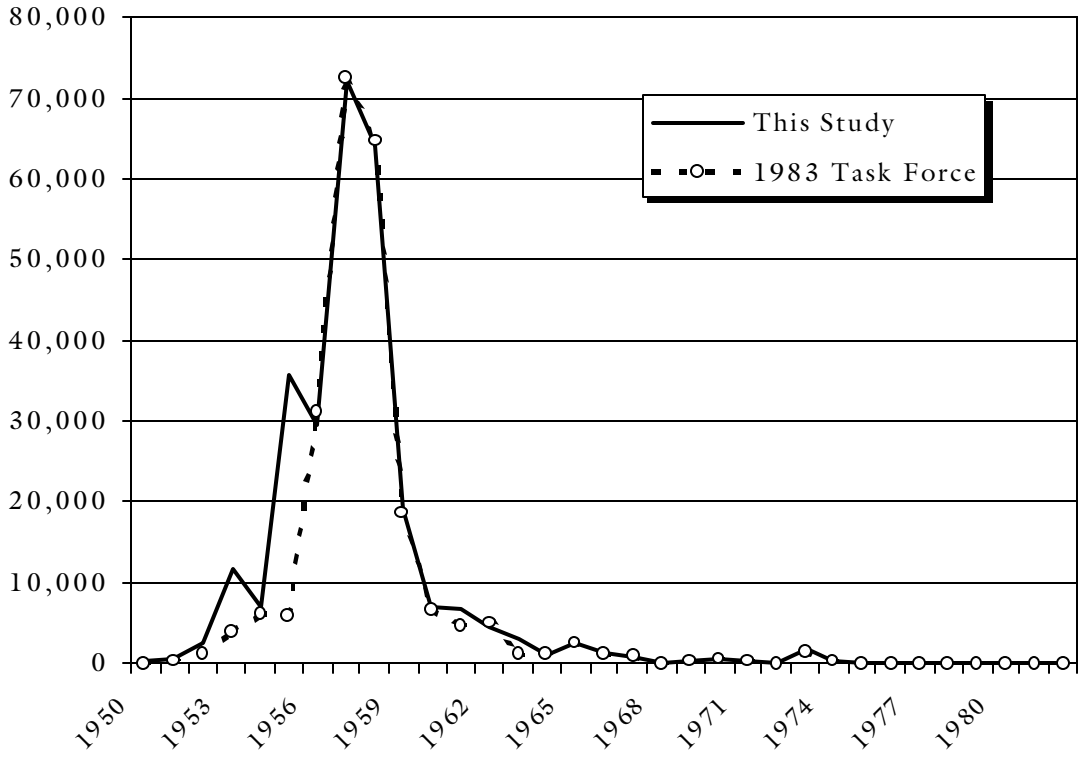


Figure 3-2: Annual Waterborne Mercury Release Estimates by the Project Team and the 1983 Mercury Task Force (pounds)

Mercury in the Environment

Project team and ORHASP members on a tour of the Alpha-4 Colex production building in 1996. Amalgam maker trays can be seen at the lower right of the photo.

Mercury can exist in the environment in several different forms, or species. Mercury used in lithium enrichment operations at Y-12 was elemental mercury, the relatively volatile form of mercury commonly found in thermometers. In the environment, elemental mercury can be converted to several different forms. The three primary forms of mercury found in the environment are elemental mercury (the dominant form in air), inorganic mercury (found in soil, water, and food), and organic mercury (commonly found in fish as methylmercury). Each of these forms behaves differently in the environment and has been associated with different health effects in people and animals exposed to high concentrations. The Task 2 team estimated doses and potential health effects for each form of mercury separately. Airborne releases of mercury may have been carried by wind down valley from Y-12 or across Pine Ridge. Waterborne releases of mercury flowed in EFPC through residential and commercial sections of Oak Ridge.

Exposure Assessment for Mercury

In estimating off-site doses from historical mercury releases, the Task 2 team selected a number of different geographic locations and groups of potentially exposed people down valley of Y-12, along EFPC within the community of Oak Ridge, and further downstream. Within these population groups, exposures were characterized for adults and children. In addition, exposures to methylmercury in fish were characterized for unborn children (in utero exposure) because toxicity studies have shown that unborn children may be particularly susceptible to adverse health effects when their mothers consumed contaminated fish during pregnancy.

The Task 2 team estimated historical mercury doses for the following populations:

- Wolf Valley Residents– who lived along the extension of Union Valley on the opposite side of the Clinch River, northeast of the Y-12 Plant. Meteorological studies indicate that this is a predominant direction of air flow from Y-12. These individuals could have inhaled airborne mercury, consumed homegrown fruits and vegetables contaminated by airborne mercury, and consumed milk and meat from "backyard" cattle that grazed on pasture contaminated by airborne mercury. Exposures to this group were evaluated for 1953 to 1962, since this was the period of significant air releases from Y-12.
- Oak Ridge Community Residents– who lived near the EFPC floodplain and may have inhaled mercury volatilized from EFPC and consumed homegrown fruits and vegetables contaminated by mercury that volatilized from EFPC. This population was assumed to have lived within one-half mile of EFPC in the western end of the city of Oak Ridge. Exposures to this group were evaluated for 1950 to 1990.

- Scarboro Community Residents– who lived in Scarboro, historically the closest residential area to the Y-12 facility. These individuals may have inhaled mercury from the Y-12 Plant and EFPC, traveled a short distance to fish or play in EFPC, and/or consumed homegrown fruits and vegetables contaminated by airborne mercury. Exposures to this group were evaluated for 1950 to 1990.
- Robertsville School Children– who attended a junior high school near the EFPC floodplain. These individuals could have inhaled mercury volatilized from EFPC and came in contact with mercury in floodplain soil. Some children in this age group were also assumed to recreate in EFPC for longer periods, and come in contact with EFPC water and sediment. Exposures to this group were evaluated for 1950 to 1990.
- The EFPC Floodplain Farm Family– who resided adjacent to the floodplain and consumed homegrown fruits and vegetables contaminated by airborne and soil mercury, consumed milk and meat from cattle that grazed in the floodplain and drank out of the creek, and fished and played in the creek for recreation. Exposures to this group were evaluated for 1950 to 1990. This is not a hypothetical reference population; the project team interviewed a number of individuals who lived on the floodplain and fit the stated characteristics of EFPC Farm Family residents.

Inhalation exposures were assumed to be to airborne elemental mercury vapor. Exposures through the remaining pathways, with the exclusion of fish consumption, were assumed to be to inorganic mercury.

Because measurements since 1970 have shown that fish collected downstream of EFPC in Poplar Creek, the Clinch River, and Watts Bar Reservoir contain elevated levels of mercury, the Task 2 team estimated doses to individuals who consumed fish from these waterways. Exposures to mercury in fish, assumed to be methylmercury, were evaluated for three categories of fish consumers based on the number of fish meals consumed per year from Poplar Creek/ Clinch River and Watts Bar Reservoir:

- Category 1 Fish Consumers- Assumed to frequently consume fish from these systems (between 52 and 130 meals per year)
- Category 2 Fish Consumers- Assumed to regularly consume fish from these systems (between 17 and 52 meals per year)
- Category 3 Fish Consumers- Assumed to occasionally consume fish from these systems (between 2 and 17 meals per year)

For each population, the project team estimated annual average daily doses of mercury (stated in terms of daily amounts of mercury taken in per kilogram of body weight) through all applicable exposure pathways. Doses were estimated using equations that take into account the amount of air, water, soil/sediment, food, or fish that was likely inhaled, ingested, or touched and the estimated concentrations of mercury in each medium during a given year. The Task 2 team estimated exposure point concentrations based on historical and current measurements of mercury in different environmental media and/or historical release data and modeling of releases to off-site locations.

The project team estimated EFPC water concentrations at downstream locations based on concentration and flow rate measurements made near Y-12 between 1950 and 1990, and application of factors to account for downstream reduction in concentrations due to mercury loss through volatilization or adherence to sediment and dilution of concentrations by additional inflow to the creek.

The Task 2 team estimated air concentrations at the Wolf Valley Resident location using estimates of annual Y-12 releases to air during 1953 to 1962 and modeling of dispersion off site. Air concentrations at the Scarboro Community due to direct airborne releases from Y-12 were estimated based on the relationship between concentrations of uranium measured in air at Scarboro between 1986 and 1995 and estimated releases of uranium from Y-12 (uranium was also historically released from Y-12 and was evaluated in Task 6 of this project; see Section 8).

Air concentrations due to volatilization of mercury from EFPC were estimated based on assumptions about the fraction of the total mercury released from Y-12 that volatilized from EFPC between Y-12 and the junction of EFPC with Poplar Creek. Recent measurements of mercury in rings of red cedars growing in the EFPC floodplain suggest that air concentrations were significantly elevated in the past. The project team assumed that on average 5% (range 1% to 30%) of the mercury discharged to EFPC escaped to air between Y-12 and the junction.

The Task 2 team estimated soil and sediment concentrations in the EFPC floodplain based on sampling conducted during the EFPC Floodplain Remedial Investigation in 1991 and 1992. Historical concentrations were estimated based on statistical analysis of samples collected from areas likely to have been visited by the populations of interest. The Task 2 team estimated soil concentrations at the Scarboro Community based on limited soil sampling conducted in Scarboro by Oak Ridge Associated Universities in 1984– these were the only soil samples collected in this area and analyzed for mercury prior to 1998.

Mercury in air and soil can be taken up by fruits or vegetables, which can then be consumed by humans. Mercury taken up into plants can also make its way into milk and meat when cattle eat the plants. The Task 2 team derived factors to describe these transfers in the environment. The project team estimated incorporation of airborne mercury into above-ground vegetation, including fruits and vegetables and pasture grass, based on measurements of airborne mercury deposition to vegetation near Oak Ridge in the late 1980s. Transfer of mercury from soil to below-ground vegetables and from soil to pasture grass was estimated based on measurements of mercury in co-located soil and plant samples from Oak Ridge in the mid-1980s and in 1993. Transfer of mercury to milk and meat after consumption of pasture by cattle was estimated based on studies reported in the scientific literature.

The numbers of fish in EFPC during the years of peak mercury releases were likely low due to poor water quality. However, anecdotal reports suggest that a few people caught and ate fish from EFPC during the 1950s and 60s. The project team estimated annual average concentrations of mercury in EFPC fish of the size and type that may have been caught for consumption based on: 1) concentrations measured in fish collected near Oak Ridge after 1970, 2) concentrations measured in fish at other sites with similarly high concentrations in water and/or sediment, 3) information about the maximum possible concentrations in fish of the size likely to have been in EFPC, and 4) evidence of levels of mercury that may be lethal to fish. Historical annual average concentrations in fish from the Clinch River/Poplar Creek and Watts Bar Reservoir that may have been caught for consumption were estimated based on data from sediment cores collected in these systems in the mid-1980s and use of equations describing the relationship between mercury concentrations in sediment and in fish. These relationships were established using sediment and fish data from EFPC, Poplar Creek, the Clinch River, and Watts Bar Reservoir.

Results of the Dose Reconstruction for Mercury

The results of the reconstruction of mercury doses can be characterized as follows. For all populations of interest, the highest doses were estimated to have occurred during the mid- to late-1950s. These were the years of highest releases of mercury from Y-12 to air and to EFPC.

Excluding exposures of fish consumers to methylmercury in fish, estimated doses to the EFPC Floodplain Farm Family are the highest of all exposure populations that were evaluated. The estimated total dose to an EFPC Floodplain Farm Family member is dominated by consumption of fruits and vegetables contaminated from airborne mercury and inhalation of airborne mercury that volatilized from EFPC.

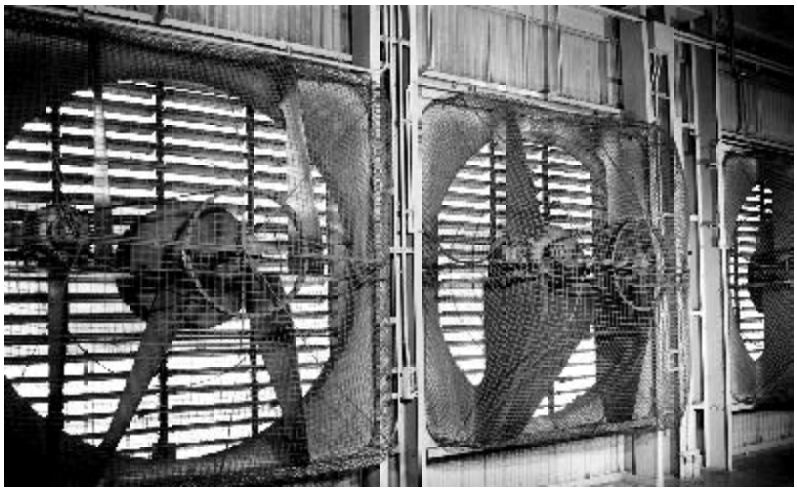
Estimated total doses to Wolf Valley ("down valley") Residents, resulting from direct air releases of mercury from Y-12, are also dominated by consumption of fruits and vegetables contaminated from airborne mercury. However, the highest doses estimated for this group are about 30- to 40-times lower than the highest doses estimated for the EFPC Farm Family.

Estimated total doses to Scarboro Community Residents are dominated by consumption of fruits and vegetables contaminated from airborne mercury, incidental ingestion of waterborne mercury, skin contact with contaminated EFPC water and sediment, and inhalation of airborne mercury due to both direct air releases of mercury from Y-12 and volatilization of mercury from EFPC. The highest estimated inhalation doses (estimated for 1955) are about nine-times lower than the highest inhalation doses estimated for the EFPC Floodplain Farm Family (estimated for 1957), due largely to the greater distance of the Scarboro Community from EFPC.

Estimated total doses to Robertsville School Students are dominated by incidental ingestion of and skin contact with mercury in floodplain soil and in EFPC water.

Estimated doses to Community Populations 1 and 2, for which exposures from airborne mercury volatilized from EFPC were evaluated, were comprised of inhalation of airborne mercury and consumption of fruits and vegetables contaminated from airborne mercury only.

Estimated methylmercury doses to individuals who consumed fish from Clinch River/ Poplar Creek were about four-fold higher than doses estimated for people who consumed the same amount of fish from Watts Bar Reservoir.



Six-foot diameter fans were installed in Colex Building 9201-5 in 1956 to increase ventilation and reduce worker exposures.

In order to put the Task 2 dose estimates in perspective and evaluate the likelihood that the estimated levels of historical exposure caused adverse health effects, the project team collected, evaluated, and summarized available studies of the toxicity of different species of mercury through various routes of exposure and established toxicity benchmark values for comparison with the estimated doses. The primary toxicity benchmark values used in this report are USEPA RfDs and LOAELs or NOAELs.

For the years that the estimated annual average elemental, total inorganic, or methylmercury doses at the upper bound (97.5th percentile) of the 95% subjective confidence interval are less than the corresponding RfD, it is not likely that adverse health effects occurred, based on current

scientific knowledge. Exceeding the RfD is equivalent to exceeding a hazard index of 1. The following general conclusions can be drawn from the Task 2 mercury dose reconstruction based on the estimated annual-average doses.

Inhalation of Airborne (Elemental) Mercury

Comparison to RfDs – The 95% UCLs on the estimated inhalation doses of elemental mercury exceeded the RfD at two locations: Scarboro for 1955 and 1957 (child) and the EFPC Farm Family 1953-1961 (child) and 1955-1959 (adult). Central estimates of inhalation dose exceeded the RfD at the Farm Family location for 1955 and 1957-1958.

Comparison to NOAELs – The 95% confidence intervals on the estimated annual average elemental mercury doses for all populations and all years were below the NOAEL. The NOAEL was established from studies of workers exposed to airborne mercury vapor for prolonged periods of time– some workers exposed to airborne mercury concentrations above the NOAEL exhibited neurological effects, including hand tremor, increases in memory disturbances, and evidence of dysfunction of the autonomic (involuntary) nervous system. The USEPA RfD is about 30 times lower than the NOAEL because it incorporates a conservative safety factor. Health effects in people exposed to elemental mercury below the NOAEL have not been reported.

Populations with the highest exposures – The highest estimated elemental mercury doses were to children who were members of the EFPC Farm Family in 1957. The upper bound on the highest estimated annual average elemental mercury inhalation dose is about 13-times higher than the USEPA RfD, but about 1/3 of the NOAEL.

Estimated doses from inhalation for Scarboro Residents during 1953-1962– (when air concentrations at this location were assumed to result from both direct airborne mercury releases from Y-12 that were transported over Pine Ridge and volatilization of mercury from EFPC) are about 15% to 40% of the inhalation doses estimated for the EFPC Farm Family during these years. During other years, estimated doses at Scarboro are about 10% of doses estimated at the EFPC Floodplain Farm Family location. The higher estimated doses at the EFPC Floodplain Farm location are due to its closer proximity to EFPC.

Likelihood of exposures above the RfD, Scarboro Residents – The estimated size of the Scarboro Community population was assumed to be between 800 and 1,200 individuals per year. Since estimated doses at the 50th percentile for this population were below the RfD for all years, it is likely that doses to most individuals in this population were below the RfD. However, because of the relatively large size of this population, it is possible that inhalation doses to a small number of people in this population during the years of highest mercury releases from Y-12 (1953-1962) may have exceeded the RfD.

Likelihood of exposures above the RfD, EFPC Floodplain Farm Family members – The estimated size of the EFPC Floodplain Farm Family population was very small (a total of between 10 and 50 individuals were assumed in this population per year). Since estimated doses at the 50th percentile to some members of this population exceeded the RfD during the years of highest mercury releases from Y-12, it is likely that doses to some individuals in this population exceeded the RfD.

Ingestion of and Contact with Inorganic Mercury in Soil, Sediment, Water, Meat, Milk, and Fruits/ Vegetables

Comparison to RfDs – The 95% UCLs on estimated inorganic mercury doses exceeded the USEPA RfD for inorganic mercury for at least one year for all six non-angler populations evaluated in this assessment: Wolf Valley Residents (child, 1955), the Scarboro Community (child, 1953-1962; adult, 1954-1959), Robertsville School Students (general student, 1955

Ingestion of and Contact with Inorganic Mercury in Soil, Sediment, Water, Meat, Milk, and Fruits/ Vegetables

Comparison to RfDs– The 95% UCLs on estimated inorganic mercury doses exceeded the USEPA RfD for inorganic mercury for at least one year for all six non-angler populations evaluated in this assessment: Wolf Valley Residents (child, 1955), the Scarboro Community (child, 1953-1962; adult, 1954-1959), Robertsville School Students (general student, 1955 and 1958; recreator, 1955-1958), the EFPC Floodplain Farm Family (child, 1950-1970, 1973; adult, 1952-1963, 1965), and the two Oak Ridge Community populations (Community Population #1 child, 1955, 1957-1958; Community Population #2 child, 1958). Central estimates of inorganic mercury dose exceeded the RfD for 1955-1958 for Scarboro children, 1953 and 1955-1959 for EFPC Farm Family children, and 1955-1958 for EFPC Farm Family adults. The 95% lower confidence limit of inorganic mercury dose just reached the RfD for EFPC Farm Family children in 1958.

Comparison to NOAELs– The 95% subjective confidence interval on estimated annual average inorganic mercury doses for all populations and all years were below the NOAEL for inorganic mercury. The NOAEL for inorganic mercury is based on kidney effects observed in rats fed high concentrations of water soluble mercuric chloride. The USEPA RfD is about 3,000 times lower than the NOAEL, because it incorporates a conservative margin of safety to account for the lack of data on the toxicity of inorganic mercury to humans. Health effects in humans from inorganic mercury at doses at or below the NOAEL have not been reported.

Populations with the highest exposures– The highest estimated inorganic mercury doses were to children who were members of the EFPC Floodplain Farm Family in 1958. The upper bound on the highest estimated annual average inorganic mercury dose is about 90-times higher than the USEPA RfD, but about a factor of four below the NOAEL. Doses to these individuals were estimated to be high because they were assumed to live close to EFPC. Inorganic mercury doses to Scarboro Community Residents during the mid-1950s to early-1960s were also estimated to potentially exceed the RfD, because it was assumed that they occasionally recreated in EFPC.

Important pathways– At five of the six locations where estimated total inorganic mercury doses exceeded the RfD, estimated doses were largely contributed by ingestion of homegrown fruits and vegetables contaminated by airborne mercury. Contact with contaminated water in EFPC was also an important pathway for Scarboro Community Residents and EFPC Floodplain Farm Family members.

Likelihood of exposures above the RfD, Wolf Valley Residents– The estimated size of the Wolf Valley Residents population was small (between 30 to 100 people in a given year). For this population, the results of this assessment suggest that only doses to young children may have exceeded the RfD, and only if they consumed very large quantities of homegrown above-ground fruits and vegetables. Because of the small size of this population and the relatively low doses estimated for them, it is likely that the number of individuals in this population who were exposed to inorganic mercury at doses above the RfD was small.

Likelihood of exposures above the RfD, Scarboro Residents– The estimated size of the Scarboro Community Residents population was relatively large (between 800 and 1,200 individuals in a given year). Since estimated doses at the 50th percentile for this population were below the RfD for most years, it is likely that doses to most individuals in this population were below the RfD. However, because of the relatively large size of this population, it is likely that inorganic mercury doses to a moderate number of people in this population during the years of highest mercury releases from Y-12 (1953-1962) exceeded the RfD, particularly for those individuals who frequently recreated in EFPC or regularly consumed above-ground fruits/ vegetables from backyard gardens. Deleterious health effects were therefore possible, but unlikely.

Likelihood of exposures above the RfD, Robertsville School Students– The estimated size of the Robertsville School general student population was between 1,500 and 2,000 students in a given year. Since estimated doses at the 50th percentile for this population were below the RfD for all years, and doses at the 97.5th percentile exceeded the RfD only during a few years in the mid-1950s, it is likely that the number of individuals in this population who were exposed to inorganic mercury at doses above the RfD was small. Doses above the RfD most likely resulted from frequent contact with schoolyard soil and EFPC water and sediment.

Likelihood of exposures above the RfD, EFPC Farm Family members– The estimated size of the EFPC Farm Family population was very small (10 to 50 individuals in a given year). Because estimated doses at the 50th percentile for this population exceeded the RfD during the years of highest mercury releases from Y-12 (1953-1962) and because this population group was assumed to live close to EFPC, it is likely that doses to some individuals in this population exceeded the RfD. Doses above the RfD most likely resulted from frequent contact with floodplain soil and EFPC water and sediment, and eating of "backyard" fruits and vegetables.

Likelihood of exposures above the RfD, Community Populations– The estimated size of the Community Populations was relatively large (1,500 to 2,000 individuals in a given year). However, results suggest that for these populations, only doses to young children may have exceeded the RfD, and only if they consumed very large quantities of homegrown above-ground fruits and vegetables during the years of highest mercury releases from Y-12 (mid-1950s) and lived closer than one mile from the creek. The number of individuals in these populations exposed to inorganic mercury at doses above the RfD was likely small.

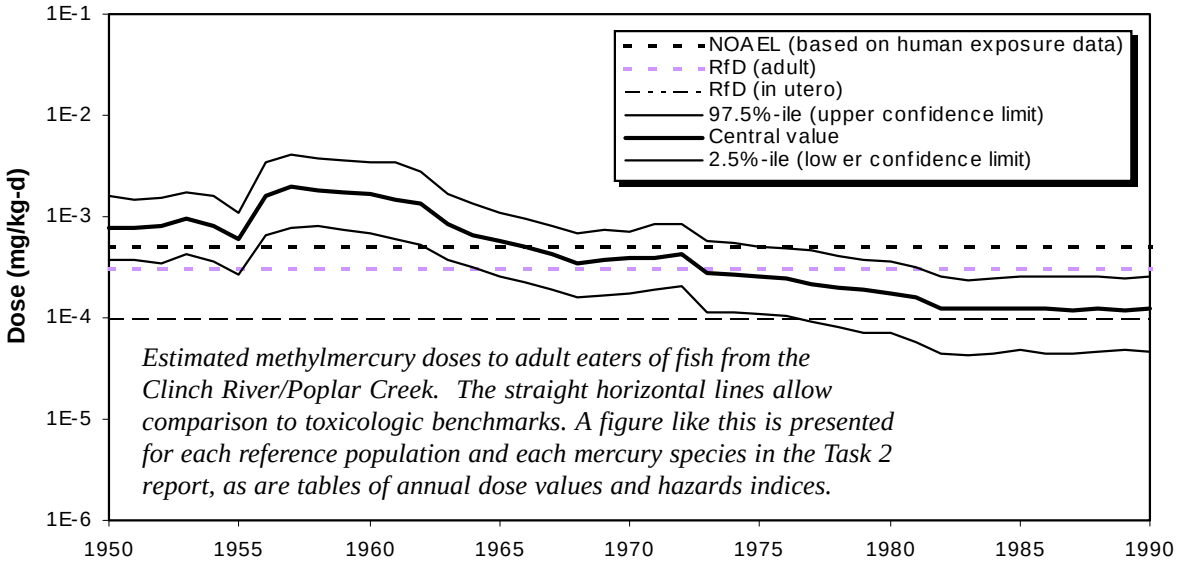
Ingestion of Methylmercury in Fish

Comparison to RfDs (Watts Bar fish)– The 95% UCLs on estimated methylmercury doses from consumption of fish exceeded the RfD based on *in utero* exposures for all years for Category 1 fish consumers, 1954-1970 and 1974-1975 for Category 2 fish consumers, and 1957-1959 for Category 3 fish consumers. Central estimates exceeded the RfD 1950-1981 for Category 1 fish consumers and 1956-1960 for Category 2. During the years of highest mercury releases from Y-12, estimated doses for Category 1 fish consumers exceeded the RfD based on *in utero* exposures even at the lower bound of the distribution (the 2.5th percentile).

Comparison to NOAELs (Watts Bar fish)– The 95% UCL on estimated methylmercury doses exceeded the NOAEL for 1956-1960 for Category 1 fish consumers, and median doses reached the NOAEL around 1958-1959. Estimated doses to Category 2 and 3 fish consumers were below the NOAEL. The NOAEL for methylmercury is based on observations of neurological effects in children who were exposed to methylmercury *in utero* when their mothers consumed methylmercury in fish during pregnancy. Health effects in humans exposed to methylmercury at doses at or below the NOAEL have not been reported.

Exposures to children (Watts Bar fish)– Based on calculations by the Task 2 team, children who ate as few as three to four meals of fish from Watts Bar Reservoir during the mid- to late-1950s may have been exposed to methylmercury at doses that exceeded the RfD based on *in utero* exposures. If they ate seven or more meals of fish per year from Watt Bar during these years, it is likely that they were exposed to methylmercury at doses that exceeded the RfD.

Exposures to adults (Watts Bar fish)– Based on calculations by the Task 2 team, adults who ate nine or more meals of fish from Watts Bar Reservoir during the mid- to late-1950s may have been exposed to methylmercury at doses that exceeded the RfD based on *in utero* exposures. If they ate about 20 or more meals per year during these years, it is likely that they were exposed to methylmercury at doses that exceeded the RfD. Adults who were not pregnant could have consumed about three times as many fish meals per year as pregnant adult females, without risk of adverse health effects from methylmercury exposure, because it is believed that adults are not as sensitive to adverse health effects from methylmercury exposure as children exposed *in utero.*



Estimated methylmercury doses to adult eaters of fish from the Clinch River/Poplar Creek. The straight horizontal lines allow comparison to toxicologic benchmarks. A figure like this is presented for each reference population and each mercury species in the Task 2 report, as are tables of annual dose values and hazards indices.

Likelihood of exposures above the RfD (Watts Bar fish)– The estimated size of the recreational angler population in Watts Bar Reservoir was large (10,000 to 30,000 individuals in a given year). Because Watts Bar Reservoir was a productive and popular recreational fishery, many people likely consumed a large number of fish from this system and, particularly during the mid-1950s and 1960s, were exposed to methylmercury at doses that exceeded the RfD.

The number of fetuses possibly affected (average doses greater than the NOAEL) was estimated using the average birth rate in the population, the fraction of women of childbearing age, their fish consumption rates, and the fraction of consumers whose doses exceeded the NOAEL for *in utero* exposure during that year.[1] The estimates were made for Watts Bar Reservoir, Clinch River/Poplar Creek, and EFPC fish consumers and summed over the years of concern. The estimated total number of affected fetuses is uncertain, but is nearer to 100 than to 1,000.

Comparison to RfDs (Clinch River/Poplar Creek fish)– The 95% UCLs on estimated methylmercury doses from consumption of fish exceeded the RfD based on *in utero* exposures for all years for Category 1 fish consumers, 1950-1982 for Category 2, and 1950-1966, 1971-1972 for Category 3. Central estimates exceeded the RfD for all years for Category 1, 1950-1972 for Category 2, and 1956-1962 for Category 3. Estimated doses exceeded the RfD based on *in utero* exposures even at the lower confidence limit (the 2.5th percentile) for 1950-1975 for Category 1 fish consumers and 1950-1954, 1956-1964 for Category 2 fish consumers.

Comparison to NOAELs (Clinch River/Poplar Creek fish)– The 95% UCL on methylmercury doses exceeded the NOAEL for 1950-1975 for Category 1 fish consumers, 1950-1964 (excepting 1955) for Category 2 fish consumers, and 1957 for Category 3 fish consumers. Central estimates of dose exceeded the NOAEL 1950-1966 for Category 1 and 1956-1962 for Category 2. For Category 1 fish consumers, even the lower confidence limit of methylmercury dose (the 2.5th percentile) exceeded the NOAEL for 1956-1962. Health effects in humans exposed to methylmercury at or below the NOAEL have not been reported.

[1]Personal communication with Paul Voillequé, ORHASP member, March 1999.

Exposures to children (Clinch River/Poplar Creek fish)– Children who ate as few as one meal of fish from Clinch River/Poplar Creek during the mid- to late-1950s may have been exposed to methylmercury at doses that exceeded the RfD based on *in utero* exposures. If they ate two or more meals of fish per year from Clinch River/Poplar Creek during these years, it is likely that they were exposed to methylmercury at doses that exceeded the RfD.

Exposures to adults (Clinch River/Poplar Creek fish)– Adults who ate two to three or more meals of fish from Clinch River/Poplar Creek during the mid- to late-1950s may have been exposed to methylmercury at doses that exceeded the RfD based on in utero exposures. If they ate 5 or more meals per year during these years, it is likely that they were exposed to methylmercury at doses that exceeded the RfD. Adults who were not pregnant could have consumed about three times as many fish meals per year as pregnant adults, without risk of adverse health effects from methylmercury exposure.

Likelihood of exposures above the RfD (Clinch River/Poplar Creek fish)– The estimated size of the recreational angler population in Clinch River/Poplar Creek was large (3,000 to 10,000 individuals in a given year). Because a large number of people occasionally fished in Clinch River/Poplar Creek and many likely consumed moderate quantities of fish from this system, it is likely that a significant number of people who caught and consumed fish from this system were exposed to methylmercury at doses that exceeded the RfD, particularly if they consumed fish from this system during the mid-1950s and 1960s.

Comparison to RfDs and NOAELs (EFPC fish)– The 95% UCL on estimated methylmercury doses from consumption of EFPC fish by Scarboro residents and EFPC Floodplain Farm Family populations exceeded the RfD for methylmercury (based on *in utero* exposures) for all years evaluated in this assessment (1950-1990). Central estimates exceeded the RfD for 1950-1983. However, doses for this population did not exceed the NOAEL.

Interviews with Oak Ridge area residents, including residents of Scarboro and people who lived near EFPC, suggest that the maximum rate of consumption of fish from EFPC was about one fish meal per month. In this assessment, the average consumption rate of fish from EFPC for adults was assumed to be about 2.5 meals per year.

Exposures to children (EFPC fish)– Children who ate more than one meal of fish per year from EFPC may have been exposed to methylmercury at doses that exceeded the USEPA RfD. If they ate two or more meals of fish per year from EFPC during these years, it is likely that they were exposed to methylmercury at doses that exceeded the RfD.

Exposures to adults (EFPC fish)– Adults who ate two to three or more meals of fish per year from EFPC may have been exposed to methylmercury at doses that exceeded the RfD based on *in utero* exposures. If they over five meals per year during these years, it is likely that they were exposed to methylmercury at doses that exceeded the RfD.

Overall Conclusions Regarding Mercury Exposures

Based on the results of the mercury dose reconstruction, the following activities may have resulted in exposure to mercury at annual average doses above the RfDs:

- Consumption of any fish from EFPC, the Clinch River, or Poplar Creek;
- Consumption of more than three or four meals of fish per year from Watts Bar Reservoir;
- Consumption of fruits or vegetables that grow above-ground from backyard gardens in Scarboro or within several hundred yards of the EFPC floodplain;
- Playing in EFPC more than 10-15 hours per year; and
- Living or attending school within several hundred yards of the EFPC floodplain or in Scarboro (from inhalation of airborne mercury).

4. POLYCHLORINATED BIPHENYLS (PCBs) IN THE ENVIRONMENT NEAR OAK RIDGE

This report presents the findings of a detailed assessment of the releases of polychlorinated biphenyls (PCBs) from the ORR and the potential for adverse effects in the local populations. Beginning with early operations in the 1940s, PCBs were used extensively on the ORR. PCBs were present at Oak Ridge mainly because the ORR was one of the largest users of electrical energy in the United States. Because of their good insulating properties and thermal stability, PCBs were present in many electrical components such as transformers and capacitors. In addition, PCBs were used as cutting fluids for lubrication and cooling during certain metal working operations.

Preliminary screening analyses conducted during the Dose Reconstruction Feasibility Study, indicated that PCBs potentially represented the most important non-radioactive cancer-causing chemical historically released from the ORR. The study team also found that sources of PCB releases to the environment and the resulting exposures to local populations were poorly characterized. As a result, Task 3 of the Oak Ridge Dose Reconstruction was initiated to reconstruct PCB doses to human populations living in and around Oak Ridge.

Because much electricity was used at the ORR, components containing PCBs were plentiful.

The objectives of Task 3 were to:

- Investigate historical releases of PCBs from the government complexes at Oak Ridge,
- Evaluate PCB levels in environmental media in the ORR area,
- Describe releases of PCBs from other sources in the Oak Ridge area, and
- Evaluate potential human exposures and health effects associated with the presence of these contaminants in the environment.

During the first 30 years of operations at the ORR, little or no attention was paid to the use, disposal, or contamination of the environment with PCBs. Few attempts were made to control the release of PCBs to the environment during this period, and minimal effort was made to track or document the amounts of PCBs used, disposed of on site, or released off site. This was because the carcinogenicity of PCBs in laboratory animals was not discovered until the 1970s. In 1977, the manufacture of PCBs was banned in the U.S. because of evidence that PCBs accumulated in the environment and caused harmful effects.

In the absence of detailed historical records regarding PCB use and disposal at the ORR, it was necessary for the project team to identify and evaluate all available information regarding processes and disposal practices at the ORR that might have resulted in the release of PCBs to the environment. Data were obtained from a variety of sources. Publicly available documents prepared by ORR contractors, the Tennessee Valley Authority (TVA), and the USEPA were

obtained and reviewed. Historical records maintained at the ORR were also reviewed to identify relevant processes, accidental spills, and general disposal practices that might have resulted in releases of PCBs. In addition, information regarding undocumented historical events was obtained through interviews with active and retired employees of the ORR and residents of Oak Ridge living adjacent to the facilities. A detailed system of data management was maintained by the project team to ensure that the information collected was thoroughly evaluated and that the sources were clearly identified.

The Histories of PCBs at the Oak Ridge Sites

In general, it appears that the primary uses of PCBs at the ORR were electrical equipment (i.e., transformers and capacitors), hydraulic fluids, heat-transfer fluids, and cutting oils. In addition, PCBs were present in relatively low levels (less than a few percent) in many products including paints, coatings, adhesives, inks, and gaskets. PCB uses, as well as the potential impact of off-site releases, differed among the three main complexes on the ORR. Therefore, separate analyses are presented for each of the facilities in the Task 3 report.

PCBs in the Environment

The migration of PCBs off-site from all of the ORR complexes was reduced due to the chemical properties of PCBs. PCBs are not mobile in groundwater and, when released to surface water, quickly bind to sediment. Because of these properties, the majority of PCBs placed in burial grounds or pits have remained in or near these units. Small lakes, ponds, and lagoons have been an integral part of the storm water and waste water management systems at the ORR. These surface water bodies have served as traps for PCBs, PCB-contaminated oils, and PCB-contaminated sediments, and have limited the movement of PCBs off the reservation. Finally, the sediments of Bear Creek, White Oak Creek, and other streams located on the ORR have entrapped a portion of the PCBs released from Y-12 and X-10 and have reduced the amount of PCBs migrating off the reservation.

Qualities of PCB Releases

Based on the available information, the project team determined that developing quantitative estimates of PCB releases from specific release points as a function of time (often called "source terms") would be difficult, if not impossible, for the following reasons. The first problem is the widespread use of PCBs on the ORR and the absence of documentation of releases. From the initial construction of Oak Ridge through the early 1970s, PCBs were viewed as nontoxic, inert substances that offered no particular hazard to workers, the general public, or the environment. As a result, there was no attempt to manage or track the use, release, and disposal of PCBs in any systematic manner. A second problem is that a PCB release that may have happened as a result of a specific event may result in an extended, low-level source of contamination to a body of water. Once PCBs enter a body of water, they may remain localized until a storm event or a change in the fundamental hydrology results in remobilization and additional transport. Rather than basing the Task 3 risk assessments on quantitative estimates of quantities of PCBs historically released, the project team estimated past exposures largely based on available environmental measurements of PCBs. Air-related pathways were an exception. These pathways were evaluated using estimates of releases and air dispersion models.

Other Sources of PCBs

Although releases to surface water and sediment transport represent the primary transport routes of PCBs to off-site locations, it also necessary to consider other, less significant pathways. For example, there is evidence that burning of PCB-contaminated material associated with both

the Y-12 Burn Yards and the Toxic Substances Control Act (TSCA) Incinerator at K-25 may have resulted in the air releases of PCBs, as well as dioxins and furans produced from the partial incineration of PCBs. In addition, there is evidence to suggest that materials containing PCBs, such as used oils or electrical equipment, may have been sold and transported off-site. It has long been recognized that PCBs were used in a large number of facilities throughout the watershed of the Tennessee River and its tributaries. Because PCBs have been detected in sediment and fish from the Tennessee River above its confluence with the Clinch River and in the Clinch River upstream of the ORR, the project team collected data on other sources of PCBs entering Watts Bar Reservoir. Available records on PCB use identified more than 22 facilities that managed PCB-containing wastes on portions of the Tennessee River above the Clinch River and on the Clinch River above the ORR.

Two independent approaches were utilized by HydroQual, Inc. in the early 1990s to evaluate the relative fraction of PCBs in Watts Bar fish attributable to Oak Ridge. One approach involved a straightforward analysis of spatial trends in fish monitoring data. The other approach entailed the development of a sediment transport model, which was used in conjunction with PCB sediment core data to predict sources and transport of PCBs at various times and locations within the watershed. Based on the results of their analyses, HydroQual concluded that historical releases of PCBs from Oak Ridge were responsible for less than 9 to 13 percent of the currently observed levels in Watts Bar fish and about half of the levels in the Clinch River. HydroQual also concluded that this estimate could be further reduced if sources of PCBs above Melton Hill Dam were considered. In addition, because of the approximate agreement between these two independent measurements, HydroQual concluded that there was strong evidence that the vast majority of PCBs currently detected in fish in the lower Watts Bar occurred as a result of releases to the Tennessee River upstream of the Clinch River. The analyses also indicated that, with the exception of three periods of elevated discharges, PCB releases to the Clinch River from all ORR sources were relatively constant over time, and the total magnitude of annual PCB releases from the 1940s through the 1990s were around nine kilograms per year.

less than 9-13% of the PCBs in Watts Bar Lake likely came from ORR sources

Identification of Exposure Pathways

The project team identified potential off-site exposure pathways that were primarily associated with releases to surface water and to air. Releases to surface water are primarily associated with White Oak Creek, Bear Creek, EFPC, Poplar Creek, the Clinch River, and Watts Bar Lake. In general, exposure pathways associated with releases to surface water have included fish consumption, dermal contact with surface water and sediments, and incidental ingestion of surface water and sediments. In addition, based on the available information regarding historical activities in the area, direct contact with flood plain soil as well as pathways associated with bioaccumulation of PCBs in vegetation and animals have been identified as complete exposure pathways for EFPC. Exposure pathways associated with bioaccumulation of PCBs in animals have been identified for Jones Island and the Clinch River. Exposures related to PCB releases in air have included both direct pathways, such as inhalation, and indirect pathways such as bioaccumulation of PCBs in vegetation and animals. These pathways are also likely complete for dioxins and furans that may have been formed during the incineration of PCBs.

The project team identified potential exposures associated with the historical sale of PCB-containing materials. Waste oils containing less than 500 ppm of PCBs may have been sold by the ORR facilities in the late 1940s. Such oil could have been used by local individuals for fuel, dust suppression, or vegetation control. Exposure pathways considered included direct contact with contaminated soil.

An important exposure pathway identified in the Task 3 report is the accumulation of PCBs in fish and the resulting exposures to the anglers and their families who consume the fish. An important issue in evaluating fish consumption is the frequency and amount of fish that an angler consumes. Fish consumption varies greatly across the local population with some people eating no fish and others obtaining a large amount of their protein needs from the consumption of fish. The types of fish consumers include commercial, recreational and subsistence anglers.

The Task 3 report presents an evaluation of the information available on historical fishing activities on the water bodies of interest, identifies potentially exposed populations of anglers, and derives estimates of fish consumption rates for the populations that were likely exposed as a result of their fishing activities. Based upon this assessment, eight distinct populations may have received exposure to PCBs through consumption of fish from water bodies in proximity to the ORR. These populations include: commercial anglers who fished Watts Bar or Clinch River/Poplar Creek; recreational anglers who fished Watts Bar, Clinch River/Poplar Creek, or EFPC; and subsistence individuals who may have fished any of these water bodies. The report also discusses the data and methodologies used to develop both the point estimates of consumption used in the level I evaluation and the distributions used in the level II and III evaluations.

As described above, potential exposure pathways that were identified included direct exposure to PCBs in water, sediment, flood plain soils, and air, as well as indirect exposure through the ingestion of contaminated food (such as fish, vegetables, beef, and milk). The project team collected site-specific demographic information regarding farming, fishing, and recreational activities through interviews with current and past residents of Oak Ridge. The project team used this site-specific information, as well as measured levels of PCBs in the various media of concern, to confirm which of the possible exposure pathways actually resulted in exposures to off-site populations. Those that were determined to be "complete" pathways were considered in the level I evaluation to identify the pathways most likely associated with off-site health risks.

Toxicology of PCBs

The assessment of exposures from the releases of PCBs requires information on the toxicity of the compounds and in particular the doses that are associated with adverse effects in animals. The Task 3 report presents a summary of the available information on the dose response of PCBs in humans and test animals. Dose-response assessment is the process of characterizing the relationship between the dose of an agent administered or received and the incidence of an adverse health effect in an exposed population. Dose-response relationships are developed based on animal studies and models of what might occur in humans or on human epidemiological evidence when such data are available. The toxicity value for the assessment of carcinogenic effects is the cancer slope factor (CSF) and the RfD is an estimate of daily exposure that is without appreciable risk of adverse noncarcinogenic effects. The RfD is significantly below the NOAEL and well below the LOAEL.

The regulatory processes used in setting the toxicity values are intended to be conservative in the face of uncertainty. As a result, the estimates of the RfD and CSF for PCBs are biased. That is, they are intended to be values that have a high probability of overestimating actual risks. The Task 3 report discuses the sources and magnitude of the biases.

The Level I Evaluation of PCB Exposures

In the level I evaluation, the project team characterized the exposure pathways by medium, selected conservative upper bound exposure parameter values, and developed exposure point concentrations in order to estimate potential PCB intakes. These intake estimates were then combined with toxicity values to estimate the risks associated with each pathway. These estimates of risk were compared to screening criteria to determine which pathways were most

likely to result in risks to off-site populations. The screening criteria or decision guides used were an excess cancer risk of 1 in 10,000 and a nominal hazard quotient (the estimated dose divided by the RfD) equal to 1 for noncancer health effects.

If risk estimates for pathways were below the decision guides, these pathways were set aside from further evaluation. Likely off-site populations were identified for those pathways for which the estimated risks exceeded the decision guides. Because of the conservative exposure and toxicity assumptions used in deriving these estimates of risk, the findings of the level I evaluation can not be taken as evidence of actual risk. The estimates are best viewed as indications of pathways that warrant additional study.

Exposure point concentrations (EPCs) for the level I evaluation were based on historical data from a variety of sources including TVA and DOE. These data were limited, particularly for years prior to the 1970s. Because this was a retrospective analysis, concentrations reported for any year were treated equally. Soil and sediment samples taken at depth were also considered, because these samples may represent historical EPCs. Because of the conservative nature of the level I evaluation, the EPCs for soil, sediment, surface water, drinking water, and aquatic biota were defined as the maximum total PCB concentrations for each medium for each water body. The EPCs for the direct air pathways were modeled using a Gaussian air dispersion model, SCREEN3. For the indirect air pathways, EPCs were established for vegetables, beef, and milk based on measured or estimated concentrations in various media.

Using site-specific information regarding historical activities and exposure pathways, the project team identified five potentially exposed populations during the screening evaluation:

- Farm families that raised beef, dairy cattle, and vegetables on the floodplain of EFPC;
- People who purchased beef and milk from cattle raised in the EFPC floodplain;
- Commercial and recreational fish consumers;
- Individuals that may have consumed turtles; and
- Users of surface water for recreational activities.

The sizes of these populations vary greatly. The number of anglers using EFPC and the number of farm families are expected to have been small, perhaps less than 20 individuals. In contrast, it is estimated that the number of individuals (anglers and their families) who consumed fish caught in Watts Bar and the Clinch River in the years since the ORR activities began is perhaps 100,000.

level I screening showed which pathways could have exceeded decision guides

Nine exposure pathways exceeded a decision guide in the level I evaluation. They are, for EFPC farm family members, ingestion of sediment, soil, and fish; ingestion of beef, milk, and vegetables that received PCBs from contaminated soil; drinking of milk that received PCBs from contaminated pasture; and contact with contaminated soil. For consumers of fish from Poplar Creek, the Clinch River, or Watts Bar Reservoir, ingestion of fish was the pathway that exceeded the decision guide. These pathways were further evaluated in a second assessment (level II evaluation). In focusing on the pathways that yielded doses above the decision guides, no judgement was made on the acceptability of the risks associated with the pathways that yielded doses below those guide values.

Instead, the project team focused its efforts to further refine exposures and risks on those pathways that exceeded the decision guides in order to focus project resources on those sources of exposure that had the highest potential for harm. The level I evaluation used a conservative

estimate of intake and risk to identify those pathways potentially associated with risks to off-site populations. This analysis was based on a determination of whether there was evidence that an individual in an exposed population could have a risk greater than the decision guides. No determination was made on how likely such a risk would actually occur or the fraction of the population exposed by a pathway would be affected. A proper evaluation of the risks to populations exposed by one or more pathways should focus on the heterogeneity of the population and the uncertainty in the estimates of exposure and risk.

The Level II Evaluation of PCB Exposures

All of the reference populations described above had large amounts of variation (heterogeneity) in the doses that specific individuals received. Certain individuals may have received trivial exposures, while others may have been significantly exposed. Therefore, it was critical to determine the fractions of the exposed groups received doses associated with levels of concern.

A second issue is the level of confidence that can be attributed to an estimate of exposure and risk. For certain pathways, there is a high confidence that exposure actually occurred; however, for others the evidence is suggestive but incomplete. PCB exposure from consumption of contaminated fish is well documented. In contrast, exposures to the families on farms that bordered EFPC are quite uncertain, because the extent of historical levels of PCB contamination in soils at the farms is largely unknown. Dose-response relationships for PCBs are also highly uncertain. Because of these uncertainties, it is important to determine the uncertainty in the estimates of risk made for various portions of the exposed populations.

The project team characterized the uncertainty and variation in risk to the individuals in the exposed populations. The level II evaluation characterizes the range of doses that plausibly occurred in the exposed populations. Similar to the level I analysis, simple dose models were used for each pathway. Doses were estimated across populations using Monte Carlo analysis.

In the level II evaluation, variability was directly modeled, and estimates of the distribution of doses in the population were directly determined. Uncertainty that occurred due to the lack of knowledge was addressed by using estimates of intake parameters that were biased with respect to uncertainty. Specifically, the parameter values were selected from the upper end of the range of plausible alternative values. The evaluation used the same toxicological criteria (RfD and cancer slope factor) as used in level I. These values overestimate cancer and noncancer risks. Thus, the distribution of cancer and noncancer risks across the population are believed to be overestimates of the distribution of actual risks in the populations.

The goal of the level II evaluation was to identify those exposed populations where there was some chance that a small fraction (five percent) of the population received risks in excess of the decision guides. Populations where this was not true were set aside and the remaining populations were subject to additional analyses. The additional analyses included a quantification of the uncertainty in the hazard assessment. In certain populations with risks in excess of the guides, there was insufficient information to allow additional assessments. When this occurred, the lack of information was identified as a critical data gap and was included in recommendations for further work.

The level II assessment evaluated risks to recreational and commercial fish consumers, farm families, and recreational users of surface water bodies near the ORR. Where a population was exposed via multiple pathways, the total intake received from all pathways was estimated. Distributions for those exposure parameters believed to make a significant contribution to the variation in the dose rate were developed, based on the range of available data, by fitting available data to various distribution types (e.g., normal, lognormal) according to accepted methods. Summaries of the parameter values and distributions used for each population, as well as the assumptions and rationale on which they were based, are presented in the Task 3 report.

The level II evaluation demonstrated that there was considerable variation in both noncarcinogenic and carcinogenic risk estimates for all of the populations evaluated. The risks to adults and children did not differ greatly and, in most cases, the ranges in the risk estimates overlapped. Adults tended to have slightly higher cancer risks because their longer exposure durations resulted in higher lifetime average daily doses. Noncancer risks also tended to be slightly higher. The estimates of risk for the median (50th percentile) and 95th percentile of the cumulative distribution of exposures in each population are presented in Table 4-1 and 4-2. The majority of the exposures for certain populations (other than those along EFPC) occurred from PCB sources other than the ORR. Estimates of cancer risk from a source of PCBs are directly proportional to the relative contribution of that source. Table 4-1 includes estimates of cancer risks fromORR releases as well as all sources for certain populations. It is more difficult to separate the relative contribution of the ORR releases for estimates of noncancer risks, because the impact of the additional exposure is a function of the level of exposure from other sources.

Because the sizes of the groups of fish consumers were determined and the distribution of risks was calculated for each population, the analysis also determined the number of excess cases of cancer that would be expected to occur in the populations. Fewer than three excess cases of cancer are expected to occur in the populations of recreational anglers who fished the Clinch River and Watts Bar since the late 1940s. Because the carcinogenic potency of PCBs assumed in this study is thought to overestimate risk, the actual number of cases is expected to be lower and may be zero. No cases are expected to occur in groups other than the recreational anglers because of the small sizes of these populations.

the level II analysis showed which populations could have had 5% or more of members above a decision guide

Results of the Level II Evaluation

The dose reconstruction results for each population of interest, stated in terms of the estimates of health risk given in Tables 4-1 and 4-2, can be summarized as follows:

Recreational Fish Consumers

Cancer and noncancer risks for recreational fish consumers at EFPC were lower than for the other bodies of water. Risks for both adults and children were below the decision guides (with the exception of children at the 95th percentile where the nominal hazard quotient was 2 in level II evaluation). The lower fish consumption rates for EFPC, based on its poor quality as a fishery, accounted for the lower risk estimates.

The risks for recreational anglers using Clinch River/Poplar Creek were higher than those at EFPC. The cancer risk for adults at the 95th percentile was 3×10^{-4}. The cancer risk estimate for children at the 95th percentile was less than the decision guide of 1×10^{-4}. The nominal hazard quotient exceeded the noncancer guide of one for both adults and children at the median and 95th percentile in level II evaluation.

Recreational anglers using Watts Bar had the highest cancer and noncancer risks of the three water bodies due to higher levels of PCBs in the fish and greater fish consumption rates. The cancer risk estimate for adults was 6×10^{-4} at the 95th percentile and for children was 1×10^{-4} at the 95th percentile.

Similar to the Clinch River/Poplar Creek analysis, the nominal hazard quotients for Watts Bar Reservoir in the level II evaluation exceeded the noncancer guide of one for both adults and children at the median and 95th percentile.

Table 4-1: Summary of Cancer Risks Evaluated in the Level II Analysis[a]

Population	Waterway					
	Adult			Child		
	East Fork Poplar Cr.	Watts Bar Reservoir	Clinch River/ Poplar Creek	East Fork Poplar Cr.	Watts Bar Reservoir	Clinch River/ Poplar Creek
Recreational Fish Consumer (All Sources)						
95th Percentile[b]	--[c]	6×10^{-4}	3×10^{-4}	--[c]	1×10^{-4}	5×10^{-5}
Median	--[c]	4×10^{-5}	2×10^{-5}	--[c]	1×10^{-5}	5×10^{-6}
Recreational Fish Consumer (ORR Releases)						
95th Percentile	1×10^{-5}	8×10^{-5}	2×10^{-4}	4×10^{-6}	1×10^{-5}	3×10^{-5}
Median	8×10^{-7}	5×10^{-6}	8×10^{-6}	3×10^{-7}	1×10^{-6}	2×10^{-6}
Commercial Angler (All Sources)						
95th Percentile	--[d]	4×10^{-5}	2×10^{-5}	--[d]	9×10^{-5}	2×10^{-5}
Median	--[d]	4×10^{-6}	2×10^{-6}	--[d]	1×10^{-5}	1×10^{-6}
Commercial Angler (ORR Releases)						
95th Percentile	--[d]	5×10^{-6}	1×10^{-5}	--[d]	1×10^{-5}	8×10^{-6}
Median	--[d]	5×10^{-7}	8×10^{-7}	--[d]	1×10^{-6}	7×10^{-7}
Farm Family						
95th Percentile	2×10^{-3}			9×10^{-4}		
Median	1×10^{-4}			1×10^{-4}		
Recreational User						
95th Percentile	4×10^{-7}			2×10^{-7}		
Median	3×10^{-8}			2×10^{-8}		

[a] Estimated risks for all sources include sources of PCBs other than the ORR.
[b] Numbers are expressed in scientific notation; for example 5×10^{-8} equals 0.00000005.
[c] There are no identified sources of PCB releases to EFPC other than the Y-12 Plant.
[d] There has been no commercial fishing of EFPC.

Table 4-2. Summary of Noncancer Risks (Hazard Quotients) Evaluated in the Level II Analysis[a]

Population	Waterway					
	Adult			Child		
	East Fork Poplar Cr.	Watts Bar Reservoir	Clinch River/ Poplar Creek	East Fork Poplar Cr.	Watts Bar Reservoir	Clinch River/ Poplar Creek
Recreational Fish Consumer						
95th Percentile	1	40	20	2	60	30
Median	0.1	4	2	0.2	5	2
Commercial Angler						
95th Percentile		40	6		50	7
Median		4	0.6		5	0.7
Farm Family						
95th Percentile	100			200		
Median	20			40		
Recreational User						
95th Percentile	0.05			0.09		
Median	0.005			0.01		

[a] Hazard quotients include the contribution of PCB sources other than the ORR and are based on the reference dose for Aroclor 1254 established by EPA.

As discussed earlier, the contribution of ORR PCB releases likely represented 9-13 % of the total amount of PCBs in Watts Bar. Therefore, at most 13% of the total cancer risk for recreational anglers using Watts Bar was attributable to the ORR. Because 13% of 6×10^{-4} is less than 1×10^{-4}, ORR releases do not appear to have resulted in cancer risks that exceed the guides.

The percentage of PCBs in the Clinch River that is attributable to the ORR releases is not as well defined. Up to one half of the PCBs in Clinch River fish may have been contributed by other sources on the Clinch River. However, even if half the PCBs were contributed other sources, the ORR releases appear to have resulted in risks above the cancer decision guide.

Commercial Anglers

In general, the risks to commercial anglers were similar to, but slightly lower than, risks estimated for recreational fish consumers. At the 95th percentile, all of the cancer risks for these populations were equal to or less than 1×10^{-4}. The nominal hazard quotients for the 95th percentile adult and child were greater than one for the Clinch River/Poplar Creek anglers and were higher for the Watts Bar Reservoir anglers in the level II evaluation.

As with recreational fish consumers, risks for commercial anglers are affected by other sources of PCBs along the rivers.

EFPC Farm Family

The estimates of cancer and noncancer risks were higher for the farm family population than the fish consumer groups. Cancer risk estimates at the 95th percentile for both adults and children exceeded the cancer decision guide. Nominal hazard quotients exceeded the noncancer decision guide for the entire range of the level II uncertainty analysis. It should be noted, however, that the actual concentrations of PCBs in soil at the farms were highly uncertain, and this uncertainty could not be characterized because of a lack of data. Thus, these estimates may not be representative of true hazards associated with those populations.

EFPC Recreational Users

Both the noncancer and cancer risks for the recreational users of EFPC were below the decision guides; at the 95th percentile, cancer risks for adults and children were 4×10^{-7} and 2×10^{-7}, respectively. Nominal hazard quotients for both age groups were also less than one.

Conclusions from the Level II Evaluation of PCB Exposures

Based on the results of the level II evaluation, the following conclusions were reached:

- Populations exposed from recreational use of EFPC do not appear to warrant additional assessment. The conservative estimates of cancer and noncancer risks developed in the level II evaluation did not exceed the decision guides at the 95th percentile.
- Exposures to PCBs from the consumption of fish in EFPC were also low. Cancer risks were well below the cancer guide. The adult angler was at the noncancer guide and the child angler was slightly above the guide. Given the limited productivity of the creek and the uncertainty in the estimates of fish consumption, no additional analyses were performed.
- Cancer and noncancer risks for the farm families greatly exceeded the decision guides. Thus, this population could be at risk from their PCB exposures and should be considered in additional analyses. However, the estimates of PCB exposures used in the assessment are highly uncertain due to the limited data on PCB levels in the farm soils. PCB levels in the sediments and flood plain of EFPC have been characterized to at least some degree in recent remedial investigations; however, the ranges of PCB concentrations historically present

in the soils of the fields, pastures, gardens, and areas around the farm houses themselves were not investigated. Because of this data gap, Task 3 investigators were unable to further assess risks to the families.

- Risks to the commercial and recreational anglers using Watts Bar and the Clinch River were similar, suggesting that future assessments need not separate the groups. The carcinogenic risks to each population were above the decision guide. However, when the contribution of the ORR was considered, risks at the 95th percentile were smaller and in the case of Watts Bar were below the decision guide. The Clinch River anglers at the 95th percentile exceeded the guide by a factor of less than two. In addition, the estimate of the total number of cancer cases expected for all populations is small (less than three). Based on these findings, the team did not believe that additional effort to characterize the uncertainty in the carcinogenic risk estimates was warranted. Therefore, no additional work was performed on assessing the carcinogenic effects for these angler populations.

The Level III Evaluation of PCB Exposures

The level III evaluation of PCB exposures was performed on recreational anglers fishing Watts Bar and the Clinch River and the children of these anglers. No additional modeling was performed for the commercial angler because their risks in the level II evaluation appeared to be similar or slightly lower than those estimated for recreational anglers. Thus, the level III evaluation for recreational anglers is applicable to commercial anglers as well.

The assessment of noncancer effects in the level II evaluation suggests that the majority of commercial and recreational anglers may have been at risk. The vast majority of anglers had nominal hazard quotients that were greater than one. However, the current noncancer decision guide is based on the assumption that any dose that exceeds the RfD is of some toxicological concern. It is not clear that findings of nominal hazard quotients greater than one (i.e., a dose greater than the RfD) imply the occurrence of adverse effects.

The Task 3 report presents a characterization of the population threshold for the noncarcinogenic effects of PCBs and uses the characterization to better estimate noncarcinogenic risk. A population threshold is the highest dose that does not cause an adverse effect in an individual who is uniquely sensitive to PCBs. The project team characterized this threshold using EPA's methodology for setting RfDs and replacing the safety factors with distributions. The distributions were based on a review of the available literature on generic approaches and by the development of a PCB-specific distribution. The PCB-specific distribution is believed to present the best use of the available toxicological data on PCBs.

As discussed above, the level II evaluation was biased with respect to the uncertainty in the estimate of dose rates and dose response. In the level III evaluation, this uncertainty is quantitatively evaluated along with the information on the variation in dose rates developed in the level II evaluation. Over the past five years, techniques have been developed for modeling both the uncertainty and variability of dose rates in exposed populations. One technique, called two-dimensional Monte Carlo, uses a "nested loop" technique that requires additional model development and computer resources. The result is the distribution of risk estimates across the exposed populations and the uncertainty bounds on those estimates. These estimates take into account the uncertainty in the estimates of dose and of the population threshold of PCB effects.

In the Level III assessment, the risks are characterized as the ratio of the fish consumer's dose to the actual population threshold. This ratio is referred to as the *"true" hazard quotient*. Because the estimates of the population threshold and the dose received are uncertain, the true hazard quotient is described in terms of probability. For example, an angler having an particular estimated exposre may be described as having a 50% chance of having a true hazard quotient

less than 0.1 and a 95% chance of having a true hazard quotient less than 0.5. This uncertainty corresponds to the range of values of the population threshold that is consistent with present toxicology of Aroclor 1254.

The two-dimensional analysis of noncancer risk estimates further characterized risks by: 1) determining the distribution of true hazard quotients across the population; 2) calculating the fraction of the population receiving doses above the threshold of PCB effects; and 3) evaluating the incremental contribution made by ORR releases to the risks from PCBs from other sources.

Results of the Level III Evaluation of PCB Exposures

Table 4-3 presents the results of the level III evaluation. These estimates of the true hazard quotients provide a more unbiased estimate of noncancer risk than given in Table 4-2. As a result, the values tend to be much lower than the earlier estimates of the nominal hazard quotients. The true hazard quotients indicate that the typical (median exposure) fish consumer for either water body is not at risk (true hazard quotient is less than one). The highly exposed (95th percentile) angler may be at risk, because the estimates of the true hazard quotients could exceed one.

The confidence intervals of the hazards indices calculated for each of the reference populations addressed in Level II or Level III assessments of exposures to PCBs are shown in Figure 4-1. These 90% confidence intervals are plotted along with the LOAEL value that is used by the USEPA as the basis for the RfD for Aroclor 1254.

While the risk of noncancer effects can be evaluated in terms of true hazard quotients, the risks can also be evaluated more directly in terms of the fraction of the population that have received doses that exceed the population threshold (Table 4-4). The results of this assessment indicate that portions of the angling populations with very high fish intakes, several percent for Watts Bar and a few percent for the Clinch River, may have received doses in excess of the population threshold. Depending on the unknown value of the population threshold, this finding is likely for Watts Bar and possible for the Clinch River. However, it is not possible to determine the fraction of the population that actually experienced adverse effects. Because of inter-individual variation in the tolerance to PCBs, the dose needed to cause an adverse effect in a typical person is higher than the dose that affects sensitive individuals. A small fraction of those who receive doses above the population threshold are likely affected.

> the level III analysis yielded distributions of risk across populations and uncertainty bounds

In order to investigate the impact of the ORR releases of PCBs relative to those from other sources, the exposure model calculations were done with and without the ORR contribution, and incremental changes noted. The analysis indicated that PCB contamination from non-ORR sources resulted in some anglers receiving doses greater than the population threshold. The releases from the ORR resulted in a small increase (1 to 2 percent of fish consumers) in the fraction of individuals receiving doses greater than the population threshold (Table 4-4). Had the ORR releases happened in the absence of the other sources, they would not likely have resulted in adverse effects.

The PCB study team recommended that additional studies of fish consumption rates be undertaken, to reduce critical uncertainties and provide a clearer understanding of the portion of the population that exceeded the threshold dose. The project team also recommended that additional soil and sediment sampling, modeling of PCB exposures to Watts Bar anglers, and modeling of PCB dose responses in humans be undertaken.

Table 4-3: Summary of Noncancer Risks (True Hazard Quotients)[a] from the Level III Analysis

Population	Waterway	
	Watts Bar Reservoir	Clinch River/ Poplar Creek
Adult Recreational and Commercial Fish Consumers		
95th Exposure Percentile	1 (0.2-8)[b]	0.5 (0.08-3)
Median Exposure	0.1 (0.02-0.5)	0.05 (0.008-0.3)

[a] True hazard quotients include PCB sources other than the ORR, and are based on the population threshold for PCBs.

[b] Estimate of the true hazard quotient with 90% confidence limits.

Table 4-4. Percent of Population Receiving a Dose Above the PCB Population Threshold

Watts Bar Fish Consumer (Adult)			
	Background[a, b]	Background + ORR	Change Due to the ORR
Refined Empirical Distribution[c]	5.0 (0.61-39)	6.6 (0.82-43)	1.6
Watts Bar Fish Consumer (Child)			
	Background	Background + ORR	Change Due to the ORR
Refined Empirical Distribution	7.5 (0.92-44)	8.9 (1.4-48)	1.4
Clinch River/Poplar Creek Fish Consumer (Adult)			
	Background	Background + ORR	Change Due to the ORR
Refined Empirical Distribution	0.55 (0-9.7)	2.2 (0-21)	1.7
Clinch River/Poplar Creek Fish Consumer (Child)			
	Background	Background + ORR	Change Due to the ORR
Refined Empirical Distribution	0.97 (0-15)	3.8 (0-29)	2.8

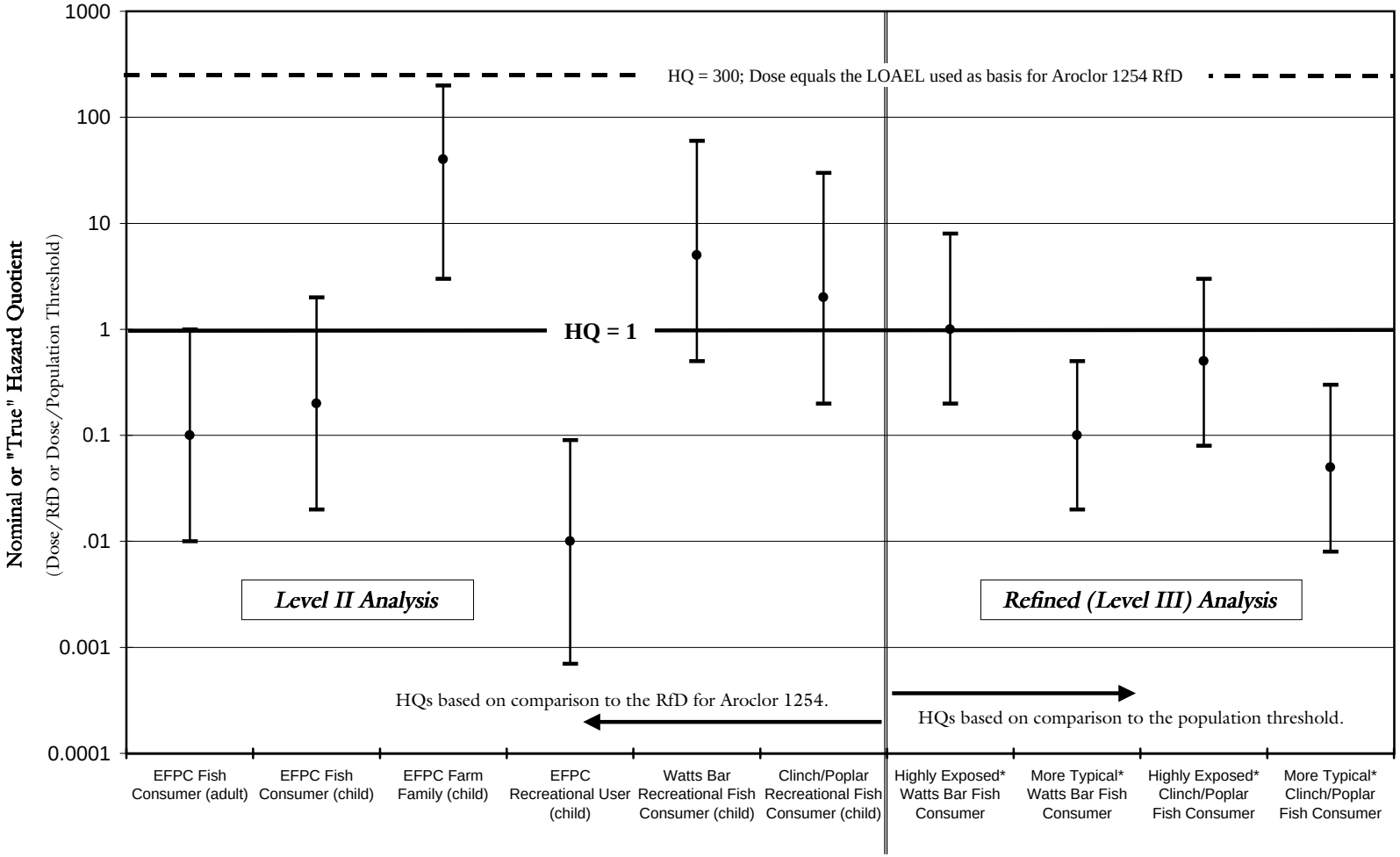
[a] Background includes risks associated with PCB releases attributable to sources other than the ORR. Based on the HydroQual analysis, 87% and 50% of the total PCB concentration in Watts Bar and the Clinch River/Poplar Creek, respectively, is assumed to be associated with other sources.

[b] Median value (90% confidence limits); values reported to 2 significant figures.

[c] A set of population threshold distributions that reflect information on PCB toxicity.

Figure 4-1: Confidence Intervals of Hazard Quotients (HQs) Calculated for PCB Exposures

(Confidence intervals are represented by 5th, 50th, and 95th percentile values)



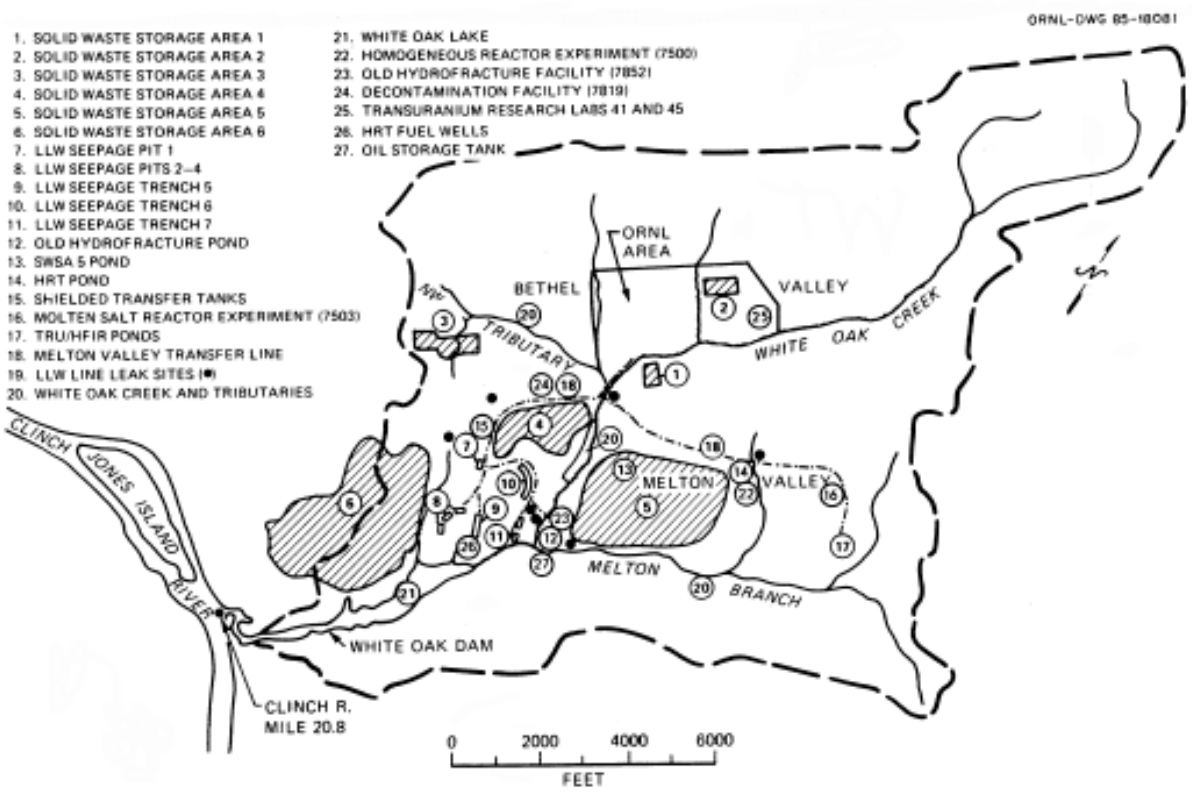
*The highly exposed fish consumer is represented by the 95th percentile of the population; the more typically exposed consumer is represented by the 50th percentile.

5. RADIONUCLIDES RELEASED FROM X-10 TO THE CLINCH RIVER VIA WHITE OAK CREEK

In the early days of the Manhattan Project, Clinton Laboratory, also referred to as the X-10 Site and now called Oak Ridge National Laboratory, was designed to operate for one year as a pilot plant for the Hanford, Washington, operations for chemical separation of plutonium. All radioactive wastes generated from the X-10 pilot plant were to be stored in large, underground tanks. The original plans changed, and in 1944 the first radioactive effluents from the X-10 site entered White Oak Creek and flowed into White Oak Lake. White Oak Lake served as the final settling basin for contaminants released to White Oak Creek. Radionuclides remaining suspended in the water were released from the X-10 site via the flow over White Oak Dam, which is located 1 km (0.6 mile) upstream from the Clinch River.

Sources of Radioactive Waste

During early X-10 operations, the chemical separation pilot plant was the major source of radioactive wastes. Some liquid wastes from the pilot plant were placed in open waste pits dug in the earth; ^{106}Ru began seeping from the pits into White Oak Lake in 1959. Strontium-90 and ^{137}Cs had also been placed in the pits, but these isotopes were retained by nearby soils; however, amounts of ^{106}Ru as high as 7.4×10^{13} Bq (2,000 curies) per year were reportedly released from White Oak Dam from 1959 to 1963. From 1944 to 1991, approximately 5.9×10^{15} Bq (160,000 curies) of radioactivity were released past White Oak Dam to the Clinch; of this amount, 91% was tritium, and the rest was fission and activation products.



Locations of the X-10 Site (ORNL) and relevant radioactive waste facilities in relationship to White Oak Creek, White Oak Lake, and the Clinch River. The "Solid Waste Storage Areas" are shallow-land burial grounds for radioactive waste.

It appears that a secondary source of radionuclide releases to the Clinch River was the scouring of contaminated sediment from White Oak Creek Embayment, the stretch of White Oak Creek between the dam and the Clinch River. After White Oak Lake was drained in 1955, heavy rainfall eroded the exposed bottom sediment, resulting in the relocation of particle-bound radionuclides (primarily ^{137}Cs) to White Oak Creek Embayment. Periodic discharges of water from Melton Hill Dam, which was completed up-river on the Clinch in 1963, resulted in the backflow of water up White Oak Creek Embayment and transport of contaminated sediments into the Clinch River. A coffer cell dam was constructed at the mouth of White Oak Creek in 1990 to prevent the backflow of water up White Oak Creek Embayment. While releases of embayment sediment essentially ceased at that time, releases of waterborne radionuclides continue, albeit at levels much reduced from earlier decades.

The purposes of Task 4 of the Oak Ridge Dose Reconstruction were to:

- Estimate the historical releases of radionuclides from the X-10 facility to the Clinch River,
- Evaluate the potential pathways by which members of the public could have been exposed to radioactivity in the Clinch River from 1944 to 1991, and
- Calculate radiation doses and health risks to reference individuals who were potentially exposed to radioactivity released to the Clinch River from the X-10 complex.

Direct measurement of the amounts of radionuclides taken up by the organs of specific individuals since 1944 is no longer feasible, because most of these radionuclides have short residence times in the human body. Therefore, a dose reconstruction was necessary to estimate past exposures and to interpret the health consequences of these exposures. This dose reconstruction relied upon independent evaluations of the amounts of radionuclides released, reported environmental measurements, and mathematical modeling to estimate past doses and health risks.

Preliminary Screening Analysis

Twenty-five radionuclides released into the Clinch River from the X-10 site from 1944 to 1991 were considered as potential contaminants of concern. To focus time and resources on the radionuclides that were most likely to have been important in terms of dose or risk to off-site individuals, a conservative screening evaluation was conducted. The screening analysis identified those radionuclides and pathways for which the estimated human health risk was below a minimum level of concern. Nine exposure pathways and 16 radionuclides, including uranium and tritium, were given low priority for further consideration because conservative screening estimates were at least a factor of ten below the decision guide of one chance in ten thousand for carcinogens. Of the eight remaining radionuclides, ^{137}Cs, ^{60}Co, ^{106}Ru, and ^{90}Sr were expected to be the most important contributors to radiation dose and subsequent excess health risk.

Radionuclides Released from White Oak Dam

A detailed investigation was performed to identify the methods used for measurements of waterborne radioactivity at White Oak Dam, the methods used for estimation of flow rates at White Oak Dam, and the uncertainties associated with these two types of measurements. Estimates of the quantities of radionuclides historically released from White Oak Dam were based on information from laboratory documents, log books, and interviews with personnel who were responsible for, or involved in, collection and/or analysis of samples of releases from White Oak Dam. Measurements of concentrations of specific radionuclides released from White Oak Dam were available for all years except 1944 to 1948. For these years, releases were calculated based on the estimated fraction that each radionuclide contributed to estimated releases of gross beta-

emitting radioactivity. Annual estimates of releases (source terms) were developed for the following radionuclides: cobalt-60, strontium-90, niobium-95, zirconium-95, ruthenium-106, iodine-131, cesium-137, and cerium-144. The uncertainties of the source terms vary over time. Factors were applied by the project team to account for uncertainty and/or bias introduced by: 1) methods used to back-fit gross beta releases to specific radionuclides, 2) scaling of White Oak Creek flow rates from the Little Chestuee, 3) White Oak Creek flow measurements, 4) flow rate estimation when White Oak Lake was drained, 5) use of non-proportional sampling rates, 6) laboratory processing, 7) detector efficiency, and 8) counting statistics. Peak annual releases for these radionuclides, as well as indications of the lengths of their periods of highest releases, are shown in Table 5-1.

Table 5-1: Summary of Peak Annual Releases for the Eight Key Radionuclides

	Peak Annual Release (curies)			Number of Years at
Radionuclide	Lower Bound	Central Estimate	Upper Bound	10% of Peak Release or More
Cs-137	50	200	510	14
Ru-106	1,600	2,100	2,700	5
Sr-90	68	190	390	18
Co-60	64	85	110	15
Ce-144	70	94	120	13
Zr-95	72	210	440	9
Nb-95	17	200	520	10
I-131	10	68	190	10

Estimated Concentrations in Water & Sediments

Measured concentrations of radionuclides in water are available for many years for several locations downstream from where White Oak Creek enters the Clinch River. These measurements varied somewhat in their locations and methods of measurement, and did not include all the radionuclides of concern. Therefore, mathematical modeling was performed to estimate annual average concentrations of radionuclides in water at specific locations downstream of White Oak Creek. A modified version of the HEC-6 aquatic transport model, called HEC-6-R, was used to estimate historical water concentrations. The estimates of annual releases of specific radionuclides from White Oak Dam were used in the modeling analysis. The uncertainty of the modeled water concentrations was much higher than the uncertainty of water concentrations obtained from measurements; therefore, measurements from specific locations and time periods were used when possible rather than model predictions when there were enough measurements to estimate annual concentrations in water. In particular, the model did not always account well for scouring of sediment after Melton Hill Dam began operation in 1963.

Concentrations of radionuclides in river sediment were estimating using the HEC-6-R model to track the sediment inventory in various sections (reaches) of the Clinch River over time. Measurements made in the 1990s were used to calibrate the sediment concentration estimates. Because of the limited availability of measurements, all sediment concentrations used in the risk assessment were based on model estimates.

Estimation of Exposures to Reference Individuals

For all locations addressed in this study, the exposure pathways of interest included ingestion of fish, milk, and meat; other exposure pathways of interest varied with location. For the **Jones Island area** [Clinch River Mile (CRM) 21 to 17], the exposure pathways of interest were ingestion of fish, meat, and milk, plus external exposure from standing on or near shoreline sediment. The exposure pathways for the **K-25/Grassy Creek area** [CRM 17 to CRM 5]

included ingestion of fish, meat, milk, and drinking water, plus external exposure to shoreline sediment. For the **Kingston Steam Plant area** [CRM 5 to CRM 2], the important pathways were ingestion of drinking water, fish, meat, and milk, plus external exposure to shoreline sediment. Exposure pathways for residents of **Kingston** [CRM 2.0 to CRM 0.0] included ingestion of drinking water, fish, and milk and meat from livestock who drank river water, plus external exposure to shoreline sediment. The four reference locations along the Clinch River that were assessed in the dose reconstruction can be seen Figure 1-1.

For each exposure pathway, reference populations were identified, with varying characteristics and population sizes. There were three categories of fish consumers:

- People in Category I were assumed to eat fish regularly, that is from 52 to 130 meals/year,
- People in Category II were assumed to eat from 12 to 52 meals/year, and
- People in Category III were assumed to eat from 2 to 17 meals/year.

The categories differ slightly from those used for the mercury dose reconstruction; the categories for the mercury assessment were changed so that they do not overlap. For all categories, it was assumed that 20 to 100% of the fish eaten was contaminated, and that 80 to 90% of the radioactivity in the fish was retained after processing for consumption.

Two reference individuals, an adult and a child, were considered for the water ingestion pathway. Children were not considered for the K-25/Grassy Creek area or the Kingston Steam Plant area, because these are industrial facilities and it is not likely that children would have drunk water from these locations. However, both children and adults were exposed via the Kingston water supply. Multiple reference individuals were considered for the milk ingestion pathway, including children who drank different amounts of home-produced milk depending on whether they were at home or in school. Adults were considered for meat ingestion and external exposure from contaminated sediment.

Water sampling at White Oak Dam (1949)

Estimation of Organ-Specific Radiation Doses

The International Commission on Radiological Protection (ICRP) developed a method for calculating radiation doses to people ingesting contaminated food or water. To reflect variability among individuals, ranges of values were developed for the factors that specify the dose per unit intake for given radionuclides. For ^{137}Cs, ^{60}Co, and ^{106}Ru, the ICRP ingestion dose factors were modified by applying several uncertainty factors, the values of which depended on the radionuclide and organ of interest. New dose conversion factors and their uncertainties were calculated for ^{90}Sr and ^{131}I for all internal organs of importance using the ICRP methodology. Each factor was specified as a range of values rather than a point estimate.

Doses from Fish Ingestion

The estimated organ doses to people who ate fish exceeded the dose estimates for all other pathways. The highest doses were for Category I fish eaters just below where White Oak Creek enters the Clinch River. Central values of the cumulative doses for 1944 to 1991 for specific organs ranged from 0.31 centisievert (cSv) to the skin to 0.81 cSv to the bone for males and from 0.23 (skin) to 0.60 cSv (bone) for females. One cSv equals 1 rem. The 95% subjective confidence intervals ranged from about 0.02 to 8 cSv. Organ doses were generally lower for females than for males, due to the lower ingestion rates assumed for females. For Category I fish eaters near Kingston, organ doses are about a factor of 8 to 9 lower than those estimated for the area near Jones Island. Estimated organ doses for Category II and III fish eaters are lower than those for Category I in proportion to the lower consumption rates for these categories.

Doses from Other Exposure Pathways

Organ doses from external exposure were about a factor of 1.1 to 3.5 lower than the doses to a Category I fish eater near K-25/Grassy Creek, with the largest doses to skin, bone, and thyroid. Adults who spent time along the shoreline but who seldom ate fish probably received the same or higher organ doses from external exposure as from eating fish.

For most organs, doses from drinking water near K-25/Grassy Creek and the Kingston Steam Plant were lower than the doses from external exposure at the same location. However, for the large intestine, bone, and red bone marrow, the doses from drinking water were higher than those from external exposure or eating fish (by Category II or III consumers) due to the presence of ^{90}Sr and ^{106}Ru.

Estimated doses from ingestion of meat and milk were lower than those for ingestion of drinking water by factors of about 10 to 1,000. The highest doses were to the large intestine, bone, red bone marrow, and (for the ingestion of milk) the thyroid gland.

Thyroid Doses to a Child from Drinking Water and Milk

The 95% subjective confidence interval for the doses to a child age 14 or below drinking milk near K-25/Grassy Creek or the Kingston Steam Plant were 0.00058 to 0.054 cSv (0.0062 central value) and 0.00055 to 0.042 cSv (0.0044 central value), respectively. The 95% subjective confidence interval for the estimated drinking water dose for a child living in Kingston was 0.000039 to 0.0021 cSv (0.00031 central value), and for the combined pathways (drinking water and milk), 0.00014 to 0.0047 cSv (0.00091 central value). The exposure time for a child drinking water was shorter than that for milk because the Kingston municipal water supply did not become a potential source of contamination until 1955.

Estimates of Excess Lifetime Risk of Cancer Incidence

Organ dose estimates were used to estimate organ-specific and total excess lifetime risks of cancer incidence. The estimates of cancer incidence per unit dose were based on cancer incidence data from the Japanese atomic bomb survivors, background incidence rates for cancer in eastern Tennessee, and the use of relative and absolute risk models to transfer epidemiologic findings in the atomic bomb survivors to people exposed to radionuclides released to the Clinch River. The uncertainty due to differences in responses between exposures at high dose rates and low dose rates was considered explicitly in the calculation of risks for each organ.

Cancer Risks from Fish Ingestion

For any given location, risks of excess lifetime cancer incidence for Category II and III fish eaters are lower than those for Category I consumers by factors of about 2 and 8, respectively, in proportion to the lower intake rates assumed for these categories (Figure 5-3). Upper bounds on the total risk from fish consumption for Category I fish eaters exceed 1×10^{-3} at Jones Island

and 1×10^{-4} at reference locations farther downstream (Figure 5-4). Central estimates exceed 1×10^{-4} at Jones Island for Category I and II fish eaters; they are between 1×10^{-5} and 1×10^{-4} for most other cases addressed, except for Category III fish eaters farther downstream than Jones Island, for which they fall between 1×10^{-6} and 1×10^{-5}.

For ingestion of fish from the Jones Island area, the upper bounds on the risk for both males and females were highest (exceeding 1×10^{-4}) for bladder, stomach, lower large intestine, lungs, and red bone marrow (leukemia). For females, the upper bound on the risk estimates for breast also exceeded 1×10^{-4}, as did the liver for males. Although the breast received among the lowest doses, the breast has the highest risk of all the organs examined. For females, the highest risks are for breast and red bone marrow (central values of 5.5×10^{-5} and 2.8×10^{-4}, respectively); for males, the highest risk is for the red bone marrow (central value of 3.7×10^{-5}). The difference between the highest and lowest organ-specific risks at any one location is about a factor of 70 to 80 for females and 40 for males, although the differences in doses were only a factor of 2 to 4. This situation illustrates the great difference in organ sensitivities to radiation-induced cancer, and underlines the importance of calculating risks as well as doses in a dose reconstruction study, because the organ with the highest dose may not be the organ at highest risk.

For Category I fish eaters near Jones Island, the 95% subjective confidence interval of the total excess lifetime risk of cancer incidence for all radionuclides and organs was 3.6×10^{-5} to 3.5×10^{-3} (2.8×10^{-3} central value) for males and 2.9×10^{-5} to 2.8×10^{-3} (2.3×10^{-4} central value) for females. The difference in risk between males and females reflects primarily the difference in meal sizes. For both males and females, the largest contribution to the total risk (about 90%) is from ^{137}Cs.

For individuals using or living on Watts Bar Reservoir, the exposures, doses, and risks are substantially lower than those for individuals using any segment of the Clinch River. The best estimate is that exposures from the past consumption of contaminated fish in Watts Bar Reservoir are 4 to 25 times less than for people eating fish from the Clinch River near the K-25/Grassy Creek area, assuming similar ingestion rates.

Cancer Risks from Other Exposure Pathways

Depending on the location, the external radiation dose from shoreline sediments contributes as much as 90% of the total risk from all pathways for a Category III fish eater; fish ingestion contributes about 10%, and drinking water from 2% to 30% of the total risk of cancer incidence. For Category II fish eaters, fish ingestion contributes 30% to 40% of the total risk, depending on location, and for Category I, about 50-60%, except for near Jones Island, where the external exposure is low and exposure via drinking water did not occur. For the drinking water or external exposure pathways alone, and combining all pathways for a Category III fish eater, upper bounds barely exceed 1×10^{-4}.

Risks of Thyroid Cancer for a Child Who Drank Water and Milk

The highest excess lifetime risk of thyroid cancer for a child who drank water and milk occurred for a girl who drank milk obtained from an area near K-25/Grassy Creek (95% subjective confidence interval, 1.1×10^{-7} to 2.5×10^{-5}; central value, 1.8×10^{-6}).

Risk Estimates for Shorter Exposure Periods

In most cases, individuals were not exposed to the various pathways over the entire period from 1944 to 1991. In addition, both the operations at the X-10 site and the releases of radionuclides to the Clinch River changed over time. To account for more realistic exposure times, risks were summarized by decade. The first two decades (1944-1953 and 1954-1963) produced the highest risks for each pathway and from all pathways combined (Figure 5-5). In the first decade, the ingestion of fish dominated the total risk; however, external exposure to shoreline sediments became increasingly important in later years. Because the ingestion of fish and exter-

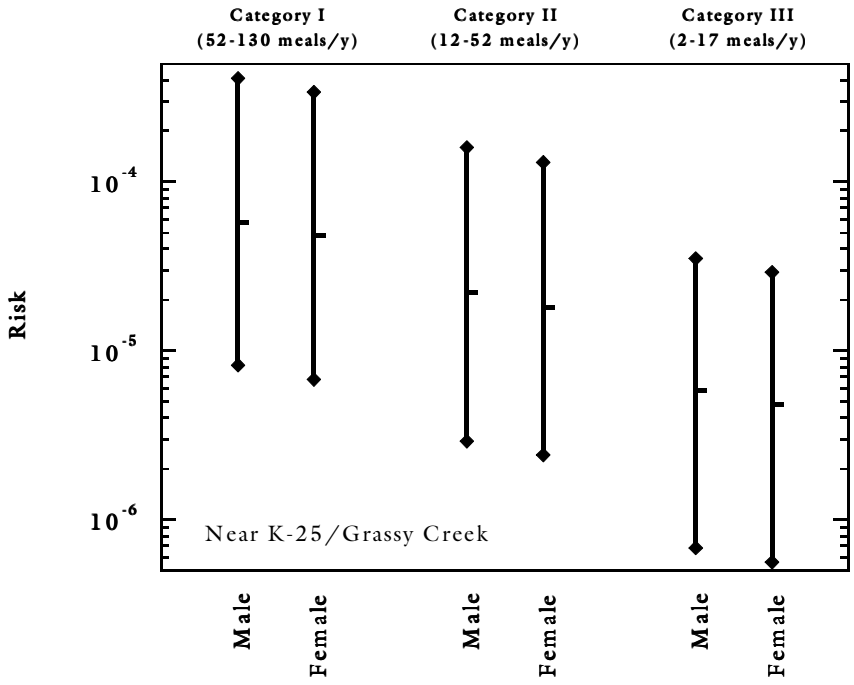


Figure 5-3: Excess lifetime risk of cancer incidence for males and females consuming fish from the Clinch River near K-25/Grassy Creek. The vertical lines indicate the 95% subjective confidence intervals of the estimated risks; the central estimates (50th percentiles) are also indicated.

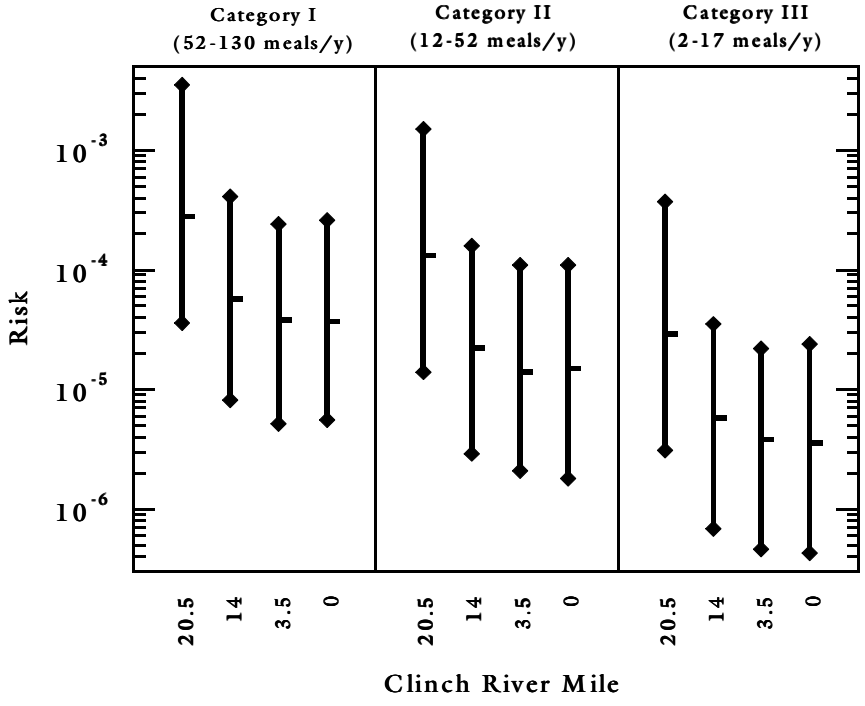


Figure 5-4: Excess lifetime risk of cancer incidence from all exposure pathways for three reference males eating fish at different rates at reference locations along the Clinch River [CRM 20.5 = Jones Island Area; CRM 14 = K-25/Grassy Creek Area; CRM 3.5 = Kingston Steam Plant Area; CRM 0 = Kingston Area]. The vertical lines indicate the 95% subjective confidence intervals of the estimated risks; central estimates (50th percentiles) are also shown. Risks for females are slightly lower than for males (See Figure 5-3).

nal exposure to shoreline sediments contributed most of the excess lifetime risk of cancer incidence, ^{137}Cs was the dominant radionuclide in all decades. In addition to risk estimates by decade, estimates of total risk per year at near K-25/Grassy Creek were also made in terms of risk per pound of fish eaten, hour of exposure to shoreline sediment, and liter of water drank.

Contribution to Uncertainty in the Risk Estimates

For all locations and ingestion rates examined, the dominant sources of uncertainty in the risk from fish ingestion are the concentration of ^{137}Cs in fish and the amount of fish eaten. The relative importance of a specific parameter depends on the location of exposure and the ingestion rates; in most cases, the bioconcentration factor is the single most important parameter affecting the overall uncertainty. For external exposure, the most important contributors to uncertainty are the concentrations of ^{137}Cs and ^{60}Co in shoreline sediments, followed by the dose-to-risk conversion factors. For internal exposure from drinking water, the most important sources of uncertainty are the amount of the radionuclide consumed, followed by the risk factors and the concentrations of ^{106}Ru and ^{90}Sr in the water. Uncertainty in dosimetry contributes less than 5% (internal) or 10% (external) of the total uncertainty, while the risk factor (except for internal exposure to ^{137}Cs) contributes 20-30%. Uncertainties in exposure parameters (such as radio-nuclide concentrations and amounts of exposure) are dominant for all pathways.

Results of Special Scenarios

Because some people consumed fish bones as well as flesh when eating fish patties, an evaluation was made of the doses and risks from substitution of 8-20% of a Category I fish consumer's intake with fish patties. Doses and risks to bone and red bone marrow were increased about 15 to 25% due to increased ingestion of ^{90}Sr that accumulated in the fish bones. However, because ^{90}Sr was a small contributor to total dose and risk from eating fish, the overall risk was not increased by the consumption of fish patties.

Exposures were also evaluated from the consumption of contaminated wildlife (fish, turtles, deer, or waterfowl) from the ORR. Risks per meal (4 to 16 ounces of meat) were estimated for the highest reported contaminant levels in these animals (in the late 1940s for fish, the 1980s for waterfowl, and the early 1990s for turtles and deer) and for more typical levels. For the most contaminated animals, risks were as high as 3×10^{-4} per meal. Risks per meal for more likely values did not exceed 2×10^{-6}. The number of people exposed to contaminated animals from the ORR has not been determined precisely, but it is likely a very small fraction of the total population exposed to contaminated fish, water, or sediment.

Conclusions of the Study of White Oak Creek Releases

The doses and excess lifetime cancer risks from the Task 4 dose reconstruction are incremental increases above those from exposure to background sources of radiation. Nevertheless, for the exposure pathways considered in this study, the doses and risks are not large enough for a resulting increase in health effects in the population to be detectable, even by the most thorough of epidemiologic investigations. In most cases, the estimated organ doses are clearly below the limits of epidemiologic detection (1 to 30 cSv) for radiation-induced health outcomes in studies of large groups of people irradiated *in utero*, as children, or as adults.

Even for Category I fish eaters, estimated upper-bound organ doses are below 10 cSv, and central values are below 1 cSv. Lower-bound doses are well below levels that have been considered as limits of epidemiologic detection in studies of other exposed populations. The large uncertainty, combined with the small number of Category I fish eaters, diminishes the statistical power available to detect a dose-response relationship through epidemiologic investigation. Therefore, it is unlikely that any trends in incidences of disease in populations that used the Clinch River and Watts Bar Lake after 1943 could be conclusively attributed to releases from the X-10 site, even though increased individual risks have been shown to have resulted.

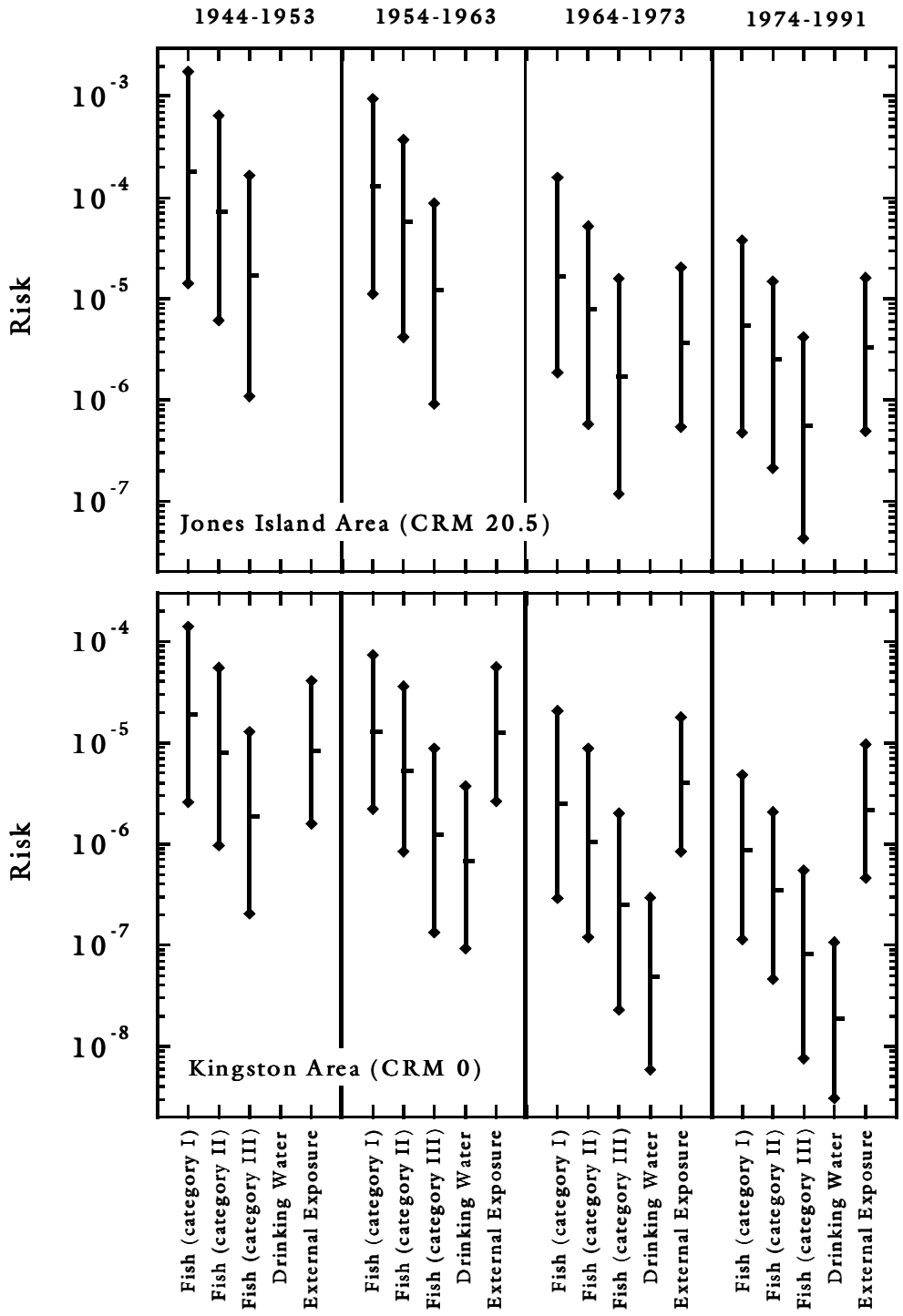


Figure 5-5: Excess lifetime risk of cancer incidence for males from eating fish, drinking water, and external exposure to shoreline sediment near Jones Island (top) and Kingston (bottom) during four time periods. The vertical lines indicate the 95% subjective confidence intervals on the risk estimates; central values (50th percentiles) are also shown. Results for females from fish ingestion are slightly lower than those for males (see Figure 5-3).

6. SYSTEMATIC REVIEW OF HISTORICAL RECORDS OF OAK RIDGE OPERATIONS

A critical element of the Oak Ridge Dose Reconstruction was the systematic searching of repositories containing records of historical operations at the ORR. The purpose of this methodical review of all records was to ensure that there were no significant, previously unidentified releases that should be included in a comprehensive dose reconstruction. This exhaustive approach to document review was a critical step towards achieving credibility with members of the public by increasing their confidence that all activities that might have affected their health have been revealed for the scientists to include in their study. The level of effort in the document search component of the dose reconstruction was unprecedented, representing the most extensive records review ever undertaken at the ORR.

Documents relevant to past ORR operations are contained in many repositories, including this DOE Records Holding Center in Oak Ridge.

The primary objectives of Task 5 were to identify all important contaminants released off-site from past Oak Ridge activities, to collect information to support ongoing investigations of known releases through systematic document searches, and to coordinate interviews with knowledgeable personnel. Review of available information focused on historical activities that led to off-site releases and identification of other potential contaminants of concern that were not identified during the Dose Reconstruction Feasibility Study.

The ORR comprises one of the largest nuclear complexes in the world, with records dating back to World War II. An unprecedented amount of records, both classified and unclassified, were involved in this effort. Types of records varied from published reports to handwritten log books. The extent of available records precluded the possibility of physically examining each and every record. However, every attempt was made to devise strategies to identify all records of potential relevance and review those records. The systematic search was designed to concentrate on those repositories that had the most potential to yield useful information for the dose reconstruction. Emphasis was placed on reviewing historical documentation not reviewed during the Dose Reconstruction Feasibility Study. A total of more than 15,000 labor hours were dedicated to this task, including a Task 5 analyst on-site full time. Approximately 70% of these total labor hours were actually spent in the document repositories.

All of the analysts involved with the record review process had significant previous dose reconstruction experience, including with the Oak Ridge Feasibility Study. Finally, analysts involved with the other six project tasks spent hundreds of additional hours in repositories conducting directed searches (that is, searches directed at finding specific data or documents that were needed by the technical analysts conducting the health risk analyses of the dose reconstruction).

Identification, Characterization & Ranking of Document Collections

The first step undertaken by the document team was to develop a comprehensive list of all repositories maintained at the three major complexes comprising the ORR: X-10, K-25 and Y-12, and any off-site repositories that housed records dealing with ORR. Table 6-1 gives a list of the 44 repositories identified. The project team then ranked the repositories by the apparent likelihood that they contained previously unidentified relevant information and placed them into three categories: High Priority Classified, High Priority Unclassified, and Lower Priority. Two of the key factors affecting rank were types of records (classified vs. unclassified) and age of records. Repositories with older (pre-1970) classified records were ranked highest.

Development of Search Methodologies

The basic strategy for review of repository holdings involved the following steps:

- Interview Records Custodians
- Debrief the Feasibility Study Team
- Characterize Cataloging System(s) Available
- Determine Best Approach for Selecting Relevant Material within Time Allocation
- Develop Sampling Approach, if necessary
- Conduct Search and Review Documents
- Document Approach and Results

Repository-specific search plans were developed based on each repository's characteristics. Two key factors affecting search strategies were the type and quality of cataloging systems available at a repository (electronic or non-electronic) and the size of its holdings.

Where possible, the project team obtained copies of electronic cataloging systems from repositories to aid in systematic searching. Any listings available for the contents of the repositories were used to make the initial selection of documents for review. For example, if a list of titles was available for a facility, an analyst initially reviewed that list to determine which documents should be examined. If the repository was not well documented or contained voluminous records, an appropriate method for sampling boxes was developed. Typically, these repositories had standard, 1 cubic foot boxes containing records. When this occurred, samples of boxes were selected and closely inspected to improve understanding of the repository holdings.

For the purposes of Task 5 activities, three domains or classes of records at ORR were identified: a priori relevant, non-relevant, and relevance undetermined. Using a given repository's finding aids (keyword search of databases, card files, bibliographies, etc.), a subset of potentially relevant records was identified. These were called a priori relevant. This project team made every effort to physically review all of the potentially relevant records.

The finding aids also allowed identification of classes of records that were clearly not relevant for a dose reconstruction and that could be excluded from the review. However, before these records were excluded, they were sampled and inspected to confirm that there was indeed no likelihood of relevant information in that class of records. For example, at the DOE Records Holding Center, the unclassified records database showed that there were classes of records that could be grouped, such as records from the accounting branch and the acquisition branch. There were 139 boxes that contained accounting/acquisition records. Twenty-two of the 139 boxes were chosen for review– approximately 16%. In most cases, at least 10% of the boxes were randomly chosen to represent a group of boxes. All of the 22 boxes turned out to be not relevant to the Oak Ridge Health Study; therefore, all 139 boxes were considered not relevant and were not physically reviewed.

Table 6-1: Ranking of Document Repositories Searched in the Oak Ridge Dose Reconstruction

Repository Name and Location	Classified?	Priority
1. X-10 Laboratory Records; X-10	Yes	High
2. Y-12 Central Files; Y-12	Yes	High
3. K-25 Site Records Center; K-25	Yes	High
4. Y-12 Records Center; Y-12	Yes	High
5. X-10 Records Center; X-10	Yes	High
6. DOE Records Holding Center; Oak Ridge	Yes	High
7. K-25 Compliance and Env. Mgmt. Doc. Ctr.; K-25	No	High
8. ORNL Director's Document Control Center; X-10	Yes	High
9. National Archives and Records Admin.; College Park, MD	Yes	High
10. Federal Records Center; Atlanta, GA	Yes	High
11. National Archives Center; Off-site	No	High
12. K-25 Envir. Restoration Prog. Doc. Mgmt. Ctr.; K-25	No	High
13. K-25 Environmental Management Doc. Ctr.; K-25	No	High
14. Information Resource Ctr. for Env. Restoration; Oak Ridge	No	Lower
15. K-25 Health & Safety Division Doc. Mgmt. Ctr.; K-25	No	High
16. Oak Ridge Associated Universities; Oak Ridge	No	Lower
17. Energy Systems Waste Mgmt. Organization; K-25	No	High
18. Y-12 Technical Library; Y-12	No	Lower
19. ORNL Central Research Library; X-10	No	High
20. Office of Scientific and Technical Info. (OSTI); Oak Ridge	Yes	Lower
21. Radiation Research Collection, Univ. of Tenn.; Knoxville	No	Lower
22. Research Reactors Division Doc. Control Ctr.; X-10	No	Lower
23. K-25 Waste Management Document Center; K-25	No	Lower
24. K-25 Waste Manifest Records; K-25	No	Lower
25. Y-12 Engineering Records Management Office; Y-12	No	Lower
26. Oak Ridge Room, Oak Ridge Public Library; Oak Ridge	No	Lower
27. Maintenance Department Repositories; X-10	No	Lower
28. Tenn. Dept. of Environment and Conservation; Oak Ridge	No	Lower
29. Tennessee Valley Authority; Knoxville	No	Lower
30. X-10 Chemical Technology Div. (4 centers); X-10	No	Lower
31. Waste Management and Remedial Action Div.; X-10	No	Lower
32. ORNL Engineering Records; X-10	No	Lower
33. Research Reactor Division Training Repository; X-10	No	Lower
34. Tower Shielding Facility Records; X-10	No	Lower
35. Quality Assurance Repository; X-10	No	Lower
36. Materials and Procurement Group Repository; X-10	No	Lower
37. Engineering Design Record Repository; X-10	No	Lower
38. Y-12 Document Response Center; Y-12	No	Lower
39. Gaseous Diffusion Plant Safety Analysis; K-25	No	Lower
40. K-25 Site Document Response Center; K-25	No	Lower
41. DOE Oak Ridge Public Reading Room; Oak Ridge	No	Lower
42. Enriched Uranium Operations Procedures; Y-12	No	Lower
43. Health, Safety, Environmental & Accountability; Y-12	No	Lower
44. X-10 Radiological Control Records; X-10	No	Lower

The third class of records, those with relevance undetermined, was the most challenging in terms of developing a viable search strategy. These were miscellaneous records that available findings aids and search strategies did not identify as relevant, but that could not be unequivocally discounted. No relevant material was believed to be in these records, but the content was somewhat ambiguous. In some of the smaller repositories, all of this material was manually reviewed within the scope of the labor hours allocated to the repository. However, in the larger repositories with massive quantities of records, 100% coverage of the relevance undetermined records could not be achieved within the scope of the project. In these cases, the analyst searched enough of the material to achieve a level of confidence that the remaining material did not contain records relevant to the dose reconstruction. At this point, the analyst sampled the remaining material to confirm that there was indeed no relevant information about new or unknown releases or information of use for other project investigations.

The sampling techniques used for both the non-relevant and relevance undetermined classes of records depended on the numbers of records, the type of record, and the size of the repository. The specific technique was determined by the analyst responsible for the repository and subsequently approved by the Task 5 Manager as part of the Repository Search Plan or subsequent memos. If the sampling of either class of records (i.e., non-relevant and relevance unknown) disclosed that there was potentially relevant information in the unreviewed material, additional searching was undertaken.

All of the document search work was subject to periodic quality assurance audits. These audits were performed and documented by the Task 5 Manager. Corrective actions and possible method improvements were identified and documented. Members of the ORHASP participated in a number of these audits.

Interviews with Key DOE / Contractor Personnel

An initial list of active and retired personnel from ORR operations and management staff and from site contractors who occupied key positions was prepared during the Dose Reconstruction Feasibility Study. These individuals were assigned to project staff to be interviewed as part of the technical investigations for other project tasks. This list was expanded as candidates were identified through ongoing investigations for the various tasks and through recommendations from the interviewees themselves. In most cases, written summaries of interviews were prepared by the interviewer(s), reviewed by the interviewee for factual accuracy, and entered into the project information database. In total, 151 interviews were formally documented, and information gathered from other interviews has been integrated into various reports of project investigations.

Directed Searches

Analysts working on each of the other six project tasks periodically performed searches directed at finding specific data or documents needed for their analyses. These directed searches involved hundreds of additional hours in the repositories. In addition, each task team provided the systematic document search team with a list of task-specific key words to augment the keyword list utilized for systematic searching using electronic finding aids. Finally, if a box was retrieved and opened in the course of a directed search, the analyst was asked to perform a systematic search of the box and provide appropriate documentation. At some repositories, such as the K-25 Site Records Center, directed searches effectively doubled the number of man-hours of document review performed and doubled the number of boxes that were reviewed.

The Project Database and Library

The project team continued use of the text-based database, InMagic, that was used in the Feasibility Study. Over 2,000 new database records were entered during this project, with documents in a series often described in a single record. For example, all of the K-25 Quality

Reports were grouped together and described in one InMagic record. Copies of key documents referenced in project reports were obtained, and these documents were described in the database. Document copies were filed numerically by ChemRisk Repository number. This collection will be maintained by TDH in Nashville. Copies of all documents that were given to the project team by ORR contractors are also available in the DOE Public Reading Room in Oak Ridge. By some time in the year 2000, the project database and scanned images of most repository documents will be available via the Internet through DOE's Comprehensive Epidemiological Data Resource (CEDR), a online public information source.

Searching of Five High Priority Classified Repositories

As discussed above, all identified repositories were ranked according to the likelihood that they contained relevant information. Following are discussions of the search strategies for five high priority classified repositories: X-10 Laboratory Records, Y-12 Records Center and Central Files, K-25 Site Records Center, and the DOE Records Holding Center.

X-10 Laboratory Records

The Oak Ridge Dose Reconstruction Feasibility Study identified X-10 Laboratory Records as one of the most important repositories to be further investigated during the dose reconstruction. This center contained approximately 2,000 cubic feet of documents from the 1940s to the present. The classified and unclassified documents were intermixed in the X-10 Laboratory Records vault; therefore, all the documents inside the vault were handled as if classified. The documents were grouped by document codes, and were arranged alphanumerically on the shelves in the vault. Over 800 systematic search hours were dedicated to reviewing these documents.

There were three major types of records: technical notebooks (commonly referred to as log books), reports and technical documents, and memos and other items of correspondence. Contents of technical notebooks typically described a procedure, logged details of an activity, contained notes on an experiment, or documented data collection. The notebooks took up approximately 25% of the vault space. Examples include graphite reactor log books, RaLa run notebooks, and experimental data collections. Reports and documents contained detailed descriptions of procedures, technical and operational information, accounts of incidents and accidents, and other information regarding the ORR and its facilities. This category of records included formal documents, technical reports, operations procedures, and annual reports of various projects and administrative units. The memos and correspondence records were mostly internal records that may have later become formal documents, attachments to formal reports, or reference documents. These records received a very thorough review during the dose reconstruction, as releases of radionuclides or chemicals during the early years (1940-1950) would have first been reported in internal memorandums.

The two databases maintained for X-10 Laboratory Records, the Central Files (CF) database and the Technical Information Document Database (TIDD), were keyword searched. These two databases contained a listing of most of the documents at Lab Records, with the exception of technical notebooks, technical memoranda ("TM" documents), and "ORNL" prefixed documents from the 1940s to 1974, and a small number of miscellaneous documents. Handwritten listings of the ORNL prefixed documents and TM documents from 1948 to 1974 were reviewed. The technical notebooks were listed in a card catalog that identified author(s), department, and date of issue. Early in this review, it was decided that the notebooks needed to be thoroughly searched and documented for future reference by the project staff. Over 2,700 logbooks from a total of over 108,000, were reviewed and annotated in a logbook database. Many of the logbooks reviewed were found to be very significant for the dose reconstruction, including operations logbooks of RaLa runs. The miscellaneous documents were individually reviewed, as there was no comprehensive listing.

No sampling of non-examined documents was necessary, because no large groups of documents, except for photo negatives and drawings, were excluded from systematic review. The section containing photo negatives and drawings was examined by various analysts to confirm that it contained only those items and not reports or other potentially relevant documents.

Y-12 Records Center and Central Files

The Y-12 Records Center and Central Files repositories are located in four vaults in two buildings , and contain over 20,000 cubic feet of records dating from the 1940s to the present. Many key project documents for other project investigations were identified in searches of these two repositories.

The Records Center contained approximately 20,000 cubic feet of records in boxes. The boxes contained documentation retired to the Records Center by various divisions at Y-12. Central Files contained approximately 700 cubic feet of shelved technical reports. The majority of the reports were produced by individuals in the various divisions at the Y-12 Plant. Databases and printouts were available for both the Y-12 Records Center and Y-12 Central Files document collections. The Central Files database had been recently audited by the Y-12 Classification Department during the 1994 Large-Scale Review project to declassify documents for public release. However, the Records Center was only in the early stages of auditing their database of boxes.

Because multiple, non-overlapping databases were available for the Records Center and Central Files, each record type required a combination of search techniques to ensure adequate review of the records. The Records Center boxes were searched using the card catalog system used prior to creation of the database in the early 1990s, the Access 7 version of the database, and a random search of boxes. Central Files reports were searched using a classified 800-page chronological printout of all documents in the database including title, authors and subject keywords; a card catalog system that identified the various divisions and their Y report series prefixes (e.g., Y/EX-21 or Y/TS-597); and a random search of documents.

The Records Center search used the card catalog system to provide general information about the classes of records retired to the Center by the various divisions. Records Center personnel used this system from the 1950s to the early 1990s. Each card identified the date and number of boxes sent to the Records Center by each division, the disposition of the records (whether or not they had been destroyed, sent to the Federal Records Center, or retained by the Records Center), and the exact location of the boxes in the vault. Although the system was outdated, it was useful for identifying classes of boxes, such as industrial hygiene, health physics, or radiation safety, that could contain information relevant to the dose reconstruction. Several boxes in every class were pulled, and their contents reviewed, to gain an understanding of the division and department names and codes used historically; these names and codes are very different from those used today. Using the knowledge of the historical Y-12 organizational structure gained from the card catalog and the review of example boxes, searches of the database were conducted to identify all boxes submitted by divisions or departments that were most likely to have contained information relevant to dose reconstruction. Over 1,000 boxes were identified by the searches. These boxes were opened, and the contents of several hundred boxes were reviewed and documented in detail.

The Central Files classified database chronological printout was reviewed in its entirety. The classified card catalog was also reviewed to identify potential divisional record series relevant to dose reconstruction. For example, the Health, Safety, Environmental and Accountability division issued reports using the Y/TS prefix, while the Alloy Division issued reports under the Y/AD prefix. This information was used to determine record series that could have been relevant to the project. Many Y-12 reports, such as Plant Quarterly reports, were issued using the Y/ prefix numbering scheme.

The last step in the search strategy was a random search. After the boxes in the Records Center and the shelved documents in Central Files were identified and reviewed, a random search of the remaining boxes and shelved documents was conducted. This search did not produce any information that was not already part of the project team's document collection. In total, the project team requested copies of several hundred documents from the Records Center and Central Files for public release.

Key documents located in the Y-12 Records Center and Central Files include: Y-12 Health Physics Reports, Y-12 Plant Quarterly Reports, 1983 Mercury Task Force files, Tennessee Eastman files (early 1940s), records of classified materials used at Y-12, original air monitoring reports for mercury processing buildings (1950-1963), and documents regarding arsenic, beryllium and lithium operations and releases.

K-25 Site Records Center

This center is located in a two-story vault that contains over 16,000 cubic feet of records. There are two types of records in the collection; the "Inactive Records" and the "Reports Collection". The Inactive Records collection consisted of approximately 15,000 one cubic foot boxes. The boxes contained documentation retired to the Records Center by various divisions at the site. The Reports Collection contained approximately 1,200 cubic feet of technical reports. The majority of the reports were produced by individuals in the various divisions at the K-25 site. At the time of initial review, comprehensive databases were not available for either of these two document collections.

Because databases were not available for either the Inactive Records or the Reports Collection, each record type required a combination of search techniques to ensure adequate review of the records. The Inactive Records were searched using 1) a card catalog type system that identified the different classes of records, 2) records custodian knowledge, and 3) a random search of boxes. The Reports Collection was searched using 1) a classified database that contained subheadings for the plant quarterly reports produced from 1971-1983, 2) a manual keyword and systematic search of a classified library card catalog that contained citations for all reports produced from 1944-1970, and 3) a random search of documents.

The Inactive Records search used the card catalog system to provide general information about the classes of records retired to the Center by the various divisions. The Records Center personnel used this system from the mid-1950s to the early 1990s. The system identified the date and number of boxes sent to the Center by each division, the disposition of the records (whether or not they had been destroyed, sent to the Federal Records Center, or retained by the Center), and the location of the boxes in the Center. Although, the system was outdated, it was useful in identifying classes of boxes, such as industrial hygiene, health physics, or plant safety that might be relevant to the dose reconstruction. The boxes in these classes were searched to determine the relevance of the records.

The records center custodian also aided in the systematic search efforts of the Inactive Records. At the beginning of the systematic search, the project team met with the records custodian and explained the type of information for which we would be searching. The records custodian helped to identify classes of records that might be useful to the study. Throughout the project the records custodian kept an "eye out" for materials he thought might be relevant to the dose reconstruction study.

The last step in the initial search strategy was the random search. Once all boxes identified through the card catalog system and the record custodian were reviewed, a random search of the remaining boxes was conducted. This search did not produce any information that was not already part of the project team's document collection.

Near the end of the systematic search of the Inactive Records, a comprehensive database of the records became available. The entire database (15,000 entries) was reviewed to identify any boxes that may have been overlooked through the initial search strategy. This review identified approximately 50 boxes that were not reviewed through the initial search strategy. The majority of these boxes were industrial hygiene records of site personnel, records that were not relevant to the off-site dose reconstruction efforts.

The project team reviewed titles for all 15,000 cubic feet of boxes and reviewed, in detail, approximately 600 cubic feet of boxes. The type of information retrieved included industrial hygiene indoor air sample results, environmental air and water sample results, cascade production logs, and decontamination logs. In total, the team requested nearly 200 documents from the Inactive Records collection be released to the public.

The Reports Collection classified database was searched using keywords similar to the keywords used for the other document centers at the K-25 site. This search identified plant quarterly reports that contained information relevant to the dose reconstruction project. The classified card catalog was keyword searched and reviewed by record series. Through review of the classified card catalog, it became apparent that reports from individual divisions at the site were grouped into a single record series. For example, the production division issued reports under the KP code, while the finance and materials group issued the reports under KFM. This information was used to determine record series that would be relevant to the project.

The project team reviewed titles for approximately 600 cubic feet of the Reports Collection and reviewed approximately 300 cubic feet of documents in the Reports Collection. The information included uranium accountability, process manuals, and division progress reports. The search resulted in request for release of approximately 300 documents.

DOE Records Holding Center

The DOE Records Holding Center contained approximately 7,750 cubic feet of both classified and unclassified documents from the 1940s to the present. The Task 5 project team felt that the classified holdings of this center represented one of the greatest potentials for containing information on previously undisclosed incidents, accidents, or operations that might have impacted off-site populations. That is, the DOE RHC provided an opportunity to review all of the records that DOE and its predecessors have maintained about themselves over the years. Consequently, significant effort (over 1,000 labor hours) was expended in the review of this repository.

The contents of the over 7,000 boxes of information were analyzed based on available box descriptions, descriptions on Form 135 submittals, and electronic databases. The classified database was found to be too unreliable for this analysis (i.e., incomplete and/or incorrect entries). To assure that no relevant material would be missed, every box containing classified material was manually reviewed. Approximately 1,900 boxes were manually reviewed, over 3750 were dispositioned based on the contents of the manually reviewed boxes, and 58 documents were requested for release to the public. In addition, task specific information was identified & reviewed. For example, nine boxes containing records concerning the S-50 plant operated by the Fercleve Corporation in the 1940s were documented for Task 6.

7. THE METHODOLOGY FOR SCREENING OF HAZARDS FROM OTHER MATERIALS

The purpose of screening in the Oak Ridge Dose Reconstruction was to permit attention and resources to be focused on the most important contaminants and to avoid dilution of resources by identifying situations that are of minor importance. A two-level screening approach was used to:

- Identify those contaminants that produced off-site doses or health risks that are clearly below established minimum levels of concern or decision guides (Level I Screen)— these materials were assigned a low priority for further study; and

- Identify those contaminants that produced off-site doses or health risks that are likely to have been above the established minimum levels of concern or decision guides (Level II Screen)— these materials were assigned the highest priority for detailed study.

The results of the screening calculations were compared to risk-based decision guides adopted by the ORHASP. As discussed earlier, for radionuclides and carcinogenic chemicals, the decision guide was a lifetime excess cancer incidence of 1 in 10,000 (10^{-4}). For noncarcinogenic chemicals, the decision guide was a Hazard Index of 1.0.

Level I Screening

The two-level screening approach used different sets of assumptions for releases, environmental transport, exposures, and lifestyles to estimate doses or health risks. Level I screening was designed to estimate the dose or risk to a "maximally exposed" reference individual who should have received the highest exposure and thus would have been most at-risk, and incorporated conservative parameter values (e.g., intake rates) not expected to lead to an underestimate of risk to any real person. For Level I screening, the screening value was compared to the appropriate decision guide as follows:

- If the screening estimate of risk to the maximally exposed individual was clearly below the decision guide, it was concluded that further study of the contaminant can be de ferred until time and resources permit further study, because risks to members of the general population would be even lower. Continued expenditure of time and resources on that contaminant is not justified as long as more important situations warrant study.

- If the screening estimate of risk to the maximally exposed individual was above the decision guide, it was concluded that the contaminant should be further evaluated in the Level II screening.

Level II Screening

Level II screening was designed to estimate the dose or risk to a more typical individual in the population of concern. Level II screening incorporated reasonable average or more typical values for the source term and parameter values. It was assumed that the Level II screening value underestimated the dose or risk for the most highly exposed individual, although the dose or risk may be overestimated for the general population. For Level II screening, the screening value was compared to the appropriate decision guide as follows:

- If the screening value was above the decision guide, it was concluded that the contaminant should be given high priority for detailed study, because it is likely that some individuals received exposures or doses high enough to warrant further study.
- If the screening value was below the decision guide, the contaminant was deferred for further study at a later time, after the highest priority contaminants have been evaluated.

Equations and Parameter Values Used in Screening

Both the Level I and Level II screening calculations used generic equations for calculation of dose and risk. The calculations included all pathways expected to be significant for the contaminant in question, based on the likely behavior patterns of nearby populations, the potential for uptake of the contaminant through food, and the relative toxicity of the contaminant through different exposure routes. Exposure pathways evaluated included inhalation, ground exposure, dermal contact and ingestion of soil or sediment, vegetable ingestion, and ingestion of meat, milk, and/or fish, as appropriate.

Exposure point concentrations used in the Level I and II screening were based on available release information (source terms) and/or measured environmental concentrations. For the Level I screen, upper bound exposure point concentrations were used, while the Level II screening used reasonable average concentrations. For example, in the Level I screening, doses and risks were typically calculated using the upper bound (e.g., 95th percentile or maximum) measured or modeled exposure point concentration at the location of the nearest downwind or downstream residence. In the Level II screening, doses and risks were typically evaluated using estimates of average measured or modeled exposure point concentrations at the nearest downwind or downstream population center.

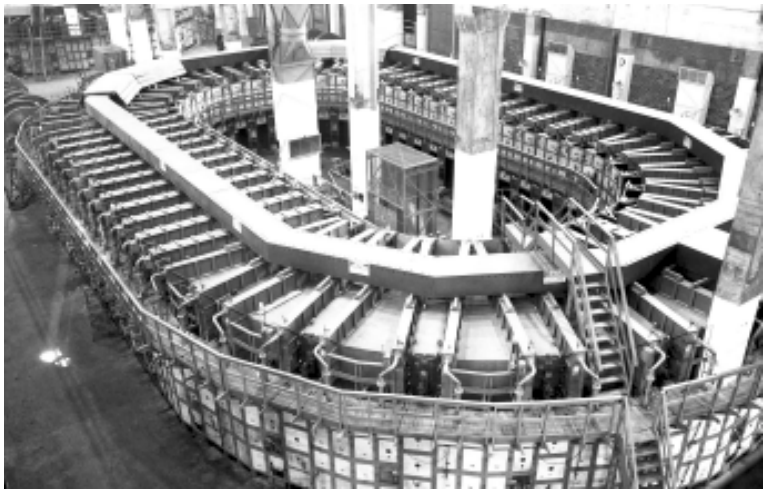
Parameter values used to calculate dose incorporated the best available information, based on historical knowledge of the Oak Ridge area, literature review, and professional judgment. In some cases, different values were used in the Level I and Level II screening. The parameters that were varied between screening levels were those specific to the target individual, including location and lifestyle factors (such as intake rates, time spent outdoors, etc.), with the Level I screening generally incorporating more conservative, or upper-bound, estimates of exposure. In most cases, contaminant-specific transfer factors (such as factors describing the transfer of a contaminant to milk or meat or uptake of a contaminant from soil into vegetation) and toxicity values were kept constant for both levels of screening. Toxicity values were established taking into consideration the most sensitive health effects endpoints for the specified target individuals. Care was taken in the Level I screening to avoid compounded conservatism leading to unrealistically extreme estimates of the risk posed by a contaminant.

Different exposure durations and averaging times were assumed for radionuclides, carcinogenic chemicals, and noncarcinogenic chemicals. For radionuclides and carcinogenic chemicals, exposure durations of 50 years and 10 years were used in the Level I and Level II screening, respectively. For carcinogenic chemicals, the risk was calculated in terms of the total intake averaged over the estimated lifetime, assumed to be 70 years, to give a lifetime average daily intake. For radionuclides, the risk was calculated in terms of the total cumulative dose, and an averaging time was not needed. For noncarcinogenic contaminants, an exposure duration and averaging time of 1 year was used, unless there was evidence that a shorter exposure or averaging time was appropriate for a given contaminant or exposure situation.

The results of the screening analyses were used to identify materials as low, medium, and high priority for further study.

8. REVIEW OF HISTORICAL URANIUM EFFLUENT MONITORING AND SCREENING EVALUATION OF POTENTIAL OFF-SITE EXPOSURES

Preliminary investigations in the Oak Ridge Dose Reconstruction Feasibility Study indicated that uranium was not among the list of contaminants that warranted highest priority for detailed investigation of potential off-site health effects. After reviewing the findings of the preliminary Feasibility Study evaluation of uranium releases, several individuals who had been long-term employees at Oak Ridge uranium facilities and a number of ORHASP members nonetheless recommended that past uranium emissions and potential resulting exposures receive closer examination. These recommendations were based on the following considerations:



Calutrons such as this "racetrack" version were used for electromagnetic enrichment of uranium in the 1940s.

- Available records of past uranium releases were found to be incomplete, and there was knowledge of substantial uranium releases that had gone unmonitored and unreported;
- The different isotopes of uranium had been evaluated separately in the Feasibility Study;
- The releases from the three ORR complexes (K-25, X-10, and Y-12) had been evaluated separately in the Feasibility Study; and
- There had been no direct evaluation in the Feasibility Study of the potential combined exposures that members of the public could have received as a result of concurrent releases of all of the uranium isotopes from the three ORR complexes.

When the Oak Ridge Dose Reconstruction was initiated in 1994, it included a Task 6 component that entailed evaluation of Oak Ridge uranium operations and effluent monitoring records to determine if uranium releases from the ORR likely resulted in off-site doses that warrant further study. The Task 6 report summarizes the methods and results of that evaluation.

The Task 6 investigation followed these basic steps:

- Information that described uranium uses and releases on the ORR was collected.
- Effluent monitoring data were evaluated for quality and for consistency with previous DOE historical uranium release reports.
- Since the airborne effluent monitoring data were found to be incomplete, updated estimates of airborne uranium releases over time were generated using the more complete data available to the project team.

- Because of the nature of the available data, the screening evaluation of potential off-site exposures to waterborne uranium was based on environmental measurements of uranium in these local surface waters. Waterborne uranium releases from the Oak Ridge complexes were not routinely measured near their individual points of origin like air borne effluents were. Waterborne releases from X-10 were routinely sampled at White Oak Dam, and the uranium isotopes were among those evaluated under the Task 4 dose reconstruction for releases from White Oak Creek to the Clinch River. Uranium concentrations were also periodically measured in samples of EFPC water collected just downstream of New Hope Pond on the Y-12 Site, and at the confluence of Poplar Creek and the Clinch River near the K-25 Site. Early Task 4 screening indicated that the uranium isotopes were not among the eight radionuclides that warranted detailed dose reconstruction.
- Air dispersion models were used to estimate uranium air concentrations at selected reference locations near each ORR facility. Due to complexities of the topography surrounding the Y-12 facility, an alternate approach to classical air dispersion modeling was used to estimate uranium air concentrations for the selected reference location. For each reference location, uranium concentrations in surface water and soil were estimated from environmental measurement data.
- A screening-level evaluation of the potential for health impacts was performed by calculating uranium intakes and associated radiation doses. A two-tiered exposure assessment methodology was employed, which provided both upper bound and more typical results. These results are called screening indices. The calculated screening indices were compared to the decision guide established by the ORHASP to assess if releases of a material warrant detailed investigation.

Quantifying Uranium Releases

Independent efforts to reconstruct estimates of past airborne uranium releases focused in most detail on the Y-12 production facility, the K-25 gaseous diffusion plant, and the S-50 liquid thermal diffusion plant. For the Y-12 Plant, releases from operations that were historically monitored were quantified by the project team based on measurements of indoor uranium concentrations and ventilation exhaust rates, or detailed stack sampling and analysis records found on archived computer tapes. For periods in which effluent sampling was not performed, or for which sampling records could not be found, air releases were estimated by the project team using averages of releases for adjacent years or using uranium production data (relative rates of production over time) to scale monitoring results from preceding or subsequent periods for which monitoring data were available.

Independent release estimates for 1944 to 1988 were determined by the Task 6 project team since the bulk of the releases occurred during this period. DOE release estimates for the period 1989 through 1995 are considered significantly more reliable due to improved monitoring.

As shown in Table 8-1 and Figure 8-1, the independent evaluation of past Y-12 airborne total uranium releases yielded results that are over seven times higher than release totals reported by the DOE, with almost 44,000 kilograms more total uranium released than officially reported. The difference between the Task 6 and DOE estimates is largely due to DOE's use of incomplete sets of effluent monitoring data and related documents, together with their use of some annual release estimates that are based on effluent monitoring data that were not adequately corrected to account for sampling biases. The Task 6 estimates also include some unmonitored releases that were not included in official release estimates.

Table 8-1: Uranium Release Totals Estimated in this Project and Reported by DOE (kg)

	USDOE	This Project	Difference
Airborne Uranium from Y-12	6,535	50,000	+ 43,465
Airborne Uranium from K-25/S-50	10,713	16,000	+ 5,287

The independent evaluation of airborne total uranium releases from K-25 and S-50 was based on analysis of uranium accountability records and incident reports, calculation of purge cascade[1] releases using monitoring data from that system, and use of results of periodic monitoring in three buildings on the K-25 Site. A database of over 1,200 documented uranium release events was developed using data from over 40 sources, and associated uranium losses were estimated.

Purge cascade releases were reconstructed by the project team for selected time periods. While they were the only airborne releases from K-25 that were monitored on a routine basis, purge cascade releases made up a small fraction of total uranium releases from K-25 (e.g., 1.5% over 1953–1955 and 0.06% for 1975). Task 6 screening also included estimates of uranium releases from a series of UF_6 cylinder fire tests conducted in 1965. K-25 airborne releases after

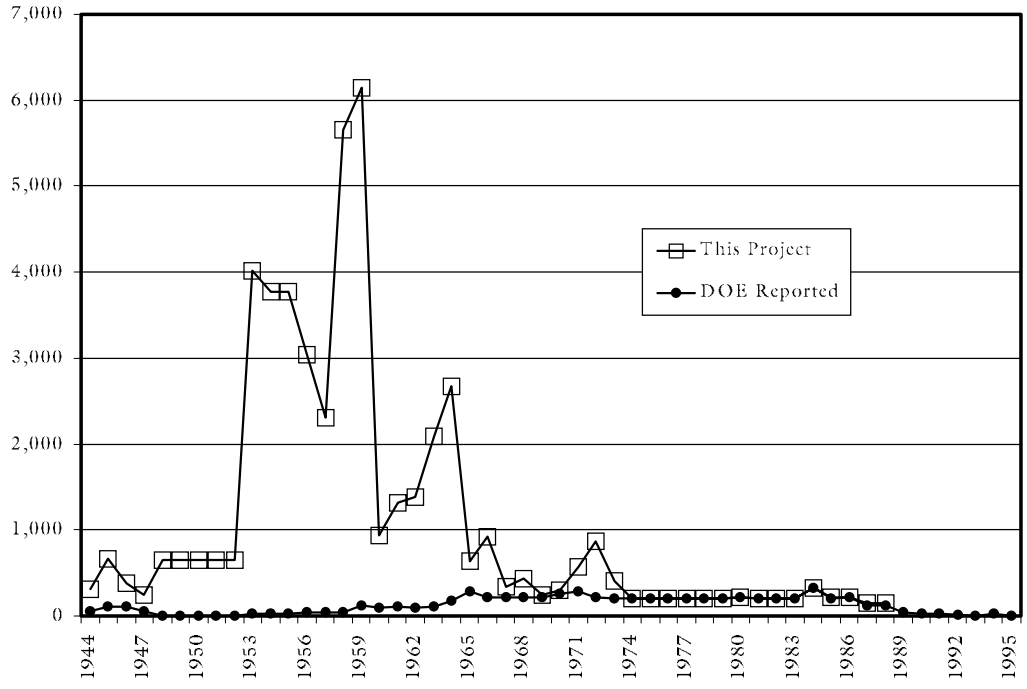


Figure 8-1: Airborne Uranium Release Estimates for the Y-12 Plant Prepared by the Project Team and Published by DOE (kg)

[1]The purge cascade was a segment of the gaseous diffusion equipment that was used to separate and remove light gases (such as air, fluorine, and coolant vapors) from the UF_6 that was being enriched. If these light gases were not removed, they would accumulate in the cascade and block the flow of enriched UF_6.

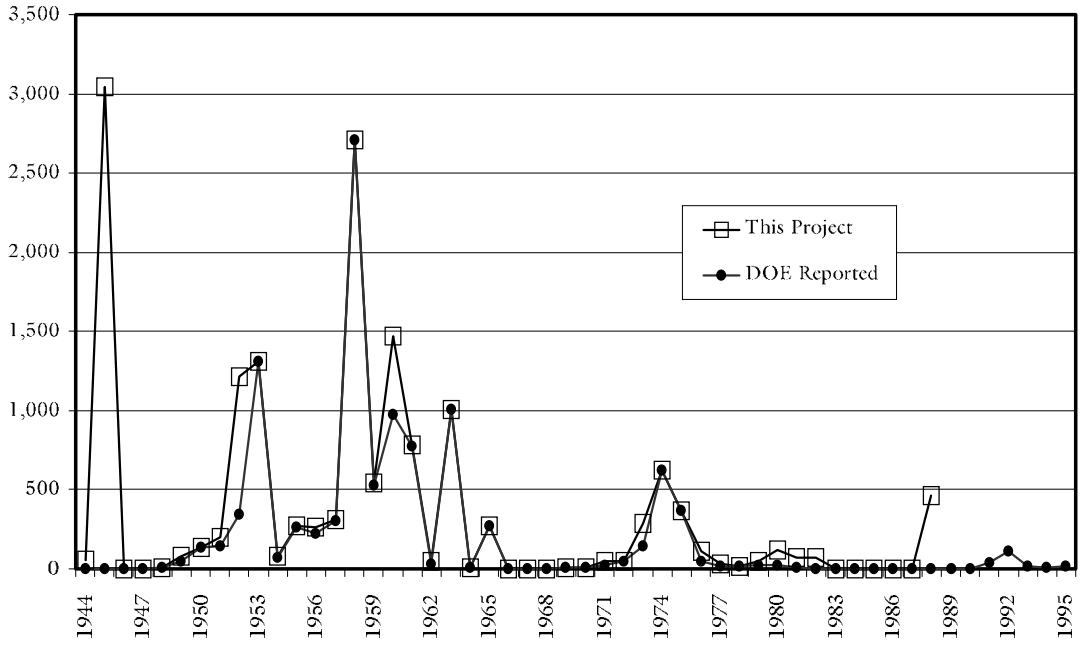


Figure 8-2: Airborne Uranium Release Estimates for the K-25/S-50 Complex Prepared by the Project Team and Published by DOE (kg)

1985 were based on data contained in DOE annual environmental reports. As shown in Table 8-2 and Figure 8-2, the independent evaluation of past K-25/S-50 airborne uranium releases yielded results that are almost 5,300 kg greater than the release totals reported by the DOE.

Estimating Uranium Concentrations in the Environment

Once uranium releases had been quantified, various techniques were used to estimate air concentrations at reference locations surrounding the ORR. Air dispersion modeling was used to identify the communities surrounding the three facilities that were likely exposed to the highest levels of airborne uranium due to releases from the ORR. Due to the considerable distances between the Y-12, K-25/S-50 and X-10 facilities, three distinct reference locations were used for the exposure assessment. The reference location for each complex was selected based on consideration of housing areas close to the facility, alignment with dominant wind directions, and habitation patterns during the periods of highest releases.

Three reference locations were selected for use in the Task 6 screening assessments. Initial screening of exposures at other nearby locations indicated these three reference locations likely received the largest impact due to past releases from the ORR facilities.

Y-12 Reference Location - Scarboro Community

For uranium releases from the Y-12 complex, the Scarboro community was selected as the reference location. The Scarboro community is located approximately 1 km north of Y-12, and is separated from the Y-12 facility by Pine Ridge. The reference location was located at what is currently the Scarboro community center. The proximity of Scarboro to the Y-12 site suggests that screening results would present upper bound values. The closest surface water body to the Scarboro community is EFPC, which runs along the south side of the Y-12 facility, turns toward the north and northwest, and passes about 0.4 mile to the northeast of the populated area of Scarboro at its closest point.

K-25/S-50 Reference Location - Union/Lawnville

For K-25/S-50 releases, the selected reference location was the Union/Lawnville community, which is located approximately 4.5 km south-southwest of the K-25/S-50 complex. Based on the initial air dispersion modeling, as well as an assessment of areas around the K-25/S-50 facilities that were inhabited, this community was selected as a suitable reference location for the assessment. The location of the community is defined by the Union Church, which is located on Lawnville Road, approximately 1 km north of Gallaher Road. The primary source of surface water is the Clinch River, which is approximately 1.5 km northeast of Union Church.

X-10 Reference Location - Jones Island (Clinch River)

The selected reference location for X-10 releases was in the area of Jones Island, which is approximately 5 km southwest of the site. This area represents the closest location off reservation from X-10, and is also along a predominant wind direction. The Task 6 assessment included evaluation of air exposure pathways from X-10 releases, soil-related pathways based on maximum soil concentrations measured near the reference location, and surface water pathways reflecting consumption of fish from and recreational use of the Clinch River.

Uranium Concentrations in the Air

Due to the complex terrain around the Y-12 facility, any analytical approach to estimating air concentrations at Scarboro that did not reflect the effects of Pine Ridge would lead to overestimation of the fraction of Y-12 releases that were transported to Scarboro. An alternative approach using measured uranium air concentrations at Scarboro was devised for this project. By relating air concentrations measured at Scarboro from 1986 through 1995 with Y-12 uranium release estimates for the same years, an empirical relative concentration (χ/Q) relationship was described. This relationship was then applied to all annual release estimates (1944–1995) to generate estimates of annual average air concentrations at Scarboro. An air dispersion model was used to estimate concentrations at the reference locations from K-25/S-50 and X-10 releases.

Uranium Concentrations in Surface Waters

The two main surface water bodies addressed in this analysis are the Clinch River and EFPC. Estimates of uranium concentrations in these surface water bodies were derived from available environmental monitoring data.

Uranium Concentrations in Soil

Estimates of soil concentrations were based on limited measurements compiled over the years of interest. Co-location of soil concentrations and reference locations was not always possible, as sampling locations used for soil measurements were selected based on the monitoring requirements for the facility and were not specific to a community. Therefore, the Task 6 team selected measured soil concentrations from locations closest to each reference location.

Because of the paucity of historical measurements of uranium in the soil near Scarboro and the lack of complete documentation of the methods used for some of the measurements that are available, some special considerations entered into the assessment of doses to Scarboro residents. The assessment used uranium concentrations measured in surface soil/sediment samples from the EFPC floodplain. The best available measurements were made in studies conducted in the 1980s, and the results were reported as uranium concentrations in units of parts per million (ppm). Detailed information about these data is not available, most significantly the concentrations of the specific uranium isotopes that were present. Evidence of earlier soil sampling in Scarboro was not located during the Task 6 investigation. The project team consulted with DOE and current and retired site contractor personnel, who were unable to supply more information regarding the abundance of the uranium isotopes in the soil samples or determine if earlier soil measurements were made in Scarboro.

Screening-Level Evaluation of Public Exposures

Once concentrations of uranium in the applicable environmental media had been quantified, the next step was to evaluate the potential significance of those concentrations. In the case of uranium, which can be chemically toxic as a heavy metal as well as hazardous as a radioactive material, this was done by estimating the radiation doses that could have been received by off-site populations and the total quantities (masses) of uranium that they could have taken into their bodies. Radiation dose estimates were then translated into screening indices, and uranium intakes were used to estimate levels of the metal that might have been present in sensitive body organs, such as the kidneys. These body burdens were compared to published data that indicate the levels above which uranium, as a toxic heavy metal, can cause adverse health effects.

The Task 6 screening assessment evaluated the potential health effects to the individuals that have lived in areas surrounding the ORR. In the more conservative Level I assessment, the maximum reported value of 70,000 pCi kg^{-1} ^{238}U from the EFPC floodplain was used, and the isotopic mixture of natural uranium was assumed in calculating a corresponding $^{234/235}U$ concentration of 76,000 pCi kg^{-1}. In the Level II assessment, a reported average value of 26 ppm total uranium from the EFPC floodplain was converted to uranium isotope concentrations using similar assumptions. The value of 26 ppm converts to concentrations of 14,000 pCi kg^{-1} $^{234/235}U$ and 12,000 pCi kg^{-1} ^{238}U. The $^{234/235}U$ component of the uranium is most important in terms of doses delivered from uranium exposure, particularly for pathways involving external irradiation of the body.

The second level of screening was considerably less conservative than the Level I analysis; less conservative "Level II" values were used for various exposure parameters (consumption rates, fractions of foods contaminated, etc.) than were used in the Level I screening assessment. The goal in Level II assessments is to remove known sources of conservative bias. For soil concentrations, an average value was used in Level II compared to a maximum measured value used for the Level I assessment. Because of the scarcity of information regarding estimates of uranium concentrations in the environment over the periods of interest, some conservatism was maintained in the uranium concentration estimates used in Level II screening to ensure that hazards to a significant portion of the potentially exposed population were not underestimated. Conservatism was probably also introduced by the use of 1980 EFPC floodplain measurements to represent concentrations at Scarboro, which is outside of the floodplain. As such, the second level of screening may be more appropriately called a Refined Level I analysis. The data that are currently available are not sufficient to support a defensible analysis of average or typical exposures to members of the Scarboro community during the years from the community's inception to the present.

A significant factor in the decision to maintain a conservative value of soil concentration in Level II screening was the uncertainty concerning the level of ^{235}U enrichment in the soil represented by the value of 26 ppm total uranium. Because of this uncertainty, the concentration corresponding to 14,000 pCi kg^{-1} $^{234/235}U$ (or 26,000 pCi kg^{-1} total uranium) was used, based on the isotopic composition of natural uranium. To illustrate how the overall results of the assessment would differ if lower concentrations of $^{234/235}U$ in soil were assumed, screening indices were also calculated for soil concentrations of 7,000 and 2,000 pCi kg^{-1} total uranium.

Annual radiation doses from uranium intake and external exposure were calculated for the adult age group for each screening assessment and then converted to screening indices using a dose-to-risk coefficient of 7.3% Sv^{-1}. The individual dose conversion factors for ^{234}U, ^{235}U, and ^{238}U were used in estimating internal and external radiation doses from uranium contamination in the environment. Screening indices for Task 6 are presented in Table 8-2.

Table 8-2: Summary of the Screening Indices from Each Task 6 Assessment
(Screening Indices in bold exceed the decision guide of 1×10^{-4})

Assessment	Level I	Level II
Exposures at the Scarboro Community *due to Releases from the Y-12 Complex*	**1.9×10^{-3}**	8.3×10^{-5}
Exposures at the Union/Lawnville Community *due to Releases from the K-25/S-50 Complex*	**2.7×10^{-4}**	4.0×10^{-5}
Exposures at the Jones Island Community *due to Releases from the X-10 Complex*	7.6×10^{-5}	Not performed

Discussion of Uranium Screening Results

The Scarboro community was associated with the highest total screening index attributable to uranium releases from the Y-12 facility. The screening indices were 1.9×10^{-3} for the Level I assessment and 8.3×10^{-5} for the Level II assessment. These values translate into potential health impacts (excess fatal and nonfatal cancer and severe hereditary effects) of about 2 in 1,000 and 8 in 100,000, respectively. While the overall Level I screening index for the Scarboro community is above the ORHASP decision guide of 1 in 10,000, the Level II value is just barely below that guide value. This indicates that the Y-12 uranium releases are candidates for further study, but that they are not high priority candidates for further study.

The Y-12 screening indices are most sensitive to $^{234/235}$U and ^{238}U concentrations in soil, $^{234/235}$U concentrations in air, and $^{234/235}$U concentrations in water. The major pathways of concern include ingestion of vegetables grown in contaminated soil, external doses from $^{234/235}$U in soil, inhalation of airborne $^{234/235}$U, and consumption of meat and milk from cattle raised on contaminated pasture. The Level II result for the Y-12 assessment in Table 8-2 is based on a $^{234/235}$U soil concentration of 14,000 pCi kg^{-1} (or 26,000 pCi kg^{-1} total uranium). Using a soil value of 7,000 pCi kg^{-1} total uranium yields a screening index of 5.8×10^{-5}, a 30% reduction from the screening index calculated for the Level II assessment. A 2,000 pCi kg^{-1} total uranium soil concentration produces an index of 5.1×10^{-5}, a 40% reduction. Note that even though these alternative soil concentrations (7,000 and 2,000 pCi kg^{-1}) represent 73% and 92% reductions in soil concentrations respectively, the reduction in the screening index for Level II is not proportional. The soil pathways represent only 38% of the total screening index from $^{234/235}$U and 51% from ^{238}U. Since the concentrations in air and water were not changed for the alternative evaluations, a given reduction in soil concentration does not equal a corresponding reduction in the total screening index. Further characterization of the extent of uranium contamination in soils should be a component of any future studies of potential exposures to residents of the Scarboro community.

Air concentrations at the Scarboro community were estimated using the empirical χ/Q approach. This approach used 10 years of measurements of uranium in ambient air at Scarboro with estimates of annual releases from the Y-12 Plant to calculate an effective annual dispersion factor that was then used to approximate air concentrations for earlier years. It is important to remember that this approach is reliant upon Scarboro air concentration measurements, which are available only for the period 1986 to 1995, and release estimates for the same years. Differences in operations and release point distributions or characteristics for periods before 1986 could call into question the applicability of the empirical χ/Q value to earlier years. In addition, information was gained late in the project that indicated that Y-12 uranium releases for some of the years used for development of the empirical χ/Q value may have been understated due to omission

of some unmonitored release estimates. It was not possible within the scope of this project to evaluate the new data sufficiently to warrant its use in this assessment. If Y-12 uranium releases during years used to develop the empirical χ/Q value applied in this assessment were indeed under reported, that would mean that the associated empirical χ/Q values were overestimated, and concentrations at Scarboro that were estimated using that approach were in turn overestimated. It is impossible to gauge the magnitude of any biases potentially introduced by this possible under reporting without closely evaluating the bases of the release estimates during the associated years in the 1980s and 1990s.

For the K-25/S-50 assessment, the total screening index for Union/Lawnville from the Level I assessment (3 in 10,000) exceeded the decision guide. The less conservative Level II screening result did not exceed the guide. This indicates that the K-25/S-50 uranium releases are candidates for further study, but that they are not high priority candidates for further study. For the Level I screening, the air pathways account for approximately 23% of the screening index; 76% of the total screening index was attributable to the soil pathways. With limited data available to characterize the soil concentrations at Union/Lawnville, these assessments are the best estimates of health impacts within the scope of Task 6.

The assessment of releases from X-10 did not yield Level I screening indices that exceed the decision guide for Level I. The releases from X-10 warrant a lower priority given the pilot-plant nature and relatively short duration of most X-10 uranium operations. Uranium in liquid effluents from X-10's White Oak Creek to the Clinch River were addressed in the Task 4 component of the Oak Ridge Dose Reconstruction. The Task 4 preliminary screening analysis for radionuclides in Clinch River water and sediments is described in Section 3 of the Task 4 report. In that report, ^{235}U and ^{238}U are identified as contaminants that were included in the screening analysis. Based on the preliminary Task 4 screening, these two uranium isotopes are identified as being among those 16 contaminants that were assigned low priority for further study based on comparison of screening results with the decision guide of 1×10^{-5} excess lifetime cancer risk applied to individual radionuclides within the Task 4 screening.

Estimates of annual-average intakes of uranium by inhalation and ingestion were also used by the project team to evaluate the potential for health effects due to the chemical toxicity of uranium compounds, specifically for damage to the kidneys. Using estimated annual average uranium intake rates via inhalation and ingestion at the Scarboro community, the project team used biokinetic modeling of uranium retention and excretion in the human body to estimate annual kidney burdens (uranium concentrations in kidney tissue) over the years of interest. Predicted uranium burdens were compared to toxicity thresholds from the scientific literature.

For the conservative Task 6 screening for chemical toxicity, uranium was assumed to be in its most soluble form (such as uranyl nitrate), and safety factors were included to minimize the potential for underestimation of the potential for toxic effects. As shown in Figure 8-4, estimated kidney burdens resulting from simultaneous intake of uranium by ingestion and inhalation under the Scarboro assessment do not exceed an effects threshold criterion of 1 microgram of uranium per gram of kidney tissue (1 $\mu g\ g^{-1}$) proposed by some scientists, but do exceed an effects threshold criterion of 0.02 $\mu g\ g^{-1}$ advocated by others who have studied uranium effects in the kidney.

Estimates of annual-average intakes of uranium were also compared to the USEPA oral RfD another method of evaluating the potential effects of ORR uranium exposures. The RfD of 3×10^{-3} mg kg^{-1} d^{-1} is primarily based on animal studies, and is conservatively set at a level to ensure that there are no adverse effects on renal function. Using estimated annual-average daily uranium intake rates via inhalation and ingestion at the Scarboro community, the project team determined the annual Hazard Indices (HIs) shown in Figure 8-5 by dividing the annual-average daily intake rates by the RfD. The average HI is well below unity, which suggests that further scudy of heavy metal toxicity from past ORR uranium exposures does not warrant high priority.

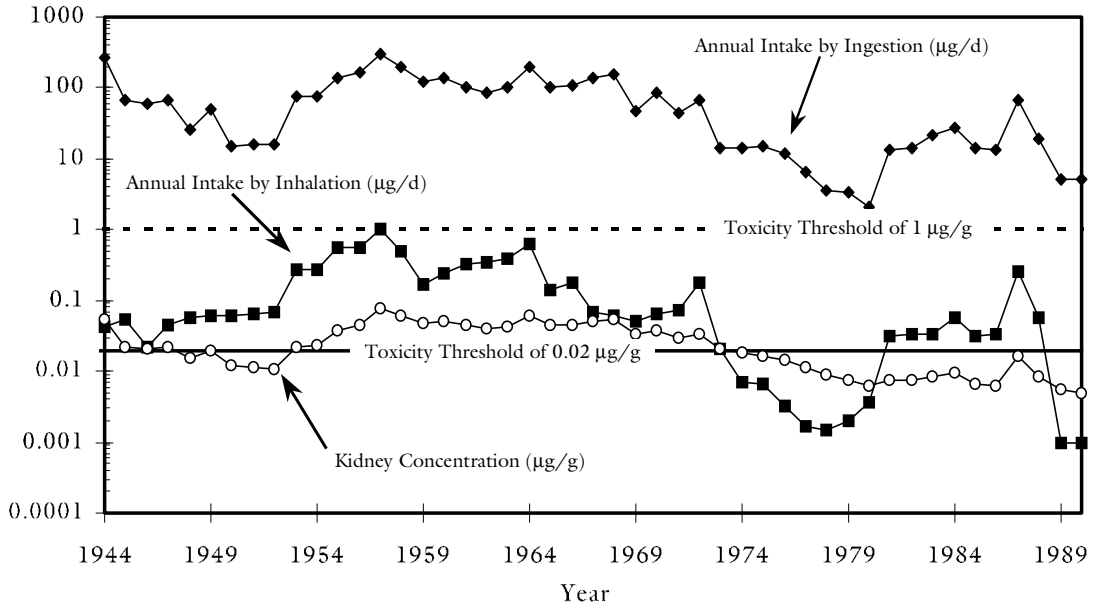


Figure 8-4: Annual Average Uranium Intakes via Simultaneous Ingestion and Inhalation with Resulting Kidney Burdens. Calculated for the Y-12 Assessment, at the Scarboro Community

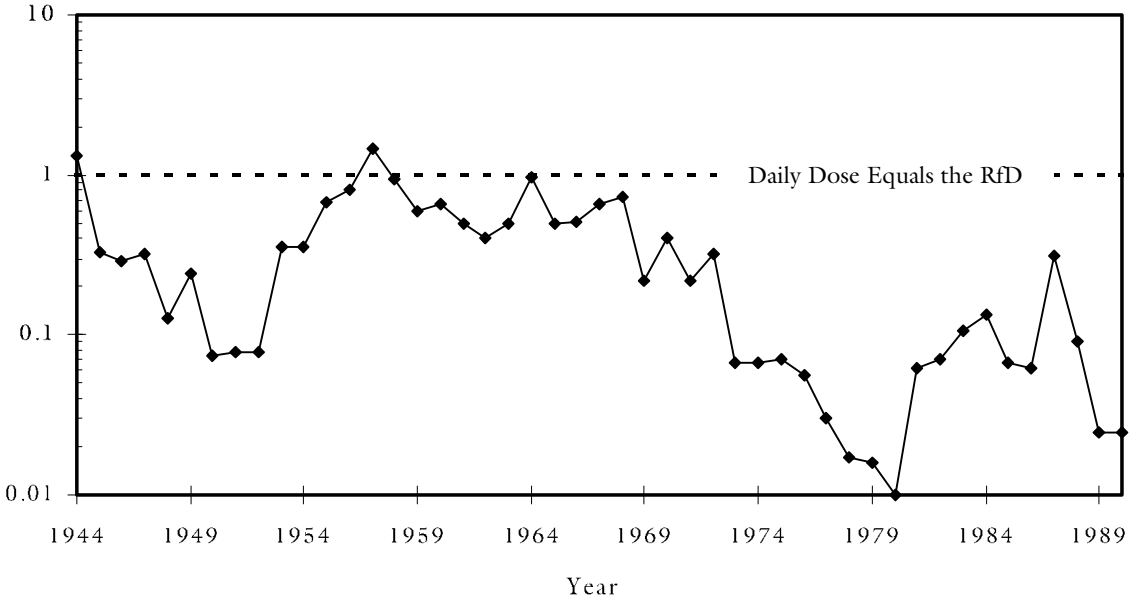


Figure 8-5: Annual Average Hazard Indices for a 70 kg Person and an Oral RfD of 3×10^{-3} mg kg^{-1} d^{-1}

A number of areas have been identified that are logical next steps in the evaluation of potential health effects from Oak Ridge uranium releases. These areas should be examined if the evaluation of Oak Ridge uranium releases were to proceed beyond the screening stage, and into a stage of refined evaluations that will likely include uncertainty and sensitivity analyses.

Activities that should be evaluated for possible followup work include:

(1) Additional records research and evaluation regarding S-50 Plant operations and releases.

(2) Additional searching for and review of effluent monitoring data for Y-12 electromagnetic enrichment operations from 1944 to 1947 and data relating to releases from unmonitored depleted uranium operations in the 1950s through the 1990s.

(3) Uncertainty analysis of the Y-12 uranium release estimates derived in this study.

(4) Additional data regarding unmonitored K-25 uranium releases should be reviewed to ensure that analyses that are thought to be bounding are sufficiently conservative.

(5) Refinement of the approach used to evaluate surface water and soil-based exposure concentrations. This refined analysis could possibly involve shifting to a source-term based approach rather than one based on environmental measurements. This would include review of release estimates to assure that the release estimates used in the screening assessments were appropriate.

(6) Evaluation of the effects of the ridges and valleys that dominate the local terrain surrounding Y-12 and Scarboro and investigation of alternative approaches to estimate air concentrations at Scarboro with an emphasis on identifying additional monitoring data. Evaluation of the uncertainty associated with air concentrations would provide upper and lower bounds of confidence in the estimates.

(7) Performance of a bounding assessment of the amounts of uranium that were handled at the X-10 site, for comparison with Y-12 and K-25/S-50, and for evaluation of the feasibility of generating a more complete air source term for uranium.

(8) Improvement of the exposure assessment to include region-specific consumption habits and lifestyles, identification of likely exposure scenarios instead of hypothetical upper bound and typical assessments, and inclusion of uncertainty analysis to provide statistical bounds for the evaluations of risk.

(9) Refinement of the chemical toxicity evaluation, possibly to include other approaches and/or models and an uncertainty analysis.

9. SCREENING EVALUATION OF ADDITIONAL MATERIALS OF POTENTIAL CONCERN

In the Oak Ridge Dose Reconstruction Feasibility Study, investigators took an intense and comprehensive, but relatively quick, "look through the key hole" at past operations on the Oak Ridge Reservation (the ORR). They performed screening calculations to identify those operations and materials that warranted detailed investigation in terms of potential off-site exposures. At the close of the Feasibility Study, the Tennessee Department of Health (TDH) and the Oak Ridge Health Agreement Steering Panel (ORHASP) recommended that detailed dose reconstructions be conducted for a number of historical activities tied to environmental releases (iodine-131 from X-10 radioactive lanthanum processing, mercury from Y-12 lithium enrichment, PCBs in the environment near Oak Ridge, and radionuclides released from White Oak Creek on the X-10 site to the Clinch River). They called for the study to also include systematic searching of historical records, an evaluation of the quality of historical uranium effluent monitoring data, and additional screening of some materials that could not be evaluated during the Feasibility Study. In addition, several questions raised during the Feasibility Study that could not be answered at the time were slated for evaluation during the dose reconstruction project.

This report presents the methods and results of the Task 7 screening of additional potential materials of concern. The Task 7 investigation included quantitative, screening-level evaluations of 10 materials or classes of materials and less detailed evaluations of 18 others. The purpose of screening in the Oak Ridge Dose Reconstruction was to permit attention and resources to be focused on the most important contaminants and to avoid dilution of resources by identifying situations that are obviously of only minor importance.

Three different methods were used by the Task 7 project team to evaluate the importance of materials in terms of their potential to pose off-site health hazards. The method selected to evaluate a given material was dependent on the quantity of the material present on-site, the form and manner in which the material was used, and the availability of environmental monitoring and release data, as well as whether the material was classified per se (i.e., its mere presence on the ORR remained classified). Fortunately, before this project was completed, the presence of any material on the ORR (at the site level) could be publicly revealed.

The methods used to screen materials were as follows:

Qualitative screening- All materials identified as having been used on the ORR were subject to qualitative screening; for some materials, the project team determined that based on evaluation of quantities used, forms used, and/or manners of usage, it was unlikely that off-site releases of the material could have been sufficient to pose an off-site health hazard; these materials were not subject to quantitative screening.

Small-quantity materials included chemicals and radionuclides used as calibration standards or check sources for laboratory instruments or analytical methods. Materials used in forms not conducive to off-site release include carbon fibers and glass fibers that were received at the K-25 site as premanufactured filaments wound on spools. These fibers were used in construction of rotors used in the centrifuge method of uranium enrichment, in a process by which they were wound on a spool and a plastic binder applied to form the tall, cylindrical

rotors. Examples of cases where manners of usage minimized the potential for significant off-site release include liquids, gases, or powders that were kept sealed in cylinders or were processed in containment systems that included multiple barriers against release.

The threshold quantity approach- Accurate estimates of inventory quantities of materials used at the Oak Ridge complexes are often not available, or in some cases not publicly releasable. It is typically much easier to determine, based on historical records or interviews of active or retired workers, if inventory quantities of a material were below a calculated threshold quantity. For a number of materials, project investigators used conservative assumptions to calculate a "threshold quantity" below which a material was highly unlikely to have posed a risk to human health through off-site releases. Threshold quantities were calculated using the following approach:

1. The maximum allowable air concentration or water concentration of a material was calculated based on the maximum allowable daily dose (assumed to be equivalent to the noncarcinogenic reference dose (RfD) or the dose that would lead to a cancer risk of 1×10^{-6}). To calculate a maximum allowable concentration, the maximum allowable daily dose was multiplied by a typical body weight and divided by a typical breathing or water ingestion rate.
2. The maximum allowable release rate to air or water was then determined, by calculating the release rate that would give an air or water concentration equal to the maximum allowable air concentration or water concentration. Release rates were calculated using conservative environmental dispersion or dilution factors.
3. The maximum allowable release rate in g s^{-1} was then converted to a maximum allowable release rate in kg y^{-1}. This quantity was assumed to be the threshold inventory quantity for the material.

Quantitative screening using a two-level screening approach- Each level used a different set of assumptions to calculate potential doses and screening-level risk indices; the goal of this approach is to identify those contaminants that produced doses or health risks to exposed individuals or populations that are clearly below established minimum levels of concern (called a Level I Screen) and identify those contaminants that produced doses or health risks to exposed individuals or populations that are likely to have been above the established minimum levels of concern (called a Level II or Refined Level I Screen).

Both the Level I and Level II screening calculations used mathematical equations for calculation of dose and risk through multiple exposure pathways. These equations relate dose to the exposure point concentration and the magnitude of intake. Pathway equations used in the screening assessment are presented in Appendix B of the Task 7 report. The equations included all pathways potentially significant for the contaminants in question; exposure pathways evaluated included inhalation, ground exposure (for radionuclides), ingestion of soil or sediment, vegetable ingestion, and ingestion of meat, milk, and/or fish.

Parameter values used to calculate dose were selected based on historical knowledge of the Oak Ridge area, literature review, and professional judgment. The parameters that were varied between screening levels included lifestyle factors such as intake rates, time spent outdoors, etc. Contaminant-specific transfer factors and toxicity values were kept constant for both levels of screening. Different exposure durations and averaging times were assumed for radionuclides, carcinogenic chemicals, and noncarcinogenic chemicals. For radionuclides and carcinogenic chemicals, exposure durations of 50 years and 10 years were used in the Level I and Refined Level I screening, respectively. For carcinogenic chemicals, the risk was calculated in terms of the total intake averaged over the estimated lifetime,

assumed to be 70 years, to give a lifetime average daily intake. For radionuclides, the risk was calculated in terms of the total cumulative dose, and an averaging time was not needed. For noncarcinogenic materials, exposure durations and averaging times of 1 year were used.

The Level I screen was designed to estimate the dose or risk to a "maximally exposed" reference individual who should have received the highest exposure and thus would have been most at-risk. This level incorporated conservative exposure parameter values (such as intake rates) not expected to lead to an underestimate of risk to any real person in the population of interest. For Level I screening, each screening-level risk estimate ("screening index") was compared to the appropriate risk-based decision guide as follows:

- If the screening index for the maximally exposed individual was below the decision guide, it was concluded that further study of the contaminant can be deferred until time and resources permit further study, because risks to members of the general population would be even lower. Continued expenditure of time and resources on that contaminant is not justified as long as there are more important situations to be studied.
- If the screening index for the maximally exposed individual was above the decision guide, it was concluded that the contaminant should be further evaluated in refined Level I screening or in Level II screening.

Refined Level I and Level II screens are designed to estimate the dose or risk to a more typical individual in the population of interest than was addressed in Level I screening. They incorporated reasonable average or more typical values for the exposure parameter values. It was assumed that the Level II screening value underestimated the dose or risk for the most highly exposed individual, although the dose or risk may be overestimated for the general population. For Refined Level I or Level II screening, each screening index was compared to the appropriate decision guide as follows:

- If the screening index was above the decision guide, it was concluded that the contaminant should be given high priority for detailed study, because it is likely that some individuals received exposures or doses high enough to warrant further investigation.
- If the screening index was below the decision guide, the contaminant was deferred for further study at a later time, after the highest priority contaminants were evaluated.

The "Refined Level I" screening evaluations described in this report were considerably less conservative than the Level I evaluations they followed. For example, many of the exposure parameter values used in the dose and risk calculations are less conservative (more realistic or more typical) than the values of the same parameters used in Level I screening. A good example would be the assumed exposure duration for carcinogens, which is 50 years in Level I screening and 10 years in Level II screening. The "Refined Level I" evaluations described in this report used the Level II exposure parameters.

While a general goal in refined screening is to reduce or eliminate sources of conservative bias, it is not always feasible or advisable to eliminate all conservative bias, or easily determined when a sufficient level of realism has been achieved. In the refined screening evaluations described in this report, some degree of conservatism was retained, particularly in the estimation of contaminant concentrations in environmental media of interest. One important reason for this is that there were very few measurements of the contaminants of concern made in the environment during the (pre-1970s) periods when levels of many contaminants in the environment were likely the highest. Measurements in process streams or effluents are even more rare. Because of the paucity of information for

some vital components of the risk assessment process, some conservatism was retained in the estimation of exposure point concentrations for the Refined Level I assessments to ensure that exposures were not underestimated for significant portions of the potentially exposed populations. Because of this, the second-level assessments are called Refined Level I assessments rather than Level II assessments.

How Contaminants of Potential Concern were Addressed

Following are summaries of the methods that were used to address the potential health significance of each contaminant that was evaluated within the Task 7 study.

- **Arsenic**– releases from K-25 and Y-12 steam plants were estimated using reported arsenic contents of the coal burned at each plant, usage rates of the coal, and an USEPA emission factor for arsenic. Air concentrations were estimated at Union/Lawnville and Scarboro, based on dispersion modeling and the empirical dispersion factor for Y-12 releases to Scarboro. Surface water exposures were evaluated based on the highest concentrations measured in Poplar Creek near the mouth of the Clinch River (for K-25 releases) and in McCoy Branch (for Y-12 releases). Exposures from arsenic in soil/sediment were evaluated based on levels measured in a sediment core collected at Poplar Creek Mile 1.0 and on measurements in sediments of McCoy Branch. Concentrations of arsenic in vegetables, meat, milk, and fish were estimated based on concentrations in air, water, and soil used with biotransfer and bioconcentration factors for arsenic from the scientific literature. Level I and Refined Level I screening assessments were performed for arsenic for cancer (for inhalation and oral exposure) and non-cancer health effects (for oral exposure).

Coal-fired steam plants such as this one at the Y-12 Plant, and the ash they produced, were sources of arsenic releases to the environment.

- **Asbestos**– The potential off-site significance of asbestos used in ORR facilities was an open question from the Feasibility Study. During the Dose Reconstruction, the project team summarized available information on the use and disposal of asbestos on the ORR. This report presents that information and discusses some factors that affect the potential for off-site releases and exposures in nearby communities. Health Studies investigators found no indication that the presence of asbestos at ORR facilities extended beyond various building materials, including thermal insulation of pipes, ducts, and vessels. The demolition of buildings and removal of asbestos containing materials would potentially lead to short-term increases of airborne asbestos in the immediate vicinity of these operations, but they would be expected to have a limited potential to affect asbestos concentrations to off-site receptors. The project team did not identify any specific asbestos-related exposure events or activities that are believed to have been associated with community exposure. In the absence of such "focal" events, it is unlikely that asbestos-related activities at ORR have resulted in off-site exposures beyond what might be expected from other sources in the community.

- **Beryllium Compounds–** were evaluated based on 1980 Y-12 stack monitoring data for total beryllium and the empirical dispersion factor for Y-12 releases to Scarboro. Beryllium exposures from surface waters were evaluated based on the maximum concentration measured in the EFPC remedial investigation. The maximum beryllium concentration measured in soil in the EFPC remedial investigation was also used. Levels in meat, milk, vegetables, and fish were estimated using the selected concentrations in air, soil, and water with biotransfer and bioconcentration factors from the scientific literature. Level I screening assessments were performed for beryllium for cancer and non-cancer health effects via inhalation and oral exposure. A Refined Level I screening was performed for beryllium as a carcinogen, as the Level I screening index exceeded the decision guide.

- **Boron carbide, boron nitride, yttrium boride, titanium boride, rubidium nitrate, Triplex Coating, carbon fibers, glass fibers, four-ring polyphenyl ether–** were evaluated qualitatively and found to have been used in very small quantities or in forms unlikely to have resulted in off-site releases. These materials were formerly classified per se, that is their presence on the ORR was classified until 1999.

- **Copper–** was evaluated based on airborne concentrations measured at the most-affected on-site air sampler, adjusted according to the ratio of dispersion model results at that sampler to those for the reference location at Union/Lawnville. Surface water exposures were evaluated based on the highest concentration reported from a special monitoring project in the Clinch River; it was measured just downstream of the K-25 Site. The highest mean concentration of copper in sediment from the Clinch River was used to evaluate soil/sediment exposure pathways; it was measured just downstream of the mouth of Poplar Creek. Levels in meat, milk, vegetables, and fish were estimated using the selected concentrations in air, soil, and water with biotransfer and bioconcentration factors from the scientific literature. Level I and Refined Level I screening assessments were performed for copper for non-cancer health effects from inhalation and oral exposure. Screening indices for inhalation exposure were evaluated based on a derived RfD based on the ACGIH Threshold Limit Value® for occupational exposure to copper in air.

- **Hexavalent Chromium–** was evaluated on a Reservation-wide basis using a composite of environmental concentration estimates from K-25 and Y-12 releases. Air exposures were based on modeling of Cr(VI) emission and drift from six gaseous diffusion process cooling towers at the K-25 Site to the reference location at Union/Lawnville. Surface water exposures were evaluated based on the maximum reported Cr(VI) concentrations in EFPC, which were measured in 1969. For a more realistic, Refined Level I analysis, the maximum Cr(VI) level measured in Poplar Creek was used. The average concentration of total chromium in soil in the EFPC remedial investigation was used in the screening; in the Level I screen, this concentration was assumed to be all Cr(VI), while in the Refined Level I screening it was assumed that one-sixth of the total chromium was Cr(VI). Levels in meat, milk, vegetables, and fish were estimated using the selected concentrations in air, soil, and water with biotransfer and bioconcentration factors from the scientific literature. Level I and Refined Level I screening assessments were performed for hexavalent chromium for cancer (from inhalation exposure) and non-cancer health effects (from inhalation and oral exposure).

- **Lead–** In the Feasibility Study's screening evaluation, lead ranked second after mercury in terms of potential noncarcinogenic health hazards to off-site populations. To be consistent with other materials screened in the feasibility study, this ranking was established using a provisional USEPA noncarcinogenic RfD for lead. Currently, however, the USEPA recommends evaluating lead exposures using the USEPA Integrated Exposure Uptake Biokinetic (IEUBK) model, which predicts blood lead concentrations in children.

No data describing measured air concentrations of lead at the location of the nearest off-site population (the Scarboro community) were identified by the project team during the Dose Reconstruction. Airborne lead concentrations at this location were estimated based on information on background concentrations of lead in air prior to the mid-1970s, when air concentrations began to decline due to discontinuing of lead use in gasoline. The project team used the highest measured surface water concentration reported for EFPC in the screening for the surface water pathways. The project team used the highest soil/sediment concentration from available environmental investigations in the screening analyses for the soil/sediment pathways; it was from the EFPC Remedial Investigation. To adjust for the possibility of higher surface soil concentrations of lead in past years, the 95% upper confidence limit (UCL) concentration was multiplied by a factor of 3.5, yielding an adjusted surface soil concentration for use in the screening. The maximum measured concentration in EFPC fish was also used. The project team calculated concentrations of lead in vegetation, meat, and milk using biotransfer factors that characterize the transfer of lead from other media, including air, water, and soil to these food products. The IEUBK model was used with the above concentration estimates to estimate blood lead concentrations in children. These estimated blood lead levels were then compared to an acceptable blood lead guidance concentration developed by the Centers for Disease Control and Prevention (CDC).

Hexavalent chromium was used as a corrosion inhibitor in the water that flowed through cooling towers such as these at the K-25 Site. Poplar Creek is at the lower left.

- **Lithium–** was evaluated based on limited stack sampling from two lithium processing buildings, used with the empirical dispersion factor for airborne releases from Y-12 to Scarboro. Surface water exposures were evaluated based on the highest quarterly average lithium concentration measured in EFPC. This concentration was not inconsistent with concentrations estimated by the project team based on documented lithium losses from process buildings and the average EFPC flow rate. Exposures from lithium in soil and sediment were evaluated based on the highest lithium concentration measured in soil in the EFPC floodplain. Levels in meat, milk, vegetables, and fish were estimated using the selected concentrations in air, soil, and water with biotransfer and bioconcentration factors from the scientific literature. Level I and Refined Level I screening assessments were performed for lithium for non-cancer health effects from inhalation and oral exposure. Screening indices for inhalation exposure were evaluated based on a derived RfD based on 10 percent of the maximum daily therapeutic maintenance dose of lithium carbonate used to control mania, a manifestation of bipolar disorder.

- **Neptunium-237–** Airborne releases of Np-237 from K-25 were estimated based on the reported mass of recycled uranium received annually, estimated Np-237 concentrations in that uranium (estimated based on the alpha activity limit on what would be accepted), and a release fraction based on estimated uranium releases divided by reported uranium inventories at K-25. A similar process was used to estimate Y-12 air releases, with the release fraction based on reported inventory differences for natural uranium (that is, estimates of

quantities lost or unaccounted for based on material accountability records). Air concentrations were estimated at Union/Lawnville and Scarboro based on dispersion modeling and the empirical dispersion factor for Y-12 releases to Scarboro. Concentrations of Np-237 in the Clinch River were estimated based on reported releases of Np-237 and transuranic radionuclides from the K-25 Site and correction for dilution by the median flow rate of the Clinch. Waterborne releases from the Y-12 Plant were estimated as three quarters of the loss that was estimated based on natural uranium inventory differences. Releases were diluted by the lower bound of measured flow rates in EFPC. Exposures from Np-237 in soil and sediment were evaluated based on the highest sediment concentration reported in the Clinch River in 1981 and the highest sediment concentration reported in the EFPC Remedial Investigation. Levels in meat, milk, vegetables, and fish were estimated using the selected concentrations in air, soil, and water with biotransfer and bioconcentration factors from the scientific literature. A Level I screening assessment was performed for Np-237 as a carcinogen due to internal radiation exposure after inhalation and oral exposure.

Np-237 and Tc-99 were contaminants in the recycled uranium used at K-25 and Y-12

- **Nickel–** Airborne concentrations of nickel near the K-25 Site were estimated based on measurements made with an air sampler located about 300 feet east of gaseous diffusion barrier production building K-1037 in the mid-1970s, corrected according to the ratio of dispersion model results for that location compared to that for the off-site reference location at Union/Lawnville. Surface water exposures were evaluated based on the highest mean concentration reported for the Clinch River as part of routine monitoring in 1975, and soil/sediment exposures were evaluated based on the highest mean sediment concentration reported for the Clinch River just upstream of the mouth of Poplar Creek in 1976. Levels in meat, milk, vegetables, and fish were estimated using the selected concentrations in air, soil, and water with biotransfer and bioconcentration factors from the scientific literature. Level I and Refined Level I screening assessments were performed for lithium for cancer from inhalation exposure and non-cancer health effects from oral exposure.

- **Niobium–** was evaluated using the threshold quantity approach, using a reference dose derived from an LD_{50} (the dose lethal to 50% of those exposed) in test animals, an empirically derived dispersion factor for airborne releases carried from the Y-12 Plant to Scarboro, and estimated average EFPC flow rates. While production rates and release estimates for niobium remain classified, information reviewed in Y-12 Plant quarterly reports and obtained in interviews indicated that usage rates of niobium never exceeded the threshold release rates to air or water that were calculated.

- **Plutonium–** In the Feasibility Study, airborne plutonium releases were estimated for plutonium separation at the X-10 Chemical Processing Pilot Plant, for radioactive barium/lanthanum processing, and for ruptures of fuel "slugs" in the Clinton Pile. For screening in the Feasibility Study, quantities of plutonium present in Clinton Pile fuel slugs were estimated based on documented rates of "product" formation. The records that documented these rates of formation did not, however, specify the isotopic composition of the plutonium "product" formed, so the project team assumed the plutonium formed and in part released to the environment was plutonium-239 (^{239}Pu). At the close of the Feasibility Study, the potential ramifications of this assumption were identified by the project team as an area that should be further addressed. During the Dose Reconstruction, the project team calculated the plutonium content of the fuel slugs for eleven isotopes of plutonium using the ORIGEN2.1 computer code. The results indicate that ^{239}Pu

comprised at least 99.9 percent of the plutonium present in Clinton Pile fuel slugs, therefore assuming the plutonium "product" was ^{239}Pu did not introduce significant inaccuracy into the Feasibility Study screening of past airborne releases of plutonium from the X-10 Site.

- **Technetium-99–** Airborne releases of Tc-99 from K-25 were estimated based on reported releases from a 1978 material balance report and from routine environmental reports in later years. Releases from the Y-12 Plant were estimated based on documentation of quantities of recycled uranium received at Y-12, the estimated concentration of Tc-99 in that uranium, and the release fraction based on reported inventory differences for natural uranium. Air concentrations were estimated at Union/Lawnville and Scarboro based on dispersion modeling and the empirical dispersion factor for Y-12 releases to Scarboro. Surface water exposures were evaluated based on the highest surface water concentration for the Clinch River (reported in 1992), and the highest concentration reported for EFPC (reported in 1993 from a sample collected near the junction of Bear Creek Road and Scarboro Road). Exposures from soil/sediment pathways were evaluated based on the highest Tc-99 concentration in sediment reported for the Clinch River (from routine sampling in the 1970s) and the highest concentration reported for EFPC in a 1984 TVA study. Levels in meat, milk, vegetables, and fish were estimated using the selected concentrations in air, soil, and water with biotransfer and bioconcentration factors from the scientific literature. Level I and Refined Level I screening assessments were performed for Tc-99 as a carcinogen due to internal radiation exposure after inhalation and oral exposure.

- **Tellurium–** was evaluated qualitatively. The project team found that its short duration of use and the method in which it was used made it unlikely that tellurium was released in quantities sufficient to pose an off-site health hazard.

- **Tetramethylammoniumborohydride [TMAB, $(CH_3)_4NBH_4$]–** was evaluated using the threshold quantity approach because inventory quantities remain classified. TMAB was formerly classified per se.

- **Tritium–** was evaluated based on deuterium inventory differences (quantities "lost" or unaccounted for in deuterium processing) and the peak documented tritium concentration in the deuterium that was processed at Y-12 from heavy water received from Savannah River. A release estimate obtained from these data was used with the International Atomic Energy Agency (IAEA) method for tritium dose assessment assuming all of the tritium that escaped was released to EFPC over a 40-year period. The resulting Level I screening index was well below the project's decision guide of 1×10^{-4} added lifetime cancer risk.

- **Zirconium–** was evaluated using the threshold quantity approach, using a reference dose derived from an ACGIH Threshold Limit Value® for occupational exposure, the empirically derived dispersion factor for air releases from Y-12 to Scarboro, and estimated average EFPC flow rates. While production information for zirconium remains classified, it was reviewed by project team members and clearly indicates that quantities of zirconium at Y-12 in any given year were less than the threshold release rates to air or water that were calculated.

TMAB was one of the materials formerly classified by its mere presense

Results of Task 7 Screening

The results of the screening analyses of materials that were quantitatively evaluated are shown in Table 9-1. For each of the 13 assessments depicted, the table identifies:

- The identity of the contaminant and its source (K-25 Site or Y-12 Plant in most cases).
- The identity of the reference location for which concentrations, doses, and screening indices were estimated. These reference locations were selected as the areas where the highest off-site exposures likely occurred.
- The calculated cancer screening index for materials evaluated as carcinogens. These values were estimated by multiplying the total dose of a chemical by its cancer potency slope factor, or the radiation dose from a radionuclide times a risk factor of 7.3% Sv^{-1}.

  Results are presented for a Level I evaluation, and for a refined Level I analysis where applicable. Values are shown in bold when they exceed the decision guide in use on the project (that is, the screening index is 1×10^{-4} or greater).
- The non-cancer screening index for materials associated with toxic effects other than cancer. These values were in most cases calculated by dividing the dose of a chemical by its USEPA reference dose. Cases where different approaches had to be used (for chemicals without established reference doses) are identified in the "Notes" column.[1]

  In cases where doses were compared to reference doses for both inhalation and ingestion, the screening index that represents the largest fraction of (or multiple of) the applicable reference dose is provided. In each case described here, the highest screening indices resulted from comparing doses from ingestion to the oral reference dose. Results are presented for the Level I evaluation, and for a Refined Level I analysis where applicable. Values are shown in bold when they exceed the decision guide in use on the project (that is, the screening index is 1 or greater).
- Notes are provided to indicate where non-standard approaches had to be used in an assessment. Notes are also provided, for non-carcinogens, to describe the relationship between the reference dose and a relevant toxicologic reference value, such as a NOAEL or LOAEL. In cases where screening indices indicate potential doses above the applicable reference dose, it is important to know how much separation there is between the reference dose and the NOAEL or LOAEL (that is, how much of a safety factor there is) in order to be able to evaluate the potential for health effects.

[1] Reference doses were derived by the project team for niobium (from an LD_{50} in mice), lithium (from the erapeutic dose of lithium carbonate), and copper and zirconium (from ACGIH Threshold Limit Values®).

Table 9-1: Summary of Screening Results for Materials Evaluated Quantitatively

Material	Cancer Screening Index	Non-Cancer Screening Index	Notes
Arsenic from K-25 *exposure for Union/Lawnville*	**Level I = 3.8×10^{-2}** **Refined Level I = 8.9×10^{-4}**	**Level I = 120** **Refined Level I = 13**	The NOAEL (from a human study) is a factor of 3 above the RfD. A non-cancer Screening Index above 3 could indicate exposures above the NOAEL.
Arsenic from Y-12 *exposure for Scarboro*	**Level I = 1.8×10^{-2}** **Refined Level I = 2.6×10^{-4}**	**Level I = 41** **Refined Level I = 4.0**	The NOAEL (from a human study) is a factor of 3 above the RfD. A non-cancer Screening Index above 3 could indicate exposures above the NOAEL.
Beryllium from Y-12 *exposure for Scarboro*	**Level I = 4.0×10^{-4}** Refined Level I = 1.3×10^{-5}	Level I = 0.066	The NOAEL (based on a rat study) is a factor of 100 above the RfD. A non-cancer Screening Index above 100 could indicate exposures above the NOAEL.
Chromium(VI) from the ORR *estimated based on Union/Lawnville air levels and EFPC/Poplar Creek water and soil/sediment data*	**Level I = 1.3×10^{-4}** Refined Level I = 1.0×10^{-5}	**Level I = 9.7** Refined Level I = 0.55	The NOAEL (based on a rat study) is a factor of 800 above the RfD. A non-cancer Screening Index above 800 could indicate exposures above the NOAEL.
Copper from K-25 *exposure for Union/Lawnville*		**Level I = 2.4** Refined Level I = 0.13	The LOAEL (from human studies of gastrointestinal effects) is a factor of 2 above the RfD. A non-cancer Screening Index above 2 could indicate exposures above the LOAEL.
Lead Releases from Y-12 *based on levels in EFPC water and soil/sediment, estimated average urban air levels prior to the 1970s*		**Level I = 5.2 to 6.7** **Refined Level I = 1.8 to 2.3**	These Screening Indices are based on the calculated range of blood lead levels divided by the CDC/USEPA action level of 10 $\mu g\ dL^{-1}$. Non-cancer Screening Indices above 1 could indicate exposures above the CDC action level.

Table 9-1: Summary of Screening Results for Materials Evaluated Quantitatively *(continued)*

Material	Cancer Screening Index	Non-Cancer Screening Index	Notes
Lithium from Y-12 *exposure for Scarboro*		**Level I = 2.3** Refined Level I = 0.29	The derived RfD is a factor of 10 below the normal therapeutic dose. Lithium toxicity can occur at doses close to therapeutic levels. A non-cancer Screening Index above 10 could indicate exposures above the therapeutic dose.
Neptunium-237 from K-25 *exposure for Union/Lawnville*	Level I = 7.3×10^{-6}		
Neptunium-237 from Y-12 *exposure for Scarboro*	Level I = 6.8×10^{-6}		
Nickel from K-25 *exposure for Union/Lawnville*	**Level I = 1.1×10^{-4}** Refined Level I = 6.1×10^{-6}	**Level I = 12** Refined Level I = 0.75	The NOAEL (from a rat study) is a factor of 250 above the RfD. A non-cancer Screening Index above 250 could indicate exposures above the NOAEL.
Technetium-99 from K-25 *exposure for Union/Lawnville*	**Level I = 3.0×10^{-2}** Refined Level I = 1.8×10^{-5}		
Technetium-99 from Y-12 *exposure for Scarboro*	**Level I = 2.7×10^{-4}** Refined Level I = 2.8×10^{-5}		
Tritium from Y-12 Heavy Water *exposure for Scarboro*	Level I = 1.6×10^{-6}		

Examination of the results in Table 9-1 shows that:

- For carcinogens, 3 of 10 analyses ended with the Level I screening (Np-237 from K-25, Np-237 from Y-12, and tritium from Y-12). In other words, the initial, most conservative screening calculations for these materials yielded results that were below the decision guide.
- For the other seven assessments of carcinogens, refined screening was performed. Of these refined assessments, two yielded results that were still above the applicable decision guide (arsenic from K-25 and arsenic from Y-12). The other five were below the decision guide with refined screening (beryllium from Y-12, chromium(VI) from the ORR, nickel from K-25, technetium-99 from K-25 and technetium-99 from Y-12).
- For non-carcinogens, 1 of 8 analyses ended with the Level I screening (beryllium from Y-12). In other words, the initial, most conservative screening calculations for beryllium yielded results that were below the decision guide in use on the project.
- For the other seven assessments, three yielded results that were still above the applicable decision guide (arsenic from K-25, arsenic from Y-12, and lead from the Y-12 Plant). The other four were below the decision guide with refined screening (chromium(VI) from the ORR, copper from K-25, lithium from Y-12, and nickel from K-25).

Several materials were quantitatively evaluated that do not appear in Table 9-1. These materials were evaluated using the threshold quantity approach, a method that does not yield numerical screening indices. Materials in this category include tetramethyl-ammoniumborohydride (TMAB), niobium, and zirconium. Based on evaluation of the limited information available on these materials, it was determined that the quantities of each that were present at the Y-12 Plant were not likely great enough to have posed off-site health hazards

Conclusions of the Screening Evaluations

Based on the qualitative and quantitative screening performed under Task 7 of the Oak Ridge Dose Reconstruction project, it was possible to separate materials into classes based on their apparent importance in terms of potential off-site health hazards. This classification process was to a great degree dependent on the information that is available concerning past uses and releases of the materials of interest. In the course of Task 7 work, it was not possible to perform extensive directed searches for records relevant to each Task 7 material to the extent that was possible for the operations and contaminants studied in detail under Tasks 1, 2, 3, 4, and 6. For some materials, very little historical information is available. As a result, it was necessary to make a significant number of conservative assumptions for some materials to ensure that potential doses were not underestimated. If, in the future, more extensive document searching is performed, some of the conclusions reached in the screening evaluations described herein might well change.

Based on the qualitative and quantitative screening, five materials used at the K-25 Site and 14 materials (or classes of materials) used at the Y-12 Plant are judged to not warrant further study related to their potential for off-site health effects. These materials are identified in the second column of Table 9-2. The materials named to this category were placed there because either:

1) Quantitative screening of the most conservative nature (Level I screening) yielded screening indices that fell below the guides in use on the project;

2) Application of a threshold quantity approach demonstrated that not enough of the material was present to have posed an off-site health hazard; or

3) In qualitative evaluation of available information by project team members, it became obvious that quantities used, forms used, and/or manners of usage were such that off-site releases could not have been sufficient to have posed off-site health hazards.

Based on quantitative screening, three materials used at the K-25 Site, three materials (or classes of materials) used at the Y-12 Plant, and one material used at all sites were identified as potential candidates for further study, but not with high priority. These materials, listed in the the third column of Table 9-2, were identified as potential candidates for further study because quantitative screening of the most conservative nature (Level I screening) yielded screening indices that exceeded a project decision guide. As shown in Table 9-2, some of these materials exceeded the decision guides as carcinogens, while others exceeded published or derived reference doses for materials that cause effects other than cancer. When less conservative, "refined" screening was performed for these materials, results in each case fell below the decision guides.

Based on quantitative screening, one material used at the K-25 Site and two used at the Y-12 Plant were identified as high priority candidates for further study. These materials, which are listed in the fourth column of Table 9-2, were identified as high priority candidates for further study because less conservative, "refined" quantitative screening yielded screening indices that exceeded the decision guide in use on the project. Arsenic achieved this status as both a carcinogen and as a non-carcinogen, while lead achieved this status as a non-carcinogen.

For the non-carcinogenic contaminants with screening indices that exceeded 1 in refined screening, it is important to evaluate the relationship between the reference dose and toxicologic reference levels such as the NOAEL or LOAEL. The importance of a screening index above 1 varies from one material to the next, because the amount of separation between the reference dose and the dose at which health effects have been shown to occur varies significantly. For this project, the materials for which this type of evaluation is most critical are arsenic and lead. Following are summaries of the relationships between screening indices for these materials and applicable NOAELs or action levels.

For arsenic, the NOAEL (from a human study) is a factor of three above the oral RfD. Non-cancer screening indices above 3 could indicate that exposures above the NOAEL occurred. Because the screening indices from the refined assessments are 13 and 4.0 for K-25 and Y-12, respectively, it is possible that doses above the NOAEL were experienced. At the same time, it is impossible to say if health effects occurred or not. For lead, it has been reported that adverse health effects can occur in children at blood lead concentrations as low as the 10 $\mu g\ dL^{-1}$ action level set by CDC in 1991. Non-cancer screening indices for lead in Table 9-1 were based on the ranges of blood lead concentrations calculated with the IEUBK model, divided by the CDC action level of 10 $\mu g\ dL^{-1}$. Because the screening indices from the refined assessment for lead range between 1.8 and 2.3, it is possible that doses above the action level were received by some children. It is less likely that doses to any adults exceeded OSHA's standard of 40 $\mu g\ dL^{-1}$.

Some of the materials evaluated in this project have very limited toxicologic information available. For example, very little is known about potential effects from exposure to lithium at levels that can be expected to occur in the environment. RfDs for niobium, lithium, copper, and zirconium are not available from the USEPA. For the purposes of this study, RfDs were derived from studies of lethal doses in mice (niobium), from ACGIH Threshold Limit Values® for the workplace (copper and zirconium), and from therapeutic doses used in humans (for lithium). If better toxicologic data become available for these materials, the analyses described herein would likely benefit from evaluation with that new information. This is particularly true for lithium, which was evaluated based on a "derived" reference dose equal to the lithium equivalent of one-tenth of the dose of lithium carbonate used in humans to control mania. Because lithium toxicity can occur at doses close to the therapeutic dose, the lack of information concerning effects of exposure to lithium at environmental levels is an important data gap.

Table 9-2: Categorization of Materials Based on Screening Results

CONTAMINANT SOURCE	NOT CANDIDATES FOR FURTHER STUDY *(Level I result less than the decision guide)*	POTENTIAL CANDIDATES FOR FURTHER STUDY *(Refined Level I result less than the decision guide)*	HIGH PRIORITY CANDIDATES FOR FURTHER STUDY *(Refined Level I result greater than the decision guide)*
THE K-25 SITE	Neptunium-237 (cancer) Evaluated qualitatively: carbon fibers, four-ring polyphenyl ether, glass fibers, Triplex coating	Arsenic (cancer) Arsenic (non-cancer) Copper powder (non-cancer) Nickel (cancer) Nickel (non-cancer) Technetium-99 (cancer)	Arsenic (cancer) Arsenic (non-cancer)
THE Y-12 PLANT	Beryllium Compounds[1] (non-cancer) Neptunium-237 (cancer) Niobium[2] (non-cancer) TMAB (non-cancer) Tritium (cancer) Zirconium[3] (non-cancer) Evaluated qualitatively: boron carbide, boron nitride, rubidium nitrate, rubidium bromide, tellurium, titanium boride, yttrium boride, zirconium	Arsenic (cancer) Arsenic (non-cancer) Beryllium Compounds (cancer) Lead (non-cancer) Lithium Compounds[4] (non-cancer) Technetium-99 (cancer)	Arsenic (cancer) Arsenic (non-cancer) Lead (non-cancer)
THE OAK RIDGE RESERVATION *(ALL COMPLEXES)*		Chromium(VI) (cancer) Chromium(VI) (non-cancer)	

[1] Forms of beryllium used include beryllium hydride, beryllium deuteride, beryllium metal, beryllium oxide, niobium beryllide, tantalum beryllide.

[2] Niobium was part of "mulburry" alloy (depleted uranium, niobium, and zirconium) and "binary" alloy (depleted uranium and niobium).

[3] Zirconium was part of "mulburry" alloy (depleted uranium, niobium, and zirconium).

[4] Forms of lithium used include lithium chloride, lithium deuteride, lithium fluoride, lithium hydride, and lithium tetraborate.

10. OVERALL SUMMARY OF PROJECT RESULTS

Figures 10-1 and 10-2 summarize the maximum estimated health risks for each contaminant addressed with a detailed dose reconstruction as part of this project. Figure 10-1 presents the maximum calculated excess cancer risks for iodine-131, PCBs, and radionuclides released to the Clinch River. The highest values were obtained for iodine-131. For a female who was born in 1952 near Gallaher Bend and drank goat milk (from one to five 8-ounce glasses per day through 1956), we are confident that excess thyroid cancer risk is greater than 1.8 in 1,000 but no more than 430 in 1,000. The central estimate is 31 in 1,000. It is important to remember that the cases presented in Figure 10-1 are those that resulted in the highest calculated cancer risks in the assessments of exposures to iodine-131, PCBs, and radionuclides from White Oak Creek. There are other reference populations and other diets for which calculations were performed that are estimated to have received significantly lower doses. In effect, the cases presented in this figure and the figure that follows represent the worst case exposures addressed in this project.

Figure 10-2 presents the maximum calculated non-cancer health risks for mercury (in elemental, inorganic, and methylmercury forms) and for PCBs. The highest hazard index values were obtained for PCB exposures to children in an East Fork Poplar Creek farm family. For a child living on an EFPC farm, we are confident that the screening index is greater than 3 but no more than 200. The central estimate is 40. Again, the cases presented in Figures 10-2 are those that resulted in the highest calculated non-cancer hazard indices in the assessments of exposures to mercury and PCBs. There are other reference populations and other diets for which calculations were performed that are estimated to have received significantly lower doses.

The confidence intervals for the maximum calculated hazard indices for exposure to the three forms of mercury and for PCBs presented in Figure 10-2 are graphed along with the values of their USEPA Reference Doses, which in each case correspond to a hazard index of 1, and the published LOAEL value or range of LOAEL values. Except for the case of methylmercury exposures from Clinch River fish, the 95% confidence intervals fall below the applicable LOAEL values.

Concurrent Exposures to Several Contaminants

Table 10-1 presents a summary of the reference locations and exposure pathways that were included for the different contaminants that were addressed in this study. This table illustrates the wide variety of reference locations and exposure pathways that were addressed in this project, which in turn is an indication of the potential complexity of exposure scenarios that could have been experienced by real people in the Oak Ridge area. Figure 1-2 illustrates how the key operations that were sources of historical releases overlapped in time during a number of periods. While the contaminants studied in this project were to a large extent studied independently, people that have lived in or near Oak Ridge could have been exposed to several contaminants at the same time.

Figure 10-1: Maximum Calculated Risks for Carcinogens Evaluated in the Oak Ridge Dose Reconstruction

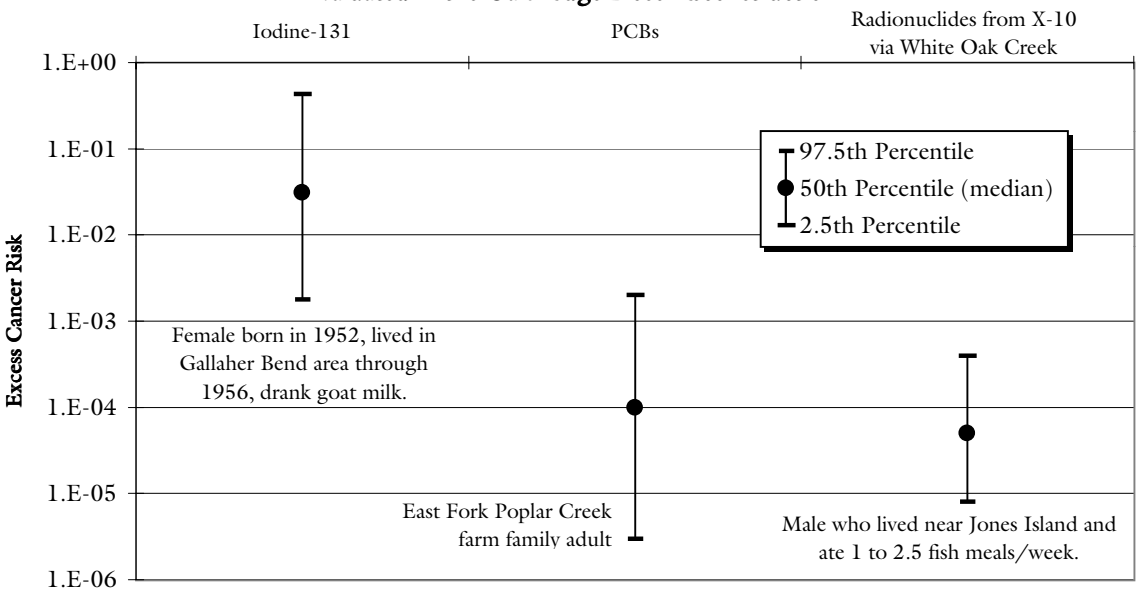


Figure 10-2: Maximum Calculated Hazard Indices for Non-carcinogens Evaluated in the Oak Ridge Dose Reconstruction

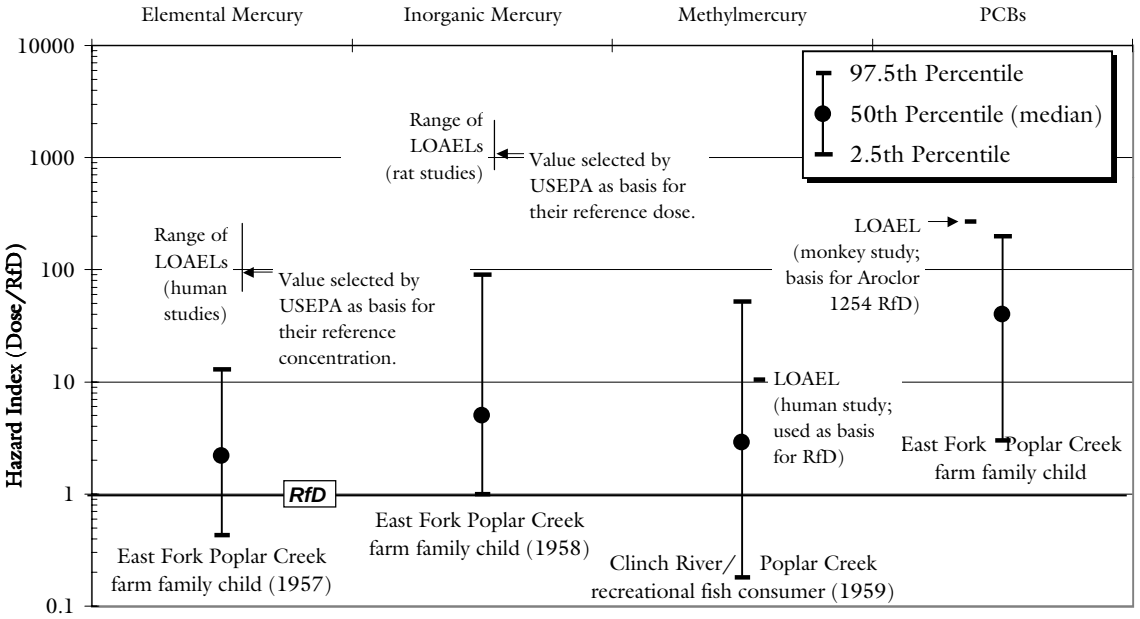


Table 10-1: Exposure Routes and Reference Populations Addressed by the Oak Ridge Dose Reconstruction

EXPOSURE ROUTES → / REFERENCE LOCATIONS ↓	Inhalation	Fish	Turtles	Backyard Cow Milk	Milk from Cows with Access to Surface Water	Goat Milk	Local Commercial Milk	Regional Commercial Milk	Mothers' Milk	Beef	Beef from Cattle with Access to Surface Water	Homegrown Vegetables	Cheese	Eggs	Drinking Water	Surface Water Ingestion (incidental)	Soil/Sediment Ingestion (incidental)	Skin Contact with Surface Water	Skin Contact with Soil/ Sediment	Irradiation from Shore Sediments
OAK RIDGE - - - - - -																				
East Fork Poplar Cr. Floodplain Farm	I, Hg		PCBs	I, Hg, PCBs	Hg		I	I	I	I, Hg, PCBs	Hg	I, Hg, PCBs	I	I		Hg	Hg, PCBs	Hg	Hg, PCBs	
Oak Ridge High School	I							I	I			I								
Jefferson Avenue	Hg											Hg								
Louisiana Avenue	Hg											Hg								
Robertsville School area	Hg															Hg	Hg	Hg	Hg	
Scarboro Community	I, Hg							I	I			I, Hg				Hg	Hg	Hg	Hg	
Townsite (Turnpike near Jackson Sq.)	I							I	I			I								
Woodland	I							I	I			I								
OTHER COMMUNITIES - - - - - - -																				
Barnardsville, Bradbury, Buttermilk Rd., Cedar Bluff, Cedar Grove, Claxton, Clinton, Dutch Valley, Dyllis, Farragut, Friendsville, Greenback, Gallaher Bend, Hardin Valley, Harriman, Hines Valley Rd., Jonesville, Karns, Kingston, Knoxville, Lawnville/ Gallaher, Loudon, Louisville, Maryville, Norwood, Oakdale, Oliver Springs, Rockford, Rockwood, Solway, Sugar Grove, Sweetwater, Wartburg	I			I		I	I	I	I	I		I	I	I						
Hope Creek, Lenoir City	I			I			I	I	I	I		I	I	I						
Wolf Valley (Union Valley)	Hg			Hg						Hg		Hg								
SURFACE WATER BODIES - - - - - - -																				
Clinch River: Jones Island Area		PCBs, WOC			WOC						WOC									WOC
Clinch River: K-25/Grassy Creek		PCBs, WOC			WOC						WOC				WOC					WOC
Clinch River: Kingston Steam Plant		Hg, PCBs, WOC			WOC						WOC				WOC					WOC
Clinch River: City of Kingston		Hg, PCBs, WOC			WOC						WOC				WOC					WOC
East Fork Poplar Creek		Hg, PCBs																		
Poplar Creek		Hg, PCBs																		
Watts Bar Reservoir		Hg, PCBs																		

Contaminant Key: I = iodine-131 from X-10; Hg = mercury from Y-12; PCBs = polychlorinated biphenyls; WOC = radionuclides from X-10 via White Oak Creek.

When individuals are exposed to several contaminants at the same time, there are a number of possible ways in which the effects of the individual contaminants can combine. The four most common types of toxicologic interactions are additivity, synergism, potentiation, and antagonism. These forms of interaction can be defined as follows:

- Additivity is when the effects of the individual contaminants combine to cause an over all effect that is equal to the sum of their effects as individual contaminants. [sometimes depicted 1 + 1 = 2, using a representation where 0 indicates no effect and increasing numbers indicate increasing adverse effect]
- Synergism is when the effects of the individual contaminants combine to cause an overall effect that is *greater than* the sum of their effects as individual contaminants [1 + 1 = 5]. An example of a synergistic effect is Valium taken with alcohol. For agents to have synergistic toxicity, they must have the same target organ, they must be capable of causing the same adverse response, and they must be present at sufficient concentra tions in affected body tissue to cause that response.
- Potentiation is when a contaminant would normally have no effect at the exposure level in question, but the presence of the other contaminant *activates* (or potentiates) the toxicity of the material. The end result is a degree of overall effect that is greater than the sum of the effects of the individual contaminants [0 + 1 = 3].
- Antagonism is when toxic materials *deactivate or decrease* the toxicity of other materi als. The end result is a degree of overall effect that is less than the sum of the effects of the individual contaminants, or there is no adverse effect at all [1 + 1 = 0].

Unfortunately, very little is known about the ways in which the effects of the contaminants that were studied in this project combine when people are exposed to environmental concentrations. There are no well-documented studies that demonstrate synergistic or antagonistic effects of the environmental contaminants of interest. Lacking a clear picture of the possible manners in which the contaminants could have interacted toxicologically, the emphasis in this project has been to describe the exposures to each contaminant that could have occurred to a number of reasonable reference populations, and to identify the time periods when exposures to several contaminants could have occurred at the same time.

The following eight example exposure conditions ("scenarios") were prepared by the project team, working with ORHASP members, to serve as examples of how off-site individuals could have reasonably been exposed to several contaminants during their residence near the ORR. These exposures were in some cases concurrent, and in some cases during different time periods. Following the description of each scenario is a summary of relevant results of the dose reconstruction that can be used to address overall health risks to the individual in that scenario.

A common denominator of 100,000 is used for presentation of estimated excess cancer risks (such as 5 in 100,000). Non-cancer risks are presented in terms of Hazard Indices, which are the ratios of estimated doses to USEPA Reference Doses. The discussion of relevant results that follows each scenario has been condensed to present the most basic of results. For more details, the reader can consult the footnotes that provide additional information (such as 95% confidence intervals and central estimates for key calculation results) or the tables in the individual reports of the project tasks that are identified in those footnotes.

Following the discussion of the individual scenarios, Figures 10-3 and 10-4 allow comparison of the calculated added cancer risks and non-cancer hazard indices across all scenarios.

Summary of Example Exposure Scenarios

Scenario & Gender	Years in Area* (Year Born)	Location of Residence	Fish Meals & Source	Milk Source	Other Features
1 F	1940 – (b. 1940)	East Fork Poplar Creek Farm	Category II Clinch River		Had a child in 1958.
2 M	1948 – (b. 1927)	Oak Ridge	Category III Watts Bar		Born outside state. Was 21 when moved to Oak Ridge.
3 F	1948 – (b. 1948)	Woodland and Scarboro	Category I Clinch River		Played in East Fork Poplar Creek.
4 M	1955 – (b. 1930)	Scarboro	None		Born outside state. Was 25 when moved to Scarboro area.
5 M	1940 – 65 (b. 1940)	Oak Ridge	Category II Clinch River		Ate contaminated deer meat(1954). Left Oak Ridge(1965).
6 F	1950 – (b. 1950)	Kingston	Category I Watts Bar		Drank only goat's milk. Fish meals include fish patties.
7 M	1950 – (b. 1950)	Bradbury Farm	Category III Clinch River		Consumed home-grown food.
8 F	1960 – (b. 1960)	Oak Ridge	None		Played in East Fork Poplar Creek.

Milk Source

Backyard Cow

Backyard Goat

Commercial Regionally Mixed

Frequency of Fish Meals

Category I
1 to 2.5 meals per week

Category II
1.5 to 4 meals per month

Category III
2 to 17 meals per year

Scenario 1 involves a female who was born in 1940 and moved in 1943 to a farm on the banks of East Fork Poplar Creek. She drank backyard cows' milk as an infant through adulthood. She played in EFPC as a child, and ate home-produced vegetables, beef, cheese, and eggs. In addition, each month she ate between 1½ and 4 meals of fish caught in the Clinch River just below the mouth of Poplar Creek. She became pregnant and had a child in 1958, and continued living in the area to the present time.

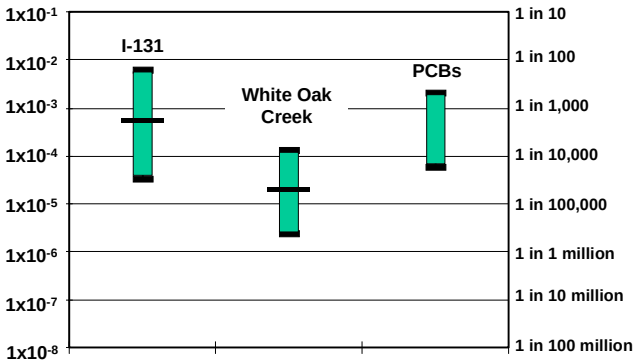
Potential for Excess Cancer–

This person's total estimated added cancer risk is dominated by exposures to iodine-131 and PCBs. Estimates are that her cancer risk was increased by about **3 to 600** in 100,000[1] from I-131 exposure[2] and by **0.3 to 200** in 100,000 by exposures to PCBs on the farm.[3] The upper confidence limit of total added risk from exposures to radionuclides from White Oak Creek[5] is at least a factor of **15** below the values for I-131 and PCBs.

The dose reconstruction for PCBs in fish addressed the group of Clinch River recreational fish consumers as a whole, but not this individual and her specified diet; for Clinch River fish consumers as a group, the added risk is between **0.04 and 30** in 100,000 from consumption of PCB-contaminated Clinch River fish.[4] If one considers this woman's fish consumption rate rather than the distribution for the population as a whole evaluated in the dose reconstruction for PCBs, one can estimate that her risk of all types of cancer from PCBs in Clinch River fish increased by an amount between **6 and 35** chances in 100,000.[6]

Consumption of mother's milk ended before I-131 releases started in 1944, so no exposures resulted from that pathway. While both the I-131 releases from RaLa processing and the White Oak Creek releases resulted in doses to the thyroid gland, the central estimate of excess thyroid cancer risk from the RaLa releases exceeds the central estimate of thyroid risk from White Oak Creek releases by over a factor of 1,000.[7]

Additional Cancer Risks- Scenario 1



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[1]The method for describing estimated added cancer risks in this section is in the form of the estimated number of excess cancer cases per 100,000 people who were exposed. This number per 100,000 people exposed is not known exactly. Rather, it is stated as a range like the 3 to 600 shown here. This means that the 95% confidence interval of added risk of cancer incidence is between 3 in 100,000 and 600 in 100,000.

[2]The 95% confidence interval is 3.3×10^{-5} to 6.1×10^{-3}, with a central estimate of 5.0×10^{-4} (see App. 11-C of the Task 1 report for details; EFPC location, female born in 1940, "Diet 1").

[3]The 90% confidence interval is 3×10^{-6} to 2×10^{-3}, with a central estimate of 1×10^{-4} (see Tab. 7-9 of theTask 3 report for details; EFPC farm family, adult age group).

[4]The 90% confidence interval is 4×10^{-7} to 3×10^{-4}, with a central estimate of 2×10^{-5} (see Tab. 7-9 of theTask 3 report for details; Clinch River/Poplar Creek recreational fish consumer, adult age group). These results reflect PCBs from all sources, ORR and other industries.

[5]The 95% confidence interval is 2.4×10^{-6} to 1.3×10^{-4}, with a central estimate of 1.8×10^{-5} (see App. 13-C in the Task 4 report for details; Cat. II fish consumer at CRM 14).

[6]Personal communication with Robert Peelle, ORHASP member. September 1999.

[7] Thyroid risk of 5.0×10^{-4} from RaLa releases divided by 3.7×10^{-7} from White Oak Creek releases (see Tab. 13B.5 in theTask 4 report) yields a factor of 1,400.

Potential for Non-cancer Effects–

This individual likely received doses of mercury and PCBs that exceeded USEPA reference doses. By the time that significant Y-12 mercury releases began in the early 1950s, this person was an adult in terms of toxic effects from mercury exposure. Estimates of methylmercury doses from fish consumption peaked in 1957[1] at from **0.92 to 5.4 times** the RfD for adult exposure (which is based on studies of humans). For 1958, the year during which she was pregnant, estimates of methylmercury dose from fish consumption range from **2.7 times to 14 times** the RfD based on *in utero* exposure[2]. Because the NOAEL for *in utero*/childhood exposure to methylmercury is only a factor of 5 above that RfD and the LOAEL is a factor of 10 above that RfD (all based on human studies), it is likely that the mercury exposure to the unborn young approached or exceeded the NOAEL and LOAEL and that deleterious health effects resulted.

It is possible that elemental mercury doses from inhalation exceeded the RfD from 1955 to 1959[3], as the upper confidence limit of dose peaked at **4.4 times** the Reference Dose (based on human studies) in 1957. It is even more likely that doses of inorganic mercury from local foods and skin contact exceeded the applicable RfD between 1953 and 1965, possibly by as much as a factor of **30** in 1957.[4] Even so, we are confident that doses by these pathways did not exceed the applicable NOAELs, because the 95% upper confidence limits of dose for the highest years are factors of **7.6 and 11** below the NOAELS for inhalation and ingestion/dermal contact of mercury, respectively[5]).

It is likely that doses of PCBs from exposures on the farm exceeded the applicable RfD. While there is much uncertainty regarding PCB levels in soils, we are confident that doses exceeded the RfD for Aroclor 1254 (based on a study with monkeys) by less than a factor of **100** as an adult[6] and **200** as a child[7]. This person's doses as an adult likely did not exceed the LOAEL, as the 90% upper confidence limit of dose is **40%** of the LOAEL for Aroclor 1254. Childhood doses likely did not exceed the LOAEL for Aroclor 1254, which corresponds to a Hazard Index of 250.

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[1]The 95% confidence interval of Hazard Index in 1957 is from 0.92 to 5.4, with a central estimate of 2.3. See Tab. X-1 and X-2 in the Task 2 report for details; Cat. II adult fish consumer, compared to adult RfD, Clinch River/Poplar Creek.

[2]The 95% confidence interval of Hazard Index in 1958 is from 2.7 to 14, with a central estimate of 7.0. See Tab. X-1 and X-2 in the Task 2 report for details; Cat. II adult fish consumer, compared to *in utero* RfD, Clinch River/Poplar Creek.

[3]The upper bound dose estimates exceed the RfD from 1955 through 1959, with a peak at 4.4 times the RfD in 1957. For 1957, the 95% confidence interval of Hazard Index is from 0.15 to 4.4, with a central estimate of 0.76. See Tab. X-1 and X-2 in the Task 2 report for details. Adult age group.

[4]The upper bound dose estimates exceed the RfD 1952–63 and 1965, with a peak at 31 times the RfD in 1957 (95% confidence interval of Hazard Index is from 0.53 to 31, with a central estimate of 2.7). Central estimates of dose exceed the RfD 1955-58, with a peak at 2.8 times the RfD in 1958 (95% confidence interval of Hazard Index is from 0.57 to 26, with a central estimate of 2.8). See Tab. X-1 and X-2 in the Task 2 report for details.

[5]Inhalation: NOAEL of 0.0029 mg/kg-d ÷ dose of 0.00038 mg/kg-d = factor of 7.6; Inorganic: NOAEL of 0.1 mg/kg-d ÷ dose of 0.0094 = factor of 11.

[6]The 90% confidence interval of Hazard Index is 2 to 100, with a central estimate of 20 (see Tab. 7-10 of the Task 3 report for details; EFPC farm family).

[7]The 90% confidence interval of Hazard Index is 3 to 200, with a central estimate of 40 (see Tab. 7-10 of the Task 3 report for details; EFPC farm family).

The dose reconstruction for PCBs in fish addressed the group of Clinch River recreational fish consumers as a whole, but not this individual and her specified diet. For Clinch River fish consumers as a group, for which a more refined uncertainty analysis could be performed, it is possible that PCB doses exceeded the population threshold for non-cancer effects, as the upper confidence limit of the True Hazard Quotient for a highly exposed (95th percentile) individual corresponds to **3 times** the threshold (that is, dose ÷ threshold dose = 3).[8]

If one considers this individual's fish consumption rate rather than the distribution for the population as a whole evaluated in the dose reconstruction for PCBs, one can estimate that her dose from PCBs in fish was up to **several times** the RfD for Aroclor 1254, but a **few percent** of the LOAEL for that mixture of PCBs (both of these toxicology reference values are based on studies with monkeys).[10] Her dose level was up to **about twice** the lower limit of the 90% confidence interval for the population threshold that project researchers calculated, but it was less than about **one third** of the median of the population threshold distribution.[9] This means that her dose would have had a less than 50 percent chance of harming the most sensitive individual in the population.

Chemical Toxicity for Scenario 1

Were toxicity reference values exceeded, yes or no?

Reference Value	Contaminant			
	methyl mercury	inorganic mercury	elemental mercury	PCBs
LOAEL	yes†	no	no	no
NOAEL	yes†	no	no	*not applicable**
RfD	yes	yes	yes	yes

†For *in utero* exposure to the fetus.

*There is no NOAEL for the PCB mixture of concern.

[8]For a highly exposed individual, the 90% confidence interval of True Hazard Quotient is from 0.08 to 3, with a central estimate of 0.5; For a more typical fish consumer (50th percentile), the 90% confidence interval of True Hazard Quotient is from 0.008 to 0.3, with a central estimate of 0.05. See Tab. ES-4 in the Task 3 report for details. These results reflect PCBs from all sources, ORR and other industries.

[9]The median (50th percentile) value of the refined empirical distribution of the population threshold for PCBs is 5.08×10^{-4} mg/kg-d (90% confidence interval from 9.3×10^{-5} to 1.8×10^{-3} mg/kg-d; see Fig. 8-3 of the Task 3 report), and the LOAEL for Aroclor 1254 is 5×10^{-3} mg/kg-d.

[10]Personal communication with Robert Peelle, ORHASP member. September 1999.

Scenario 2 addresses a male who was born outside of Tennessee in 1927 and moved to Oak Ridge in 1948 at the age of 21. He lived in early Oak Ridge housing around the Alexander Hotel, drank commercially available milk, and ate vegetables from a home garden. He ate between 2 and 17 meals per year of fish caught in Watts Bar Reservoir. This individual stayed in Oak Ridge the remainder of his life.

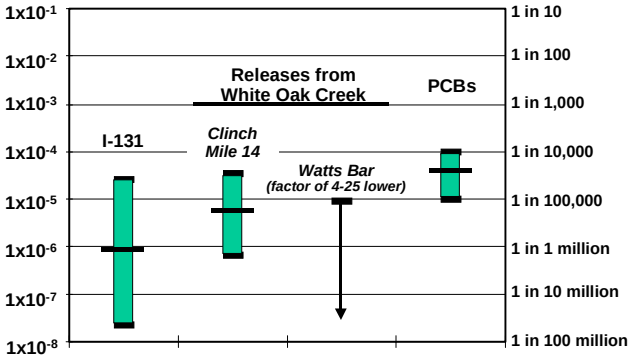
Potential for Excess Cancer–

This man's estimated cancer risks were increased by about **0.002 to 3** in 100,000 from I-131 exposure[1] and less than an additional **0.9** in 100,000 from exposures to radionuclides released from X-10 via White Oak Creek.[2]

The dose reconstruction for PCBs in fish addressed the group of Watts Bar recreational fish consumers as a whole, but not this individual and his specified diet; for Watts Bar fish consumers as a group, the added risk is between **0.09 to 60** in 100,000 from exposures to PCBs in fish that were eaten.[3] If one considers this individual's fish consumption rate rather than the distribution for the population as a whole evaluated in the dose reconstruction for PCBs, and applies a simple correction for 50 years of residence rather than the 70 years typically assumed, one can estimate that this man's risk of all types of cancer from PCB intake was increased by an amount between **1 and 10** chances in 100,000.[4]

The risks to this individual from both I-131 and radionuclides from White Oak Creek are over-estimated above to a certain degree, due to the fact that he moved to the area in 1948 and missed the potential exposures that began in 1944 from these sources. The calculation results summarized herein reflect the releases that began in 1944. However, it is clear that the majority of I-131 releases occurred between 1948 and 1956, and most of the radioactivity releases from White Oak Creek also post-dated 1947.

Additional Cancer Risks- Scenario 2



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[1]The 95% confidence interval is 2.2×10^{-8} to 2.6×10^{-5}, with a central estimate of 8.3×10^{-7} (see App. 11-C of the Task 1 report for details; "OR Townsite" location, male born in 1930, "Diet 3"). Diet 3 includes regionally mixed commercial milk and inhalation.

[2]The 95% confidence interval is 6.8×10^{-7} to 3.5×10^{-5}, with a central estimate of 5.8×10^{-6} (see App. 13-C in the Task 4 report for details; Cat. III male fish consumer at CRM 14). Concentrations in Watts Bar Res. were typically lower than those at CRM 14 by a factor between 4 and 25; $3.5\times10^{-5} \div 4 = 8.8\times10^{-6}$ or 0.88×10^{-5}.

[3]The 90% confidence interval is 9×10^{-7} to 6×10^{-4}, with a central estimate of 4×10^{-5} (see Tab. 7-9 of the Task 3 report for details; Watts Bar Reservoir adult recreational fish consumer). These results reflect PCBs from all sources, ORR and other industries.

[4]Personal communication with Robert Peelle, ORHASP member. September 1999.

Potential for Non-cancer Effects–

While it is likely that doses of mercury received by this individual did not exceed applicable USEPA Reference Doses, there is a good possibility that the RfD for PCBs was exceeded. A Reference Dose could have been exceeded from consumption of PCBs in fish from Watts Bar Reservoir. The dose reconstruction for PCBs in fish addressed the group of Watts Bar recreational fish consumers as a whole, but not this individual and his specified diet; the estimated dose to a highly exposed Watts Bar fish consumer in the refined uncertainty analysis ranged from **0.2 to 8 times** the population threshold for non-cancer effects[1]. Even at 8 times the threshold, peak doses were likely below the LOAEL, which for adults corresponds to a dose about 10 times the median population threshold value.[2]

If one considers this individual's fish consumption rate rather than the distribution for the population as a whole evaluated in the dose reconstruction for PCBs, one can estimate that his dose was up to **3 times** the EPA Reference Dose, though only about **two-thirds** the lower limit of the 90% confidence interval for the population threshold calculated by project researchers in their refined analysis. At this dose level, deleterious health effects are quite unlikely. (The toxicity data used were obtained using monkeys)

Estimates of methylmercury doses from fish consumption peaked at between **4 to 40 percent** of the RfD in 1958[3]. Estimates of elemental mercury doses via inhalation peaked at between **0.3% and 6%** of the RfD in 1957[4], and inorganic mercury doses via ingestion and skin contact peaked at between **0.2% and 57%** of the RfD in 1957[5].

Given these results for PCBs and mercury, non-cancer health effects are unlikely to be observed.

Chemical Toxicity for Scenario 2

Were toxicity reference values exceeded, yes or no?

Reference Value	Contaminant			
	methyl mercury	inorganic mercury	elemental mercury	PCBs
LOAEL	no	no	no	no
NOAEL	no	no	no	*not applicable**
RfD	no	no	no	**yes**

*There is no NOAEL for the PCB mixture of concern.

[1]For a highly exposed individual, the 90% confidence interval of True Hazard Quotient is from 0.2 to 8, with a central estimate of 1; For a more typical fish consumer (50th percentile), the 90% confidence interval of True Hazard Quotient is from 0.02 to 0.5 with a central estimate of 0.1. See Table ES-4 in the Task 3 report for more details. These results reflect PCBs from all sources, ORR and other industries.

[2]The median (50th percentile) value of the refined empirical distribution of the population threshold for PCBs is 5.08×10^{-4} mg/kg-d (90% confidence interval from 9.3×10^{-5} to 1.8×10^{-3} mg/kg-d; see Figure 8-3 of the Task 3 report), and the LOAEL for Aroclor 1254 is 5×10^{-3} mg/kg-d.

[3]The 95% confidence interval of Hazard Index in 1958 is from 0.042 to 0.43, with a central estimate of 0.17. See Tables X-1 and X-2 in the Task 2 report for more details; Category III adult fish consumer, Watts Bar Reservoir.

[4]The 95% confidence interval of Hazard Index in 1957 is from 0.0026 to 0.063, with a central estimate of 0.013. See Tables X-1 and X-2 in the Task 2 report for more details; Community Population No. 2 adult.

[5]The 95% confidence interval of Hazard Index in 1957 is from 0.0019 to 0.57, with a central estimate of 0.031. See Tables X-1 and X-2 in the Task 2 report for more details; Community Population No. 2 adult.

Scenario 3 involves a female who was born in 1948 in what is now the Woodland area of Oak Ridge and moved to the Scarboro Community in 1952. She played in EFPC almost every day in the summer from age 5 to age 10. She drank commercial milk at both locations, and ate vegetables from a home garden. She ate from one to 2.5 meals per week of fish caught from the Clinch River near Kingston Steam Plant, and continued living in Scarboro to the present time.

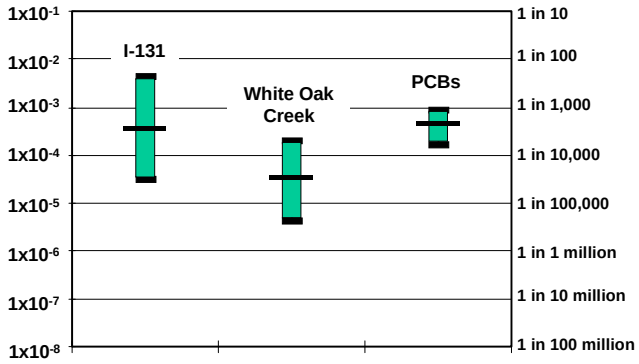
Potential for Excess Cancer–

The total added cancer risk to this individual was likely dominated by her exposure to iodine-131 in commercial milk and inhaled at Woodland and Scarboro. The move to Scarboro occurred just before the most significant I-131 releases occurred. The estimates of added thyroid cancer risk from her I-131 exposure from RaLa releases range from **3.2 to 420** in 100,000[1] based on the statewide average background rate for women. While the assumed "Diet 3" does not include consumption of locally grown vegetables, this pathway would not have made a significant contribution to total risk, which is dominated by milk and inhalation. If the reported background thyroid cancer rate for African-American women in the U.S. had been used in the calculations, the estimated risks would have been about **half** of those shown.

Estimates of excess cancer risks range from **0.43 to 20** in 100,000 from radionuclides released from White Oak Creek.[2] The dose reconstruction for PCBs in fish addressed the group of Clinch River recreational fish consumers as a whole, but not this individual and her specified diet; for Clinch River fish consumers as a group, the added risk is between **0.04 and 30** in 100,000 from consumption of PCB-contaminated Clinch River fish.[3] The central estimate of excess cancer risk from PCBs from playing in EFPC[4] is about a factor of **700** lower than the added risk from eating Clinch River fish.

If one considers this individual's fish consumption rate rather than the distribution for the population as a whole evaluated in the dose reconstruction for PCBs, one can estimate that her risk of all types of cancer from PCB intake was increased by an amount between **17 and 90** chances in 100,000.[5]

Additional Cancer Risks- Scenario 3



[1]The 95% confidence interval is 3.2×10^{-5} to 4.2×10^{-3}, with a central estimate of 3.3×10^{-4} (see App. 11-C of the Task 1 report for details; "OR Scarboro" location, female born in 1950, "Diet 3"). This person's actual thyroid risk would be somewhat lower because she was born in 1948 rather than 1950, and she lived in Woodland 1948-1951 rather than in Scarboro. Diet 3 includes regionally mixed commercial milk and inhalation.

[2]The 95% confidence interval is 4.3×10^{-6} to 2.0×10^{-4}, with a central estimate of 3.1×10^{-5} (see App. 13-C in the Task 4 report for details; Cat. I female fish consumer at CRM 3.5).

[3]The 90% confidence interval is 4×10^{-7} to 3×10^{-4}, with a central estimate of 2×10^{-5} (see Tab. 7-9 of the Task 3 report for details; Clinch River adult recreational fish consumer). These results reflect PCBs from all sources, ORR and other industries.

[4]The 90% confidence interval is 1×10^{-9} to 4×10^{-7}, with a central estimate of 3×10^{-8} (see Tab. 7-9 of the Task 3 report for details).

[5]Personal communication with Robert Peelle, ORHASP member. September 1999.

Potential for Non-cancer Effects–

It is highly likely that this person's methylmercury exposures from consumption of Clinch River fish exceeded the RfD; central estimates of dose exceed the adult RfD from the early 1950s through 1972, and lower confidence limits exceed the adult RfD for the early 1950s through 1964 excepting 1955. The 95% confidence interval of dose for 1957 is from **2.6 to 14 times** the RfD[1] for adults. Since the corresponding NOAEL is less than twice the adult RfD and the LOAEL is just over 3 times that RfD, it is almost certain that her dose exceeded the NOAEL. For childhood exposure or protection of the unborn, a lower RfD is applied. Estimated methylmercury doses peak in 1957, when they range from **7.9 to 42 times** the *in utero* RfD[2]. Because the NOAEL for *in utero*/childhood exposure to methylmercury is only a factor of 5 above the RfD (based on human studies), it is possible that this person's exposure to methylmercury approached or exceeded the NOAEL as a child (95% upper confidence limits of dose are **15-16 times** the *in utero*/child RfD for 1950 and 1951 when she was considered a child for mercury effects). However, because mercury concentrations calculated based on limited sediment core samples were likely overestimated before 1953, it is unclear whether health effects were likely to have resulted from that *in utero* exposure.

It is highly unlikely that doses of elemental mercury to this individual exceeded the applicable RfD; the upper confidence limit of dose peaks at **67%** of the RfD for elemental mercury inhalation in 1955.[3] It is possible that inorganic mercury doses exceeded the applicable RfD between 1954 and 1959, as the upper confidence limits of dose exceed the RfD for those years, with doses ranging from **0.063 to 4.7 times** the RfD in 1955[4]. In all cases, inorganic mercury doses were well below the NOAEL, which is a factor of 330 times higher than the RfD. The RfD and NOAEL for inorganic mercury were determined in rat experiments.

Noncancer risks from PCBs from playing in EFPC are relatively small, with estimates of dose ranging from **0.03% to 0.5%** of the RfD.[5] The dose reconstruction for PCBs in fish addressed the group of Clinch River recreational fish consumers as a whole, but not this individual and her specified diet; for Clinch River fish consumers as a group, the upper confidence limit of PCB dose peaks at **three times** the population threshold for non-cancer effects.[6] Even this upper

Chemical Toxicity for Scenario 3

Were toxicity reference values exceeded, yes or no?

Reference Value	Contaminant			
	methyl mercury	inorganic mercury	elemental mercury	PCBs
LOAEL	yes	no	no	no
NOAEL	yes	no	no	*not applicable**
RfD	yes	yes	no	yes

*There is no NOAEL for the PCB mixture of concern.

[1]The 95% confidence interval of Hazard Index in 1957 (based on the adult RfD) is from 2.6 to 14 with a central estimate of 6.5. See Tab. X-1 and X-2 in the Task 2 report for details; Clinch River Cat. 1 adult.

[2]The 95% confidence interval of Hazard Index in 1957 (based on the *in utero* RfD) is from 7.9 to 42 with a central estimate of 20. See Tab. X-1 and X-2 in the Task 2 report for details. This RfD should be applied to pregnant mothers and to children (defined as age 6 months to 3 years for mercury exposure).

[3]The 95% confidence interval of Hazard Index for 1955 is 0.033 to 0.67, with a central estimate of 0.13. See Tab. X-1 and X-2 in the Task 2 report for details.

[4]The 95% confidence interval of Hazard Index is from 0.063 to 4.7, with a central estimate of 0.47. See Tab. X-1 and X-2 in the Task 2 report for details.

[5]The 90% confidence interval of Hazard Index is 0.0003 to 0.05, with a central estimate of 0.005 (see Tab. 7-10 of the Task 3 report for details).

[6]For a highly exposed individual, the 90% confidence interval of True Hazard Quotient in the refined analysis is from 0.08 to 3, with a central estimate of 0.5; For a more typical fish consumer (50th percentile), the 90% confidence interval of True Hazard Quotient is from 0.008 to 0.3, with a central estimate of 0.05. See Tab. ES-4 in the Task 3 report for details. These results reflect PCBs from all sources, ORR and other industries.

confidence limit value dose is well below the LOAEL, which for adults corresponds to a dose about 10 times the median population threshold value.[7]

If one considers this person's fish consumption rate rather than the distribution for the population as a whole evaluated in the dose reconstruction for PCBs, one can estimate that her exposure to PCBs from eating fish produced a dose that was **4 to 20 times** the EPA Reference Dose, and so at most could have been **about equal to** the median value of the population threshold dose estimated by this project's investigators.[8] This means that her PCB dose has up to a 50 percent chance of harming the most sensitive individual in the population. Still, the upper limit of her estimated dose was only about 1/10 the LOAEL observed in experimental monkeys. This girl had some chance of deleterious effects from the Clinch River fish she ate. Her recreational activities in East Fork Poplar Creek, by contrast, would not have resulted in PCB exposures that approached the RfD, even at the upper end of the range of estimated doses.

[7]The median (50th percentile) value of the refined empirical distribution of the population threshold for PCBs is 5.08×10^{-4} mg/kg-d (90% confidence interval from 9.3×10^{-5} to 1.8×10^{-3} mg/kg-d; see Fig. 8-3 of the Task 3 report), and the LOAEL for Aroclor 1254 is 5×10^{-3} mg/kg-d.

[8]Personal communication with Robert Peelle, ORHASP member. September 1999.

Scenario 4 addresses a male who was born outside of Tennessee in 1930 and moved to the Scarboro Community in Oak Ridge in January 1955. He continues to live in Scarboro. This man drank very little milk, all from commercial sources, and ate local vegetables grown near Solway. He had no contact with EFPC water or sediments, and did not eat fish caught in local waters.

Potential for Excess Cancer–

Since this man moved to Oak Ridge as an adult after most of the iodine-131 releases from lanthanum processing had occurred and he drank very little milk, he experienced only a small increase in lifetime risk of developing thyroid cancer. All significant added cancer risks to this individual are attributable to his iodine-131 exposure from commercial milk, inhalation, and consumption of local vegetables. His added risk of thyroid cancer is significantly overestimated by the range of **0.003 to 3** in 100,000[1] reported for a male born in 1930 and present in Scarboro during all the X-10 RaLa processing and drinking a typical amount of regionally-mixed commercial milk. If one adjusts these values to reflect lower rates of milk consumption and local presence for only about 30 percent of the total RaLa releases, upper-bound risks are about **1 in 100,000** for a person who drank an average amount of milk, or about **0.3 in 100,000** for a person who drank a negligible amount of milk.[2] If the reported background thyroid cancer rate for African-American men in the United States had been used in the calculations, the estimated risks would have been **about half** of those shown.

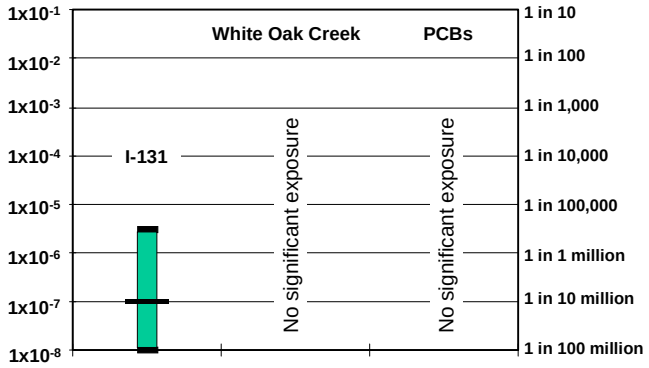
[1]The 95% confidence interval is 2.8×10^{-8} to 2.9×10^{-5}, with a central estimate of 9.6×10^{-7} (see App. 11-C of the Task 1 report for details; "OR Scarboro" location, male born in 1930, "Diet 3"). This person's actual thyroid risk would be lower because he moved to the area in 1955 (experiencing only the final 2 y of RaLa releases) and he drank very little milk. These calculations assumed exposure to RaLa releases from 1944-1956 and a higher rate of milk consumption than this man practiced. Diet 3 includes regionally mixed commercial milk.

[2]Personal communication with Robert Peelle, ORHASP member. September 1999.

While the contribution of I-131 from vegetables grown in Solway was not included in "Diet 3", comparison of doses from "Diet 3" and Solway vegetables makes it clear that the vegetables did not make a significant contribution to his total added thyroid cancer risk.[3]

There are no significant exposure pathways identified for this individual relevant to PCBs in the environment near Oak Ridge or to radionuclides released from White Oak Creek.

Additional Cancer Risks- Scenario 4



[3]The central estimate of total dose from commercial milk and inhalation at Scarboro (0.48 cGy) is about 50 times the total dose he would have received from ingestion of vegetables grown at Solway (0.0097 cGy). See Appendix 11-C of the Task 1 report for details; "OR Scarboro" and Solway locations, male born in 1930.

Potential for Non-cancer Effects–

It is highly unlikely that this man's doses from inhalation of elemental mercury exceeded the applicable RfD. Upper confidence limits of elemental mercury dose from inhalation exceed the RfD for no years, with doses peaking in 1955 at from **3.3% to 67%** of the RfD[1]. Because he did not use EFPC or eat above-ground vegetables grown near the creek, he did not likely receive significant inorganic mercury dose from ingestion or dermal contact.

There are no significant exposure pathways identified for this person for methylmercury or PCBs in the environment near Oak Ridge.

Chemical Toxicity for Scenario 4

Were toxicity reference values exceeded, yes or no?

Reference Value	Contaminant			
	methyl mercury	inorganic mercury	elemental mercury	PCBs
LOAEL	no	no	no	no
NOAEL	no	no	no	*not applicable**
RfD	no	no	no	no

*There is no NOAEL for the PCB mixture of concern.

[1]The 95% confidence interval of Hazard Index is from 0.033 to 0.67, with a central estimate of 0.13. See Tab. X-1 and X-2 in the Task 2 report for details; adult Scarboro resident.

Scenario 5 involves a man who was born in 1940, and in 1943 moved to a home near where the Oak Ridge swimming pool is. He drank commercial milk as an infant and child. He fished a lot and ate between 1.5 and 4 meals each month of fish caught in the Clinch River near the current location of Bull Run Steam Plant, upstream from the ORR. When 14, he shot a deer that was contaminated with radionuclides released to White Oak Creek. He and members of his immediate family consumed the deer. This person moved from the Oak Ridge area in 1965.

Potential for Excess Cancer–

The estimated added cancer risk to this individual is attributable to iodine-131 from commercial milk and inhalation and PCBs from Clinch River fish. Where he fished, the PCBs would have come from sources upstream of the ORR. The estimate of his added risk of thyroid cancer is from **0.08 to 50** in 100,000.[1]

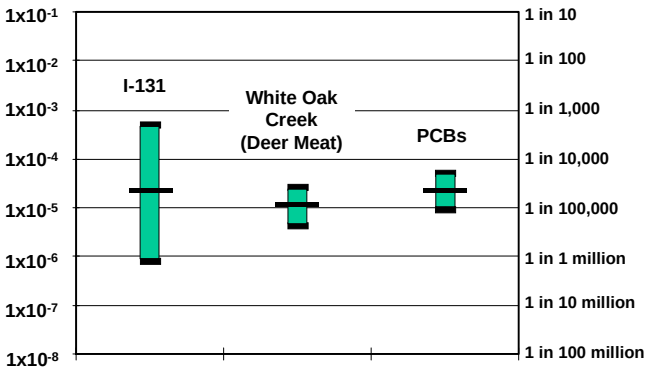
The dose reconstruction for PCBs in fish addressed the group of Clinch River recreational fish consumers as a whole, but not this individual and his specified diet; this man's added risk from consumption of PCBs in fish is likely less than one-half the computed range of **0.04 to 2.5** in 100,000[2] because he fished upstream of the ORR's PCB sources.

If one considers this individual's fish consumption rate rather than the distribution for the population as a whole evaluated in the dose reconstruction for PCBs, and applies simple correction factors to reflect residence in the area for 20 years rather than the 70 typically assumed and for fishing at a location up-stream of the ORR, one can then estimate that his risk of all types of cancer from PCB intake was increased by **less than 6** chances in 100,000.[3]

The consumption of contaminated deer meat, conservatively estimated based on one meal from the deer with the highest reported Cs-137 concentration, could have raised this individual's cancer risk by an additional **0.4 to 2.6** in 100,000[4]. While the man likely ate more than one meal from the deer, it is unlikely that the deer he hunted had contamination of the same magnitude found in the maximum reported animal.

The fact that the man moved away in 1965 had no effect on his I-131 exposures from Oak Ridge RaLa releases, which ended in October 1956. If pathways applied for exposure to Clinch River radionuclides, his moving would have mattered– that is not the case here, as the Bull Run plant is up-river from the mouth of White Oak Creek.

Additional Cancer Risks- Scenario 5



[1]The 95% confidence interval is 8.1×10^{-7} to 5.0×10^{-4}, with a central estimate of 2.2×10^{-5} (see App. 11-C of the Task 1 report for details; "OR High School location, male born in 1940, "Diet 3"). Diet 3 includes regionally mixed commercial milk.

[2]The 90% confidence interval is 4×10^{-7} to 5×10^{-5}, with a central estimate of 5×10^{-6} (see Tab. 7-9 of the Task 3 report, child age group, for details). The risks at the stated location would likely have been less than half of these values, as ORR facilities contributed about half the PCBs found in the Clinch farther downstream, upon which these values are based (see Section 4 of this report).

[3]Personal communication with Robert Peelle, ORHASP member. September 1999. The upstream correction factor had a value of 2 in this calculation.

[4]The 95% confidence interval of risk from consumption of a single meal from confiscated deer #409 is 4.2×10^{-6} to 2.6×10^{-5}, with a central estimate of 1.1×10^{-5} (see Tab. 14.5 in the Task 4 report).

Potential for Non-cancer Effects–

It is unlikely that doses of mercury received by the person in this scenario exceeded applicable Reference Doses. He ate fish from a location where mercury contamination from Y-12 releases was not present. The estimates of elemental mercury dose to this man through inhalation peak in 1957, for which doses ranged from **0.3% to 6.3%** of the Reference Dose[1], and estimated doses of inorganic mercury through ingestion and dermal contact peak in 1957 at from **0.19% to 57%** of the applicable Reference Dose[2].

The dose reconstruction for PCBs in fish addressed the group of Clinch River recreational fish consumers as a whole, but not this individual and his specified diet; his estimated PCB dose from consumption of fish from the identified area of the Clinch River (upstream of the ORR) was likely less than half of the reported **8% to 3** times the population threshold for non-cancer effects, based on the refined uncertainty analysis for Clinch River fish eaters as a group.[3] Doses of PCBs from fish ingestion were very likely below the LOAEL, which for adults corresponds to a dose about 10 times the median population threshold value.[4]

If one considers this individual's fish consumption rate rather than the distribution for the population as a whole evaluated in the dose reconstruction for PCBs, and applies a simple correction factor to reflect that fish were collected at a location up stream of the ORR, one can then estimate that this man's dose exceeded the EPA Reference Dose by **up to a factor of 4**, but it was **below** the estimated lower limit of the 90% confidence interval for the distribution of the population threshold doses calculated by project scientists and **less than 2%** of the LOAEL observed for experimental monkeys.[5]

Chemical Toxicity for Scenario 5

Were toxicity reference values exceeded, yes or no?

Reference Value	Contaminant			
	methyl mercury	inorganic mercury	elemental mercury	PCBs
LOAEL	no	no	no	no
NOAEL	no	no	no	*not applicable**
RfD	no	no	no	**yes†**

*There is no NOAEL for the PCB mixture of concern.
†From PCB sources upstream of the ORR.

[1]The 95% confidence interval of Hazard Index for Community Population No. 2 is from 0.0026 to 0.063, with a central estimate of 0.013 (see Tab. X-2 in the Task 2 report for details; adult age group).

[2]The 95% confidence interval of Hazard Index for Community Population No. 2 is from 0.0019 to 0.57, with a central estimate of 0.031 (see Tab. X-2 in theTask 2 report for details; adult age group).

[3]For a highly exposed (95th percentile) fish consumer, the 90% confidence interval of True Hazard Quotient in the refined analysis is from 0.08 to 3, with a central estimate of 0.5; For a more typical fish consumer (50th percentile), the 90% confidence interval of True Hazard Quotient is from 0.008 to 0.3, with a central estimate of 0.05. See Tab. ES-4 in the Task 3 report for details. The risks at the stated location would likely have been less than half of these values, as ORR facilities contributed about half the PCBs found in the Clinch farther downstream, upon which these values are based.

[4]The median (50th percentile) value of the refined empirical distribution of the population threshold for PCBs is 5.08×10^{-4} mg/kg-d (90% confidence interval from 9.3×10^{-5} to 1.8×10^{-3} mg/kg-d; see Fig. 8-3 of theTask 3 report), and the LOAEL for Aroclor 1254 is 5×10^{-3} mg/kg-d.

[5]Personal communication with Robert Peelle, ORHASP member. September 1999.

Scenario 6 addresses a female born in 1950 within the city of Kingston. Goat milk was the only milk she drank her entire life. She drank water from the Kingston water supply, and ate from 1 to 2.5 meals per week of fish caught in Watts Bar Lake. Some of these meals were homemade fish patties. This individual swam in Watts Bar Reservoir about twice a week from May through September from about 1951 to 1960. She often walked along the shoreline each evening during the part of the year when the water was drawn down. She remains in Kingston to the present time.

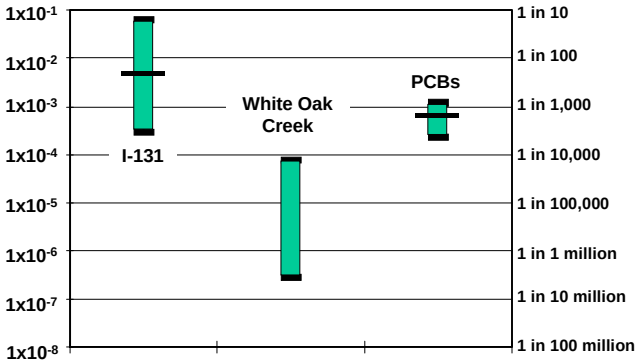
Potential for Excess Cancer–

The total estimated cancer risk to this individual is clearly dominated by her consumption of iodine-131 in goat milk. The estimates of added risk of thyroid cancer range from **30 to 6,100** in 100,000.[1] All other risks are lower by a factor of about 100 or more.

The estimated dose to this individual from consumption of fish flesh and fish patties contaminated by releases from White Oak Creek was likely greater than **0.03** in 100,000 but less than **8** in 100,000.[2] The risks from radionuclide exposure from White Oak Creek are overestimates to some extent because the individual was not present prior to 1950, while releases began in 1944. Radionuclide risks from fish consumption are over ten times higher than from shoreline exposure and Kingston drinking water.[3]

The dose reconstruction for PCBs in fish addressed the group of Watts Bar recreational fish consumers as a whole, but not this individual and her specified diet; for Watts Bar fish consumers as a group, estimates of excess cancer risk from intake of PCBs in fish range from **0.09 to 60** in 100,000.[4] If one considers this woman's fish consumption rate rather than the distribution for the population as a whole evaluated in the PCB study, one can estimate that her risk of all types of cancer from PCB intake was increased by between **23 and 120** chances in 100,000.[5]

Additional Cancer Risks- Scenario 6



[1]The 95% confidence interval of thyroid cancer risk is 3.0×10^{-4} to 6.1×10^{-2}, with a central estimate of 4.8×10^{-3} (See App. 11-C of the Task 1 report, Kingston, female born in 1950, "Diet 4" for details).

[2]The 95% confidence interval is 7.1×10^{-6} to 3.2×10^{-4}, with a central estimate of 4.4×10^{-5} (see Tab. 14.2 in the Task 4 report for details; Cat. I female fish consumer at CRM 14, 8%-20% of fish as patties). Levels in Watts Bar were typically lower than CRM 14 by a factor between 4 and 25; $7.1\times10^{-6} \div 25 = 2.8\times10^{-7;}$ $3.2\times10^{-4} \div 4 = 8.0\times10^{-5}$.

[3]The 95% confidence interval of risk for Kingston drinking water is 8.7×10^{-8} to 4.5×10^{-6}, with a central estimate of 8.3×10^{-7} (see App. 13-C of the Task 4 report for details). The 95% conf. interval of risk per hr/y of shoreline exposure (1963) is 1.8×10^{-9} to 2.9×10^{-8}, with a central estimate of 7.7×10^{-9} (see Tab. 13.12 in the Task 4 report).

[4]The 90% conf. interval is 9×10^{-7} to 6×10^{-4}, with a central estimate of 4×10^{-5} (see Tab. 7-9 of theTask 3 report; adult Watts Bar recreational fish eater). These results reflect PCBs from all sources, ORR and other industries.

[5]Personal communication with Robert Peelle, ORHASP member. September 1999.

Potential for Non-cancer Effects–

It is likely that doses of methylmercury received by this individual from eating fish exceeded the applicable Reference Doses. Methylmercury doses could have exceeded the RfD based on adult exposure from 1955 through 1967, with doses peaking in 1958 at from **82% to 3.3 times** the RfD[1]. The NOAEL for methylmercury exposure (which is based on *in utero* exposure) is estimated to have been exceeded at the 95% upper confidence limit from 1956 through 1960 (by up to a factor of about **2**)[3], and is equaled by the central estimate of dose in 1959. This person's doses were high enough that deleterious health effects cannot be ruled out because the NOAEL for childhood exposures is applied.

It is unlikely that this woman would experience non-cancer health effects from PCB exposure. The dose reconstruction for PCBs in fish addressed the group of Watts Bar recreational fish consumers as a whole, but not this individual and her specified diet. For Watts Bar fish consumers as a group, estimated doses from the refined analysis for a highly exposed individual ranged from **0.2 to 8 times** the population threshold for non-cancer effects[4]. However, even the upper confidence limit dose is below the LOAEL, which for adults corresponds to a dose about 10 times the median population threshold value.[5]

If one considers this woman's fish consumption rate rather than the distribution for the population as a whole evaluated in the dose reconstruction for PCBs, one can estimate that her dose from PCBs in eaten fish (6% to 13% of which likely came from the ORR) was estimated to be **up to 30 times** the EPA Reference Dose for Aroclor 1254.[6] Her dose could have been **more than** the median value of the population threshold distribution calculated by project researchers, yet it was **at least 8 times less than** the LOAEL from experiments with monkeys. There is less than a 50% chance that her PCB dose would harm the most sensitive individual in the population.

Chemical Toxicity for Scenario 6

Were toxicity reference values exceeded, yes or no?

Reference Value	Contaminant			
	methyl mercury	inorganic mercury	elemental mercury	PCBs
LOAEL	no	no	no	no
NOAEL	yes	no	no	*not applicable**
RfD	yes	no	no	yes

*There is no NOAEL for the PCB mixture of concern.

[1]The 95% confidence interval of Hazard Index for Watts Bar Cat. 1 fish eaters in 1958 (based on the RfD for adults) is from 0.82 to 3.3, with a central estimate of 1.6 (see Tab. X-2 in the Task 2 report for details).

[2]The 95% confidence interval of Hazard Index for Watts Bar Cat. 1 fish eaters in 1958 (based on the RfD for *in utero* exposure) is from 2.5 to 9.9, with a central estimate of 4.9 (see Tab. X-2 in the Task 2 report for details).

[3]The 95% upper confidence limit of dose for Watts Bar Cat. 1 fish consumers in 1958 is 9.9×10^{-4} mg/kg-d, or about 2 times the NOAEL of 5×10^{-4} mg/kg-d (see Tab. X-1 in the Task 2 report for details).

[4]For a highly exposed (95th percentile) individual, the 90% confidence interval of True Hazard Quotient in the refined analysis is from 0.2 to 8, with a central estimate of 1; for a more typical fish eater (50th percentile), the 90% confidence interval of True Hazard Quotient is from 0.02 to 0.5, with a central estimate of 0.1. See Tab. ES-4 in the Task 3 report for details. These results reflect PCBs from all sources, ORR and other industries.

[5]The median (50th percentile) value of the refined empirical distribution of the population threshold for PCBs is 5.08×10^{-4} mg/kg-d (90% confidence interval from 9.3×10^{-5} to 1.8×10^{-3} mg/kg-d; see Figure 8-3 of theTask 3 report), and the LOAEL for Aroclor 1254 is 5×10^{-3} mg/kg-d.

[6]Personal communication with Robert Peelle, ORHASP member. September 1999.

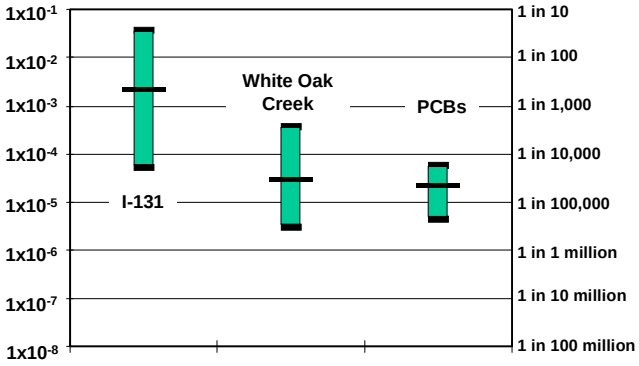
Scenario 7 focuses on a male born near Bradbury in 1950. He drank backyard cows' milk as an infant through adulthood. He grew up on a farm and consumed home produced vegetables, beef, cheese, and eggs. This individual ate between 2 and 17 meals each year of fish caught in the Clinch River near Jones Island. He has continued to live on the farm.

Potential for Excess Cancer–

The total estimated cancer risk to this individual is dominated by his exposure to iodine-131 from backyard cow milk and locally produced foods. Excess thyroid cancer risk ranges from **5.4 to 3,600** in 100,000.[1] Contributions to total risk from radionuclides released from White Oak Creek and from PCB exposure are much lower. Radionuclide risks from Clinch River exposures range from **0.31 to 37** in 100,000.[2]

The dose reconstruction for PCBs in fish addressed the group of Clinch River recreational fish consumers as a whole, but not this individual and his specified diet; for Clinch River fish consumers as a group, risks from PCB intake range from **0.04 to 30** in 100,000.[3] If one considers this individual's fish consumption rate rather than the distribution for the population as a whole evaluated in the dose reconstruction for PCBs, and applies a factor to correct for the fact that fish were taken up stream from the most significant ORR sources, one can estimate that his risk of all types of cancer from PCB intake was increased by an amount between **0.5 and 6** chances in 100,000.[4]

Additional Cancer Risks- Scenario 7



[1]The 95% confidence interval is 5.4×10^{-5} to 3.6×10^{-2}, with a central estimate of 2.1×10^{-3} (see App. 11-C of the Task 1 report for more details; Bradbury location, male born in 1950, "Diet 1").

[2]The 95% confidence interval of risk to a Cat. III fish consumer near Jones Island is 3.1×10^{-6} to 3.7×10^{-4}, with a central estimate of 2.9×10^{-5} (see App. 13-C of the Task 4 report for more details).

[3]The 90% confidence interval is 4×10^{-7} to 3×10^{-4}, with a central estimate of 2×10^{-5} (see Tab. 7-9 of the Task 3 report for details; Clinch River adult recreational fish consumer). These results reflect PCBs from all sources, ORR and other industries.

[4]Personal communication with Robert Peelle, ORHASP member. September 1999. The up-stream correction factor had a value of 2 in this calculation.

Potential for Non-cancer Effects–

It is unlikely that this individual would experience non-cancer health effects from PCB exposure, and he ate fish from a location where mercury contamination from Y-12 releases was not present.

The dose reconstruction for PCBs in fish addressed the group of Clinch River recreational fish consumers as a whole, but not this individual and his specified diet; for Clinch River fish consumers as a group, the 95% confidence interval of PCB dose from the refined uncertainty analysis approach ranged from **8% to 3 times** the population threshold for non-cancer effects.[1] Even this upper confidence limit value dose is below the LOAEL, which for adults corresponds to a dose about 10 times the median population threshold value.[2]

If one considers this individual's fish consumption rate rather than the distribution for the population as a whole evaluated in the dose reconstruction for PCBs, and applies a factor to correct for the fact that fish were taken up stream from the most significant ORR sources, one can estimate that the central value of the PCB dose estimated for this man from his ingestion of fish contaminated with PCB's (most of which may not have come from ORR sources) was **less than** the EPA Reference Dose.[3] His dose was **up to one-third** of the lower limit of the 90% confidence interval for the population threshold that was developed by the project team (Reference Doses and population threshold values are based on data obtained in studies with monkeys). Non-cancer health effects are most unlikely for this person.

Chemical Toxicity for Scenario 7

Were toxicity reference values exceeded, yes or no?

Reference Value	Contaminant			
	methyl mercury	inorganic mercury	elemental mercury	PCBs
LOAEL	no	no	no	no
NOAEL	no	no	no	*not applicable**
RfD	no	no	no	**yes**

*There is no NOAEL for the PCB mixture of concern.

[1]For a highly exposed (95th percentile) person, the 90% confidence interval of True Hazard Quotient in the refined analysis is from 0.08 to 3, with a central estimate of 0.5; for a more typical fish consumer (50th percentile), the 90% confidence interval of True Hazard Quotient is from 0.008 to 0.3, with a central estimate of 0.05. See Tab. ES-4 in the Task 3 report for details. These results reflect PCBs from all sources, ORR and other industries.

[2]The median (50th percentile) value of the refined empirical distribution of the population threshold for PCBs is 5.08×10^{-4} mg/kg-d (90% confidence interval from 9.3×10^{-5} to 1.8×10^{-3} mg/kg-d; see Fig. 8-3 of the Task 3 report), and the LOAEL for Aroclor 1254 is 5×10^{-3} mg/kg-d.

[3]Personal communication with Robert Peelle, ORHASP member. September 1999. The upstream correction factor had a value of 2 in this calculation.

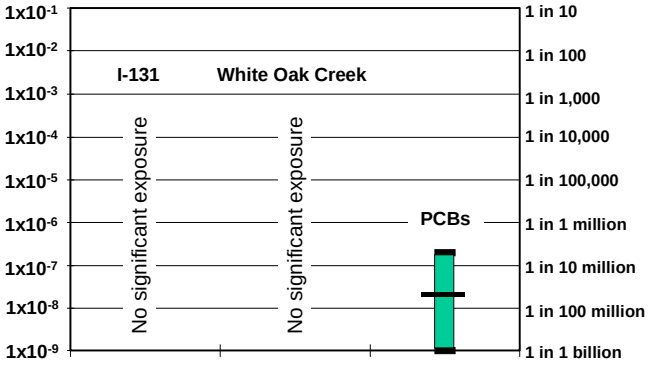
Scenario 8 involves a female born in 1960 in Oak Ridge. She lived in West Village near Lower Louisiana Avenue her whole life. She drank backyard cow's milk as an infant through adulthood. This individual ate locally grown vegetables, but no local fish. She attended Robertsville Junior High School, and played in or near EFPC about once a month.

Potential for Excess Cancer–

The only exposure pathways evaluated for carcinogens that are relevant to this individual are for PCBs from recreating in EFPC. Iodine-131 releases from X-10 RaLa processing ended in 1956 when the program left Oak Ridge, so milk consumption was not a source of exposure to this woman from RaLa processing as it could have been had she been born between 1944 and 1956. No exposure pathways fromClinch River radionuclide contamination appear relevant. Excess cancer risks due to PCB exposure from recreating in EFPC as a child range from **0.0001 to 0.02** in 100,000.[1]

Cancer health effects are unlikely for this person.

Additional Cancer Risks- Scenario 8



[1]The 90% confidence interval is 1×10^{-9} to 2×10^{-7}, with a central estimate of 2×10^{-8} (see Tab. 7-9 of theTask 3 report for details; EFPC Recreational User, child).

Non-cancer Effects–

It is highly unlikely that doses of elemental mercury or PCBs received by this individual exceeded the applicable Reference Dose. The estimates of elemental mercury dose to this woman through inhalation after her birth in 1960 are highest in 1960, for which doses ranged from **0.11% to 3.1%** of the Reference Dose.[1] The 95% confidence intervals of elemental mercury dose to a Robertsville School child via inhalation in 1970 or later peak at from **0.0024% to 0.065%** of the applicable RfD.[2]

The 95% confidence interval of PCB doses from recreating in EFPC as a child ranges from **0.07% to 9%** of the Reference Dose.[3]

Calculated 95% upper confidence limit doses of inorganic mercury received by children exceed the applicable RfD at Community Location No. 1 and/or Robertsville School for each year from 1955 through 1958, but these are all years that elapsed before the individual in this scenario was born. The estimated dose of inorganic mercury through ingestion and dermal contact in 1960 is from **0.050% to 25%** of the RfD for children,[4] and doses are lower than that for each subsequent year. The 95% confidence interval of inorganic mercury dose to a Robertsville School child after 1969 peaks at from **0.0093% to 29%** of the RfD.[5]

It is therefore unlikely that non-cancer health effects would be experienced by this individual.

Chemical Toxicity for Scenario 8

Were toxicity reference values exceeded, yes or no?

Reference Value	Contaminant			
	methyl mercury	inorganic mercury	elemental mercury	PCBs
LOAEL	no	no	no	no
NOAEL	no	no	no	*not applicable**
RfD	no	no	no	no

*There is no NOAEL for the PCB mixture of concern.

[1]The 95% confidence interval of Hazard Index for a Community Population No. 1 child is from 0.0011 to 0.031, with a central estimate of 0.0048 (see Tab. X-2 in the Task 2 report for details).

[2]The 95% confidence interval of Hazard Index for Robertsville School Students in 1970 is from 0.000024 to 0.00065, with a central estimate of 0.00012 (see Tab. X-2 in the Task 2 report for details).

[3]The 90% confidence interval of Hazard Index is 0.0007 to 0.09, with a central estimate of 0.01 (see Tab. 7-10 of the Task 3 report for details; EFPC Recreational User, child).

[4]The 95% confidence interval of Hazard Index for a Community Population No. 1 child in 1960 is from 0.00050 to 0.25, with a central estimate of 0.011 (see Tab. X-2 in the Task 2 report for details).

[5]The 95% confidence interval of Hazard Index for Robertsville School Students in 1970 is from 0.00093 to 0.287, with a central estimate of 0.0093 (see Tab. X-2 in the Task 2 report for details; Robertsville School Student who was a recreational user of EFPC).

Figure 10-3: Summary of Calculated Excess Cancer Risks for All Special Scenarios Addressed

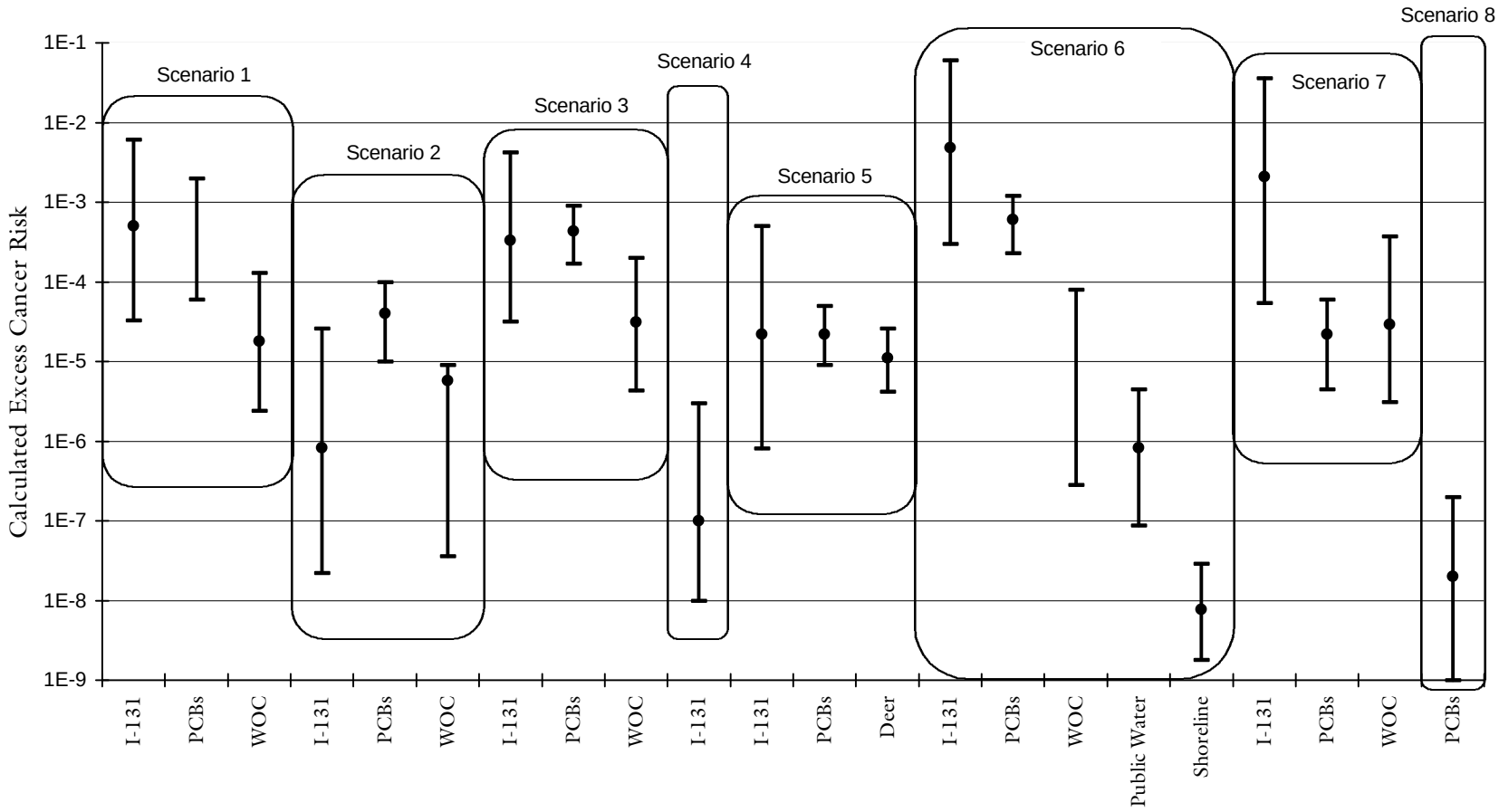
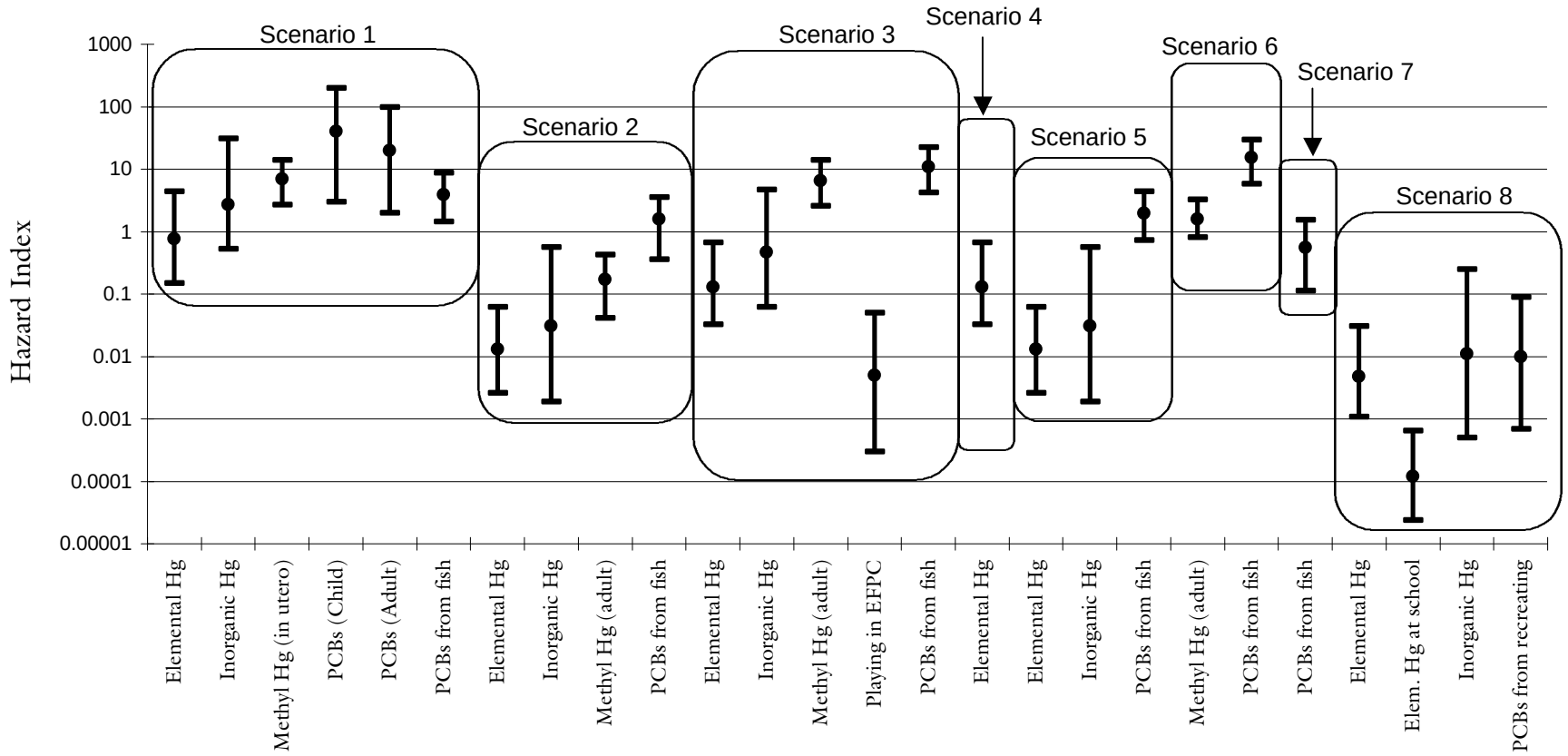


Figure 10-4: Summary of Calculated Noncancer Exposures for Peak Years in the Sample Scenarios



11. REPORTS OF THE OAK RIDGE DOSE RECONSTRUCTION

The names of the leaders of the project tasks are underlined.

- Iodine-131 Releases from Radioactive Lanthanum Processing at the X-10 Site in Oak Ridge, Tennessee (1944-1956)– An Assessment of Quantities Released, Off-Site Radiation Doses, and Potential Excess Risks of Thyroid Cancer. The report of project Task 1.

  A. I. Apostoaei, R. E. Burns, F. O. Hoffman, T. Ijaz, C. J. Lewis, S. K. Nair, T. E. Widner

- Mercury Releases from Lithium Enrichment at the Oak Ridge Y-12 Plant– a Reconstruction of Historical Releases and Off-Site Doses and Health Risks. The report of project Task 2.

  G. M. Bruce, S. M. Flack, T. R. Mongan, T. E. Widner

- PCBs in the Environment Near the Oak Ridge Reservation– A Reconstruction of Historical Doses and Health Risks. The report of project Task 3.

  J. Avantaggio, N. Bonnevie, P. Gwinn, J. Hamblen, P. S. Price, C. Schmidt, T. E. Widner

- Radionuclides Released 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 report of project Task 4.

  A. I. Apostoaei, B.G. Blaylock, B. P. Caldwell, S. M. Flack, J. H. Gouge, F. O. Hoffman, C. J. Lewis, S. K. Nair, E. W. Reed, K. M. Thiessen, B. A. Thomas, T. E. Widner,

- Uranium Releases from the Oak Ridge Reservation– A Review of the Quality of Historical Effluent Monitoring Data and a Screening Evaluation of Potential Off-Site Exposures. The report of project Task 6.

  J. E. Buddenbaum, R. E. Burns Jr., J. K. Cockroft, T. Ijaz, J. J. Shonka, T. E. Widner

- Screening-level Evaluation of Additional Potential Materials of Concern. The report of project Task 7.

  G. M. Bruce, J. E. Buddenbaum, R. E. Burmeister, J. K. Cockroft, S. M. Flack, T. Ijaz, T. E. Widner.
  (K.M. Thiessen also managed a prortion of the Task 7 effort.)

- Project Summary Report, Oak Ridge Dose Reconstruction.

  T. E. Widner (based in part on contributions of all the above authors)

glossary

absorbed dose- the basic measure of radiation exposure of specific tissues or the whole body; it is the amount of energy absorbed per unit mass of tissue. The historic unit is the rad; the modern unit is the gray (Gy); 1 gray = 100 rad.

acute - short-term. Acute exposures are typically defined as those lasting less than 14 days.

ADD - Average Daily Dose. Exposure expressed as the mass of a substance received by an individual per unit body weight per unit time (i.e., mg/kg-day), averaged over the exposure duration.

alloy - a former Y-12 codeword for lithium; also, a substance composed of two or more metals, or metal(s) and a nonmetal.

alpha buildings - five Y-12 buildings which housed the first stages of the electromagnetic enrichment process.

alpha particle - a positively charged particle that is ejected spontaneously from the nuclei during the decay of certain radioactive elements such as uranium. Physically, it is identical to a helium nucleus, with two neutrons and two protons, and has a mass number of 4 and an electrostatic charge of +2. Generally, alpha particles have very low-penetrating power; even the most energetic alpha particle will fail to penetrate the skin. Alpha-emitting isotopes only pose a health hazard if directly introduced into the body either by inhalation or ingestion.

amalgam - an alloy of mercury with another metal.

angler - usually a person who fishes with line and hook. Used in this report to mean any fish consumer, including members of a family who ate fish caught by another person.

anthropogenic - caused by man's activities.

Aroclors - commercial mixtures of polychlorinated biphenyls.

Askarels - commercial mixtures of polychlorinated biphenyls and chlorinated benzenes.

averaging time - The period of time over which a dose is averaged. Usually a function of the effect being evaluated.

background radiation - the radiation received by man from natural and environmental sources including cosmic rays, radiation from the naturally radioactive elements in the environment, and natural concentrations of radionuclides in the body (carbon-14, potassium-40). The usually quoted average individual exposure from background radiation for a person living in the continental United States is 250 to 300 millirem per year.

becquerel- the modern unit of amounts of radioactivity. A radioactive substance with an activity of one becquerel (Bq) undergoes one disintegration (nuclear transformation) per second. One kilobecquerel (kBq) is one thousand becquerels (1000 Bq). One megabecquerel is one million becquerels (1,000,000 Bq or 10^6 Bq).

bias - a systematic error of measurements that results in either an over- or underestimation of the result. Bias is not the same as accuracy, which is a measure of how close a value is to the true number.

bioaccumulation - the net accumulation of a substance by an organism as a result of uptake from all environmental sources.

biokinetic modeling - the use of mathematical models to quantify the movement and accumulation of ingested or inhaled material throughout the human body.

biotransfer factors - measure of an organic chemical's potential to accumulate in the tissues of an organism relative to the total uptake of the chemical.

body burdens - concentration of chemical accumulated in the tissues of an exposed organism.

calibration - the check or correction of the accuracy of a measuring instrument to assure proper operational characteristics.

calutrons - production scale mass spectrometers that were used at Y-12. Magnetic fields were used to separate the lighter U-235 isotope from the heavier, more naturally-abundant U-238 isotope. From California University cyclotron.

carcinogen - A substance capable of increasing the occurrence rate of cancer in either animals or humans.

cascade - A system of gaseous diffusion process components arranged so as to enrich uranium in its U-235 component. Porous gaseous diffusion barrier was contained in stages, the basic units of the enrichment process. Because each stage provided only about 0.2% enrichment, a number of stages were connected together to form cells, and a large number of cells were connected in series to provide the needed enrichment. The system of cells was called a cascade because about half the introduced gas flowed to the next higher stage, while the remaining portion flowed to the next lower stage.

chronic - persisting over a long period of time. Chronic exposures are generally greater than 1/10 of expected lifetime, e.g., chronic exposures for humans are defined as greater than seven years (lifetime = 70 years).

Colex - a column-based chemical exchange for enrichment of lithium in its ^{6}Li component.

commercial angler - An individual who fishes as an occupation.

confidence limits - the upper and lower values that define a confidence interval.

confidence interval - a subjective confidence interval represents the values between which we are confident the true but unknown value of what we are estimating lies. With a 95% confidence interval, we are 95% confident that the true but unknown value of what we are estimating is no higher than the 95% upper confidence limit (the 97.5th percentile), and no lower than the 95% lower confidence limit (the 2.5th percentile). The 50th percentile, the median, as a central estimate.

congeners- Specific PCB molecules.

glossary

CSF - Cancer Slope Factor. The slope factor is used to estimate an upper-bound probability of an individual developing cancer as a result of a lifetime of exposure to a particular level of a carcinogen.

curie- the historical unit of radioactivity. A radioactive substance with an activity of one curie (Ci) undergoes 37 thousand million (37,000,000,000) disintegrations (nuclear transformations) per second.

demography - the study of locations, qualities, and activities of human populations.

depleted uranium - on the ORR, depleted uranium consists mostly of U-238 and usually contains between 0.14 and 0.20% uranium-235 by weight. Natural uranium contains 0.72% uranium-235, while enriched uranium contains greater than 0.72% uranium-235 by weight. For example, depleted uranium was generated as a result of the K-25 gaseous diffusion uranium enrichment and is found in the tailings portion of the process outputs.

dermal - of or relating to the skin.

detector - a material or device that is sensitive to radiation and which can produce a response signal suitable for measurement or analysis. This response can be converted to a characteristic that can be counted or measured as in a radiation instrument.

directed searches - document searches aimed at collecting specific data or other relevant information that is needed.

DOE - the U.S. Department of Energy.

dose - in toxicology, the rate of intake of a hazardous agent or contaminant per unit body weight. It is usually expressed in units of milligrams (mg) of the contaminant per kilogram (kg) of body weight per day (mg/(kg-day)). For radiation, absorbed dose represents the total energy deposited in a unit mass of tissue. See absorbed dose, equivalent dose, and effective dose.

dose conversion factor- an estimate of the equivalent dose to a tissue or the effective dose per unit intake of a radionuclide or per unit exposure to contaminated air, water, or ground surfaces. For internal exposure, the dose conversion factors depend upon age because of changes in metabolism and organ size during the period between birth and maturity.

dose reconstruction- the process of estimating doses that were received by members of the public following releases of toxic materials to the environment around an industrial facility.

dose-response relationship- the numerical link between the dose received and the risk of a particular effect. For a linear dose response relationship, the slope of the line fit to the graph of effects as a function of dose defines the risk per unit dose. For carcinogens, a linear extrapolation of the observed relationship to lower doses is often used to estimate risks at those doses.

dosimetry- the process of measuring or calculating the radiation or chemical dose to specific organs or to the whole body.

effective dose- in radiation protection, the product of the equivalent dose to a tissue and the appropriate tissue weighting factor. The historical unit of effective dose is the rem; the modern unit is the sievert (Sv); 1 sievert (Sv) = 100 rem.

effluent - air emission or liquid discharge, containing contaminants, that has been released to the environment from a facility.

EFPC - East Fork Poplar Creek.

elemental mercury - a shiny, silver-white, extremely dense, odorless liquid, that is the familiar species of mercury found in thermometers; tends to be relatively insoluble in water. Symbolized by the notation Hg^0.

Elex - an electrical exchange process for enrichment of lithium in its ^6Li component.

endpoint - The effect resulting from exposure to a chemical or physical agent.

enriched uranium - on the ORR, uranium typically containing between 0.95% and $\geq$99% uranium-235. Natural uranium contains 0.72% uranium-235, while depleted uranium contains less than 0.72% uranium-235.

enrichment of uranium - a process in which the relative abundance of one of the isotopes of uranium is increased with respect to the others. These processes in the past used the difference in the mass of the isotopes to increase the relative fraction of one isotope over the others. The resultant material is enriched in one particular isotope (usually uranium-235) and depleted in its other isotope (uranium-238).

EPC - Exposure Point Concentration. The concentration of a chemical in the environment that will be contacted over the exposure period.

epidemiology - the study of diseases and their occurrence in human populations.

equilibrium- a state of balance between opposing forces; in chemistry, the stage in a reversible chemical reaction at which the products of the forward reaction are consumed by the reverse reaction at the same rate as they are formed.

equivalent dose- in radiation protection, the product of the absorbed dose to a tissue and the radiation weighting factor selected for the type and energy of the radiation incident on the body or emitted by a source within it. The historical unit of equivalent dose is the rem; the modern unit is the sievert (Sv); 1 sievert (Sv) = 100 rem.

exposure - Contact of an organism with a chemical or physical agent. Exposure is quantified as the amount of the agent available at the exchange of boundaries of the organism (e.g., skin, lungs, gut) and available for absorption. Exposure to the chemical may occur through direct means (e.g., ingestion of contaminated sediment, inhalation of contaminated air) or indirectly (e.g., consumption of fish exposed to contaminated sediments).

exposure duration - The length of time, usually in years, over which an exposure occurs.

glossary

exposure parameters- Terms or variables in equations that are used to calculate exposures to a contaminant.

exposure parameter distribution -Range of numbers representing the possible values and associated probability of occurrence representing a particular exposure parameter. Exposure parameter distributions can occur in a number of forms, including triangular, lognormal, normal, cumulative, etc.. Each of these forms refers to the shape of the curve defined by the distribution.

exposure pathways - mechanisms by which an agent reaches an individual. Each exposure pathway includes a source of releases to the environment, a process by which the contaminant reaches an individual, and a set of behaviors that define an individual's interaction with the contaminants and the resulting dose received by the individual.

exposure point - a location where people may come into contact with contaminants in environmental media such as air, soil, water, and food also called a reference location.

exposure routes - mechanisms through which an individual may contact contaminants in environmental media (*e.g*., air, soil, or water). Some commonly encountered exposure routes are: inhalation of contaminated air, ingestion of contaminated soil, water, and food stuffs, and dermal contact with contaminated soil or water.

external dose- a radiation protection term that refers to the dose received by organs or tissues as the result of an exposure to a source of radiation that is outside the body.

external exposure pathways - exposure routes arising from close proximity to radioactive material that is not taken into the body. Examples of external exposure are immersion in contaminated air or water and exposures from contaminants in or on the ground. Through these pathways, beta and gamma emitting radionuclides can impart a radiation dose to a nearby person without entering the body of the person. Also see immersion.

extrapolation - inference or estimation by projecting or extending from known information.

gaseous diffusion enrichment - a process by which uranium hexafluoride is passed through a series of semipermeable molecular barriers for the purpose of separating the lighter uranium-235 isotope from the heavier, more naturally-abundant uranium-238 isotope (see enrichment of uranium).

gray- the modern unit of absorbed dose. A dose of 1 gray (Gy) corresponds to the absorption of one joule of energy per kilogram of tissue. One gray equals 100 rads.

gross alpha radioactivity - radioactivity measured in terms of alpha particles emitted, with no determination of their energy or the identity of the specific radionuclides from which they were emitted.

hazard index- for non-carcinogenic chemicals, the ratio of the estimated dose to an exposed person to the reference dose (RfD).

health impact - a deleterious health effect occurring as the result of exposure to a hazardous material.

health physics - the science concerned with recognition, evaluation, and control of health hazards associated with ionizing and nonionizing radiation.

HFIR - the High Flux Isotope Reactor at ORNL.

HRT - the Homogeneous Reactor Test program at ORNL. Also called Homogeneous Reactor Experiment 2. Focused on an experimental, liquid-fueled nuclear reactor.

ICRP - International Commission on Radiological Protection.

immersion - surrounding of an individual by an atmosphere or a body of water; can result in radiation exposure if the medium is contaminated by gamma and/or beta-emitting radionuclides.

incidental ingestion - inadvertent consumption of non-food material (i.e., soil, sediment, and water) during defined activities.

inorganic mercury - a group of compounds or "salts" present after the mercury ion (Hg^{+} or Hg^{2+}) forms a chemical bond with elements other than carbon, such as chlorine or sulfur, or with hydroxide (OH^{-}) ions. Elemental mercury and inorganic mercury compounds are often grouped under the generic term "inorganic mercury"; however, in this report, inorganic mercury refers only to mercury salts.

intake rate - A measure of exposure expressed as the mass of a substance entering an individual per unit body weight per unit time (e.g., mg/kg-day).

internal dose- a radiation protection term that refers to the dose received by organs or tissues as the result of an intake of radioactive material; the intake may result from breathing contaminated air, consuming contaminated water or food, or penetration of the radioactive material through intact or broken skin.

in utero- in the uterus, before birth

isotopes - atoms with the same number of protons, but different numbers of neutrons in their nuclei. For example, carbon-13 and carbon-14 are isotopes of the element carbon, with the numerals denoting the approximate atomic weights.

K-25- the code name for one of the three main complexes on the ORR. At the K-25 facility, once known as the Oak Ridge Gaseous Diffusion Plant (ORGDP), uranium was enriched in its uranium-235 component using the gaseous diffusion process.

LADD - Lifetime Average Daily Dose. Exposure expressed as the mass of a substance received per unit body weight per unit time (i.e. mg/kg-day), averaged over an individual's lifetime (i.e., 70 years).

large-scale review - a Y-12 classified document review program conducted in 1994 to provide environmental, safety, and health information to the public, comply with DOE Tennessee Oversight Agreement, and declassify or downgrade documents.

lifetime risk- the chance that a health effect will occur at some time in the life of an individual exposed to a toxic substance.

LLW - low level (radioactive) waste.

LOAEL - Lowest Observed Adverse Effect Level. In toxicologic tests, the lowest exposure level at which there are statistically or biologically significant increases in frequency or severity of adverse effects between the exposed population and the control group.

Mercury Files - the collection of documents assembled by the Mercury Task Force in 1983.

Mercury Task Force - a group appointed by the Y-12 Plant Manager in 1983 to collect historical data on mercury accountability, study mercury salvage and recovery, and summarize studies of mercury impacts on worker health and the environment.

metallic mercury - an alternate name for elemental mercury, like that often found in thermometers.

methylmercury - an organic mercury compound, produced by bacteria and chemical processes, that is easily absorbed by fish and other aquatic fauna. Can accumulate in organisms to higher concentrations than in the surrounding media.

MF- modifying factor

millirem - one-thousandth of a rem, 1×10^{-3} rem.

Monte Carlo simulation - a mathematical technique that uses random selection to simulate the effect of uncertain knowledge of input parameters on the answer provided by an equation or model. The technique characterizes the range of values associated with the output of a model based on information regarding the uncertainty associated with each input parameter.

natural uranium - uranium containing 0.72% U-235. Sometimes called "normal" uranium. Contrast with enriched uranium, which contains more than the natural concentration of U-235, and depleted uranium, which contains less than 0.72% U-235.

NOAEL - No Observed Adverse Effect Level. The highest dose in a toxicologic study at which there are no statistically significant differences between frequencies or severity of adverse effects seen in exposed and control groups of test animals.

nominal hazard quotient - The ratio of the calculated intake rate to a known or "safe" dose, such as the chronic RfD.

noncarcinogenic - causing health effects other than cancer.

organic mercury - compounds present after mercury combines in a chemical bond with carbon. An example is methylmercury.

ORGDP - Oak Ridge Gaseous Diffusion Plant

ORNL - Oak Ridge National Laboratory

ORR - the Oak Ridge Reservation.

parts per million (ppm) - parts of a substance contained in a million parts of air (or water) by volume.

PCB - Polychlorinated Biphenyl

PDF - probability density function; a subjectively defined function that quantitatively expresses the state of knowledge about a parameter value by characterizing the degree of belief that the true but unknown value of the parameter lies within a specified range of values for that parameter.

percentiles - if a large set of data is arranged from its smallest value to its largest, and this list is divided into 100 classes containing nearly equal numbers of data points, then each percentile represents the highest value within that class. Thus 5% of the data are less than or equal to the 5th percentile, and approximately 95% of the data are greater than or equal to the 5th percentile. The median is defined as the 50th percentile, which divides the data (approximately) into halves.

picocurie - one millionth of a millionth of a curie, 1×10^{-12} Ci (see curie).

population threshold- the highest dose that does not cause a adverse effect in the most sensitive individual in a population.

ppm - parts per million

productivity - the amount of living tissue produced per unit time in an ecological system.

purge cascade - A segment of the gaseous diffusion process equipment that was used to separate and remove light gases (such as air, fluorine, and coolant vapors) from the uranium hexafluoride that was being enriched. If these light gases were not removed, they would accumulate at the top of the cascade and block the flow of enriched uranium hexafluoride.

rad- the historical unit of absorbed dose. A dose of 1 rad corresponds to an absorption of 100 ergs of energy per gram of tissue. A millirad (mrad) is equal to 1 one-thousandth of a rad (0.001 rad). One gray (Gy) equals 100 rads.

radiation weighting factor- a measure of the potential for a radiation type to cause health effects at low doses. These factors are the same for all tissues, ranging from 1 for photons and electrons to 20 for alpha particles and some neutrons.

radioactivity - the spontaneous emission of radiation, generally alpha or beta particles, often accompanied by gamma rays, from the nucleus of an unstable isotope.

radionuclide- an isotope of a particular chemical element that undergoes spontaneous transformation accompanied by the emission of radiation. Radionuclides behave chemically in the same way as non-radioactive isotopes of the same element.

recreational angler - an individual primarily catching fish as a recreational activity.

recreational user - an individual participating in outdoor activities that might result in exposure to contaminated soil water, or sediment (e.g., swimming, picnicking, hiking, etc.).

reference dose (RfD) - for non-carcinogenic chemicals, an estimate of the largest amount that an individual of a certain size can take in on a daily basis over a lifetime that is not anticipated to result in adverse effects. It is usually expressed in units of milligrams of the chemical per kilogram of body weight per day, mg kg^{-1} day^{-1}.

reference location - a geographic location within the assessment domain where concentrations are calculated by a model.

rem- the historical unit of effective dose from radiation. One hundred rem equals one sievert (Sv).

reservation - in this report, refers to the Oak Ridge Reservation.

retrospective analysis- an analysis that evaluates past releases and resulting exposures.

RfD - the USEPA's "reference dose"; a dose rate of a chemical that is not expected to cause adverse health effects over a lifetime of daily exposure (expressed in units of milligrams per kilogram of body weight per day; mg kg^{-1} day^{-1}).

risk- the chance that an exposure to a toxin will cause a health effect, such as cancer. Also, the chance that one will be injured as the result of participating in a particular activity.

risk factor- a general term used to describe the link between exposure to a toxin, or to a dangerous activity, and the likelihood that an adverse health effect will result. In some cases it may be described as a dose-response relationship.

RM - River Mile; zero mileage is at the mouth of river (i.e., where it empties into another water body).

sievert- the modern unit of effective dose. One sievert (Sv) equals 100 rem; 1 mSv equals 100 mrem.

slope factor- for carcinogenic chemicals, an upper bound estimate derived following EPA guidance, of the slope of the dose-response relationship, given as a risk per unit dose.

source term- a description of the quantities of radioactive and chemical contaminants that were released to the environment. It includes information about the size, timing, duration, and form of the releases.

SWSA- Solid Waste Storage Area.

systematic search- a document search aimed at ensuring that no potentially relevant information was overlooked.

threshold- the highest dose that does not cause deleterious effects in an individual.

threshold dose- the lowest intake rate of a chemical at which a specific measurable adverse effect is observed and below which it is not observed.

total uncertainty - characterization of uncertainty due to lack of information and variability in a population.

TRU- transuranic; that is, of or pertaining to elements heavier than uranium.

true hazard quotient- the ratio of the calculated intake rate to an estimate of the population threshold.

TSCA - Toxic Substances Control Act

TVA - Tennessee Valley Authority

two-dimensional analysis - a model of uncertainty in risk where uncertainty and variability are separated.

UF_6 - uranium hexafluoride or "hex," was in K-25 enrichment operations and received at Y-12 for weapons production.

uncertainty - a lack of knowledge or certainty about the true but unknown value of a parameter. Can be expressed using a quantitative probability density function (PDF). Uncertainties in reconstructing doses can arise from a number of sources, including uncertainties about the accuracy of historical measurements, absence of data at exposures points, lack of knowledge about some physical processes and operational procedures, and the approximate nature of mathematical models used to predict the transport of released materials.

uranium - a naturally-occurring, radioactive metal which, in natural ores, has an atomic weight of approximately 238. The two principal natural isotopes are U-235 (0.7%) and U-238 (99.3% of natural uranium). Natural uranium also includes a very small amount of the daughter U-234 by weight. U-234 activity becomes more significant as U-235 enrichment increases.

variability - Variations in a measured parameter that occur as the result of the natural heterogeneity associated with the parameter.

X-10- the code name for one of the three main facilities on the ORR. The first reactor (the Clinton pile) and fuel reprocessing operations were located at X-10. The first production of plutonium-239 was accomplished at X-10. Radioactive lanthanum was recovered from reactor fuel at an X-10 facility during 1944-1954. ORNL was established at this site in 1947.

Y-12- the code name for one of the three main facilities on the ORR. At Y-12, ^{235}U was separated from natural uranium using electromagnetic separators (called calutrons) that were similar to cyclotrons. Later, separation of ^{6}Li from natural lithium using a process that employed large amounts of mercury was accomplished in Y-12 facilities. Lithium-6 was used in bombs employing nuclear fusion. Nuclear weapon components that employed ^{235}U were manufactured at Y-12.

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