Releases of Contaminants from Oak Ridge Facilities and Risks to Public Health

final report of the

Oak Ridge Health Agreement Steering Panel

Acknowledgments

The members of the Oak Ridge Health Agreement Steering Panel wish to commend all the efforts and accomplishments of the various project contractors and their staffs. The employees of ChemRisk, SENES, and Shonka Research Associates were thorough and insightful in their investigations and demonstrated knowledge and experience, as well as persistent curiosity, concerning the phenomena that occurred during and after periods of contaminant releases to areas surrounding the Oak Ridge Reservation. We also appreciate the willingness and diligence of contractor employees in responding to the many questions and concerns raised by members of the Panel, the Tennessee Department of Health, the Department of Energy, and interested members of the general public. The sustained efforts of ChemRisk's project manager for the Phase II effort, Tom Widner, are particularly appreciated.

The Panel also commends the constant and helpful actions of the Tennessee Department of Health leadership and staff in conquering all of the many technical and administrative challenges that have arisen during the course of the project. In addition, they provided insightful comments and questions about all the reports. The work of Pat Turri is especially appreciated; the project could not have been completed without his tireless efforts.

Several employees of the Department of Energy and its plant operations contractors in Oak Ridge also played key roles in the success of the health effects study. Timothy Joseph, with the Environment, Safety, and Quality Division of the Oak Ridge Operations Office (ORO), managed ORO's effort throughout the project, providing continued support, and Gabe Marciante, ORO's Classification Officer, made numerous valuable contributions. Contractor employees Steve Wiley at Y-12, Sheila Thornton at K-25, and Joe Weaver at ORNL also provided a great deal of cheerful, cooperative support for the information gathering activities.

Several individuals were critically important in efforts to communicate results of the study. Lynn Freeny and Anna Conover of DOE/EASI Photography provided extensive help in identifying photographs to be used in public communications, and Tom Walker of the American Museum of Science and Energy showed great skill and patience in creating the related museum display.

Finally, the Panel wishes to commend those members of the general public who live in or near Oak Ridge who were willing to give time and attention to the health effects studies. Some members of the public provided very constructive input throughout the entire study process.

Cover photo: Early temporary housing and other structures at the Manhattan Engineering District (later the City of Oak Ridge), 1944

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The Panel*

James Alexander

Barbara Brooks

Paul Erwin

Joseph Hamilton

Jacqueline Holloway

Patrick Lipford

Norma Morin

Robert Peelle

James Smith

Paul Voillequé

Nasser Zawia

** For roles and affiliations, see page 83.*

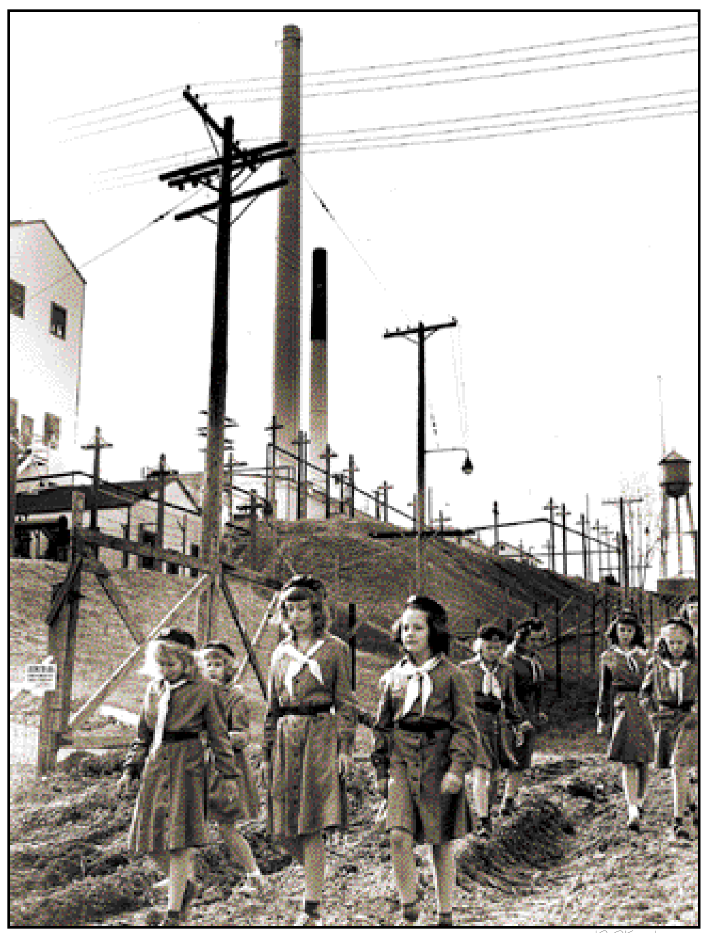
Project Director

Patrick Lipford
Tennessee Department of Health

Report Designer/Editor

Leo Williams
Clarity Communications

Above, the Scarboro School girls basketball team, January 1948. Below, children enjoy a swimming hole in Oak RIdge on Independence Day, 1946. At right, Girl Scouts visit the X-10 facility, later called Oak Ridge National Laboratory in 1951.



DOE photos

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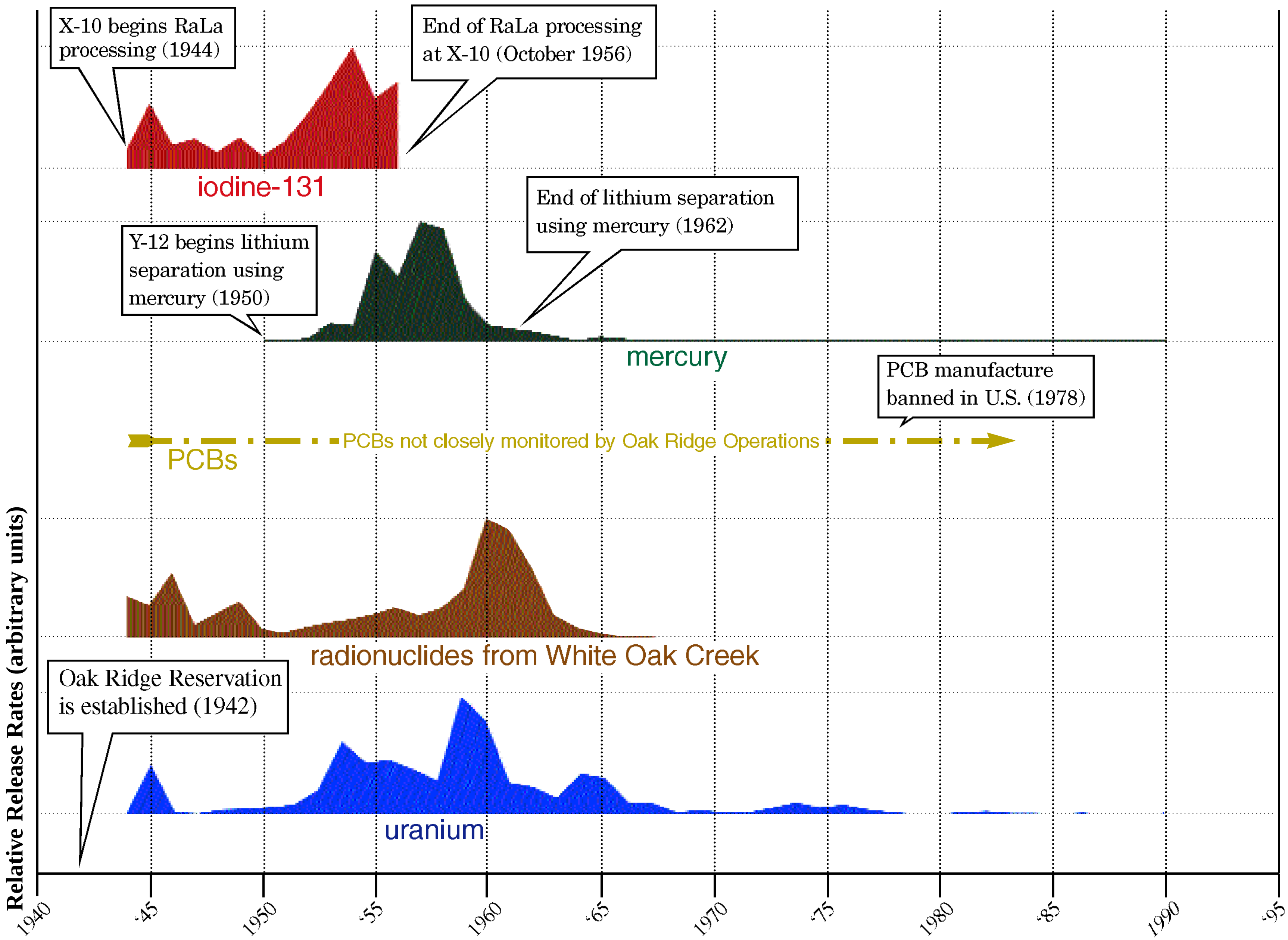
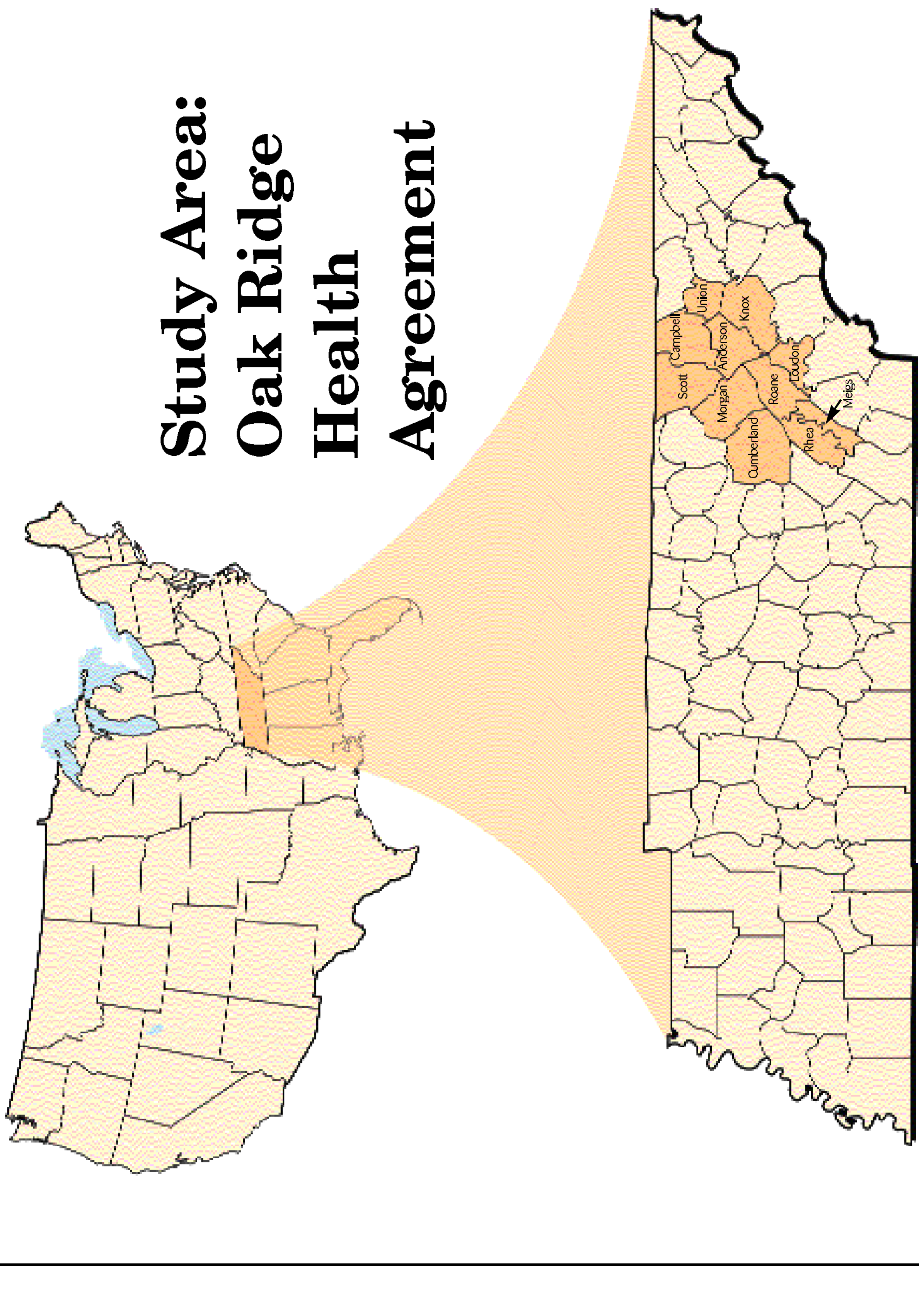



Study Area:
Oak Ridge
Health
Agreement
Campbell
Union
Knox
Scott
Anderson
Morgan
Loudon
Roane
Cumberland
Rhea
Meigs

Have the releases of toxic and radioactive substances from the Oak Ridge federal plants harmed people who lived nearby?

In the early 1990s, this question prompted Tennessee's public health officials to pursue an in-depth study of potential off-site health effects at Oak Ridge. Environmental contamination of the region by the U.S. government's industrial operations on the Oak Ridge Reservation (ORR) has occurred since 1943. In 1991, the U.S. Department of Energy (DOE) and the State of Tennessee, through the Tennessee Department of Environment and Conservation, entered into the "Tennessee Oversight Agreement," which included a number of environmental regulatory oversight functions. The oversight agreement also established a DOE funding source that allowed the Tennessee Department of Health (TDH) to undertake a two-phase research project aimed at determining whether environmental pollutant releases from the ORR created public health problems.

In accordance with the Health Studies Agreement, 12 individuals were appointed by the TDH Commissioner to form the Oak Ridge Health Agreement Steering Panel, referred to in this report as either "ORHASP" or "the Panel." The Panel has been in place since early 1992 with two primary responsibilities to TDH: first, performing technical oversight of work conducted by contractors and, second, providing some reflection of community opinion to guide project activities.

> The Panel, in place since early 1992, provided technical oversight and some reflection of community opinion.

In support of the oversight agreement's health studies provisions, DOE has provided about $14 million in direct funding to the State of Tennessee. Most of the technical work for the studies has been performed by independent contractors competitively selected and managed by TDH's Office of Communicable and Environmental Disease Service.

Phase I of the health studies was a 16-month effort. It focused primarily on assessing the feasibility of doing historical dose reconstruction and identifying the contaminants most likely to have had off-site health consequences. The feasibility study, completed in late 1993, determined that enough information existed and that Phase II of the project should place highest priority on full dose reconstruction for four major releases.

Phase II began in mid-1994 and was completed in early 1999. In addition to the full dose reconstruction analyses, the Phase II effort included more detailed health effects screening analyses for releases of uranium and several other toxic substances that had not been fully reviewed in Phase I. Also, between 1994 and 1995, the Vanderbilt University Department of Preventive Medicine performed a study to determine if epidemiologic studies in the Oak Ridge area would be able to show an association between released contaminants and health effects in the population.

None of the Phase I or Phase II project activities attempted to address workplace risks. The worker populations at the ORR facilities have been the subject of a number of epidemiologic studies, and results have been published in various journals. Information and data about these studies are also in a public-use database via the Internet at *http://cedr.lbl.gov*. Instead of workplace risks, the health agreement studies focused on people in nearby communities who may have been exposed to the various contaminants carried off site over the years by wind or water.


DOE photo

Y-12 Plant, July 1945

Nevertheless, the panel believes that some components of this study will be helpful in answering health effects questions posed by workers as well as the general public. Two such components are the study's intensive document searches and ORHASP's sustained and successful efforts to persuade DOE to declassify information important to the project.

The Phase II dose reconstruction studies, the health effects screening analyses for uranium and some other radionuclides and chemicals, and a continuation of the Phase I information search activities were conducted by three firms placed under contract by TDH in 1994. ChemRisk, a Division of McLaren-Hart Environmental Services, Inc., took the lead on the project and was supported by two major subcontractors, SENES Oak Ridge, Inc., and Shonka Research Associates, Inc.

Was Anybody Hurt?

The dose reconstruction project reports present detailed assessments of the risks posed by contaminants released from the ORR facilities and describe the more important environmental pathways through which people were exposed. The results suggest it is likely that some people were hurt by the releases. The project reports present estimates of the number of people who could have become ill as a result of exposure to the ORR environmental pollutants. Two groups were most likely to have been harmed: local children drinking milk from a "backyard" cow or goat in the early 1950s, and fetuses carried in the 1950s and early 1960s by women who routinely ate fish taken from the contaminated creeks and rivers located downstream of the ORR. Details are presented beginning on page 25.

The Panel believes that the dose reconstruction project results provide a valuable information resource for regulators, researchers, health care professionals, and interested residents. While the results cannot tell a specific individual whether a given exposure made him or her sick, or will in the future, the results provide useful information about groups of people with common characteristics and behavior patterns.

In the Phase I dose reconstruction feasibility study, scientists performed screening analyses on many substances and chemical compounds that had been used in the Oak Ridge plants. They conservatively estimated the relative risks posed by the more hazardous materials that available records indicate were released in substantial quantities. The dose reconstruction study concentrated on the four priority releases identified in the feasibility study, estimating doses and risks both for cancer and for health problems other than cancer. Using historical operations records, whatever monitoring data were available, and computer modeling, the Phase II scientists identified the principal time periods of pollutant releases and the most significant environmental pathways. Levels of exposure were estimated considering the lifestyles of those people most likely exposed to the releases. By using current knowledge of toxicologic responses following inhalation or ingestion of carcinogenic (cancer-causing) substances, risk estimates were formulated for the carcinogenic materials. Non-carcinogenic substances were compared to the Environmental Protection Agency (EPA) Reference Doses and to other guide values.

The dose reconstruction project estimates of risks are applicable to identified groups composed of persons similarly situated. Here, the term “risk” refers to the probability of a clinically observable adverse health effect. These results cannot be used to predict adverse health effects for any particular individual. Even if the collective risk for a group of people were known precisely, it would still not be possible to predict which individuals in the group would suffer adverse health effects.

In the dose reconstruction project, scientists looked both at radioactive contaminants such as iodine-131 and non-radioactive toxic contaminants such as mercury. For most of the radioisotopes that were evaluated, the project team scientists estimated the risk of cancer without addressing other possible, secondary, health effects. The chemical toxicity of most radioactive materials is unimportant because, at exposure levels considered radiologically significant, the mass of radioactive material is extremely small. For uranium, however, which has a long half-life, chemical toxicity was considered explicitly. For toxic chemical exposures, the Phase II scientists evaluated non-cancer health effects such as developmental problems. For example, ingestion of organic mercury at doses above 0.001 milligrams per kilogram per day can impair the

Voluntary and Involuntary Risks

Most people will agree that living a normal life in modern American society involves the acceptance of various types of risk.

Some of the risks are unavoidable, or “involuntary.” There are limited practical actions one can take to avoid risks associated with things like hurricanes, earthquakes, bolts of lightning or other similar natural phenomena. These will kill or injure a predictable number of U.S. residents every year.

Other risks are “voluntary;” people are willing to accept them in spite of any danger involved. Activities such as skydiving, snow skiing and motorcycle riding involve substantial risks to those who make personal decisions to do these things for pleasure. Most reasonable people would agree that these risks are being accepted voluntarily.

The studies performed as part of the Oak Ridge Health Agreement have sought to estimate the excess risks associated with exposure to the environmental pollutants that have been released from the Oak Ridge Reservation over the years. Until the advent of the modern environmental protection laws in the early 1970s, these risks were imposed on the local population largely in an involuntary manner. That is, local citizens were not usually informed of the releases nor were they given any voice in decisions that might have affected the magnitude or distribution of the imposed risks.

To help put the ORR dose reconstruction risk estimates that are presented in this report in some kind of perspective, some risk factors associated with various aspects of normal life in the United States are presented in the table on the next page.

Risks from a variety of sources

Risk	Risk as a Power of 10	Meaning	Description
1.0	1×10^{0}	1 chance in 1	Total risk of dying from all causes.
0.4	4×10^{-1}	2 chances in 5	Average lifetime risk in the U.S. of contracting some type of cancer.
0.2	2×10^{-1}	1 chance in 5	Average lifetime mortality risk in the U.S. from cancer or cancer-related disease.
0.1	1×10^{-1}	1 chance in 10	Lifetime risk of traffic accident death in U.S. for frequent motorcycle riders.
0.09	9×10^{-2}	1 chance in 11	Average lifetime risk to smokers of dying from lung cancer or smoking-induced emphysema.
0.0125	1.25×10^{-2}	1 chance in 80	Risk of dying from cancer caused by background radiation.
0.011	1.1×10^{-2}	1 chance in 90	Lifetime risk in the U.S. of dying in an automobile accident.
0.0033	3.3×10^{-3}	1 chance in 300	Lifetime risk of death in the U.S. resulting from household accident.
0.0025	2.5×10^{-3}	1 chance in 400	Average lifetime mortality risk in the U.S. caused by an accidental or intentional gun shot wound.
0.0018	1.8×10^{-3}	1 chance in 560	Average lifetime risk in the U.S. of being murdered.
0.0014	1.4×10^{-3}	1 chance in 700	Increased lifetime cancer risk associated with frequent exposure to “second-hand” smoke.
0.0001	1×10^{-4}	1 chance in 10,000	ORHASP’s Decision Guide for cancer risk due to radiation or chemical exposure. Upper risk limit used by EPA for some regulatory decisions.
0.00001	1×10^{-5}	1 chance in 100,000	Lifetime risk in the U.S. of being injured or killed by lightning.
0.000002	2×10^{-6}	1 chance in 500,000	Lifetime risk in the U.S. of being killed by a tornado.
0.000001	1×10^{-6}	1 chance in 1,000,000	Lifetime risk in the U.S. of drowning in a bathtub. Lower risk limit used by EPA for some regulatory decisions.

learning ability of young children.

To estimate risks associated with exposures to toxic chemicals, researchers can use regulatory guidelines known as Reference Doses (RfDs) that have been specified for many substances by the EPA. The RfDs, which are usually based on animal studies, are designed to establish “safe” levels of lifetime daily chemical exposure below which adverse human health effects are not expected, even among people who may be sensitive to the chemical.

Historical records are incomplete and there are substantial uncertainties in the estimates being made.

The dose reconstruction scientists performing the Phase II studies have attempted to characterize the effects of exposures to several different ORR contaminants. The contractor research team and the Panel recognize that there has been very little research focused on the potential effects of exposures to more than one contaminant at a time. Potential health effects from exposures to combinations of ORR contaminants were taken to be additive. Scenarios for eight hypothetical residents exposed to more than one contaminant are presented beginning on page 41.

Historical records are often incomplete and there are substantial uncertainties in the estimates being made. In many situations it is necessary to formulate approximations about key elements of the analysis because complete information is not available. When assumptions must be made, it is a scientific challenge to develop ranges of parameter estimates and otherwise reasonable scenarios on which to base further analysis. Each element of uncertainty reduces the precision of the risk calculations. The Panel believes that appropriate steps have been taken in these studies to acknowledge the uncertainties encountered. *(For more information on uncertainty, see page 58.)*

Summary of Risks Associated with the Most Significant Contaminant Releases

Based on what is generally known about the health risks posed by exposures to various toxic chemicals and radioactive substances, the Panel believes that past releases from the Oak Ridge Reservation were likely to have harmed some people. Information in the text that follows provides details about the most significant exposure pathways and the dose reconstruction estimates of associated risks. More detailed summary information is given in later sections of this report. In-depth information is available in the individual project reports prepared by the various Phase II contractors. Titles of all of the contractor-prepared reports for Phase II are listed in Appendix A on page 75.

The doses and risks estimated in a dose reconstruction effort cannot be known with precision, so the goal was to estimate the interval within which the actual value almost surely lay. For example, the study scientists might have reported that persons who consumed a meal of local fish were exposed to some toxicant at a level of 0.2 to 20 micrograms per kilogram body weight. This would mean that the scientists believe with 95 percent confidence that the dose was greater than 0.2 but less than 20 micrograms per kilogram. The estimates were balanced, with results above that range just as unlikely as those below. Sometimes central values are quoted, with equal chances that the true value was higher or lower than the central estimate. In the example given, the central estimate would typically have been about 2 micrograms per kilogram. The 95 percent confidence intervals do not imply equal probability of occurrence for each value within the range.

Radioactive Iodine Releases from X-10 RaLa Operations

From September 1944 to October 1956, chemical processing operations separated barium-140, the parent radionuclide of radioactive lanthanum-140, from irradiated fuel slugs. These operations were carried out at the Oak Ridge National Laboratory (ORNL), then more commonly referred to as the "X-10" site. Significant routine airborne releases of iodine-131 were associated with these operations, with the peak year being 1954. The relatively short half-life of iodine-131, only eight days, limited the exposure period of concern to nearly the same period as the RaLa operations. Because about 30 percent of ingested or inhaled iodine will concentrate in the thyroid gland, the dose reconstruction scientists evaluated the risks of thyroid cancer in the persons exposed.

The highest exposures resulted from drinking contaminated milk from "backyard" dairy animals (i.e., a local family milk cow or goat) that grazed pastures contaminated during the period of the RaLa operations. Girls exposed before age 5 were at greatest risk. The dose reconstruction results suggest that between six and about 80 excess cases were produced in people exposed within 24 miles (38 kilometers) of ORNL, most after 1970. For the whole region within 124 miles (200 kilometers), between 25 and 150 excess cases were estimated. All these estimates are based on an assumption that the number of additional cases is proportional to the "background rate" for this type of disease. Three or four times as many thyroid cancers may actually occur beyond the number clinically diagnosed, so an excess of undiagnosed cases may have also been produced. In addition, it is possible that the ORNL iodine-131 releases also caused benign thyroid nodules, which occur more frequently than thyroid cancers.

Mercury Releases from Y-12

Large quantities of elemental mercury were used at Y-12 in the 1950s and 1960s in complex physical/chemical processes that separated stable isotopes of lithium. In 1976, DOE estimated that the total inventory of elemental mercury that had been assembled at Y-12 for these operations was approximately 24 million pounds. The dose reconstruction project team's review of the available Y-12 operations records for the period 1950 through 1982 resulted in estimates that about 70,000 pounds of mercury were released to the atmosphere through building vents and that approximately 280,000 pounds were lost to East Fork Poplar Creek (EFPC). The total release of about 350,000 pounds exceeded the estimate previously published by DOE's 1980s Mercury Task Force by about 60,000 pounds.

Organic mercury was most hazardous for people who ate significant quantities of fish from Poplar Creek, the Clinch River, or Watts Bar Reservoir.

Mercury is found in the environment in three general chemical categories: elemental or metallic mercury, inorganic compounds and organic compounds. The dose reconstruction project evaluated the toxic effects from these three forms separately. The health problems related to mercury are non-cancerous.

The dose reconstruction project results indicate that some children living in the Scarboro community and a few persons residing on farms along East Fork Poplar Creek during the peak years of airborne releases (1953 through 1959) may have inhaled enough elemental mercury to cause damage to the central nervous system. In the late 1950s, farm family residents along East Fork Poplar Creek and a small number of children from Scarboro could also have suffered short-term kidney damage from exposure to inorganic mercury.

Organic mercury, specifically methylmercury, was most hazardous for people who ate significant quantities of fish from Poplar Creek, the Clinch River, or Watts Bar Lake during this period. There may have been up to 300,000 individuals who consumed fish from these waterways within the last 50 years. Fetuses of pregnant women who regularly ate contaminated fish from these waterways were at the highest risk for brain damage. During the years 1953–1977, the dose to many fetuses exceeded the highest level for which health effects have not been observed. It is estimated that the number of fetuses exposed at that level was likely nearer to 100 than to 1,000.

Polychlorinated Biphenyl Releases

Polychlorinated biphenyl (PCB) compounds have been used throughout the United States, including the ORR, since the 1940s. Although the continued manufacture of PCBs was banned by the Toxic Substances Control Act in 1978, many applications are still allowed as long as the PCBs are used in a "totally enclosed" manner. Considerable quantities of liquid PCBs remain in use at the ORR facilities.

Unlike most of the other contaminants investigated in these studies, PCBs were used heavily throughout the region, not just at DOE's facilities in Oak Ridge. As a result, it is estimated that only 6 to 13 percent of the total PCB contamination now found in lower Watts Bar Lake sediment (i.e., downstream of the confluence of the Tennessee and Clinch Rivers) originated from the ORR facilities. All of the PCB contamination currently found in East Fork Poplar Creek came from Y-12. On the Clinch River below Melton Hill Dam, half or more of the total PCB contamination can be attributed to ORR sources.

DOE photo

X-10 Site (Oak Ridge National Laboratory) looking northwest in 1947.The dark building on the left is the radioactive lanthanum processing building.

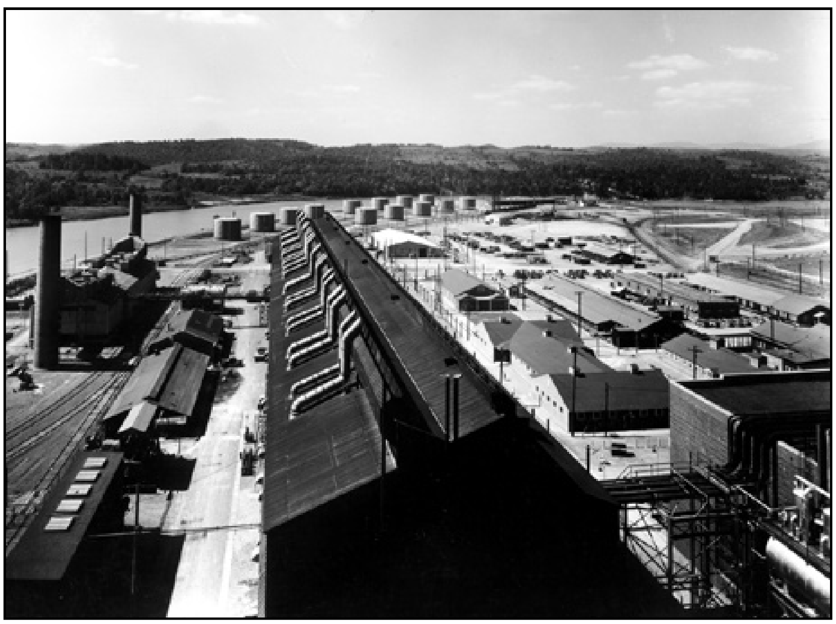
Dose reconstruction estimates of consumption of fish taken from the Clinch River or Watts Bar Lake suggest that fewer than three excess cancers have occurred due to PCB contamination originating from the ORR. This estimate is considered cautious because, despite being a carcinogen for certain test animals, PCBs have not been observed to cause cancer in humans. The studies, however, have been limited. The non-cancer risks associated with PCBs are also uncertain because not all toxicologic effects on humans, particularly at low doses, are well understood. Nevertheless, from the dose reconstruction results it appears that East Fork Poplar Creek farm families and heavy consumers of fish from Watts Bar and the Clinch River were likely exposed to levels of PCBs that would not be considered acceptable by today's environmental regulatory standards.

Radionuclide Releases from ORNL (X-10) via White Oak Creek

Radionuclides that were discharged from ORNL in wastewater or leaked out of ORNL's burial grounds into White Oak Creek were investigated as a possible cause of cancer in people living or working downstream. Of the more than two dozen radionuclides that have been released to White Oak Creek over the years, eight were identified as historically most important: cesium-137, iodine-131, strontium-90, cobalt-60, ruthenium-106, niobium-95, zirconium-95 and cerium-144. White Oak Creek enters the Clinch River at the upstream end of Jones Island. People who ate fish caught downstream for the next few miles, or who otherwise used the riverbed heavily, experienced some slight increased cancer risk. Fortunately, water consumption in this reach of the Clinch was limited to livestock. The dose reconstruction project investigators were unable to identify any instances in which sediment was dredged from the river and applied to farm land. Either of these pathways could have produced higher doses and risks. Although the White Oak Creek releases caused increases in radiation dose, the calculated exposures were small, and less than one excess cancer is expected.

Screening Analyses

Dose reconstruction seeks to estimate a realistic, plausible range of exposure levels for members of the general public. For the Oak Ridge Reservation, however, people have been exposed to numerous environmental contaminants by different pathways (inhalation, ingestion, etc.). Generally in such cases, exposures and risks are dominated by only a few contaminants, each following a specific pathway. "Screening" analyses are used to assess the relative importance of each contaminant and pathway in contributing to the overall exposure and risk.



DOE photo

The S-50 facility, 1945

Screening calculations were performed for two purposes. The first screen, or Level I, was used to eliminate materials from further consideration. Because the Level I calculations intentionally biased estimates to overpredict consequences, materials for which screening indices did not approach the Panel's decision guides under these conditions were not considered further. Level II analyses were designed to separate the materials that remain into two groups: those that received high priority and those whose priority for dose reconstruction was lower. Depending on the toxicity characteristics of the contaminant, one of two decision guides was used. For carcinogens, a lifetime risk of one chance in 10,000 (0.0001 or 10^{-4}) was selected by the Panel. For non-carcinogens, the guide was a hazard index (i.e., the ratio of the average daily intake to the EPA Reference Dose) of 1.0. Additional details about the screening analysis procedures and ORHASP's decision criteria are presented later in this report, along with the results.

Uranium Releases

The initial screening analyses performed in Phase I did not place uranium among the priority contaminants. It was believed, however, that reported uranium releases had been substantially underestimated and that further analysis was warranted. During Phase II, detailed screening analyses were performed for releases from Y-12 and K-25. The analyses focused on the location of the populated areas closest to the release points of uranium. The closest is Oak Ridge's Scarboro community, situated just over Pine Ridge less than a half mile from Y-12. The results of refined uranium screening analyses found cancer screening indexes that were slightly below the panel's decision guide for carcinogens.

The Phase II uranium screening results are uncertain for a number of reasons: (1) appropriate air and soil monitoring data for years of highest releases are absent; (2) there are large uncertainties associated with the atmospheric dispersion and transport mechanisms of airborne uranium; and (3) information concerning the amounts of uranium released during past years is very incomplete. Because of these uncertainties, the Panel has made several recommendations *(see page 14).*

Releases of Other Hazardous Substances

Over the years, many radionuclides and hazardous chemicals have been used at the ORR facilities. Most significant contaminants were identified in Phase I. Resource and schedule constraints, however, precluded thorough screening of a few materials of potential concern at that time. Accordingly, screening analyses for these materials were included in the work scope for Phase II. The substances screened during Phase II were asbestos, arsenic, beryllium, hexavalent chromium, lead, lithium, nickel, neptunium, technetium and several "formerly classified" substances.

The screening analyses suggest that lead releases from Y-12 and arsenic leached from steam plant ash piles at K-25 and Y-12 should receive priority for any future dose reconstruction investigations. According to the Panel's decision guidelines and procedure, the screening results suggest beryllium, hexavalent chromium, lithium, copper, nickel and technetium-99 also qualify for dose reconstruction but at a priority lower than for the lead and arsenic releases. With even the most conservative assumptions concerning potential material losses, none of the formerly classified substances at either Y-12 or K-25 qualified for additional evaluations.

With even the most conservative assumptions concerning potential material losses, none of the formerly classified substances at either Y-12 or K-25 qualified for additional evaluation.

Because the second-level screening calculations employed some assumptions that tended to inflate the screening indices, the Panel has recommended that more environmental data be collected before any decision is made to undertake additional dose reconstruction work *(see pages 14–15).*

Recommendations

Eight recommendations formulated by the Panel at the conclusion of the Phase II work are presented below. Additional discussion regarding each recommendation is included in the Recommendations and Discussion section of this report *(see page 71)*.

1. Three specific initiatives directed to public health intervention should be undertaken:

(a) In partnership with a local college or university, a periodic series of workshops should be conducted for local physicians and other health professionals who need to be educated on ORR environmental and occupational health issues arising from the Oak Ridge Health Agreement studies and other related health studies as results become available.

(b) In partnership with a local community college or community outreach program, a public information colloquium should be conducted to provide continuing dialogue and education on environmental and occupational health issues relevant to past, current and future ORR operations.

(c) A partnership working group of local, state and federal public health officials, health care professionals and representatives of the greater Oak Ridge community should be established to evaluate the need for a formal clinical evaluation process. If such a process is determined to be feasible, the group should formulate recommendations for the development of: **(1)** a goal for a formal community clinical evaluation process; **(2)** the types of and qualifications for health care professionals who would be involved in the clinical evaluations of concerned members of the community; and **(3)** protocol guidelines for individual clinical evaluations and referral for follow-up examinations. The Panel suggests that the results contained within this report and the other reports published as part of the Oak Ridge Health Agreement studies serve as a basis for the development of such protocol guidelines.

2. Formal epidemiologic studies of populations exposed to iodine-131, mercury, PCBs, and radionuclides from White Oak Creek are unlikely to be successful and should not be performed at this time.

3. The Department of Energy, the Environmental Protection Agency, the State (and perhaps other agencies) should undertake a coordinated program to obtain needed information and satisfy stakeholder concerns. A soil sampling program is vital to gain information relevant to the historic contamination levels in residential areas closest to the ORR plants. Detailed sampling is recommended in all of the most closely situated neighborhoods and also in a few residential areas at greater distances. Any decision about additional dose reconstruction studies should be deferred until the results of the recommended soil sampling program have been obtained and carefully interpreted.

4. DOE should undertake a program to measure the atmospheric dispersion of controlled tracer releases from representative stacks and vents at Y-12. The primary goal of these measurements would be to define the transport of a non-depositing tracer such as SF_6 from Y-12 to populated areas of Oak Ridge, including the Scarboro and Woodland communities, which are both relatively close to the plant.

5. More definitive information is needed to better understand the potential toxic effects of exposures to mixtures of contaminants — mercury and PCBs for example — on the same organ systems. Studies relating to this topic should be undertaken by one or more appropriate government-sponsored public health research agencies.

6. DOE should take action to assure that copies of the important documents used in the health effects studies are properly indexed and retained at a secure location, irrespective of future shifts of contractor responsibility at the ORR facilities.

7. DOE should assure the long-term continuation of the ORR environmental monitoring program. The program should include routine measurements in critical media for those materials found to be most important in the health agreement studies, if the material in question could still be present in the local environment. Specifically, the ORR program should: **(a)** continue to monitor the remaining environmental burden of mercury in East Fork Poplar Creek within the Y-12 plant, in the lower East Fork Poplar Creek floodplain and in sediment in the downstream watercourses, tracking the resulting methylmercury risk to consumers of fish taken from downstream fisheries; and **(b)** assure that the program continues to monitor uranium contamination originating from Y-12, with due consideration of isotopic form.

8. In the area of statewide health effects registries, **(a)** the State should continue efforts to improve the accuracy and completeness of the cancer incidence registry, and **(b)** the State should continue to seek funding for a statewide birth defects registry.

DOE photo

The Oak Ridge Reservation in May 1992, seen from above.

Primary Activities

The Phase I Dose Reconstruction Feasibility Study

The first step in the Phase I study was to assess the availability of the contaminant release records and environmental sampling data necessary to support a formal dose reconstruction project. The feasibility study results clearly indicated that there were data and information on priority contaminants sufficient to perform dose reconstruction analyses.

> The feasibility study indicated that enough data existed on priority contaminants to perform dose reconstructions.

From a historical perspective, two radionuclide releases from the ORR were found to be most significant. These were releases of iodine-131 to the air from RaLa processing, and releases of cesium-137 and other radionuclides from White Oak Creek. The two most important non-radioactive contaminants were mercury and PCBs. These pollutants were considered the "priority contaminants" for the Phase II dose reconstruction project. While it was suspected at the end of Phase I that several other materials might also have posed a threat to public health, study researchers could not locate enough information to screen those materials properly in the time available. Accordingly, screening analyses for these materials were deferred to the Phase II effort.

The Phase II Dose Reconstruction Project, including Screening Analyses

Between the completion of Phase I and the formal initiation of the Phase II work, TDH assembled a subcommittee to help draft a formal "request for proposal" that would facilitate competitive procurement of the Phase II dose reconstruction project work.

The scope of work for Phase II included seven specific project tasks. These tasks are listed on the following page.

After a comprehensive evaluation of proposals submitted in response to the request, the Phase II contract was awarded to ChemRisk, a Division of McLaren-Hart Environmental Services. ChemRisk staff were supported in various aspects of the work by employees of two major subcontractors. SENES Oak Ridge, Inc. performed much of the technical work on Tasks 1 and 4. Shonka Research Associates, Inc. took the lead on Task 5; this firm also assisted ChemRisk in directed document searches for additional information deemed relevant to the other Phase II tasks.

Results from each of the Phase II tasks were documented in comprehensive task-specific reports published by ChemRisk. ChemRisk also prepared a Project Summary report for the entire Phase II effort. A complete chronological listing

The Oak Ridge Reservation: An Historical Perspective

The Oak Ridge Reservation (ORR) was established in 1942 as part of the Manhattan Project, the federal government's World War II effort to develop and produce the first nuclear weapons.

Four separate facilities were built at that time: the Y-12 Plant and the K-25 Site, both created to separate the U-235 isotope from the more plentiful U-238 isotope; the X-10 Site, now referred to as the Oak Ridge National Laboratory, created to demonstrate capabilities for producing and separating plutonium-239 for weapons; and the S-50 Site, a liquid thermal diffusion uranium enrichment plant that was shut down after less than a year of operation.

Since the early days of the World War II Manhattan Project, each of the three remaining ORR plants has taken on a variety of additional research or production functions. Hazardous pollutants have been released from each of these major industrial sites in varying quantities over the years, with the larger releases occurring from the mid-1940s to the early-1970s. By 1976, most of the current federal environmental protection laws had been established, particularly the Clean Air and Clean Water acts. These laws, along with the Resource Conservation and Recovery Act and several others, effectively limit modern-day environmental releases to levels far below those deemed acceptable in earlier years.

The Y-12 Plant is located on 800 acres about two miles south of downtown Oak Ridge and less than a half mile from the Scarboro community. Now home to some of DOE's nuclear weapons disassembly and renovation operations, the plant was originally built in 1943 to house equipment for the electromagnetic

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The seven tasks of Phase II

Task 1	**Estimate doses and risks caused by the iodine-131 releases from X-10's radioactive lanthanum (RaLa) processing**
Task 2	**Estimate exposures and risks caused by mercury releases from the Y-12 lithium enrichment operations and ancillary activities**
Task 3	**Estimate exposures and risks caused by the PCBs released to the environment by the ORR facilities**
Task 4	**Estimate doses and risks caused by the radionuclides released from ORNL to White Oak Creek and the Clinch River**
Task 5	**Continue and expand the systematic search of historical records related to releases from the ORR to the off-site environment**
Task 6	**Evaluate the quality of historical uranium effluent monitoring and more thoroughly screen the potential off-site health effects of uranium releases**
Task 7	**Perform additional screening of potential off-site releases of materials not fully evaluated during the Phase I feasibility study**

of these and the other reports and documents published during the course of the Oak Ridge Health Agreement Studies is provided in Appendix A. These documents are available to the general public *(see page 75)*.

The final health agreement study reports will become available on the Department of Energy's Environment, Health and Safety Internet Web site. TDH also plans to make the final reports available on compact discs.

Tennessee's Cancer and Birth Defects Registries

As part of the Oak Ridge Health Agreement, DOE provided the State with funding to perform a quality assurance review of the existing cancer registry and to create a birth defects registry.

Hospitals in Tennessee have been required since 1983 to report cancer cases to the Tennessee Cancer Registry. To complete the quality verification task, tumor registrars visited hospitals throughout Tennessee to re-abstract cases dating from 1991 and 1992. Results from this effort suggested that about 10 percent of diagnosed cancer cases in Tennessee were not entered into the registry database. Cases are more likely to go unreported by hospitals that diagnose fewer than 100 cases per year, probably because these smaller hospitals cannot always provide their staffs with adequate training in abstracting skills. Although not funded by the DOE grant, TDH has taken steps intended to improve reporting and to ensure that all pathology laboratories and physicians' offices also report malignant tumors to the registry.

DOE's Health Agreement funding also allowed for the creation of a new Tennessee Birth Defects Registry. Initially scoped to record birth defects and fetal deaths in Tennessee hospitals in 1991, 1992, and 1993, the registry was set up to receive data on any birth defect diagnosed before the age of 1.

> TDH hopes to find a new source of funding to continue the birth defects registry, and the Panel recommendations support this goal.

The birth defects registry was assembled from data taken from other reporting sources, including: (1) the Tennessee Birth System, (2) the Tennessee Fetal Death System, (3) the Tennessee Death System, (4) Medicaid, (5) local health department records, (6) Tennessee Children's Special Services, (7) the Tennessee Hospital Discharge Data System, and (8) the Tennessee Newborn Laboratory Screening test results. Potential cases were verified by reviewing medical records. All hospital records were reviewed for any infant with a birth defect diagnosed within the first year.

For the three-year period of record a total of 220,875 births were recorded, and 18,700 cases, including fetal deaths, were identified as requiring database verification against hospital medical records. Some of these infants had received care at multiple hospitals and had more than one set of records. Of the 18,700 that TDH investigated, 7,800 (42 percent) were found to have had at least one major birth defect diagnosed before the age of 1.

TDH hopes to find a new source of funding to continue the birth defects registry, and the Panel's recommendations support this goal. Some design changes are being considered. For example, the new design will request that certain health care centers that admit infants with birth defects (e.g., the Tennessee Regional

Historical Perspective

Continued from previous page

separation of uranium isotopes. These devices, called calutrons, were used to enrich the uranium contained in the atomic bomb that was dropped on Hiroshima. After the war, Y-12's mission was greatly expanded to include numerous high-precision machining and other special processing functions associated with the manufacture of components of more complex thermonuclear weapons. During the Cold War, when enriched lithium-6 was needed for weapons, a column-exchange process called Colex was built and operated at Y-12. The process used large quantities of mercury as an extraction solvent.

Y-12's historical Cold War missions were curtailed dramatically in 1992, following the political collapse of the Soviet Union. Today, Y-12 continues to support DOE's weapons laboratories in New Mexico and California, hosts several smaller-scale operational functions deemed necessary for the maintenance of the U.S. nuclear weapons stockpile, and functions as DOE's primary secure storage site for highly enriched uranium.

The Oak Ridge National Laboratory, whose main campus was known before 1947 as the X-10 Site, occupies 2,900 acres 10 miles southwest of downtown Oak Ridge. It was established in 1943 as the site of the prototype graphite-moderated reactor needed to produce the fissile plutonium-239 isotope. Larger reactors patterned after the Oak Ridge Graphite Reactor were built at Hanford, Washington, and produced the plutonium-239 used in the first atomic bomb, which was tested at the Trinity Site in New Mexico, and the third atomic bomb, which was dropped on Nagasaki. Since then, ORNL has evolved into a national

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Historical Perspective

Continued from previous page

research laboratory working in a wide variety of fields such as nuclear, materials, computer, biological, and environmental sciences.

The K-25 Site occupies 1,500 acres about 10 miles west of downtown Oak Ridge. In 1944, after one of the largest construction efforts in world history, uranium isotope separation processes were initiated in the massive, U-shaped K-25 process building. In 1954, after the addition of four process buildings, the K-25 Site was renamed the "Oak Ridge Gaseous Diffusion Plant" (ORGDP) to better reflect the entire plant's principal mission. After DOE's decision in 1987 to shut down all of the gaseous diffusion operations in Oak Ridge permanently, the plant site was returned to the original "K-25 Site" designation. Beginning in 1997, DOE named the K-25 Site the "East Tennessee Technology Park," to enhance ongoing efforts to attract "reindustrialization" tenants from the private sector. Portions of the K-25 Site are now also referred to as the "Oak Ridge Heritage Center" by the commercial business development community.

The former S-50 Site, now part of the K-25 Site, hosted a prototype facility in 1944 and 1945 that was intended to demonstrate the feasibility of a thermal diffusion uranium enrichment process. After several successive failures to effectively enrich uranium, the equipment and plant buildings were dismantled.

Perinatal Centers) begin reporting case data to TDH. Other birth defects cases will be identified from a review of TDH's vital records files. The new system will be designed with the goal of identifying and registering cases very soon after initial diagnosis. TDH hopes this will facilitate intervention services.

Secondary Activities

The Feasibility of Epidemiology for Off-Site Effects

In this effort, epidemiologists from Vanderbilt University's Department of Preventive Medicine explored the feasibility of using dose reconstruction results to support formal epidemiologic studies.

The feasibility study suggested that a "cohort" study could be undertaken that would identify the individuals who lived near the ORR during the times of the highest releases. Diets and living patterns would be studied to allow an exposure estimate for each individual based on results from the dose reconstruction project. Health histories would then be examined, and results would be grouped according to estimated exposures. Other variations within the cohort sample that might disrupt, or "confound," the interpretation would also be considered.

The difficulties associated with such a cohort study would include:

- ✓ Learning enough about the lifestyles of aging individuals during the time of heaviest exposure (i.e., 40 to 50 years ago) to address possible "confounders" and to obtain valid exposure estimates;
- ✓ Obtaining a study group large enough, and with sufficiently varied exposures, that mathematical analytical techniques would yield statistically valid conclusions.

For iodine-131, many people were exposed around 1950 at levels that are expected to have increased rates of thyroid disease. The effects of methylmercury doses to fetuses in the late 1950s are also expected to have harmed some persons. Epidemiologic studies of these exposures would be quite demanding, however, and a detailed analysis would be needed to show whether such a study could be definitive for either contaminant.

Exposure to cesium-137 and other radionuclides released from ORNL via White Oak Creek increased the cancer risk for certain populations at specific times, but the small risks that were estimated (i.e., less than one excess case of cancer) preclude an effective epidemiologic study. Similarly, exposure to PCBs was estimated to produce poorly defined increases of risk that would be too small for an epidemiologic study to detect.

Mercury, PCBs, and waterborne radionuclides including cesium-137 that were released from ORNL are still present at some level in the creeks, rivers, and lake sediments downstream of the ORR. The 30-year half-life of cesium-137 and the persistence of both mercury and PCBs in sediments suggest that some level of human exposure continues to the present day. Current doses from each of these contaminants, particularly mercury and PCBs, could be assessed through hair, urine, and blood samples. Samples could also be preserved to permit future studies as assay techniques improve or if new contaminants of concern are identified. The epidemiologic feasibility study indicated that studies of the prevalence of contaminants in humans should be considered.

The Panel believes that studies of the current prevalance of contaminants in the bodies of nearby residents would not yield meaningful results about historical releases.

Because present exposures to these off-site contaminants are believed to be considerably smaller than those estimated for the period 30 to 50 years ago, the Panel believes that studies of the current prevalence of contaminants in the bodies of nearby residents would not yield meaningful results about historical releases.

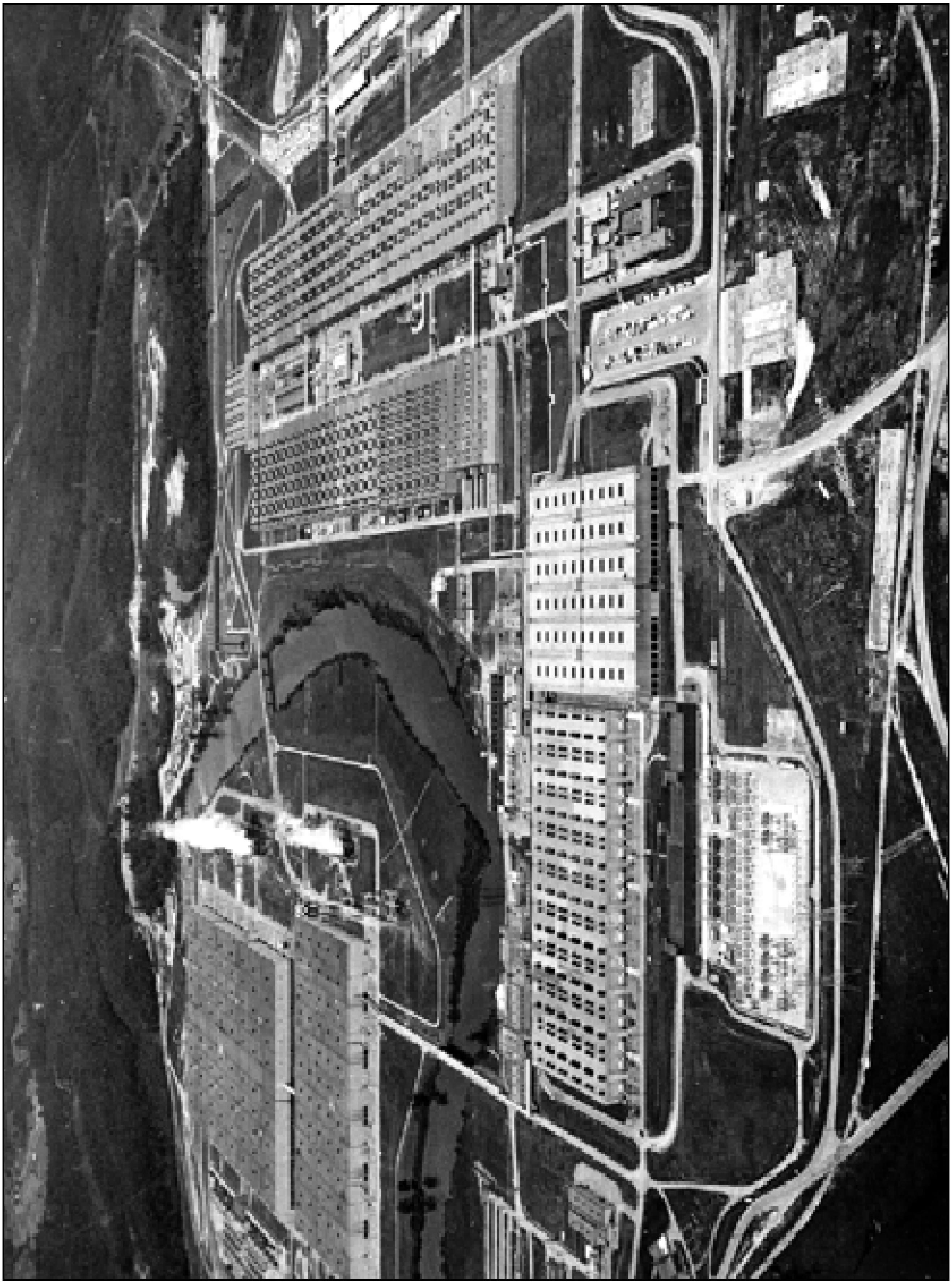
The 1994 Knowledge, Attitudes, and Beliefs Survey

In early 1993, the Panel and the ORR Local Oversight Committee decided to cosponsor a public opinion survey on environmental pollution issues of mutual concern. A contract was subsequently awarded to the University of Tennessee Sociology Department's Social Science Research Institute to conduct a telephone survey of adults in the eight-county region surrounding the ORR.

The questions included in the telephone survey were formulated during three focus group sessions composed of numerous individual citizens and public interest groups, including the Citizen's Working Group for East Fork Poplar Creek, the League of Women Voters' Environmental Committee, the Oak Ridge Environmental Quality Advisory Board, the Save our Cumberland Mountains group and the Tennessee Citizens for Wilderness Planning group. Other citizen's groups were invited to participate in the focus group sessions, but declined to do so.

The survey was conducted in October and November 1993. Of the 7,045 individuals contacted, 3,283 consented to the 30-40 minute interview. The survey questions covered subjects such as local perceptions of general environmental quality, the perceived health effects of releases from the ORR and the perceived trustworthiness of various organizations involved with the ORR. The findings of this survey, entitled "Report of Knowledge, Attitudes, and Beliefs Survey of Residents of an Eight-County Area Surrounding Oak Ridge, Tennessee," were published in August 1994. The report is available in the Oak Ridge Library.

DOE photo



The K-25 Site, 1959

The Rationale for Dose Reconstruction

Dose reconstruction seeks to estimate doses of radiation or toxic substances as realistically as possible for a variety of people, taking into account their diets, lifestyles, and places of residence. These dose values — given as ranges to reflect the fact that they are based on imperfect information — are essential in evaluating whether contaminant releases may have contributed to a given health problem and in estimating the risk to people from exposure to these contaminants.

By providing information on exposures and risks, this dose reconstruction complements ongoing public health surveillance conducted statewide by TDH for cancer, birth defects, and other health problems. It is not meant to replace health investigations or descriptive epidemiologic studies, which attempt to determine whether there are excess cases of a particular disease at a specific time and place.

> *By providing information on exposures and risks, this dose reconstruction complements ongoing public health surveillance.*

Results of dose reconstruction are, however, especially helpful in exploring "cause and effect" relationships. That is, the information is essential for rigorous epidemiologic studies that seek to correlate diseases or other health problems with specific contaminant exposures.

In epidemiologic studies, by evaluating actual cases of observed health effects, researchers try to determine if an excess of a certain type of health problem exists in a group of exposed people when compared to another group of people who were not exposed. The two groups should be as similar as possible, except for the level of exposure to one or more of the environmental contaminants.

Two technical experts, one in dose reconstruction and the other in epidemiology, were invited to address the Panel. From their presentations, it was apparent that the ideal situation would be to carry out both types of studies. To do an effective epidemiologic study, scientists must already have relatively complete information on both the locations of the exposed persons and the extent of the exposures.

In the absence of reliable information on pollutant releases (i.e., quantities, timescales, off-site pathways, and the locations and numbers of people who may have been exposed), the Panel decided it would be most productive to continue comprehensive investigations in an effort to obtain this type of information, and then to use the data to support dose reconstruction analyses.

Dose Reconstruction Results for the Major Contaminant Releases

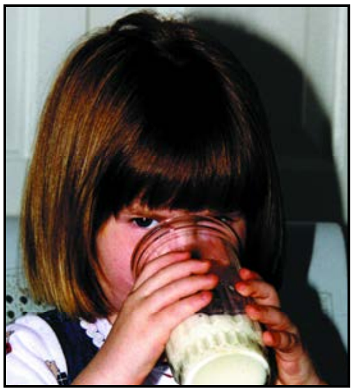
The following pages present selected results from the dose reconstructions for the priority contaminants. As indicated in the Summary, project scientists estimated the range of doses from a specific contaminant released from the ORR, and then calculated a range of risks within which they were 95 percent confident the true value lay. The methods they used inherently took into account the fact that no single numerical result could ever uniquely represent the complicated situation in which nearly every piece of information gleaned from records contained knowledge that was itself imprecise. The calculations explicitly adopted the whole range of each input value considered possible, and each calculation was repeated hundreds of times by using random combinations of the possible values of each of the inputs. Input values reflected both the variability of exposed individuals and their ways of life and the uncertainties in releases, dispersion by wind and water, and environmental behavior. The researchers used all the available historical information to correctly represent the existing knowledge about the exposures studied.

As detailed elsewhere, for radioactive substances and carcinogenic chemicals, ranges of numerical risks (e.g., of cancer incidence) could be estimated that can be understood somewhat like probabilities or "odds" in a game of chance or in actuarial tables. For non-cancer effects, the ranges of doses estimated to have been received by persons with the described characteristics and habits are compared to toxicity standards. When the number of persons fitting the description can be determined, the number of persons who received more than the threshold dose can be approximated. This procedure will not, however, determine how many people, if any, may actually have experienced adverse health effects.

DOE photo

Jones Island is located just downstream from Oak Ridge National Laboratory. White Oak Lake and White Oak Creek are visible at the lower left.This photo was taken in 1987.

At right, the Oak Ridge Graphite Reactor is shown in 1943, during construction. Irradiated fuel from the reactor was used in a chemical separation process that released radioactive iodine, which can cause thyroid cancer. Young girls who drank contaminated milk were at highest risk.



DOE photo

IODINE-131 RELEASES

from X-10 Radioactive Lanthanum Processing

Task 1

^{131}I

Radioactive Iodine

Period of releases
Sept. 1944 to Oct. 1956

Population of most concern
People born between 1944 and 1954 who lived in nearby communities and drank milk exclusively from a backyard dairy animal.

Highest excess cancer risk
The excess lifetime risk of thyroid cancer ranges from 2 to 400 chances in 1,000 for females born in 1952 living near Gallaher Bend who drank milk primarily from backyard goats.

Oak Ridge National Laboratory, originally known by the code name X-10, released significant quantities of radioactive iodine to the air from September 1944 to October 1956. Releases were associated with extraction of the fission product barium-140, the parent radionuclide of radioactive lanthanum-140 (also known as “RaLa”), from irradiated reactor fuel slugs. In this process, irradiated fuel slugs were dissolved in a bath of nitric acid shortly after they were removed from a reactor. It was necessary to process the fuel slugs with minimum delay because barium-140 has a radiological half-life of only 12.8 days. Meeting this time constraint meant that some volatile, short-lived isotopes in the fuel slugs, in particular iodine-131 with a half-life of eight days, also could be released during the processing. Lanthanum-140 was extremely useful for research on implosion bombs because it emits an intense, penetrating gamma ray (1.6 million electron volts) as it decays. Radioactive lanthanum was first produced to support weapon design research conducted at Los Alamos National Laboratory in New Mexico. It was also used for atmospheric radiation tracking and for radiation warfare experiments.

When the Oak Ridge RaLa processing operations began, existing X-10 facilities were used for the first nine months. The process

Thyroid disease and airborne releases of iodine-131

The thyroid is a small gland located in the front of the neck. Its primary function is to help regulate the body's metabolism. It does this by producing thyroid hormones. The thyroid requires iodine to make these hormones. These hormones are important in the regulation of body temperature, in energy production and regulation, and in producing proteins needed for normal body functions.

Diseases that affect the function of the thyroid are usually related to production of too little thyroid hormone (hypothyroidism) or too much thyroid hormone (hyperthyroidism). Thyroid disease can also involve tumors or growths of the thyroid (commonly called nodules), which can be either malignant (cancerous) or benign.

Radiation may affect cells in the thyroid gland so they do not function properly, or may cause them to multiply abnormally. Radioactive iodine taken into the body is expected to be harmful to the thyroid gland because it concentrates there. It is known that a child's thyroid gland is more easily injured by x-rays than an adult's.

Thyroid disease occurs more frequently in women than in men; the reasons are not fully understood.

Thyroid disease occurs more frequently in women than in men. In Tennessee, the average lifetime risk of thyroid cancer in women is about 40 chances in 10,000, compared with 15 chances in 10,000 for men. Nationwide, reported rates for African-Americans are about a factor of two lower than for whites. The reasons for differences between genders and races are not understood, but in the latter case genetic differences and access to health care may contribute.

was relocated to a new, specially designed facility completed in May 1945. In the first few years, irradiated uranium fuel slugs came from the Clinton Pile, later called the Oak Ridge Graphite Reactor. Beginning in 1948, irradiated fuel slugs were transported by train from the more powerful reactors that had been built at the Hanford Reservation in Washington state. The Hanford slugs contained much higher levels of both barium-140 and iodine-131.

Over the years, the RaLa facilities at ORNL were gradually used far beyond the limits of the process design. Even though production levels increased to more than 60 times the original design capacity, the basic dissolving and precipitation equipment was never changed. By 1956, new and larger-scale RaLa processing equipment was ready for use at a relatively remote location in Idaho, and the operations at ORNL were discontinued.

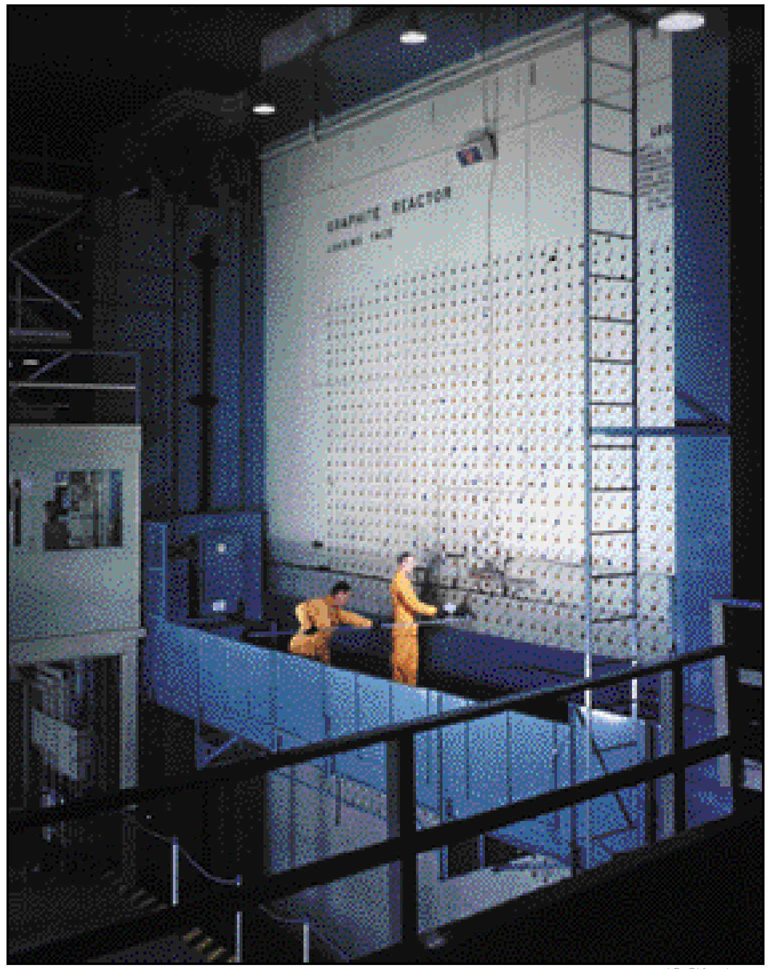
Over the 13 years of RaLa operations at ORNL, about 30,000 reactor fuel slugs were dissolved in 730 batches. The total iodine-131 releases during this period are estimated to have been between 9,000 and 40,000 curies. As many as 500 curies were released during a fuel slug processing accident that occurred on the evening of April 29, 1954. In this accident, fuel slugs had been placed in the dissolver unit and allowed to stand dry for over 28 hours. As a result, the slugs had become thermally very hot. When acid was added to the dissolver to start the process operations, the excess heat caused an unusually violent chemical reaction. This reaction pushed the acid solution back up the acid feed pipe and also up the fuel slug loading chute. The accident began about 5 p.m., with the peak releases of iodine-131 lasting about 30 minutes.

Because the thyroid gland contains nearly all of the iodine normally found in the human body, the dose reconstruction for this scenario focused on this single organ. The dose to the thyroid is estimated by computing the amount of energy absorbed from the decay of iodine-131 per gram of thyroid tissue. The highest doses from routine releases occurred in the nearby communities of Buttermilk Road, Bradbury, Hope Creek, and Gallaher Bend. Doses related to the 1954 accident were evaluated separately. Females less than 5 years old at the time of exposure were at greatest risk of developing thyroid cancer.

Results from the dose reconstruction project are given in terms of "excess risk" for thyroid cancer. Some people in the region would have developed thyroid cancer even if there had been no RaLa operations conducted at ORNL. This underlying disease rate is known as the "background" incidence. The dose reconstruction project calculated the thyroid cancer risk that an individual who grew up in the area would have incurred over and above the background risk. It is assumed that the added risk is proportional both to the dose received and to the background rate of disease.

The dose reconstruction project also evaluated the risks from various dietary exposure routes. These analyses indicated that milk consumption contributed most to the risk associated with the iodine-131 releases. Persons who did not consume milk were at much lower risk, but consumption of cottage cheese, eggs, leafy garden vegetables, human breast milk, and meat also contributed to the dose.

Ingestion of milk from a backyard dairy animal in the vicinity of ORNL posed the greatest risk both because the animal took in greater amounts of iodine-131 and because the milk was consumed shortly after it was produced. Because iodine-131 decays quickly, the time required for processing and distribution reduced the dose associated with commercial milk. A three-day delay between production and consumption reduces the dose by about 25 percent. Mixing of milk produced in different areas had a greater effect on the concentration of iodine-131 in commercial milk. For a person in an area of high contamination, the risk from consumption of local commercial milk was three to four times lower than the risk from consumption of milk from a backyard cow. The risk of consuming milk from a regional dairy was smaller still.



DOE photo

The Oak Ridge Graphite Reactor, showing the fuel-loading face. This photo was taken in 1960.

Iodine-131 doses caused by the RaLa program were estimated at 41 representative locations within 24 miles (38 kilometers) of ORNL. Urban centers within this distance include the City of Oak Ridge, Clinton, Oliver Springs, Kingston, Harriman, and Lenoir City. The study also included Knoxville, the largest city in the region, about 22 miles to the east. At each of these locations, females born from 1940 to 1956 who as children drank milk from any local or regionally mixed source faced an excess lifetime cancer risk directly attributable to the ORNL RaLa operations. The estimated risk depends on whether a dairy or a backyard cow was the source of the milk, the location of the pasture(s), her date of birth, and the amount of milk and other contaminated foods she consumed.

A girl born in 1940 or early in 1956 had about one-fifth the excess risk of a girl born in 1952, the year of peak risk for both girls and boys. The range of possible excess risks for a girl born in 1952 and fed regionally mixed commercial milk was from three chances in 100,000 to five chances in 1,000, with a central value of four in 10,000. If, by contrast, this girl had consumed commercial milk produced locally in Wartburg, the risk range for a girl born in 1952 was five in 1,000,000 to one in a 1,000 with a central value of seven in 100,000. That location experienced the least risk of those studied, while at Bradbury, close to ORNL, the range of risk for a girl born in 1952 who drank locally produced commercial milk was from two in 10,000 to four in 100, with a central value of three chances in 1,000. The risk to boys born at the same time would have been about four times less in each example (*see table on page 29*).

At particular risk are females who lived in the vicinity of ORNL and drank milk only from a backyard cow. For a girl born in 1952 and living in the Bradbury community, about 3.5 miles south-southwest of ORNL, the central value of excess risk of thyroid cancer was about nine chances in 1,000, assuming she drank amounts typical for her age and she also ate locally grown produce. The range of her possible excess risk values for thyroid cancer is from six to 1,400 chances in 10,000. Had a girl with similar diet, age and other circumstances lived in Wartburg, her risk is estimated to range from one chance in 100,000 to five chances in 1,000, with a central value of three chances in 10,000.

Areas most significantly affected by releases from the 1954 accident were in the west part of Oak Ridge, near the location of Salem Road, and the communities of Jonesville, Norwood and Oliver Springs (SEE ERRATA, PAGE 94, #2). Winds during the accident were to the north and northwest. In each case, the central estimate of lifetime cancer risk is about two in 100,000. Fringes of the dispersion plume may have extended as far as the Woodland and Scarboro communities in Oak Ridge, and perhaps even as far as the current Oak Ridge High School area. There were probably no dairy animals at any of those urban locations. The uncertainties in risk estimates for the 1954 accident are much larger than for the routine releases because of the variability in wind direction, which affects the estimated path of the iodine-131 plume.

> ORNL was not the only source of iodine-131 in East Tennessee. Another was fallout from above-ground nuclear weapons tests.

It is known that contaminated goat's milk will contain much higher levels of iodine-131 than cow's milk produced from the same pasture. As a result, girls born in the early 1950s, living relatively close to ORNL and drinking milk exclusively from backyard goats would have received the highest thyroid doses from iodine-131. In the dose reconstruction analyses for goat's milk consumption, infants and children 10 and older were assumed to drink as much goat's milk as was typical for cow's milk, while children ages 1 through 9 who drank goat's milk were assumed to consume about one-third less milk than those who depended on cow's milk.

Risks were calculated at more than 30 locations where the use of goat's milk was either known or considered plausible. Of these, the greatest risk was found at Gallaher Bend, about two miles east of ORNL. For a female at that location, born in 1952, who drank milk only from a backyard goat, the central value of estimated excess thyroid cancer risk was about 30 in 1,000, with a 95 percent confidence range between two and 400 chances in 1,000.

ORNL was not the only source of iodine-131 in the East Tennessee area. Another was fallout from the above-ground nuclear weapons tests conducted by the United States and other nuclear powers in the 1950s and 1960s. In East Tennessee, most of the iodine-131 deposited by fallout came from the Nevada Test Site (NTS) during the years 1952, 1953, 1955, and 1957. A detailed analysis of iodine-131 in fallout from the Nevada Test Site was published by the National Cancer Institute (NCI) in 1997. (National Cancer Institute. 1997. Estimated Exposures and Thyroid Doses Received by the American People from Iodine-131 in Fallout Following Nevada Atmospheric Nuclear Bomb Tests. Washington, DC: U.S. Department of Health and Human Services.) Specific estimates of iodine-131 deposition and thyroid doses for all 3,100 counties in the continental United States are provided on NCI's Internet site. The NCI deposition estimates for East Tennessee counties were used to compute thyroid doses, along with estimates of uncertainties, for females born after January 1, 1952, in Anderson, Roane, Loudon, and Knox counties. The NCI information includes different dose estimation factors for backyard cow's milk, goat's milk, and commercial milk.

For East Tennessee locations, the iodine-131 dose from Nevada Test Site fallout depended less on location than on diet and age at the time of exposure. Doses from goat's milk were the highest, doses from backyard cow's milk were five to six times lower than from goat's milk, and doses from commercial milk were about three times lower still.

The dose reconstruction team evaluated communities near ORNL (Norwood, Gallaher Road, Bradbury, Lenoir City, and Solway) to determine the combined dose and cancer risk posed by fallout from the Nevada Test Site and RaLa processing at ORNL. At Bradbury, about 3.7 miles southwest of ORNL, the doses attributable to the ORNL releases are roughly twice those calculated for the NTS releases. At Gallaher Road (Lawnville) and Solway, about 4.6 miles west and 8.4 miles east-northeast of the facility, respectively, doses from the Nevada Test Site were about the same as those from ORNL. Doses at Norwood, about seven miles north, that were attributable to ORNL's releases were estimated to be four to five times smaller than the NTS doses. Doses at locations more than 24 miles from ORNL are dominated by Nevada Test Site fallout, as are doses at some closer locations that are less often visited by winds from ORNL. All these results are for girls born in 1952 and on a diet of backyard cow's milk.

Iodine-131 released from ORNL was widely dispersed over East Tennessee pastures. Contaminated commercial milk was delivered to numerous distributors and local retail outlets and was then brought into individual homes. A large number of children would have experienced a small increased risk of contracting thyroid cancer. Using census tract data for the periods of the ORNL iodine-131 release, the dose reconstruction team estimated the total number of excess thyroid cancer cases induced in people in the exposed population. The approximate ranges of these estimates were:

✓ 6-80 excess thyroid cancer cases within

Excess Thyroid Cancer Risk Estimates for Representative Females Born in 1952, Residing Near the ORR, and Consuming Milk from Identified Sources

Direction/ Distance (miles from X-10)	Location	Excess Lifetime Risk of Thyroid Cancer (chances per million)[a]: Backyard Cow's Milk[b]	Commercial Milk
E / 3.9	**Gallaher Bend**	710 – 170,000 [c]	270 – 49,000
E / 7.5	**Hardin Valley**	370 – 83,000	120 – 23,000
E / 13	**Cedar Bluff**	160 – 40,000	60 – 11,000
E / 22	**Knoxville**	73 – 18,000	27 – 4,900
NE / 16	**Clinton**	100 – 24,000	38 – 6,400
NNE / 15	**Dutch Valley**	61 – 16,000	25 – 4,400
N / 8.3	**Oliver Springs**	52 – 16,000	20 – 4,100
NW / 17	**Wartburg**	13 – 4,800	5 – 1,100
WSW / 5.8	**Lawnville**	390 – 91,000	160 – 25,000
WSW / 12	**Kingston**	140 – 35,000	55 – 9,600
WSW / 17	**Rockwood**	66 – 17,000	24 – 4,500
SW / 3.7	**Bradbury**	600 – 140,000	210 – 36,000
S / 9.0	**Hines Valley**	170 – 42,000	63 – 12,000
SSW / 12	**Loudon**	110 – 29,000	40 – 7,200

[a] The 95 percent subjective confidence intervals for the risk estimates are shown.

[b] Diet is also assumed to include consumption of local garden vegetables, which make a small contribution to the dose.

[c] An alternative notation for the same risk is "0.00071 – 0.17." The upper bound corresponds to a risk of about 1 chance in 6 of contracting thyroid cancer.

24 miles of ORNL,
✓ 10-100 excess thyroid cancer cases within 62 miles of ORNL,
✓ 25-150 excess thyroid cancer cases within 124 miles of ORNL.
(Note: The totals for the larger regions include the excess cases projected for the smaller regions.)

Most of these radiation-induced cancers may already have occurred. These estimates are based on the background incidence of thyroid cancer diagnosed within the region for the time periods of concern. Postmortem pathology studies suggest that many thyroid cancers are not detected, so additional cases of cancer may have been induced above the estimates presented above.

Other forms of thyroid disease are known to be induced by radiation exposure. Of these, an excess of benign thyroid nodules is most likely to have occurred around the ORR. The number of benign nodules in the population is estimated to be 10 to 20 times the number of cancers. The clinical significance of benign thyroid nodules was not evaluated in this study.

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 in Seattle, Washington, and funded by the CDC. This nine-year study evaluated whether the occurrence of thyroid disease was associated with thyroid radiation dose in a group of 3,441 people who were exposed as children to iodine-131 from the Hanford Nuclear Reservation during the 1940s and 1950s. While thyroid disease was observed among the study participants, the draft study results, which are under review, was not able to show a relationship between the estimated dose to the thyroid from iodine-131 and the amount of thyroid disease in the study population (SEE ERRATA, PAGE 94, #3).

Other recent studies of environmental iodine-131 exposures and thyroid disease gave different results. A study of 2,473 Utah, Nevada, and Arizona residents exposed to Nevada Test Site fallout as children reported an association between the occurrence of thyroid neoplasia (cancer or nodules) and iodine-131 dose to the thyroid (*Kerber, et. al., JAMA, 270:2076-2082, 1993*). A 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*), in reviewing the ongoing Chernobyl studies, 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 a relationship between iodine-131 exposure and

Short stack from which some radioactive iodine was released during RaLa processing. This photo was taken around 1946.

DOE photo

Task 2

Hg

Mercury

Period of release

1950-present
(highest 1953-60)

Population of most concern

Methylmercury: Fetuses of pregnant women who ate fish taken from the contaminated creeks and rivers downstream of the ORR during the period of highest releases to East Fork Poplar Creek.

Elemental Mercury: East Fork Poplar Creek farm families, Scarboro residents.

Inorganic Mercury: East Fork Poplar Creek farm families

Exposures

Methylmercury: Exceeded the "no observed adverse effect level" (*see sidebar page 33*) for many moderate consumers of fish from Poplar Creek or the Clinch River around 1960.

Elemental Mercury: Exceeded the EPA's Reference Dose (*see sidebar page 33*) during years of highest releases for East Fork Poplar Creek farm families and Scarboro residents.

Inorganic Mercury: Exceeded the Reference Dose only for East Fork Poplar Creek farm families.

East Fork Poplar Creek begins at Y-12 (left, shown in 1988) and eventually flows into Poplar Creek and the Clinch River. One concern over mercury that entered the creek from Y-12 is its effect on people consuming fish from the Clinch and from Watts Bar Reservoir.

DOE photos

MERCURY RELEASES

from Lithium Separation at the Y-12 Plant

Mercury was used at Y-12 during the 1950s and 1960s in the physical/chemical column-based exchange, or Colex, process that enriched naturally occurring lithium feedstocks by selectively removing the lighter lithium-6 isotope for use in thermonuclear weapons being produced at that time. The total mercury inventory was more than 24 million pounds, from which approximately 350,000 pounds were discharged either to East Fork Poplar Creek in wastewater or to the atmosphere. Dissolved mercury contamination has been present in waste releases from Y-12 Plant since the early 1950s. Mercury releases to East Fork Poplar Creek came largely from a process step used in the 1950s that involved a nitric acid wash, or purification, of the mercury. Spills from equipment failures account for the remaining inventory lost to the creek. The dose reconstruction project team estimated that about 280,000 pounds of mercury were released to the creek by these mechanisms. These releases continue to this day, although the heaviest by far were from 1953 through 1960. Total mercury released to East Fork Poplar Creek during more recent times, 1983-1993, is estimated to be below 500 pounds.

The headwaters of East Fork Poplar Creek rise within the Y-12 complex. After leaving the plant, the creek winds through residential portions of Oak Ridge and uninhabited portions of the ORR before joining Poplar Creek just upstream of K-25. A relatively short distance down-

The Health Effects of Mercury

One can be exposed to mercury in a variety of ways: by breathing mercury vapor, drinking contaminated water, or eating contaminated fish and other foods. Mercury can also enter the body directly through the skin.

Mercury is a naturally occurring chemical element found in a variety of forms. Long-term exposure can cause permanent damage to the brains and kidneys of adults and to the brains of developing fetuses.

Mercury found in thermometers is in the form metallic mercury. Mercury can also combine with other chemicals to form either inorganic or organic mercury. One form of organic mercury, methylmercury, bioaccumulates in fish. As a result, rather low levels of metallic or inorganic mercury in ocean or lake sediment can, over time, still seriously contaminate edible fish. Soluble inorganic compounds like mercuric chloride can reach the blood stream if ingested, while insoluble compounds like mercuric sulfide are less available to the bloodstream.

The particular health effect caused by mercury depends on the chemical form to which one is exposed. Organic mercury in contaminated fish eaten by the mother is most likely to harm the brain of a developing fetus. Metallic mercury that is inhaled is most likely to do brain damage. Inorganic mercury salts consumed in contaminated food or water are most likely to damage the kidneys. Similar effects are found from short-term exposure to metallic or inorganic mercury, but full recovery is more likely once the body clears itself of the contamination.

Mercury has not been shown to cause cancer in either test animals or accidentally exposed humans.

stream of K-25, Poplar Creek enters the Clinch River.

Airborne releases of mercury came primarily from ventilation systems, which exhausted contaminated air from the active work areas within the Colex process buildings. The study team estimated that about 70,000 pounds of mercury were released into the atmosphere, mainly during the years of highest production.

Mercury exists in three basic chemical categories: metallic (elemental), inorganic and organic. Humans can be harmed in different ways depending on the chemical form of the mercury to which they are exposed. The Colex process used mercury in an amalgam (metal alloy mixture). Most releases to East Fork Poplar Creek were in the form of nitrates from the acid wash. The chemical form of released mercury is changed as it moves through the natural environment. For this reason, the dose reconstruction project team evaluated the health risks posed by mercury in each of its three general chemical forms.

Local fish consumption categories used for estimates of methylmercury ingestion

Category	Frequency of fish meals
Heavy	1 to 2.5 a week
Moderate	1 per week to 1 every three weeks
Light	1 every three weeks to 1 every six months

A "fish meal" consists of six ounces.

The mercury released in air exhausts was primarily in the elemental form, which can readily vaporize. Chronic human inhalation of elemental mercury doses greater than 0.01 milligrams per kilogram per day can cause brain damage. Inorganic mercury, usually as chloride or sulfide salts, is commonly found in soil, water and food. Chronic ingestion of the inorganic forms at a rate greater than 0.3 milligrams per kilogram per day can cause kidney damage in rats.

Organic mercury, usually found in a form called "methylmercury," will biochemically evolve from inorganic mercury that has been introduced into natural aquatic sediments and will bioconcentrate in fish flesh. When pregnant women ingest more than about 0.001 milligrams per kilogram per day of methylmercury in contaminated fish, their fetuses may sustain severe brain damage and other serious birth defects.

It is difficult to estimate how many people might actually have been harmed as a result of exposure to the elemental or inorganic mercury released from Y-12. The available information on mercury toxicity has been derived from studies on animals and research on humans following relatively high accidental exposures to workers or members of the public.

The highest doses of elemental and inorganic mercury from the ORR were to farm family residents along East Fork Poplar Creek and to children in the Scarboro community about one-half mile from Y-12. People living in these locations were exposed to mercury in the air, through contact with contaminated water and sediment, and from eating food raised in contaminated soil near the creek. Some elemental mercury is believed to have escaped from the creek into the air. Although Scarboro is closer to Y-12 than are the farm locations, farm families lived closer to the creek. The dose reconstruction team estimated that, altogether, from 6,000 to 10,000 people lived in Scarboro between 1950 and 1990 and from 40 to 200 people altogether lived on farms along East Fork Poplar Creek.

The only group likely to have received doses of elemental mercury higher than the Reference Dose (RfD, *see sidebar*) were East Fork Poplar Creek farm family children.

None of the population groups studied likely received doses of inorganic mercury higher than the no observed adverse effect level (NOAEL, *see sidebar*). Farm family children from 6 months to 3 years old likely received doses higher than the inorganic mercury RfD from 1953 to 1958, while adults likely received doses higher than the RfD from 1955 to 1958. Children in Scarboro or elsewhere who played actively in East Fork Poplar Creek likely received doses higher than the RfD from 1955 to 1958, while adults in the community most likely received doses below the RfD.

The results of the dose reconstruction studies for methylmercury suggest that the highest risk from methylmercury was to fetuses of pregnant women who ate significant quantities of fish taken from the Clinch River or Poplar Creek in the late 1950s and early 1960s.

Most people do not consume freshwater fish (*see Jacobs et. al. Risk Analysis, 18: 233, 1998*). Those who did consume fish from the contaminated fishery were divided into three categories, as illustrated below. About half (48 percent to 52 percent) of the women age 15 to 44 were characterized as light consumers, 20 percent to 28 percent as moderate consumers and 24 percent to 28 per-

Population of consumers of local fish

Populations of Fish Consumers	**Number of persons per year**
Watts Bar	10,000–30,000
Clinch River/Poplar Creek	3,000–10,000
East Fork Poplar Creek	10–30

LOAELs, NOAELs, and RfDs as Chemical Exposure Safety Guidelines

The ORR dose reconstruction research team compared estimated mercury doses and other non-carcinogenic toxic chemical doses to a variety of regulatory criteria drawn from various published toxicity studies.

To establish safety criteria for exposure to chemical hazards, toxicologists often estimate a dose below which there will be minimal chance for any adverse effect. The general approach for setting exposure limits for non-cancer endpoints involves identifying the critical effect of the specific chemical of interest and observing outcomes at various dose levels, usually in animal experiments. Uncertainty factors, also referred to as safety factors, are then applied to extrapolate the animal results to the human population. The critical effect is usually chosen as the health endpoint that shows up in test animals at a dose lower than any other health problem.

The magnitude of the dose corresponding to a critical effect endpoint is usually either: (a) the highest dosage administered that did not cause any adverse health effect, called the “no observed adverse effect level” or NOAEL; or (b) the lowest dosage that did produce an observed adverse effect, called the “lowest observed adverse effect level” or LOAEL. The NOAEL and LOAEL doses are usually established on laboratory data from tests on animals, but human data are also sometimes available from occupational or public exposure incidents. Even when the LOAEL is reached, this means some adverse effect was observed but not necessarily that the effect was life-threatening.

The Environmental Protection Agency (EPA) has developed Reference Doses (RfDs) for many chemicals, defined as “an estimate of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime.” The RfD is usually either the NOAEL or the LOAEL dose divided by an appropriate safety factor, typically in a range of 10 to 100. A safety factor as high as 1,000 can be used when

Continued on the next page

LOAELs, NOAELs and RfDs

Continued from previous page

the data are insufficient.

Although using uncertainty factors of 10, 100, or even 1,000 may result in RfDs lower than strictly necessary to protect public health, the values may still sometimes underestimate the actual risks. It is important to point out that calculated levels of chemical exposure such as those presented in these studies are not risk estimates. Exposures of individuals to doses above the RfD does not mean that they will certainly develop symptoms of adverse effects to a specific chemical. The RfD is a safe guideline provided by EPA to help individuals put their exposure in context. The RfD for chronic exposure is expected to be applicable to exposure every day for the individual's entire lifetime.

When evaluating the potential significance of a chemical exposure, one should not rely exclusively on the RfD. Because the safety factors for chemicals may vary widely, exposure to doses twice that of the RfD can have different meanings depending on, for example, whether the exposure is to PCBs or methylmercury. Therefore, toxic chemical doses should be examined within a framework that includes the NOAEL and the LOAEL and whether the values are based on animal or human studies.

It is also important to point out that NOAELs are derived from study populations and not the general population. They are highly dependent on the size of the population studied and the critical effect measured. For example, a study that examines a few endpoints in only a small number of animals may result in a higher NOAEL (and thus a higher RfD) than would be derived from a comprehensive study involving many animals that can detect more subtle effects. Very often it is not feasible to use large numbers of animals, and therefore failure to observe effects at low doses may be due to the low statistical power of the study. This is further complicated by the fact that, for some chemicals, it is not known whether a threshold actually exists.

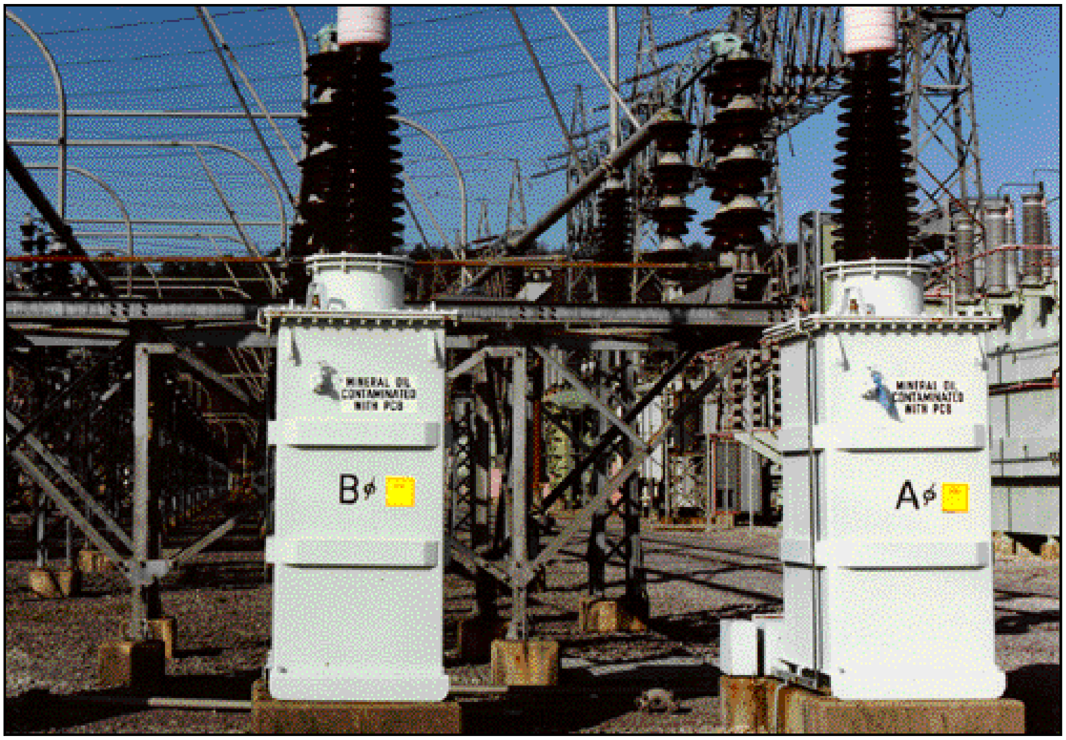
cent as heavy consumers.

Almost all fetuses of women who were heavy consumers of fish from the Clinch River and Poplar Creek would have received doses higher than the NOAEL from 1956 through 1962 (most of these also above the LOAEL), and higher than the RfD from about 1953 through 1976. Most fetuses whose mothers were moderate consumers probably received doses higher than the NOAEL from 1956 through 1962, and higher than the RfD from about 1953 through 1973. A few fetuses whose mothers were light consumers of fish from the Clinch River and Poplar Creek received doses higher than the NOAEL around 1957, and most fetuses probably received doses higher than the RfD from 1956 through 1962.

No fish were sampled for mercury until 1970, so the methylmercury concentrations in fish were estimated by using a correlation between the mercury concentrations in sediment and in fish. Sediments also were not sampled at the time, so values in this study were based on dating of core samples from the 1980s. The resulting large uncertainties led to large reconstructed methylmercury dose estimates even for 1950, before the Y-12 mercury inventory was significant. It is not believed that there were significant doses before 1953, and that belief is reflected in the previous paragraph.

Methylmercury levels in fish downstream in Watts Bar Lake were not as high as those in the Clinch River but still presented a risk. Up to half the fetuses of pregnant women who were heavy consumers of contaminated fish taken from Watts Bar Lake are estimated to have received doses higher than the NOAEL from 1956 through 1960, and during this period almost all received doses higher than the RfD. Fetuses whose mothers were moderate consumers are unlikely to have received doses higher than the NOAEL, but most of them likely did receive doses higher than the RfD from 1956 through 1960. A small fraction of fetuses whose mothers were light consumers of fish from Watts Bar Lake are thought to have received doses above the RfD from 1957 through 1959.

The number of fetuses that may have been affected (average doses greater than the NOAEL) in a particular year was computed by using the average birth rate in the population, the fraction of women of childbearing age in the population, their fish consumption rates, and the fraction of consumers whose doses exceeded the NOAEL for *in utero* exposure during that year. The estimates were made for Watts Bar, Clinch River/Poplar Creek, and East Fork Poplar Creek fish consumers and summed over the years of concern. The estimated number of fetuses placed at risk is uncertain, but is nearer to 100 than to 1,000.



DOE photo

PCB-contaminated mineral oil transformers in the switchyards at K-25.This photo was taken in 1991.

PCBs
from the Oak Ridge Reservation

Task 3

PCBs

Polychlorinated Biphenyls

Period of highest release
1950s to 1970s

Population of most concern
Consumers of fish taken from waterways downstream of the ORR.

Health effects expected
From ORR releases, fewer than three additional cancer cases in fish consumers. For noncancer effects, an additional 1,000 or 2,000 fish consumers were pushed above doses corresponding to “true hazard quotients” greater than 1.The unusually sensitive portion of this group would be expected to suffer some deleterious effect.

The class of chemical compounds called “polychlorinated biphenyls” (PCBs) was used widely on the Oak Ridge Reservation as at industrial sites throughout the country. Because PCBs are nonflammable and chemically stable, they were used at the Oak Ridge facilities and elsewhere in transformers, capacitors, hydraulic systems, and as a nonflammable cutting oil.

It is difficult to estimate the amount of PCBs released from the ORR. Before the early 1970s, PCBs were not considered to be particularly hazardous, and use and disposal practices were not closely monitored. Since the amounts of PCBs released from the DOE plants could not be firmly established, doses to persons off site were estimated based on the levels of PCBs observed in the nearby environment in more recent times.

PCBs typically bind to sediments in lakes and rivers and may persist there for decades. As a result, leaks and spills are likely to create sources of chronic low-level exposure that can persist for many years. Unlike most of the other pollutants addressed by the health agreement studies, PCBs were used widely by other industries in the region. Investigators identi-

The Health Effects of PCBs

Fish are the major source of PCB exposure around the ORR, since they accumulate the chemical. These PCB compounds originate in contaminated water and sediment, and then reach the diet of fish. In addition, predatory fish concentrate PCBs by eating smaller, contaminated fish.

In laboratory animal experiments, PCBs have produced liver damage, alterations in immune response, reproductive and developmental effects and cancer. As a result of the cancer data, the Department of Health and Human Services has concluded that PCBs may reasonably be anticipated to cause cancer in humans. Because human cancer risk estimates for PCBs are extrapolated from animal studies in a way that likely could overestimate risk to humans, the estimated risks to humans are likely too high. In limited studies, PCBs have not been shown to cause cancer in humans.

The most sensitive effects of PCBs in humans are neurodevelopmental disturbances, alterations of immune response in offspring, and hypothyroidism. The Environmental Protection Agency has established a Reference Dose for PCB exposure. This EPA Reference Dose is estimated by applying successive safety factors to the results of relevant experiments on laboratory animals. The investigative team on this project combined the same data in a recently proposed way to recognize the uncertainty in establishing a safe dose without depending on fixed safety factors thought to be unrealistic.

Each of the thousands of PCB doses estimated for Clinch River or Watts Bar fish consumption was divided by a "population threshold dose" drawn at random from a distribution having a lower 90 percent confidence limit about five times the RfD for Aroclor 1254 (2×10^{-5} milligrams per kilogram per day) and an upper 90 percent confidence limit about 40 percent of the observed LOAEL for Aroclor 1254 (5×10^{-3} milligrams per kilogram per day) in rhesus monkeys. The quotient is defined as the "true hazard quotient" for that case. Aroclor 1254 was the most hazardous of the PCB compounds used on the ORR. The value of the true hazard quotient for each trial was combined with values from all the other trials to yield results for exposure from consumption of fish from local rivers.

The uncertain "population threshold" was defined as the largest sustained dose that would not cause deleterious health effects in the human population. Therefore, the portion of the population estimated to have experienced a true hazard quotient larger than 1 is considered to be the population at some risk.

fied more than 20 facilities along the Clinch and Tennessee rivers upstream from the ORR that also discharged PCB-contaminated wastes.

Releases from K-25 are of particular concern because this facility is located at the western edge of the ORR and releases flow almost directly off site. Y-12 releases to East Fork Poplar Creek on the east side of the ORR are also of concern because the creek flows through the Oak Ridge community directly after leaving the plant. Releases from Y-12 to Bear Creek and from ORNL to White Oak Creek are of less concern because they must travel greater distances before reaching off-site locations. As a result, PCBs from these releases have tended to settle in stream beds on the ORR.

People eating fish from the Clinch River appear to have been at greatest risk for illness from Oak Ridge PCB releases; at least half of the PCBs now found in Clinch River sediments below the ORR were probably released from the plants. While PCB levels in fish at Watts Bar Reservoir were also high enough to be of concern, investigators concluded that only 6 to 13 percent of this PCB contamination came from ORR sources.

Investigators also looked at public exposure to PCBs from the burning of oils and contact with waste oils, but concluded these did not pose enough hazard to warrant further study. They considered several groups that may have been exposed to PCBs in area waterways, focusing eventually on persons who ate fish caught from the Clinch River and Watts Bar Lake.

There is concern about both the cancer and non-cancer health effects on persons who ate many meals of PCB-contaminated fish taken from the Clinch River or lower Watts Bar Lake. Extrapolating from carcinogenicity tests performed on various lab animals over the years, the ORR health studies investigators estimated that fewer than three excess cancers have been caused by PCBs from the Reservation. In limited studies, PCBs have not been shown to cause cancer in humans.

For central values of the uncertain parameters, Health Studies scientists estimate that about 4 percent of consumers of fish from the Clinch River and 7 percent of consumers of fish from Watts Bar Lake experienced a chronic PCB dose from all sources large enough to pose a non-cancer health concern. For extreme values of the uncertain parameters such as the population threshold dose, the fraction of fish consumers for whom there could be a health concern from the total PCBs present ranged to 20 percent for the consumers of fish from the Clinch River and to 40 percent for consumers of fish from Watts Bar Lake.

The portion of the PCBs derived from the ORR would have produced no health concerns in Watts Bar had no PCBs from upstream sources been present. As noted, about 90 percent of the PCBs in Watts Bar are from upstream sources. Altogether, the Oak Ridge contribution increased by 1 or 2 percent the total number of consumers of fish from the region whose doses corresponded to true hazard quotients greater than unity. This percentage corresponds to about 1,500 fish consumers (*see PCB sidebar on page 36)*.

These 1,500 persons had their PCB doses raised by ORR releases to a level where the population threshold model predicted that the unusually sensitive among them would be expected to suffer some deleterious health effect. Risk analysis techniques for PCB exposures are not sufficiently advanced to support conclusions much more precise than this, even if the actual doses to individuals were known.

To permit more conclusive estimates, investigators indicated that additional information would be needed. The data would include consumption rates of fish and turtles, PCB levels in core samples from the Clinch River and Watts Bar Lake, PCB concentrations in soils near East Fork Poplar Creek, and PCB concentrations in beef cattle grazing near the creek (SEE ERRATA, PAGE 94, #4). (*See page 69 for information concerning ATSDR's 1997 study of persons known to eat significant quantities of fish taken from Watts Bar.*)

Oak Ridge National Laboratory (upper right), waste burial grounds and White Oak Lake (center) and the Clinch River (bottom left). Highway 95 crosses White Oak Dam. This photo was taken in 1991.

DOE photo

RADIONUCLIDE

Releases from ORNL (X-10) via White Oak Creek

Task 4

Radionuclides

^{137}Cs ^{106}Ru ^{60}Co ^{90}Sr

^{95}Nb ^{95}Zr ^{144}Ce ^{131}I

Period of release

1944-present
(heaviest from 1944-63)

Population of most concern

Consumers of fish taken from the Clinch River near the mouth of White Oak Creek.

Health effects expected

Less than one excess cancer case from 50 years of contaminated fish consumption.

About 160,000 curies of radioactive material were released from White Oak Creek into the Clinch River between 1944 and 1991. Residents who used the river for food or water or walked along its shores were exposed to radiation. Dozens of different radioactive isotopes were released. Persons exposed to these substances had a slightly increased risk of various forms of cancer.

The highest risk resulting from these releases was due to the consumption of fish caught in the Clinch River. The more Clinch River fish an individual has eaten, and the closer those fish were to the confluence of White Oak Creek when they were caught, the greater the risk. The highest risk would have been to an individual who frequently ate fish caught very near the mouth of the White Oak Creek since the mid-1940s.

The dose reconstruction scientists estimated that a man who ate from 52 to 130 fish meals a year for 50 years from this specific area faced an excess cancer risk ranging from 4 to 350 in 100,000 with a central estimate of 28 in 100,000. The most likely cancer would be leukemia. A woman in the same situation would have faced an excess cancer risk of 3 to 280 in 100,000, with a central estimate of 23 in 100,000. The most likely malignancy result would be breast cancer or leukemia. Men are at higher risk in this situation because they tend to eat larger meals.

The risk from these exposures goes down proportionally for individuals who eat fewer fish. The exposure also goes down for fish caught farther downstream. For example, a male eating the same amount of fish as above, but caught in Watts Bar Lake at the confluence of the Tennessee and Clinch Rivers, would have a risk in a range between less than 1 and 26 in 100,000. Although releases from White Oak Creek have increased the cancer risk of nearby residents, the number of cancers expected from these releases is less than one, far too low to be detected by any epidemiologic study.

This task began with an evaluation of about two dozen radioactive substances. The initial screening concluded that only eight were of concern. Of those, the most significant were cesium-137, cobalt-60, ruthenium-106, and strontium-90. Also included were zirconium-95, niobium-95, iodine-131, and cerium-144.

The study looked at a variety of ways in which people could have been exposed to these radionuclides. The most significant pathway was the consumption of fish, but a few people may have been exposed in several other ways. Since 1955, the City of Kingston's municipal water supply has been taken from the Tennessee River just upstream of the confluence with the Clinch River. The dose reconstruction team estimated the amount of radiological contamination resulting from Clinch River backflow that could have entered the Kingston water intake as well as the effect of water treatment. A second exposure pathway involved drinking milk or eating beef from cows that drank from the river. In addition, walking along the banks of the river would lead to exposure to radiation from contaminated shoreline sediments. Persons were also exposed by eating wildlife, such as deer, turtles, and waterfowl, that had lived on the ORR and had consumed water or vegetation contaminated by these waste discharges.

For the majority of these exposure routes, the most significant time was within the first two decades of release, 1944 to 1963. Downstream of Jones Island, however, external exposure along the shoreline gradually became the most important exposure route for those who used the shoreline. Around the State Route 58 bridge, the shoreline external exposure is estimated to have increased somewhat for a while after 1963. The construction of the Melton Hill Dam increased the amount of radioactive material entering the Clinch River (See Errata, page 94, #5).

Most of these releases were the result of early waste disposal practices at ORNL, known early on as the Clinton Laboratory or the X-10 site. This site was originally envisioned as a temporary facility, operat-

DOE photo

Sample collection at White Oak Dam, 1949

What is a curie?

A curie is a measure of how "active" a radioactive substance is: the greater the number of curies, the more radiation emitted during a given time. A curie of radioactivity is equal to 37 billion nuclear disintegrations per second. For cesium-137, each such disintegration involves emission of a beta particle.

See page 63 for a general discussion of the cancer risks from exposure to multiple radionuclides.

ing for one year as a pilot plant for operations at the Hanford Reservation in Washington state and focusing on the chemical separation of plutonium. All radioactive wastes from X-10 were first stored in underground tanks. Beginning in 1944, when plans changed and the facility was not closed down, radioactive wastes were released to White Oak Creek. White Oak Creek flows into White Oak Lake before joining the Clinch River, and the lake served as the final settling basin for contaminants released to the creek. Contaminants that did not settle out of the water flowed over White Oak Dam, which is located about a half mile upstream from the Clinch River.

The earliest radioactive wastes from ORNL were derived from the Clinton Pile, later renamed the Oak Ridge Graphite Reactor, and the chemical processing facilities associated with this early reactor. Later, releases resulted from several other reactor operations, numerous on-site chemical processing facilities, seeps from the shallow land burial pits used for many years to dispose of low level radioactive wastes, and the use of ORNL from 1955 to 1963 as the regional disposal site for radioactive waste generated at various government and commercial installations throughout the Southeast.

Releases of cesium-137, which contributed most to the risk, were highest from 1955 to 1959. White Oak Lake was drained in 1955 and the lake level stayed low until 1960. This allowed the high creek flows accompanying heavy rains, especially in the winter and early spring of 1956, to scour the sediments in which radionuclides had accumulated. Releases during these years are believed to be responsible for the relatively high concentrations of cesium-137 found in subsequent sediment cores and samples from White Oak Creek below the lake, the Clinch River, and lower Watts Bar Lake.

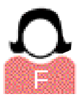
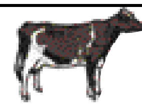
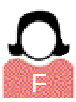
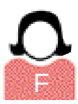
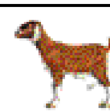
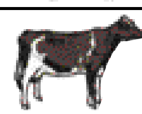
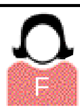
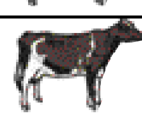
DOE photo

In the early years, radioactive waste at ORNL was stored in gunite (concrete) tanks, shown here during construction in 1943. Each held 170,000 gallons.

Exposure Scenarios

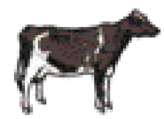
The following subsections of this report describe risk estimate scenarios for eight hypothetical individuals, all of whom were presumed to have lived near the ORR for a number of years and would have been exposed to more than one of the ORR environmental contaminants. The Panel believes these examples are based on reasonable assumptions concerning lifestyles of a variety of typical individuals. Some of the scenarios relate to persons who might have faced some of the highest postulated risks protracted over relatively long periods of time, while others deal with persons who were at less risk.

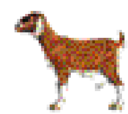
The calculated results for the hypothetical exposure scenarios should help provide insight into the full range of potential increased health risks that have been faced by people living in the communities surrounding the ORR. Differences in location, time of exposure, age, gender, activity, and dietary habits affect the estimated additive risks from exposure to multiple contaminants. It was not possible to estimate effects of conceivable but unknown interactions of multiple contaminants.

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

* The number of "Years in Area" provides a general idea of the time period over which the individual's exposures to various contaminants were calculated. The time periods were different, depending on the contaminant. For iodine-131, no doses were estimated for years beyond 1956, and for the radionuclides released from White Oak Creek, no exposures were calculated beyond 1991. PCB exposures were assumed to continue during residence in the area.

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

A Woman Raised on an East Fork Poplar Creek Farm

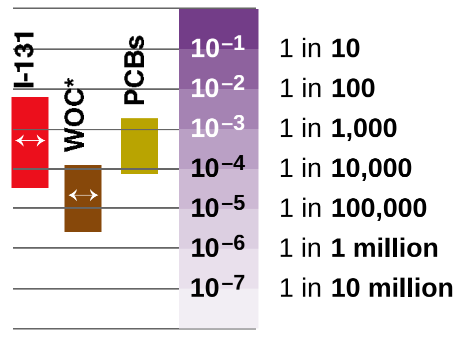
In this scenario, a woman is born in 1940; in 1943, she moved to a farm on the banks of East Fork Poplar Creek in Oak Ridge. She drank backyard cow's milk as a child and adult. She played in East Fork Poplar Creek as a child and ate vegetables, beef, cheese, and eggs that were produced on the farm. Each month she ate between 1.5 and 4 meals of fish taken from the Clinch River just below the mouth of Poplar Creek. She became pregnant and had a child in 1958. She continues to live in the Oak Ridge area.

Discussion of Cancer Risks

This woman's additional cancer risk is dominated by the risk of thyroid cancer because of childhood exposure to iodine-131, primarily in milk. It was estimated that her thyroid cancer risk was increased by an amount between 30 chances in a million and 6,000 chances in a million. Also, her additional general cancer risk from exposure to PCBs on the farm and in fish she ate was estimated to be between 60 and 2,000 chances in a million.

The fish that she consumed were contaminated also by radionuclides released from White Oak Creek. This exposure increased her cancer risk by a smaller amount that ranged from about 2 to 130 chances in a million.

Additional Cancer Risks



**WOC = Radionuclides from White Oak Creek*
↔ = central estimate

Discussion of Non-Cancer Effects

This woman could easily have received doses of elemental and inorganic mercury and PCBs from East Fork Poplar Creek that exceeded the corresponding EPA Reference Doses (RfDs) for deleterious non-cancer health effects.

For the elemental mercury she inhaled, her estimated dose at the upper confidence limit exceeded the RfD by as much as a factor of 4 from 1955 to 1959. Her estimated doses of inorganic mercury — from food and from skin contact — exceeded the RfD each year between 1952 and 1965, possibly by as much as a factor of 30. Even in years of peak exposure, however, her doses were at least 10 times less than the applicable NOAELs. (In the case of inorganic mercury, the NOAEL was determined from subchronic exposure studies on rats.)

Chemical Toxicity
Guide value exceeded, yes or no?

Guide	methyl mercury	inorganic mercury	elemental mercury	PCBs
LOAEL	**yes**[a]	no	no	no
NOAEL	**yes**[a]	no	no	*
RfD	**yes**	**yes**	**yes**	**yes**

** There is no NOAEL for the PCB of concern.*
[a] For the fetus

The PCB doses this woman received from exposures on the farm almost certainly exceeded the RfD. While there is much uncertainty regarding PCB levels in soils, these doses were as large as 100 times the RfD for an adult and as large as 200 times the RfD for a child. Her PCB dose likely stayed below the LOAEL that was determined from studies of monkeys' subchronic exposure to Aroclor 1254, the most hazardous PCB in wide use on the ORR.

In eating fish from the Clinch River, she was exposed to more PCBs and to methylmercury. Her dose from PCBs in fish was estimated to be up to several times the RfD for Aroclor 1254, but a few percent of the LOAEL, all based on monkey data. Project researchers established a population threshold distribution designed to represent the range of possible values for the highest dose that would not harm the most sensitive individual. This woman's dose level was up to twice the lower limit of the 90 percent confidence interval for this distribution, but was less than a third of its median. Her dose would have had less than a 50 percent chance of harming the most sensitive individual in the population.

Her methylmercury doses peaked in 1957, when they were estimated to range between one and 5 times the RfD for adult exposure. In 1958, the year during which she was pregnant, her dose was in the range of three to 14 times the RfD for *in utero* exposures. The NOAEL for fetal exposure is 5 times this RfD, and the LOAEL is 10 times this RfD (all based on human data). This unborn may have been exposed above these guide levels and could have suffered deleterious health effects.

Scenario #2

A Man Who Moved to Oak Ridge in 1948 at Age 21

This scenario involves a 21-year-old man who moved from another state to the Jackson Square area of Oak Ridge in 1948. He drank commercially available milk and ate vegetables from a home garden. Each year, he ate from 2 to 17 meals of fish taken from Watts Bar Lake. He continued to live in Oak Ridge.

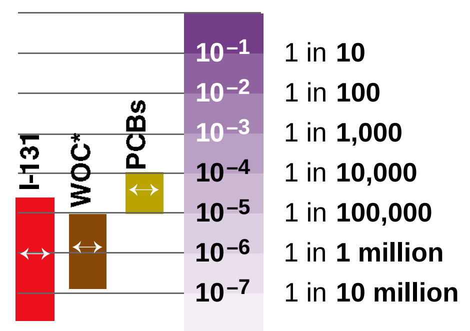
Discussion of Cancer Risks

Since this man was already an adult during releases of iodine-131, most of his increased cancer risk is attributable to the PCBs he consumed in fish from Watts Bar Lake. His increased lifetime risk of developing cancer because of PCB exposure was estimated to be between 10 and 100 chances in a million.

His increased risk of thyroid cancer from being exposed to iodine-131 in regionally mixed commercial milk and air was smaller, almost certainly less than 30 chances in a million (See Errata, page 94, #6).

Although he ate fish during the years of highest contaminant releases from White Oak Creek, he faced only a small risk of cancer because of radionuclides in the fish he consumed. The range of risk estimates was from 0.1 to 10 chances in a million.

Additional Cancer Risks



**WOC = Radionuclides from White Oak Creek*
↔ = central estimate

Discussion of Non-Cancer Effects

No adverse health effects from mercury exposure are expected for this man. The pathways for his exposure to mercury contamination (i.e., methyl-mercury from fish ingestion, elemental mercury from inhalation of mercury vapor, and inorganic mercury from ingestion of local food stuffs and from skin contact) all resulted in doses that did not exceed the applicable EPA Reference Dose (RfD).

As for the PCBs he consumed in fish, his dose is estimated to have been up to more than three times the RfD. Project researchers established a population threshold distribution designed to represent the range of possible values for the highest dose that would not harm the most sensitive individual. This man's PCB dose was only about two-thirds the lower limit for the 90 percent confidence interval of this distribution. (The toxicity data used were determined from studies using monkeys.)

Given these results for mercury and PCBs, it is very unlikely that non-cancer health problems resulted.

Chemical Toxicity
Guide value exceeded, yes or no?

LOAEL	no	no	no	no
NOAEL	no	no	no	*
RfD	no	no	no	**yes**
Guide	methyl mercury	inorganic mercury	elemental mercury	PCBs

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

Scenario #3

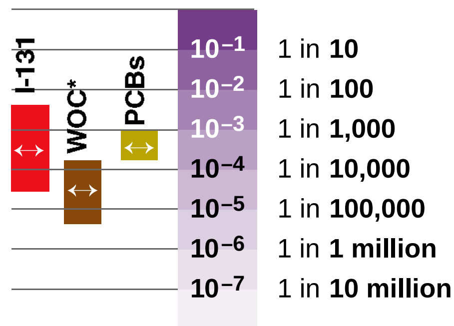
A Woman Raised in the Scarboro Community

This scenario involves a woman born in 1948 in what is now the Woodland community. She moved to the Scarboro community in 1952 and continues to live there. She played in East Fork Poplar Creek almost every day in the summer from age 5 to age 10 (i.e., from 1953 to 1958). She drank commercial milk and ate vegetables from a home garden. She likes fresh fish and has eaten from one to 2.5 meals a week of fish caught from the Clinch River near the Kingston Steam Plant.

Discussion of Cancer Risks

This woman's additional cancer risk is dominated by an increased risk of thyroid cancer resulting from exposure to iodine-131 in the regionally mixed commercial milk she drank and in the air she breathed from 1948 to 1956 (SEE ERRATA, PAGE 94, #6). Her additional lifetime risk of developing thyroid cancer was estimated to range from 30 to 4,000 chances in a million, based upon the statewide average background rate for women. If the reported background rate for African-American women in the United States had been used in the calculations, the estimated risks would be about half of those shown.

Additional Cancer Risks



**WOC = Radionuclides from White Oak Creek*
↔ = central estimate

This person's consumption of fish contaminated with PCBs and radionuclides released from White Oak Creek resulted in smaller contributions to her increased cancer risk. Estimates of her increased overall cancer risk from PCBs ranged from 170 to 900 chances in a million, and her increased risk from radionuclides ranged from four to 200 chances in a million.

Her exposure to PCBs in East Fork Poplar Creek increased her risk of cancer by a very small amount, estimated to be a thousand times less than her increased cancer risk from eating fish from the Clinch River.

Discussion of Non-Cancer Effects

Since this woman consumed a large amount of fish from the Clinch River, her exposure to methylmercury exceeded EPA's Reference Dose (RfD). Estimates of her methylmercury dose are highest for 1957, ranging from about three to 14 times the RfD for adults. Since the corresponding NOAEL is less than twice the adult RfD and the LOAEL just over 3 times that RfD, it is almost certain that her dose exceeded the NOAEL. Her childhood consumption of methylmercury in fish possibly resulted in adverse health effects.

Chemical Toxicity

Guide value exceeded, yes or no?

Guide	methyl mercury	inorganic mercury	elemental mercury	PCBs
LOAEL	yes	no	no	no
NOAEL	yes	no	no	*
RfD	yes	yes	no	yes

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

It is unlikely that her exposure to elemental mercury from playing in the creek and inhaling mercury vapor exceeded the applicable RfD; at most it reached two-thirds this value in 1955. With inorganic mercury, however, it is possible that her doses were as much as five times the RfD from 1954 to 1959. In all years, however, these inorganic mercury doses were far below the NOAEL, which is about 300 times the RfD. The RfD and NOAEL for inorganic mercury were determined using data from rat experiments.

Her exposure to PCBs associated with fish consumption produced a dose that was 4 to 20 times the EPA RfD. Project researchers established a population threshold distribution designed to represent the range of possible values for the highest dose that would not harm the most sensitive individual, and this woman's doses could have been near the median value of this distribution. 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 97.5 percent confidence level of her estimated dose was only about one-tenth the LOAEL (determined from studies on experimental monkeys). This woman 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.

Scenario #4

A Man Who Moved to the Scarboro Community in 1955 at Age 25

This scenario considers a man who moved to the Scarboro community from outside the state in January 1955 at the age of 25, and has lived there the rest of his life. He drank very little milk, all from commercial sources, and ate local vegetables grown near Solway. He had no contact with East Fork Poplar Creek water or sediments, and he did not eat fish caught in local waters.

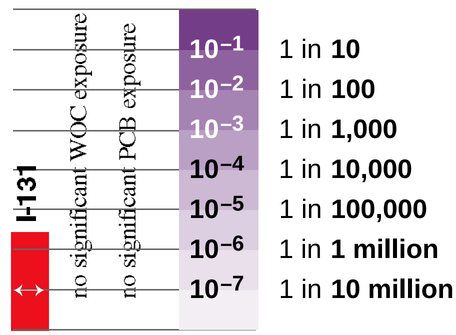
Discussion of Cancer Risks

Since this man drank little milk and moved to Oak Ridge as an adult after most iodine-131 releases had occurred, he experienced only a small increase in his lifetime risk of developing thyroid cancer. The range of this adjusted risk would extend only up to about 10 chances in a million for a person who drank an average amount of regionally mixed commercial milk, or up to three in a million for a person who drank a negligible amount of milk (SEE ERRATA, PAGE 94, #6). If the reported background rate for non-white men in the United States had been used in the calculations, the estimated risks would be about half of those shown.

This man did not eat local fish, so it was estimated that he received no added risk from PCBs or radionuclides originating at the Oak Ridge site.

No carcinogenic health effects would be expected for people who fit this scenario.

Additional Cancer Risks



**WOC = Radionuclides from White Oak Creek*
↔ = central estimate

Discussion of Non-Cancer Effects

This man experienced minimal additional risks of non-cancer health effects. None resulted from PCBs or methylmercury because he did not consume fish from local waters. His inhalation of elemental mercury did not result in estimated doses that exceeded the EPA Reference Dose (RfD). If he had experienced the typical exposure pathways assumed in the calculations for Scarboro residents, his inorganic mercury dose from ingestion and skin contact could have exceeded that RfD by as much as about five times in 1955, a peak year. Since he did not use East Fork Poplar Creek or eat the local above-ground vegetables that exposed some Scarboro residents, however, his dose of inorganic mercury was unlikely to have exceeded the RfD.

Chemical Toxicity
Guide value exceeded, yes or no?

Guide	methyl mercury	inorganic mercury	elemental mercury	PCBs
LOAEL	no	no	no	no
NOAEL	no	no	no	*
RfD	no	no	no	no

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

Scenario #5

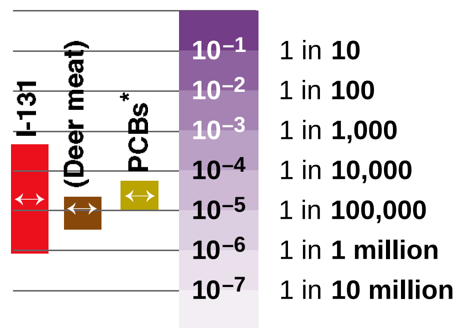
A Man Raised Near the Oak Ridge Swimming Pool

In this scenario, a man born in 1940 moved in 1943 to a location near the Oak Ridge outdoor swimming pool. He drank commercial milk as an infant and child. He fished frequently, and every month he ate between 1.5 and 4 meals of fish caught in the Clinch River upstream of the ORR. In 1954, he shot a deer that was contaminated with several radionuclides, primarily cesium-137, released to White Oak Creek and he and members of his family consumed it. In 1965, he left the Oak Ridge area.

Discussion of Cancer Risks

This man was exposed to iodine-131 in the regionally mixed commercial milk he drank and in the air. It was estimated that his additional lifetime risk of developing thyroid cancer was in the range from one to 500 chances in a million (SEE ERRATA, PAGE 94, #6). The fact that the man moved away from Oak Ridge in 1965 had no effect on his estimated exposure to iodine-131, because the major iodine releases occurred before 1957.

Additional Cancer Risks



** PCBs from upstream sources*
↔ = central estimate

The PCBs in fish he ate did not come from the ORR. They increased his risk of developing cancer by less than 60 chances in a million. The fish he ate had no radionuclides from White Oak Creek

His risk of developing cancer was increased by a small amount because he consumed contaminated deer meat; almost surely the increase was less than 26 chances in a million. This estimated increase was based on his consuming one meal of deer meat with the highest amount of cesium-137 (measured in the 1980s) in a deer taken from the ORR. While it is likely that this young man ate more than a single meal of contaminated deer meat, it is also likely that it contained less contamination than that assumed in this scenario.

Discussion of Non-Cancer Effects

Since this young man ate fish from a region of the Clinch River where mercury contamination from Y-12 was not present, no risk from methylmercury occurred. PCBs in the fish did not come from the ORR, but a dose was calculated for him anyway. This dose exceeded the EPA Reference Dose (RfD) by up to a factor of 4. Project researchers established a population threshold distribution designed to represent the range of possible values for the highest dose that would not harm the most sensitive individual. This man's dose was less than the lower limit of the 90 percent confidence interval of this distribution and less than 2 percent of the LOAEL determined from studies using monkeys. Health effects from his PCB exposures were quite unlikely.

Chemical Toxicity

Guide value exceeded, yes or no?

Guide	methyl mercury	inorganic mercury	elemental mercury	PCBs
LOAEL	no	no	no	no
NOAEL	no	no	no	[a]
RfD	no	no	no	**yes**[b]

[a] *There is no NOAEL for the PCB of concern.*
[b] *PCB releases were from upstream facilities*

This person inhaled elemental mercury. His highest estimated dose, occurring in 1957, was only a small percentage of the RfD. His doses of inorganic mercury from skin contact with soil and from ingestion of local vegetables also peaked in 1957 at about half the RfD. It is very unlikely that his exposure to these contaminants resulted in non-cancer health effects.

Scenario #6

A Woman Born in Kingston in 1950 and Allergic to Cow's Milk

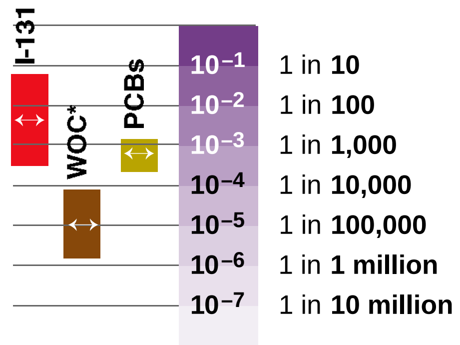
This scenario is for a woman born in 1950 who drank only goat's milk and has never lived anywhere other than the city of Kingston. Her drinking water came from the Kingston water supply, and every week she ate between 1 and 2.5 meals of fish taken from Watts Bar Lake. Some of these meals were homemade fish patties made from Watts Bar fish. Until about age 10, she swam in Watts Bar Lake about twice a week from May through September. She also walked along the shoreline each evening during the part of the year when the water was drawn down.

Discussion of Cancer Risks

This woman's increased lifetime risk of developing cancer is dominated by an increased risk of thyroid cancer from her consumption of iodine-131 in goat's milk. Her additional risk of developing this cancer was estimated to be in the range from 300 chances in a million to 60,000 chances in a million. The central value of her range of risk is 4,800 chances in a million.

She faces a much smaller risk of developing cancer because of her consumption of fish flesh and patties contaminated with radionuclides released from White Oak Creek. If the fish had been taken where the Clinch River joins the Tennessee River at Watts Bar Lake, the increased risk would have ranged from five to 200 chances in a million. If the fish came from other places in the lake, her cancer risk from fish contaminated with radionuclides is at least a factor of three smaller.

Additional Cancer Risks



**WOC = Radionuclides from White Oak Creek*
↔ = central estimate

The PCBs in fish she consumed increased her overall risk of cancer by an amount between 200 and 1,200 chances in a million.

Her increased risk of cancer from ingesting radionuclides present in Kingston drinking water and from being exposed to them while walking the lake shoreline is less than one-tenth of her excess cancer risk from her ingestion of contaminants in fish.

Discussion of Non-Cancer Effects

It was estimated that doses of methylmercury received by this individual through her consumption of fish exceeded the EPA Reference Dose (RfD). Her doses exceeded the adult-based RfD from 1955 through 1967, peaking in 1958 with a dose in the range from 0.8 to three times this adult RfD. Comparing her doses to the NOAEL for methylmercury, which is based on *in utero* exposure, the high end of the range estimated for her doses was about twice this NOAEL for the years of peak exposure. Her doses were large enough that deleterious health effects cannot be ruled out because the NOAEL for childhood exposures is applied.

Chemical Toxicity
Guide value exceeded, yes or no?

Guide	methyl mercury	inorganic mercury	elemental mercury	PCBs
LOAEL	no	no	no	no
NOAEL	**yes**	no	no	*
RfD	**yes**	no	no	**yes**

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

This woman's doses from eating fish contaminated with PCBs, 6 to 13 percent of which came from the ORR, were estimated to be up to 30 times the EPA RfD for Aroclor 1254. Project researchers established a population threshold distribution designed to represent the range of possible values for the highest dose that would not harm the most sensitive individual. This woman's doses could have been more than the median value of this population threshold distribution, yet they were at least eight times less than the LOAEL determined in studies of experimental monkeys. There is less than a 50 percent chance that this person's dose would have harmed the most sensitive individual in the population.

Scenario #7

A Man Born Near the Bradbury Community in 1950

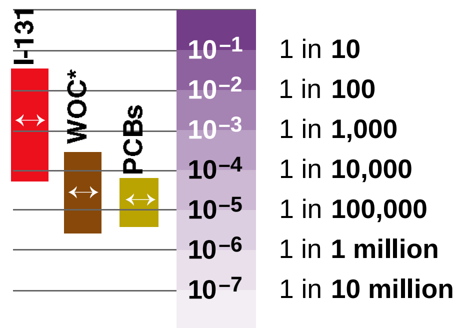
The man depicted in this scenario was born in 1950 on a farm near the Bradbury community. He grew up on the farm, drinking backyard cow's milk as an infant and adult, and consuming home-grown vegetables, beef, cheese and eggs. Every year, he also ate between two and 17 meals of fish taken from the Clinch River near Jones Island. He has continued to live on the farm.

Discussion of Cancer Risks

The additional cancer risk estimated for this man is dominated by his exposure to iodine-131 from the milk and homegrown food he ate. His lifetime risk of developing thyroid cancer was increased by an amount from 50 to 36,000 chances in a million.

His ingestion of fish contaminated with PCBs and with radionuclides released from White Oak Creek contribute to his increased risk of developing cancer, but the median risks from these exposures are nearly 100 times smaller than from exposures to RaLa-related iodine-131. Jones Island is upstream of most PCB releases from the Reservation.

Additional Cancer Risks



*WOC = Radionuclides from White Oak Creek
↔ = central estimate

Discussion of Non-Cancer Effects

The central value of the PCB dose estimated for this man from his ingestion of fish contaminated with PCBs was less than the EPA Reference Dose (RfD). Most ORR-related PCBs entered the river downstream of Jones Island. Project researchers established a population threshold distribution designed to represent the possibilities for the highest dose that would not harm the most sensitive individual, and the upper range of this man's estimated doses was one-third of the lower limit for the 90 percent confidence interval of this distribution. (Both RfDs and population threshold ranges were determined from data obtained in studies using monkeys.)

Chemical Toxicity
Guide value exceeded, yes or no?

Guide	methyl mercury	inorganic mercury	elemental mercury	PCBs
LOAEL	no	no	no	no
NOAEL	no	no	no	*
RfD	no	no	no	**yes**

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

No other contaminants or pathways are pertinent to this scenario. His Bradbury farm is located too far from sources of mercury for air, vegetables or soil to be contaminated with elemental or inorganic mercury. Also, the local fish he consumed came from the Jones Island area of the Clinch River. This area is several miles upstream of the river's confluence with mercury-contaminated Poplar Creek, so there was no pathway for additional health risks from Y-12 methylmercury.

Non-cancer health effects are most unlikely for this person.

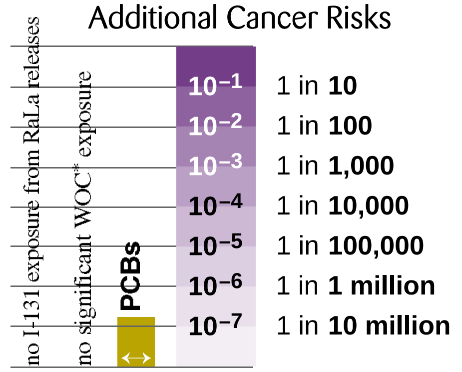
Scenario #8

A Woman Born in Oak Ridge in 1960

This scenario concerns a woman born in 1960 who has lived on lower Louisiana Avenue in Oak Ridge her entire life. She drank backyard cow's milk as an infant and adult. She ate locally grown vegetables but no fish caught in local waters. She attended Robertsville Junior High School, adjacent to East Fork Poplar Creek, and from 1973 to 1975 she played in or near the creek about once a month.

Discussion of Cancer Risks

This woman was born several years after the major releases of iodine-131 from ORNL had ceased, so an increased risk of thyroid cancer was not calculated for her. Since she did not consume local fish, the only pathway that might have increased her cancer risk was exposure to PCBs from playing in East Fork Poplar Creek. This increased her lifetime cancer risk by an amount estimated to be much less than one chance in a million. Cancer health effects are unlikely for her.



**WOC = Radionuclides from White Oak Creek*

↔ = central estimate

Discussion of Non-Cancer Effects

The age, time of possible exposure, location, and lifestyle of this individual resulted in estimated doses that were all less than one-third of the applicable EPA Reference Doses (RfDs). For example, her dose of PCBs from playing in the creek as a child was estimated to be less than 9 percent of the RfD, and she had no additional risk from methylmercury because she did not consume fish from local waters. She should not experience non-cancer health effects.

Chemical Toxicity

Guide value exceeded, yes or no?

Guide	methyl mercury	inorganic mercury	elemental mercury	PCBs
LOAEL	no	no	no	no
NOAEL	no	no	no	*
RfD	no	no	no	no

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

DOE photo

The Y-12 Steam Plant is shown in the foreground of this photograph, taken in 1985. Directly behind the steam plant is Building 9201-4 (Alpha 4), and the building partially shown at left is 9201-5 (Alpha 5). Alpha 4 and Alpha 5 were used from 1943-47 for the electromagnetic enrichment of uranium using calutrons. From about 1955-62, they housed the equipment for enrichment of lithium using the Colex process.

The Phase II portion of the Oak Ridge Health Agreement Studies also included screening analyses for a variety of chemicals and radionuclides. The purpose of these analyses was to determine whether there were other contaminant releases that should receive the same detailed attention given to the four priority contaminant releases studied in the Phase II dose reconstruction effort.

Because of concerns about the completeness and accuracy of DOE's historical quantitative estimates for releases of uranium from Y-12 and K-25, it was decided at the end of the Phase I dose reconstruction feasibility study that a more detailed, independent evaluation of uranium releases would be needed as part of Phase II.

In addition, conclusive screening analyses had not been completed during Phase I for several other contaminants. It was believed that more thorough evaluation was needed in Phase II concerning the off-site health implications of several other toxic substances that may have been released from one or more of the Oak Ridge plants; these substances include arsenic, beryllium, copper, and hexavalent chromium. Issues also remained concerning several materials whose existence and/or use at the plants was then still classified as secret information pursuant to the Atomic Energy Act of 1954. Further analyses were also needed regarding releases of several other radionuclides, specifically tritium (hydrogen-3), neptunium-237, and technetium-99. There were also some relatively minor issues associated with the Phase I analyses that had been performed for asbestos and plutonium. Finally, a review of the Phase I Feasibility Study screening results and discovery of some new information led to a decision to include three more substances in the Phase II effort: lead, nickel, and lithium.

It was decided to perform a more detailed, independent evaluation in Phase II of uranium releases

Screening Methods

Investigators performed the Phase II screenings in two basic steps, using methodology more advanced than the relative method used in the Dose Reconstruction Feasibility Study. Both of these steps made use of ORHASP's decision guide values *(see page 57)* (SEE ERRATA, PAGE 94, #7). The first, called a Level I screen, was designed to identify those contaminant releases and pathways having relatively low priority. The assumptions used were cautious, or conservative, estimates that were designed to err on the side of overestimating the risk from releases.

If cancer was the health effect of primary concern, the result of the calculation is called the cancer screening index. That index was compared to the ORHASP decision guide value for lifetime cancer risk of one in 10,000 (1×10^{-4}). If the health concern was an outcome other than cancer, the chronic exposure Reference Dose for the chemical was used as the guide value for screening. In a few cases where RfDs have not been specified by EPA, some other guideline was used. If the Level I screening estimates for a particular toxic substance were below the relevant guide values, that substance was not evaluated further. In some cases, refined Level I calculations were performed to test the sensitivity of the screening index values to critical parameters. All of the substances whose Level I screening indices exceeded the guide value, however, were considered eligible for dose reconstruction analysis.

The eligible substances were then considered in the next step of the screening analyses, called Level II. Assumptions used for the Level II screening analyses were intended to be representative of actual conditions and were expected to provide unbiased estimates of potential health effects. If the Level II screening estimate for a contaminant still exceeded the decision guide value, that contaminant was given a "high priority" designation for formal dose reconstruction analysis. Some real individuals could have risks higher than a Level II screening index. The second step screening calculations actually performed employed some cautious assumptions, tending to inflate the screening indices, and the results do not fully meet the intention of the Level II analysis. These are called "refined Level I analyses." Such results are biased high and designations of "higher priority" have to be interpreted carefully.

In some cases, particularly with regard to various soil and sediment sampling data, screening calculations had to rely on the existing data deemed most relevant to the contaminant of interest, even if the data were not fully appropriate. There were a number of reasons for such situations:

- ✓ Measurements that would have been most useful for the screening calculations were not always performed in the past in anticipation of such data needs.
- ✓ Results of previous measurements were not always available at the locations for which the screening calculations were performed.
- ✓ Often, the times at which samples were collected did not corresponded to the time periods when the highest levels of contamination would have been present.
- ✓ The medium that was sampled may not have been the most relevant to the screening pathway being analyzed (e.g., creek sediment samples were collected but soil samples were not.)

As a result of differences between the data that were desired and the data that were actually available, it was necessary to make compromises in the selection of data for the screening calculations. Had more complete data been available that were directly applicable to the contaminant being screened, the results of some of the screening calculations may have been different.

The screening calculations for uranium uptake from soil in the Scarboro community illustrate the difficulty encountered. No historic soil samples were available from the Scarboro area for the time period of greatest interest (1950-1970). Sampling was performed recently (*Department of Energy, 1998. Scarboro Community Environmental Study. Oak Ridge, TN*), but the results are not representative of earlier years because only surface soil was sampled. In the absence of more appropriate soil samples, the uranium concentration in a sediment sample from East Fork Poplar Creek was used in the screening calculations, even though these samples were also obtained in relatively recent years. Estimates of soil concentrations from uranium deposition in Scarboro (*P. Voillequé, 1998*) suggest that the sediment sample concentration used may have been 10 times higher than the peak concentration in Scarboro soil. Collection and analysis of cores of soil from a variety of locations have been recommended as a possible means to resolve this question and to check the validity of the screening calculation *(see page 72, Recommendation 3)*.

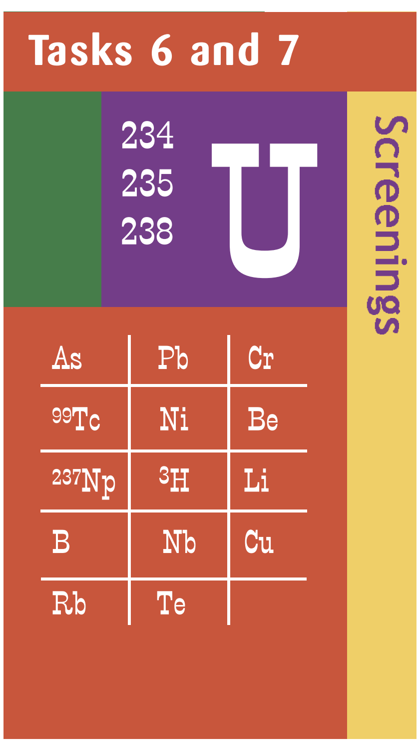
> **In some cases, particularly with regard to soil and sediment sampling, screening calculations had to rely on inadequate data.**

For some of the toxic substances used at Y-12 or K-25 in relatively small operations or research procedures, where available information was sometimes quite limited, a more qualitative approach was used that did not involve comparing the screening estimates with the Panel's decision guides. Instead, the analyses relied upon an understanding of the operations involving the substance, the maximum quantity that could have been present, the chemical and physical form of the material, and the manner in which it was used. For some of the substances evaluated, it was clear that, even if the entire available inventory were released to air or water, the resulting environmental concentrations would still have

DOE photo

The Scarboro community is immediately across Pine Ridge from the Y-12 Plant, as shown in this 1985 photo.

Screening Results for Uranium Releases



Various large-scale uranium operations have been conducted throughout the history of the ORR. Available records indicated relatively large quantities of uranium had been released to the surrounding environment from the 1940s through the early 1970s. Nevertheless, the Phase I feasibility analyses for the documented uranium releases did not produce results suggesting that dose reconstruction would identify any significant potential for adverse health effects. Several persons who had been long-term ORR plant employees and some members of the Panel believed this result should be re-examined. For example, it was known at the end of the Phase I work that the available records concerning uranium releases were incomplete. In addition, it was known that the previous estimates of uranium releases to the environment, particularly the atmospheric releases reported by DOE's various Y-12 and K-25 operations contractors, drastically understated the actual quantities of uranium that had been involved. These factors resulted in a decision by the Panel to include a second, more thorough evaluation of ORR uranium releases in the Phase II effort.

The Phase II uranium release investigations produced an estimate that Y-12's various uranium processing and machining operations released about 50,000 kilograms of total uranium to the air from 1944 to 1995. This was more than seven times the 6,500 kilograms previously acknowledged by DOE. At K-25 and S-50, the Phase II investigators estimated that about 16,000 kilograms of

Uranium: ORR Operations and Potential Health Effects

Elemental uranium is an extremely dense, silver-colored metal usually found in nature as an oxide. Very small concentrations of uranium are typically present in rocks, soil, water, plants, and animals. This uranium, along with potassium-40, radium-226, thorium-232, and about 25 other naturally occurring radioisotopes, contributes to the background radiation dose all people receive from terrestrial sources. A typical soil sample has a uranium concentration of two parts per million.

In nature, uranium exists primarily as three isotopes: uranium-238, uranium-235, and uranium-234. Most prevalent by far is uranium-238, with a half-life of 4.5 billion years. Uranium-238 accounts for 99.28 percent of the mass of uranium found in nature. Almost all of the remaining fraction, or 0.72 percent, is uranium-235, with a half-life of just over 700 million years. The traces of uranium-234 found in natural deposits (0.0054 percent of the total mass) are from decay of uranium-238. The half-life of uranium-234 is just under 250,000 years, relatively short compared to the half-lives of uranium-238 and uranium-235.

Uranium "enrichment" refers to several complex industrial processes that increase the proportion of uranium-235 to uranium-238. Uranium-235 is the primary isotope used in conventional nuclear power plants and, along with plutonium-239, in nuclear weapons. "Depleted" uranium, in which the uranium-235 content is less than 0.72 percent, and usually only about 0.1 to 0.4 percent, is used extensively in the "secondary" part of several thermonuclear weapon devices.

All three of the naturally occurring uranium isotopes are primarily alpha-particle emitters, although uranium-235 decay also releases gamma radiation. Since alpha radiation cannot effectively penetrate the outer skin layer, the most significant radiological hazards associated with uranium relate to ingestion or inhalation. The radiological hazard depends on the chemical and physical form of the uranium and the relative fraction of the total uranium mass that is uranium-234/235. Because of the very small difference in mass, the traditional enrichment technologies could not effectively separate the minute uranium-234 fraction from uranium-235. Accordingly, uranium-234 was enriched along with the uranium-235. While uranium-234 makes up only a very small percentage of the total weight of enriched uranium, it accounts for a much more significant fraction of the total activity present. As the enrichment levels increase, uranium-234 rapidly becomes the major alpha radiation source. External radiation exposure to the penetrating gamma radiation from the uranium-235 decay also becomes more important.

It is known that sustained exposure to elevated levels of uranium, as a toxic chemical, can be dangerous to human health. Test animals have developed kidney disease after they have been exposed to large amounts of natural uranium in food, drinking water, air, or on the skin. It is not known whether natural uranium causes reproductive or birth defects in humans, but animal studies suggest that excessive uranium ingestion may adversely affect reproduction capability and the normal development of fetuses.

uranium were released to the air. This is about 1.5 times the 11,000 kilograms that had been reported by DOE.

Using these new estimates of total releases, the Phase II investigators recalculated the potential health risks to nearby residents using the conservative Level I screening methods. These results indicated that the increased cancer risks for residents near both Y-12 and K-25 were high enough to warrant further study.

Estimates for Y-12 focused on residents of the Scarboro community, located only about one half mile north of Y-12. The level I screening indicates that the cancer screening index for residents was about two in 1,000 (2×10^{-3}) for just the Y-12 releases. For K-25 (which also included the estimated releases from the 1944-45 S-50 plant operations), investigators focused on a location about a half mile west of the K-25 Site boundary on the opposite side of the Clinch River near Campbell Bend. The Level I screening index for a resident at this location also exceeded the 1×10^{-4} guide value with a value of three in 10,000 (3×10^{-4}). Calculations for the residential area chosen to study the relatively small uranium releases from ORNL, about 2.5 miles southwest at Jones Island, did not exceed the decision guide value. The Level I cancer screening index for ORNL was eight in 100,000 (8×10^{-5}).

Since the guide value for Level I screening was exceeded at Y-12 and K-25, a refined Level I screening (which still included some conservative parameters) was performed for those sites. It yielded screening indices for both Y-12 and K-25 that were less than the guide value. The refined Level I indices were eight in 100,000 (8×10^{-5}) and four in 100,000, respectively.

Estimated risks from releases of uranium, neptunium-237, and technetium-99 from Y-12 have been grouped together because the other two isotopes were contaminants of recycled uranium feed material that was processed, so these releases are best studied together. The sum of the refined Level I screening indices for these Y-12 releases was about 12 parts in 100,000, just over the Panel's decision guide for radiological risk. Because of the lack of directly applicable soil concentration data and uncertainties in atmospheric dispersion of Y-12 effluents, the Panel has recommended that, as a next step, both issues be evaluated further *(see Recommendations 3 and 4, pages 72-73)*. At K-25, the sum of the refined Level I screening indices was about 6 in 100,000.

Exposure to uranium can also cause non-cancer effects, primarily kidney damage. The screening index exceeded the guide value for two out of 47 years. No further refined analyses were pursued. Comparison against a proposed more restrictive guide value indicated that kidney burden would have exceeded that level for many years.

Screening Results for Other Contaminants

The table on this page summarizes the screening results for carcinogenic chemicals and radionuclides including uranium. The screening procedure identified arsenic releases to water as higher priority items at both

Screening results (cancer)

Higher priority for further study
Refined Level I [or Level II] index greater than 10^{-4}

Plant	Contaminant
K-25	Arsenic
Y-12	Arsenic

Qualify for further Study
Level I index greater than 10^{-4}
(Refined Level I index less than 10^{-4})

Plant	Contaminant
K-25	Chromium Nickel Technetium-99 Uranium
Y-12	Beryllium Technetium-99 Uranium

Not candidates for further study
Level I index less than 10^{-4}

Plant	Contaminant
K-25	Neptunium-237
Y-12	Neptunium-237 Tritium

Screening results (non-cancer)

Higher priority for further study
Refined Level I index greater than 1

Plant	Contaminant
K-25	Arsenic
Y-12	Arsenic Lead

Qualify for further Study
Level I index greater than 1
(Refined Level I index less than 1)

Plant	Contaminant
K-25	Copper Nickel
Y-12	Chromium Lithium

Not candidates for further study
Level I index less than 1

Plant	Contaminant
K-25	Carbon fibers Polyphenyl Ether Glass fibers Triplex coating
Y-12	Beryllium [a] Boron [a] Niobium Rubidium Tellurium TMAB [b] Tritium Uranium Zirconium

a Beryllium and boron were used in a variety of chemical forms.

b Tetramethylammonium-borohydride

K-25 and Y-12. The cancer risk indices for arsenic were estimated to be three to nine times the Panel's decision guide. These releases were associated with the coal-burning process steam generation facilities at each of the plants. Hexavalent chromium, used as a corrosion inhibitor in recirculating cooling water systems, was another contaminant that qualified for further study, but at a lower priority than arsenic and lead. Similarly, releases of respirable nickel powder and technetium-99 to the air at K-25 were also identified at a lower priority for possible further study, based on Level I screening results.

As indicated above, the Level I screening results for neptunium-237 releases from K-25 indicated that this radionuclide was not of concern. A similar result was obtained for both neptunium-237 and tritium (hydrogen-3) releases from Y-12. According to the Level I screens, however, releases of airborne beryllium compounds, technetium-99, and uranium isotopes from Y-12 stacks did qualify for further study. The refined Level I screening indices for these materials did not exceed the decision criterion. Further evaluation of environmental levels is appropriate before any detailed analyses of these lower priority contaminants are undertaken *(see Recommendation 3, page 72).*

The table on this page contains the results of screening for contaminants that cause health effects other than cancer. Based on the study's screening procedure, only arsenic releases to water were identified at K-25 with a higher priority for further study. At Y-12, releases of arsenic to water and airborne releases of lead were also placed in the higher priority category. Some arsenic exposures could exceed the NOAEL for non-cancer effects. The expected blood concentrations of lead were evaluated and found to exceed the public health intervention "action level" proposed for lead in 1991. Automobile exhaust was a large source of lead in the environment in the years when the Y-12 releases occurred. The Y-12 releases would have been in addition to those that produced internal contamination now considered to be unacceptable.

Based on the results of the Level I screens, releases of copper and nickel to water at K-25 and lithium compounds and chromium to water at Y-12 all qualified for further study. The refined Level I screens for these materials were lower than the decision criteria, however, so only the lower priority designation is specified.

Alternative screening techniques revealed that a number of contaminants, some of which had classified aspects, were not candidates for further study. In some cases, qualitative screening was used, and in other cases, the amounts of material used were compared with amounts that could have caused releases that would have been of concern. Contaminants in this category at K-25 were carbon and glass fibers, 4-ring polyphenyl ether, and Triplex coating. A larger number of such contaminants were found at Y-12. Included in this group were a\ variety of metallic compounds: beryllium in various forms, the niobium used in "mulberry" and "binary" uranium alloys, rubidium compounds, tellurium, and the zirconium used in the mulberry alloy. Compounds of boron, including tetramethylammoniumborohydride (TMAB), were also evaluated and found not to qualify for further study.

ORHASP's Decision Guides

In 1994, the Panel began to investigate numerical criteria that could be used to guide decisions about the allocation of resources and about the relative importance of contaminants for the Phase II dose reconstruction project. Guide values were needed to help decide which of the contaminants released from the ORR should be studied in greatest detail. A related question was whether the estimated risks from a particular contaminant were so low that further detailed study of exposures was not warranted. It was deemed desirable to establish the guide values in advance and to have a structured approach for decision making. The guides were also used within each dose reconstruction task to identify which exposure pathways could safely be neglected.

The Panel firmly believed it was important to obtain input from the public on this matter. A draft "issue paper" was prepared and distributed for public comment. Many differing opinions were expressed about the complex issues involved in the selection of risk guide values. After much deliberation, the Panel adopted a lifetime screening risk guide for clinically detectable health effects of one in 10,000 (e.g., 0.0001 or 1 x 10^{-4}). This means that there is one chance in 10,000 that the exposure would cause an effect during the life of the exposed person. Screening risk calculations for cancer due to exposures to radionuclides and carcinogenic chemicals were compared directly to this guide value.

> The Panel established guide values to determine if risks from a certain contaminant were so low that detailed study of exposures was not warranted.

Toxic chemicals produce a variety of clinically detectable effects, but the risk of such effects is often not proportional to the level of exposure or the dose received. For these effects, the Panel selected a dose equal to the published EPA Reference Dose (RfD) as the guide value. RfDs are usually specified in units of milligrams per day per kilogram of body weight. The RfD is a lifetime daily intake limit below which no observable clinical health effects would be expected, even in sensitive individuals.

The selection of these particular criteria as evaluation thresholds for the consideration of more extensive health effects studies should not be construed to mean that the Panel believes that these risk levels have been or should be universally adopted as "acceptable" levels of involuntary risk. Information received by the Panel at several of its public meetings indicates that there is a broad range of opinion about the acceptability of various voluntary and involuntary risks faced by the average person living in our society. The Panel considered that it should be flexible in application of the guide values. The Panel recognizes that risk assessments are often quite complex and that there may be yet-unproved health effects caused by exposure to multiple contaminants that would not be predicted by analyses that can consider only one contaminant at a time.

Uncertainties in Dose and Risk Estimates

Dose and risk estimates made during Phase II of the health studies reflected the underlying uncertainty of each factor going into the calculation.

For example, consider a representative woman born in 1952, living in the Bradbury community and drinking milk from a backyard cow. When risks were calculated for this woman, investigators faced uncertainties in factors such as the amount of iodine-131 released from ORNL and the distribution of that iodine in the environment. Her lifetime risk for thyroid cancer as presented in the Health Studies is in fact a distribution of many estimates of that risk. The calculation was performed repeatedly, with the uncertain parameters sampled randomly and each set used to obtain one risk estimate. Repeating this type of Monte Carlo process several hundred or more times produced a distribution of possible results.

> Estimated risks have a broad range of values because there are many steps that lead to the final results, and each has uncertainties.

The answer is presented as the “95 percent subjective confidence interval.” For the representative girl from Bradbury cited above, that range of lifetime risks was from six to 1,400 in 10,000. Only 2.5 percent of the values calculated for this situation were below six in 10,000, and only 2.5 percent were above 1,400 in 10,000. Thus, the scientists have high confidence (95 percent) that the true risk lies within the quoted range. The width of the range of estimates is a measure of the uncertainty in the result. The median of the estimates was a risk of 9 in 1,000; that is, half of the estimates in the distribution were lower than that value, and half were higher. The bounding estimates are much less probable.

The range of values quoted in the studies is the best guide to the risks faced by a real girl in this situation. The likelihood of a particular risk estimate for a young girl who really lived in Bradbury is not known, but there is high confidence that her risk lies in the quoted range.

The range in risks is as broad as it is — from six to 1,400 chances in 10,000 — because there are many steps that lead to the final result, and each had uncertainties. The releases of iodine-131 from RaLa processing were not measured. Neither were there measurements of the air, vegetation, and milk contamination that resulted from the releases. If milk from Bradbury had been measured for contamination at the time, for example, the process of estimating doses and risks would be much less uncertain and our range of risk estimates would be narrower than it is.

Scientists involved in the health study were explicit in showing the range of parameter values throughout their calculations; this was a guiding principle for the four dose reconstruction tasks. The calculation of lifetime risks of thyroid cancer serves to illustrate the data needed for dose reconstruction. In each element used in the calculation, the information obtained was incorporated as a distribution of possible values. The main elements for thyroid cancer risk are as follows:

- ✓ Amount of iodine-131 in the fuel that was dissolved (calculated based upon reactor physics);
- ✓ Decay of the iodine-131 before processing (calculation based on records of delay or travel times);
- ✓ Fraction of the iodine-131 that was released from the dissolver (based upon limited data and expert opinion);

- ✓ Chemical forms of the iodine released (based upon opinions of experts with relevant operational experience);
- ✓ Efficiency of scrubbers, not always used as designed, for removal of iodine-131 from the discharge (based upon some data and opinions of experts);
- ✓ Atmospheric dispersion of the iodine-131 (10-year average dispersion parameters based upon reliable meteorological data from later years; ridge and valley terrain adds additional uncertainty for some locations);
- ✓ Changes in chemical form of iodine-131 in the atmosphere (based upon limited experimental data and judgment);
- ✓ Deposition of iodine-131 onto pasture grass and leafy vegetables (based upon limited local experimental data, local rainfall data; modeled amounts compared with field measurements elsewhere);
- ✓ Pasture consumption by cattle and goats (based upon published data);
- ✓ Uptake of iodine-131 into cows' and goats' milk (based upon measurements in species of cows used locally and opinion of scientists with expertise applicable to local conditions; uptake into goats' milk based upon data in the literature);
- ✓ Percentage of milk produced available to be drunk (based on data collected after 1950);
- ✓ Mixture of milk distributed commercially (based upon records of milk distribution);
- ✓ Milk consumption by children (based upon survey data for children of various ages);
- ✓ Iodine metabolism and factors affecting thyroid dose (based upon age-dependent models of iodine uptake and loss; autopsy and ultrasound measurements of thyroid masses for various ages);
- ✓ Relationship between risk and dose (assumed to be linear and based primarily upon results for x-ray exposure of individuals of various ages; risks taken to be proportional to the underlying background lifetime risk of thyroid cancer, which is estimated to be about 4 chances in 1,000 in Tennessee.
- ✓ Relative biological effectiveness of iodine-131, which delivers the dose at a lower rate than was used for x-ray (based upon expert judgment);
- ✓ Numbers of cancers caused (based upon census data on numbers of persons of various ages present in the area during the period of iodine-131 releases).

Scientists involved in the health study were explicit in showing the ranges of parameter values throughout their calculations.

The selected distribution for each of the parameters involved in the calculation is discussed in the Task 1 report. When the information was particularly uncertain, a broader distribution was selected. For example, field data obtained at another location might not be totally appropriate for an assessment that refers to the Oak Ridge area and use of such data entails added uncertainty. By using the Monte Carlo procedure for the risk calculations, the researchers assured that the full range of values for each variable is reflected in the distribution of risk estimates for the representative girl from Bradbury.

The most important contributors to the uncertainties in thyroid cancer risk estimates for children are uncertainty about the relationship between dose and risk (32 percent) and about transfer of iodine-131 from air to pasture (18 percent). Also contributing are uncertainty about the size of the thyroid (10 percent), fractional uptake of iodine (7 percent), and the relative biological effectiveness of iodine-131 (6 percent). These are also the biggest sources of uncertainty about the number of thyroid cancers.

For other contaminant releases, some uncertainties were smaller. Data were found in historic records for the radionuclide discharges over White Oak Dam and mercury releases to East Fork Poplar Creek. Uncertainties in the measurements were considered in the calculations. The initial measurements for White Oak Creek were relatively crude (total gross beta activity), and it was necessary to make assumptions about the isotopic composition of the early releases. The additional uncertainty was considered. Some validation of the release and transport model calculations was performed. Environmental transport uncertainties were common to most tasks. Radionuclide release and environmental measurements could be used to check the models that were employed in Tasks 1 and 4 and gave assurance that the predicted values were not unreasonable.

For PCBs, the Reference Dose and cancer risk factor are based upon animal data and include safety factors to assure protection of human health.

Each of the tasks also dealt with uncertainties that were unique for that task. Examples for the RaLa iodine-131 releases and for the White Oak Creek radionuclide releases have already been noted. Another example is the fraction of mercury in East Fork Poplar Creek that was volatilized from the stream. That fraction is an uncertain parameter based on very limited experimental data and measurements of mercury at two locations along the path of the creek. For PCBs, the Reference Dose and cancer risk factor are based upon animal data and include safety factors to assure human health protection. There is substantial uncertainty about the magnitude of the estimated cancer risks, because PCBs have not been shown to cause cancer in humans. For non-cancer effects, the researchers developed a modified "true hazard quotient" that reflects uncertainties in the toxicologic data that are available. Whenever possible, our results have also been compared to NOAELs and LOAELs, which also serve as guidelines. The overall effects of released mercury and PCBs also depend upon uncertain estimates of the numbers of people consuming fish from the Clinch River and Watts Bar Lake and the amounts of such fish consumed.

Project scientists made concerted efforts to locate the most appropriate information upon which to base dose and risk estimates. The ranges of results presented are broad because they reflect the full range of uncertainties in the underlying information.

Atmospheric Dispersion Modeling

The usefulness of dose reconstruction study results is dependent primarily on three factors: **(1)** realistic estimates of the pollutant release from the source, **(2)** reasonable assumptions regarding the potential routes of pollutant dispersion into the human environment, and **(3)** accurate concepts of the potential health effects associated with the different levels of pollutant dose. In the absence of extensive dosimetry or environmental monitoring data during the time periods when pollutants were being released, mathematical models had to be used to evaluate various modes of release, environmental transport mechanisms, possible routes of pollutant uptake into the bodies of exposed persons, and the potential for adverse health effects.

The air dispersion pathway was considered either dominant or relatively important for five of the seven tasks undertaken in Phase II of the health agreement studies. For example, Task 1 focused exclusively on the releases of radioactive iodine-131 to the atmosphere resulting from the radioactive lanthanum (RaLa) operations carried on at the Oak Ridge National Laboratory from 1944 to 1956. Task 1 included the most complex air dispersion modeling undertaken during the Phase II studies. For this analysis, scientists at SENES Oak Ridge, Inc., developed a customized computer code for air dispersion modeling. The code employs a modification of the Gaussian plume dispersion model. In addition to the basic plume dispersion of the iodine-131 releases, the model also considered removal of iodine from the plume by wet and dry deposition mechanisms and the potential chemical transformations of iodine as a function of downwind distance. No computer accessible meteorological database (e.g., wind speed, direction, and atmospheric stability for each hour of model simulation) exists for the years 1944 to 1956. Input data included extrapolation of the meteorological record from an ORNL meteorological station for the period 1987 to 1996. The results of the modeling were subjected to a "reality check" by using a public-domain air dispersion model endorsed by EPA in 1995. Even more precise model validation work was performed using more recent measurements of radioiodine in ORNL releases and in locally produced milk. These measurements were taken from 1967 to 1969.

Less complicated air dispersion calculations, employing variations of the EPA model, were used to evaluate air transport of elemental mercury releases from Y-12, uranium releases from Y-12 and K-25, and several other pollutant release scenarios. The transport of PCBs in air was evaluated with an even simpler air dispersion model. In most cases, the dispersion models that were used had some capability to reflect local effects, but the complex ridge and valley terrain in the area was not modeled explicitly.

Atmospheric Transport of Y-12 Releases to the Scarboro Community

When the dose reconstruction project began, it was not widely known that there had been airborne pollutant transport from Y-12 to the Scarboro Community and other parts of Oak Ridge. The populated areas are not very far from the facility, but they lie in different valleys. In particular, the presence of Pine Ridge between Y-12 and Scarboro had been thought to be an effective barrier to atmospheric transport. Scarboro is a focal point of this discussion because it is the portion of Oak Ridge closest to Y-12 facilities, which released uranium and mercury to the air.

There was no air sampling station in Scarboro during the years when releases from Y-12 were highest. Recent air sampling data, collected between 1986 and 1995, showed elevated levels of uranium-235. The presence of that radionuclide in excess of its natural abundance is a clear indication that at least some enriched uranium releases from Y-12 were carried to Scarboro during those years. Natural and depleted uranium were also released from Y-12, but those releases are more difficult to distinguish from uranium that is naturally present in the air.

> There was no air monitoring station in Scarboro during the years when releases from Y-12 were highest.

Soil sampling data in Scarboro from the environmental monitoring program in recent years and from the 1998 Scarboro Community Environmental Study also show the presence of small amounts of enriched uranium. These results, which were obtained only for the top layer of soil, do not provide a basis for estimating soil contamination levels during the years of highest release or the cumulative deposition of uranium. Releases of depleted uranium from Y-12 have reduced the observed enrichment of uranium in soil samples and add to the problem of interpreting the results.

Prediction of atmospheric transport and dispersion in hill and valley settings is very complicated. It is even more complex for Y-12 releases because there were many release points and the discharges were close to the tops of buildings. Initial estimates of air concentrations of uranium were performed by using an atmospheric dispersion model for flat terrain. This model assumed that there were no physical barriers between Y-12 and Scarboro and other parts of Oak Ridge. The assumption that Pine

Ridge did not exist was found to lead to significant overestimates of air concentrations in Scarboro and other Oak Ridge locations.

An alternative approach, which a majority of the Panel approved, used empirical dispersion factors based on release estimates and environmental measurements. The method utilizes the ratio of measured air concentrations in Scarboro to the measured or estimated releases. The concentration of uranium in air at the Scarboro station is symbolized by the Greek letter "χ" and the sum of the release rates from Y-12 stacks and vents is symbolized by "Q". The ratio (χ/Q), called "chi over Q", is a measure of the average amount of dispersion of the releases between the several release points at Y-12 and the Scarboro monitoring station. For pollution sources and exposed persons separated by complex terrain, site specific measurements of (χ/Q) can, in principle, provide the most reliable estimates of atmospheric dispersion. The quality of estimated dispersion ratios, however, depends upon the quality of the data that are used in the calculation with respect to both release rates and environmental air concentrations.

> A majority of the Panel approved use of empirical dispersion factors based on release estimates and environmental measurements.

Environmental air monitoring procedures and methods of analysis that were used during the period 1986-1995 were reviewed briefly and found to be adequate. In particular, data on concentrations of uranium in air at the Scarboro station were examined for use in calculations of (χ/Q) for that location.

During the course of the uranium screening work, the reliability of the uranium release estimates previously reported by DOE's operations contractors were the subject of a detailed, independent review by the health effects study team. Their attention was particularly focused upon the periods of highest releases during earlier years of operation in the 1950s and early 1960s. Releases of uranium from Y-12 during the years 1944 through 1988 were recalculated and these higher adjusted estimates were used in the screening calculations. Reported releases of uranium from Y-12 during the past two decades were much lower than those in earlier years. Because they had little direct effect on the screening calculations, the uranium releases reported by DOE's contractors after 1988 were accepted without re-evaluation. At that time, the Panel did not expect that release data for recent years would be needed for evaluating the dispersion factor.

Use of the DOE estimates of release rates (Q) in the calculation of (χ/Q) values was considered acceptable (conservative) because it was anticipated that those choices would not lead to underestimates of the ratio. This expectation was based on previous review of data for earlier years. That review showed that the official estimates were generally lower than those generated independently in this study.

Historically, much greater attention was devoted to preventing and monitoring losses of uranium enriched in the isotope uranium-235 (enriched uranium) than was given to natural or, especially, depleted uranium (from which much of the uranium-235 had been removed). It was more likely that releases of natural and depleted uranium were underestimated.

Because release estimates for uranium-234 and uranium-235 were combined, the dispersion parameters were also computed for the combination of the two isotopes. Neither the distribution of values based on uranium-234/235 nor the distribution based upon uranium-238 reflects any simple mathematical form. This is perhaps not surprising when one considers that there were many different stacks and vents that released uranium and the importance of each may have changed from year to year. The median (i.e., 50th percentile) estimate of the dispersion parameter, obtained by using only data for uranium-234/235, is about a factor of four lower than that obtained using all of the data. The difference is related to four high values that are found in the distribution of estimates based on the uranium-238 data for years when reported uranium-238 releases were low compared to other years. These values may be related to underestimation of releases of depleted uranium in those years or some other factor. It is not possible to provide a definitive answer without a detailed review. As a conservative approach, the higher χ/Q result obtained by using all of the data was used in the screening calculation.

Exposures to Multiple Contaminants

Non-Radioactive Hazardous Chemicals

The Oak Ridge Health Studies have identified exposure pathways and public health risks separately for each contaminant of concern. While this is a valid approach, contaminants can interact toxicologically with one another in a variety of ways. The interaction between contaminants can affect the specific toxic effects resulting from chemical exposures. It can also affect the way in which these chemicals are taken into the body and, eventually, eliminated. It is difficult to conduct risk assessments on chemical mixtures without full knowledge of the toxicological interactions between these chemicals. When one encounters a mixture of chemicals, one must consider the potential for combined effects. This approach ensures that risks are not underestimated.

The dose reconstruction tasks have identified waterborne radionuclides, mercury, PCBs, and radioactive iodine as being among the hazards to which people may have been exposed simultaneously. For example, a resident of the Scarboro community who also ate fish taken from Watts Bar Lake would have been simultaneously exposed to mercury, PCBs, radioiodine, and various other radionuclides, including uranium from Y-12. People eating fish from Watts Bar were likely exposed to mercury, PCBs, and low levels of radionuclides. The ORR health studies developed several specific scenarios for such multiple exposures, but large amounts of experimental data and analysis would be required to allow prediction of the exact combined effect.

Many people were exposed to more than one toxic substance released from the ORR to the environment.

One approach to modeling these interactions would be to identify common health effects for contaminants of concern. The risks from each could then be added to produce a combined risk. Mercury and PCBs, for instance, are both known to produce developmental and nervous system effects. Another example of similar action is kidney effects from exposure to both mercury and uranium. In this study, health effects from exposures to combinations of ORR contaminants were assumed to be additive.

Radionuclides

Research throughout the last several decades on the effects of radiation has lead to the conclusion that observed biological effects are proportional to the absorbed dose, at least over the range of higher level exposures where data are available. In the analysis, the distribution of radioactive isotopes among the body tissues is considered and doses to individual organs are estimated.

Radiation dose is defined as the amount of radiation energy absorbed in a unit mass of tissue. Therefore, for a mixture of radionuclides in the body, this principle allows for the effects of the various radionuclides to be combined by adding together the dose contribution from each. For example, one can estimate the risk of lung cancer by adding the lung dose contributed by each radionuclide separately. The greater the absorbed dose to the lung, the greater the risk of lung cancer.

This principle was used in the dose reconstruction project to estimate dose and risks to people for all relevant organs and radionuclides. In a preceding section of this report, information is provided for persons who consumed fish taken from the Clinch River below the entrance of White Oak Creek. In developing these risk estimates, it was determined that the fish in this waterway were contaminated with cesium-137, ruthenium-106, strontium-90, and cobalt-60. Therefore the risk estimation procedure had to consider a mixture of these four radionuclides, each of which is distributed differently in the body. The resulting risk is calculated by considering the radiation dose each nuclide contributes to the total organ dose and by then estimating the total cancer risk for each specific organ. The total, or "whole-body" risk is then simply the sum of the individual organ risks. This procedure is based on the assumption that the cancer risk for any of the organs is small.

When dealing with the adverse biologic effects of multiple radioactive substances, the principal concern is the combined radiation dose, not the chemical toxicities.

Another related issue has to do with the combined chemical toxicity and radiological risk associated with a given radioisotope. Questions are often raised concerning the possibility of synergistic effects. This would seem unlikely, however, because the amount by weight of a radiological contaminant, in most cases, is minuscule compared to levels traditionally of concern in the study of chemical toxicity. This is because the overall toxicity of practically all radioactive substances is determined by the substance's radiological decay properties, and not the chemical properties. For example, the industrial hygiene personnel exposure limit for airborne lead in all chemical and isotopic forms is 50 micrograms per cubic meter of air. The radiological protection air exposure limit set for lead-210, based on its radiological hazards, is about 100 million times lower than the industrial hygiene standard.

When dealing with the adverse biologic effects of multiple radioactive substances in the body, the principal concern is the combined and cumulative absorbed radiation dose, not the chemical toxicities of the individual radionuclides that compose the mixture. Caution must be exercised when generalizing for all radionuclides and all situations. For those radionuclides that have particularly long radiological half-lives (e.g., uranium-238 with a half-life of 4.5 billion years), the chemical toxicity, and not the radiological dose, can become the more dominant health concern. Furthermore, one cannot always directly add the calculated absorbed doses for mixtures of radionuclides with a variety of half-life durations. This is because long-lived radionuclides deliver radiation dose to the body over a longer period of time than the short-lived radionuclides. In this case, the radiation dose rate can have a modifying influence on the biological effectiveness of a given dose. For beta and gamma radiation, a protracted dose will usually have less adverse biologic effect than the same dose delivered over a few hours.

There is limited information on how the effect of absorbed dose on one organ can influence the effect of dose on another organ. For example, if a radiation dose to the thyroid is sufficient to affect thyroid function, what interactive, physiological effect might occur for a radiation dose delivered to the same person's lung, liver, or kidney? For radiation doses associated with typical environmental and occupational exposures, such potential interactive effects have not been extensively studied.

Document Searches

Contractors for the Oak Ridge Health Study conducted the most intensive search of documents ever performed for the Oak Ridge Reservation. This effort was indispensable to the investigations being undertaken.

The Oak Ridge Reservation is one of the world's oldest, largest, and most complex nuclear facilities, with an enormous collection of records dating back to the early 1940s. The analysts involved in this systematic search all had substantial previous experience in dose reconstruction including work on the Oak Ridge Dose Reconstruction Feasibility Study. These analysts devoted more than 15,000 hours to the systematic document search, with one analyst on-site full time. In addition, investigators working on specific dose reconstructions and screenings spent thousands of hours conducting directed searches for specific items or classes of data.

The systematic document search had three primary objectives:

- ✓ To identify all important off-site contaminant releases from the Oak Ridge Reservation, dating back to its creation during World War II;
- ✓ To collect information to support ongoing investigations of releases that are known;
- ✓ To coordinate interviews with people who were involved in past operations or are otherwise knowledgeable about them.

> The Oak Ridge Reservation is one of the oldest, largest, and most complex nuclear facilities in the world. It has an enormous collection of records dating back to the early 1940s.

The sheer volume of documents, ranging from published reports to handwritten log books, made it impossible for analysts to examine them all. In response, they developed strategies to ensure that documents of potential significance were identified and examined. Forty-four repositories were identified housing tens of thousands of cubic feet of records, both on site and off site, and the search was designed to focus its attention on those repositories that were likely to provide the most useful information.

Many people were interviewed, both active and retired, who occupied key positions at Oak Ridge. Of these interviews, 151 were documented formally, and information from a number of others was incorporated into specific investigations and the resulting reports.

This massive, systematic document search has not been as high profile as other areas of the Oak Ridge Health Studies. Nevertheless, it guaranteed the completeness of the studies as a whole and should prove to be an invaluable resource to investigators in the future.

Information Declassification

Relatively early in the Phase I dose reconstruction feasibility study, several complex issues were identified related to information sources that remained classified by the Department of Energy pursuant to the Atomic Energy Act of 1954. For example, certain key facts related to the use of elemental mercury in the lithium isotope separation operations conducted at Y-12 during the 1950s and early 1960s were still designated "secret" by DOE. There were also a number of substances used in nuclear weapon component manufacturing at Y-12 that could not be identified except in properly classified and controlled documents.

DOE photo

Contractors for the Oak Ridge Health Study conducted the most intensive search ever of documents related to the Oak Ridge Reservation.

In addition, at the beginning of the ORR health studies, much of the information about the basic processes historically conducted at the Oak Ridge Gaseous Diffusion Plant (K-25) remained classified. In particular, information concerning the gaseous diffusion barrier material manufacturing activities formerly conducted at the K-25 Site could not be included in the Phase I reports.

Shortly after these potential problems with classified information were identified, a special subcommittee was formed comprised of ORHASP members who held active DOE "Q" clearances. This subcommittee would periodically request classified discussion meetings with cognizant Q-cleared DOE and DOE contractor staff and then report back to the full Panel regarding the general nature of the matters that were discussed. During the Phase I classified meetings, the ORHASP Q-cleared subcommittee specifically requested that DOE conduct declassification reviews for several items of information deemed particularly relevant to ORR public health issues.

As the Phase I studies were nearing completion, there was considerable discussion at Panel meetings regarding potentially serious quality assurance issues associated with withholding classified, but otherwise fully relevant, information from the Phase I reports. The Panel briefly considered the need to publish a "classified supplement" as part of the Phase I effort but there was broad disagreement within ORHASP regarding the efficacy of such an approach.

Several Panel members believed that ORHASP could not withhold any relevant information on the basis of classification and still maintain an open and trustful relationship with the general public. Although several informal draft reference documents were created during the dose reconstruction feasibility study, it was finally decided that there was no real need to assemble any formal, classified supplements to any of the Phase I final reports.

At about the same time that the Phase II ORR health studies were initiated, as part of a nationwide campaign to improve public credibility, former DOE Secretary Hazel O'Leary directed various agency security officials to undertake a massive information declassification review. Within the first six months of the nationwide review, DOE announced that one key fact of intense interest to the ORR health studies had been declassified. This was the total quantitative estimate of elemental mercury that had been assembled at Y-12 for use in the lithium-6 separation operations, about 24 million pounds.

As DOE's massive declassification review effort continued throughout 1996 and 1997, additional important information of interest to the ORR health studies became available for unrestricted public release. Finally, in December 1997, Secretary O'Leary's successor, Dr. Federico Peña, held a national press conference at which he officially announced many of the major results of the DOE-wide declassification review. Of specific interest to the Panel was DOE's decision to declassify all formerly classified names of materials at each of the DOE operations sites.

At the end of the ORR Phase II health studies, all formerly classified information needed to complete our studies has now been declassified and is included in the final Phase II reports that are being released to the public. The Panel commends DOE for its massive declassification effort in response to the public's interest and right to know about any and all former operational releases that may have affected public health and safety.

Technical Direction and Quality Assurance

ORHASP Technical Oversight and Document Reviews

A major goal of both TDH and the Panel was to assure that the work of the health agreement studies contractors attained the highest standards of quality. The Panel includes technical experts able to assess the work of the study team as well as local citizens familiar with events that occurred in Oak Ridge. About five, two-day ORHASP meetings were held each year until mid-1998. As final draft reports from the Phase II work began to appear, the frequency of ORHASP's meetings doubled. All ORHASP meetings were open to the public. Appendix B is a complete listing of all ORHASP meetings.

ORHASP's meetings usually included presentations by the contractor report authors concerning analysis methods and preliminary results. Both were often accompanied by vigorous debates that included local citizens. Panel members and the public were not hesitant to suggest ways in which the studies could be improved. The study teams tried to use the best available methods and to be responsive to suggestions and recommendations.

Members of the Panel reviewed some or all sections of each draft report, and some Panel members submitted formal written comments to TDH which were then distributed to the contractors and other Panel members. Responses to comments were usually presented by the contractor authors in both oral and written formats. Controversial points were often discussed at length. Since the contractor authors are responsible for the report findings, each point was eventually resolved in a manner satisfactory to the contractor. In all instances when a majority of the Panel desired a change, the contractor authors were able to concur.

Outside Technical Reviews

Additional technical reviewers outside DOE, ORHASP, and contractor organizations were also chosen for each final task report. These reviewer's names are listed in Appendix C, along with each reviewer's professional credentials and affiliations. Copies of the comments resulting from these external peer reviews were distributed by TDH to both Panel members and to the contractor report authors and very carefully evaluated. External peer review comments often resulted in significant corrections or other important revisions to draft reports.

Public Involvement

Both the TDH staff and the Panel have been in contact with concerned members of the community throughout the course of the health agreement studies project. These contacts have included numerous public meetings, public availability sessions, and direct public involvement in the Panel's regular business meetings. Every meeting of the Panel has been open to the public and members of the public have been free to make comments and ask questions. A list of every meeting conducted by the Panel is presented in Appendix B with an indication of which meetings included planned public participation sessions. Technical presentations at ORHASP meetings are provided in Appendix D. The following discussion describes several of the more important contacts with members of the public and related TDH/ORHASP activities that have occurred during the course of the health agreement studies.

Public Concerns about Heavy Metal Poisoning and Autoimmune Disease

In May 1993, ORHASP heard a presentation from Dr. William Reid, a local cancer specialist who believed he was diagnosing a higher than normal occurrence of various autoimmune diseases among his patients from the Oak Ridge region. He also believed this excess disease was caused by heavy metals and other pollutants released from the ORR plants. The Panel studied the information presented by Dr. Reid. Subsequently, several of his patients had an opportunity to be evaluated by Dr. Howard Frumkin with the Rollins School of Public Health at Emory University.

Public Concerns about Amyotrophic Lateral Sclerosis (ALS)

Several members of the public came to the Panel in the early stages of the Phase II work with the concern that exposure to mercury or other contaminants released from the ORR may have caused a local cluster of ALS cases. Amyotrophic Lateral Sclerosis is a severely debilitating degenerative neurological disease that is always fatal, and is also referred to as "Lou Gehrig's disease."

In general response to these concerns, in August 1994 the Panel sponsored a presentation from Dr. Leonard Kurland of the Mayo Clinic. Dr. Kurland discussed epidemiologic research that had been done on ALS and advised the Panel that this research had established no link between ALS and environmental pollutant exposures.

Preliminary Evaluations of Epidemiologic Issues

In June 1995, the Panel hosted a round-table discussion that included local environmental and health activists and three prominent physicians: Dr. Howard Frumkin, chairman of the Department of Environmental and Occupational Health at the Rollins School of Public Health at Emory University, Dr. Beth Bowen, assistant professor of Family Medicine at Morehouse School of Medicine, and Dr. Lewis Pepper, assistant professor of Public Health at the Boston University School of Public Health. At the time, the group discussed developing and circulating a questionnaire throughout the community to help assess the prevalence of health problems.

ORHASP Interactions With Residents of the Scarboro Community

In later years, a special effort was made by the Panel to initiate a public outreach initiative focused on the Scarboro community. Scarboro is an African-American community that is located less than a half-mile of the Y-12 plant. Two members of the Panel, Ms. Jacqueline Holloway and Dr. Nasser Zawia, were particularly active in these outreach efforts. On November 16, 1995, and again on September 24, 1997, the State, the Panel, and the dose reconstruction contractors made presentations and held question and answer sessions in the Scarboro Community.

State/Anderson County Community Diagnosis Process

The "Community Diagnosis" process was facilitated by TDH's East Tennessee Regional Office and carried out by the Anderson County Health Council. A community diagnosis involves a series of steps that begin with a community needs assessment, followed by problem identification, prioritization of health concerns, and planning for intervention implementation. New data that were collected for the community needs assessment involved a community stakeholder survey of 274 respondents. Although not a scientifically random survey, the stakeholders represented a cross-section of the community including young families, single parents, the elderly, business leaders, consumers, and both rural and urban residents.

In 1995, the Health Council worked with several members of the Panel to develop additional questions for the Community Stakeholder Survey to address environmental issues. A special emphasis was placed on securing an adequate sample of respondents from the Scarboro community of Oak Ridge because of its close proximity to the Oak Ridge Reservation. Of the 274 participants, 30 were from the Scarboro community. Of the 274, eight percent responded that they believed that they had experienced health problems at work (at DOE-owned plants). Eleven percent responded that they believed they had experienced health problems from exposure to environmental pollution.

The Health Council also reviewed extensive secondary data on morbidity and mortality and primary data collected through a behavioral risk factor survey. Other community assessment activities included focus group discussions (six separate groups in 1995, and additional groups in 1997, specifically in Scarboro); a knowledge and attitude survey conducted in 1995 by the Lancaster consulting Group; a community forum of 80 Anderson County residents in August 1996; a United Way needs assessment which included a household survey, a key informant survey, and a compilation of demographic and secondary data.

Using all these sources of opinions, comments, and both primary and secondary data collection, the Anderson County Health Council then went through a structured prioritization process. The five leading health concerns in rank order were: (1) cardiovascular disease, (2) cancer, (3) cerebrovascular disease, (4) family violence, and (5) lack of dental care.

Environmental health issues *per se* were not specifically identified in the list of the top ten priorities. Cancer from all sources, however, was identified as a major health concern. General population concerns about environment pollution, including radiation, were expressed in the countywide focus groups which took place in December 1995 and in one of the four focus group discussions that took place in Scarboro in 1997.

ATSDR's Survey of Watts Bar Fish Consumers

As a follow-up to general public interests and an informal recommendation from the Panel, in September 1997, the Agency for Toxic Substances and Disease Registry (ATSDR) conducted a formal mercury and PCB exposure investigation involving the current usage of the Watts Bar Lake fishery. This study was conducted to determine if people are currently being exposed to chemicals in the environment at levels that could affect their health. In particular, ATSDR was interested in determining whether or not people eating fish and/or turtles from the Watts Bar Reservoir had levels of PCBs that would suggest a need for concern.

The ATSDR staff interviewed more than 550 people who fished in the Watts Bar Reservoir area. Of those 550, 116 volunteered to participate in the exposure investigation and most of these were people who had reported eating moderate to large amounts of fish or turtles from the Watts Bar Reservoir in the last year.

Blood samples were collected from each participant and sent to a laboratory to determine PCB and mercury levels. The results of this investigation showed that the PCB levels in blood of the exposure participants were not different from those found in the general population. Only five of the 116 people tested had PCB levels that were higher than 20 micrograms per liter, and 46 participants had no detectable PCBs at all. Follow-up counseling was provided to participants who had elevated blood levels of PCBs. This follow-up provided an opportunity to learn more about other possible past routes of exposure and to suggest ways to reduce future exposure.

Only one blood sample out of the 116 tested was found to have a significantly elevated level of mercury, and follow-up counseling was provided to this individual. No mercury was detected in the blood samples of 89 of the participants.

At the time the ATSDR study results were published, the Panel noted that the current prevalence and concentrations of PCBs and mercury in blood samples are related to current exposures, not to historical exposures to those contaminants. The results of the ATSDR exposure investigation were communicated to the public, both in a public forum and through mailing of information.

Final Repository for Health Studies Documents

ChemRisk has assembled an inventory of documents that have been used in the research performed in Phases I and II of the project. At the conclusion of all work, this collection of documents will be transferred to the Tennessee Department of Health’s offices in Nashville. Specifically, a secure room suitable for long-term storage has been identified in the Cordell Hull Building near the State Capitol that will serve as the permanent repository for the Oak Ridge Health Studies documents. When the repository has been established, these information resources will be made available on request to government officials, qualified researchers, and other interested members of the public.

The final task reports may be found in the Department of Energy’s Public Reading Room in Oak Ridge, currently located in Building 1916-T2, 230 Warehouse Road, Oak Ridge, Tennessee; and in the Oak Ridge Public Library in the Oak Ridge Civic Center complex at 1401 Oak Ridge Turnpike, Oak Ridge, Tennessee. The Panel has recommended that DOE-ORO consolidate all relevant documents from the Y-12, ORNL, and K-25 storage areas and maintain them as an indexed collection in a centralized, secure location *(see page 73, Recommendation 6)*.

Eight recommendations formulated by the Panel at the conclusion of the Phase II work are presented below. Below each is a brief discussion of the Panel's basis for making the recommendation.

1. Three specific initiatives directed to public health intervention should be undertaken:

(a) In partnership with a local college or university, a periodic series of workshops should be conducted for local physicians and other health professionals who need to be educated on ORR environmental and occupational health issues arising from the Oak Ridge Health Agreement studies and other related health studies as results become available.

(b) In partnership with a local community college or community outreach program, a public information colloquium should be conducted to provide continuing dialogue and education on environmental and occupational health issues relevant to past, current, and future ORR operations.

(c) A partnership working group of local, state, and federal public health officials, health care professionals, and representatives of the greater Oak Ridge community should be established to evaluate the need for a formal clinical evaluation process. If such a process is determined to be feasible, the group should formulate recommendations for the development of: (1) a goal for a formal community clinical evaluation process; (2) the types of and qualifications for health care professionals who would be involved in the clinical evaluations of concerned members of the community; and (3) protocol guidelines for individual clinical evaluations and referral for follow-up examinations. The Panel suggests that the results contained within this report and the other reports published as part of the Oak Ridge Health Agreement studies serve as a basis for the development of such protocol guidelines.

The Panel believes that the findings of the dose reconstruction project will be helpful in understanding risks to the community at large from past ORR operations. These findings, however, have limitations as far as how they might be helpful to concerned individuals in the local communities. Furthermore, other investigations and studies relating to health effects from ORR operations have been completed, are ongoing, or are planned. Accordingly, this three-part recommendation is offered by the Panel for consideration by DOE, the State of Tennessee, and other government agencies (e.g., ATSDR, CDC, EPA), as well as the community at large, recognizing that the financial and other resources needed for such follow-up work have not yet been identified. The Panel's primary objective with this recommendation is to encourage some specific public health follow-up actions that the Panel believes would be helpful to the people living near the ORR.

2. Formal epidemiologic studies of populations exposed to the primary ORR contaminants (iodine-131, mercury, PCBs, and radionuclides released to White Oak Creek) are unlikely to be successful and should not be performed at this time.

Based on the results of both the dose reconstruction project and the epidemiologic feasibility study, the Panel has concluded that some persons who lived near the ORR at times and places where exposures were the most significant have probably experienced detrimental health effects. It is unlikely, however, that current state-of-the-art epidemiologic research techniques could detect the health effects associated with the levels of exposure estimated by the dose reconstruction analyses. Accordingly, the Panel does not recommend that any epidemiologic studies be undertaken at this time. If a decision is made to perform such studies in the future, it is recommended that the exposure results from the dose reconstruction study be used to help define the local population groups most at risk.

3. The Department of Energy, the Environmental Protection Agency, the State (and perhaps other agencies) should undertake a coordinated program to obtain needed information and satisfy stakeholder concerns. A soil sampling program is vital to gain information relevant to the historic contamination levels in residential areas closest to the ORR plants. Detailed sampling is recommended in all of the most closely situated neighborhoods and also in a few residential areas at greater distances. Any decision about additional dose reconstruction studies should be deferred until the results of the recommended soil sampling program have been obtained and carefully interpreted.

Recent surface soil samples and air samples collected over a number of years have already demonstrated transport of airborne contaminants from Y-12 to inhabited areas, particularly the Scarboro community. Detailed sampling in nearby neighborhoods and in those at greater distances is needed. Samples to define contamination of historically inhabited areas nearest to K-25 and ORNL are also needed.

Because contaminants are not all held firmly by the top layer of soil, it is essential that soil cores be obtained. The depth of the cores must be sufficient to encompass the region of downward migration of the contaminants from the times of significant releases as documented in this study. Detailed profiles of contaminant concentrations as a function of depth below the surface are recommended to aid in understanding the history of contamination and to demonstrate that the region of contaminant migration has been adequately defined. Sampling sites that have been protected since the periods of greatest facility releases should also be sought. Sequential aerial photographs of the area may be helpful. Archived soil samples, collected during earlier years, may also be worthy of further analyses with modern techniques.

On the basis of Phase II analyses, the most relevant contaminants for areas near Y-12 are uranium, mercury, lead, beryllium, chromium, and arsenic. Relevant contaminants for areas near K-25 are uranium, arsenic, chromium, nickel, and copper. Possible contamination of residential areas by airborne lead released from ORNL should be considered. The possible use of iodine-129 (half-life of 17 million years) in soil as a tracer for iodine-131 released during processing of reactor fuel to extract radioactive lanthanum (RaLa) should also be evaluated. Although contributions from releases of iodine-129 at other fuel processing facilities and atmospheric weapons testing will also be present in soil, the iodine-129 signal from the RaLa releases may still be detectable in areas close to the ORR.

For uranium, it is essential to use sophisticated analytical methods that define the isotopic contributions (U-234, U-235, and U-238) to the total uranium mass in each section of the soil core. The specific activities of each isotope and their respective contributions must then be used in dose and risk estimates. For other contaminants, state-of-the-art methods that are both reliable and have low limits of detection (high sensitivity) must be employed.

4. DOE should undertake a program of measurements of atmospheric dispersion of controlled tracer releases from representative stacks and vents at Y-12. The primary goal of these measurements would be to define the transport of a non-depositing tracer from Y-12 to populated areas of Oak Ridge, including the Scarboro and Woodland communities that are both relatively close to the plant.

Completion of the recommended measurement program will have multiple benefits. The data will help to resolve an important issue identified in the dose reconstruction project. In the study, the annual average dispersion parameter was estimated by using release information for uranium that is known to be incomplete. Controlled tracer releases and concentration measurements will overcome this difficulty. Measurements during the controlled releases can also be used to check whether current locations of environmental air sampling stations are the most appropriate for the areas they are intended to represent. Results of the measurements should definitely be used to reassess the estimates of uranium air contamination in Scarboro obtained during Phase II. The results could also be useful for future environmental assessment and impact statement calculations involving atmospheric releases from Y-12.

Releases of uranium at some level from both existing and new facilities can be expected to be a continuing feature of DOE operations at the Oak Ridge Reservation. For that reason, it will be useful to characterize fully the current and future releases of uranium from Y-12 stacks and vents. Besides release rates, information about particle size and chemical form are needed for dose and risk calculations. The combination of better source term characterization and reliable environmental data can be used to develop more reliable estimates of dispersion of that depositing contaminant.

5. More definitive information is needed to better understand the potential toxic effects of exposures to mixtures of contaminants — mercury and PCBs for example — on the same organ systems. Studies relating to this topic should be undertaken by one or more appropriate government-sponsored public health research agencies.

It should be noted that the fisheries downstream of the ORR releases are still contaminated with both of these pollutants. Past studies of the effects of one or the other contaminant in natural systems may have been influenced by the presence of the other.

6. DOE should take action to assure that copies of the important documents used in the health effects studies are properly indexed and retained at a secure location, irrespective of future shifts of contractor responsibility at the ORR facilities.

Experience gained during the course of the project has shown that, without diligent attention and concern, documents that are important to the health effects studies may not survive. Contractors change, and this leads inevitably to personnel changes and loss of institutional memory about document collections and their importance. To avoid future losses of information, the Panel strongly recommends a single, secure repository under DOE's direct control for all documents that have been used in the Oak Ridge Health Studies.

7. DOE should assure the long-term continuation of the ORR environmental monitoring program. The program should include routine measurements in critical media for the materials for which releases have been found to be important in the health agreement studies if the material in question could still be present in the local environment. Specifically, the ORR program should: (a) continue to monitor the remaining mercury environmental burden in East Fork Poplar Creek within the Y-12 plant, in the lower East Fork Poplar Creek floodplain, and in sediment in the downstream watercourses, tracking the resulting methylmercury risk to consumers of fish taken from downstream fisheries; and (b) assure that the program continues to monitor uranium contamination originating from Y-12, with due consideration of isotopic form.

High-risk materials identified in the health agreement studies include iodine-131, mercury, PCBs, all three of the major isotopes of uranium, cesium-137, arsenic, and lead. Risk estimates should be formulated in the annual environmental monitoring reports for any and all remaining credible pathways for each these pollutants; and all major exposure parameters used in the risk calculations should be clearly delineated. Sampling for methylmercury, PCBs, and radionuclides in fish found in Poplar Creek, the Clinch River, and downstream in Watts Bar Lake should also be included. The position and efficacy of the current air monitor in the Scarboro community should be assured, and a second air monitoring station on top of Pine Ridge should also be considered. In general, DOE is urged to continue air monitoring for all alpha-particle emitters, so long as alpha-emitting materials are being used in quantity. Alpha-particle monitoring should be continued in other nearby locations. Such observations should be reported for each uranium isotope instead of categories such as "total uranium."

8. In the area of statewide health effects registries, (a) the State should continue efforts to improve the accuracy and completeness of the cancer incidence registry, and (b) the State should continue to seek funding for a statewide birth defects registry.

Most of the contaminants evaluated during the dose reconstruction are cancer agents and several are associated with birth defects. The Panel and TDH evaluated the quality of the State's Cancer Registry data and concluded there was a need for training in hospitals to improve the completeness and accuracy of cases. It was further determined that all cases are not being identified since only hospitals and laboratories are required by law to report. Therefore, the State should continue to evaluate the quality of data received and the law requiring reporting should be amended to require reporting by all facilities diagnosing or treating cancer patients.

Also, during this project, the Panel reviewed data presented about birth defects occurring in Tennessee residents. Historically, the State has not maintained a registry of adverse birth outcomes. The three years of birth defects data gathered during the project provided the Panel with a hint of the prevalence of these events. If there is any hope for a better understanding of these events and for early intervention, the State must acquire funding for a statewide birth defects registry.

Appendix A

Reports from the Oak Ridge Health Agreement Studies

Report of Knowledge, Attitudes and Beliefs Survey of Residents of an Eight-County Area Surrounding Oak Ridge, Tennessee

M. Benson, W. Lyons, J.M. Scheb, University of Tennessee, August 1994.

ORHASP: Feasibility of Epidemiologic Studies

P.B. Thappa, Vanderbilt University School of Medicine, July 1996.

Dose Reconstruction Feasibility Study

G.P. Brorby, G.M. Bruce, J.E. Buddenbaum, J.K. Lamb, L.B. Walker, T.E. Widner, ChemRisk, September 1993.

Task 1

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 (Vol. 1 and 1A)

A. I. Apostoaei, R. E. Burns, F. O. Hoffman, T. Ijaz, C. J. Lewis, S. K. Nair, T. E. Widner, ChemRisk, 1999.

Task 2

Mercury Releases from Lithium Enrichment at the Oak Ridge Y-12 Plant - A Reconstruction of Historical Releases and Off-Site Doses and Health Risks (Vol 2 and 2A)

G. M. Bruce, S. M. Flack, T.R. Mongan, T. E. Widner, ChemRisk, 1999.

Task 3

PCBs in the Environment Near the Oak Ridge Reservation - A Reconstruction of Historical Doses and Health Risks (Vol. 3)

J. Avantaggio, N. Bonnevie, P. Gwinn, J. McCrodden-Hamblen, P. S. Price, C. Schmidt, ChemRisk, 1999.

Task 4

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 (Vol. 4 and 4A)

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, ChemRisk, 1999.

Task 6

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 (Vol. 5)

J. E. Buddenbaum, R. E. Burns, J. K. Cockroft, T. Ijaz, J. J. Shonka, T. E. Widner, ChemRisk, 1999.

Task 7

Screening-Level Evaluation of Additional Potential Materials of Concern (Vol. 6)

G. M. Bruce, J.E.Buddenbaum, R. E. Burmeister, J. K. Cockroft, S. M. Flack, T. Ijaz, T. E. Widner, ChemRisk, 1999.

Phase II

Project Summary Report — The Oak Ridge Dose Reconstruction (Vol. 7)

T. E. Widner, ChemRisk, 1999.

Appendix B

ORHASP Meeting Dates and Locations

Meeting #	Date	Location
1	April 20-21, 1992	Nashville
2	June 11-12, 1992	Oak Ridge
Community Meeting	June 11, 1992 7:00 p.m.	Oak Ridge Civic Center
3	July 28-29, 1992	Knoxville
4	Oct. 5-6, 1992	Nashville
5	Dec. 8-9, 1992	Harriman
Community Meeting	Dec. 8, 1992 6:30 p.m.	Kingston Community Center
6	Feb. 17-18, 1993	Nashville
7	May 3-4, 1993	Oak Ridge
Community Meeting	May 3, 1993 7:00 p.m.	Robertsville Middle School
8	May 19, 1993	
Community Feedback Sessions	1:00-4:00 p.m. 6:00-8:00 p.m.	Oak Ridge Kingston
9	June 22-23, 1993	Oak Ridge
Technical Workshop	June 23, 1993 6:00 p.m.	TDEC's Oak Ridge Office
10	June 24, 1993	
Community Feedback Sessions	1:00-4:00 p.m. 6:00-8:00 p.m.	Oak Ridge Kingston
11	Aug. 24-25, 1993	Knoxville
12	Sept. 22-23, 1993	Nashville
13	Oct. 13-14, 1993	Oak Ridge
Community Meeting	Oct. 13, 1993 7:00 p.m.	Robertsville Middle School

Meeting #	Date	Location
14	March 31 - April 1, 1994	Nashville
15	June 16-17, 1994	Oak Ridge
16	Aug. 17-18, 1994	Oak Ridge
Community Meeting	Aug. 17, 1994 7:00 p.m.	Oak Ridge Mall
17	Oct. 25-26, 1994	Harriman
Community Meeting	Oct. 25, 1994 6:30 p.m.	Kingston Community Center
18	Dec. 13-14, 1994	Nashville
19	Feb. 16-17, 1995	Oak Ridge
Community Meeting	Feb. 16, 1995 6:30 p.m.	Oak Ridge Civic Center
20	April 26-27, 1995	Oak Ridge
Community Meeting	April 26, 1995 6:30 p.m.	Oak Ridge Civic Center
21	June 27-29, 1995	Oak Ridge
Community Meeting	June 27, 1995 6:30 p.m.	Oak Ridge Civic Center
22	Sept. 7-8, 1995	Oak Ridge
23	Nov. 15-17, 1995	Oak Ridge
Community Meeting	Nov. 16, 1995 6:30 p.m.	Oak Valley Baptist Church
24	May 1-3, 1996	Oak Ridge
25	Sept. 19-20, 1996	Oak Ridge
Community Meeting	Sept. 19, 1996 6:30 p.m.	Oak Ridge High School
26	Dec. 5-6, 1996	Oak Ridge
27	March 19-21, 1997	Knoxville

Meeting #	Date	Location
Community Meeting	March 19, 1997 1:30 p.m.	UT Meeting Center
28	May 21-23, 1997	Oak Ridge
29	July 16-17, 1997	Nashville
30	Sept. 24-25, 1997	Oak Ridge
Community Meeting	Sept. 24, 1997 6:30 p.m.	Scarboro Community Center
31	Nov. 19-21, 1997	Oak Ridge
32	Jan. 22-24, 1998	Oak Ridge
33	March 18-20, 1998	Oak Ridge
34	June 29-30, 1998	Oak Ridge
35	Aug. 13-15, 1998	Oak Ridge
36	Sept. 14-15, 1998	Oak Ridge
37	Oct. 5-7, 1998	Oak Ridge
38	Nov. 16-17, 1998	Oak Ridge
39	Dec. 14-15, 1998	Oak Ridge
Public Comment Session	Dec. 14, 1998 1:30 p.m.	Oak Ridge Mall
40	Jan. 12-13, 1999	Oak Ridge
Public Comment Sessions	Jan. 12, 1999 1:00 p.m. 7:00 p.m.	Oak Ridge Mall Robertsville Middle School
41	Feb. 10-11, 1999	Oak Ridge
42	March 29-30, 1999	Oak Ridge
43	April 16-17, 1999	Oak Ridge
44	May 3-4, 1999	Oak Ridge
45	June 18-19, 1999	Oak Ridge
46	July 9-10, 1999	Oak Ridge
47	Aug. 16-17, 1999	Oak Ridge
48	Sept. 16-17, 1999	Oak Ridge

Appendix C

External Technical Peer Review of Draft Phase II Documents

Individuals listed below reviewed draft project reports prepared by ChemRisk and its subcontractors and provided comments to the contractors and the Panel. The appearance of their names does not necessarily indicate their agreement with the results and conclusions of the final study documents. These reviews suplemented the thorough technical reviews provided by a number of ORHASP members.

Task-1: Radioactive Iodine Released from X-10

Selected by the Tennessee Department of Health

Andre Bouville, Ph.D., *National Cancer Institute (NCI)*
Charles Land, Ph.D., *National Cancer Institute*
Judith Qualters, Ph.D., *Centers for Disease Control and Prevention (CDC)*
Felix Rogers, Ph.D., *Centers for Disease Control and Prevention (CDC)*
Robert Whitcomb, Ph.D., *Centers for Disease Control and Prevention (CDC)*

Selected by DOE-ORO

Joseph Alvarez, Ph.D., CHP, *Auxier and Associates*
John Auxier, Ph.D., CHP, *Auxier and Associates*
James D. Berger, M.S., CHP, *Auxier and Associates*
Michael Bollenbacher, M.S., CHP, *Auxier and Associates*
Keith Eckerman, Ph.D., *Lockheed Martin Energy Research Corporation*
George Kerr, Ph.D., *Lockheed Martin Energy Research Corporation*
Frank O'Donnell, *Lockheed Martin Energy Research Corporation*
Howard Pritchard, Ph.D., CHP, *Auxier and Associates*

Task-2: Mercury Releases from Lithium Enrichment at Y-12

Selected by the Tennessee Department of Health

Richard Canady, Ph.D., *Agency for Toxic Substances and Disease Registry (ATSDR)*
Mark McClananan, Ph.D., *Centers for Disease Control and Prevention (CDC)*

Task-3: PCBs in the Environment near the Oak Ridge Reservation

Selected by the Tennessee Department of Health

Richard Canady, Ph.D., *Agency for Toxic Substances and Disease Registry*

Task 4: Radionuclides Released to White Oak Creek

Selected by the Tennessee Department of Health

Felix Rogers, Ph.D., *Centers for Disease Control and Prevention*

Selected by DOE-ORO

John Auxier, Ph.D., CHP, *Auxier and Associates*
James D. Berger, M.S., CHP, *Auxier and Associates*
Michelle Landis, M.S., CHP, *Auxier and Associates*
Howard M. Pritchard, Ph.D., *Auxier and Associates*

Task 6: Uranium Effluent Monitoring

Selected by the Tennessee Department of Health

Robert Dyer, *Retired K-25 employee*
Bernd Kahn, Ph.D., *Georgia Institute of Technology*
Sam Keith, *Agency for Toxic Substances and Disease Registry*

Selected by DOE-ORO

John Auxier, Ph.D., CHP, *Auxier and Associates*
James D. Berger, M.S., CHP, *Auxier and Associates*
Michael Bollenbacher, M.S., CHP, *Auxier and Associates*
Leslie W. Cole, M.S., CHP, *Auxier and Associates*
Kenneth Ladrach, M.S., CHP, *Auxier and Associates*
Michael Littleton, M.S., CHP, *Auxier and Associates*
Howard Pritchard, Ph.D., CHP, *Auxier and Associates*

Other Reviewers, Advisers and Consultants

In addition to the persons listed above, we would like to acknowledge the following compensated and uncompensated reviewers, advisers and consultants to the project teams.

Terrence P. Barton, *private consultant*
Nicolas Bloom, *Frontier Geosciences*
Antoinette Brenkert, *ORNL*
William D. Burch, *ORNL retiree*
Leland Burger, *Battelle PNL retiree*
E. E. Choat, *former Y-12 worker*
Sandra G. Doty, *private consultant*
Frank Gifford, *Oak Ridge meteorologist*
Ralph Turner, *Frontier Geosciences*
Fred Weber, *University of Tennessee*
C. W. "Hap" West, *Y-12 retiree*
Robert Wichner, *ORNL*
Christopher Wren, *Ecologic Services for Planning, Ltd.*
Orlan Yarbro, *ORNL retiree*

Appendix D

Guest Speakers at ORHASP Meetings

Date	Speaker	Topic
Oct. 5, 1992	**Dr. Robert Cook** *Oak Ridge National Laboratory*	*"Overview of Clinch River Environmental Restoration"*
	Dr. Jim Ruttenber *Health Sciences Center, University of Colorado*	*"Dose Reconstruction"*
	Dr. Genevieve Matanoski *Johns Hopkins University*	*"Epidemiological Studies"*
May 4, 1993	**Dr. Puru Thappa** *Vanderbilt University*	*"Proposal to Support Health Studies"*
	Dr. William Reid *Oak Ridge Physician*	*"Proposal for X-Ray Fluoresence Study"*
March 31, 1994	**Dr. Michael Benson** *University of Tennessee*	*"Knowledge, Attitudes and Beliefs Survey"*
	Ms. Jean Moss *Tennessee Dept. of Health*	*"Birth Defects Registry and Cancer Registry Improvement Program"*
April 1, 1994	**Dr. Puru Thappa** *Vanderbilt University*	*"Proposal for an Epidemiology Feasibility Study"*
Aug. 17, 1994	**Dr. Puru Thappa** *Vanderbilt University*	*"Ecologic Cancer Studies"*
Aug. 18, 1994	**Dr. Leonard Kurland** *Mayo Clinic*	*"Amyotrophic Lateral Sclerosis and Multiple Sclerosis"*
Oct. 25, 1994	**Dr. Scott Davis** *Fred Hutchinson Cancer Research Center*	*"Hanford Iodine-131 Epidemiologic Study"*
Feb 16, 1995	**Dr. Puru Thappa** *Vanderbilt University*	*"Health Effects Associated with Mercury and PCBs"*
	Dr. Joseph L. Lyon *University of Utah*	*"Assessments of Leukemia and Thyroid Diseases in Relation to Fallout in Utah"*
April 26, 1995	**Dr. Donna Cragle** *Oak Ridge Associated Universities*	*"Results of Cancer Registry Quality Improvement Program"*

Date	Speaker	Topic
April 27, 1995	**Dr. Puru Thappa** *Vanderbilt University*	*"Draft of Epidemiologic Feasibility Study"*
June 28, 1995	**Dr. Louis Pepper** *Boston University* **Dr. Elizabeth Bowen** *Morehouse School of Medicine* **Dr. Howard Frumkin** *Emory University*	*"Roundtable Discussion of Community Assessments"*
Nov. 16, 1995	**Mr. Earl Leming** *TDEC DOE Oversight Office*	*"Overview of Environmental Monitoring at the Oak Ridge Reservation"*
	Ms. Mary Layne Van Cleave *Tennessee Department of Health*	*"Community Diagnosis Plan"*
May 1, 1996	**Dr. Tim Meredith** *Vanderbilt University*	*"Update on Center for Clinical Toxicology"*
May 2, 1996	**Mr. Frank Kornegay** *Oak Ridge National Laboratory*	*"Oak Ridge Reservation Air Monitoring System"*
	Mr. David Kendall *University of Tennessee*	*"The Common Ground Process"*
Sept. 19, 1996	**Dr. Maurice Knuckles** *Meharry Medical School*	*"Introduction to Meharry's Environmental Health Division"*
May 22, 1997	**Mr. Earl Leming** *TDEC DOE Oversight Office*	*"State overview of TSCA Incinerator"*
March 19, 1998	**Mr. David Carden** *DOE-ORO*	*"Overview of Scarboro Soil Sampling Program"*

Appendix E

Current and Past ORHASP Members, Key TDH Staff

Current Panel Members

Oak Ridge Reservation Worker Representative

Jacqueline Holloway — Ms. Holloway is recently retired from the Oak Ridge National Laboratory Biology Division, where she served as an Atomic Trades and Labor Council Health and Safety representative. Ms. Holloway is very active in both professional and community arenas. She has worked on numerous election campaigns and serves on several community committees and boards of directors. She also serves as an Anderson County Commissioner and a member of the Permanent Roane State Community College Campus Task Force. She has been a member of the Panel during both Phases I and II.

City of Oak Ridge Representative

James Alexander, M.S.C.E., M.P.A. — Mr. Alexander has 25 years of experience within DOE as an environmental, health and safety, and quality assurance compliance specialist. He is currently employed by British Nuclear Fuels, Limited (BNFL), serving as regulatory compliance manager for several large decontamination and decommissioning projects currently under way at the K-25 Site. He is an adjunct instructor of environmental law for the University of Tennessee's Engineering Graduate School. He is a registered professional engineer in 14 states and is a certified hazardous materials manager. He was employed by the DOE Oak Ridge Operations Office as an environmental engineer from 1975 to 1988. As a member of the City of Oak Ridge's Environmental Quality Advisory Board, Mr. Alexander has represented the City of Oak Ridge on ORHASP for both Phases I and II of the health agreement studies.

At-large Representatives

Paul Campbell Erwin, M.D., M.P.H. — Dr. Erwin is Director of the East Tennessee Region, Tennessee Department of Health. He received his M.D. from the University of Alabama at Birmingham, School of Medicine, and his M.P.H. from Johns Hopkins University, School of Hygiene and Public Health. He has certification with the American Board of Internal Medicine and the American Board of Preventive Medicine (Public Health and General Preventive Medicine). He has membership in the American College of Physicians, the American Public Health Association, the American College of Preventive Medicine and the American College of Epidemiology. He was a fellow in International Health at the Aga Khan University, Karachi, Pakistan, from 1988-1990 and was a scholar with the Public Health Leadership Institute for 1995-1996. Dr. Erwin joined ORHASP at the beginning of the Phase II study effort.

Robert Peelle, Ph.D. — Dr. Peelle was a nuclear physicist at Oak Ridge National Laboratory from 1954 to 1991, and worked on many studies involving gamma rays and nuclear particles. He has extensive knowledge of past plant projects. Dr. Peelle served as a Roane County Commissioner for 22 years, headed the Environmental and Safety Committee of the Clinch River MRS Task Force, and was a member of the East Fork Poplar Creek Working Group, established by DOE as a sounding board for cleanup of mercury in East Fork Poplar Creek and its flood plain. He was a founder of Tennesseans for Wilderness Planning, a statewide environmental group, and was involved in strip-mine control legislation and its amendment. He served on the Oak Ridge Reservation Environmental Management Site Specific Advisory Board from 1995-99, and served as chairman in its first year. Dr. Peelle joined ORHASP shortly after work began on Phase II.

Technical Experts

Joseph Hamilton, Ph.D. — Dr. Hamilton is the Landon C. Garland Distinguished Professor of Physics at Vanderbilt University. His field of expertise is nuclear physics, where he has published over 650 research papers and numerous books, delivered many research papers around the world, and chaired 10 international conferences. He has directed the research of 55 graduate students and 90 post doctoral fellows. His awards include the Jesse Beams Gold Medal for Research, 1975, Professor of the Year for the State of Tennessee, 1991, the American Association for the Advancement of Science Award for International Cooperation in 1995, and honorary Ph.D.s from Mississippi College, the University of Frankfurt, and the University of Bucharest. Dr. Hamilton has a high degree of familiarity with the work at Oak Ridge. In 1981, he founded and serves as director of the Joint Institute for Heavy Ion Research in Oak Ridge, which has brought over 3,000 scientists to Tennessee. He has received awards for teaching physics to non-science majors and has lectured around the world on issues related to science and society. Dr. Hamilton has served on ORHASP during both phases of the health studies.

Norma Morin, Ph.D., M.P.H. — Dr. Morin is an epidemiologist with the Colorado Department of Public Health and Environment. She is the Project Director of the health-related initiatives on the Rocky Flats nuclear weapons plant near Denver, Colorado. These study initiatives include a toxicologic review, dose reconstruction, toxicity assessment, and risk characterization; elements similar to ones in the Oak Ridge Health Studies Agreement. She is co-principal investigator of a cancer incidence and mortality study among workers at Rocky Flats. Dr. Morin served on an advisory committee for Lawrence Berkeley Laboratory assisting in the development of the U.S. Department of Energy Comprehensive Epidemiological Data Repository for Nuclear Weapons Facilities. She received her M.P.H. from the Tulane University School of Public Health and Tropical Medicine and her Ph.D. from the Johns Hopkins University School of Hygiene and Public Health. Dr. Morin has been a member of ORHASP for both Phases I and II of the health agreement studies.

Paul Voillequé, M. Bas. Sci., M.S. — Mr. Voillequé is President of MJP Risk Assessment, Inc. in Idaho Falls, Idaho. He is a Board Certified Health Physicist whose broad interests in the field of radiation protection range from personnel protection and internal dosimetry to the behavior of radionuclides within nuclear facilities and in the environment around them. Since 1990, Mr. Voillequé has worked as part of a team doing historic dose reconstruction work at three sites; Fernald, Rocky Flats, and Savannah River. He also served on the Thyroid/Iodine-131 Assessments Committee of the National Cancer Institute, which was evaluating the consequences of releases of iodine-131 from weapons testing in Nevada. He has participated on ORHASP through both study phases, and during most of Phase II of the health agreement studies, Mr. Voillequé has served as Chairman of the Panel.

Nasser Zawia, Ph.D. — Dr. Zawia holds a Ph.D. in Pharmacology and Toxicology from the University of California at Irvine and was employed as an Associate Professor in the Department of Pharmacology and the Division of Environmental Health at Meharry Medical College in Nashville. He is currently an Associate Professor of Toxicology at the University of Rhode Island. His primary research focus is on the adverse effects of environmental agents on the development of the brain. Prior to coming to Meharry, Dr. Zawia was a staff fellow at the National Institute for Environmental Health Sciences. He is actively involved in the teaching and training of graduate, medical, dental and nursing students. He is a recipient of research grants from the National Institutes of Health, the National Science Foundation and the Environmental Protection Agency. He has published extensively in the field of toxicology in both national and international journals and is known for his work on heavy metals and developmental gene expression. Dr. Zawia is a member of the Society for Toxicology and the Society for Neuroscience. He joined the Panel shortly after the initiation of the Phase II work.

Tennessee Department of Health Representative

Patrick Lipford, M.S. — Mr. Lipford is a Public Health Program Director with the Tennessee Department of Health and currently serves as Project Director for the Oak Ridge Health Studies, succeeding Bonnie Bashor in this function. He has a bachelor's degree in political science from the University of Tennessee and a master's degree in geography from the University of Memphis. Before joining the state in March 1995, he worked in marketing and public relations for private industry, with extensive experience in environmental testing and remediation.

Centers for Disease Control and Prevention Representative

James M. Smith, Ph.D. — Dr. Smith is Chief of the Radiation Studies Branch within the National Center for Environmental Health at the Centers for Disease Control and Prevention (CDC) in Atlanta. He has served on many national and international committees concerned with radiation dosimetry and the biological effects of radiation, was a member of the Hanford Health Effects Review Panel, and is currently a member of the Rocky Flats Health Advisory Panel. Dr. Smith has served on the Editorial Board of the Health Physics Journal and is Adjunct Associate Professor at Emory University's School of Public Health. He has been a member of ORHASP during both Phases I and II of the health agreement studies.

Department of Energy Representative

Barbara Brooks, M.S. — Ms. Brooks joined the Office of Epidemiologic Studies in DOE's Office of Health in late 1990 with more than 20 years of federal experience. In addition to serving as DOE's representative on several state advisory panels for health studies, her responsibilities also include program management for a university project concerning the measurement of biokinetics of the actinides in humans and management oversight of DOE's new Comprehensive Epidemiological Data Resource (CEDR). She has a master's degree in health physics from the University of Tennessee and a bachelor's degree in physics from Southern Illinois University. Ms. Brooks joined ORHASP about midway in the Phase I work, replacing Bonnie Richter as DOE's representative on the Panel.

Former Panel Members

Former At-Large Representatives:

Eugene Fowinkle, M.D., M.P.H. — Dr. Fowinkle has been the Associate Vice-Chancellor for Health Affairs at Vanderbilt University since 1983. From 1969 to 1983, he served as the Commissioner of Public Health for the State of Tennessee. He has also authored and co-authored numerous articles relating to public health issues. He has had many special appointments including on the Public Health and Epidemiology Task Force of the President's Commission on Three Mile Island. He has a great deal of expertise on both medical issues and public health policies. During Phase I, he was the designated Chairman of ORHASP and served from 1992 to 1994.

Ralph Hutchison — Mr. Hutchison is coordinator of the Oak Ridge Environmental Peace Alliance (OREPA). He lives in Lake City, Tennessee, and serves as pastor of the Bethel Presbyterian Church in Dandridge, Tennessee. OREPA has published A Citizen's Guide to Oak Ridge and publishes a quarterly newsletter. He participated on ORHASP during all of Phase I and all but the last few months of Phase II.

William Busse — Mr. Busse was the executive director of the American Lung Association of Tennessee from 1966 to 1992. He holds a Bachelor of Arts in Political Science and has taken several graduate courses in management. He is a member and consultant to the Kaiser Family Foundation Planning Committee for Tennessee Community Based Health Promotion Program. Mr. Busse is a member of the American Public Health Association, the Tennessee Public Health Association, and several other associations and committees concerned with public health. Mr. Busse was appointed as an at-large representative to the Panel during Phase I and served from 1992 to 1994.

Former Technical Experts

Owen Hoffman, Ph.D. — Dr. Hoffman, President and Director of the Center for Risk Analysis, SENES Oak Ridge Incorporated, has expertise in environmental transport and modeling and has served on health study oversight committees for the Hanford Thyroid Disease Study and the Rocky Flats dose reconstruction project. Dr. Hoffman served on the Panel during Phase I from 1992 to 1994.

Former Tennessee Department of Health Representatives:

Mary Yarbrough, M.D., M.P.H. — Until 1995, Dr. Yarbrough was the director of the Division of Environmental Epidemiology, Tennessee Department of Health (TDH). She has a Bachelor of Science in Biomedical Engineering, completed residencies in internal medicine and preventive medicine, and received a Master of Public Health with emphasis in international health. Prior to working for TDH, Dr. Yarbrough was involved in international health studies as a Henry Luce Scholar in Southeast Asia, a consultant for the International YMCA in Zambia, and a consultant with the World Health Organization in Geneva, Switzerland. As project director of the Tennessee Health Studies Agreement during Phase I and the initial phases of Phase II, 1992-1994, Dr. Yarbrough served as the principal TDH representative to the Panel.

Mary Layne Van Cleave — Ms. Van Cleave is a biostatistician and former Director of the Environmental Epidemiological Division of the Tennessee Department of Health. She was Project Director for the Oak Ridge Health Agreement Studies and was responsible for providing epidemiologic support to the Oak Ridge Heath Agreement Steering Panel, as well as supervising the statewide Childhood Lead Poisoning Prevention Program. She designed and developed the procedures for the new Tennessee Birth Defects Registry and participated in the development of a Quality Improvement Plan for the Tennessee Cancer Reporting System.

Bonnie Bashor — Ms. Bashor is Director of the Tennessee Department of Health's Environmental Health Studies and Services (EHSS) section. She received a B.S. in Zoology from the University of Tennessee and an M.S. in Biochemistry from Vanderbilt University. As Director of the EHSS, she manages the Chattanooga Creek Health Study and the State's Environmental Health Consultation Program.

Former Department of Energy Representative

Bonnie Richter, Ph.D., M.P.H. — Dr. Richter is an epidemiologist with the Office of Epidemiologic Studies in the DOE Headquarters' Office of Health. Prior to joining DOE, she worked at the Agency for Toxic Substances and Disease Registry. During the first half of the Phase I effort, she served as the Project Officer for DOE on the Oak Ridge Health Studies Agreement grant and was the Department of Energy's official representative on the Panel.

Key TDH Staff

Patrick Turri, M.S. — Mr. Turri has served as project manager for the Oak Ridge Health Agreement Studies since the initiation of the project in 1991. He has served the State since 1970 as an industrial hygienist, environmental engineer, and program director. Mr. Turri received his B.S. in Chemical Engineering and his M.S. in Engineering Administration from the University of Tennessee in Knoxville. He has also received specialized training in applied epidemiology and biostatistics from the Centers for Disease Control Epidemic Intelligence Service and in radiation health physics from Oak Ridge Associated Universities.

Appendix F

Glossary of Technical Terms Used in This Report

absorbed dose	in radiation protection, 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 of absorbed dose is the rad; the modern unit of absorbed dose is the gray (Gy); 1 gray = 100 rad.
air sampling	the collection and analysis of contaminants within a measured quantity of air from a defined location. Samples of air are collected to measure or to detect the presence of radioactive substances, particulate matter, or chemical pollutants. Samples can be taken from rooms, exhaust systems, stacks, or ambient air.
alpha particle	a positively charged particle that is ejected spontaneously in the decay of certain radioisotopes such as uranium-235. 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. Alpha particles interact strongly with matter. All their energy is dissipated in a short distance by ionization of many atoms. Alpha particles cannot penetrate through the skin, but if emitted inside the body, they can produce a large dose in a localized volume.
Atomic Energy Commission (AEC)	a federal agency created in 1946 to manage the development, use, and control of nuclear energy for military and civilian application. Abolished by the Energy Reorganization Act of 1974 and succeeded by the Energy Research and Development Administration. The responsibilities of AEC/ERDA were divided in 1977 between the Nuclear Regulatory Commission and the Department of Energy.
background radiation	the radiation received by people from natural sources including cosmic rays, radiation from the naturally occurring radioactive elements in the environment, and natural concentrations of radionuclides in the body (carbon-14 and potassium-40, for example).
beta particle	a charged particle emitted from the nucleus of an atom (iodine-131, for example) having the same charge (+ or –) and mass as an electron.
bias	a systematic error of measurements or estimates that leads to either an over- or underestimate of the result.
bioaccumulation	the net accumulation of a substance by an organism as a result of uptake from all sources.
biokinetic modeling	the use of mathematical models to quantify the movement and accumulation of ingested or inhaled material among the parts of the human body.
calutrons	production scale mass spectrometers at Y-12 that were used to electromagnetically separate the lighter U-235 isotope from the more naturally-abundant U-238 isotope.

chronic	persisting over a long period of time. Chronic exposures are generally greater than 1/10 of expected lifetime.
Colex	a column-based chemical exchange process for enrichment of lithium in its lithium-6 component.
confidence interval	a range of values in a statistical distribution inside which scientists are confident the true value lies.
confidence limits	the upper and lower values that define a confidence interval.
curie	the historical unit of radioactivity. A radioactive substance with an activity of one curie (Ci) undergoes 37 billion (37,000,000,000) disintegrations per second.
demography	the study of locations, qualities, and activities of human populations.
depleted uranium	depleted uranium contains less uranium-235 than natural uranium. At the ORR, depleted uranium contains 0.1 to 0.4% uranium-235.
directed searches	document searches aimed at collecting specific data or other relevant information needed by a project team.
dose	in toxicology, the acute intake of a hazardous agent or contaminant per unit body weight, usually expressed as milligrams (mg) of contaminant per kilogram (kg) of body weight (mg/kg). For longer-term exposures, it refers to daily intake of the substance per unit body weight: mg/kg per day, also written mg/(kg-day). For some substances, the dose may be defined for a particular organ or tissue. For radiation, the absorbed dose is the total energy deposited in a unit mass of a particular organ or tissue.
dose reconstruction	the process of estimating doses that were received by members of the public following releases of toxic or radioactive materials to the environment around an industrial facility.
dosimetry	a general term to describe the process of measuring or calculating the radiation or chemical dose to specific organs or to the whole body.
effluent	is a treated or untreated air emission or liquid discharge containing contaminants that has been released into the environment from a facility.
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.
endpoint	an observed effect resulting from exposure to a chemical or physical agent.
enriched uranium	on the ORR, uranium typically containing between 0.95% and 99% uranium-235. Natural uranium contains 0.72% uranium-235.
enrichment of uranium	a process designed to increase the relative abundance of uranium-235 with respect to uranium-238.
epidemiology	the study of diseases and their patterns of occurrence in human populations.

exposure	contact of an organism with a chemical or physical agent.
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 a person's interaction with the contaminants and the resulting dose received by the individual.
gamma radiation (gamma rays)	energetic electromagnetic radiation (photons) originating from the nucleus of a radionuclide; energies usually exceed those of x-rays.
gaseous diffusion enrichment	a process by which uranium hexafluoride is passed through a network of semipermeable molecular barriers for the purpose of separating the lighter uranium-235 isotope from the heavier, more naturally-abundant uranium-238 isotope.
half-life	the time required for 50 percent of a radioactive substance to decay. Iodine-131 has a half-life of about eight days, so an original amount of 1 curie would be reduced to 0.5 curie in eight days and to 0.25 curie in 16 days.
health physics	the science concerned with recognition, evaluation, and control of health hazards associated with ionizing and nonionizing radiation.
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.
involuntary risk	a risk over which the exposed individual has little or no control; a risk that the individual did not choose and may not know about.
isotopes	atoms of the same chemical element having different masses.
K-25	the original name of one of the three main complexes on the Oak Ridge Reservation. 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. K-25 is also the building name for the first process building there.
lithium deuteride	a compound of lithium and deuterium, an isotope of hydrogen.
LOAEL	Lowest Observed Adverse Effect Level. In dose-response toxicologic experiments, 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 its appropriate control group.
median	the median identifies the value ("central value" in the present report) in any distribution of similar quantities for which there is equal probability of a lesser or greater value. (For example, the median vehicle speed on a highway is 73 mph if half the vehicles are going faster than 73 mph and half slower.)

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 alternative name for elemental mercury.
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.
Monte Carlo simulation	here, a mathematical technique that uses random selection among all values thought possible to simulate the effect of uncertain knowledge of input parameters on the answer provided by an equation or model.
natural uranium	uranium with the isotopic composition found in nature. Sometimes called "normal" uranium. See "uranium."
NOAEL	No Observed Adverse Effect Level. The highest dose in a toxicological study at which there are no statistically or biologically significant differences between the frequencies or severity of adverse effects observed in exposed and control populations of test animals.
organic mercury	a group of compounds present when mercury combines in a chemical bond with organic carbon. An example is methylmercury.
PCBs	short for polychlorinated biphenyl compounds; a generic term used to describe many similar compounds that are chemically stable and nonflammable, properties that make them useful as insulators and in cutting oils.
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.
population threshold	for the discussions in this study on PCB toxicity, the population threshold is the highest dose that does not cause a deleterious effect in the most sensitive individual in a population. This quantity is an estimated quantity that takes a range of values derived from the same experiments that led the EPA to establish the RfD. An individual's personal threshold may be considerably higher than the population threshold.
radioactivity	the spontaneous emission of ionizing 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 eventual spontaneous transformation accompanied by the emission of radiation. Radionuclides behave chemically in the same way as non-radioactive isotopes of the same element.

Reference Dose (RfD)	for non-carcinogenic chemicals, an EPA estimate of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime.
Reservation	for purposes of this report, used to refer to the Oak Ridge Reservation.
risk	the chance that an exposure to a toxic substance 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 risk per unit dose of a toxic substance or the risk per unit exposure to a hazard.
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.
threshold dose	the lowest intake rate of a chemical at which a specific adverse effect is observable and below which it is not observable. (The threshold dose is concept, not the result of a direct experiment.)
"true hazard quotient"	for discussions on PCB toxicity in this report, the name given to the ratio of a calculated dose to a value randomly chosen from the distribution of possible population thresholds.
uncertainty	a lack of knowledge about the true but unknown value of a parameter. Can be expressed using a quantitative probability density function (PDF).
uranium	a naturally occurring, radioactive metal. The two principal natural isotopes are uranium-235 (0.7% of natural uranium) and uranium-238 (99.3% of natural uranium).
variability	variations in a measured parameter that occur as the result of the natural heterogeneity associated with the parameter, as the variability among the weight of humans.
voluntary risk	a risk knowingly (and willingly) accepted by the individual.
x rays	a form of electromagnetic radiation, usually produced by bombarding a metal target with fast electrons. X rays are typically less energetic than gamma rays.
X-10	the original name of one of the three main facilities on the Oak Ridge Reservation. The first reactor (the Clinton Pile, later called the Graphite Reactor) and fuel reprocessing operations were located at X-10, leading to the first production of plutonium-239. Radioactive lanthanum was recovered from reactor fuel at an X-10 facility during 1944-56. The Oak Ridge National Laboratory was established at this site in 1947.
Y-12	the name of one of the three main facilities on the Oak Ridge Reservation. At Y-12, the radionuclide uranium-235 was separated from natural uranium using electromagnetic separators (called calutrons). Later, separation of the isotope lithium-6 from natural lithium using a process that employed large amounts of mercury was accomplished in Y-12 facilities. Nuclear weapon components have been manufactured at Y-12.

Appendix G

Acronyms Used in This Report

ALS	Amyotrophic Lateral Sclerosis
ATSDR	Agency for Toxic Substances and Disease Registry
CDC	Centers for Disease Control and Prevention
CEDR	Comprehensive Epidemiological Data Resource (of DOE)
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
Colex	Column Exchange
DOE	Department of Energy
EFPC	East Fork Poplar Creek
EPA	Environmental Protection Agency
HTDS	Hanford Thyroid Disease Study
LOAEL	Lowest Observed Adverse Effect Level
NCI	National Cancer Institute
NOAEL	No Observed Adverse Effect Level
ORGDP	Oak Ridge Gaseous Diffusion Plant
ORHASP	Oak Ridge Health Agreement Steering Panel
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
PCBs	polychlorinated biphenyls
RaLa	Radioactive Lanthanum
RCRA	Resource Conservation and Recovery Act
RfD	Reference Dose
SF_6	sulfur hexafluoride
TDH	Tennessee Department of Health
WOC	White Oak Creek
χ/Q	Chi over Q

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Errata

The following sections were changed after this document was printed.

1. This item was changed in the Table of Contents from:

The Phase Dose Reconstruction Feasibility Study

to:

The Phase I Dose Reconstruction Feasibility Study

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2. This sentence on page 28 was changed from:

Areas most significantly affected by releases from the 1954 accident were in the west part of Oak Ridge near Wiltshire Drive and the communities of Jonesville, Norwood and Oliver Springs.

to:

Areas most significantly affected by releases from the 1954 accident were in the west part of Oak Ridge, near the location of Salem Road, and the communities of Jonesville, Norwood and Oliver Springs.

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3. This sentence on page 30 was changed from:

While thyroid disease was observed among the study participants, the draft study results, which are under review, did not show a relationship between the estimated dose to the thyroid from iodine-131 and the amount of thyroid disease in the study population.

to:

While thyroid disease was observed among the study participants, the draft study results, which are under review, was not able to show a relationship between the estimated dose to the thyroid from iodine-131 and the amount of thyroid disease in the study population.

4. This sentence was changed from:

The data would include consumption rates of fish and turtles, PCB levels in core samples from the Clinch River and Watts Bar Lake, PCB concentrations in soils near East Fork Poplar Creek, PCB concentrations in beef cattle grazing near the creek, and PCB blood levels in persons who eat fish from these waters now.

to:

The data would include consumption rates of fish and turtles, PCB levels in core samples from the Clinch River and Watts Bar Lake, PCB concentrations in soils near East Fork Poplar Creek, and PCB concentrations in beef cattle grazing near the creek.

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5. These sentences on page 39 changed from:

The exception is exposure from walking along the shore of the river. As contaminated sediments built up over the years, this exposure source would have continually increased. After the concentrations of radionuclides in the White Oak Creek discharges were dramatically decreased, however, the strength of this source would have diminished as well.

to:

Downstream of Jones Island, however, external exposure along the shoreline gradually became the most important exposure route for those who used the shoreline. Around the State Route 58 bridge, the shoreline external exposure is estimated to have increased somewhat for a while after 1963. The construction of the Melton Hill Dam increased the amount of radioactive material entering the Clinch River.

6. The highlighted phrases on pages 43-46 (Scenarios 2-5) changed from:

milk

to:

regionally mixed commercial milk

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7. These sentences were changed from:

Investigators performed the Phase II screenings in two basic steps, both of which made use of ORHASP's decision guide values *(see page 57)*.

to:

Investigators performed the Phase II screenings in two basic steps, using methodology more advanced than the relative method used in the Dose Reconstruction Feasibility Study. Both of these steps made use of ORHASP's decision guide values *(see page 57)*.