PUBLIC HEALTH ASSESSMENT

White Oak Creek Radionuclide Releases

Oak Ridge Reservation (USDOE)

Oak Ridge, Roane County, Tennessee

EPA Facility ID: TN1890090003

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Prepared by:

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Foreword

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

Since 1986, ATSDR has been required by law to conduct a public health assessment at each of the sites on the EPA National Priorities List. The aim of these evaluations is to find out if people are being exposed to hazardous substances and, if so, whether that exposure is harmful and should be stopped or reduced. If appropriate, ATSDR also conducts public health assessments when petitioned by concerned individuals. Public health assessments are carried out by environmental and health scientists from ATSDR and from the states with which ATSDR has cooperative agreements. The public health assessment program allows the scientists flexibility in the format or structure of their response to the public health issues at hazardous waste sites. For example, a public health assessment could be one document or it could be a compilation of several health consultations—the structure may vary from site to site. Whatever the form of the public health assessment, the process is not considered complete until the public health issues at the site are addressed.

Exposure

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

Health Effects

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

ATSDR uses existing scientific information, which can include the results of medical, toxicologic, and epidemiologic studies and the data collected in disease registries, to determine the health effects that may result from exposures. The science of environmental health is still developing, and sometimes scientific information on the health effects of certain substances is not available. When it touches on cases in which this is so, this report suggests what further public health actions are needed.

Conclusions

This report presents conclusions about the public health threat, if any, posed by a site. Any health threats that have been determined for high-risk groups (such as children, the elderly, chronically ill people, and people engaging in high-risk practices) are summarized in the Conclusions section of the report. Ways to stop or reduce exposure are recommended in the Public Health Action Plan section.

ATSDR is primarily an advisory agency, so its reports usually identify what actions are appropriate to be undertaken by EPA, other responsible parties, or the research or education divisions of ATSDR. However, if there is an urgent health threat, ATSDR can issue a public health advisory warning people of the danger. ATSDR can also authorize health education or pilot studies of health effects, full-scale epidemiology studies, disease registries, surveillance studies or research on specific hazardous substances.

Community

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

Comments

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

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Acronyms

ALS	amyotrophic lateral sclerosis
AOEC	Association of Occupational and Environmental Clinics
ATSDR	Agency for Toxic Substances and Disease Registry
BEIR	Biological Effects of Ionizing Radiation
Bq	becquerel
BSCP	Background Soil Characterization Project
CDC	Centers for Disease Control and Prevention
Ce 144	cerium 144
CEDR	Comprehensive Epidemiologic Data Resource
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFRF	consolidated fuel recycling facility
Ci	curie
cm	centimeter
Co 60	cobalt 60
COC	contaminant of concern
COPD	chronic obstructive pulmonary disease
CRM	Clinch River Mile
Cs 137	cesium 137
D&D	decontaminating and decommissioning
DOE	U.S. Department of Energy
EE/CA	Engineering Evaluation/Cost Analysis
EEWG	Exposure Evaluation Work Group
EMWMF	Environmental Management Waste Management Facility
EFPC	East Fork Poplar Creek
EPA	U.S. Environmental Protection Agency
ERAMS	Environmental Radiation Ambient Monitoring System
ETTP	East Tennessee Technology Park
FACA	Federal Advisory Committee Act
FAMU	Florida Agriculture and Mechanical University
FFA	Federal Facility Agreement
GAAT	gunite and associated tanks
Gy	gray
H3	tritium
HF	hydrofracture facility
HFIR	high flux isotope reactor
Hg	mercury
HHS	U.S. Department of Health and Human Services
HRE	homogeneous reactor experiment
HRSA	Health Resources and Services Administration
IAG	interagency agreement
ICRP	International Commission on Radiological Protection
IHP	intermediate holding pond
IROD	Interim Record of Decision
I 131	iodine 131

Acronyms (continued)

ISG	in situ grouting
ISV	in situ vitrification
IWMF	interim waste management facility
LEFPC	Lower East Fork Poplar Creek
LLW	low-level waste
LLLW	liquid low-level waste
LWBR	Lower Watts Bar Reservoir
MCL	maximum contaminant level
MeV	million electron volts
mg/kg	milligrams per kilogram
mrem	millirem
μCi/mL	microcuries per milliliter
μR/hr	microroentgen per hour
MRL	minimal risk level
MS	multiple sclerosis
mSv	millisievert
MVST	Melton Valley storage tanks
Nb 95	niobium 95
NCEH	National Center for Environmental Health
NCRP	National Council on Radiation Protection and Measurements
NHF	new hydrofracture facility
NIOSH	National Institute for Occupational Safety and Health
NOAEL	no observed adverse effect level
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NRC	U.S. Nuclear Regulatory Commission
OHF	Old Hydrofracture Facility
OREIS	Oak Ridge Environmental Information System
ORGDP	Oak Ridge Gaseous Diffusion Plant
ORHASP	Oak Ridge Health Agreement Steering Panel
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
ORRHES	Oak Ridge Reservation Health Effects Subcommittee
OU	operable unit
P&A	plugging and abandonment
PCB	polychlorinated biphenyl
pCi	picocurie
PCM	Poplar Creek mile
PDF	portable document format
PHAP	Public Health Action Plan
PHAWG	Public Health Assessment Work Group
ppb	parts per billion
ppm	parts per million
PWSB	process waste sludge basin
PWTP	Process Waste Treatment Plant

Acronyms (continued)

rad	radiation absorbed dose
RaLa	radioactive lanthanum
RAR	Remedial Action Report
RCRA	Resource Conservation and Recovery Act
RER	remediation effectiveness report
RfD	reference dose
Rh	rhodium
RI/FS	Remedial Investigation/Feasibility Study
ROD	Record of Decision
Ru 106	ruthenium 106
SDWA	Safe Drinking Water Act
SDWIS	Safe Drinking Water Information System
SNF	spent nuclear fuel
SRS	sediment retention structure
Sr 90	strontium 90
Sv	sievert
SWSA	solid waste storage area
TDEC	Tennessee Department of Environment and Conservation
TDOH	Tennessee Department of Health
TRM	Tennessee River Mile
TRU	transuranic waste
TSCA	Toxic Substances Control Act
TSF	tower shielding facility
TVA	Tennessee Valley Authority
TWRA	Tennessee Wildlife Resources Agency
U 233	uranium 233
U.S.ACE	U.S. Army Corps of Engineers
WAC	waste acceptance criteria
WAG	waste area grouping
WBRIWG	Watts Bar Reservoir Interagency Work Group
WIPP	waste isolation pilot plant
WOC	White Oak Creek
WOCE	White Oak Creek Embayment
W_R	radiation weighting factor
W_T	tissue weighting factor
Zr 95	zirconium 95

I. Summary

ORR Background

In 1942, the federal government established the Oak Ridge Reservation (ORR) in Anderson and Roane Counties in Tennessee as part of the Manhattan Project to research, develop, and produce special radioactive materials for nuclear weapons. Four facilities were built at that time. The Y-12 plant, the K-25 site, and the S-50 site were created to enrich uranium. The X-10 site was created to demonstrate processes for producing and separating plutonium. Since the end of World War II, the role of the ORR (Y-12 plant, K-25 site, and X-10 site) has broadened widely to include a variety of nuclear research and production projects vital to national security.

Over the years, ORR operations have generated a variety of radioactive and nonradioactive wastes. A portion of these remain in old waste sites, and some pollutants have been released into the environment. Consequently, in 1989, the ORR was added to the U.S. Environmental Protection Agency's (EPA's) National Priorities List (NPL). Under a Federal Facility Agreement (FFA) with EPA and the Tennessee Department of Environment and Conservation (TDEC), the U.S. Department of Energy (DOE) is conducting cleanup activities at the ORR. These agencies are working together to investigate and to take remedial action on hazardous wastes generated from both past and present site activities.

ATSDR's Involvement and Other Health Activities at ORR

The Agency for Toxic Substances and Disease Registry (ATSDR), one of several agencies within the U.S. Department of Health and Human Services (HHS), is the principal federal public health agency charged with evaluating human health effects of exposure to hazardous substances in the environment. ATSDR, a sister agency to the Centers for Disease Control and Prevention (CDC), has for many years worked closely with the CDC's National Center for Environmental Health (NCEH). In December 2003, ATSDR and NCEH—both charged with controlling and preventing diseases related to environmental causes—consolidated their administrative and management functions and are now known as NCEH/ATSDR. For more information on these and other affiliated agencies, please refer to http://www.atsdr.cdc.gov/ and http://www.cdc.gov/.

Since 1991 ATSDR has responded to requests and addressed health concerns of community members, civic organizations, and other government agencies in the affected areas of the ORR by working extensively to determine whether levels of environmental contamination in off-site areas present a *public health hazard*, that is, a source of potential harm to human health as a result of past, current, or future exposures. During this time, ATSDR has identified and evaluated several public health issues and has worked closely with many parties. While the Tennessee Department of Health (TDOH) conducted the Oak Ridge Health Studies to evaluate whether off-site populations have been exposed in the *past*, ATSDR's activities focused on *current* public health issues related to Superfund cleanup activities at the site. Prior to this public health assessment, ATSDR addressed current public health issues related to off-site areas, including the East Fork Poplar Creek area and the Watts Bar Reservoir area. The agency's Oak Ridge Reservation Web site at http://www.atsdr.cdc.gov/HAC/oakridge/ contains additional information on ATSDR's ORR-related public health activities.

During Phase I and Phase II of the Oak Ridge Health Studies, the TDOH conducted extensive reviews and screening analyses of the available information and identified four hazardous substances related to past ORR operations that could have been responsible for adverse health effects: radioactive iodine, mercury, polychlorinated biphenyls (PCBs), and radionuclides from White Oak Creek. In addition to the dose reconstruction studies on these four substances, the TDOH conducted additional screening analyses for releases of uranium, radionuclides, and several other toxic substances.

To expand on TDOH efforts—but not duplicate them—ATSDR scientists conducted a review and a screening analysis of the department's Phase I and Phase II screening-level evaluation of past exposure (1944–1990) to identify contaminants of concern for further evaluation. Using this review, ATSDR scientists are conducting public health assessments on X-10 iodine 131 releases, Y-12 mercury releases, K-25 uranium and fluoride releases, PCB releases from X-10, Y-12, and K-25, and other topics such as the Toxic Substances Control Act (TSCA) incinerator and off-site groundwater. In spring 2004 ATSDR completed a public health assessment on Y-12 uranium releases and in this public health assessment evaluates radionuclides released from White Oak Creek. In conducting these public health assessments, ATSDR scientists are evaluating and analyzing the data and findings from previous studies and investigations to assess the public health implications of past, current, and future exposures.

ATSDR's Evaluation of Exposure to Radionuclide Releases From X-10

As stated, this public health assessment evaluates the releases of radionuclides to the Clinch River (and the Lower Watts Bar Reservoir, or LWBR) from the ORR via White Oak Creek, assesses past, current, and future exposure to radionuclide releases for people who use or live along the Clinch River (and within the White Oak Creek study area; that is, the area along the Clinch River from the Melton Hill Dam to the Watts Bar Dam), and addresses the community health concerns and issues associated with the radionuclide releases from White Oak Creek. This document does not address the release of other contaminants of concern such as mercury, radioactive iodine, PCBs, uranium from the K-25 facility, and fluorides, nor does it address exposures to those contaminants. ATSDR will evaluate these contaminants and other topics in separate public health assessments. Please note that this document only evaluates **off-site exposures** to White Oak Creek radionuclide releases for downstream residents and others who use or who live along these waterways. It does not evaluate any exposures potentially occurring on site at the reservation, including exposures to workers and other individuals who may contact contaminants while at the ORR.

Most of the radioactive contamination in White Oak Creek came from ORR's X-10 facility (formerly Clinton Laboratories and now known as the Oak Ridge National Laboratory [ORNL]). The entire ORNL site encompasses approximately 26,580 acres. The main operations at the laboratory take place on about 4,250 acres—the original X-10 site. The ORNL site is located in two valleys: Bethel Valley and Melton Valley. In 1943, the X-10 site was built as a "pilot plant" to demonstrate plutonium production and separation. The government had planned to run the X-10 site for 1 year, but this time frame was made indefinite as operations at the facility were broadened. Over time, operations at X-10 grew to include nuclear fission product separation, nuclear reactor safety and development, and radionuclide production for worldwide use in the medical, industrial, and research fields. Today, the ORNL site is globally recognized as a research and development laboratory.

White Oak Creek travels south along the X-10 border, flows through or past several contaminated sources in Melton Valley (e.g., solid waste storage areas), and ultimately empties into White Oak Lake. The government had anticipated using this man-made lake as a “settling basin” for radionuclides released from the X-10 site. Some of the contaminants, however, did not settle in White Oak Lake. Instead, they flowed over White Oak Dam into the White Oak Creek Embayment, and then entered the Clinch River. As contaminants in White Oak Creek surface water enter the Clinch River, their concentrations will dilute; and when the Clinch River meets the Tennessee River, the concentrations will dilute even further. The ORR-related surface water and sediment that traveled through the Clinch River eventually flowed into the LWBR. The LWBR, which is located downstream of the ORR, extends from the confluence of the Clinch River and the Tennessee River to the Watts Bar Dam. Between 1944 and 1991, approximately 200,000 curies of radioactive waste were discharged from X-10 into the Clinch River via White Oak Creek.

ATSDR concluded that past, current, and future exposures to radionuclides released from White Oak Creek to the Clinch River/Lower Watts Bar Reservoir are not a public health hazard.

People who used or lived along the Clinch River or Lower Watts Bar Reservoir in the past, or who currently do so or will in the future, might have or might yet come in contact with X-10 radionuclides that entered the Clinch River or Lower Watts Bar Reservoir via White Oak Creek. However, ATSDR’s evaluation of data and exposure situations for users of these waterways indicates that the levels of radionuclides in the sediment, surface water, and biota are—and have been in the past—too low to cause observable health effects.

Past Exposure (1944–1991)

ATSDR evaluated past exposure to radionuclides released into the Clinch River from the X-10 site via White Oak Creek. ATSDR’s evaluation showed that the estimated external and internal radiation doses were not expected to cause harmful health effects. Therefore, ATSDR concluded that past off-site exposure to those radionuclides traveling from X-10 to the Clinch River via White Oak Creek was not a public health hazard.

To evaluate past exposure to radionuclide releases from the X-10 site via White Oak Creek, ATSDR primarily relied on data generated during Task 4 of the TDOH’s *Reports of the Oak Ridge Dose Reconstruction, Radionuclide Releases to the Clinch River from White Oak Creek on the Oak Ridge Reservation—an Assessment of Historical Quantities Released, Off-Site Radiation Doses, and Health Risks* (referred to as the “Task 4 report”). The Task 4 team conducted a screening process that allowed the team to estimate the dose and subsequent risk (to individuals and to target organs) associated with exposure to 24 radionuclides in Clinch River sediment, surface water, and biota. The team assumed that individuals would have been exposed between 1944 and 1991—a period of up to 48 years—and that exposure to radionuclides would have occurred during recreational activities or from the consumption of water, milk, fish, local meats, or local crops. The Task 4 team used conservative screening parameters with the intention of calculating estimates of risk that are not likely to underestimate the actual risk to any exposed individual. Meaning, for each radionuclide and exposure pathway evaluated, the Task 4 team expected these calculated estimates to overestimate the risk for most or all real individuals.

Through its screening process, the Task 4 team concluded that 16 out of 24 radionuclides released from White Oak Creek to the Clinch River did not need further evaluation because the estimated screening indices, (i.e., the calculated probabilities of developing cancer), were below the minimal level of concern. The Task 4 team further studied the following radionuclides: cobalt 60 (Co 60), strontium 90 (Sr 90), niobium 95 (Nb 95), ruthenium 106 (Ru 106), zirconium 95 (Zr 95), iodine 131 (I 131), cesium (Cs 137), and cerium 144 (Ce 144). In addition, the team eliminated the following pathways from further analysis:

- swimming,
- irrigation,
- produce ingestion, and
- contact with dredged sediment.

The pathways requiring additional evaluation included drinking water, fish consumption, external radiation from contaminants in shoreline sediments, and ingestion of milk and meat from cattle that grazed near the river.

For this public health assessment, ATSDR used the Task 4 report results to re-evaluate past radionuclide exposures. ATSDR also used the report to estimate doses to community members who consumed local livestock or milk, or who used the Clinch River downstream from the mouth of White Oak Creek for recreation or for drinking water. These estimated doses for past radionuclide exposures to community members varied by critical organ, by pathway of exposure, and by gender.

ATSDR's evaluation indicated that people who ate fish taken from that part of the Clinch River near Jones Island received the highest estimated doses of radiation. Doses from fish consumption exceeded dose estimates for all exposure pathways by at least a factor of 6. Primarily, the dose depended on how often people ate fish and on the area of the Clinch River where the fish were collected. The highest cumulative organ doses (1944–1991) were for individuals who consumed fish frequently (1 to 2.5 fish meals per week) and caught their fish near Jones Island, close to the mouth of White Oak Creek. For people consuming fish from the Jones Island area of the Clinch River, estimated organ doses were higher than doses received by people who walked along the shore or who ingested water, milk, meat, and fish at locations downstream of Jones Island.

The Task 4 authors predicted that from any of the exposure pathways, human bone surface received the highest radiation dose. The higher doses to the bone reflect the additional contribution from Sr 90. Still, the maximum annual dose of radiation to the whole body received by people who lived on or used the Clinch River (4 mrem per year) is well below (25 times less than) the 100 mrem per year dose recommended for the public by ATSDR, by the International Commission on Radiological Protection (ICRP), by the U.S. Nuclear Regulatory Commission (NRC), and by the National Council on Radiation Protection and Measurements (NCRP). Furthermore, the estimated annual whole-body dose of 4 mrem is about 2% of the 360 mrem that the average U.S. citizen receives each year from background radiation (i.e., levels typically found in the environment and in sources from human activities and products, such as medical x-rays).

The maximum dose to the whole body over a lifetime (estimated committed effective dose of 278 mrem over 70 years) from all water and sediment exposure pathways is well below (18 times less than) ATSDR's radiogenic cancer comparison value of 5,000 mrem over 70 years. Doses below this value are not expected to result in observable health effects. Radiation lifetime doses to critical organs (e.g., bone, lower large intestine, red bone marrow, breast, and skin) are also less than ATSDR's comparison values. ATSDR also conducted a separate analysis of possible exposures to radionuclides for Happy Valley residents who relied on the K-25 water intake along the Clinch River for their drinking water. ATSDR's estimated annual whole-body dose of 14 mrem from drinking water at Happy Valley in the past is at least 7 times lower than ATSDR's MRL of 100 mrem/year and the ICRP, NRC, and NCRP recommended maximum dose for the public of 100 mrem/year. Therefore, people who lived along or used the Clinch River and who in the past were exposed to levels of radionuclides from White Oak Creek were exposed at levels that are not considered to be a public health hazard.

Current and Future Exposure (1988–Present and Future)

ATSDR evaluated current and future exposure to radionuclides released from the X-10 site to the Clinch River and the LWBR via White Oak Creek. ATSDR evaluated current exposure to radionuclides via consumption of surface water, dermal contact with surface water and sediment, and consumption of fish and game. ATSDR's review of environmental data collected in and around the Clinch River and LWBR areas shows that the following practices

- *annual environmental monitoring,*
- *institutional controls intended to prevent disruption of sediment,*
- *on-site engineering controls to prevent off-site contaminant releases, and*
- *DOE continuing its expected appropriate and comprehensive system of monitoring (e.g., of remedial activities and contaminant levels in media), maintenance, and institutional and engineering controls,*

have limited exposure to the current levels of radionuclides in surface water, sediment, fish, and game to the point that radionuclides are not expected to cause any current or future harmful health effects. Given this evaluation, ATSDR concludes that current and future off-site exposure to radionuclides in the Clinch River and the LWBR via White Oak Creek is not a public health hazard.

In its evaluation of current exposures and doses related to releases from White Oak Creek, ATSDR used, for data from 1989 to 2003, DOE's Oak Ridge Environmental Information System (OREIS). OREIS contains data related to compliance, environmental restoration, annual site summary reports, and surveillance activities, which include but are not limited to studies of the Clinch River embayment and the Lower Watts Bar Reservoir. ATSDR also obtained 1989–1994 data from ATSDR's 1996 health consultation entitled *Health Consultation for U.S. DOE Oak Ridge Reservation: Lower Watts Bar Reservoir Operable Unit. Oak Ridge, Anderson County, Tennessee. Atlanta, Georgia: U.S. Department of Health and Human Services. February 1996.* These data include environmental sampling from the 1980s and 1990s that DOE, TVA, and various consultants had collected and assembled, as well as data from TVA's 1993 and 1994 annual radiological environmental reports for the Watts Bar Nuclear Plant. ATSDR prepared the 1996 health consultation to respond to community members' concerns about possible exposures to contaminants left in place in LWBR sediment. As part of this process, ATSDR evaluated potential hazards from exposure to either undisturbed or dredged LWBR contaminated sediment and reviewed institutional controls intended to prevent disruption of the contaminated sediment as outlined by the 1991 Watts Bar Interagency Agreement.

ATSDR evaluated *current* exposures to radionuclides via consumption of surface water, dermal contact with surface water and sediment (i.e., shoreline and dredged channel sediment), and consumption of fish and game. ATSDR based its evaluation of *future* exposures on current doses and exposures related to

- releases from White Oak Creek,
- data on current contaminant levels in the LWBR and the Clinch River,
- data on radionuclide concentrations in White Oak Creek,[1]
- institutional controls now in place to monitor contaminants in the LWBR and in the Clinch River, and
- consideration of the possibility that remedial activities could release radionuclides to White Oak Creek.

The cities of Kingston, Spring City, and Rockwood draw drinking water from the Tennessee River system. TDEC's Division of Water Supply regulates drinking water at all public water systems in Tennessee under EPA's Safe Drinking Water Act. As a requirement of this program, TDEC ensures that all public water systems in the state meet safe drinking water standards for a variety of chemical contaminants and radionuclides. TDEC's monitoring of the Kingston, Spring City, and Rockwood public water supplies indicates that the drinking water consistently meets safe drinking water standards. Using these results, ATSDR considers this water safe for consumption and for other household uses.

[1] These data show that the radionuclide releases as well as the concentrations in the water and along the shoreline have decreased over time because of remedial actions and preventive measures at X-10, physical movement of sediments from the area, and radiological decay.

Lower Watts Bar Reservoir (1988–Present and Future)

ATSDR estimated committed effective doses—that is, doses to the whole body that occur over a lifetime—for persons who have been exposed to radionuclides by

- contacting shoreline or dredged sediment,
- swimming in or showering with surface water,
- ingesting surface water, or
- eating fish from the LWBR.

In deriving exposure doses for LWBR, ATSDR scientists used worst-case hypothetical exposure scenarios with conservative (i.e., protective) assumptions that produce doses much higher (i.e., overestimate exposure) than the levels to which people are actually exposed. ATSDR's estimated doses vary by potential pathway of exposure to radionuclides, ranging from 3.5 mrem from swimming in or showering with Lower Watts Bar Reservoir surface water over a period of 70 years to 1,400 mrem over a period of 70 years from walking on and handling contaminated sediments dredged from the LWBR deep river channels. Nonetheless, ATSDR's conservatively derived, committed effective dose to the whole body for all pathways combined is less than 1,900 mrem—2.5 times below ATSDR's radiogenic CV of 5,000 mrem. ATSDR derived the *radiogenic comparison value* of 5,000 mrem over 70 years after reviewing the peer-reviewed literature and other documents developed to review the health effects of ionizing radiation. Doses below this value are not expected to result in observable health effects. Furthermore, the estimated annual whole-body dose is less than 30 mrem, which is below (3 times less than) the dose of 100 mrem per year recommended for the public by ATSDR, ICRP, NCRP, and NRC. Therefore, ATSDR considers that the current exposures associated with the detected level of radionuclides in sediment, surface water, and fish of the LWBR pose no threat to public health.

Clinch River (1989–Present and Future)

ATSDR's estimated committed effective dose to the whole body for all exposure pathways along the Clinch River combined is, for persons to 70 years of age, less than 240 mrem—over 20 times below ATSDR's radiogenic CV of 5,000 mrem over 70 years. The estimated annual whole-body dose is less than 3.4 mrem—nearly 30 times below ATSDR's screening comparison value (see text box) and about 30 times below ICRP's, NCRP's, and NRC's recommended value for the public of 100 mrem/year. The current radiation doses from exposure to radionuclides along the Clinch River varied by organ. ATSDR's estimates show that the *bone* receives the highest total committed equivalent dose over an average (to age 70) lifetime of exposure to radionuclides detected along the Clinch River. The highest committed equivalent doses to the bone were associated with a 15-year-old ingesting goose muscle or liver (230 mrem) and fish (114 mrem) over a period of 55 years. Much lower bone doses were associated with ingestion of Clinch River water (2.8 mrem) and external exposures from walking on sediment (13 mrem) and swimming (1.2 mrem) in the study area. That said, however, the bone dose estimate from all pathways combined, based on exposures for adults occurring over a 50-year period, is less than 218 mrem over 50 years. This is at least 1,788 times lower than the doses of 390,000 to 620,000 mrem associated with bone cancers in radium dial workers. For all pathways combined for adults following 50 years of exposure, the committed equivalent dose of 270 mrem to the lower large intestine was about 18 times less than ATSDR's radiogenic comparison value of 5,000 mrem over 70 years. For adults, the committed equivalent dose to the skin over a 50-year exposure is less than 6 mrem—1,500 times below the 9,000 mrem value based on the Biological Effects of Ionizing Radiation (BEIR) V report of patients irradiated for the treatment of ringworm. Therefore, ATSDR considers that current exposures to detected levels of radionuclides in sediment, surface water, fish, geese, and turtles of the Clinch River pose no threat to public health.

Comparison values (CVs) are doses (health guidelines) or substance concentrations (environmental guidelines) set well below levels known or anticipated to result in adverse health effects. *Health guidelines* are derived based on data drawn from the epidemiologic and toxicologic literature with many uncertainty or safety factors applied to ensure that they are amply protective of human health. *Environmental guidelines* are derived from the health guidelines and represent concentrations of a substance (e.g., in water, soil, and air) to which humans may be exposed via a particular exposure route during a specified period of time without experiencing adverse health effects.

During the public health assessment process, ATSDR uses CVs as screening levels. Substances detected at concentrations or doses above CVs might be selected for further evaluation.

Given its evaluation, ATSDR concludes that the levels of radionuclides released from White Oak Creek to the Clinch River and to the LWBR would not be expected to result in harmful health effects for either adults or children who have used or who might continue to use the waterways for recreation, food, or drinking water. **ATSDR therefore concludes that past, current, and future uses of these watersheds do not pose a health hazard**.

II. Background

II.A. Site Description

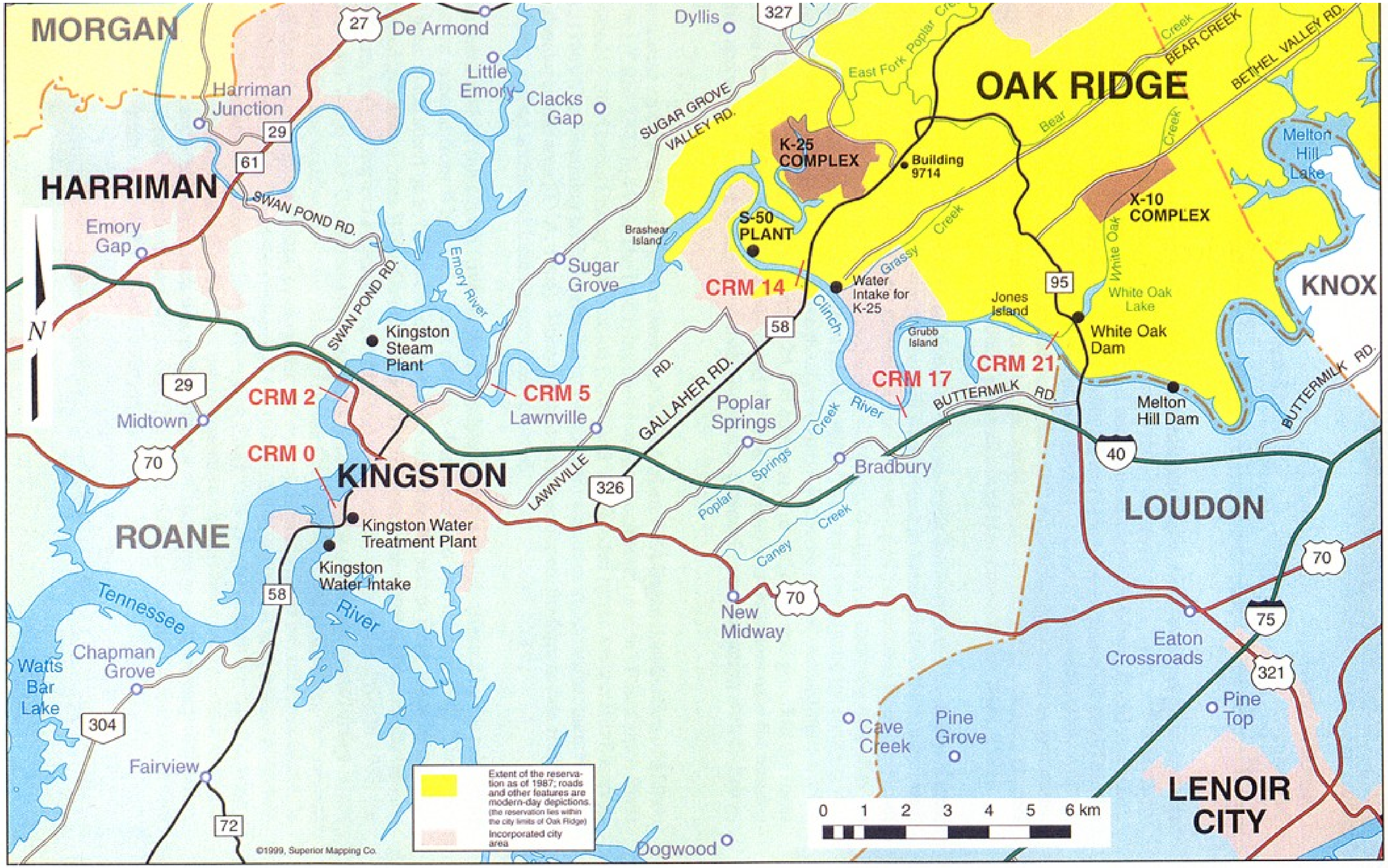
In 1942, during World War II, the U.S. government, under the Manhattan Project initiative, developed the Oak Ridge Reservation (ORR) to produce and study nuclear material needed to make nuclear weapons (ChemRisk 1993b; ORHASP 1999; TDOH 2000). The ORR is located in eastern Tennessee, approximately 15 miles west of Knoxville, and is situated in both Roane and Anderson Counties (ChemRisk 1993b; Jacobs Engineering Group Inc. 1996; ORNL et al. 2002). The southern and western borders of the ORR are formed by the Clinch River, and most of the reservation lies within the Oak Ridge city limits (EUWG 1998). The ORR plants are isolated from the city's populated areas. Figure 1 shows the location of the ORR.

When in 1942 the federal government acquired the ORR, the reservation consisted of 58,575 acres (91.5 square miles). Since that time the federal government has transferred 24,340 (38.0 square miles) of the original 58,575 acres to other parties (e.g., City of Oak Ridge, Tennessee Valley Authority [TVA]), with the U.S. Department of Energy (DOE) maintaining control of the remaining 34,235 acres (53.5 square miles) (Jacobs Engineering Group Inc. 1996; ORNL et al. 2002). Please see Figure 2 for the original and current ORR boundaries.

Under the Manhattan Project, the government constructed four facilities at the ORR. The X-10 site (formerly known as the Clinton Laboratories and now part of what is referred to as the Oak Ridge National Laboratory [ORNL]) was built to produce and separate plutonium. The K-25 site (formerly known as the Oak Ridge Gaseous Diffusion Plant [ORGDP] and now referred to as the East Tennessee Technology Park [ETTP]), the Y-12 plant (now known as the Y-12 National Security Complex), and the former S-50 site (now part of the ETTP) were developed to manufacture enriched uranium (ChemRisk 1993b; Jacobs Engineering Group Inc. 1996; TDEC 2002; TDOH 2000).[2]

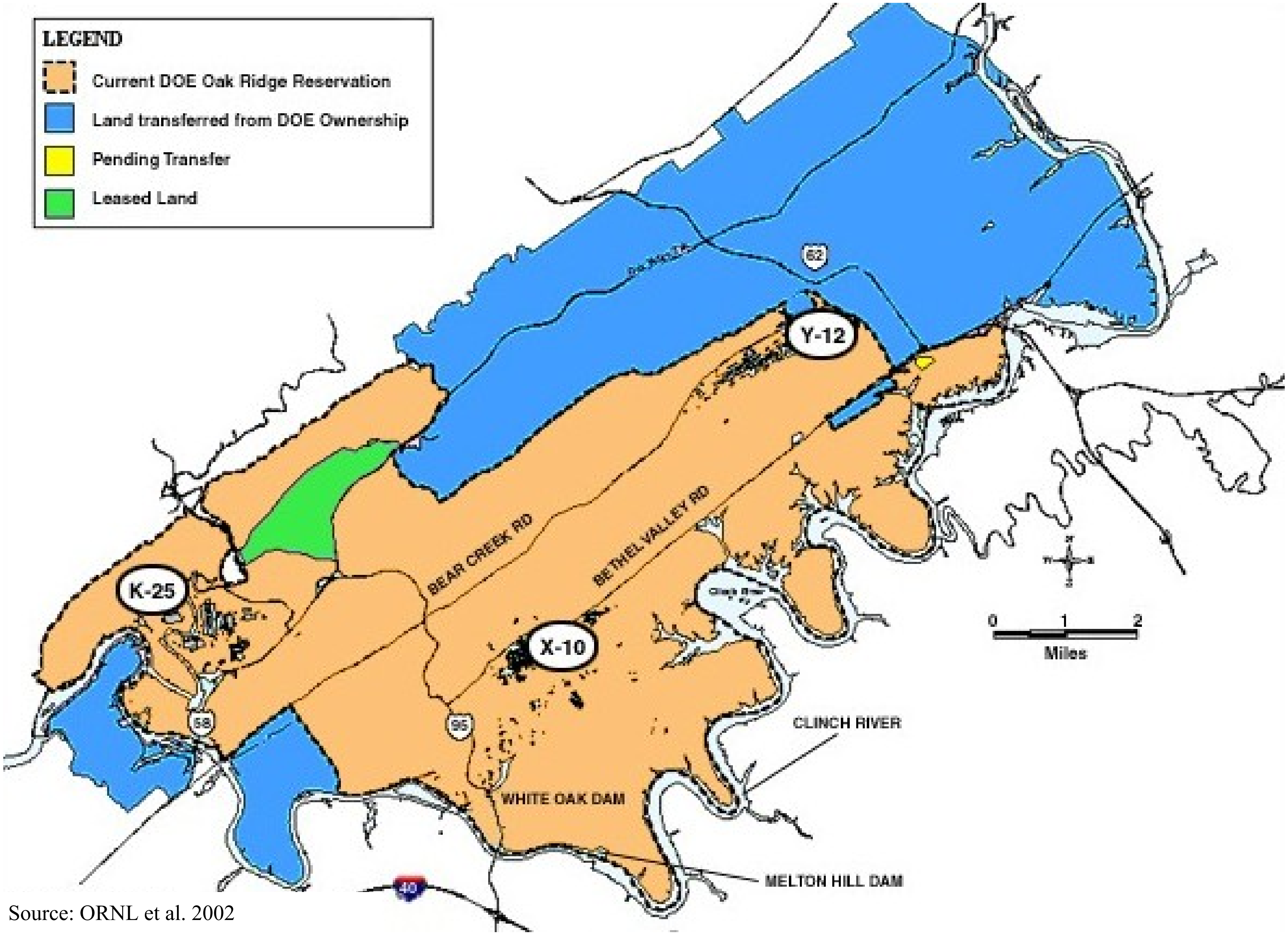
[2] Since this health assessment focuses on radionuclide releases from X-10 to the Clinch River via White Oak Creek, the other main facilities on the ORR are not discussed in detail.

Figure 1. Location of the Oak Ridge Reservation



Source: ChemRisk 1999a

Figure 2. Original and Current ORR Boundaries



Source: ORNL et al. 2002

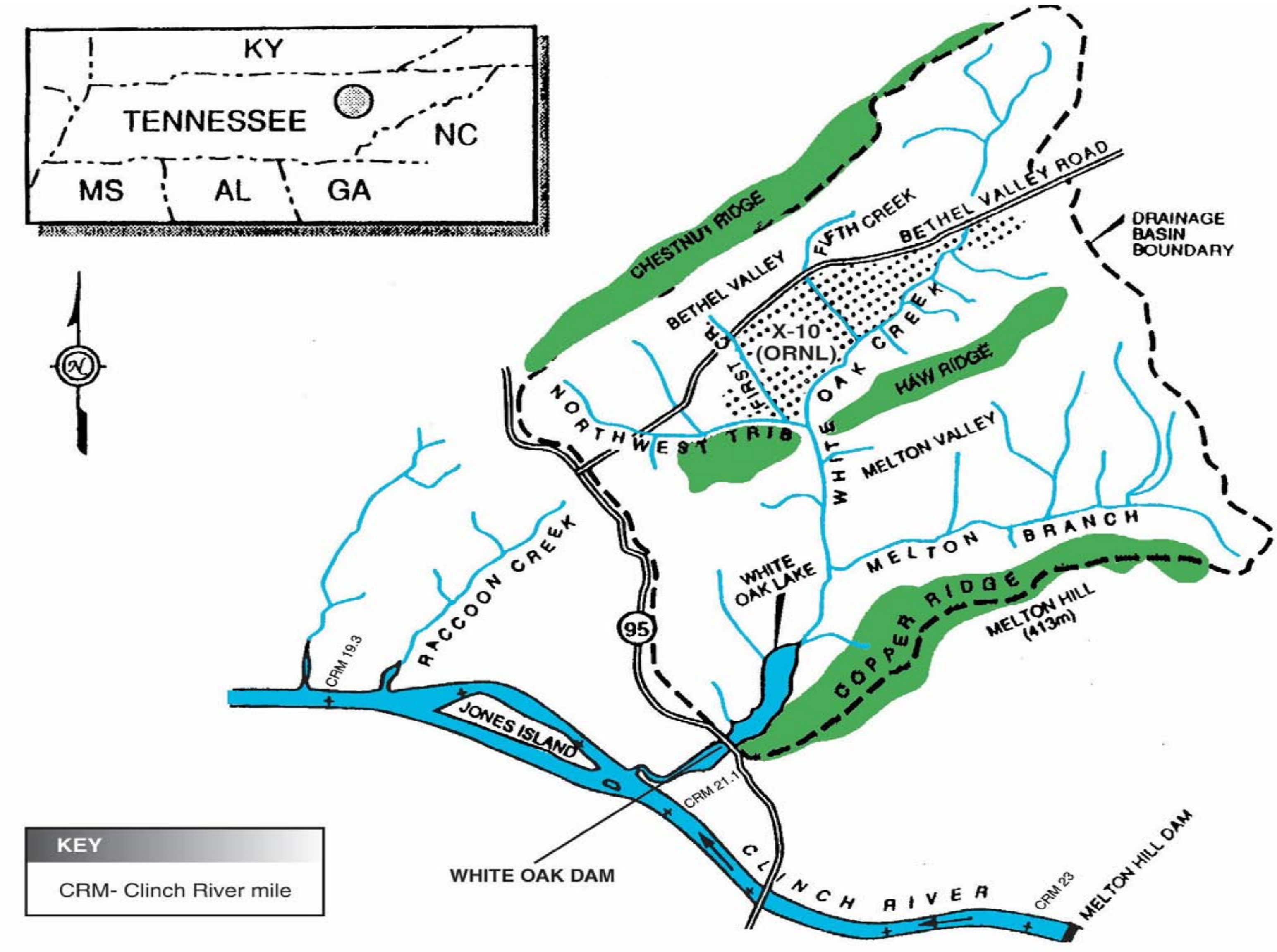
X-10 is now known as the Oak Ridge National Laboratory (ORNL). The entire ORNL site encompasses approximately 26,580 acres and is located in Roane County. The main operations at the laboratory take place on about 4,250 acres—the original X-10 site (Bechtel Jacobs Company LLC et al. 1999; ORNL et al. 1999; TDEC 2002).

The X-10 site is about 10 miles southwest of the city center of Oak Ridge, and is surrounded by heavily forested ridges including Chestnut Ridge, Haw Ridge, and Copper Ridge (ChemRisk 1999a; TDOH 2000). The X-10 site is situated within two watersheds: Bethel Valley and Melton Valley (ORNL et al. 1999). Please see Figure 3 for the location of X-10 in relation to Bethel Valley and Melton Valley. The main laboratory at X-10 is located along Bethel Valley Road, within Bethel Valley (ChemRisk 1999a; ORNL et al. 1999). The X-10 site also contains remote facilities and waste storage areas in Melton Valley (ORNL et al. 1999). White Oak Creek, which begins in Bethel Valley, flows in a southerly direction along the eastern border of the plant and travels through a gap in Haw Ridge before entering Melton Valley (ChemRisk 1993b, 1999a). From Melton Valley, White Oak Creek joins the Clinch River at Clinch River Mile (CRM) 20.8 below Melton Hill Dam (ChemRisk 1999a). See Figure 4 for the location of White Oak Creek and the relationship between X-10, White Oak Creek, White Oak Dam, the Clinch River, and the Watts Bar Reservoir.

Before 1963, the Clinch River close to CRM 20.8 was characteristic of a riverine system. Near the mouth of Grassy Creek, at about CRM 14, the Clinch River "becomes wider, the flow decreases, and Watts Bar Reservoir has a greater influence on the water conditions" (Blaylock 2004). Also before 1963, except during floods on the Clinch River, little backflow entered the White Oak Creek Embayment (Hoffman 2005).

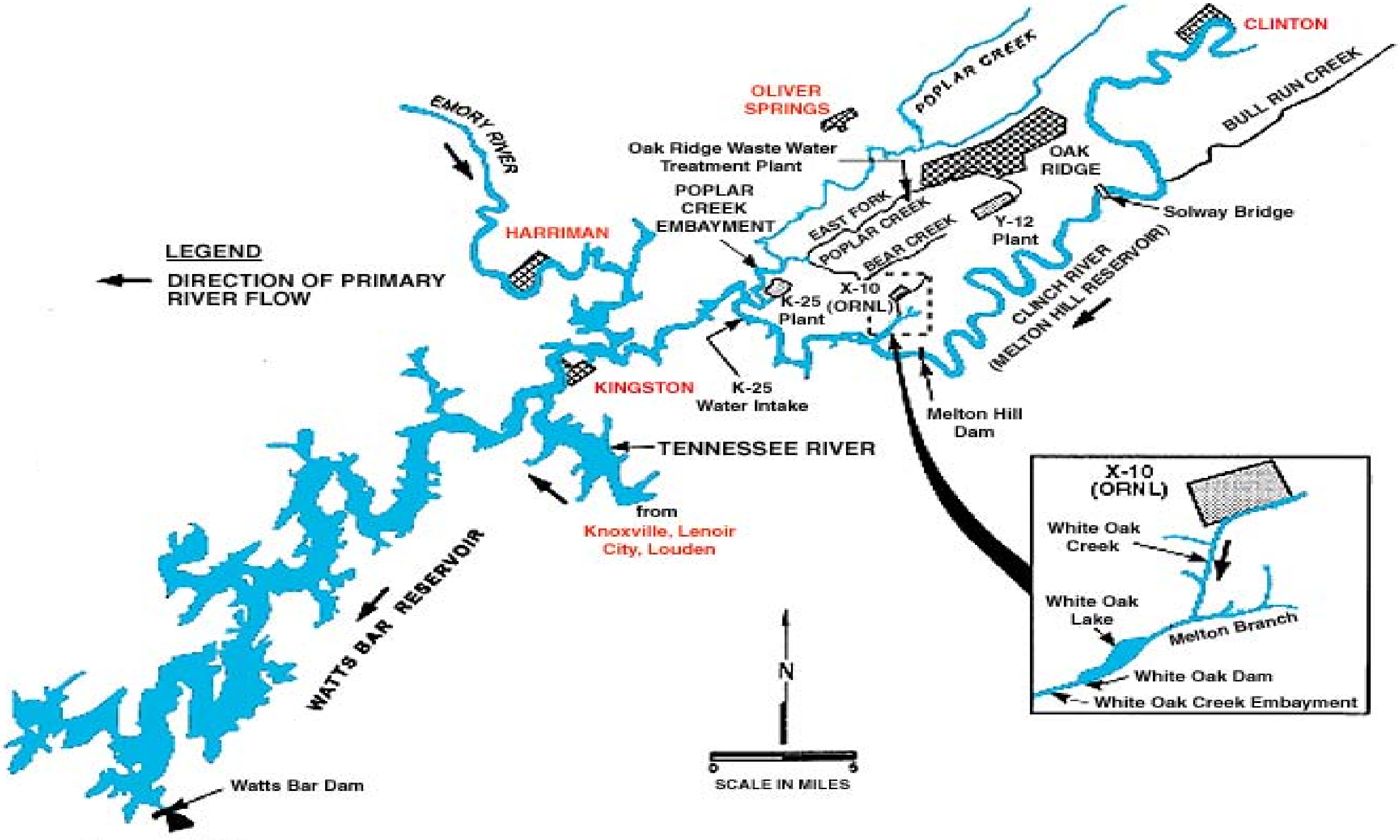
After the construction of the Melton Hill Dam was completed in 1963, the flow of the Clinch River changed. In the morning and evening, Melton Hill Dam releases water when power demands are being met. During remaining times of the day, flow past the mouth of White Oak Creek is extremely minimal. The volume of water released on a daily basis during peak periods is about the same as the quantity of releases prior to Melton Hill Dam's construction, although during peak operations the flow past the mouth of White Oak Creek is significantly higher (Blaylock 2004). The water surge into and out of the embayment, caused by daily releases of

Figure 3. Location of X-10 in Relation to Bethel Valley and Melton Valley



Source: ChemRisk 1999a

Figure 4. Location of White Oak Creek and the Relationship Between X-10, White Oak Lake, White Oak Dam, the Clinch River, and the Watts Bar Reservoir



Source: ChemRisk 1993b

water from Melton Hill Dam and flood flows in White Oak Creek, eroded sediments containing cesium 137 and other contaminants (SAIC 2005). This large volume of water released from Melton Hill Dam caused a backflow up White Oak Creek Embayment and scoured the embayment sediment (Hoffman 2005). "This increased flow can influence the distribution of radionuclides released from White Oak Creek and the deposition of the radionuclides in the Clinch River" (Blaylock 2004). See Figure 1 for the locations of CRM 20.8 and 14, Melton Hill Dam, Watts Bar Reservoir, Clinch River, and White Oak Creek.

II.B. Operational History

Beginning in the early 1940s, the ORR used radioactive material for various processes, such as uranium enrichment, plutonium production, plutonium separation, and the development of separation processes for additional radionuclides (ChemRisk 1993b; Jacobs Engineering Group Inc. 1996).

The X-10 site was built in 1943 as a "pilot plant" to demonstrate plutonium production and chemical separation. The government had intended to operate the facility for only 1 year. This initial time period was, however, extended indefinitely as operations were continued and expanded at X-10 (ChemRisk 1993b; ChemRisk 1999a; TDOH 2000). Because X-10 was developed to produce and separate plutonium, the main plant contained two parts that were both built in 1943: 1) a plutonium production plant called the "Clinton Pile" and later referred to as the ORNL graphite reactor, and 2) a chemical pilot plant developed to separate and purify plutonium. The chemical pilot plant focused on recovering small amounts of plutonium from fuel that was irradiated in the Clinton Pile (ChemRisk 1993b).

After World War II, the facility broadened its focus to include non-weapons related activities, such as the physical and chemical separation of nuclear fission products, the creation and assessment of nuclear reactors, and the production of a range of radionuclides for global use in the medicinal, industrial, and research disciplines (ChemRisk 1993b; U.S.DOE 1994a). In the 1950s and 1960s, the X-10 site became a worldwide research center to study nuclear energy and to investigate the physical and life sciences that are related to nuclear energy. From 1958 to 1987, the Oak Ridge Research Reactor operated to support various scientific experiments at X-10. For a long period of time, this reactor was the main radionuclide supplier to the "free world" for medical, research, and industrial purposes (Johnson and Schaffer 1992; Stapleton 1992; Thompson 1963).

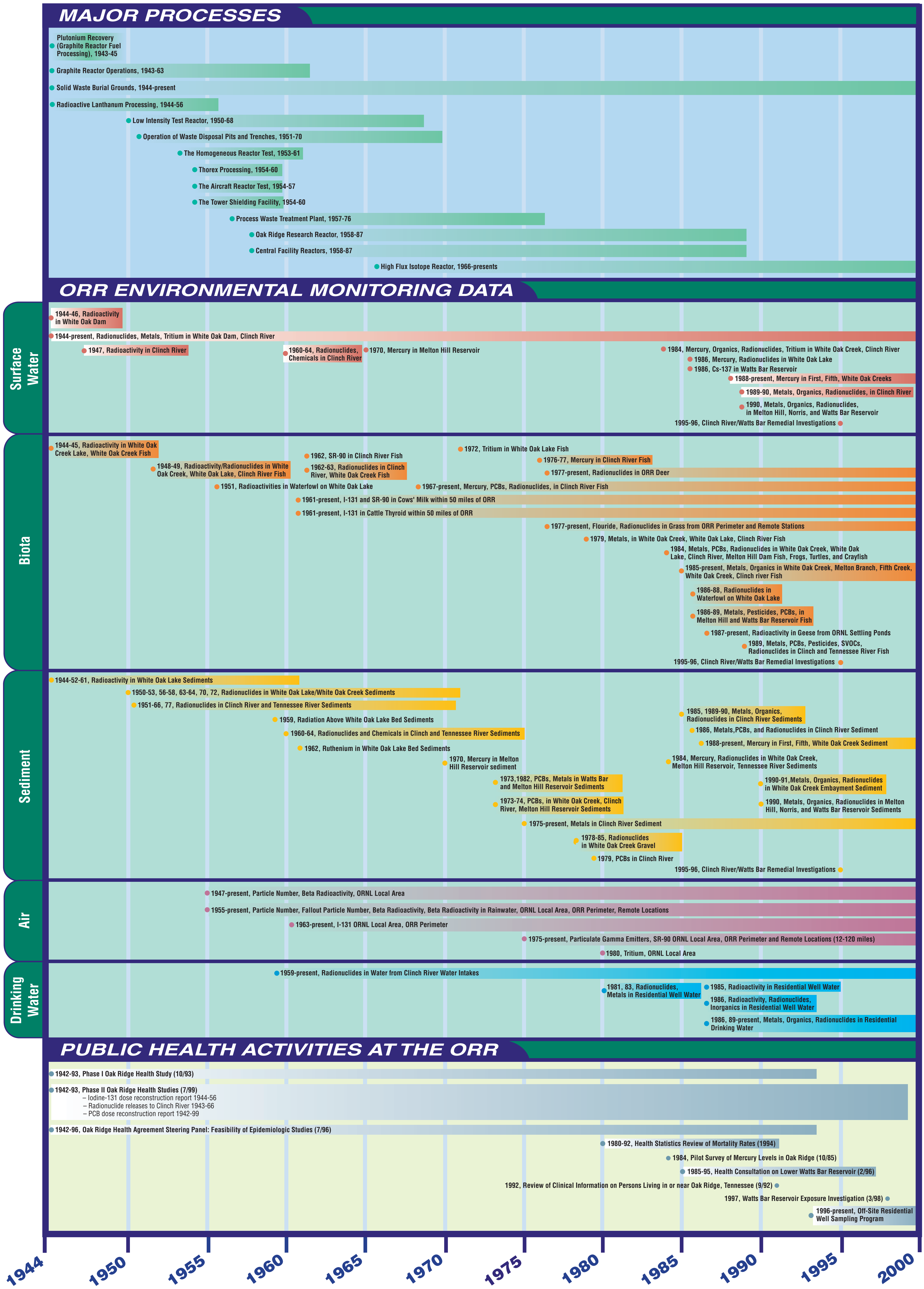
Following the establishment of the U.S. DOE in the 1970s, the research focus at X-10 was extended to include the study of energy transmission, conservation, and production (UT-Battelle 2003). For more than 50 years, the ORR has been the site for extensive scientific investigation by scores of ecologists and environmental scientists. The ORR is a natural haven for wildlife and plants with many rare and endangered species. Today, the X-10 site receives worldwide recognition as a facility for extensive research and development in several areas of science and technology. In addition, the X-10 site produces numerous radioactive isotopes that have significant uses in medicine and research (TDEC 2002). See Figure 5 for a time line of the major processes at the X-10 site.

The operational history of X-10 is described in greater detail in the 1993 Dose Reconstruction Feasibility Study (ChemRisk 1993b). The main processes and activities that are associated with off-site releases of contaminants from X-10 include: 1) production of radioactive lanthanum (RaLa processing) (1944–1956), 2) Thorex processing of short-decay irradiated thorium (approximately 1954–1960), 3) graphite reactor operations (1943–1963), 4) processing of graphite reactor fuel for plutonium recovery (1943–1945), and 5) waterborne and airborne waste disposal (1943–present). For additional details, please see Section 2.1 and 2.3 of *Oak Ridge Health Studies Phase I Report—Volume II—Part A—Dose Reconstruction Feasibility Study. Tasks 1 & 2: A Summary of Historical Activities on the Oak Ridge Reservation with Emphasis on Information Concerning Off-Site Emission of Hazardous Material* (ChemRisk 1993b).

Because the government had planned to run the X-10 site for only 1 year, minimal waste had been expected from the facility's chemical separation processes (ChemRisk 1993b; ChemRisk 1999a; Jacobs Engineering Group Inc. 1996). As a result, the intended waste disposal practices quickly proved insufficient for the amount of wastes generated at X-10. When X-10 began operating in 1943, liquid wastes were put into several underground "gunite" tanks[3] (ChemRisk 1999a; Jacobs Engineering Group Inc. 1996; ORHASP 1999; Spalding and Boegly 1985). These

[3] Tanks were constructed of a water, concrete, and sand mixture called "gunite," which was sprayed over a wire mesh and steel reinforcing rod frame (USDOE 2000).

X-10 Facility Time Line

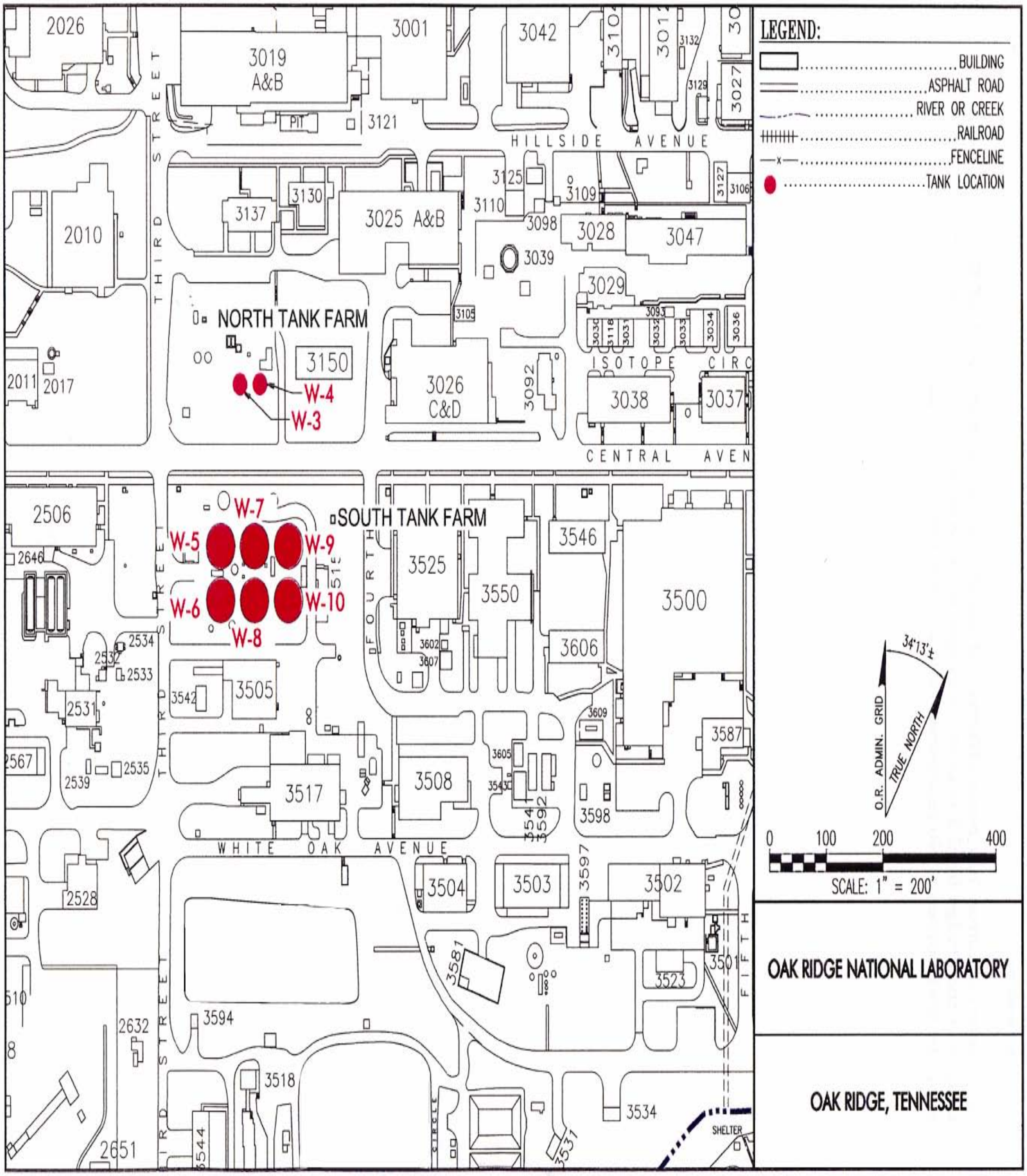


tanks, which are divided into the North Tank Farm and the South Tank Farm, are located in Bethel Valley within the center of X-10's main facility area (SAIC 2002). Please see Figure 6 for the location of the tanks.

Each gunite tank held 170,000 gallons, but the amount of liquid wastes and sludges quickly filled up the tanks. The sludges were kept in the gunite tanks; however, the liquid wastes were held until enough radioactivity was lost through decay before the liquid waste (combined with diluting water) could be released to White Oak Creek (ChemRisk 1999a; Jacobs Engineering Group Inc. 1996; ORHASP 1999; Spalding and Boegly 1985; USDOE 1996a). The creek received the liquid wastes from the tanks and storm water drainage as it flowed through the X-10 facilities. In June 1944, the 3513 Pond was created as a supplementary settling basin for gunite tank liquids and as a basin where short-lived radionuclides could further decay before being released to White Oak Creek (Jacobs Engineering Group Inc. 1996; Spalding and Boegly 1985).

Prior to emptying into the Clinch River, White Oak Creek flows through several contaminated areas in Melton Valley (for example, the old hydrofracture facility) before it runs into White Oak Lake (on-site) (TDOH 2000). This lake was used as a final "settling basin" since 1943 for radionuclides released from X-10 (Blaylock et al. 1993; ChemRisk 1999a; TDOH 2000; USDOE 2002a). See Figure 7 for a photograph (1991) of the X-10 site, White Oak Lake, the X-10 disposal area, and the Clinch River. White Oak Lake was made when White Oak Dam was built across White Oak Creek in 1943. This dam was used as a basin for further settling of the solids that remained (Jacobs Engineering Group Inc. 1996). Please see Figure 4 for the location of White Oak Dam. But some waste products did not settle into the 3513 Pond or White Oak Lake; instead, some of the flow spilled over White Oak Dam into the White Oak Creek Embayment and then reached the Clinch River (TDOH 2000; USDOE 2002a). Most of the wastes released to White Oak Creek are associated with former operations at X-10. This waste includes but is not limited to radionuclides. The X-10 site began discharging radioactive waste to the Clinch River via White Oak Creek in 1943. Thus, the Tennessee Department of Health (TDOH) conducted Task 4 of the *Reports of the Oak Ridge Dose Reconstruction, Radionuclide Releases to the Clinch River from White Oak Creek on the Oak Ridge Reservation—an Assessment of Historical Quantities Released, Off-Site Radiation Doses, and Health Risks* to evaluate whether off-site

Figure 6. Location of the Gunite Tanks at the X-10 Site



Source: SAIC 2002

Figure 7. Photograph (1991) of the X-10 Site, White Oak Creek, White Oak Lake, White Oak Dam, X-10 Disposal Areas, White Oak Creek Embayment, Sediment Retention Dam, and the Clinch River

Source: TDOH 2000

populations have been exposed to radioactive waste from X-10 between 1944 and 1991 (the Task 4 dose reconstruction is used to examine past exposures in this public health assessment).

Since 1944, solid wastes generated by X-10 were disposed of at six solid waste storage areas (SWSAs) (USDOE 1994a). The first three SWSAs (1-3) are located in Bethel Valley and the remaining three SWSAs (4-6) are located in Melton Valley (ChemRisk 1993b, 1999a). For a map of these solid waste storage areas, please see Figure 8. Between 1955 and 1963, these waste storage areas were allocated as the Southern Regional Burial Ground by the Atomic Energy Commission. Throughout this time period, the X-10 site functioned as a main disposal location for wastes from more than 50 off-site installations (e.g., Knolls Atomic Power Laboratory, Battelle Memorial Institute), various research facilities, small contractors, several isotope consumers, and Atomic Energy Commission installations (EUWG 1998; Lockheed Martin Energy Systems, Inc. 1998). Please see Table 1 for more information on these disposal areas.

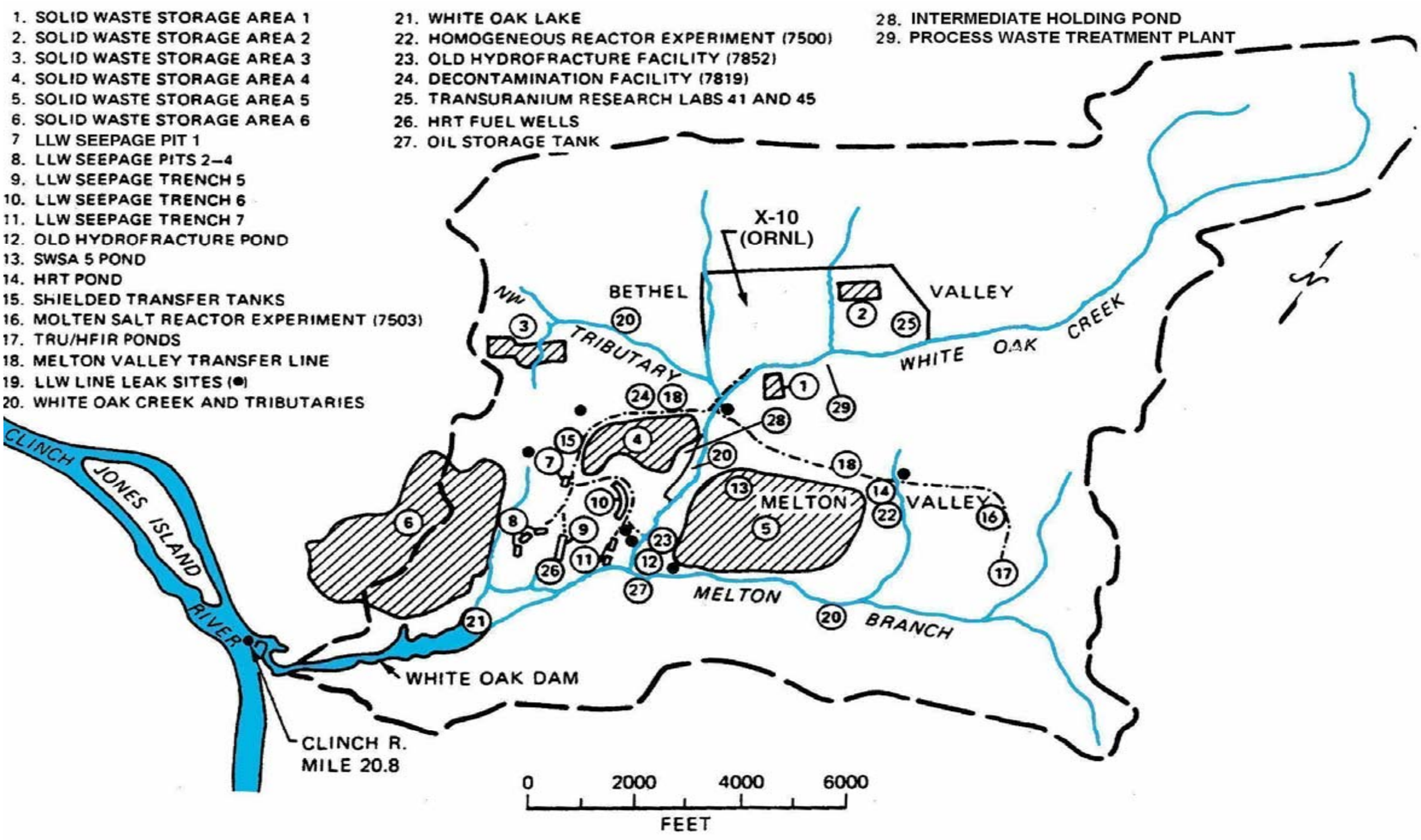
Table 1. Solid Waste Disposal Areas at the X-10 Site

Disposal Area	*Period of Operation*	*Status*	*Acreage*
1	1943–1944	Closed	1
2	1944–1946	Closed	4
3	1946–1951	Closed	6
4	1951–1959	Closed	23
5	1959–1973	Closed	50
6	1969–Unknown	Closed	68 (14.5 acres are usable)

Source: Bates 1983; TDEC 2006a

While X-10's operations continued, the amount of wastes generated at the site continued to increase. During X-10's early years of operation, after liquid radioactive wastes were initially treated they were pumped into an Intermediate Holding Pond (IHP) adjacent to the east side of SWSA 4 (see Figure 8 for the general location of the IHP next to SWSA 4 and Section II.C.2. for IHP-related remedial activities). The "hottest" radioactive substances decayed in the pond; the radionuclides that did not settle into the pond flowed downstream to the Clinch River (TDEC 2003a). In addition, between 1951 and 1976 the facility alternately used seven unlined "earthen pits" for liquid waste disposal (Spalding and Boegly 1985). A process waste treatment plant (PWTP), shown on Figure 8, was built in 1957 to retrieve fission products from these (and

Figure 8. Location of Solid Waste Storage Areas (SWSAs) at the X-10 Site



KEY
HFIR- high flux isotope reactor; HRT- homogenous reactor test; LLW- low-level waste; SWSA- solid waste storage area; TRU- transuranic

Source: ChemRisk 1999a

additional) liquid wastes before their disposal (a more advanced facility replaced this in 1976) (USDOE 1994a). In 1960, the "earthen pit" (also known as a low-level waste [LLW] seepage pit) was changed to an "earth-covered trench" (also called a LLW seepage trench) to reduce inadvertent radiation exposure and rainwater buildup.[4] Over time, leaks occurred at several of these pits, which resulted in the releases of various radionuclides (Spalding and Boegly 1985).

Trenches were used until 1966, when "hydrofracture technology"[5] was initiated for liquid waste disposal (Spaulding and Boegly 1985). The first hydrofracture facility operated between 1964 and 1979; 26 injections were made during this time period. A newer facility started performing injections in June 1982, but this operation was discontinued in 1984 because of uncertainties related to potential leaching into deep groundwater (Boyle et al. 1982; Ohnesorge 1986). ATSDR evaluates hydrofracture technology in its public health assessment on groundwater (available at http://www.atsdr.cdc.gov/HAC/PHA/region_4.html#groundwater).

In addition to releases from disposal areas, radioactive substances were discharged when White Oak Lake was partially drained in October 1955. The lake was drained to give X-10 a greater capacity to handle large discharges and to lessen the chance that ducks would live in the contaminated water (Blaylock et al. 1993). Before it could revegetate, severe rains in 1956 caused a flood that eroded the bottom sediment of White Oak Lake (Blaylock et al. 1993; ChemRisk 1999a). This resulted in the largest discharge of Cs 137 at the lake and also caused radionuclides in particulate form to deposit in the White Oak Creek Embayment. Sedimentation had covered this large amount of released cesium. Eventually, however, with the backflow of water from Melton Hill Dam into the Clinch River, the cesium gradually became uncovered (Hoffman 2005). In the early 1990s, a coffer cell dam was built at the mouth of White Oak Creek to prohibit water backflow to the White Oak Creek Embayment. After this dam was completed, the natural scouring of sediment at the embayment was prevented (ChemRisk 1999a).

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[4] These trenches operated hydraulically in a manner similar to a septic tank drain field, but with the waste being retained closely downstream rather than upstream; in this case, by virtue of the electrostatically polar nature of the clay and shale particles surrounding the trenches. These particles attracted and held a large fraction of the radioisotopes seeping out of the trenches. The trenches were also originally known as "intermediate level" liquid waste disposal trenches.

[5] Hydrofracture technology uses hydraulic pressure to create cracks in the shale bedrock layers that are below the disposal area. Low-level waste alkaline solutions are combined with cement and infused with pressure into the fracture zone. This grout mixture seals the cracks and stagnates wastes that are in the deep shale formation.

DOE predicted that 70% to 80% of radioactive substances released from X-10 to surface waters resulted from seepage at waste disposal areas (USDOE 1988). Mainly because of these disposal practices at X-10 and the heavy rains in 1956, approximately 200,000 curies of radioactive waste were discharged from White Oak Creek into the Clinch River between 1944 and 1991 (ATSDR et al. 2000; TDOH 2000). Please see Table 2 for the estimated discharges of radionuclide releases to the Clinch River via White Oak Creek (Jacobs Engineering Group Inc. 1996). Table 3 is a summary of peak annual releases from White Oak Dam for the eight "key" radionuclides—those that were identified for further evaluation based on a pathway and disease incidence analysis of 24 radionuclides (ChemRisk 2000). For additional details regarding the radioactive waste disposal history of the X-10 site, please see Section 2.1.5 of *Oak Ridge Health Studies Phase I Report—Volume II—Part A—Dose Reconstruction Feasibility Study. Tasks 1 & 2: A Summary of Historical Activities on the Oak Ridge Reservation with Emphasis on Information Concerning Off-Site Emission of Hazardous Material* (ChemRisk 1993b) and also Section 2.0 of Task 4 of the *Reports of the Oak Ridge Dose Reconstruction, Radionuclide Releases to the Clinch River from White Oak Creek on the Oak Ridge Reservation—an Assessment of Historical Quantities Released, Off-Site Radiation Doses, and Health Risks* (ChemRisk 1999a). For information on current remedial activities, see Sections II.C.1. (Bethel Valley Watershed), II.C.2. (Melton Valley Watershed), and II.C.3. (Off-Site Locations) in this document.

Table 2. Estimated Discharges (in curies) of Radionuclides From White Oak Creek [a]

Year	Cs 137	Ru 106	Sr 90	TRE [b]	Ce 144	Zr 95	I 131	Co 60	H 3	TRU[c]
1949	77	110	150	77	18	180	77			0.04
1950	19	23	38	30		15	19			0.04
1951	20	18	29	11		5	18			0.08
1952	10	15	72	26	23	19	20			0.03
1953	6	26	130	110	7	8	2			0.08
1954	22	11	140	160	24	14	4			0.07
1955	63	31	93	150	85	5	7	7		0.25
1956	170	29	100	140	59	12	4	46		0.28
1957	89	60	83	110	13	23	1	5		0.15
1958	55	42	150	240	30	6	8	9		0.08
1959	76	520	60	94	48	27	1	77		0.68
1960	31	1,900	28	48	27	38	5	72		0.19
1961	15	2,000	22	24	4	20	4	31		0.07
1962	6	1,400	9	11	1	2	0.4	14		0.06
1963	4	430	8	9	2	0.3	0.4	14		0.17
1964	6	190	7	13	0.3	0.2	0.3	15	1,900	0.08
1965	2	69	3	6	0.1	0.3	0.2	12	1,200	0.50
1966	2	29	3	5	0.1	0.7	0.2	7	3,100	0.16
1967	3	17	5	9	0.2	0.5	0.9	3	13,300	1.03
1968	1	5	3	4	0.03	0.3	0.3	1	9,700	0.04
1969	1	2	3	5	0.02	0.2	0.5	1	12,200	0.20
1970	2	1	4	5	0.06	0.02	0.3	1	9,500	0.40
1971	1	0.5	3	3	0.05	0.01	0.2	1	8,900	0.05
1972	2	0.5	6	5	0.03	0.01	0.3	1	10,600	0.07
1973	2	0.7	7		0.02	0.05	0.5	1	15,000	0.08
1974	1	0.2	6		0.02	0.02	0.2	0.6	8,600	0.02
1975	0.6	0.3	7				0.3	0.5	11,000	0.02
1976	0.2	0.2	5				0.03	0.9	7,400	0.01
1977	0.2	0.2	3				0.03	0.4	6,200	0.03
1978	0.3	0.2	2				0.04	0.4	6,300	0.03
1979	0.2	0.1	2.4				0.04	0.4	7,700	0.03
1980	0.6	0	1.5				0.04	0.4	4,600	0.04
1981	0.2	0.1	1.5				0.04	0.7	2,900	0.04
1982	1.5	0.2	2.7				0.06	1.0	5,400	0.03
1983	1.2	0.2	2.1				0.004	0.3	5,600	0.05
1984	0.6	0.2	2.6				0.05	0.2	6,400	0.03
1985	0.4	0.007	3.0					0.6	3,700	0.008
1986	1.0	0	1.8					0.54	2,600	0.024
1987	0.6	0	1.2					0.12	2,500	0.006
1988	0.4	0	1.1					<0.07	1,700	
1989	1.2	0	2.9					0.13	4,100	
1990	1.1	0	3.1					0.12	3,100	
1991	1.7		2.7					0.12	2,100	
1992	0.6		2.1					0.04	1,900	
1993	0.5		2.1					0.04	1,700	
1994	0.5		2.8					0.07	2,200	
Total	**699.6**	**6,931.6**	**1,214.6**	**1,295**	**341.93**	**376.61**	**175.33**	**325.58**	**183,100**	**5.248**

Source: Blaylock et al. 1993; Martin Marietta Energy Systems, Inc. 1992, 1993; USDOE 1988

a All digits were carried through to avoid any errors from rounding numbers. Only the first two are significant.

b Total of rare earth elements, excluding cerium.

c Transuranic radionuclides.

Blank cells indicate that no data were reported.

The four radionuclides expected to be of most concern are highlighted in gray.

Table 3. Summary of Peak Annual Releases From White Oak Dam for the Eight Key Radionuclides (1944–1991)

Radionuclide	*Peak Annual Releases (curies)*			*Number of Years at 10% of Peak Release or More*
	Lower Bound	*Central Estimate*	*Upper Bound*	
Cesium 137	50	200	510	14
Ruthenium 106	1,600	2,100	2,700	5
Strontium 90	68	190	390	18
Cobalt 60	64	85	110	15
Cerium 144	70	94	120	13
Zirconium 95	72	210	440	9
Niobium 95	17	200	520	10
Iodine 131	10	68	190	10

Source: ChemRisk 2000
Annual estimates were based on data in log books, interviews with knowledgeable parties, and laboratory documents.

II.C. Remedial and Regulatory History

As a result of several on-site processes that produced nonradioactive and radioactive wastes, on November 21, 1989, EPA listed the ORR on the final National Priorities List (NPL) (EUWG 1998; USDOE 2001a; USEPA 2002a). The DOE is performing remediation activities at the reservation under a Federal Facility Agreement (FFA), which is an interagency agreement between the DOE, EPA, and TDEC. The EPA and TDEC, along with the public, help DOE select the details for remedial actions at the ORR (USDOE 2003a). These parties work collaboratively to ensure that adequate remediation activities are used, and to ensure that hazardous waste related to previous and current ORR activities is completely studied and appropriate remedial action is taken (USDOE 1996b, 2003a). DOE is conducting its investigations of the ORR under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), a program that requires an FFA be established for all NPL sites owned by the federal government (EUWG 1998; USEPA 2002b). In addition, DOE is incorporating response procedures designated by CERCLA, with mandatory actions from the Resource Conservation and Recovery Act (RCRA) (USEPA 2002b). See Figure 5 for a time line of major processes, environmental data, and public health activities associated with the X-10 site.

> The Federal Facility Agreement was implemented at the ORR on January 1, 1992. This is a legally binding agreement used to establish schedules, procedures, and documentation for remedial activities at the ORR (EUWG 1998). The Federal Facility Agreement is available online at http://www.bechteljacobs.com/pdf/ffa/ffa.pdf.