"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 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 & Schaffer 1992, Stapleton 1992, and 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 (ChemRisk 1999a; Jacobs Engineering Group Inc. 1996; ORHASP 1999; Spalding and Boegly 1985). These 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.

Figure 5. X-10 Facility Time Line

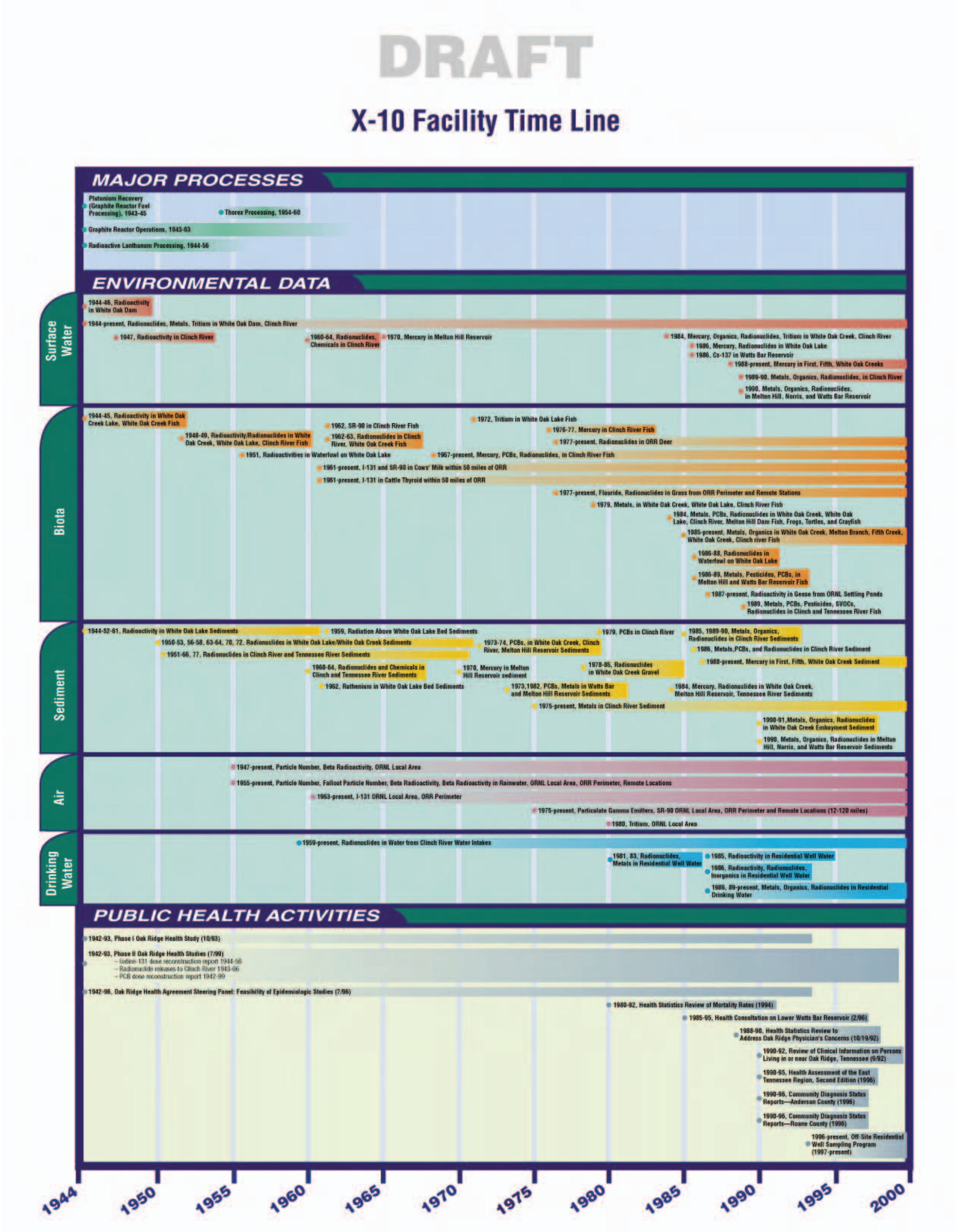
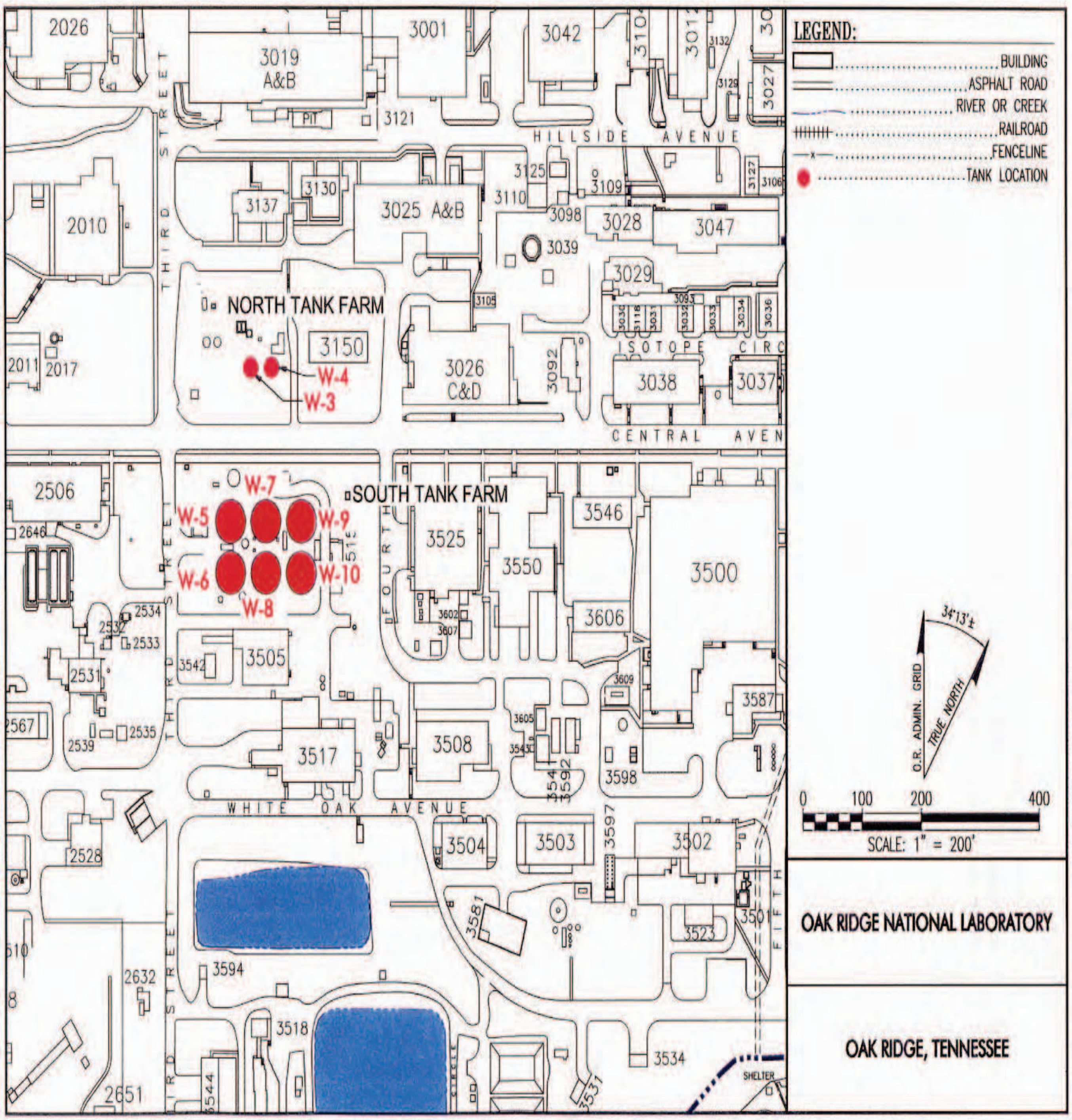


Figure 6. Location of the Gunite Tanks at the X-10 Site



Source: SAIC 2002

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; U.S. DOE 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; U.S. DOE 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, the waste traveled over White Oak Dam and reached the Clinch River (TDOH 2000). Most of the waste product releases 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* to evaluate whether off-site 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).

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

The above photograph from 1991 shows X-10/ORNL (upper right), White Oak Lake (lower center), X-10/ORNL disposal area (above White Oak Lake), and the Clinch River (lower left).

Source: TDOH 2000

Since 1944, solid wastes generated by X-10 were disposed of at six solid waste storage areas (SWSAs) (U.S. DOE 1994a as cited in Jacobs Engineering Inc. 1996). 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; ChemRisk 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 (Lockheed Martin Marietta Energy Systems, Inc. 1998). Please see Table 1 for additional 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	Open for retrievable storage only past 1973.	50
6	1969–Unknown	Current status is not indicated.	68 (14.5 acres are usable)

Source: Bates 1983 as cited in ChemRisk 1993b

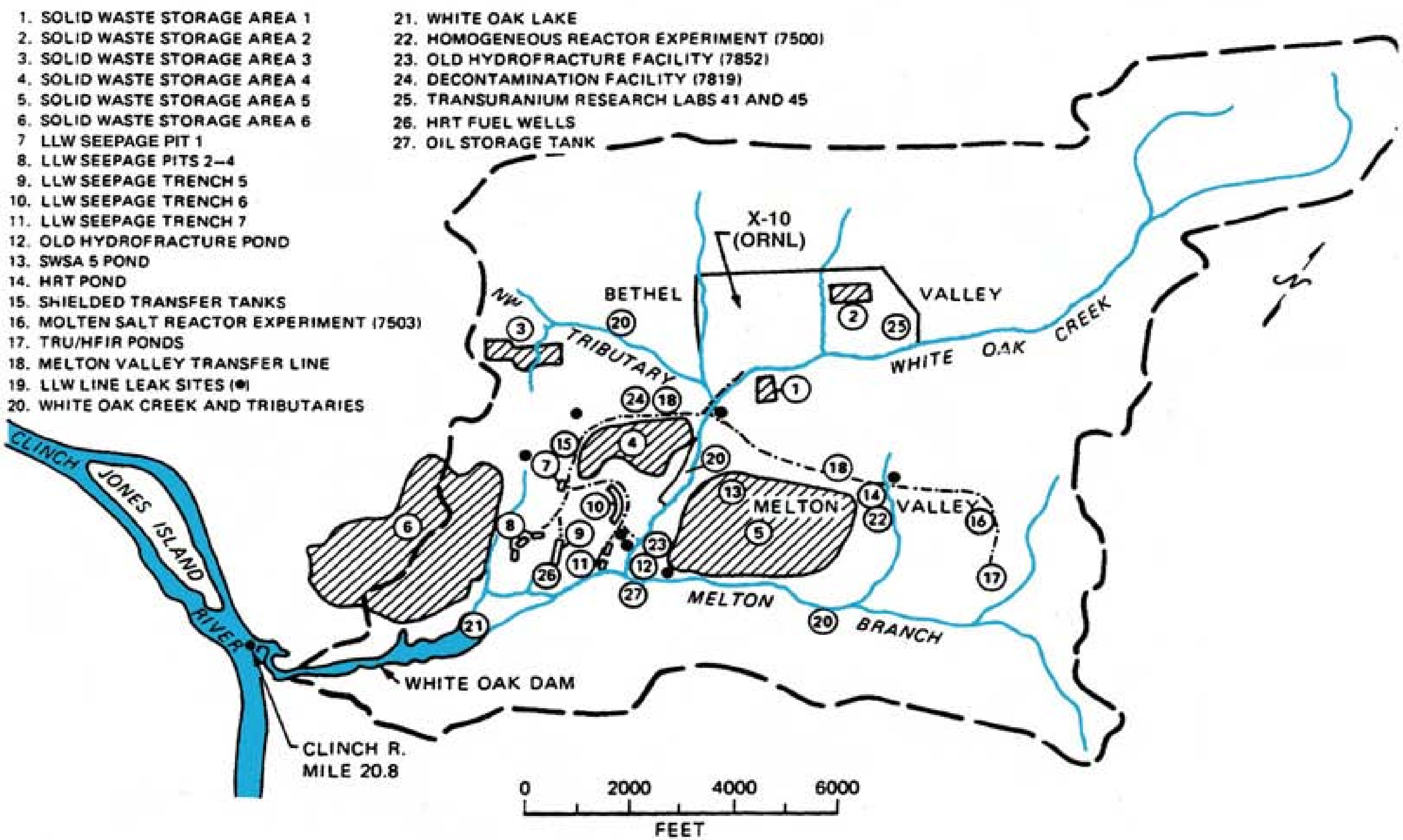
While X-10's operations continued, the amount of wastes generated at the site continued to increase. During X-10's early years of operation, after liquid radioactive wastes were initially treated they were pumped into an Intermediate Holding Pond (IHP) adjacent to the east side of SWSA 4 (see Figure 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 "earthen pits" for liquid waste disposal (Spalding and Boegly 1985). A wastewater treatment process plant was built in 1957 to retrieve fission products from these (and additional) liquid wastes before their disposal (a more advanced facility replaced this in 1976) (U.S. DOE 1994a). In 1960, the "earthen pit" was changed to an "earth-covered trench" to reduce inadvertent radiation exposure and rainwater buildup. 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"[2] 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 will evaluate hydrofracture technology in its future public health assessment on groundwater.

In addition to releases from disposal areas, radioactive substances were discharged when White Oak Lake was partially drained in October 1955 (Blaylock et al. 1993). 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. 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).

[2] 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.

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



KEY
CFRF-consolidated fuel recycling facility; HFIR-high flux isotope reactor; HPRR-health physics research reactor; TSF-tower shielding facility

Source: ChemRisk 1999a

DOE predicted that 70% to 80% of radioactive substances released from X-10 to surface waters resulted from seepage at waste disposal areas (U.S. DOE 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, Martin Marietta Energy Systems, Inc. 1993, and DOE 1988 as cited in Jacobs Engineering Group Inc. 1996

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.