Implications and Remediation Efforts for Uranium and Mercury Contaminated Soils and Water at the Y-12 Site on the Oak Ridge Reservation in Oak Ridge, TN

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1. Abstract

The Y-12 National Security Complex on the Oak Ridge Reservation in Oak Ridge, TN has a long history of nuclear operations and handling. Since as early as the Cold War, the site has been a source of myriad contamination issues involving uranium and mercury. Over the past several decades, there has been substantial remediation efforts of legacy heavy metal contamination. However, continued work and research is needed to return the site to its intended end-use purpose. This paper will focus on the legacy of uranium and mercury contamination on the Oak Ridge Reservation from nuclear production, and will explore a few of the many ongoing remediation efforts being employed to combat its environmental presence.

2. Introduction

On the verge of World War II in 1939, the great race among the world's leading scientists was on to develop nuclear energy. Hungarian refugee scientists Leo Szilard and Enrico Fermi discovered the ability to generate massive amounts of power from nuclear chain reactions of uranium (Atomic Heritage Foundation, 2017). However, Germany had already seized control of large uranium mines, indicating their scientists were well ahead of the game (Atomic Heritage Foundation, 2017). Szilard penned an urgent note, signed by Einstein to United States President Franklin D. Roosevelt on August 2, 1939, urging expedited research in America along with government cooperation (Atomic Heritage Foundation, 2017). As Roosevelt took heed, thus began the search for ideal sites to prepare materials for constructing what would become the world's first atomic bomb under the moniker *The Manhattan Project*. However, the creation of such a weapon would not only succeed in bringing an end to World War II in 1945, but would also place America at the forefront of the arms race.

Following the end of World War II, America found itself still at major disagreement with the Soviet Union, which inevitably led to the Cold War, lasting from 1947 until 1991 (History, 2009). During the Cold War, The United States began constructing hydrogen bombs using the sites originally constructed for the *Manhattan Project*. However, these weapons would require a new fuel source, and as a result would leave a contamination legacy for generations to come. This paper will focus on the legacy of uranium and mercury contamination on the Oak Ridge Reservation from producing atom and hydrogen bombs, and will explore the ongoing remediation efforts being employed to combat its environmental presence.

3. Site Selection

In 1942, Leslie Groves was named the commander of the *Manhattan Project* and was tasked with finding the ideal location to build the facilities (Johnson and Jackson, 1981) that would manufacture the components needed to produce the United States' first atomic bombs *Little Boy* (fueled by highly enriched uranium) and *Fat Man* (fueled by highly enriched plutonium 239) (Atomic Heritage Foundation, 2014). One of three sites selected would be located in Anderson and Roane counties in Tennessee (shown in Figure 1), and cover 32,671 acres, (DOE/ORO-251). The Oak Ridge Reservation was ideally situated to provide ample water, access to railroads, and was also accessible to motor vehicles, while being tucked away in private (Johnson and Jackson, 1981).

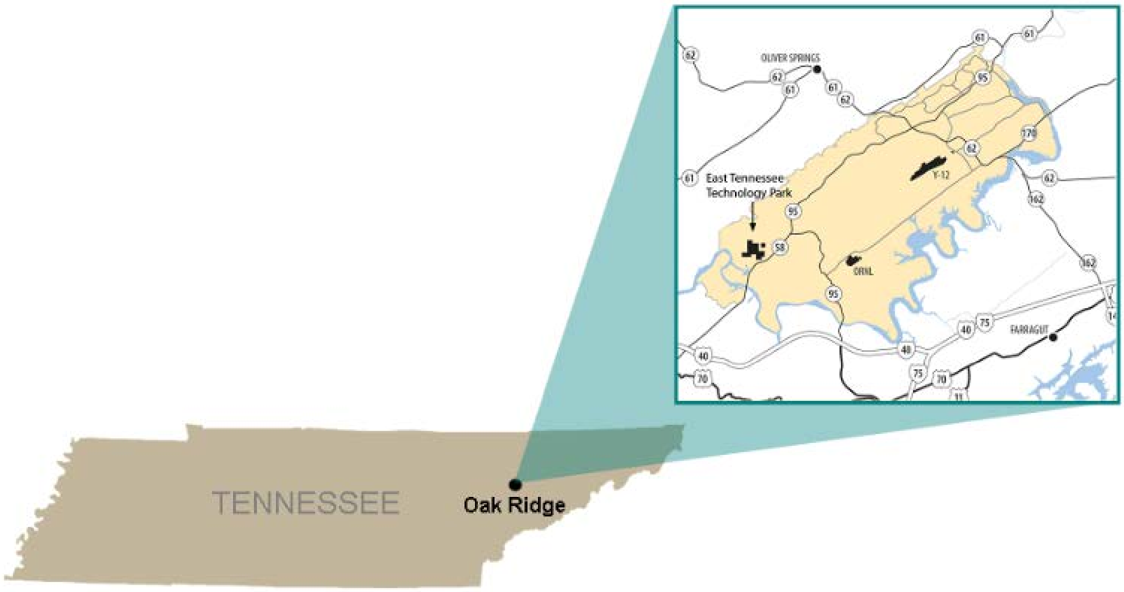


Figure 1 Location of the Oak Ridge Reservation in Oak Ridge, Tennessee. (Garland et al., 2013).

4. Y-12 National Security Complex on the Oak Ridge Reservation

The Y-12 National Security Complex is one of several sites that comprises the Oak Ridge Reservation. When Y-12 construction began in February of 1943, the primary function of the site was to produce enriched uranium-235 using electromagnetic separation from uranium-238 isotopes (Y-12 Mercury Task Force Files, 2017) that would be used in *Little Boy* during World War II (OREM, 2017).

With the end of World War II and the beginning of the Cold War, the function of Y-12 transitioned in the 1950s. The new objective of the site was to produce lithium deuteride to fuel the new hydrogen bombs being produced (Y-12 Mercury Task Force Files, 2017). Part of the process to separate the lithium-6 and lithium-7 isotopes required a solution of lithium in mercury, in which millions of pounds of mercury from the National Stockpile were utilized (Y-12 Mercury Task Force Files, 2017). Subsequently, extensive amounts of mercury were released into the environment (OREM, 2017).

Finally, with the Cold War ending, the function of Y-12 was no longer producing weapons, but was to disassemble weapons, demolish facilities no longer used, store uranium, and to remediate legacy contaminants (OREM, 2017).

4.1 Geology of the Oak Ridge Reservation

It is important to understand the underlying geology of the Oak Ridge Reservation to have a better understanding of groundwater flows, which is the major source of contaminant transport, and other hydrologic features of the site. Having a better understanding of these systems is pertinent in modeling scenarios, which is implemented when planning widespread remediation strategies. In 1992, the Oak Ridge Hydrologic and Geologic Study (ORRHAGS) Project determined that the Oak Ridge Reservation is situated almost entirely on sedimentary rocks and contains a variety of geologic structures (Hatcher et al., 1992). The Oak Ridge Reservation is located in a fold-thrust belt in the Tennessee portion Appalachian Mountain Range (Hater et al., 1992). Nine stratigraphic units underlie the Oak Ridge Reservation: the Rome Formation, Conasauga Group, Knox Group, Chickamauga Group, Reedsville Shale, Sequatchie Formation, Rockwood Formation, Chattanooga Shale, and the Fort Payne Formation (Hatcher et al., 1992). The three primary groups are the Knox, Conasauga, and the Chickamauga (DOE/OR/01-2718&D1). Systematic fractures, also known as joints, are the most common and important geologic feature on the reservation (Hatcher et al., 1992). Doubling a fracture can increase groundwater flow rate by a factor of eight, according to the cubic law (ORNL/TM-12026.). The Oak Ridge Reservation hosts five soil orders: Entisols, Intceptisols, Alfisols, Ultisols, and Mollisols (Hatcher et al., 1992). Primarily, the orders contain soils belonging to the clay, fine, or loamy families (Hatcher et al., 1992). Table 1 details the soil taxonomy of the Oak Ridge Reservation (Hatcher et al., 1992). The karstic nature of the reservation, combined with the prevalent jointing and various soil orders, forms an impressive conduit system that controls groundwater movement on and around the Oak Ridge Reservation (Hatcher et al. 1992).

Table 1 Soil taxonomy of the Oak Ridge Reservation *(Hatcher et al., 1992).*

Order	Suborder	Great Group	Subgroup	Family
Entisols	Aquents	Fluvaquents	Typic Fluvaquents Aeric Fluvaquents	fine-silty, coarse-silty, fine-loamy, or loamy-skeletal
	Fluvents	Udifluvents	Typic Udifluvents Aquic Udifluvents	fine-silty, coarse-silty, fine-loamy, or loamy-skeletal
Intceptisols	Ochrepts	Dystrochrepts	Typic Dystrochrept Ruptic-Ultic Dystrochrepts	loamy-skeletal or fine-loamy
Alfisols	Aqualfs	Ochraqualfs	Typic Ochraqualfs Aeric Ochraqualfs	fine or fine-loamy
	Udalfs	Hapludalfs	Typic Hapludalfs Ultic Hapludalfs	fine
Ultisols	Aquults	Ochraquults	Typic Ochraquults Aeric Ochraquults	clayey or loamy-skeletal
	Udults	Hapludults Ochreptic Hapludults	Typic Hapludults	clayey, fine-loamy, or loamy-skeletal
		Paleudults	Typic Paleudults	fine-loamy, loamy-skeletal or clayey
Mollisols	Udolls Rendolls	Argiudolls ———	Typic Argiudolls Lithic Rendolls	fine

4.2 Hydrology

In regards to the three primary geologic groups, the Knox Group with underlying Maynardville Limestone portions of the Conasauga Group is classified as a single hydrologic unit, the Knox aquifer, while the shale and siltstone portions of the Conasauga group along with the Chickamauga Group are considered to be aquitards (DOE/OR/01-2718&D1). The Upper East Fork Poplar Creek (UEFPC) Watershed encompasses a drainage area of 1,170 acres, and extends to Poplar Creek and Bear Creek (DOE/OR/01-2718&D1). Figure 2 shows the location of the UEFPC watershed, along with other watersheds, located on the Oak Ridge Reservation (ORR End Use Working Group, 1998). Average precipitation in Oak Ridge, TN is roughly 137 cm per year, of which 90% does not reach the water table, but exits the Oak Ridge Reservation via surface streams (DOE/OR/01-2718&D1). Streams on the reservation, such as Poplar Creek, Bear Creek, and White Oak Creek, along with any contaminants they may be carrying, such as mercury, are discharged into (DOE/OR/01-2718&D1) the Clinch River, (ORNL/TM-12026), and eventually reach the Lower Watts Bar Reservoir of the Tennessee River (DOE/OR/01-2718&D1).

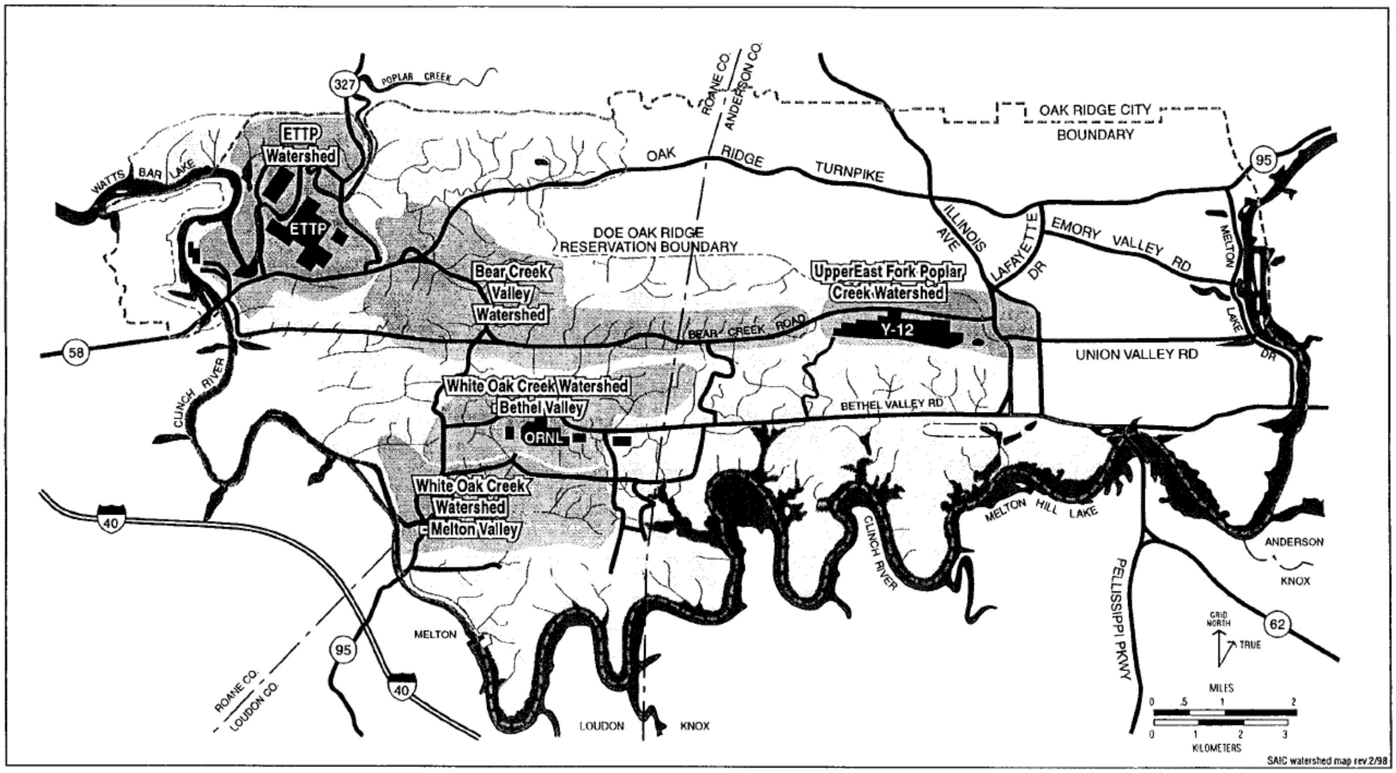


Figure 2 Watersheds on the Oak Ridge Reservation (ORR End Use Working Group, 1988).

4.3 Uranium at Y-12

Uranium is one of the heaviest, naturally occurring metals, and is found primarily in the isotopic form of uranium-238, but also as uranium-235 (World Nuclear Association, 2017), and uranium-234 (EPA*b, 2017).* The primary exposure routes to uranium are through inhalation of contaminated air or dust particles, or through ingestion of contaminated food and water (EPA*b*, *2017*). External exposure to uranium is innocuous since uranium emits alpha radiation which is blocked by human skin (EPA*b,* 2017). In comparison, though, almost 99% of uranium inhaled or ingested may be excreted from the body via urine within a few days, but even the small amount of uranium that may reside in the body can enter the blood stream, which can cause adverse health effects (Aimaq, 2004).

Milling processes for nuclear weapons and reactor fuel are the primary methods of uranium contamination at Y-12 (Vishnivetskaya et al., 2011) through the crushing and grinding of the uranium-238 ores (Thomas and Gates, 1999) to increase the amount of uranium-235 (PHA, 2004). Additional means of initial and continued uranium contamination at the Y-12 site includes four unlined disposal ponds, called the S-3 Ponds area, which received a myriad of mixed wastes, including uranium, from the 1950s through the 1980s (ORNL/TM-2001/27). Each pond is estimated to hold 2.5 million gallons of liquid waste, and was capped over in the late 1980s, now serving as a paved parking lot, as shown in Figure 3. (ARC-2007-D2540-030-04) While the Resource Conservation and Recovery Act (RCRA) cap prevents above-ground contamination, leaching through the cap is causing groundwater and surface contamination issues (ORNL/TM-2001/27). Leached uranium from this cap is anticipated to be responsible for 26% of the uranium contamination in the Bear Creek Watershed (ARC-2007-D2540-030-04). As uranium leaches and enters nearby waterways, it easily biomagnifies in food chains (Vishnivetskaya et al., 2011). There is also a uranium and nitrate-containing groundwater plume that partially intercepts Bear Creek (Vishnivetskaya et al., 2011). Uranium constitutes 98% of total exposure risk in Bear Creek, located 1.86 miles downstream of its introductory point (DOR/OR/02-1701&D3). Unfortunately, due to missing data for air and soil monitoring during the mid-1940s through 1960s and incomplete data on uranium releases in recent years, the precise amount of uranium released into the environment from the Y-12 site is not known. (Aimaq, 2004). Estimates by the DOE acknowledge 6,500 kilograms of uranium was released, while the Oak Ridge Health Agreement Steering Panel conjectures 50,000 kilograms were released into the environment (ORHASP, 1999).

Figure 3 S-3 Ponds are before and after capping (*ARC-2007-D2540-030-04)*

4.3.1 Uranium Health Concerns

Health concerns from exposure to uranium differ between site workers and the general public living in close proximity to the Oak Ridge Reservation. Once uranium that is not excreted enters into the blood stream, it remains in the soft tissues, kidneys, or bones where it can persist for years (PHA, 2004).

Early Y-12 workers were internally exposed to alpha radiation through inhalation of uranium dusts (Loomis and Wolf, 1996). A study by Loomis and Wolf looked at the cause and rate of mortality for Y-12 workers between 1943 and 1990 (1996). Using a study population of just over 10,000 employees, it was found that there was a 20% increase in lung cancer related deaths, along with elevated rates of death from brain, pancreas, prostrate, kidney, breast, and other lymphopoietic cancers (Loomis and Wolf, 1996). A separate study by Frome et al. looked at Y-12 employees from 1943-1985, and also found elevated instances of mortality from lung and lymphopoietic cancers (1997). Fortunately, in 1974, the Nuclear Regulatory Commission (NRC) was created, which regulates, enforces, and helps protect workers (USNRC, 2018). Current workers at the Oak Ridge Reservation are protected under the Code of Federal Regulations, Title 10, Chapter III, Part 835, in which monitoring for myriad contaminants, including mercury and uranium, is detailed (e-CFR, 2018). Employees at the Y-12 site undergo extensive monitoring and, at a minimum, an annual physical.

Table 2 Comparison of uranium exposure by pathway percentage (PHA, 2004).

Exposure Pathway to Humans	% Pathway Contributes to Total Radiation Dose	
	U 234/235	U 238
Inhalation of resuspended dust	2%	3%
Ingestion of soil	<1%	1%
Consumption of meat from livestock that ingested soil	<1%	<1%
Consumption of milk from dairy cows that ingested soil	<1%	1%
Consumption of vegetables grown in contaminated soil	30%	43%
Consumption of meat from livestock that ate pasture grown in contaminated soil	<1%	<1%
Consumption of milk from dairy cows that ate pasture grown in contaminated soil	<1%	1%
External exposure to contaminated soil	3%	<1%

Although citizens living in the vicinity of the Oak Ridge Reservation are not susceptible to elevated concentrations of uranium via inhalation, exposure through ingestion via

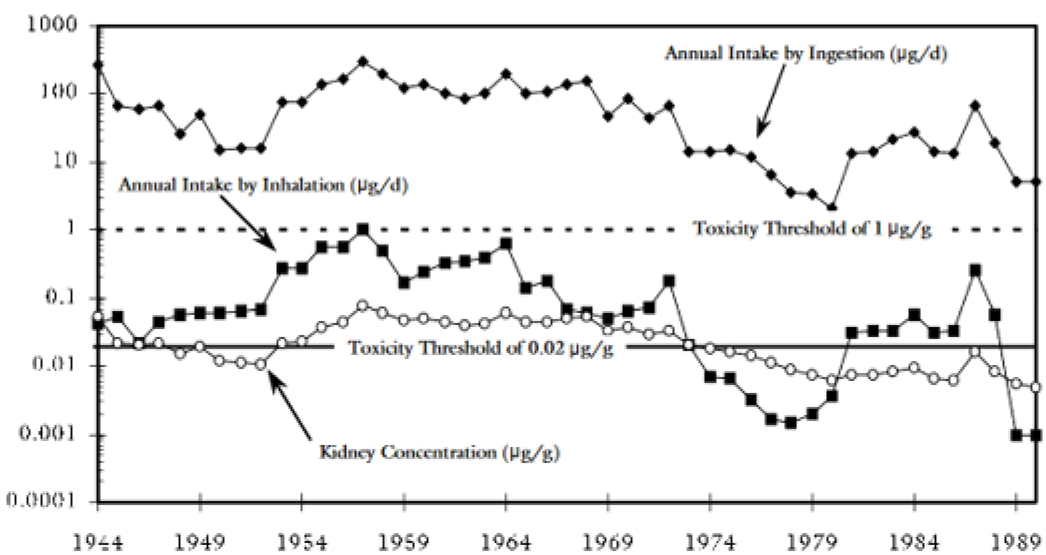


Figure 4 Uranium intake via simultaneous ingestion and inhalation with resulting kidney effects (ChemRisk, 2007)

contaminated water and food are of concern. Table 2 shows that consumption of vegetables grown in contaminated soils is the major soil exposure pathway, followed by inhalation of suspended dust, and external exposure to contaminated soil (PHA, 2004). Figure 4 shows the levels of uranium intake via simultaneous ingestion and inhalation along with the resulting kidney effects (ChemRisk, 2007). Currently, the maximum contaminant level (MCL) for uranium in drinking water is 30 µg/L (which was raised from 20 µg/L in 2000). Consuming water above the MCL level over an extended period of time may cause kidney toxicity and cancer (EPA*c*, 2000). Table 3 demonstrates that out of the several different water ways that are impacted from site tributaries, the two waterbodies that have uranium concentrations greater than the current MCL are on-site and restricted from the general public (PHA, 2004). Waterbodies that are off-site and accessible by the general public have MCL levels well below 30 µg/L (PHA, 2004). Combining exposure to

Table 3 Uranium concentration of waterbodies on the Oak Ridge Reservation (PHA, 2004).

Location	Mean Concentration (µg/L)
Scarboro drainage ditches (off site)	0.197
Upper EFPC (on site)	33.5
Lower EFPC (off site)	12.8
Bear Creek (on site)	159
Lower EFPC (on site after joining with Bear Creek)	8.4

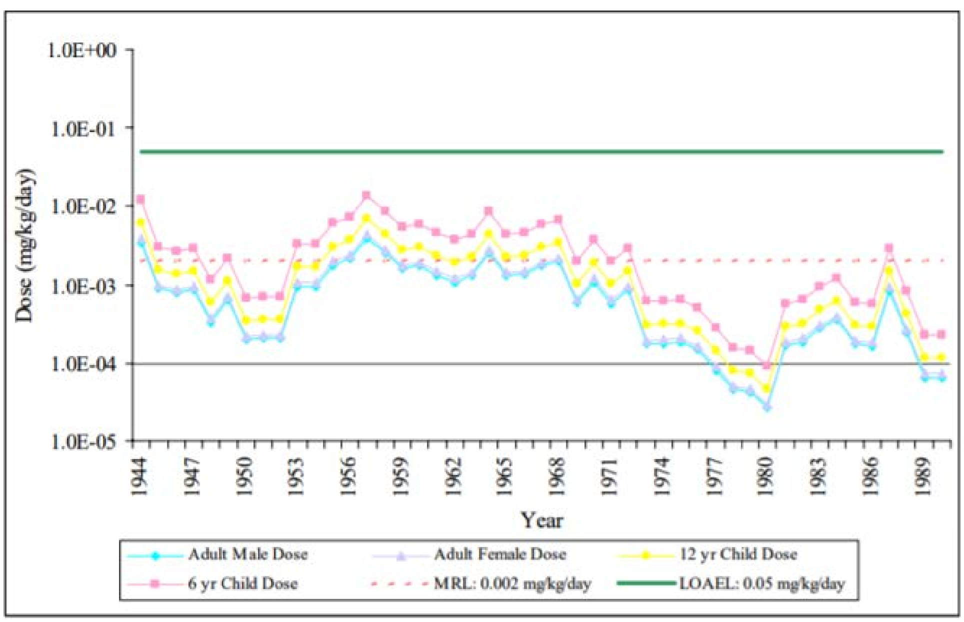


Figure 5 Ingestion of uranium for citizens living in close proximity to Y-12 on the Oak Ridge Reservation (PHA, 2004)

uranium-contaminated soils and water, Figure 5 depicts that ingestion of uranium for all citizens living in close proximity to Y-12 on the Oak Ridge Reservation, separated by age and sex, was well below the lowest observed adverse effect level (LOAEL), and were therefore not exposed to levels of uranium expected to cause harmful effects (PHA, 2004).

4.4 Mercury at Y-12

Elemental mercury is a shiny, silver metal that is liquid at room temperature, which allows it to easily maneuver and adhere to other materials (EPA*a*, 2017). Mercury is present in three different forms at Y-12 on the Oak Ridge Reservation: elemental, inorganic, and methylmercury (ORHASP, 1999). Humans are primarily exposed to mercury via two different routes: ingestion through water intake or fish consumption, or inhalation, and can cause severe health implications (EPA*a*, 2017).

Although mercury is a naturally-occurring element, the amounts of elemental mercury released into the environment from the Y-12 site vastly exceeds what would be found under natural conditions. In 2000, it was reported that historical mercury releases to the air was approximately 73,000 pounds (ChemRisk, 2007). A study concluded in 1983 determined that between the 1950s and 1960s, roughly 733,000 pounds of elemental mercury was released into the entire environment from the Y-12 plant (DOE/OR/01-2718&D1). Figure 6

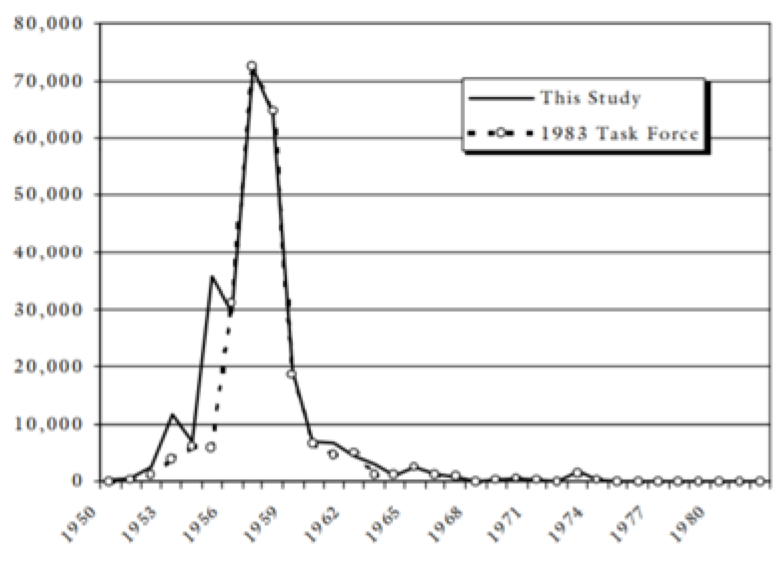


Figure 6 Yearly trend of waterborne mercury contamination from Y-12 between 1950 and 1980 (ChemRisk, 2007).

depicts the yearly trend of waterborne mercury contamination from Y-12 between 1950 and 1980 (ChemRisk, 2007). The Department of Energy reports that 170,000 pounds of mercury are contained in the soils and sediment of the east fork of Poplar Creek, but annually, an estimated 500 pounds of mercury escapes the watershed, and has been detected as far as 118 miles downstream (DOE/OR/01-2718&D1). The 118-mile stretch from the Oak Ridge Reservation has seven water intakes which provides over 43,000 people with drinking water (DOE/OR/01-2718&D1). Mercury released at the Y-12 site is more responsible for the potential non-cancer health risks than any other historically used materials on the entire Oak Ridge Reservation (ChemRisk, 2007).

Not only does the river serve as a source of drinking water, but ample boating and fishing opportunities are a popular hobby in the area. As elemental mercury is released into the nearby waterways surrounding the Y-12 plant via leaks or spills, it accumulates, and is then transformed into methylmercury (MeHg), a highly toxic form of mercury (EPA*a,* 2107), by microbial processes (Kretchik, 2007). A study by Vishnivetskaya et al. reported that the elemental mercury concentrations tend to decrease with distance away from the site, but MeHg concentrations increase as distance away from the site increases (2011). Methylmercury settles on the bottom of the water column, which is susceptible to being ingested by bottom-feeding fish. Methylmercury is a “stickier” form of mercury, so as the fish ingest the sediment, the MeHg stays in their body longer (Ainza et al., 2010). Water quality parameters such as dissolved organic carbon and pH have been determined to impact the amount of methylmercury accumulation in the water body. Decreasing pH and dissolved organic carbon can cause an increase in mercury levels in fish. (USGS, 2000). Or, if methylmercury is exposed to prolonged sunlight, it can be broken down to a gaseous form and be released back into the atmosphere (USGS, 2000). While all forms of mercury can accumulate, MeHg accumulates to a greater extent and biomagnification occurs (Kretchik, 2007). In fish muscles, more than 90% of mercury present is often in the form of MeHg (Jenssen et al., 2012).

4.4.1 Mercury Health Concerns

According to the World Health Organization (WHO), mercury poisoning can cause deleterious effects on the central and peripheral nervous system, digestive and immune systems, lungs, kidneys (2017). Behavioral and neurological problems such as tremors, short-term memory loss, insomnia, neuromuscular effects, headaches, and other cognitive and motor dysfunctions may also occur in individuals exposed to elevated levels of mercury (WHO, 2017).

Employees at the Y-12 site during the 1950s and 1960s were exposed to mercury vapors as well as small amounts of inorganic mercury (Y/EX-21/DELREV). During this time, 41% of roughly 700 air samples were found to have an average of 0.13 mg/m^3, which is in excess of the 0.1 mg/m^3 guideline (Y/EX-21/DELREV). In 1956, Dr. R. Kehoe of the Kettering Institute, University of Cincinnati, visited the site and explained that if work protection measures were not increased and employees showing signs of mercury poisoning were not removed from their jobs,

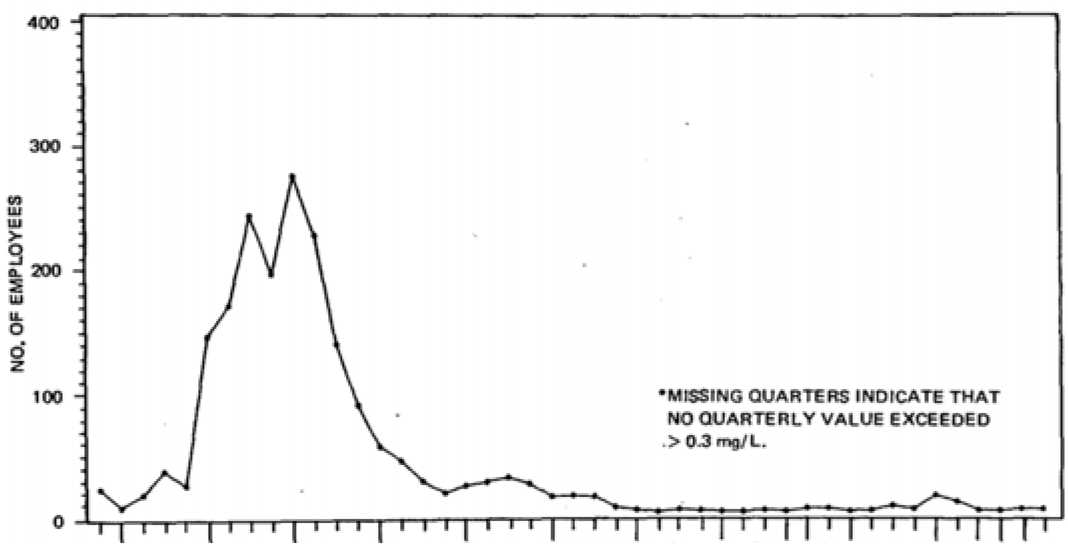


Figure 7 Number of employees with quarterly urinalysis levels exceeding 0.3 mg Hg/L between 1953 and 1971 (*Kallenbach, 1988)*

Y-12 would encounter “the same difficulties experienced by the hatters industry” (Y/EX-21/DELREV). A urinalysis monitoring program was adopted in 1953 with Plant Action Value (PAV) of 0.3 mg/L (Y/EX-21/DELREV). Over 2,000 Y-12 workers were exposed to mercury and had urinalyses performed (Kallenbach, 1988). Figure 7 shows the number of Y-12 employees whose mercury urinalysis was great than the PAV from 1953 until 1971. In 1974, a medical checkup of 50 original Y-12 workers was performed by a National Institute for Occupational Safety and Health (NIOSH) official, and found no symptoms of mercury poisoning (Y/EX-23). In 1983, Oak Ridge Associated Universities (ORAU) performed a mortality study, and determined mortality rates for Y-12 workers exposed to mercury was not significantly different from non-exposed Y-12 workers, or the United States population as a whole (Y/EX-23). However, a study published in 1988 examined the health of mercury exposed Y-12 workers employed between 1953 and 1966 (Kallenbach, 1988). This study concluded that workers exposed to mercury, nearly thirty years later, experienced lightheadedness, dizziness, memory disturbance, trouble grasping objects, and clumsiness (Kallenbach, 1988). In 2012, the Agency for Toxic Substances and Disease Registry released a final report for mercury exposure from the Y-12 plant (ATSDR). ATSDR determined that current mercury exposure at the plant is not at levels to cause any harmful health effects to workers (2012).

The highest mercury doses citizens living near the Oak Ridge Reservation received were likely during the 1950s, which was when the largest amounts of mercury were being discharged into the air and water from the Y-12 site (ChemRisk, 2007). Some residents living along the eastern fork of Poplar Creek may have inhaled enough elemental mercury to cause damage to the central nervous system, and a small number of children could even have experienced short-term kidney damage due inorganic mercury exposure (ORHASP, 1999).

Monitoring of measurements of the methyl mercury concentrations in fish located in Poplar Creek, the Clinch River, and Watts Bar Reservoir on the Tennessee River began in the 1970s (ChemRisk, 2007). Since then, it has been noted that at given times, MeHg levels have been elevated to levels that could cause negative health effects for those who consume the fish (ChemRisk, 2007). Over the course of the last 50 years, up to 300,000 individuals could have consumed fish from Poplar Creek, the Clinch River, or Watts Bar Lake, and those consuming significant amounts of fish were at high risk for consuming concentrations of mercury that could cause adverse health effects (ORHASP, 1999). Figure 8 represents the estimated MeHg doses to adult consumers of fish from the Clinch River/Poplar Creek area from 1950 until 1980 (ChemRisk, 2007).

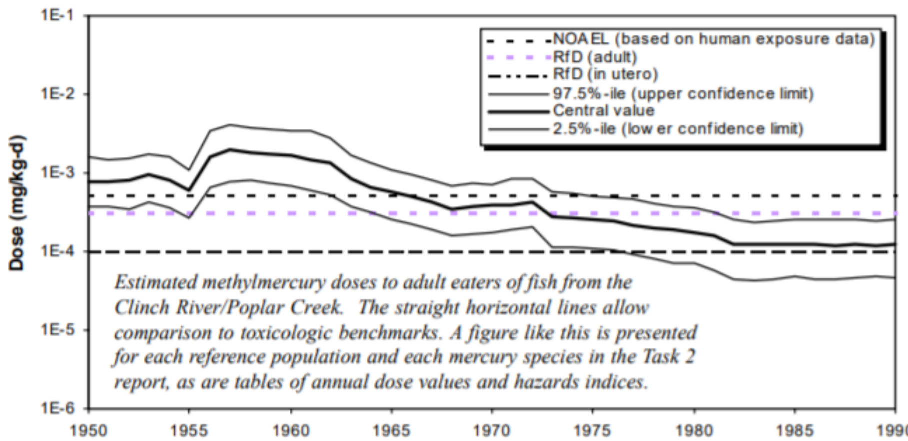


Figure 8 Estimated MeHg doses to adult consumers of fish from the Clinch River/Poplar Creek area from 1950 until 1980 (ChemRisk, 2007).

According to Shimshack, Ward, and Beatty, "Fetuses and nursing infants are at risk because mercury readily passes through the placenta, concentrates in umbilical tissues, and leaches into breast milk" (2007). Fetal development issues become evident after the concentration of mercury in the cord blood exceeds 5.8 µg per liter (Hylander & Goodsite, 2006). 98% of methylmercury accumulates in the human brain, which poses a great hazard to Central Nervous System of developing fetuses (Chein et al., 2010). Hylander and Goosite discovered that IQ decreases 1.5 points every time the concentration of mercury in the blood doubles (2006). In the United States, it was estimated that between 316,588 (7.8%) and 637,233 (15.8%) of all infants born had cord blood mercury levels exceeding the limit of 5.8 μg per liter (Nair et al., 2014). In areas near contaminated waters surrounding the Oak Ridge reservation, it is estimated that 100 fetuses were exposed at hazardous levels (ORHASP, 1999). Mothers exposed to high levels of mercury during pregnancy often bear children that exhibit neurodevelopmental problems during the last two trimesters of pregnancy (Chien et al., 2010).

5. The Turning Point

After years of the Oak Ridge Reservation spewing uranium and mercury into the surrounding environment, a new environmental movement was taking shape in the United States. In 1986, the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) was first established (EPA*d*, 2017). The purpose of the NCP was to provide a structured and procedural process to prepare and respond to accidental releases of oil, hazardous substances, pollutants, and contaminants (DOE/OR/01-2718&D1). Following the creation of the NCP in 1970, the Environmental Protection Agency (EPA) formed and set forth the first Clean Air Act (EPA, 2018). The ultimate purpose of the EPA was to fund environmental research, monitoring, and enforcement to protect human health (EPA*f*, ~~,~~2018). The Clean Air Act set the first air quality standards in the United States, and in its first 20 years is estimated to have prevented more than 200,000 premature deaths by reducing the amount of harmful pollutants in the air (EPA*ff*, 2018). In 1972 the Clean Water Act was passed with the intent of reducing the amount of pollution in waterways by preventing additional pollution from entering into the waterways, maintaining integrity of wetlands, and to assist publicly owned wastewater treatment facilities (EPA*f*, 2018). The Resource Conservation and Recovery Act (RCRA) was passed in 1976 and gives authority to the EPA to control the generation, transportation, storage, and disposal of hazardous waste

(EPA*ff*, 2018). Finally, in 1977, the Department of Energy formed and took control of the Oak Ridge Reservation (DOE/OR/01-2718&D1). By 1980, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as Superfund, was created (DOE/OR/01-2718&D1). CERCLA developed a nationwide program for emergency response, information gathering, analysis, and liability for responsible parties and site cleanup for abandoned or uncontrolled hazardous waste sites (EPA*e*, 2017). The Superfund portion of CERCLA was created to finance the emergency response and cleanups (EPA*e*, 2017). CERCLA was then implemented into the NCP in 1982 (EPA*e*, 2017), and Appendix B of the NCP is the National Priorities List (NPL) which identifies sites in need of remedial actions (DOE/OR/01-

Table 4 Timeline of events pertinent to forming the regulations and standards that govern operations on the Oak Ridge Reservation.

Year	Action
1968	National Oil and Hazardous Substances Pollution Contingency Plan (NCP)
1970	EPA is established
1970	Clean Air Act
1972	Clean Water Act
1974	Safe Drinking Water Act
1974	US Nuclear Regulatory Commission created
1976	Resource Conservation and Recovery Act
1977	Department of Energy is formed
1980	Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as Superfund, was created
1982	CERCLA implemented into the NCP
1986	RCRA permits issued to the Oak Ridge Reservation
1989	Oak Ridge Reservation added to the National Priorities List (NPL) as a Superfund site

2718&D1). Although some environmental monitoring and remediation activities had been underway on the Oak Ridge Reservation prior to 1986, the State of Tennessee and the EPA began issuing RCRA permits to incorporate corrective actions to clean up hazardous waste releases on the site (DOE/OR/01-2718&D1). Finally, in 1989, the Oak Ridge Reservation was officially added to the NPL as a Superfund site with CERCLA becoming the primary regulator (DOE/OR/01-2718&D1). The new classification of the Oak Ridge Reservation as a Superfund site along with the implementation of each of these environmental acts worked together to heighten environmental awareness and amplify remedial actions. Table 4 provides a concise timeline of events pertinent to forming the regulations and standards that govern operations on the Oak Ridge Reservation.

6. Remediation Efforts

Efforts to remediate legacy wastes to regulatory standards can be costly and complex (Burger and Gochfield, 2016). Before remediation efforts begin on a site, a thorough evaluation of the contaminants present and their concentrations, environmental impacts, and economic needs to fund the remediation must be considered (Burger and Gochfield, 2016). Table 5 shows the nine CERCLA evaluation criteria before a remediation method is selected. At the Y-12 site on the Oak Ridge Reservation, uranium and mercury remediation has been of great importance to protect the people working at the site and living in proximity to the Reservation, and well as to protect and enhance the surrounding environment.

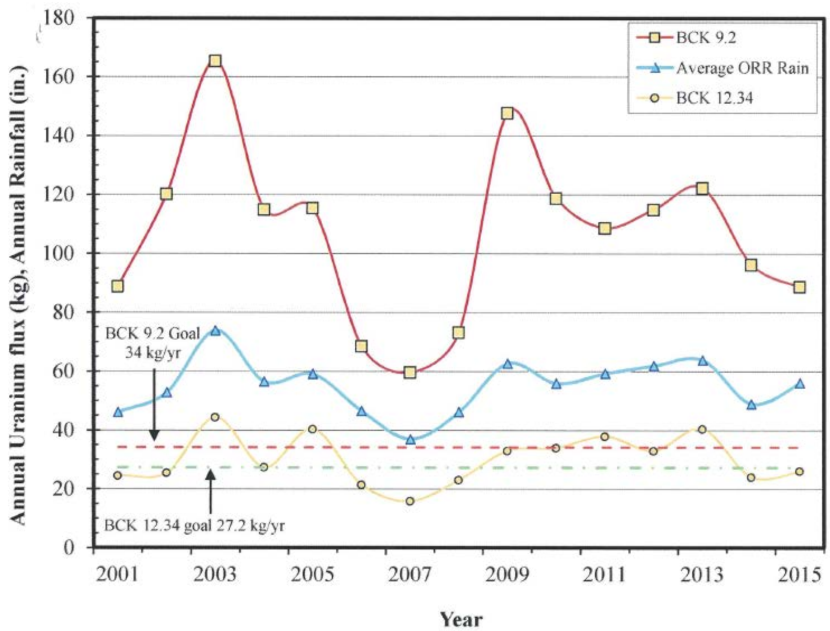
Table 5 Nine CERCLA evaluation criteria before a remediation method is selected (DOE/OR/01-1750&D4).

Overall protection of human health and the environment. This criterion addresses whether an alternative provides adequate protection of human health and the environment and how risks posed through each exposure pathway are eliminated, reduced, or controlled through treatment, engineering controls, and/or institutional controls.
Compliance with applicable or relevant and appropriate requirements. Section 121(d) of CERCLA requires that remedial actions at CERCLA sites at least attain legally applicable or relevant and appropriate federal and state requirements, standards, criteria, and limitations, which are collectively referred to as ARARs, unless such ARARs are waived under CERCLA 121(d)(4).
Long-term effectiveness and permanence. This criterion addresses expected residual risks once cleanup levels have been met and the ability of a remedy to maintain reliable protection of human health and the environment over time. Includes the magnitude and nature of risks associated with untreated waste and/or treatment residuals, and consideration of the adequacy and reliability of any associated institutional or engineering controls.
Reduction of toxicity, mobility, or volume through treatment. This criterion addresses the degree to which treatment is used to address the principal hazards of the site; the amount of material treated; the magnitude, significance, and irreversibility of specific reductions; and the nature and quantity of treatment residuals.
Short-term effectiveness. This criterion addresses the effect of implementing an alternative relative to potential risks to the general public during the action period, potential impacts to workers and the environment during the action period, the effectiveness and reliability of mitigative measures, and the time required to achieve protection of workers and the environment.
Implementability. This criterion addresses the technical and administrative feasibility of a remedy from design through construction and operation, including the availability of services and materials, the ease of implementation, the ability to monitor effectiveness, administrative feasibility, and coordination with other governmental entities
Cost. This criterion addresses both capital costs and O&M costs, as well as the combined present worth cost.
State acceptance. This criterion addresses comments and input from the state of Tennessee on the consideration of alternatives and identification of the preferred alternative.
Community acceptance. This criterion addresses comments and input made by the community on the remediation alternatives under consideration.

6.1 Uranium Remediation at Y-12

Although the initial remediation action of adding a multi-layer RCRA cap atop the S-3 Ponds area was completed in 1988, uranium is still able to leach from the bottom of the ponds into the groundwater, and discharge into the surface water in Bear Creek, thus requiring additional remediation efforts (DOE/OR/02-1701&D3). Two specific monitoring points are used on Bear Creek; Bear Creek Kilometer (BCK) 9.2 and BCK 12.34 (DOE/OR/01-2707&D1). BCK 9.2 serves as a comparison to risk-based concentrations for residential exposure, while BCK 12.34 is the near the Bear Creek headwater and is near the integration point for contaminated surface water from the S-3 Pond area (DOE/OR/01-2707&D1). The amount of uranium that is mobilized from the S-3 Ponds areas is highly dependent on the amount of rainfall that occurs, as demonstrated in Figure 9. (DOE/OR/01-2718&D1). Three preferential flow pathways from the

S-3 Ponds to Bear Creek have been identified, and termed Pathway 1, Pathway 2, and Pathway 3 (DOE/OR/01-1750&D4). Pathways 1 and 2 contain high



Post-ROD uranium flux at BCK 9.2 and BCK 12.34 and annual rainfall at the ORR.

Figure 9 (DOE/OR/01-2707&D1)

concentrations of uranium, with the total uranium concentrations in the groundwater in this area ranging from 1.2 to 14 mg/L (DOE/OR/02-1701&D3), while Pathway 3 contains smaller amounts of uranium (DOE/OR/01-1750&D4). Although uranium concentrations in the groundwater are expected to naturally decrease over time, new remediation efforts are being implemented to better protect human health and the environment (DOE/OR/02-1701&D3). Experiments with various treatment methods in 1998 at Pathways 1 and 2 discovered that Dowex 21K resin, peat moss, and zero-valent iron (ZVI) were most successful to attenuate uranium contaminated groundwater (DOE/OR/02-1701&D3). Although ZVI treatments lowered uranium concentrations in the groundwater, dissolved iron was produced and added to the groundwater (DOE/OR/02-1701&D3). Peat moss did not remove as much uranium from the groundwater as the ZVI, but it also did not produce any secondary contamination (DOE/OR/02-1701&D3). Finally, the Dowex 21K resin was found to be effective in removing uranium from groundwater with high amounts of total dissolved solids, but is expected to deteriorate over time

(DOE/OR/02-1701&D3). The ultimate goal for the S-3 Ponds site is to reduce uranium flux to 34 kg/year at BCK 9.2 and 27.2 kg/year at BCK 12.34 by utilizing existing trenches, then implementing in situ or ex situ treatment methods (DOE/OR/02-1701&D3). Pathway 1 treatment implements a funnel and gate design, while Pathway 2 uses a reactive barrier wall design to intercept and treat uranium contaminated groundwater (DOE/OR/01-1750&D4). Contaminated groundwater moving via Pathway 3 will be treated using a reactive barrier with iron metal filling (DOE/OR/01-1750&D4), but has not yet been implemented (DOE/OR/01-2718&D1). In 2007, the remedial actions for Pathways 1 and 2 were shut down (DOE/OR/01-2718&D1). As of 2016, the S-3 Ponds Pathway 3 remedial action, which will also address contamination moving via Pathways 1 and 2, is still awaiting implementation, but is undergoing consistent monitoring (DOE/OR/01-2707&D1).

6.2 Mercury Remediation at Y-12

Remediation to fully address the issue of mercury being released into the environment from the Y-12 site has been quite extensive, and has independently examined the workers, processes, buildings and rubble, soil, and outfalls contributing to the problem to provide a whole solution. In brief, below is a historic timeline of previous and on-going mercury remediation at Y-12.

During the 1950s and 1960s, simple mercury protection measures for workers included increasing ventilation in buildings, supplying showers, and requiring shoe covers to be worn and removed when leaving the work areas (Y/EX-21/DELREV). Operating systems would no longer utilize pre-used gaskets, would have proper drainage valves installed, and spills and leaks would be collected (Y/EX-21/DELREV). However, environmental mercury contamination remained a problem.

In the late 1980s, portions of the Y-12 sewer systems were re-lined to prevent leaks and reduce releases (DOE/OR/01-2718&D1). In 1990, under the Reduction of Mercury in Plant Effluents (RMPE) program, operations using mercury were stopped (DOE/OR/01-2718&D1). In 1991, a CERCLA record of decision was made to ensure no residual contamination was left in any old storage tanks (DOE/OR/01-2718&D1). By 1992, the RMPE program had reduced mercury loading from 150 g/day in 1983 to 15 g/day (WSRC-STI-2008-00212). In 1998, a bypass was constructed to route Poplar Creek flow around Lake Reality, a pond known to convert inorganic mercury to methylmercury and trap and export mercury (Y/ER-293). Throughout the 2000s, monitoring of mercury, planning and designing, and construction on a water treatment system were taking place (DOE/OR/01-2718&D1). By 2012, contaminated sediments were removed from the storm sewers, Upper East Fork Poplar Creek, and Lake Reality, more water treatment systems were implemented, and surface water monitoring continued (DOE/OR/01-2718&D1).

Currently, most of the mercury contamination from Y-12 is being sourced from Outfall 200, and is now a remediation priority. The preliminary design for the new Outfall 200 Mercury Treatment Facility (OF200 MTF) began in 2014, was finalized as of January 2017 (UCOR-4889), and the facility groundbreaking event was held on November 20, 2017 (Huotari, 2017). The OF200 MTF is a two-part design, termed the Headworks and the Mercury Treatment Facility (MTF), which is connected by a high-density polyethylene (HDPE) pipeline, and will a treatment capacity of 3,000 gpm during a base flow, and stormwater capture of 40,000 gpm.(UCOR-4889). In the first part of the design, the Headworks, mercury contaminated flow water is captured and treated, and will allow excess stormwater flow to bypass the system and be stored in a 2 million gallon storage tank until it can be fed into the system and properly treated at the second part of the system, the MTF (UCOR-4889). The MTF system is comprised of multiple outdoor tanks, treatment equipment, and treatment buildings. (UCOR-4889). The outdoor equipment is comprised of several different tanks, such as equalization, process reaction, bulk chemical, and sludge settling tanks, along with clarifiers and thickeners (UCOR-4889). Equipment housed inside the treatment building includes a multi-media filtration system, filter clear well and backwash basins and pumps, filter presses, polymer make-down systems, and an operations support and control area (UCOR-4889). Figures 10 and 11 provide illustrations of the new Outfall 200 Mercury Treatment Facility (Huotari, 2017).

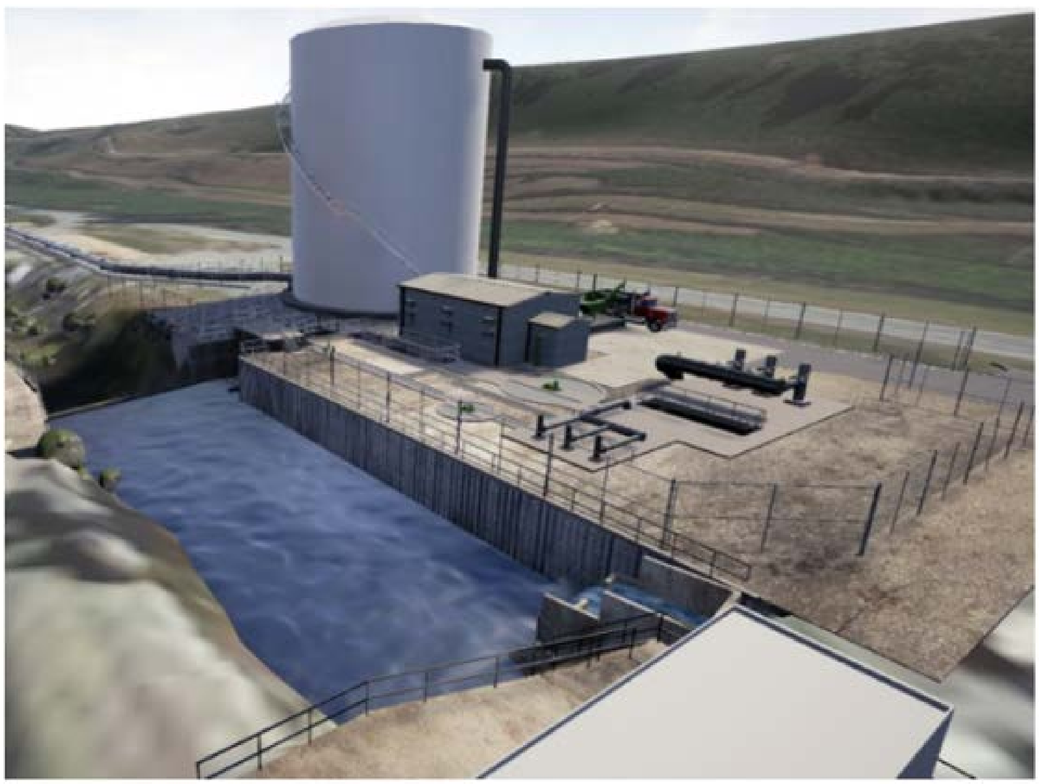


Figure 10 Headworks Facility of the Outfall 200 Mercury Treatment Facility *(Huotari, 2017).*

Figure 11 Mercury Treatment Facility of the Outfall 200 Mercury Treatment Facility (Huotari, 2017).

7. Future expectations

Remediation efforts underway at the Y-12 site on the Oak Ridge Reservation are not solely intended to remove legacy wastes from the environment and prevent future occurrences. Each site on the reservation has a future land-use goal, as shown in Figure 12 (Garland et al., 2013). At Y-12, the eastern end of the plant is being remediated to be used for industrial purposes, such as leased office or research space. The middle portion of Y-12 will, hopefully, be used for recreation, such as utilizing the currently capped and fielded burial grounds for walking parks. Finally, the western end will ultimately be remediated in full affect so the land can be used in an unrestricted manner. However, even though these areas will be remediated, they will still need to be monitored throughout their existence and may even need to utilize boundary controls or property record notices to ensure their remediation method is still intact and performing to its standard to protect the environment and those residing in proximity. (Garland et al., 2013)

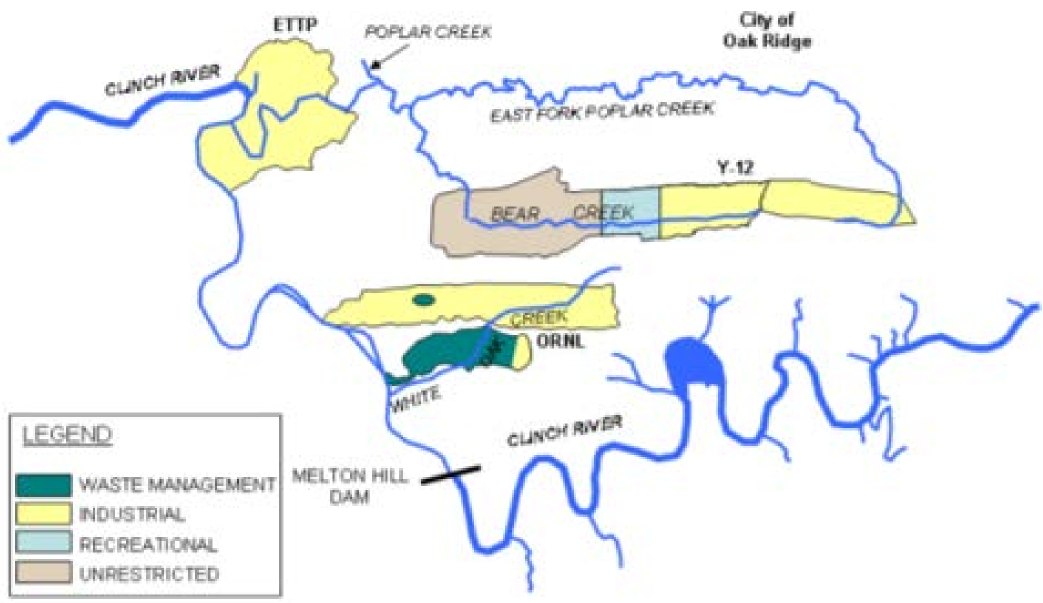


Figure 12 Future ORR land-use goal (Garland et al., 2013).

8. Conclusion

The Oak Ridge Reservation, and the Y-12 site specifically, has an interesting history that has left behind innumerable legacy wastes, including uranium and mercury. Unfortunately, these contaminants have not only been problematic on-site, but have migrated downstream over the last several decades. More recently, myriad remediation efforts have been underway to prevent more contamination and to restore the environment. Methods such as capping historical uranium-waste disposal trenches and using the area as a paved parking lot, and building a new water treatment structure to reduce mercury flux in streams are only a small fraction of the remediation work and research taking place at Y-12. Fortuitously, positive remediation results have already been seen, and can only be expected to improve as time allows a new generation to experience more education, research, and the birth of new ideas.

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