Document ID: EDF-6225
Revision ID: 1
Effective Date: 01/30/06

Engineering Design File

Project No. 23415

Engineering Test Reactor Complex Chemical Constituent Source Term

Idaho Cleanup Project

The Idaho Cleanup Project is operated for the
U.S. Department of Energy by CH2M ◆ WG Idaho, LLC

431.02
01/30/2003
Rev. 11

ENGINEERING DESIGN FILE

EDF No.: 6225 EDF Rev. No.: 1 Project No.: 23415

1. Title: Engineering Test Reactor Complex Chemical Constituent Source Term

2. Index Codes:
Building/Type ______ SSC ID N/A Site Area RTC

3. NPH Performance Category: ______ or ☒ N/A

4. EDF Safety Category: ______ or ☒ N/A SSC Safety Category: ______ or ☒ N/A

5. Summary:

This engineering design file (EDF) describes and quantifies the chemical constituents source term of the Engineering Test Reactor (ETR) complex. This EDF describes these chemical constituents that may pose a risk to human health or the environment, their location, use in the ETR facilities, and physical form or configuration. The quantities are based on either calculations (employing various assumptions) or approximations. Another objective of this EDF is to provide information necessary to conduct a risk assessment in support of the decommissioning of the ETR complex that is to be performed in accordance with an engineering evaluation/cost analysis.

6. Review (R) and Approval (A) and Acceptance (Ac) Signatures:
(See instructions for definitions of terms and significance of signatures.)

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Doc. Control	Ac	Carly Anderson	Carly Anderson	1/30/06

7. Distribution:
(Name and Mail Stop)

8. Does document contain sensitive unclassified information? ☐ Yes ☒ No
If Yes, what category:

9. Can document be externally distributed? ☒ Yes ☐ No

10. Uniform File Code: 6102 Disposition Authority: ENV1-h-1
Record Retention Period: Records Schedule Matrix

11. For QA Records Classification Only: ☒ Lifetime ☐ Nonpermanent ☐ Permanent
Item and activity to which the QA Record apply:

12. NRC related? ☐ Yes ☒ No

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13. Registered Professional Engineer's Stamp (if required)
N/A

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ACRONYMS

CFA	Central Facilities Area
DOE	U.S. Department of Energy
EDF	engineering design file
EE/CA	engineering evaluation/cost analysis
EPA	U.S. Environmental Protection Agency
ETR	Engineering Test Reactor
GEEL	General Electric Experimental Loop
INL	Idaho National Laboratory
MTR	Materials Test Reactor
PCB	polychlorinated biphenyl
PRGs	preliminary remediation goals
RCRA	Resource Conservation and Recovery Act
RTC	Reactor Technology Complex
TRA	Test Reactor Area
VCO	Voluntary Consent Order

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Engineering Test Reactor Complex Chemical Constituent Source Term

1. INTRODUCTION AND PURPOSE

This engineering design file (EDF) describes and quantifies the chemical constituent source term of the Engineering Test Reactor (ETR) complex. This EDF includes a general description of the chemical constituents present in the complex that may pose a risk to human health or the environment, their location and use in the ETR facilities, and physical form or configuration. The quantities expressed in this document are based either on calculations (employing various assumptions), or have been approximated. In addition, this EDF provides information necessary to conduct a risk assessment to support the decommissioning of the ETR complex to be performed in accordance with an engineering evaluation/cost analysis (EE/CA).

2. FACILITY HISTORY AND DESCRIPTION

The Idaho National Laboratory (INL) is a government-owned facility managed by the U.S. Department of Energy (DOE) and is located 54 km (34 mi) west of Idaho Falls, Idaho (see Figure 1). It encompasses 2,305 km^2 (890 mi^2) of the northeastern portion of the Eastern Snake River Plain. The ETR (see Figure 2) is an inactive nuclear research complex comprising several buildings and structures that occupy the southeastern section of the Reactor Technology Complex (RTC), formerly the Test Reactor Area (TRA). It is located approximately 3.5 mi north of the Central Facilities Area (CFA).

The ETR was designed and constructed to meet the need for higher and more uniform neutron fluxes and to provide larger spaces for testing than were available at the Materials Test Reactor (MTR). It became the most advanced nuclear fuels and materials test reactor in the United States when it began operating in 1957 as a 175-megawatt light-water cooled and moderated, beryllium-reflected reactor. The reactor core first achieved criticality in October 1957, and full power was achieved in 1958. The ETR nuclear reactor facility was used for materials research primarily for the Naval Reactors Program (water loop testing programs), in which many kinds of fuels and materials were subjected to a high neutron flux environment to evaluate their characteristics for use in many types of reactors. Later, the facility was used for fuel accident simulations for the Liquid Metal Fast Breeder Reactor Safety Program.

2.1 ETR Complex Physical Description

The ETR complex (see Figure 2) was constructed between 1955 and 1957, with subsequent modifications completed in 1960 and 1972. The reactor operated until 1981. By 1982, the ETR had been placed in a cold, dark, and dry condition. Radioactive water has been drained from the reactor pressure vessel, primary coolant system, water loop experiment piping and vessels, both canal sections, degassing tank and associated piping, and resin tanks. Other water systems that were drained include the secondary coolant water (including heat exchangers), utility water, the two demineralized systems (low and high pressure), and water in heating and cooling units. The fuel in the reactor, as well as irradiated fuel in the storage canal, was removed and shipped to the Idaho Nuclear Technology and Engineering Center for long-term storage.

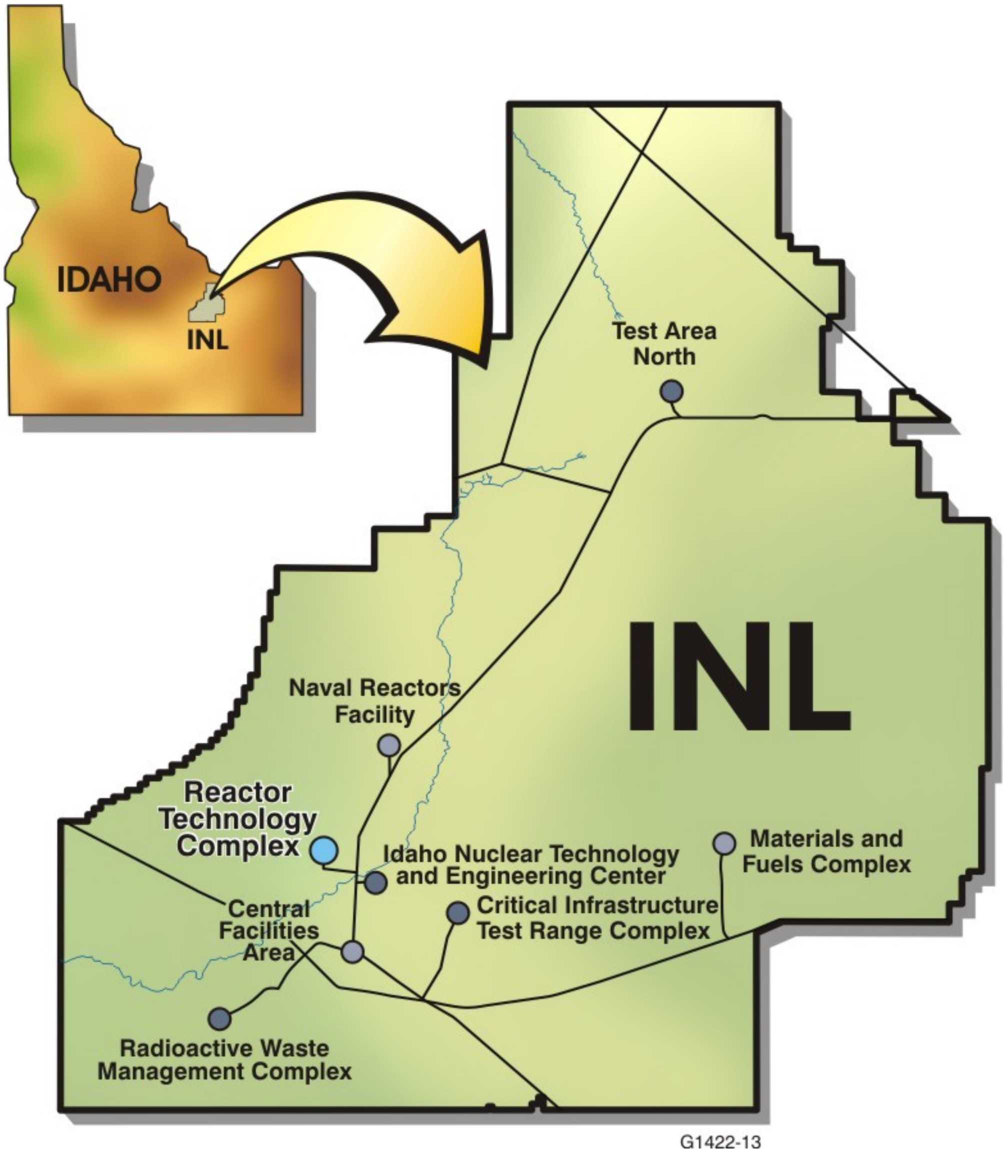

Figure 1. Map of the Idaho National Laboratory Site showing the location of the Reactor Technology Complex and other major facilities.

Figure 2. The ETR Complex looking northeast (photo taken in 1996). The gray building in the left middle foreground is the TRA-642 reactor building.

For purposes of this EDF, the ETR complex includes the following buildings and structures:

1. TRA-642 ETR Building is a steel-framed building with a main floor and two subgrade floors. The building measures 136 × 112 ft, and extends 58 ft above grade and 38 ft below grade. The reactor building houses the multi-diameter reactor vessel, along with the canal, subpile room, control rod access room, console floor, and experiment cubicles in the basement.

2. TRA-643 ETR Compressor Building adjoins the reactor building along its east side. It measures 124 ft 8 in. from east to west, and 108 ft north to south. The building is 30 ft 5 in. high. The compressor building housed the equipment piping, air filtration units, air heating units, etc. used to supply large quantities of heated, hydrocarbon-free air to various experiments. The exterior walls consist of pumice block and metal panels above.

3. TRA-644 ETR Heat Exchanger Building is located immediately south of the compressor building and includes the 12 primary coolant/secondary coolant system heat exchangers and associated piping, as well as degassing tank room, cubicle exhaust booster blower room, demineralizer wing, and secondary pipe pit. The heat exchangers and associate piping have been drained.

4. TRA-648 ETR Electrical Building housed the major electrical equipment for the ETR facility, consisting of the 13.8-kV, 4,160-V, and 480-V switchgear; No. 1 Emergency Diesel Generator; five-motor generator units; and one lead-acid storage battery bank (removed). The building is a two-level structure consisting of the upper story and a basement level referred to as the cable vault. The building, measuring 54 × 115 × 16.5 ft high, adjoins the reactor building along its north wall.

5. TRA-704 ETR Primary Filter Pit was constructed in 1960 as part of the General Electric Experimental Loop (GEEL) Loop 99 upgrade. The 8-in. Loop 99 exhaust line was connected to these two filters located inside the filter pit and which were operated in parallel.

6. TRA-705 ETR Secondary Filter Pit, constructed as part of the ETR GEEL Loop 99 upgrade, contains two polishing filters connected in parallel. The effluent piping from these polishing filters is connected to the filter plant exhaust line that was routed to the ETR stack. Both sets of polishing filters are equipped with 8-in. bypass lines. These filters have been removed.

7. TRA-706 ETR Delay Tanks are two tanks operated in series that provided holding capacity for Loop 99 exhaust gas (originally installed in 1960 as part of the ETR GEEL Loop 99 modifications) to allow decay of radionuclides. The delay tanks have a capacity of 35,000 gal each and are 10 ft inside diameter× 60 ft long. The tanks are fitted with five baffles spaced 10 ft apart to increase holding time of air in the tank. The east tank received effluent from the first (west) delay tank and discharged to the secondary filters (TRA-705).

8. TRA-755 ETR Filter Pit is an underground concrete vault that shields three air filters (TRA-755-101, TRA-755-102, TRA-755-103), which have been removed from the underground vaults. Two of these filter vessels had a capacity of 1,000 gal, while the smaller vessel had a capacity of 317 gal. The filters were designed to remove radioactive particles from the exhaust air. The filter effluent was routed through a 20-in. overhead exhaust line to the ETR stack. Bypass lines were included to route exhaust around the filters; however, these lines were not normally used. Exhaust fans drew a vacuum across the filters during startup and shutdown.

9. The GEEL pipe tunnel begins beneath the reactor building basement floor, runs under the AGS cubicle, and terminates at the Delay Tanks. The GEEL system, designed as an integral part of the ETR, consisted of three inpile tubes, Loop 33, Loop 66, and Loop 99. The loop exhaust lines are 4 in., 8 in., and 8 in. in diameter for Loops 33, 66, and 99, respectively. These pipes exit the subpile room through the northwest wall and enter the GEEL cubicle. The lines turn downward in the cubicle and enter the GEEL exhaust tunnel. These three pipes pass through the GEEL exhaust tunnel to the Filter Plant (TRA-755), located north-northwest of TRA-643. During the Loop 99 upgrade in 1960, a new 8-in. exhaust line was routed through a new tunnel to the Primary Filter Vault (TRA-704), located north of the Compressor Building. The GEEL tunnel system was taken out of service in 1964.

    Figure 3 shows the location of these buildings and structures within RTC.

Some of the auxiliary and support facilities for the ETR have already been demolished or are planned for demolition during FY 2005. Those buildings and structures that have already been demolished, removed, and disposed of include TRA-656 Maintenance Storage Building, TRA-753 ETR Stack and above-ground ductwork, TRA-752 Transformer Station, TRA-645 ETR Secondary Pump House, TRA-647 Administration Building, TRA-655 ETR Air Intake Building, TRA-663 Superior Diesel Building (also referred to as the ETR Standby Power Building or the No. 2 Diesel Building), and the TRA-751 ETR Cooling Tower Basin. In addition, the filter vessels in TRA-705 and TRA-755 have been removed and disposed.

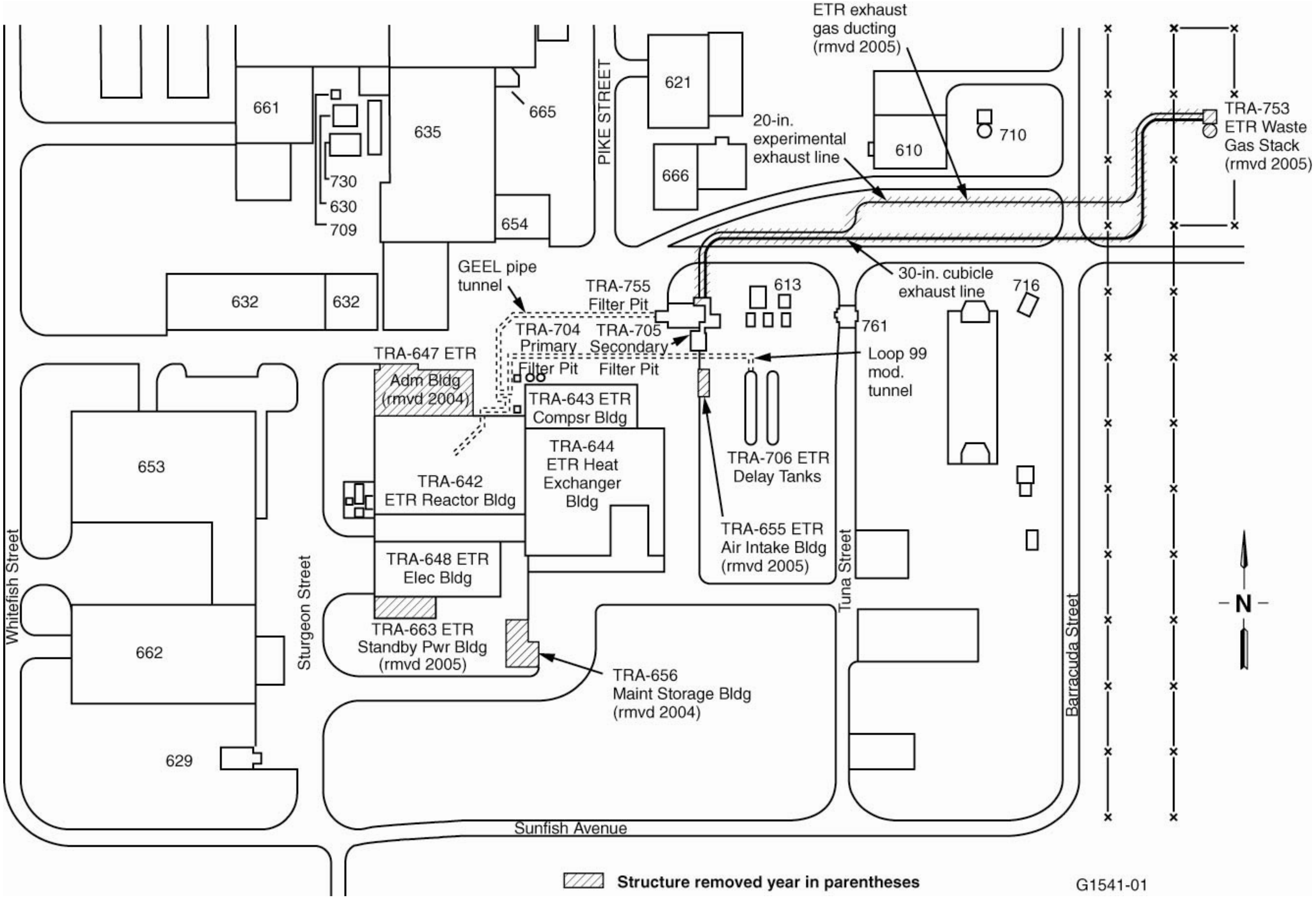

Figure 3. Map of the Reactor Technology Complex, including the southeastern portion where ETR buildings and structures are located.

3. CHEMICAL CONSTITUENTS CONSIDERED FOR SOURCE TERM

The chemical constituents within the ETR facilities that were quantified are taken from the U.S. Environmental Protection Agency (EPA) Region 9 list of preliminary remediation goals (PRGs). PRGs are used for screening and for initial cleanup goals for contaminated sites. According to EPA Region 9 Superfund, "Frequently Asked Questions," exceedance of a PRG may prompt further evaluation of the potential risks posed by that contaminant.

Table 1 presents the list of PRGs considered for this chemical constituent source term based on what is reasonably expected to be present in the ETR facilities. These constituents are comprised almost exclusively by materials of construction for facility operational components and systems. Further explanations as to why certain constituents were not included as part of the source term are discussed in Section 4.1.1.

Table 1. List of EPA Region 9 PRGs considered for the ETR chemical constituent source term.

Constituent	CAS No.	Use in the ETR Complex
Organic Compounds		
Polychlorinated biphenyls, unspecified mixture, high risk, e.g., Aroclor 1254	11097-69-1	Dielectric fluid in transformers and capacitors, lamp ballasts, additive for paint formulations
Freon 113	76-13-1	Refrigeration and air conditioning equipment
Inorganics (metals)		
Aluminum	7429-90-5	Material of construction for various reactor vessel components
Antimony and compounds	7440-36-0	Metal alloy (hardening alloy for lead)
Barium and compounds	7440-39-3	Additive for concrete block shielding; paint pigment
Beryllium and compounds	7440-41-7	Moderator and reflector in nuclear reactors (Be reflector)
Boron	7440-42-8	Neutron absorber reactor controls, additive to shielding/high-density concrete
Cadmium and compounds	7440-43-9	High neutron absorber ("black" control rods)
Chromium, total 1:6 ratio Cr VI: Cr II	7440-47-3	Significant hardening/corrosion resistance alloy of stainless steel and inorganic pigment (paints)
Cobalt	7440-48-4	Dryer in paints, metal alloy
Copper and compounds	7440-50-8	Electric wiring, switches, plumbing, heating, alloy of brass and bronze, electroplating protective coatings

Table 1. (continued).

Constituent	CAS No.	Use in the ETR Complex
Iron	7439-89-6	Major structural material (I-beams, rebar, siding, roofing, piping and tanks, ducting, etc.)
Lead	7439-92-1	Radiation shielding, concrete wall anchors, waste pipe packing material, paint additive
Manganese and compounds	7439-96-5	Significant nonferrous alloy (hardener) of metals (e.g., stainless steel)
Mercury and compounds	7487-94-7	Mercury vapor and fluorescent lamps
Mercury (elemental)	7439-97-6	Electrical equipment (switches, thermostats)
Nickel (soluble salts)	7440-02-0	Significant alloy of metals (e.g., stainless steel, low-alloy steels, copper and brass), gray control rod poison
Silver and compounds	7440-22-4	Electronic equipment, electric conductors (bus bars), brazing alloys, electrical contacts
Tin (inorganic)	7440-31-5	Significant alloy of bronze, tinned wire, paint additive
Vanadium	7440-62-2	Steel alloy, found in paint
Zinc	7440-66-6	Alloy of brass and bronze, galvanizing iron and other metals (stainless steel)

4. QUANTIFICATION METHODS USED TO DETERMINE CHEMICAL CONSTITUENT SOURCE TERM

The total quantity of the chemical constituent source term was determined by several means. These include reviews of various historical documents, drawings, and photographs; interviews with INL personnel knowledgeable with ETR facility operations; interviews with other site personnel knowledgeable of reactor and utility systems; interviews with Voluntary Consent Order (VCO) program personnel; review of analytical data; and conducting walk-downs of the various facilities. Some areas that were not accessed (such as those posted and managed as a high contamination or a high radiation area) were evaluated by reviewing available documents, drawings, photographs, and videos of these areas.

4.1 Assumptions and Baseline for Source Term Calculations/Estimates

Several assumptions are included to explain more fully how source term values were calculated, or estimated, and why certain specific materials have been omitted from consideration for quantification. Quantities reported in this EDF have all been calculated in, or converted to, the international system of units and are expressed in kilograms, or kg. These quantities were rounded to the nearest 10, unless the quantity was less than 10 kg or is a fractional amount.

Assumptions used as a basis for quantifying the source term, the particular chemical constituent that was quantified, and calculation/estimation methodologies used, are presented in the following sections.

The baseline used for establishing the quantity of remaining hazardous constituents considers "Alternative 2–Grouting Reactor Vessels in Place," that is presented in the proposed list of alternatives for the EE/CA for the MTR and ETR vessels. Alternative 2 of the EE/CA provides that the reactor vessels would be filled with a grout, and the aboveground portions of the vessel would be encapsulated in a concrete monolith. The aboveground reactor buildings would be demolished. Belowgrade structures and systems including piping and utility systems would be abandoned in place. In addition, hazardous constituents not removed under the VCO and inactivation activities would remain in place and be managed under the INL Institutional Control Program. Void spaces exterior to the reactor vessel would be backfilled to grade. As such, the source accounted for in this EDF includes all materials in the ETR complex that are under consideration for abandonment below grade, the abovegrade portion of TRA-642, and the reactor vessel and all of its internals.

4.1.1 Assumptions for Omitting Certain Material Constituents

Certain material constituents were not included in the quantification based on the following reasons:

- The chemical source term does not include any constituents found in materials, wastes, or components that have been, or are in the process, of being removed for disposal—either under actions performed by the VCO, or under the decommissioning activities described in Environmental Checklists TRA-04-006 and ICP-05-015[a]. As such, all lead used for biological shielding, which is the primary use of lead in the ETR complex, is not included in the quantity of lead calculated for this source term, with exceptions noted in Section 5.8. Other regulated materials/wastes that have been, or will be removed and disposed of before performing removal actions (such as a Non-Time Critical Removal Action) under the Comprehensive Environmental Response, Compensation and Liability Act include other hazardous and mixed wastes (such as mercury switches and thermostats, mercury and sodium vapor lamps, circuit boards containing lead or silver soldering) regulated under the Resource Conservation and Recovery Act (RCRA), and wastes regulated under the Toxic Substance Control Act such as polychlorinated biphenyl (PCB) articles and equipment.

- The source term does not include any chemical constituents contained in residual lubricating oils, hydraulic fluids, and other petroleum-based fluids (including possible residuals) that have already been drained (or are planned to be drained) from diesel generators, pump motors, elevators hydraulic systems, and other operational equipment/components.

- Freon 113 may be present in some of the facility utility equipment/components, but will be removed during preliminary decommissioning activities.

- PCBs (congeners Aroclor 1254 and 1260) that were considered in this report are found in coated (painted) surfaces such as walls, floors, and structural steel. However, calculations determined that the total quantity of these PCBs is approximately 5 g in all building and structure painted surfaces, and therefore they were omitted due to the very small quantity.

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[a] This document determined that the level of environmental review per the National Environmental Policy Act (NEPA), for certain specific decommissioning activities within TRA-642, is a categorical exclusion.

- This chemical constituent source term does not include asbestos-containing materials, either in friable or non-friable forms that may be found in pipe and tank/vessel insulation, fire doors, transite panels, and other potential asbestos-containing material. Asbestos is not listed as an EPA Region 9 PRG contaminant. Friable asbestos will be removed and disposed as required by the National Emission Standards for Hazardous Air Pollutants "Standard for Demolition and Renovation," 40 CFR § 61.145. Undisturbed asbestos, or asbestos found in high radiation, high contamination, and/or inaccessible locations greater than 3 ft below ground surface may be managed in place, as allowable.

- Inorganics such as fluorides and chlorines are not known or suspected to be present in any locations within the ETR complex, or they are assumed present only in negligible amounts.

- Several inorganic constituents (all metals) are assumed present in materials of constructions only as very small alloyed amounts, for which there are no readily available industry specifications or other material descriptions that can be used to accurately quantify. These metals include arsenic, molybdenum, selenium, thallium, and vanadium. However, some of these metals were quantified in painted surfaces, based on analytical results of the paint samples collected in 2005 within the ETR complex. The amounts for PCBs (organic) and antimony, barium, cobalt, copper, vanadium (metals) calculated for painted surfaces was not considered to be significant enough quantities (all were <0.2 kg) to warrant inclusion in this report.

- While it is documented that cadmium control rods were once used in the reactor core, an ETR report indicates that these control rods were slated to be replaced by hafnium control rods due to their susceptibility to deterioration in the reactor (Brown 1964). There is no evidence of any cadmium control rods that are currently present in the reactor vessel.

- Strontium and uranium were not considered for the potential list because strontium is specified under the EPA Region 9 PRGs as stable form only, while uranium is listed for chemical toxicity only, as opposed to radiological properties (such as, isotopes of uranium, such as U-235).

- It is documented that all sodium and NaK (sodium-potassium) has been removed from Sodium Loop Safety Facility experiment support system components and piping.

- Other assumptions and considerations that were identified for this EDF to simplify quantity estimation for the constituents of concern are:

- It is assumed that there are no discernible quantities of chemical contaminants in any of the primary and secondary coolant systems. Water in these systems were drained and disposed of during 1982 deactivation activities. These systems, however, are considered from the aspect of a radiological source term, which is covered under a separate EDF.

- It is assumed that the chemicals that are normally tracked by the INL Chemical Management System, such as solvents, adhesives, pesticides or herbicides, will be used for their intended purpose and will not remain in any of the buildings and structures as leftover or discarded products. Overall, no organic chemical constituents were quantified for this source term.

4.1.2 Additional Assumptions for Source Term Calculations and Estimates

The following assumptions were used for calculating quantities of chemical constituents:

- The densities of stainless steel and carbon steel are assumed to be identical (7.9 g/cm^3).
- All stainless steel is assumed to be 304 type, which, on average, contains 19% chromium, 10% nickel, and 2% manganese.
- Carbon steel alloys (per ASTM A 29) contain small percentages of chromium, nickel and manganese. The averages for these are: 0.49% chromium; 0.43% nickel, and 0.81% manganese.
- Other specific assumptions for calculating quantities of metals are detailed for each particular metal.
- For paints, the total surface area covered by paint is assumed to be the surface area of the following:
    - The main reactor floor area (18,247 ft^2)
    - Canal (5,494 ft^2)
    - Reactor console floor and balcony (28,007 ft^2)
    - Loop cubicle areas (annulus gas, M-3 and P-7 cubicle, J-10/L-10 cubicle, C-7/M-13/N-14 cubicle, F-10/H-10 cubicle, L-12/M-7 cubicle, C-13/G-16 cubicle, and helium system cubicle (7,556 ft^2)
    - Control access room (414 ft^2)
    - Subpile room (554 ft^2)
    - Heat exchanger building basement (5,486 ft^2).

  These areas yield a total surface area for calculation purposes of 65,758 ft^2.
- Weight of applied paint is assumed to be 5 g/ft^2. This is the concentration used by Waste Generator Services in mass balance calculations for waste disposal purposes.

5. QUANTITIES OF INORGANIC CHEMICAL CONSTITUENTS IN THE ETR FACILITIES

The majority of the hazardous constituent quantities are from inorganic constituents, which are found in materials of construction and to a much lesser extent, in coated (painted) exterior surfaces. The most prevalent materials of construction by quantity, including metal alloys, include aluminum, barium copper, chromium, manganese, and nickel.

The inorganic constituents quantified for painted surfaces were based on the presence of these metals in the paint chips sampled in the subgrade areas. For purposes of this report, the paints considered to be representative of subgrade areas within the ETR complex include gray and white. Averages of the concentrations were used to quantity the total amount of the constituent in the painted surfaces.

Note that the total amount of contaminants found in paint and other coatings (Permagum) were calculated separately for the TRA-706 delay tanks, and are presented in Appendix A. The values for lead and chromium that were calculated for the delay tanks have been added to the amounts for lead and chromium only.

5.1 Aluminum

Aluminum is a material of construction for various nuclear components at the ETR facility. The major aluminum components (associated with the reactor vessel internals) are listed below.

There are several items that might include aluminum as part of their composition, in either solid aluminum form or aluminum-alloyed materials of construction (various electrical and mechanical components and equipment). However, these were not quantified due to the uncertainty and difficulty of deriving a definable estimate.

These aluminum components and materials are constructed of 6061-T6 aluminum. Major parts constructed of aluminum include:

- Aluminum reflector pieces
- Aluminum filler pieces
- Shock section
- Guide tube
- Refueling platform
- Transfer tube
- Aluminum barrier (canal).

Based on material inventory in a spreadsheet developed for ETR complex waste volumes, the estimated quantity of aluminum is 3,340 kg.

5.2 Antimony

Antimony is an alloy of certain types of materials. It is alloyed with zinc and lead as a material of construction in concrete lag shield anchors, which were used with lag bolts for hanging or anchoring various items/system components.

The percentage by composition of the lag shield anchors is 75% zinc, 2% antimony, and 23% lead. The calculated weight of antimony in paint was considered negligible due to its very small mass and is not included as part of the overall quantity of antimony.

A typical (representative) lag shield anchors is assumed to be of medium duty, 0.5 in. in diameter, and 3.0 in. long. It has a weight of 60 g.

There are several different types of lag bolts in the MTR facilities. A rough order of magnitude estimate of the number constructed of zinc and antimonial lead is 500.

Thus, the number of lag shield anchors (500) × typical weight of an average anchor (0.060 kg) × percent of antimony as an alloy material (0.02) = 0.75 kg antimony in lag shield anchors.

The total weight of antimony in the ETR complex is 0.6 kg.

5.3 Barium and Compounds

Barium is present as an additive to some of the high-density (magnetite mixed with barytes, or barium sulfate) concrete block walls in ETR and is a common paint pigment. However, the calculated weight of barium in paint was considered negligible and is not included as part of its overall quantity in the ETR complex.

Barytes were added to the high-density concrete (i.e., concrete mixed with magnetite) to enhance the neutron shielding properties of the concrete. Based on the 1982 ETR characterization report, the only portion of the ETR complex identified as having high-density concrete containing barium includes the magnetite/baryte containing cubicle walls.

Densities of high-density concrete with magnetite for the ETR facility averages 222 lb/ft^3, or the equivalent of 3.55 g/cm^3 (3,550 kg/m^3).

The total volume of the cubicle walls is assumed to be 1/8 of the total concrete volume estimated for all of the loop cubicles (walls, floors, and ceiling), which is 765 m^3/8, yielding 95.6 m^3.

<u>Assumptions:</u>

- The percent aggregate of the barite in the concrete mixture is estimated to be around 50%. Therefore, the barium composition in the high-density concrete is 113 lb/ft^3 (1,810 kg/m^3)[b].
- The mass of the barium (as barium sulfate) is calculated as:
  - Volume of concrete (95.6 m^3) × density of the barium in the concrete (1,810 kg/m^3) = 173,036 kg.
  - To derive an adjusted mass for elemental barium (in the barium sulfate compound), the weight of the barium sulfate is multiplied by the ratio of the atomic weight of barium and the atomic weight of barium sulfate ($Ba/BaSO_4$). This ratio is 137.34/233.3976, or 0.5884. Multiplied by the weight of the barium sulfate yields 101,814 kg

Thus, the total estimated weight of barium in the ETR complex is 101,810 kg.

5.4 Beryllium and Compounds

The only identified component constructed of beryllium in the ETR complex is found in the reactor core, which contains a beryllium reflector that was installed in March 1970. It is assumed that the beryllium used in its manufacture originated from a source where the percentage of the beryllium used for its construction was relatively high. The ETR replacement beryllium was analyzed for chemical and physical (such as, tensile strength) properties by the Brush Beryllium Company. The analyses indicated that the beryllium closely resembled “S200 structural grade beryllium,” although some samples were actually closer to nuclear grade specifications.

According to EDF-4986, the given mass of the beryllium reflector is 714.2 kg.

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[b] Lotus Note from Harry Heidkamp, ICP project engineer, dated August 18, 2005.

Given an average percentage of 98.5% beryllium yields a total weight of the beryllium of 704 kg.

The total quantity of beryllium in the ETR reactor vessel is 700 kg.

5.5 Boron (as boron carbide)

Boron is a material that is used as a neutron absorber in nuclear operations.

Boron is found in the form of boron carbide and is used for shielding purposes in the horizontal ion chamber drive assembly. The ion chamber drive assembly contains a boron disk that measures 0.25 in. (0.64 cm) × 5 in. (12.7 cm) in diameter. The density of boron carbide is 2.6 gm/cm^3.

Based on drawings, the estimated amount of boron (as boron carbide) is volume of boron (81 cm^3) × density of boron (2.6 gm/cm^3) = 211 g = 0.2 kg.

Boron has also been added to the high-density concrete as boron frits (1% by weight) to fill the void space of the interior of the ion chamber drive assembly. The estimated interior volume of the chamber is 600 in.^{3}, or 9,830 cm^3. Given that the density of high-density concrete is 3.5 g/cm^3, the total weight of the concrete in the void space is 34,405 g (34.4 kg). One percent of this amount yields 0.34 kg boron.

The total amount of boron in the ETR complex is 0.5 kg.

5.6 Chromium

Chromium is not known to exist in significant quantities within the ETR facilities other than in an alloyed form, principally as a major alloy in stainless steel components. It is also found in much smaller percentages of carbon steel. For simplifying the calculated inventory estimate, it is assumed:

1. Major components are constructed of 304 stainless steel
2. Stainless steel (such as in the form of 304 stainless) is composed of, on average, 19% by weight chromium
3. Carbon steel contains an average percentage of 0.49% chromium.

In general, stainless steel components that were included in the estimate of the chromium inventory consist of the reactor vessel components, external thermal shield, canal liner, experiment cubicle piping and valves, cubicle equipment (such as pumps, heaters, resin columns, and in-pile tubes), various piping, tanks, and miscellaneous components located both within and outside the footprint of the ETR building, such as primary coolant piping, off-gas pipe runs, and delay tank baffles.

To a lesser degree, chromium is also an alloy of certain carbon steels, which for the purposes of these calculations is assumed to be 0.49%. Carbon steel components include structural steel, concrete rebar, tanks and piping, pipe supports, pumps and motors, and heat exchanger shells.

The methodology of estimating the amount of chromium is based on estimates of meltable metals volumes found in the *ETR Complex Characterization Report* (Kaiser et al. 1982). These meltable volumes include primarily stainless steel, carbon steel, and lead, and may also include very small amounts of other alloyed materials, which were not specified in the ETR characterization report. The meltable metal volumes (assumed to be contaminated) were summed for the applicable ETR facilities, which include:

- TRA-642 reactor main floor, 900 ft^3
- TRA-642 reactor building basement (excludes experiment cubicles, rod access control room, subpile room GEEL tunnel, warm and hot waste pits), 427 ft^3
- Annulus gas system cubicle, 101 ft^3
- C-13/G-16 cubicles, 33 ft^3
- Control rod access room, 11 ft^3
- GEEL tunnel and delay tanks, 1,089 ft^3
- TRA-643 compressor building (primary piping system), 246 ft^3
- TRA-644 heat exchanger building (lower levels, with pump pits), 1,118 ft^3.

The total meltable metal volume as summed above is 3,925 ft^3. Assuming that lead in the ETR complex amounts to roughly 650,000 lb (or an equivalent 825 ft^3) yields approximately 3,100 ft^3 of stainless and carbon steel, considered to be the effective remainder of the meltable metal. The ratio of carbon steel to stainless steel, as derived from the waste volumes in the ETR waste volume spreadsheet, is approximately 3:1. Thus, from the meltable metal volumes, the volume distributed between carbon and stainless steel, at a 3:1 ratio is 2,325 ft^3 carbon steel, and 775 ft^3 stainless steel.

The densities of carbon steel and stainless steel are virtually identical, so it is assumed that each has a density of 7.9 g/cm^3 (7,900 kg/m^3). Converting the units for the volume of the carbon steel (2,325 ft^3) and stainless steel (775 ft^3) gives 65.8 m^3 for carbon steel, and 21.9 m^3 for 304 stainless steel. Thus,

$(7{,}900\ kg/m^3) \times (21.9\ m^3) = 173{,}010$ kg 304 stainless steel

$(7{,}900\ kg/m^3) \times (65.8\ m^3) = 519{,}820$ kg carbon steel.

At 19%, the total mass of chromium in stainless steel is mass of 304 stainless steel (173,010 kg) × percent chromium in 304 stainless steel (0.19) = 32,872 kg.

Its mass in carbon steel is mass of carbon steel (519,820 kg) × percent chromium in carbon steel (0.0049) = 2,547 kg.

The total estimated quantity of chromium in the ETR complex is the sum of those two values, or 35,420 kg.

5.7 Copper and Compounds

Copper is found in numerous industrial materials and components, both in virtually pure forms and alloyed forms. Alloyed forms include brass (copper-zinc-lead alloy), which is assumed to be forging brass–60% copper, 38% zinc, and 2% lead by weight), and bronze (assumed to be commercial bronze), which is 90% copper and 10% tin by weight. The ETR complex contains several components constructed of copper and copper alloys, including copper wiring, copper tubing and piping; copper motor/pump rotors and windings, bearings, pressure fittings, gauges and flow indicators, springs, control valves, and various electrical parts, such as switches and relays. Copper is also found in very small fractions in paint chips collected from walls, floors, and facility components, but because of its extremely small quantity was not included in the overall inventory.

Assumptions for calculating the total quantity of copper (within pure and alloyed copper) include the following:

5.7.1 Copper

- Copper wiring is based on a rough order of magnitude estimate[c] of 60,000 lb (27,216 kg) for TRA-642 alone. An additional 25% of copper is added for additional buildings and structures, yielding a total 75,000 lb (34,019 kg) of copper wiring.
- A total of 5000 linear ft of copper piping and tubing, which is considered to have an average nominal size of 0.375 in. (0.95 cm) with the weight per linear ft (30.5 cm) of 0.269 lb (0.12 kg).
- An estimated total of 50 pump and motor rotors and windings are found in the ETR complex. The average weight of the copper per unit (based on 25-hp output) is assumed to be 11.4 kg.
- An estimated 250 springs at 2.3 kg copper per spring.

5.7.2 Copper alloys (brass and bronze)

- An estimated 150 gauges and flow indicators (bronze construction), at 0.4 kg of copper (based on 90% copper by weight) per unit
- An estimated 400 pressure fittings (brass), at 0.066 kg of copper per fitting
- An estimated 50 brass control and relief valves (brass), at an average weight of 7 kg of copper per valve
- An estimated 300 bearings (bronze construction), at 2.1 kg of copper per bearing

The total estimated weight of copper (see itemized summary in Table 2) in the ETR facility is 36,840 kg.

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[c] Conversation August 8, 2005, with Loran Marler, INL estimator for electrical utilities, who indicated that based on the type of building, 60,000 lb was typical for the poundage of copper conduit in TRA-642.

Table 2. Estimated quantity of copper in the ETR complex.

Component	Linear ft, or Weight (kg) of Copper (adjusted for alloyed forms) per Component	Total Equivalent Weight (kg)
Wiring	Various gauge sizes	34,019
Tubing and piping	5,000 linear ft	610
Rotor motors (wound and cast)	11.4 kg/component	570
Bearings[a]	2.1 kg	630
Control and relief valves	7 kg/valve	350
Springs	2.3 kg	575
Pressure fittings	0.066 kg	26
Gauges and flow indicators[a]	2.1 kg	60
Total weight of copper	36,840 kg	
a. Bearings, gauges, and flow indicators are assumed to be constructed of bronze.		

5.8 Lead

Most of the lead in the ETR complex is used for radiation shielding. This lead, in the form of lead bricks, sheets, shot, various forms, pigs, and poured lead (such as, eternal thermal shield) will be removed and disposed of as mixed hazardous waste at an off-site licensed disposal facility. It is also possible that some of the lead may be suitable for reuse at the INL.

It is possible that not all lead shielding can be removed safely, given that there may be some areas within ETR where conditions prevent adequate worker protection (e.g., high-contamination/high-radiation areas, confined space). It may also prove impractical to remove other lead that is present in the ETR buildings and structures, including concrete lag shield anchors (contain lead as an alloy) that are embedded in concrete walls, lead wool pipe packing, and lead packing found in the pipe joints of cast iron piping.

There are several types of concrete wall anchors in the ETR complex. A conservative estimate of those constructed of zinc alloyed with antimonial lead is 500. The average lead anchor (also referred to as lag shield anchor), is assumed to be of medium duty, 0.5 in. in diameter, 3.0 in. long, and constructed of metals with the following percentages: zinc (75%) alloyed with antimonial lead (2% antimony, 23% lead).

The weight of a typical lag shield anchor (refer to Section 5.2) is 60 g.

Thus, the total number of anchors (500) × typical weight of a lag shield anchor (0.060 kg) × percent lead in each anchor (23%) = 6.9 kg lead in lag shield anchors.

Other lead includes lead wool and lead pipe packing. The estimated quantity of these lead forms, which is a rough order of magnitude estimate due to the inherent difficulty in attempting to quantify such amounts prior to actual decommissioning activities, is 15 kg.

Lead is present in brass components at an assumed average percentage of 2.0%. The total estimated weight of lead in brass fixtures and components in the ETR complex is 12.5 kg.

In painted surfaces, lead was detected at an average concentration of 5,197 mg/kg in the painted wall and floor surfaces in the subgrade levels. The total quantity of lead in paint was calculated as follows:

- Surface area of areas considered: 65,758 ft^2
- Lead concentration (average of gray and white paints sampled): 5,197 mg/kg
- Weight of lead in paint: total surface area (65,758 ft^2) × average weight of paint/ft^2 (5 g/ft^2) = 328,790 g × 0.001 kg/g = 328.8 kg paint × average lead concentration (5,147 mg/kg lead) = 1,709 g (1.71 kg) lead.

The calculated quantity of lead in the Permagum coating on the TRA-706 delay tanks (see Appendix A) is 1.6 kg.

The total estimated quantity of lead to be left in the ETR complex, from the sum of lead quantities in lag shield anchors, lead wool and lead pipe packing, brass, sealant and paint is 40 kg.

5.9 Manganese and Compounds

Manganese is assumed to be present only in alloyed form. The quantity of manganese has been calculated based on an assumed average percentage in 304 stainless steel of 2%, and an average percentage of 0.81% in carbon steel components.

Based on the calculated estimate quantity for stainless steel, the quantity of manganese is derived by multiplying the mass of 304 stainless steel by the given alloyed percentage typical of manganese in 304 stainless steel, yielding (173,010 kg) × (0.02) = 3,460 kg.

Its mass in carbon steel is the mass of carbon steel (519,820 kg) × percent manganese in carbon steel (0.0081) = 4,211 kg.

The total estimated quantity of manganese in the ETR complex is 7,670 kg.

5.10 Nickel

Nickel is present in ETR as a significant alloy of stainless steel of 10% (under the assumption that these components are constructed from 304 stainless steel), and a much smaller average percentage of 0.43% in carbon steel components.

Based on the calculated estimate quantity for stainless steel, the quantity of nickel is derived by multiplying the mass of 304 stainless steel in the ETR complex by the given alloyed percentage typical of nickel in 304 stainless steel, which yields: (173,010 kg) × (0.1) = 17,300 kg.

Its mass in carbon steel is the mass of carbon steel (519,820 kg) × percent nickel in carbon steel (0.0043) = 2,235 kg.

Nickel is also present within the reactor vessel as a material on eight gray control rods. These control rods each contain three poison plates (dimensions 24 × 8 × 1/32 in.), two spacers (dimensions

3.75 × 2.5 × 9/16 in.), and two side plates (dimensions 24 × 3.75 × 3/16 in.), constructed of nickel. The total volume of the nickel for each control rod is 62.25 in.^3, or 1,020 cm^3. The density of nickel is 8.91 g/cm^3.

Thus, number of control rods (8) × volume of nickel within each gray control rod (1,020 cm^3) × density of nickel (8.91 g/cm^3) = 72.7 kg nickel within the control rods.

The total estimated quantity of nickel in the ETR complex is 19,610 kg.

5.11 Silver and Compounds

Silver is an element that is commonly used in electronic equipment, such as electric conductors (bus bars), brazing alloys, and electrical contacts. It is most prevalent (as far as quantifiable amounts) in electrical contacts. Typical quantities are 8–10 ounces (227–283 g) for large-size contacts, and 0.5–1 ounce (15–30 g) for small-size contacts[d].

A rough order of magnitude estimate for the total number of electrical contacts within motor control centers and other electrical control panels within the ETR complex is 500. Of these, 75% are assumed to be small–size contacts, and 25% large-size contacts. These contacts are assumed to be pure silver.

Small contacts

Number of contacts (375) × average weight of contact (17.5 g) = 6,562.5 g = 6.5 kg.

Large contacts

Number of contacts (125) × average weight of contact (255 g) = 31,875 g = 31.9 kg.

The total amount of silver in the form of electrical contacts is 40 kg.

5.12 Tin

Tin is present as an alloy of bronze and as a very small fractional percentage of painted coatings (incidental ingredient of paints sampled from walls and floors in the ETR facility). The calculated weight of tin in paint was considered negligible and is not included as part of the overall quantity of tin.

Tin is a component of commercial bronze, which is used in components such as water gauges, flow indicators, bearings, valves and drain cocks. Based on literature found under http://www.evanstechnology.com/bronze.html, bronze is typically composed of 90% copper and 10% tin. The total estimated weight of bronze is based on those components identified for the calculation of copper in the ETR complex (see Section 5.7). Given that the quantity of bronze is estimated at 757.5 kg, the quantity of tin is 10% of that weight, or 75.8 kg.

The total estimated quantity of tin is 80 kg.

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[d] Conversation with Loran Marler, INL estimator for electrical utilities, August 8, 2005, who indicated that based these are typical values for electrical contacts that contain silver.

5.13 Zinc

Zinc is present as an alloy of brass and as a small percentage of painted coatings (as zinc chromate, a pigment used in paint formulations) sampled from walls and floors in the ETR facility).

Zinc is a component of commercial brass, which is used in components such as valve and pressure fittings. Based on literature found under http://www.evanstechnology.com/bronze.html, forging brass is typically composed of 60% copper, 38% zinc, and 2% lead. Thus, the total estimated weight of brass is based on those components identified for the calculation of copper in the ETR complex (see Section 5.7). The total estimated weight of brass components (considered for this source term) in the ETR complex is 628 kg.

Thus, the total weigh of components (628) × percentage of zinc in brass (0.38) = 239 kg.

Galvanized conduit piping is zinc electroplated for corrosion resistance. The amount of zinc in this form assumes the following:

- The conduit piping has an average inside diameter of 3 in. (7.62 cm) in diameter.
- The length of the conduit is assumed to be 15,000 linear ft (457,200 cm).
- The type of plating on electrical conduit is continuous electroplating, which produces a thickness of the zinc coating up to 25 microns (0.0025 cm). The coating is on the exterior of the conduit only.
- The coating is assumed to be 100% zinc, which has a density of 7.14 g/cm^3.
- Surface area of a conduit is 2 πrh = (2) × (π) × (3.81 cm) × (457,200 cm) = 10,944,880 cm^2.

Thus, the mass of the zinc = surface area of the conduit (10,944,880 cm^2) × thickness of the coating (0.0025 cm) × density of the zinc (7.14 g/cm^3) = 195,366 g = 195 kg zinc.

The weight of a typical lag shield anchor is 60 g. There are an estimated 500 lag anchors composed of a zinc-antimonial lead alloy.

Thus, the number of anchors (500) × mass of a typical anchor (0.060 kg) × percentage of zinc in each anchor (0.75) = 22.5 kg zinc in lag shield anchors.

In painted surfaces, zinc was detected at an average concentration of 5,147 mg/kg in the painted wall and floor surfaces. The total quantity of zinc in paint was calculated as follows:

- Surface area of areas considered: 65,758 ft^2.
- Zinc concentration (average of gray and white paints sampled): 5,147 mg/kg.
- Weight of zinc in paint: total surface area (65,758 ft^2) × average weight of paint/ft^2 (5 g/ft^2) = 328,790 g × 0.001 kg/g = 328.8 kg paint × average zinc concentration (5,147 mg/kg zinc) = 1,692 g (1.69 kg) zinc.
- The weight of zinc in paint is 1.69 kg.
- The estimated weight of zinc as an alloy of brass components is 239 kg.

- The estimated weight of zinc as zinc plating on galvanized conduit is 195 kg.

- The estimated weight of zinc contained in lag shield anchors 22.5 kg.

- The total weight of zinc is 460 kg.

6. SUMMARY OF CHEMICAL CONSTITUENT QUANTITIES IN THE ETR COMPLEX

Table 3 summarizes the estimated quantities of chemical constituents in the portions of the ETR complex that are projected to be left in place per the end state scenario of “Alternative 2–Grouting Reactor Vessels in Place” that is described in Section 4.1.

Table 3. Summary of chemical constituent quantities in the ETR complex.

Chemical Constituent	Location(s)	Use/Form	Quantity (kg)
Aluminum	ETR vessel	Reactor components	3,340
Antimony	Concrete walls and floors	Alloy used in concrete wall lag shield anchors	0.6
Barium (and compounds)	High-density concrete used in cubicle walls	Additive for heavy concrete used in nuclear shielding (cubicle walls), paint pigment	101,810
Beryllium (and compounds)	ETR vessel	Neutron reflector in the pressure vessel	700
Boron	Shielding for ion chamber drive assembly	Shielding in the ion chamber drive assembly, added to concrete	0.5
Chromium	Piping and other operations components throughout ETR complex	Piping, vessels, and other components constructed of stainless steel	35,420
Copper (and compounds)	ETR complex	Wiring, tubing, rotors, bearings, brass and bronze components, electrical equipment	36,840
Lead	Wall and floor anchors, piping	Shielding, alloy of concrete wall lag shield anchors, pipe packing, brass alloy	40
Manganese (and compounds)	Piping and other operations components throughout ETR complex	Metal alloy found in piping, vessels, and other components constructed of stainless steel	7,670
Nickel	Piping and other operations components throughout ETR complex, gray control rod poison	Metal alloy found in piping, vessels, and other components constructed of stainless steel	19,610
Silver (and compounds)	Electrical control panels	Electrical contacts	40
Tin	ETR complex	Alloy of bronze (used in gauges, bearings, and flow indicators)	80
Zinc	ETR complex	Significant alloy of brass	460

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Appendix A

Mass Balance Calculations for Permagum and Paint Coatings, ETR TRA-706 Delay Tanks and Associated Components

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Appendix A

Mass Balance Calculations for Permagum and Paint Coatings, ETR TRA-706 Delay Tanks and Associated Components

Basis

The ETR delay tanks galvanized corrugated enclosures are coated with a tarry substance referred to as "Permagum." Samples were collected in 1999 from the surface of the tanks' outer galvanized enclosure. The Permagum is also present on the concrete end walls in which the enclosure ends are embedded. The total metals analysis reported detectable concentrations of lead at 2,540 mg/kg, barium at 59.7 mg/kg, and chromium at 45.8 mg/kg. The painted surfaces of the tanks' exterior wall showed detectable concentrations of total metals that include barium (149 mg/kg), chromium (3,390 mg/kg), and lead (1,040 mg/kg). However, the concentrations of the lead in the Permagum and lead and chromium in the delay tanks paint can be mass balanced to show that their theoretical TCLP values do not exceed RCRA regulatory limits for these TCLP metals.

Assumptions

Density, stainless steel: 8.03 g/cm^3 (501.3 lb/ft^3)

Density, carbon steel: 7.83 g/cm^3 (488.8 lb/ft^3)

Density of reinforced concrete: 149.8 lb/ft^3

Density of the tar: 1.2 g/cm^3

Density of dried paint assumed to be 0.65 g/cm^3 (40.6 lb/ft^3)

Delay tanks and miscellaneous components/materials

Dimensions of the ETR delay tank (per tank):

Diameter: 10 ft (radius = 5 ft)

Length: 61 ft, 2-in. long

Wall thickness: 0.375 in.

Tank exterior surface area: 2,010.6 ft^2

Baffle dimensions: 10 ft diameter, 2.0625 in. thick, assume 90% solid

Weight of each baffle plus bracing/struts:
$(\pi\ 5^2)\ (0.0052\ \text{ft})\ (0.9) = (12.15\ \text{ft}^3) \times (501.3\ \text{lb/ft}^3) = 184\ \text{lb} + 25\% = 230\ \text{lb (kg)}$

Total exterior surface area: 2,010.6 ft^2

Tank weight: (2,010.6 ft^2) × (0.03125 ft) = (62.8 ft^3) × (488.8 lb/ft^3) = 30,712 lb

Baffles/bracing: (230 lb) (5 baffles) = 1,150 lb

Insulation/miscellaneous: 400 lb

Total weight of each delay tank (including 5 baffles, baffle bracing, and insulation):
32,262 lb (14,634 kg/each)

Cylindrical delay tank galvanized corrugated enclosure

Dimensions of the cylindrical delay tank galvanized corrugated enclosure (each enclosure):

Diameter (average): 15 ft, 6 in. (radius = 7.75 ft)

Length: 64 ft

Wall thickness: 0.375 in.

Enclosure exterior surface area: 3,116 ft^2

Total weight of each enclosure = (3,116 ft^2) × (0.03125 ft) = (97.375 ft^3) × (488.8 lb/ft^3) = 47,597 lb

Concrete end walls

Dimensions of the concrete end walls (each wall):

Height: 18 ft
Length: 39 ft
Thickness: 1 ft, 4 in.

Density of reinforced concrete: 149.8 lb/ft^3

Total weight of each wall = (18 ft) × (39 ft) × (1.33 ft) × (149.8 lb/ft^3) = 139,862 lb

Delay tanks (w/baffles/insulation/miscellaneous): 64,524 lb (29,268 kg)
Tank enclosures: 95,194 lb (43,179 kg)
Concrete end walls: 279,724 lb (126,881 kg)

Total weight of all structures: 439,442 lb (199,327.5 kg)

Tar

Applied thickness assumed to be 24 mil (0.002 ft)

Density of the tar: 1.2 g/cm^3

Area covered:
exterior tank enclosures (6,232 ft^2) + concrete walls, front/back/sides (2,856 ft^2) = 9,088 ft^2

Weight of tar applied to structures: (9,088 ft^2) × (0.002 ft) × (74.9 lb/ft^3) = 1,361.4 lb (617.5 kg)

Paint

Dried applied thickness assumed to be 8 mil (0.00066 ft)

Density of dried paint assumed to be 0.65 g/cm^3 (40.6 lb/ft^3)

Area covered:
exterior surface area of both delay tank (4,021 ft^2) + interior surface area (4,021 ft^2) = 8,042 ft^2

Weigh of paint applied to tanks = (8,042 ft^2) × (0.00066 ft) × (40.6 lb/ft^3) = 215 lb (97.5 kg)

Lead concentration (Permagum coating) 2,540 mg/kg

Lead concentration paint 1,040 mg/kg

Chromium concentration paint 3,390 mg/kg

Mass balance, lead in the Permagum coating

(2,540 mg/kg) × (617.5 kg) = 1.56845E+06 mg/(43,179 kg +126, 881 kg)

= 1.56845E+06 mg ÷ 20/170,060 kg

= 0.46 mg/kg lead

Mass balance, lead in the paint (on delay tanks)

(1,040 mg/kg) × (97.5 kg) = 101,400 mg/29,268 kg

= 101,400 ÷ 20/29,268 kg

= 0.17 mg/kg lead

Mass balance, chromium in the paint (on delay tanks)

(3,390 mg/kg) × (97.5 kg) = 330,525 mg/29,268 kg

= 330,525 ÷ 20/29,268 kg

= 0.56 mg/kg chromium