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Engineering Design File

Radiological Characterization of ETR for Disposal

Idaho National Engineering and Environmental Laboratory

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ENGINEERING DESIGN FILE

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5. Summary:
This EDF documents analysis of the Engineering Test Reactor (ETR) reactor building (TRA-642), the compressor building (TRA-643), and the heat exchanger building (TRA-644) and their contents for activities of selected radioisotopes in anticipation of permanent disposal of the reactor facility. The analysis considered activated structures remaining in the reactor vessel, the contents of tanks and piping systems within the facility, surface contamination of floors, walls, and ceilings of contaminated building rooms, and selected other components. Computer codes used include MCNP4C for determining activation fluxes for the various structures in the reactor vessel and ORIGEN2 for determining the activities of the isotopes of interest in those structures. Additionally, facility drawings were used to estimate contaminated surface areas in various rooms and cubicles of the buildings. Strong reliance was made on measurements made in 1982, 1996, and 1997 in estimating surface activity concentrations and inventories in tanks.

We found that the overall activity as of January 2005 in buildings TRA-642, TRA-643, and TRA-644 is 141,000 Ci. However, only 1.39 Ci is on building surfaces. The rest is in the activated structures in the reactor vessel. The majority of the inventory, more than 78,000 Ci, is H-3 in the beryllium reflector. Another 48,900 Ci is Ni-63 and 1,370 Ci is Co-60 in the neutron absorbers that constituted the gray control rods. Of the 1.39 Ci surface contamination, nearly all is on exposed surfaces in the various rooms and cubicles, and only 9.4 μCi is estimated to be in tanks in TRA-642. Most of the activity on surfaces is Ni-63 but Co-60 and Cs-137 contribute substantially as well.

The beryllium reflector is estimated to be 9.0 times the threshold for classification as transuranic waste because of uranium impurity thought to be in the beryllium. It also is approximately 74 times the threshold for Class C as defined in 10 CFR 61. None of the other structures meet the transuranic classification. The gray control rod poison sections are more than 4,000 times the Class-C threshold, and the black poison sections are more than 400 times that threshold. Taken in their entirety, the activated structures are about 20.6 times the Class-C threshold. Excluding the beryllium and the nickel poison sections, the remainder of the activated structures are about 10.4 times the Class-C threshold.

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EXECUTIVE SUMMARY

The Engineering Test Reactor (ETR) first became operational in 1957 and operated until 1981. It was specifically designed to have high neutron flux levels in large in-core test spaces. Shortly after its shutdown, a characterization was performed in which measurements were made of surface contamination using smear samples. Analyses were made of gamma-, beta-, and alpha-emitters on smear samples. Based on average values of those smear-sample data and on estimates of surface areas in the ETR facility, estimates were made of isotopic inventories on exterior surfaces. Activation-product inventories were estimated based on gamma field measurements inside the core.

The present study sought to refine those estimates and update them to estimate activities for a range of selected radioisotopes as of January 2005. Activation products were estimated by first creating a fairly detailed numerical model of the ETR reactor core and the structures near it. The MCNP4C code was used with that model to determine flux levels in the various regions of the core and surrounding structures. Using those fluxes, the ORIGEN2 code was used with the reactor power history, detailed component masses, and detailed material compositions to estimate inventories of radioisotopes in January 2005.

Surface activities were estimated on the basis of the smear-sample data from 1982, 1996 and 1997 and scaling factors among the prominent isotopes observed on smear samples developed in 1997. Because the surface areas in the 1982 characterization were approximate, new estimates were made of contaminated surface areas using available drawings and graphical techniques. In prior work, it had been discovered that the removal efficiency of smear samples was low. Accordingly, the estimates of surface contamination based on smear sample data were increased by a factor of 1,000 to compensate for that collection efficiency. It had been previously determined that alpha activity on contaminated surfaces was inconsequential.

The consequence of these analyses was a total estimated radioactivity in January 2005 for the three buildings, TRA-642, TRA-643, and TRA-644 of 141,000 Ci. Of that 78,000 Ci is H-3 in the beryllium reflector, 48,900 Ci is Ni-63 and 1,370 Ci is Co-60 in the nickel neutron absorbers that comprised the gray control rod poison sections. 1.39 Ci is on surfaces in the three buildings, and 9.4 μCi is in tanks in TRA-642.

The transuranic inventory in the beryllium reflector is approximately 9.0 times the threshold value for classification as TRU waste (activities greater than 100 nCi/g of isotopes having atomic numbers greater than 92 with half-lives greater than 20 years). Transuranics are also responsible for the beryllium being 74.4 times the Class-C threshold for disposal. None of the other activated structures exceeds the TRU classification threshold, but the nickel neutron absorbers are more than 4000 times the Class-C threshold.

Taken together, the remainder of the activated structures (excluding the Be and the Ni poison sections and the Be reflector) exceed the Class-C threshold by 10.4 times, mainly because of Ni-63 and Nb-94 in the grid plate, inner tank, and black control rod shock absorber assemblies and for Pu-241 in the F-10 and M-13 in-pile tubes.

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FIGURES

TABLES

ACRONYMS

AGS	annulus gas system
ATR	Advanced Test Reactor
ETR	Engineering Test Reactor
FS&R	filling, storage and re-melt system
GEEL	General Electric experimental loops
GEFP	General Electric Flight Propulsion Project
HAD	hazard assessment document
PAED	Phillips Atomic Energy Division
PBF	Power Burst Facility
PCS	primary coolant system
SLSF	Sodium Loop Safety Facility
TRA	Test Reactor Area

1.0 OBJECTIVE

The objective of this study is to update and refine the radiological characterization[1] of the Engineering Test Reactor (ETR) reactor building (TRA-642) together with the compressor building (TRA-643) and the heat exchanger building (TRA-644) in anticipation of facility disposal.

2.0 INTRODUCTION

The ETR operated from 1957 until 1981 at the Test Reactor Area (TRA), an aerial view of which is in Figure 1. At the time it entered service, it was the largest, most advanced nuclear fuels and materials test reactor in the United States at 175 MWth. Figure 2 shows a vertical elevation of the reactor structure.

Figure 1. The Engineering Test Reactor (circled) was the second large reactor built at the Test Reactor Area.

The ETR was specifically designed to have high neutron flux levels and large internal test spaces. The maximum thermal neutron flux was 8×10^{14} n/cm^2/s. The combined fast and epithermal flux was 2.5×10^{15} n/cm^2/s.[2]

The ETR core was arranged in an array of 7.62 x 7.62-cm (3 x 3-in) elements. Each location has a reference address (e.g., C-7). The fuel region consisted of a 10 x 10 array. The region outside the beryllium reflector (Figure 3) was also arranged in a grid of the same spacing. Fuel height was 91.4 cm (36 in).

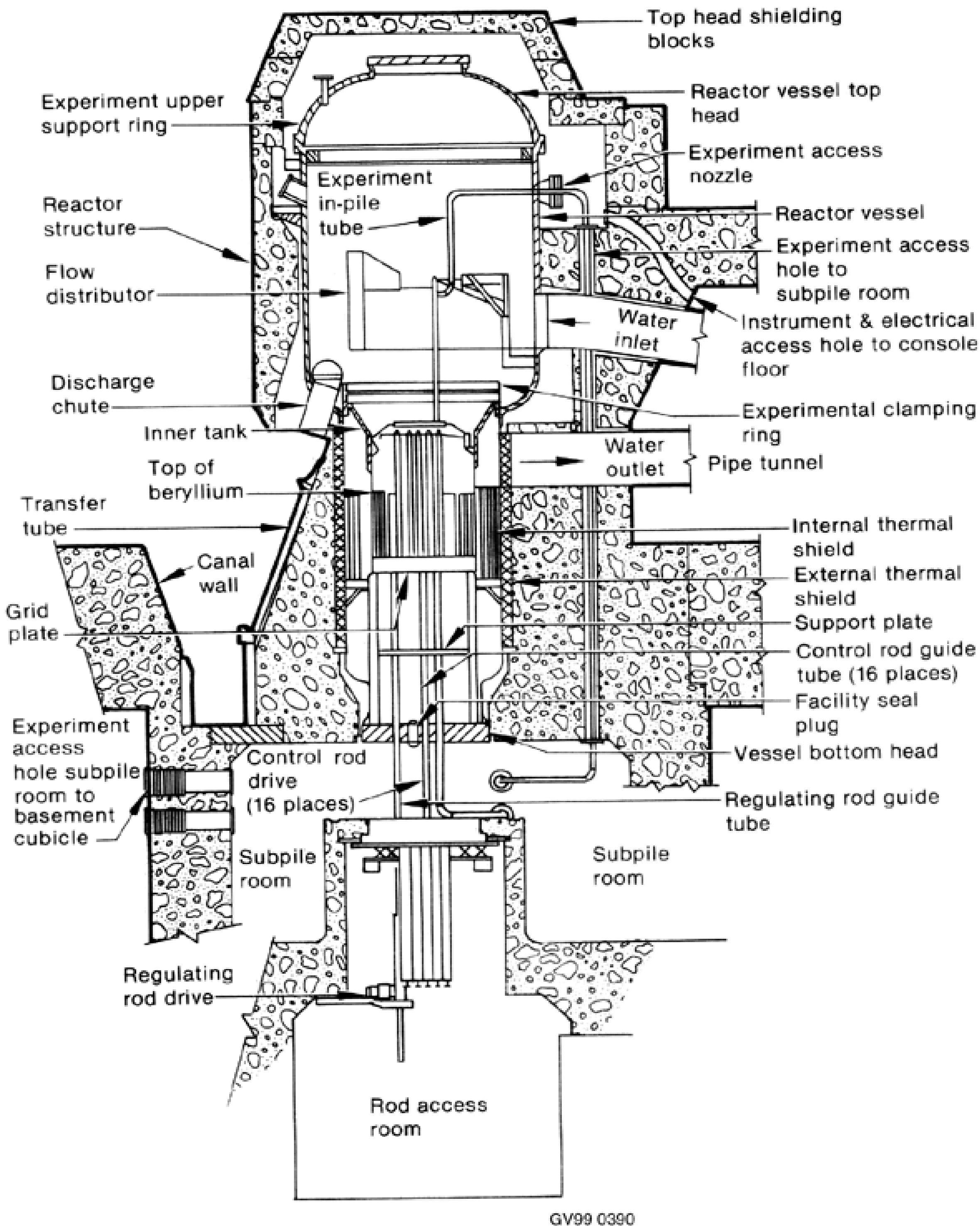

Figure 2. Vertical elevation showing the major elements making up the ETR.

Various fuel and plug configurations were used at different times to accommodate testing. Figure 3 shows those locations that were used for experiments. Numbered circles were control rod locations. Those numbered 1 through 4 are “black” control rods using cadmium as the neutron absorber. The remainder are “gray” control rods, meaning that they are not totally opaque (absorptive) to neutrons. They used Type-A nickel as the neutron absorber. The black object in the north beryllium reflector face was the neutron source. Aluminum filler pieces occupied the region between the aluminum reflector pieces and the inner tank wall. Holes in the beryllium reflector were for capsule experiments, but they were filled with aluminum plugs when not in use for experiments.

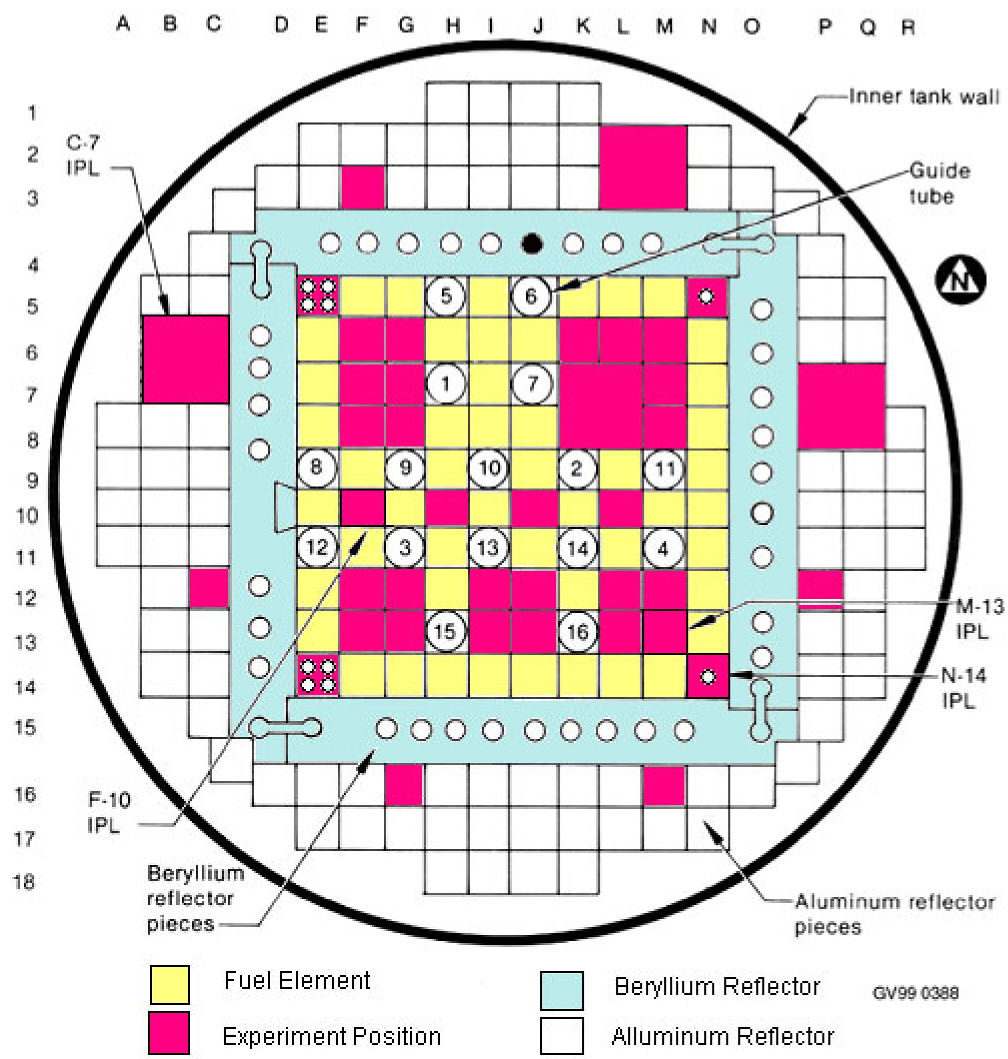

Figure 3. The ETR core had a flexible configuration with a large number of possible test locations.

After initial testing of the reactor, full power operation was achieved in 1958. From then through 1972, the ETR produced approximately 487,728 megawatt-days. In 1972 a decision was made to have the ETR support the Department of Energy's breeder reactor safety program. Conversion of the reactor for this purpose started in May 1973. The new assignment focused on safety programs relating to reactor fuel, core design, and operation for the liquid metal fast breeder reactor program. These were performed in the Sodium Loop Safety Facility (SLSF). The reactor was modified with a new top closure, which was especially designed to accommodate a new irradiation loop. Other modifications included the addition of a helium coolant system and a sodium handling system in support of the test facility. The beryllium reflector had been replaced previously, in 1970, and disposed of. Testing in the reactor began again in October 1975. For the period 1975 to 1981 the reactor produced approximately 12,376 megawatt-days.[3] Figure 4 shows the approximate power history based on these data.

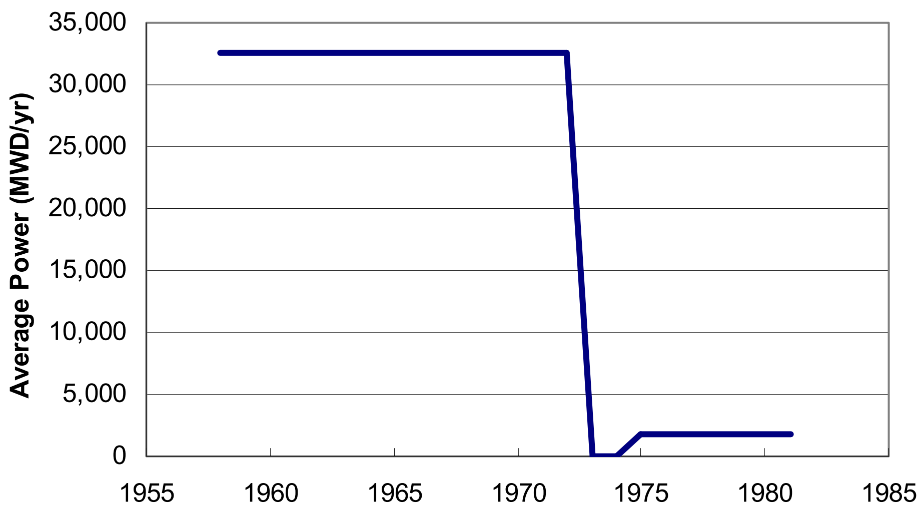

Figure 4. Approximate power history for the ETR.

In December 1981, deactivation was begun, which included removing the neutron source and all fuel from the reactor, draining the primary coolant system (and all other liquid systems in the facility), preparing all major equipment for long-term storage, and performing characterization of the entire ETR facility.[3]

Figure 5 is a photograph taken in 1982 during the characterization. It shows the components remaining in the reactor vessel. Key components are labeled. The bright beam-like structures in the core over rows 9 and 11 and columns H, J, and K are stainless steel auxiliary supports holding the top ends of the control rod guide tubes. Other items seen there include grid adapters, x-baskets, c-4x pieces, and R-4x pieces. Neutron absorber (poison) sections, mechanical shock absorber sections, and spacers are stored in the control rod guide tubes.[4] The control-rod connecting shafts were of 17-4 stainless, but they were so far below the core they will contribute little to the overall facility radioisotope inventory.

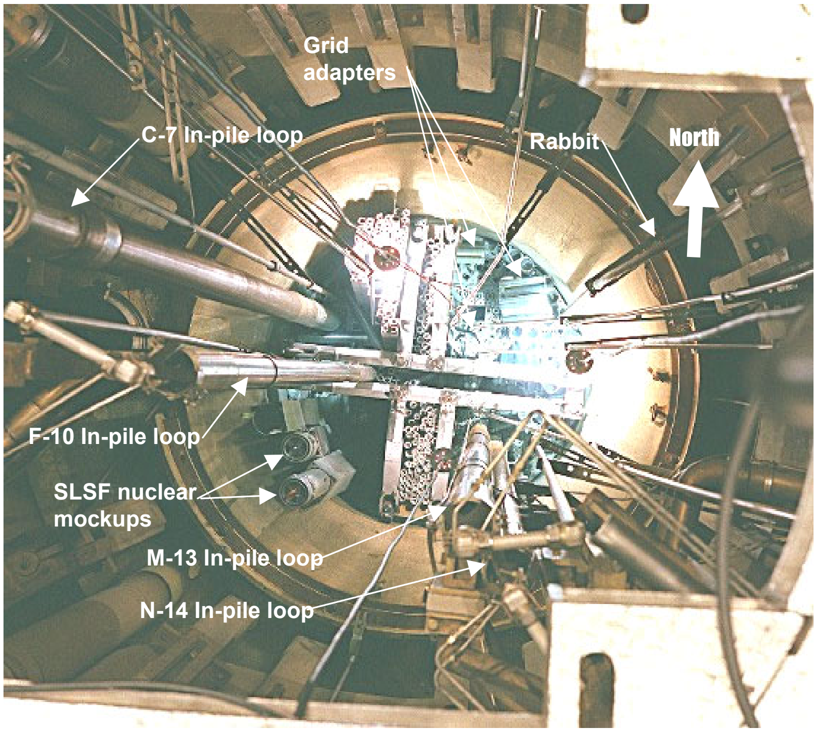

Figure 5. Photograph of the ETR core from above showing items remaining in the reactor vessel.

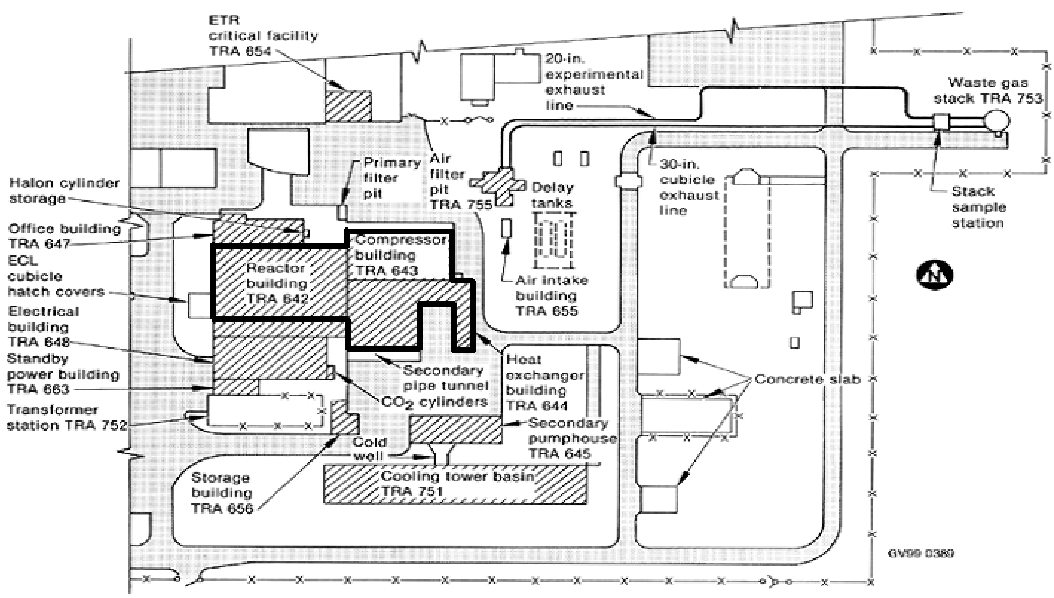

Figure 6. Relative locations of the buildings for this study, TRA-642, TRA-643, and TRA-644.

3.0 RADIOLOGICAL ZONE DEFINITIONS

In this section, we define various radiological zones within the ETR facility that will be considered in this report. This study involves three buildings: the reactor building (TRA 642), the compressor building (TRA-643), and the heat exchanger building (TRA-644). The geographic relationship between these buildings is shown in Figure 6. For convenience, we follow here the zone definitions used in the 1982 characterization.[3] We present only summary descriptions here. For detail, see specific sections referred to from Ref. 3.

3.1 Reactor Building

The reactor building (TRA-642) has three main levels, as shown in Figure 7: the main hall, the console level, and the basement with the loop cubicles and a sub-pile room. To these may be added the pipe tunnel and the control rod access room.

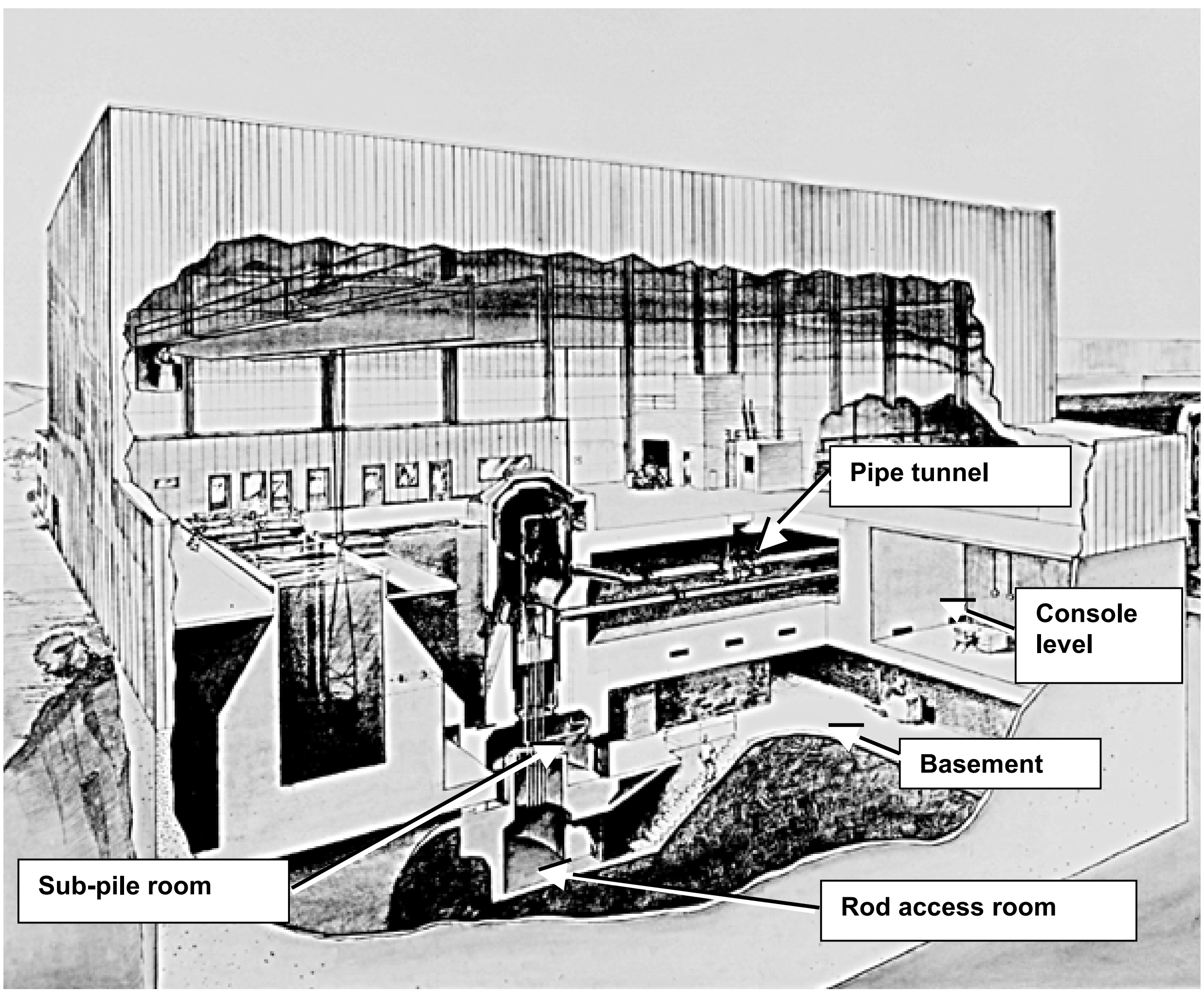

Figure 7. Rendering of the ETR building configuration looking north.

The following sections describe the various zones or regions in the ETR reactor building.

3.1.1 Reactor Pressure Vessel

The pressure vessel is shown in Figure 2. For present purposes, it consists of

1. The top head
2. The reactor vessel with the discharge chute
3. The experimental clamping ring
4. The inner tank with rod guide tube supports
5. The beryllium reflector
6. The grid plate
7. The aluminum reflector outside the beryllium
8. The internal thermal shield
9. The external thermal shield
10. The support plate
11. The control rod guide tubes
12. The facility seal plug
13. The vessel bottom head

The water inlet and outlet pipes will be considered separately. Further, from Figure 5, it appears that the flow distributor has been removed. To the above may be added items known to remain inside the reactor vessel that are not part of the core itself.

14. The C-7 in-pile loop (February 1960)
15. The F-10 in-pile loop (July 1961)
16. The M-13 in-pile loop (November 1967)
17. The N-14 in-pile loop (December 1966)
18. The SLSF nuclear mockups (little or no irradiation assumed)
19. Miscellaneous fillers, adapters, and plugs

The dates following loop identifications are when they were installed in the reactor.[5]

Experience with other reactors (c.f., Ref. 6) has shown that only structures within about 1 m from the core edge experience any significant (in terms of contribution to total inventory) activation from neutrons. From Figure 2 it is evident that activated structures include the various in-pile tubes still in the core, the beryllium reflector, the internal and external thermal shields, the grid plate, the support plate, the inner tank, and the control rod guide tube support structure. The control rods themselves with their drive assemblies have been removed from the reactor vessel, stored in the J-10/L-10 Cubicle area in the reactor basement, and replaced with steel plugs at the lower seals.[7] The control rod guide tubes remain, but, like other aluminum structures, there are no activation products of consequence. We do not include the control rod shafts nor the shock assemblies in activation calculations because the rod shafts were made of aluminum and did not activate appreciably, and the shock assemblies, though stainless steel, were outside the high-flux region during reactor operation.

3.1.2 Nozzle Trench

The nozzle trench is that part of the structure above the main floor but inside the parapet that surrounds the top closure. The contaminated area includes the outside surface of the top head and the inside of the top head shielding blocks. Contamination in this area is surface contamination, not activation.

3.1.3 Reactor Biological Shield

This is the concrete structure that surrounds the reactor vessel. More particularly, it is that which is above the reactor building main floor. For purposes of this study, some of the concrete immediately outside the core may become slightly activated, but that should be inconsequential in light of the shielding effect of the thermal shields. MCNP4C calculations found no appreciable flux in the concrete region. The biological shield is considered to have surface contamination only.

3.1.4 Canal

The canal is visible in Figures 2 and 7. It is nominally 6.1 m (20 ft) deep with an additional 0.3 m (1 ft) freeboard above the water level to the top of the parapet. The parapet extends approximately 0.9 m (3 ft) above the main floor. The canal is in a “T” configuration. The stem of the “T”, or working canal, is 10.7 m (35 ft) long and 2.4 m (8 ft) wide. It connects at the base of the “T” (east end) with the reactor vessel where it is tapered over the last 2 m (7 ft). A deeper well there (2.7 m or 9 ft) under the discharge chute facilitated fuel and experiment removal. The cross or storage canal on the west end of the reactor building runs 18.3 m (60 ft) in the north-south direction and is 3.7 m (12 ft) wide. The total wetted area of the canal, including the freeboard, is approximately 522 m^2 (5,616 ft^2).

Drain and fill pipes connect the canal with the 17.88 m^3 (5,000 gal) warm sump tank, as shown in Figure 8.

3.1.5 Elevators and Stairs

Figure 9 shows the floor plan for the reactor building. It is equipped with a freight elevator in the northeast corner. Adjacent to it is a personnel elevator. Also in the northeast corner, as well as in the southeast corner, are stairways going to the basement level. Spiral stairways are also located to the northwest and southwest of the reactor shield that go down to the console floor.

On the lower levels, a stairway goes from the basement floor to the rod-access room, and another spiral staircase goes from the console floor to the basement in the southwest corner of the building.

3.1.6 Reactor Building Main Room

The main hall of the reactor building is 41.5 m (136 ft) long, 34.1 m(112 ft) wide, and 17.7 m (58 ft) high above the floor. Walls are insulated metal sandwich panel siding, taped to be

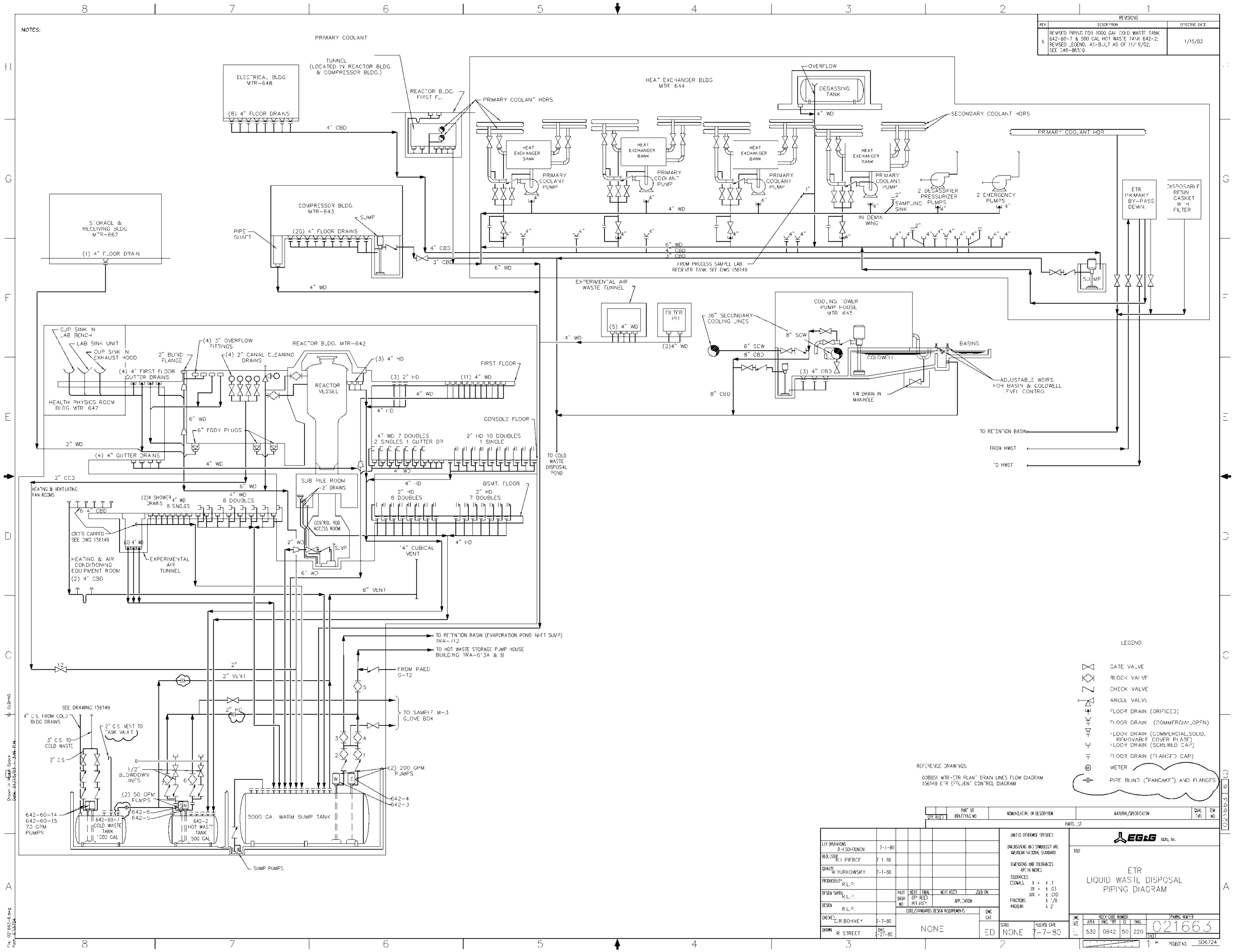

Figure 8. ETR liquid waste disposal piping diagram.

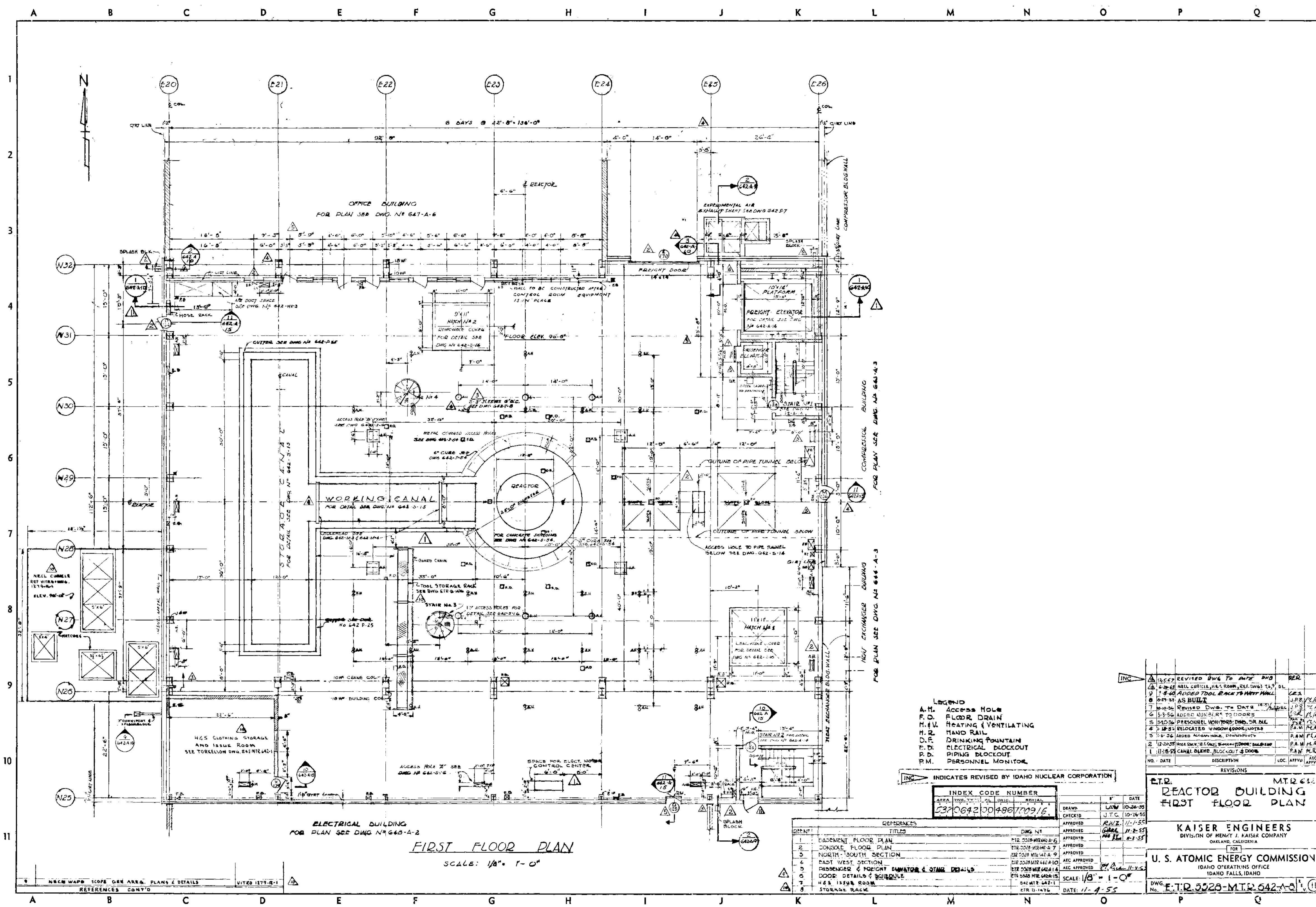

Figure 9. Floor plan for the ETR reactor building.

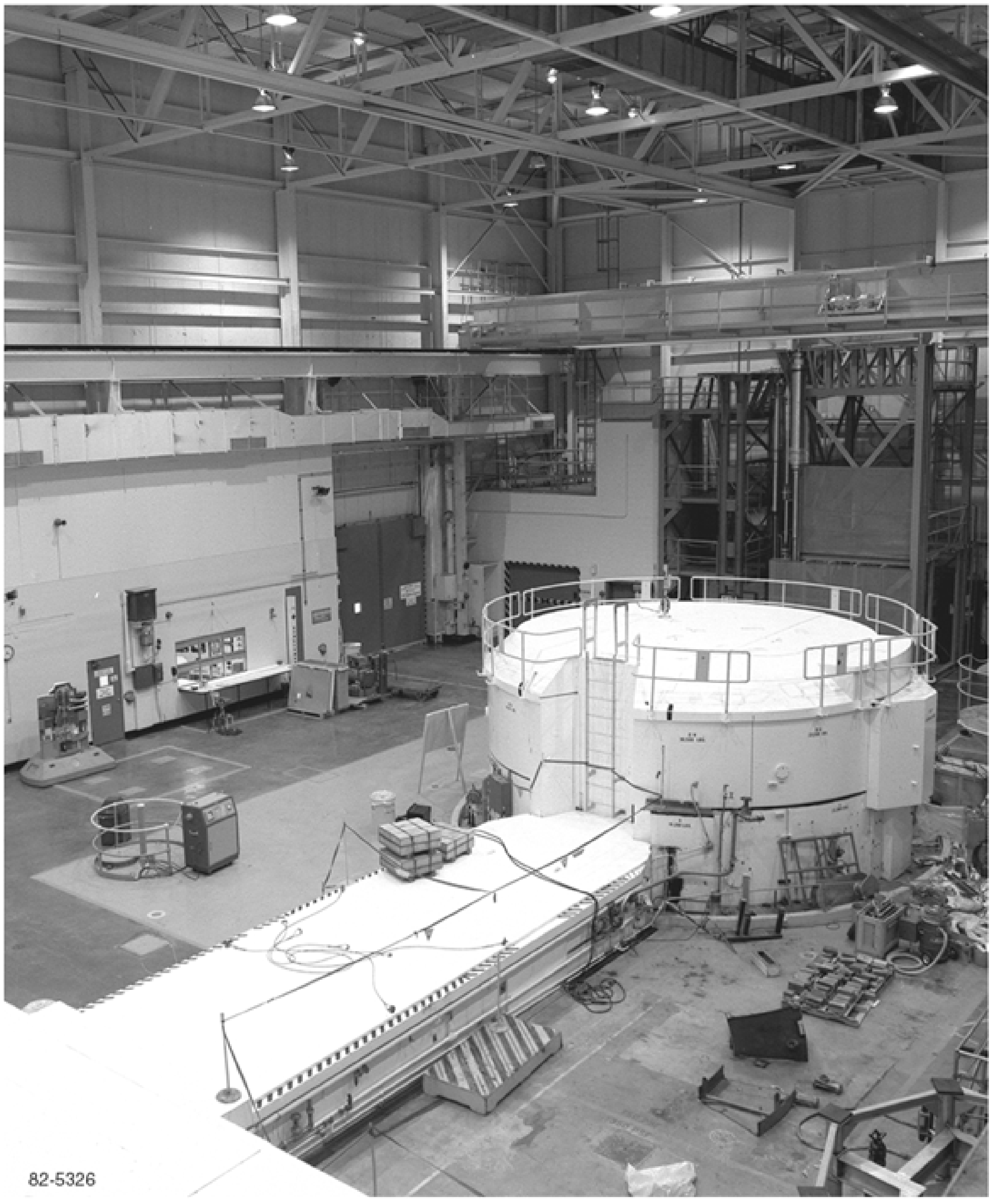

Figure 10. ETR main reactor room. The biological shield covers the top head of the reactor.

gas tight. Additions to the room surface include the walls surrounding the elevators and stairwells and a ventilation duct in the northwest corner. Roof girders, overhead cranes, and associated catwalks make additional contributions to main room surface area. Figure 10 shows the main reactor room. In the mid-lower left of the photo is one of the spiral stairways going down from the main floor.

3.1.7 Reactor Building Console Floor and Balcony

The console floor and balcony are at the first level below the main floor. The console floor has the same floor area as the main floor, which excludes the footprint of the reactor and the canal. Figure 11 shows the layout of the console floor. The balcony is a partial level 10 ft above the console floor, as shown in Figure 12. It occupies a space nominally 11 m (36 ft) wide on the south side of the reactor, the primary coolant system (PCS) tunnel, and working canal and east of the south wing of the storage canal.

3.1.8 Experimental cooling loop cubicles

Two underground cubicles are located on the west side of and adjacent to the main reactor building. Both are accessible through top hatches. They were originally designed to provide auxiliary cooling to particular experiments. Now both are empty.[8]

3.1.9 Reactor Building Basement (except cubicles and FS&R facility)

The basement is arranged as shown in Figures 13 and 14. The area near the core is subdivided into a number of cubicles to support the various experiments. Cubicle walls and the wall surrounding the reactor vessel are high density concrete (shaded). Other walls are standard concrete.[9]

3.1.10 Warm and Hot Waste Pits

Two pits were built below the basement floor at ETR. One of these houses a 3.8-m^3 (1,000-gal) cold waste tank and a 1.9-m^3 (500-gal) hot waste tank. The pit in which they reside is the hot waste pit. The other pit holds an 18.9-m^3 (5,000-gal) warm sump tank. It is referred to as the warm waste pit. These tanks appear at the lower left in Figure 8. These pits are located just inside the north wall of the reactor building, nearly at the center, as shown in Figures 13 and 14.

3.1.11 Annulus Gas System Cubicle

The annulus gas system cubicle is located on the basement level in the northeast quadrant of the reactor perimeter (see Figure 14). Its function changed over time, but most recently it was used to house equipment for the annulus gas and on-line cover gas sampling systems, which were part of the Sodium Loop Safety Facility (SLSF) project. "The cubicle has also been known as the G-12 cubicle, the PAED G-12 [Phillips Atomic Energy Division] cubicle, the GEFP-2 [General Electric Flight Propulsion Project] primary cubicle, and the GEEL [General Electric Experimental Loops] cubicle. All these names reflected the cubicle's past service."[10] Figure 15 shows the current contents of the cubicle.

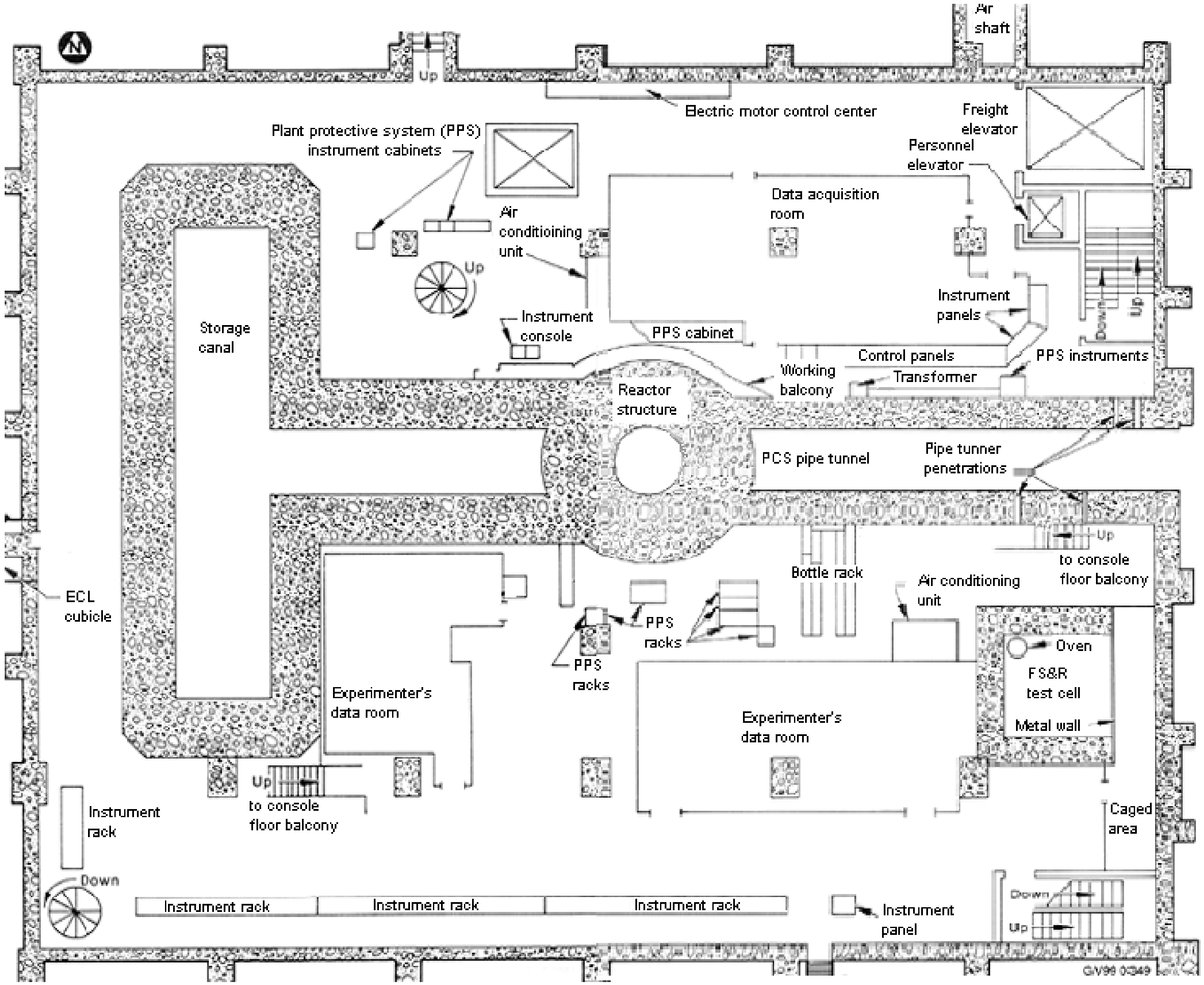

Figure 11. Console floor layout

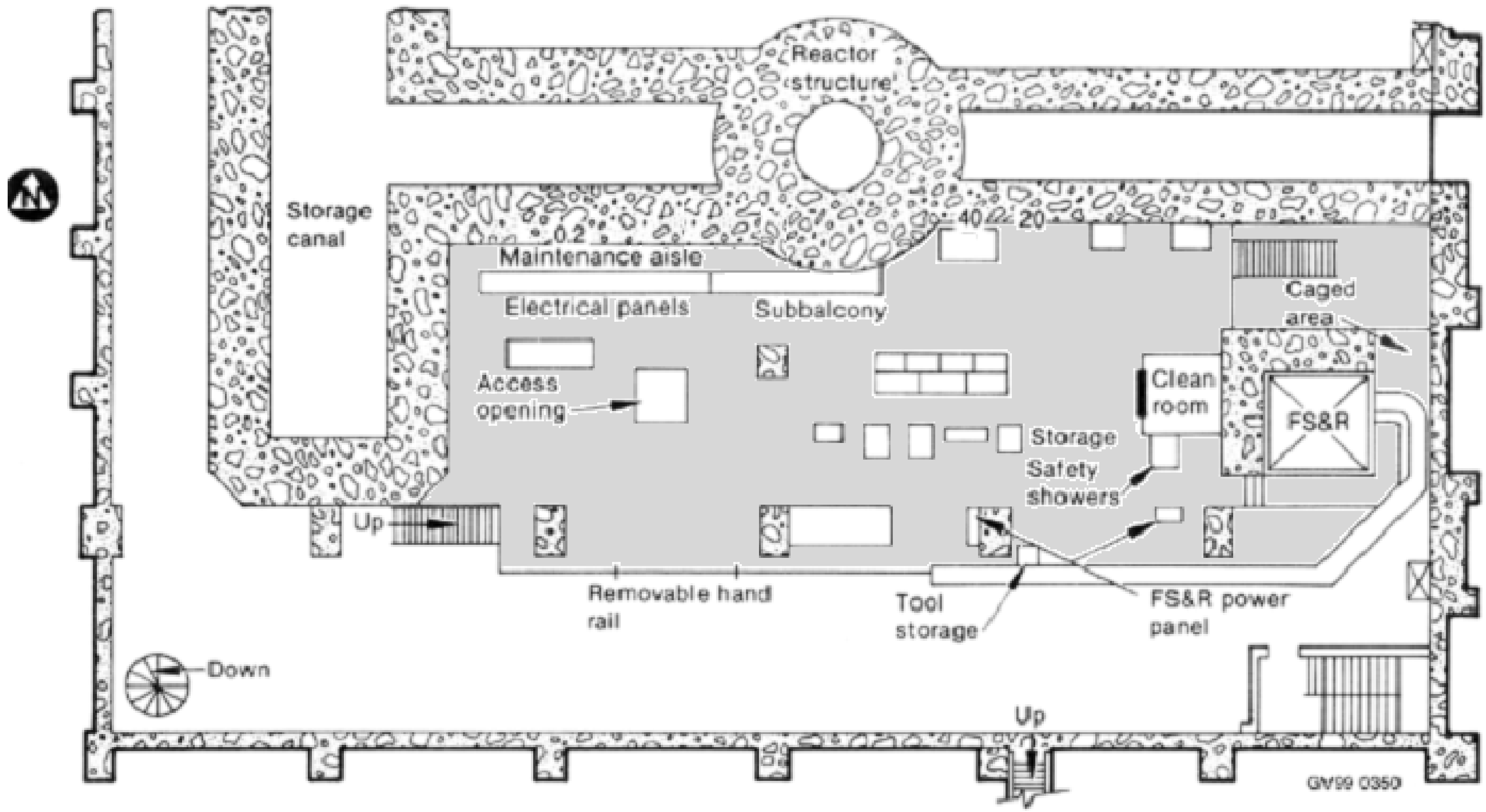

Figure 12.The balcony (shaded) covers much of the south side of the console floor.

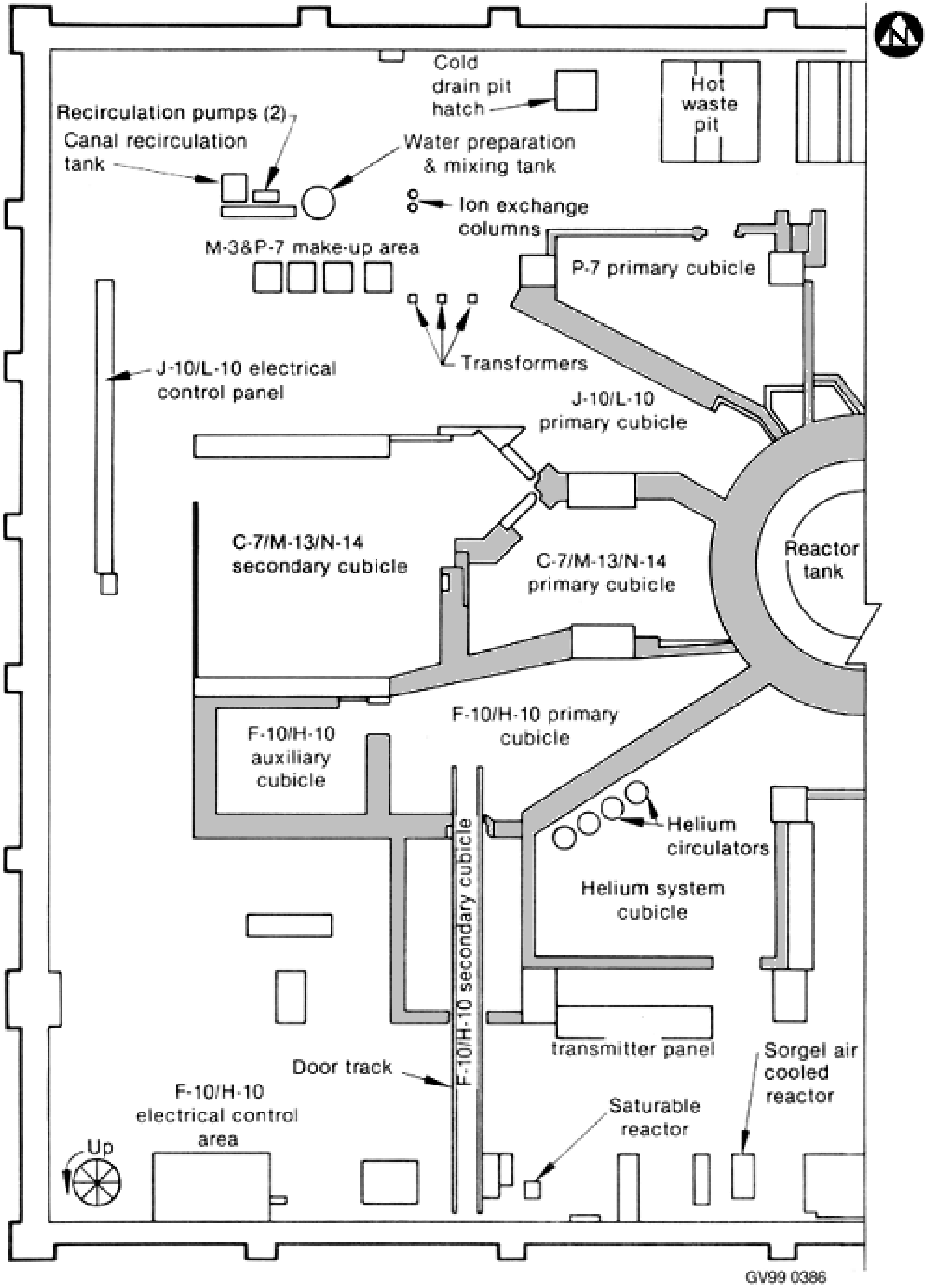

Figure 13. Layout of the west end of the ETR basement.

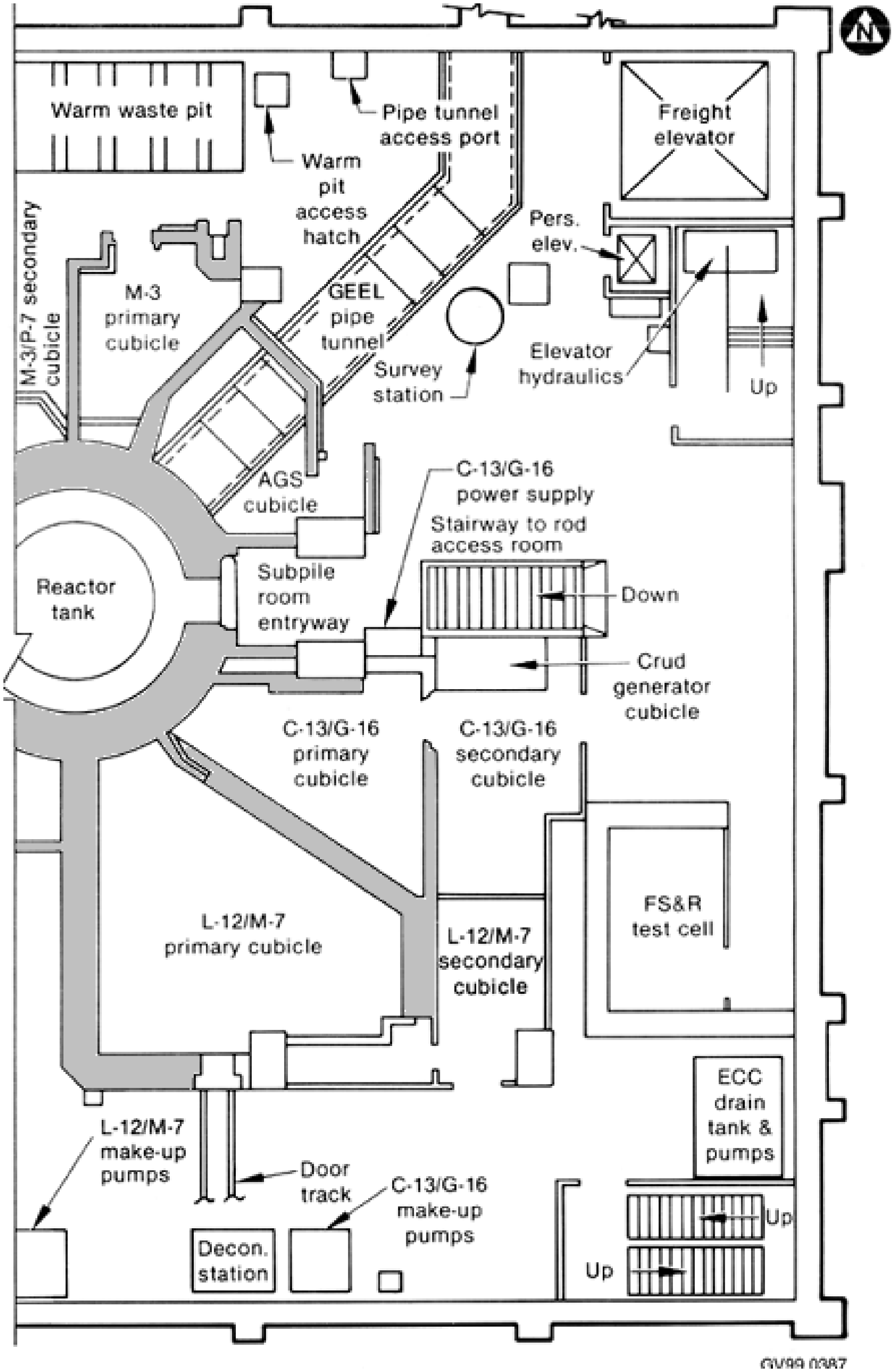

Figure 14. Layout of the east end of the ETR basement.

Figure 15. Annular gas system cubicle contents.

3.1.12 M-3 and P-7 Cubicles

These cubicles are on the north side of the reactor core (see Figures 13 and 14) with the P-7 cubicle to the west of the M-3 cubicle. These cubicles housed supporting equipment for experiments in the M-3 and P-7 core positions (see Figure 3).[11]

3.1.13 Water Loop Cubicles

Progressing counterclockwise about the reactor core, the water loop cubicles consisted of the J-10/L10, the C-7/M-13/N-14, the F-10/H-10, the L-12/M-7, and the C-13/G-16, cubicles (see Figures 13 and 14). These cubicles contained equipment used in support of various in-pile experimental loops. The cubicles also provided shielding for that equipment.[12]

3.1.14 Helium System Cubicle

The helium system cubicle is in the south-southwest sector of the basement (Figure 13). Though not heavily used, its most recent application was to house the helium recirculating system used to remove heat from the SLSF.[13]

3.1.15 SLSF Filling, Storage, and Remelt (FS&R) Facility

The filling, storage and re-melt (FS&R) system was housed in a cubicle near the south end of the east wall of the basement floor (Figure 14). This system was mainly used to support loop assembly, preparation, and out-of-reactor testing operations for the SLSF, which involved liquid sodium coolant.[14]

3.1.16 Rod Access Room

The rod access room is at the bottom of the reactor core, at a level below the basement level (see Figure 7). Room layout is shown in Figure 16. It provided reactor operators with access to the reactor control rods and drive mechanisms that were used to control reactor operation.

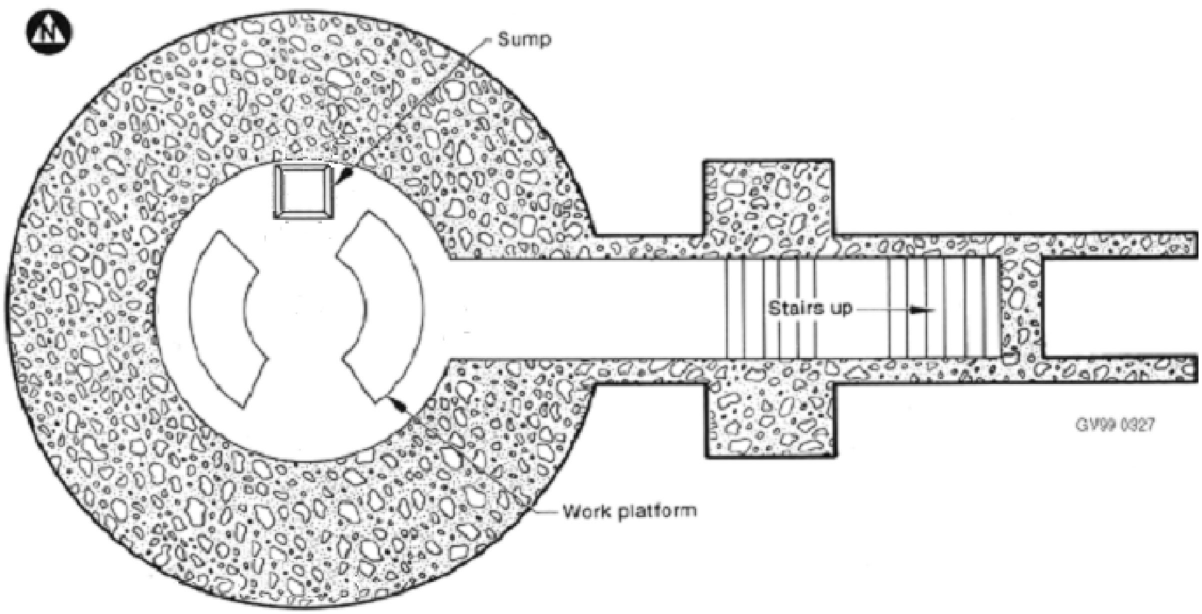

Figure 16. ETR control rod access room.

3.1.17 Sub-pile room

The sub-pile room layout is shown in Figure 17. Its main function was to provide access for experimenters to the base of the reactor where experiment leads and ducts could be routed to the various experiment cubicles. There were 38 holes through the room wall for such purposes.[15]

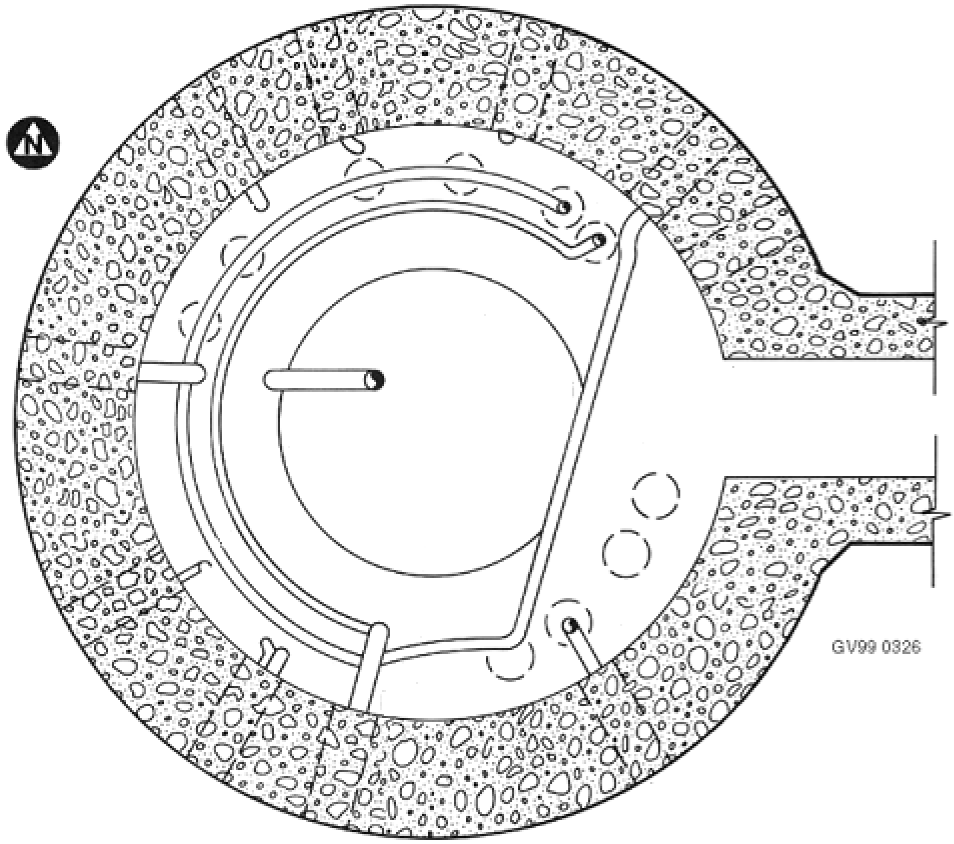

Figure 17. Sub-pile room layout.

3.1.18 GEEL (General Electric Experiment Loop) Tunnel

Shown in Figure 14 is the GEEL pipe tunnel extending northeast from the reactor core. This tunnel was installed to allow ducts from the GEEL to exit the reactor building. The tunnel begins beneath the reactor building basement floor, runs under the annulus gas system (AGS) cubicle, and then underground beyond, and north and east of, the reactor building, and ends at the delay tanks.[16] Figure 18 shows the interior of that tunnel. The delay tanks are underground, east of the compressor building and are not part of this study.

Figure 18. Interior of the GEEL tunnel looking toward the northeast

3.2 Compressor Building

Building TRA-643 is the compressor building that housed the equipment used to supply large quantities of heated, hydrocarbon-free air to various experiments. In the building (Figure 19) is the process control room (at the east end) that was used to control all plant services to the reactor and the sample laboratory (on the south side) that was used to conduct chemistry samples on the reactor primary and secondary coolant systems.[17]

A floor plan of the compressor building is shown in Figure 20. The compressor building is 38 m (124 ft 8 in) in the east-west direction at its north boundary, 32.9 m (108 ft) in the north-south direction at the east boundary, and is 9.3 m (30 ft 5 in) high. At the south wall, the primary coolant system (PCS) pump pits extend 3.1 m (10 ft 3 in) above the floor, and 6.4-34.1 m (21-112 ft) from the wall. The area above the PCS pump pits was used for storage. A 1.2-m (4-ft) high, 1/2-in. plywood barrier separates contaminated storage items from non-contaminated items. The storage area contained primarily experiment spare parts, handling tools, and lifting fixtures.[17]

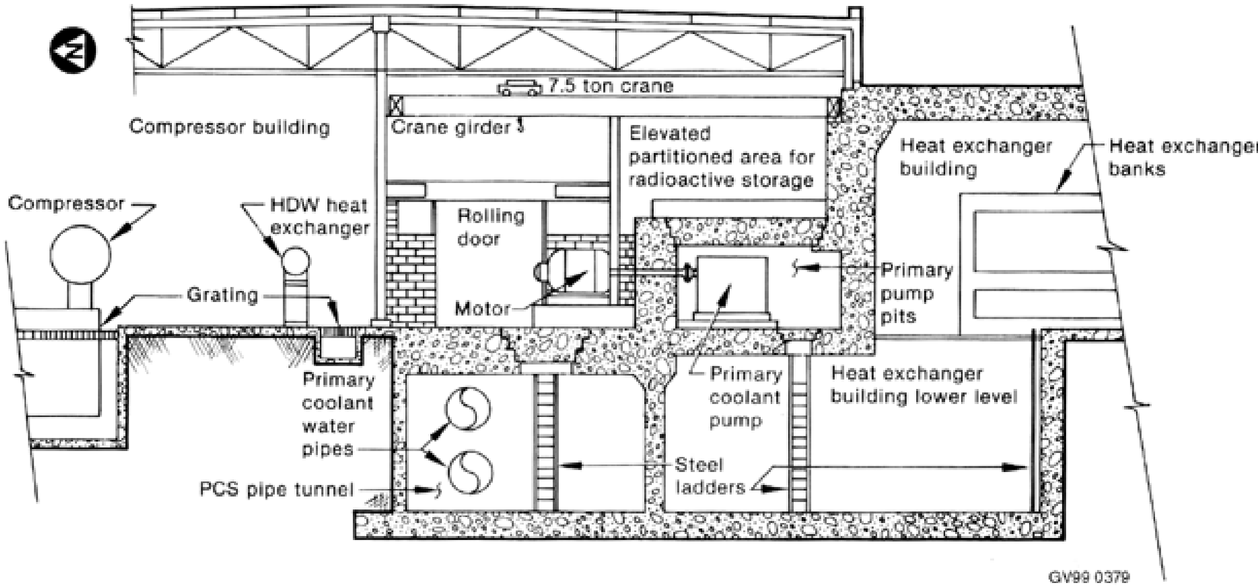

Figure 19. Elevation cutaway drawing of the ETR compressor building (TRA-643).

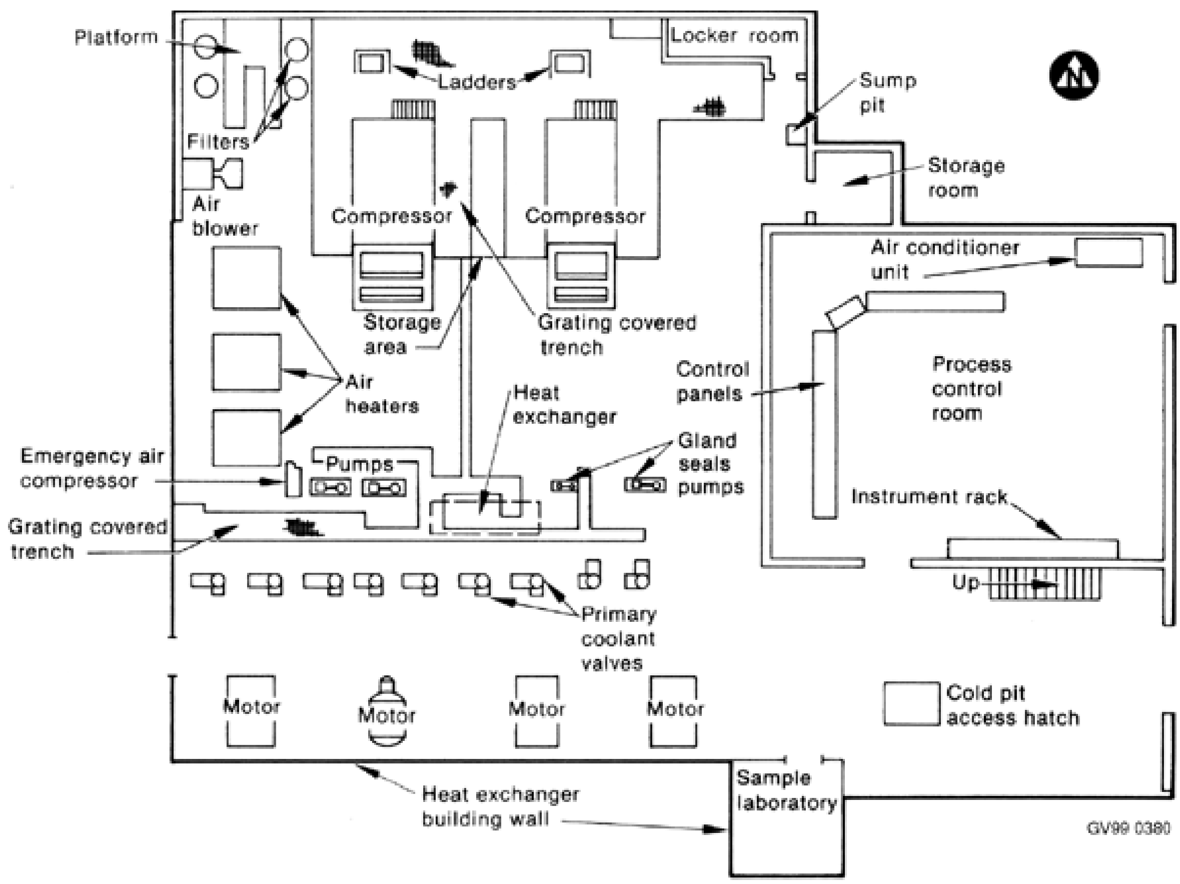

Figure 20. Floor plan of the ETR compressor building (TRA-643).

3.3 Heat Exchanger Building

The heat exchanger building (TRA-644) is adjacent to and east of the reactor building and south of the compressor building. The building includes (a) a main room and lower level, (b) a demineralizer wing (valve room and tank room), (c) a degassing tank room, (d) a cubicle exhaust booster blower room, and (e) a secondary pipe pit. The primary function of the heat exchanger building main room was to house the 12 primary coolant/secondary coolant system heat exchangers and associated piping. The primary-to-secondary heat exchangers each contain 1700 1.6-cm (5/8-in) OD tubes.[18] Figure 21 shows an artists cutaway rendering of the heat exchanger building. Further detail may be found in Ref. 18.

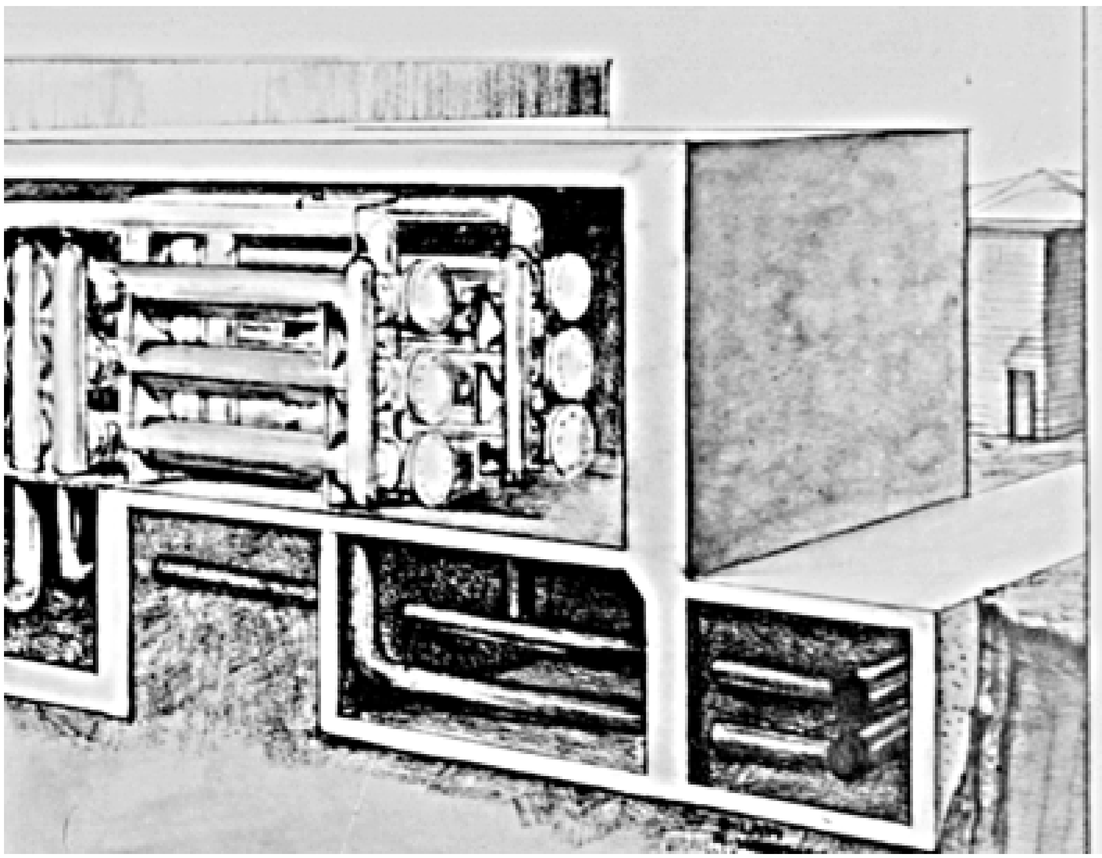

Figure 21. Artist's cutaway rendering of the ETR heat exchanger building (TRA-644).

4.0 ANALYTICAL APPROACH

The 1982 characterization[3] provided a good description of the facility status and its radiological contamination. A further assessment was conducted in 2002 incident to preparing a hazards assessment document (HAD) for the ETR.[19]We rely heavily on the estimates generated in those studies for contamination on surfaces and in tanks and pipes. In this report, we update the estimates of such radiological contamination, arriving at an improved isotopic distribution and decaying the activities to January of 2005. We also provide a more precise estimate of activated structures in the core.

4.1 Activated Structures

For activated material within the reactor vessel and nearby, new calculations were performed, making use of the MCNP-4C code[20] to estimate neutron fluxes at various locations; then, using the ORIGEN2 code[21] with more detailed mass and composition data than has been used in the past, to calculate activation and fission products. The radioisotopes of interest are listed in Table 1.

Table 1. Radioisotopes of concern for ETR radiological characterization.

Isotope	Decay Product	Half Life (yr)	Isotope	Decay Product	Half Life (yr)
H-3	β^-	1.23E+01	Th-228	α	1.91E+00
Be-10	β^-	1.60E+06	Th-229	α	7.30E+03
C-14	β^-	5.73E+03	Th-230	α	7.54E+04
Cl-36	β^-	3.01E+05	Th-232	α	1.40E+10
Mn-54	ε	8.55E-01	Pa-231	α	3.28E+04
Ni-59	ε	7.60E+04	U-232	α	7.00E+01
Co-60	β^-	5.27E+00	U-233	α	1.59E+05
Ni-63	β^-	1.00E+02	U-234	α	2.46E+05
Zn-65	ε, β^+	6.68E-01	U-235	α	7.04E+08
Sr-90	β^-	2.91E+01	U-236	α	2.35E+07
Nb-94	β^-	2.00E+04	U-238	α	4.47E+09
Tc-99	β^-	2.13E+05	Np-237	α	2.14E+06
Ru-103	β^-	1.08E-01	Pu-238	α	8.77E+01
Ru-106	β^-	1.02E+00	Pu-239	α	2.41E+04
Ag-108m	ε, β^+	1.30E+02	Pu-240	α	6.56E+03
Ag-110m	β^-	6.84E-01	Pu-241	β^-, α	1.44E+01
Sb-125	β^-	2.76E+00	Pu-242	α	3.75E+05
I-129	β^-	1.57E+07	Pu-244	α	8.00E+07
Cs-134	β^-	2.07E+00	Am-241	α	4.33E+02
Cs-137	β^-	3.02E+01	Am-243	α	7.37E+03
Ce-144	β^-	7.25E-01	Cm-243	α	2.91E+01
Eu-152	ε, β^+	1.35E+01	Cm-244	α	1.81E+01
Eu-154	β^-	8.59E+00	Cm-245	α	8.50E+03
Pb-210	β^-	2.23E+01	Cm-246	α	4.76E+03
Ra-226	α	1.60E+03	Cm-247	α	1.56E+07
Ac-227	β^-	2.18E+01	Cm-248	α	3.48E+05

ε indicates electron capture.

Table 2 lists the structures within the reactor vessel and nearby that underwent significant activation during ETR operation. Only the activated portions making a significant contribution to the total inventory are included in mass and volume listings. Some of these, for example the beryllium reflector and the black control rod poison assemblies, experienced different irradiation histories because of different installation times.[a]

Table 2. ETR core structures with significant activation.

Component	Main Materials	Volume (m^3)	Mass (kg)
External Thermal Shield	Pb, SS	0.330	2,580.9
External Tank	304-SS, Steel	1.405	1,365.0
Gray Control Rod Poison	Type A Ni	0.017	154.1
Black Control Rod Poison	Cd	0.005	37.3
Internal Thermal Shields	304-SS	1.031	8,245.5
Inner Tank	304-SS, Steel	0.478	2,769.2
Grid Plate	304-SS	0.445	2,277.4
Upper Support Frame	304 SS	0.028	219.7
Beryllium Reflector	Be	0.421	714.2
C-7 In-Pile Tube	304-SS	0.009	73.7
F-10 In-Pile Tube	304-SS	0.004	34.4
M-13 In-Pile Tube	304-SS	0.004	34.4
N-14 In-Pile Tube	304-SS	0.004	34.4
Core and Shield Support Beams	304-SS	0.005	108.2

A number of small pieces, including spacers, adapters, and plugs were placed on the top of the ETR core at the time of shutdown. So far as we can determine (see Appendix D),[22] the items thus placed were low activity aluminum. There appear to be no highly activated stainless steel components on the core top that have not been accounted for.

For convenience, the activation characteristics of the in-pile tubes were represented in the calculations by those of their nuclear mockups. The nuclear mockups were designed to provide the same neutronic response in the core as the actual test trains. Even though the actual test trains are more complex and contain small components of materials other than those of the mockups, the basic contribution to radionuclide inventories was judged to be given with sufficient accuracy by the mockup parameters.

4.2 Surface Contamination

For the remainder of the facility, radioactive inventories are all surface contamination. All liquids have been removed, but sludge remains in the warm and hot waste tanks and in the canal.[23] Radioactivity surveys were conducted in each of the radiation zones listed in Section 3.0

[a] The beryllium reflector was changed in the spring of 1970, and the black poison rods (sprayed cadmium) were installed between April 17, 1961 and March 18, 1962 (see ETR Operations Branch Progress Report for Cycle No. 36 and Operations Branch Progress Report for Cycle No. 45.) Replaced items were disposed of.

as part of the previous characterization.[24] The surveys identified locations of hot spots as well as general background levels for each of the radiation zones. Smears of removable contamination were taken at various locations on walls, floors, and other surfaces in each zone. Gross beta-gamma counts and a check for alpha contamination were performed on each smear in 1982. At least one external smear from each zone was analyzed for Sr-90. Internal smears and sludge samples were taken from tanks and pipes known or suspected to carry internal contamination. In-situ gamma spectroscopy was performed at various locations within the ETR facility to provide relative abundance of gamma-emitting isotopes and look for isotopes not appearing on smear samples.[25]

It should be noted that there was at least one fuel failure in the ETR involving the melting of some fuel plates, which would have resulted in fission products and actinides getting into the primary coolant stream.[26] Further details are in Appendix B. That may be a reason why the ETR surface contamination contains different isotopes than does that in the PBF.[27]

4.2.1 Building TRA-642

Table 3 lists the various radiation zones considered here and in Ref. 3 for the ETR reactor building (TRA-642) and the associated surface contamination radioisotopes observed in each.

Table 3. Isotopes observed in 1982 on external surfaces and within tanks and ducts (internal) in the various radiation zones of the ETR reactor building.

Zone	Description	Isotopes found		Ref. 3 page
		External	Internal	
1.	Reactor pressure vessel	Co-60	N/A	209
2.	Nozzle trench	Cs-137, Co-60	N/A	215
3.	Reactor biological shielding	Indeterminate	Indeterminate	219
4.	Canal (sludge)	Mn-54,Cs-137, Co-60, Sr-90, U-235, Pu-239,Pu-240, Am-241	N/A	221-225
5.	Elevators and stairs	Clean	N/A	227
6.	Reactor building main room	Cs-134, Cs-137, Co-60, Sr-90, Ag-108m	N/A	228
7.	Reactor building console floor and balcony	Cs-134, Cs-137, Co-60, Sr-90, Mn-54, Nb-95, Zr-95	N/A	235
8.	Emergency cooling loop cubicles (underground west of building)	Cs-134, Cs-137,Co-60	N/A	249

Zone	Description	Isotopes found		Ref. 3 page
		External	Internal	
9.	Reactor building basement (except cubicles and FS&R facility)	Cs-134, Cs-137,Co-60 + α	N/A	253

Zone	Description	Isotopes found		Ref. 3 page258
		External	Internal	
10	Warm and Hot Waste Pits (beneath basement)	Cs-134, Cs-137, Co-60	Sr-90, Am-241, Pu-238, Pu-239, Pu-240	258
11.	Annulus gas system cubicle	Ag-108m, Cs-137, Co-60	Sr-90, U-235, Pu-238, Pu-239, Pu-240	266
12.	M-3 and P-7 cubicles	Cs-137, Co-60	Sr-90, U-235, Am-241, Pu-238, Pu-239, Pu-240	271
13.	Water loop cubicles (with separate sections, one for each group of primary and secondary cubicles in the reactor building basement)	Cs-134, Cs-137, Co-60, Mn-54	Sr-90, Am-241, Pu-238, Pu-239, Pu-240	278-308
14.	Helium system cubicle	Cs-137, Co-60	N/A	309
15.	SLSF filling, storage, and remelt (FS&R) facility	Clean	N/A	314
16.	Rod access room	Cs-137, Co-60, Mn-54	N/A	319
17.	Sub-pile room	Cs-137, Co-60, Mn-54, Sb-125, Sr-90	N/A	324
18.	GEEL (General Electric Experiment Loop) tunnel	Cs-137, Co-60	N/A	328

4.2.1.1 External Contamination

The dominant isotopes on surfaces were Co-60 and Cs-137[28] with Mn-54, Sb-125, and Sr-90 also found. Mn-54 and Sb-125 were in very low concentrations.

In March of 1996, smear surveys were performed in the primary and secondary cubicles of the ETR. These samples were analyzed for Sr-90 and gamma-emitting isotopes. Only Cs-137 and Co-60 were identified in quantity. They occurred in a relative abundance of 95% Cs-137 and 5% Co-60. Trace Sr-90 was observed and scaled in relative abundance to Cs-137. Additional measurements were made in February of 1997 by collecting dust, paint chips, and other material from cubicle surfaces. The samples taken were analyzed for beta-emitters Ni-59, Ni-63, C-14, Tc-99, I-129, and gross alpha activity. All radioisotopes sought were found except Ni-59, which was below the detection limits of the instruments used. Gross alpha counts were very low. Tables 4 and 5 summarize those data using averages within the cubicle for gamma- and beta-emitters, respectively. The average values shown are averages for the various cubicles, not averages for the individual samples.

Table 4. Average 1996 activities of selected isotopes on smear samples from ETR cubicles.

Cubicle	Co-60 (pCi/100 cm^2)	Cs-137 (pCi/100 cm^2)	Sr-90 (pCi/100 cm^2)
C-7	701	21,975	12
F-10	320	6,500	13
J-10	139	433	18
L-10	445	5,643	25
L-12	420	3,790	38
M-3	194	2,306	99
M-7	458	1,051	148
P-7	164	246	148
Average	355	5,243	63

Table 5. Average 1997 beta-emitter and gross alpha activities in ETR cubicle debris.

Cubicle	Ni-63 (pCi/g)	C-14 (pCi/g)	Tc-99 (pCi/g)	I-129 (pCi/g)	Gross Alpha (pCi/g)
C-13	563	ND*	15	ND	21
F-10	6,200	32	ND	27	25
M-13	29	ND	ND	ND	
L-10	288	8	16	ND	7
P-7	3,425	49	43	ND	28
M-3	199	67	ND	ND	95
Average	1,784	39	25	27	35

*ND indicates no detectable quantities were observed.

A lesson from the recent measurements at the Power Burst Facility (PBF) was that smears are not very effective in removing surface contamination in reactor facilities. Removal efficiencies may be very low.[29] For evaluation, the factor of 1.0E-03 was assumed in PBF estimates, and it was used again here.

The scaling factors listed in Table 6 below were developed in Ref. 30 for relative isotopic abundances on ETR surfaces as of 1997. They allow estimation of beta-emitter concentrations given known activities of gamma emitters Co-60 and Cs-137. A scaling factor was developed in Ref. 30 for Sr-90 as well, but it was not used here because we had the measurements of Table 4.

Table 6. Scaling factors for relative isotopic activity in 1997 from Ref. 30.

Radionuclide	Ratio	Scaling Factor
Ni-63	Ni-63/Co-60	4.2
C-14	C-14/Co-60	6.4E-02
Tc-99	Tc-99/Cs-137	9.03E-04
I-129	I-129/Cs-137	5.87E-04

To estimate surface contamination in ETR, we first found areas for all the significant contaminated surfaces. That was done largely by graphical means from drawings, not relying on approximations made by others. In the main reactor hall, we added 20% to the surface area, based on engineering judgment, to account for cranes, catwalks, ducts, etc. For the cubicles listed in Table 4, we applied the specific activities listed there for Co-60, Cs-137, and Sr-90. We scaled the other isotopes in Table 6 from the Co-60 and Cs-137 values. We then decay-corrected the resulting activities from February 1997 to January 2005 and amplified them for the assumed smear collection efficiency of 1.0E-03. For areas not identified in Table 4, including areas other than cubicles, the process used involved scaling using local total activity data where available and average total activities in other areas, as detailed in Appendix C.

4.2.1.2 Internal Contamination

The internal contamination identified in Table 3 consists mostly of long-lived isotopes. They will be at essentially the same concentrations they were in 1982. The only quantitative comparison between gamma field measurements and isotopic activities provided in Ref. 3 (p. 261) are those listed here in Table 7.

Table 7. Isotopic estimates for sludge in the warm and hot waste tanks as of 2002.

Isotope	Warm Waste Tank (Ci)	Hot Waste Tank (Ci)
Cs-134		4.79E-08
Cs-137	4.32E-10	4.37E-06
Co-60	2.88E-08	6.10E-07
Sr-90	1.30E-07	1.16E-05
Field (mR/h)	1.20E+03	1.40E+03

It is interesting that the warm waste tank had approximately the same gamma field but only about 1% of the inventory of radioisotopes in comparison with the hot waste tank. The warm waste tank also had about 100 times as much Sr-90 relative to Cs-137 as the hot waste tank. The Sr-90 does not directly contribute to the gamma field because it decays with a β^- and no associated gamma ray. However, Sr-90 decays to Y-90, which decays with a short half-life to Zr-90, and that reaction does have a strong gamma associated with it. The Zr-90 is stable. This appears to account for the similarity in gamma fields in spite of the difference in inventories.

We neglected activity in piping other than the tanks because it is deemed be lower per unit surface area than what is in the sludge in the tanks, and the activities listed in Table 7 are so low in comparison with other isotopic inventories as to make no significant difference in the overall facility inventory. It was also the practice to decontaminate loops whenever practical.[5]

4.2.2 Buildings TRA 643 and TRA-644

For radioisotope inventories in the compressor building (TRA-643) and in the heat exchanger building (TRA-644), we relied on the HAD[19] and considered that these two buildings include the following zones or sources identified in the HAD.

- Compressor building primary coolant system (PCS) pipe tunnel
- Compressor building storage area
- Heat exchanger building bypass valve
- Heat exchanger building tank room
- Heat exchanger building main room
- Heat exchanger building basement
- Heat exchanger building degassing tank
- Heat exchanger building emergency shutdown pump pits
- Heat exchanger building degasifier pump pits

For each of those areas, the HAD identified a total number of curies based on average count rates from smear samples taken in 1982 and surface areas. No decay was accounted for in the HAD for isotopes with half-lives greater than 3 years.[31] For present purposes, those 1982 total inventories were increased by a factor of 10^3 to account for smear collection efficiency. The distribution of the activity among the isotopes was obtained by assuming they were the same as the average ETR surface activity values. To get those, the average ETR isotopic abundances calculated for 2005 were back-scaled to 1982, and the activities given in the HAD for the various areas listed above were apportioned to the isotopes of Tables 4 to 6 using those relative abundances. Then, the resulting activities were decayed from 1982 to 2005.

5.0 RESULTS

In this section are discussed the summary results of activation calculations. Details may be found in Appendix A.

5.1 Activated Components

Table 8 lists the specifics of components considered in the activation calculations for ETR.

Table 8. Radioactivity in activated structures in the ETR.

Structure	Total Curies	Tritium Curies	Non-Tritium Ci
Be Reflector	7.99E+04	7.99E+04	3.37E+01
Grid Plate	2.87E+03	1.13E+01	2.86E+03
I-Beams (all 6)	2.36E-03	3.73E-06	2.36E-03
C-7 In-Pile Tube	3.19E+02	3.51E-01	3.19E+02
F-10 In-Pile Tube	8.57E+02	2.66E-01	8.56E+02
M-13 In-Pile Tube	4.67E+02	2.67E-01	4.67E+02
N-14 In-Pile Tube	2.34E+02	2.15E-01	2.34E+02
Upper Support Grid	5.78E-04	9.12E-07	5.77E-04
Inner Tank	5.66E+03	7.62E+00	5.66E+03
Internal Themal Shields	1.43E+02	2.26E-01	1.43E+02
External Thermal Shield	5.77E-02	1.96E-03	5.57E-02
External Tank	1.90E-01	4.54E-03	1.85E-01
Black Rod Poison	1.55E+03	2.83E-01	1.55E+03
Gray Rod Poison	5.05E+04	3.32E-04	5.05E+04
Total	1.43E+05	7.99E+04	6.26E+04

The concrete biological shield is not listed in Table 8, but there will be a small amount of activated material in it. Concrete is known[32] to contain Li (20 mg/kg), Cl (45 ±18 kg/kg), Co (9.8±10.3 mg/kg), Eu (0.55±0.38 mg/kg) and U (2.7±0.9 mg/kg). For the ETR, the neutron flux at the location of its greatest intensity in the concrete is only 10^{-8} of its value in the core. Therefore, the contribution made to the total inventory by activation of the concrete is miniscule. On the 100-year timescale, activity in irradiated concrete is dominated by H-3.[33]

5.2 Surface Contamination

Table 9 shows the estimates of surface contamination by isotope for the three buildings that comprise this study. Of the 1.70 total curies on surfaces, nearly all of it is in the reactor building (TRA-642), and about 53% of the activity is Cs-137. Ni-63 makes up about 35% of the surface contamination. Co-60 adds about 7% on surfaces.

5.2 Tanks and Piping

As noted earlier, the only significant inventories in tanks and piping were associated with sludge in the warm and hot waste sumps in the reactor building. Decaying the inventories observed in 1982 (Table 7) to 2005 gives the values listed in Table 10.

6.0 DISCUSSION AND FINDINGS

6.1 Computer Code Usage

The two computer codes formed the basis for the activation calculations in the present work. These are MCNP4C and ORIGEN2.

The MCNP4C code is maintained under INEEL configuration control tracking number 64573. The code was implemented and used by Dr. James R. Parry who is well qualified to use it.[34]

ORIGEN2 calculations were performed by Michael L. Carboneau. Mr. Carboneau is the INEEL custodian for the ORIGEN2 code, which is maintained under configuration control tracking number 64556. He is most qualified to perform calculations with it.

Together, these two codes have demonstrated a remarkable ability to provide good estimates of activation products in structures in and around reactor cores. Remaining calculations were performed with the aid of the EXCEL spreadsheet program.6.2 Uncertainties

The total uncertainty associated with the estimated neutron activation product inventory for ETR is due to a combination of at least two individual uncertainty values: (1) the uncertainty in the alloy composition for the precursor element that neutron activates to the isotope of concern (e.g., Mo is in stainless steel and Mo98 + n transmutes to Tc99; so Mo is the precursor for Tc99), and (2) the uncertainty in the computer code to accurately predict the isotope inventory (due to uncertainties in decay or cross-section data and mathematical models in the code). Aluminum is not considered a major contributor to the activation product inventory for PBF and is ignored in this analysis. Typical impurities in aluminum also do not add significantly to the radioisotopic inventory. The fundamental uncertainty in the ORIGEN2 code is at least 10%. For the ETR analysis, the ORIGEN2 calculated results are only known to within 20%. Some of this is due to the way the power history data were modeled. There is also uncertainty as to the masses of components inside the reactor vessel, particularly the in-pile tubes. There is a further measure of uncertainty in the detailed compositions of the various materials. Often, reported assay data indicate upper limits on impurities, and these are usually used. However, there is no guarantee that the impurities included in that process really are there. That has consequences when the significant activation products are due to the impurities, as will be seen below. The present approach will be conservative.

Table 9. Summary of surface contamination (Ci) estimated as of January 2005 for the various buildings of the ETR.

Zone		C-14	Co-60	Ni-63	Sr-90	Tc-99	I-129	Cs-137	Total Gamma	Total Beta	Total
Reactor Building (TRA-642)											
Reactor Vessel		4.53E-04	2.85E-03	2.86E-02	1.58E-07	3.40E-10	2.21E-10	3.21E-07	2.85E-03	2.91E-02	3.19E-02
Nozzle Trench		3.11E-06	1.96E-05	1.96E-04	1.08E-09	2.33E-12	1.52E-12	2.21E-09	1.96E-05	2.00E-04	2.19E-04
Biological Shield (over cap)		7.58E-05	4.77E-04	4.79E-03	2.64E-08	5.69E-11	3.70E-11	5.38E-08	4.77E-04	4.86E-03	5.34E-03
Canal		3.81E-03	2.40E-02	2.41E-01	1.33E-06	2.86E-09	1.86E-09	2.70E-06	2.40E-02	2.45E-01	2.69E-01
Main Room		9.89E-04	6.22E-03	6.25E-02	3.44E-07	7.43E-10	4.83E-10	7.02E-07	6.22E-03	6.35E-02	6.97E-02
Console Floor		1.14E-03	7.20E-03	7.23E-02	3.98E-07	8.59E-10	5.58E-10	8.11E-07	7.20E-03	7.34E-02	8.06E-02
Balcony		1.91E-04	1.20E-03	1.20E-02	6.64E-08	1.43E-10	9.31E-11	1.35E-07	1.20E-03	1.22E-02	1.34E-02
Emergency Cooling Loop Cubicles		9.95E-04	6.27E-03	6.29E-02	3.47E-07	7.48E-10	4.86E-10	7.06E-07	6.27E-03	6.39E-02	7.02E-02
PCS Pipe Tunnel		3.20E-04	2.01E-03	2.02E-02	1.11E-07	2.40E-10	1.56E-10	2.27E-07	2.01E-03	2.05E-02	2.25E-02
Hot Waste Pit		1.25E-04	7.87E-04	7.90E-03	4.35E-08	9.39E-11	6.11E-11	8.87E-08	7.87E-04	8.03E-03	8.81E-03
P-7 Primary Cubicle		1.29E-05	8.11E-05	8.15E-04	1.54E-04	2.73E-07	1.77E-07	2.58E-04	3.39E-04	9.82E-04	1.32E-03
J-10/L-10 Primary Cubicle		9.57E-06	6.03E-05	6.05E-04	1.64E-05	4.21E-07	2.74E-07	3.98E-04	4.58E-04	6.32E-04	1.09E-03
C-7/M-13/N-14 Primary Cubicle		5.59E-05	3.52E-04	3.53E-03	1.27E-05	2.47E-05	1.61E-05	2.34E-02	2.37E-02	3.64E-03	2.74E-02
C-7/M-13/N-14 Secondary Cubicle		1.20E-04	7.53E-04	7.56E-03	2.72E-05	5.30E-05	3.44E-05	5.00E-02	5.08E-02	7.80E-03	5.86E-02
F-10/H-10 Primary Cubicle		2.78E-05	1.75E-04	1.76E-03	1.50E-05	7.97E-06	5.18E-06	7.53E-03	7.71E-03	1.81E-03	9.52E-03
F-10/H-10 Auxiliary Cubicle		1.43E-05	8.98E-05	9.02E-04	7.69E-06	4.09E-06	2.66E-06	3.87E-03	3.96E-03	9.30E-04	4.89E-03
F-10/H-10 Secondary Cubicle		2.18E-05	1.37E-04	1.38E-03	1.17E-05	6.25E-06	4.07E-06	5.91E-03	6.05E-03	1.42E-03	7.47E-03
Helium System Cubicle		1.21E-04	7.62E-04	7.65E-03	4.22E-08	9.10E-11	5.91E-11	8.59E-08	7.62E-04	7.77E-03	8.54E-03
L-12/M-7 Primary Cubicle		6.99E-05	4.40E-04	4.42E-03	8.39E-05	8.91E-06	5.79E-06	8.42E-03	8.86E-03	4.59E-03	1.34E-02
L-12/M-7 Secondary Cubicle		2.73E-05	1.72E-04	1.72E-03	3.27E-05	3.47E-06	2.26E-06	3.28E-03	3.45E-03	1.79E-03	5.24E-03
C-13/G-16 Primary Cubicle		3.62E-05	2.28E-04	2.29E-03	1.26E-08	2.72E-11	1.77E-11	2.57E-08	2.28E-04	2.32E-03	2.55E-03
C-13/G-16 Secondary Cubicle		3.42E-05	2.16E-04	2.16E-03	1.19E-08	2.57E-11	1.67E-11	2.43E-08	2.16E-04	2.20E-03	2.41E-03
Crud Generator Cubicle		1.57E-05	9.87E-05	9.91E-04	5.46E-09	1.18E-11	7.66E-12	1.11E-08	9.87E-05	1.01E-03	1.11E-03
Subpile Room Entryway		3.48E-05	2.19E-04	2.20E-03	1.21E-08	2.62E-11	1.70E-11	2.47E-08	2.19E-04	2.24E-03	2.46E-03
AGS Cubicle		1.18E-04	7.46E-04	7.49E-03	4.13E-08	8.90E-11	5.78E-11	8.41E-08	7.46E-04	7.60E-03	8.35E-03
GEEL Pipe Tunnel		5.22E-06	3.28E-05	3.30E-04	1.82E-09	3.92E-12	2.55E-12	3.70E-09	3.28E-05	3.35E-04	3.68E-04
M-3 Primary Cubicle		1.00E-05	6.31E-05	6.33E-04	6.78E-05	1.68E-06	1.09E-06	1.59E-03	1.65E-03	7.13E-04	2.36E-03
M-3/P-7 Secondary Cubicle		4.59E-06	2.89E-05	2.90E-04	3.10E-05	7.70E-07	5.00E-07	7.27E-04	7.56E-04	3.27E-04	1.08E-03
Warm Waste Pit		1.42E-04	8.96E-04	8.99E-03	4.95E-08	1.07E-10	6.95E-11	1.01E-07	8.96E-04	9.13E-03	1.00E-02
Sub-Pile Room		1.76E-05	1.11E-04	1.11E-03	6.14E-09	1.32E-11	8.60E-12	1.25E-08	1.11E-04	1.13E-03	1.24E-03
Rod Access Room		4.23E-05	2.66E-04	2.67E-03	1.47E-08	3.18E-11	2.07E-11	3.00E-08	2.66E-04	2.72E-03	2.98E-03
Other Basement Areas		9.10E-03	5.73E-02	5.75E-01	3.17E-06	6.83E-09	4.44E-09	6.46E-06	5.73E-02	5.84E-01	6.41E-01
	Subtotals	**1.81E-02**	**1.14E-01**	**1.15E+00**	**4.67E-04**	**1.12E-04**	**7.25E-05**	**1.05E-01**	**2.20E-01**	**1.17E+00**	**1.38E+00**
Compressor Building (TRA-643)											
GEEL Tunnel (Part)		5.46E-06	3.24E-06	4.67E-06	3.17E-06	5.48E-06	5.48E-06	2.69E-07	3.50E-06	2.43E-05	2.78E-05
PCS Pipe Tunnel		3.49E-05	2.07E-05	2.99E-05	2.03E-05	3.50E-05	3.50E-05	1.72E-06	2.24E-05	1.55E-04	1.77E-04
Storage Area		7.18E-06	4.25E-06	6.14E-06	4.17E-06	7.20E-06	7.20E-06	3.53E-07	4.61E-06	3.19E-05	3.65E-05
	Subtotals	**4.75E-05**	**2.82E-05**	**4.07E-05**	**2.76E-05**	**4.77E-05**	**4.77E-05**	**2.34E-06**	3.05E-05	2.11E-04	**2.42E-04**
Heat Exchanger Building (TRA-644)											
Bypass valve		6.78E-07	4.02E-07	5.80E-07	3.94E-07	6.80E-07	6.80E-07	3.34E-08	4.35E-07	3.01E-06	3.45E-06
Tank room		3.79E-06	2.24E-06	3.24E-06	2.20E-06	3.80E-06	3.80E-06	1.87E-07	2.43E-06	1.68E-05	1.93E-05
Main room		1.99E-05	1.18E-05	1.71E-05	1.16E-05	2.00E-05	2.00E-05	9.82E-07	1.28E-05	8.86E-05	1.01E-04
Basement		7.58E-05	4.49E-05	6.48E-05	4.40E-05	7.60E-05	7.60E-05	3.73E-06	4.86E-05	3.37E-04	3.85E-04
Degassing tank		2.89E-06	1.71E-06	2.47E-06	1.68E-06	2.90E-06	2.90E-06	1.42E-07	1.86E-06	1.28E-05	1.47E-05
Primary pump pits		9.37E-06	5.55E-06	8.02E-06	5.45E-06	9.40E-06	9.40E-06	4.61E-07	6.01E-06	4.16E-05	4.77E-05
Emergency shutdown pump pits		7.58E-07	4.49E-07	6.48E-07	4.40E-07	7.60E-07	7.60E-07	3.73E-08	4.86E-07	3.37E-06	3.85E-06
Degassifier pump pits		6.28E-07	3.72E-07	5.37E-07	3.65E-07	6.30E-07	6.30E-07	3.09E-08	4.03E-07	2.79E-06	3.19E-06
	Subtotals	**1.14E-04**	**6.74E-05**	**9.74E-05**	**6.61E-05**	**1.14E-04**	**1.14E-04**	**5.60E-06**	7.30E-05	5.06E-04	**5.79E-04**
Totals (all bldgs)		**1.83E-02**	**1.14E-01**	**1.15E+00**	**5.60E-04**	**2.73E-04**	**2.34E-04**	**1.05E-01**	**2.20E-01**	**1.17E+00**	**1.39E+00**

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Table 10. Estimated 2005 radioisotopic inventories (Ci) in ETR tanks.

Isotope	Warm Waste Tank	Hot Waste Tank	Total
Cs-134	0.0000E+00	2.1858E-11	2.1858E-11
Cs-137	2.5517E-10	2.5812E-06	2.5815E-06
Co-60	1.4145E-09	2.9960E-08	3.1375E-08
Sr-90	7.5314E-08	6.7204E-06	6.7957E-06
Total	7.6984E-08	9.3316E-06	9.4085E-06

Estimated uncertainties associated with surface contamination come from two main sources. One is the uncertainty associated with the assignment of an average contamination level, based on disintegration rate measured on smear samples and gamma field readings. The readings themselves have some uncertainty of measurement, and the averages assigned may or may not be formally representative of the activity levels in the room. The greater uncertainty is associated with radionuclide collection efficiency of the smear sample process. That will vary from location to location, a function of the type of contamination, the surface composition and texture, humidity, and other circumstances. Our multiplication of reported smear sample readings by a factor of 1,000 to account for that collection inefficiency should make these estimates conservative. We believe the calculated values are conservative. We consider the uncertainty associated with surface activity measurements to be approximately 50%.

6.3 Total Activity

The total activity in the facility as of January 2005 is dominated by tritium in the beryllium reflector. As shown in Table 8, that amounts to almost 80,000 Ci from a total of almost 143,000 Ci. That tritium is integrally bound in the beryllium and will stay there indefinitely unless the beryllium is heated above 550°C or corrodes.[35,36] With a half-life of only 12.3 years, it will effectively disappear in the first 100 years.

The next most active inventory is Ni-63 in the gray control rods. These used nickel as the neutron-absorbing medium. It is very highly activated and accounts for more than 50,000 Ci.

Of the remaining activity, the majority is in the grid support plate. Isotopically, the remaining activity is dominated by Ni-63 and Co-60. Other components with substantial inventories of these isotopes are in the inner tank and the internal thermal shields, all of which are made from 304 SS.

The total activity on facility surfaces and in tanks is estimated at only 1.39 Ci, of which 1.15 Ci is the beta-emitter Ni-63. Even considering the uncertainties, surface activity pales in comparison with activated structures in the core.

6.4 Transuranic Waste

A finding significant to disposal of ETR and its contents is that the beryllium reflector is almost certainly transuranic. The validity of that finding is keyed to our assumption regarding the uranium content of that material.

The beryllium reflector now in ETR was installed in March 1970 following the discovery that the first reflector had become embrittled.[37] INEEL Drawing 400635 for the replacement reflector calls for material meeting Brush Wellman specification S-200-E, a strong suggestion that Brush Wellman may have furnished the beryllium for that reflector.

Beryllium installed in the Advanced Test Reactor (ATR) near that time had been supplied by Kwecki Berylco, Industries and had approximately 30 mg/kg uranium impurity.[38] Later material furnished to ATR by Brush Wellman was found to have significantly higher uranium impurity, in the range of 70 to 100 mg/kg.[35] The reason for the higher uranium impurity was that the later material was mined as bertrandite near Delta, Utah where there are significant uranium deposits. Even though some uranium removal processing was done at the mine, processing only removed about 90% of the uranium in the ore, and Brush Wellman had no motivation to take the uranium down further.[39] However, material mined before 1969 would have come from a different site and may have been much lower in uranium impurity.

It was assumed in the analyses performed in this work that the uranium content in the beryllium reflector was 30 mg/kg. Our calculations indicate the TRU threshold is exceeded by a factor of approximately 9.5 for that uranium concentration. Thus, there would need to be strong evidence that the uranium impurity in the beryllium was less than 3 mg/kg to have much possibility for not being transuranic. No measurements on domestic beryllium have shown uranium that low, although it would be possible to produce such material from beryl ore, and material originating in Kazakhstan would probably be that low in uranium impurity.[39]

None of the other structures was found to exceed the TRU classification threshold, although several, for example the F-10 and M-13 in-pile tubes, were estimated to be in excess of 10% of the TRU level, as is shown in Table 11. Uncertainty could call the F-10 and M-13 in-pile tubes into question. Zero values there are not true zeros, but the numbers are less than 10^{-4}.

Table 11. Transuranic classification activity fractions in various components in or near the ETR core.

Structure	TRU Fraction
Be Reflector	946%
Grid Plate	27%
I-Beams (all 6)	0%
C-7 In-Pile Tube	22%
F-10 In-Pile Tube	65%
M-13 In-Pile Tube	57%
N-14 In-Pile Tube	33%
Upper Support Frame	0%
Inner Tank	7%
Internal Thermal Shields	0%

Structure	TRU Fraction
External Thermal Shield	0%
External Tank	0%
Black Rod Poison	45%
Gray Rod Poison	0%

We recommend that before disposal of the beryllium, samples be collected and analyzed definitively to verify the estimates provided here as to its TRU classification.

6.5 Greater than Class-C Waste

We also examined isotopic concentrations (Ci/m^3, Ci/g-actinides) of the activated structures to determine which, if any of the components are greater than Class-C as defined in 10 CFR 61. Taken collectively, the waste has more than 20.6 times the sum-of-fractions activities for Class-C classification. The most virulent offender is the gray control rod poison assemblies. As a group, they are more than 4,000 times the Class-C limit, due to the Ni-63 and in lesser measure to Co-60. The beryllium reflector is 74 times the Class-C threshold, mostly due to actinides. For the beryllium, the most offensive isotope is Np-237 at 83.6 times the threshold value. Next is Pu-240 at 28.3 times the Class-C threshold concentration. In the other structures, Nb-94 is at 16.8 times the Class-C threshold., Pu-241 is at 3.4 times, and Ni-63 is 3.1 times the threshold. The only individual structures with the sum-of-fractions below the Class-C threshold are the upper support frame, the I-beams holding up the grid plate and thermal shield, the internal and external thermal shields, and the external tank.

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APPENDIX A
ACTIVATED STRUCTURES DATA

Here are listed data relevant to the quantitative estimates of radioactivity in activated structures. Table A-1 lists assumed values for volume, mass, composition, and neutron flux for activated structures in and near the reactor vessel. Table A-2 lists the detailed compositions assumed for the various materials in the activated structures. Table A-3 lists the specific isotopic contributions to the total inventory for each of the activated structures.

APPENDIX A

Table A-1.Configuration data for activated structures in the ETR reactor vessel

Gray Control Rods						
	Component	Material	Volume cc	Mass gm	Neutron Flux (nt/cm^2-sec/MW)	Density gm/cc
H5	Poison	Type A Nickel	1.445E+03	1.284E+04	2.759E+12	8.885
J5	Poison	Type A Nickel	1.445E+03	1.284E+04	2.609E+12	8.885
J7	Poison	Type A Nickel	1.445E+03	1.284E+04	3.183E+12	8.885
E9	Poison	Type A Nickel	1.445E+03	1.284E+04	8.870E+11	8.885
G9	Poison	Type A Nickel	1.445E+03	1.284E+04	1.737E+12	8.885
I9	Poison	Type A Nickel	1.445E+03	1.284E+04	3.191E+12	8.885
M9	Poison	Type A Nickel	1.445E+03	1.284E+04	2.278E+12	8.885
E11	Poison	Type A Nickel	1.445E+03	1.284E+04	7.432E+11	8.885
I11	Poison	Type A Nickel	1.445E+03	1.284E+04	1.389E+12	8.885
K11	Poison	Type A Nickel	1.445E+03	1.284E+04	1.668E+12	8.885
H13	Poison	Type A Nickel	1.445E+03	1.284E+04	6.141E+11	8.885
K13	Poison	Type A Nickel	1.445E+03	1.284E+04	7.672E+11	8.885
		Total	1.734E+04	1.541E+05		

Black Control Rods						
	Component	Material	Volume cc	Mass gm	Neutron Flux (nt/cm^2-sec/MW)	Density gm/cc
H7	Poison	Cadmium	1.180E+02	1.021E+03	4.537E+12	8.65
	Stainless Steel	304 SS	1.050E+03	8.312E+03	4.537E+12	7.916
K9	Poison	Cadmium	1.180E+02	1.021E+03	2.997E+12	8.65
	Stainless Steel	304 SS	1.050E+03	8.312E+03	2.997E+12	7.916
G11	Poison	Cadmium	1.180E+02	1.021E+03	1.508E+12	8.65
	Stainless Steel	304 SS	1.050E+03	8.312E+03	1.508E+12	7.916
M11	Poison	Cadmium	1.180E+02	1.021E+03	3.222E+12	8.65
	Stainless Steel	304 SS	1.050E+03	8.312E+03	3.222E+12	7.916
		Total	4.672E+03	3.733E+04		

External Thermal Shield						
	Component	Material	Volume cc	Mass gm	Neutron Flux (nt/cm^2-sec/MW)	Density gm/cc
	Whole Component	Lead	3.052E+06	3.479E+07	7.057E+06	11.4
		SS-304	2.297E+04	1.819E+05	7.057E+06	7.916
		Carbon Steel	3.300E+05	2.581E+06	7.057E+06	7.82
		Total	3.405E+06	3.755E+07		

APPENDIX A

Table A-1 Continued.

Small External Tank

	Component	304 SS Volume cc	Carbon Steel Volume cc	304 SS Mass gm	Carbon Steel Mass gm	Neutron Flux (nt/cm^2-sec/MW)	304 SS Density gm/cc	Carbon Steel Density gm/cc
	Above Active Core	32327	2.661E+05	2.559E+05	2080564	4.200E+05	7.916	7.82
	Active Core	22739	1.871E+05	1.800E+05	1463441	2.866E+07	7.916	7.82
	Below Active Core	30307	2.494E+05	2.399E+05	1950545	2.031E+06	7.916	7.82
	Whole Component	85373	7.026E+05	6.896E+05	4.819E+06	8.514E+06	7.916	7.82
		Total	1.405E+06	1.365E+06				

Internal Thermal Shields

	Component	Material	Volume cc	Mass gm	Neutron Flux (nt/cm^2-sec/MW)	Density gm/cc
	1st (innermost) Shield	304 SS	1.607E+05	1.285E+06	2.695E+09	7.916
	2nd Shield	304 SS	1.967E+05	1.574E+06	5.563E+08	7.916
	3rd Shield	304 SS	2.662E+05	2.129E+06	1.984E+08	7.916
	4th (outermost) Shield	304 SS	4.071E+05	3.257E+06	7.407E+07	7.916
		Total	1.031E+06	8.245E+06		

Inner Tank

	Component	Material	Volume cc	Mass gm	Neutron Flux (nt/cm^2-sec/MW)	Density gm/cc
	Whole Component	304 SS	4.775E+05	2.769E+06	7.252E+10	7.916

Beryllium Reflector

	Component	Material	Volume cc	Mass gm	Neutron Flux (nt/cm^2-sec/MW)	Density gm/cc
	Whole Component	Beryllium	3.861E+05	7.142E+05	2.518E+12	1.85

APPENDIX A

Table A-1 Concluded.

3 X 3 IPT's						
	Component	Material	Volume cc	Mass gm	Neutron Flux (nt/cm^2-sec/MW)	Density gm/cc
F10	Above Active Core	304 SS	1.317E+03	1.042E+04	2.280E+09	7.916
	Active Core	304 SS	1.316E+03	1.041E+04	4.112E+12	7.916
	Below Active Core	304 SS	1.710E+03	1.354E+04	9.016E+10	7.916
N14	Above Active Core	304 SS	1.317E+03	1.042E+04	1.961E+09	7.916
	Active Core	304 SS	1.316E+03	1.041E+04	1.586E+12	7.916
	Below Active Core	304 SS	1.710E+03	1.354E+04	1.867E+10	7.916
M13	Above Active Core	304 SS	1.317E+03	1.042E+04	4.596E+09	7.916
	Active Core	304 SS	1.316E+03	1.041E+04	3.655E+12	7.916
	Below Active Core	304 SS	1.710E+03	1.354E+04	5.626E+10	7.916
		Each	4.343E+03	3.438E+04		

6 X 6 IPT's						
	Component	Material	Volume cc	Mass gm	Neutron Flux (nt/cm^2-sec/MW)	Density gm/cc
C7	Above Active Core	304 SS	1.317E+03	1.042E+04	3.804E+08	7.916
	Active Core	304 SS	4.006E+03	3.172E+04	3.913E+11	7.916
	Below Active Core	304 SS	3.991E+03	3.159E+04	1.394E+10	7.916
		Total	9.314E+03	7.373E+04		

Upper Support Frame						
	Component	Material	Volume cc	Mass gm	Neutron Flux (nt/cm^2-sec/MW)	Density gm/cc
	Whole Component	304 SS	2.775E+04	2.197E+05	9.193E+04	7.916

Support Grid						
	Component	Material	Volume cc	Mass gm	Neutron Flux (nt/cm^2-sec/MW)	Density gm/cc
	Whole Component	347 SS	4.453E+05	2.277E+06	1.713E+11	7.92

I-Beams						
	Component	Material	Volume cc	Mass gm	Neutron Flux (nt/cm^2-sec/MW)	Density gm/cc
	Whole Component	304 SS	4.873E+03	1.082E+05	7.631E+05	7.916

APPENDIX A

Table A-2. Detailed composition of materials in and around the ETR core, used in ORIGEN2 calculations.

	Concentration (g/kg)						
Isotope	304 SS	347 SS	SA-212 Grade B Steel	Be	Cd	Pb	Ni-200
H-1	0.006998	0.006998	0.000000	0.000000	0.000000	0.000000	0.000000
H-2	0.000002	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000
He-3	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
He-4	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Li-6	0.000008	0.000008	0.000019	0.000000	0.000000	0.000000	0.000000
Li-7	0.000122	0.000122	0.000281	0.000650	0.000000	0.000000	0.000000
Be-9	0.000000	0.000000	0.000000	988.011752	0.000000	0.000000	0.000000
Be-10	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
B-10	0.000922	0.000922	0.000000	0.000120	0.000000	0.000000	0.000000
B-11	0.004078	0.004078	0.000000	0.000530	0.000000	0.000000	0.000000
C-12	0.790473	0.632378	3.260701	0.790473	0.000000	0.000000	1.482137
C-13	0.009527	0.007622	0.039299	0.009527	0.000000	0.000000	0.017863
N-14	0.468137	0.358573	0.083667	0.204586	0.000000	0.000000	0.000033
N-15	0.001863	0.001427	0.000333	0.000814	0.000000	0.000000	0.000000
O-16	0.149599	0.149599	0.000000	5.345666	0.000000	0.000000	0.000011
O-17	0.000064	0.000064	0.000000	0.002277	0.000000	0.000000	0.000000
O-18	0.000337	0.000337	0.000000	0.012057	0.000000	0.000000	0.000000
F-19	0.000000	0.000000	0.000000	0.069167	0.000000	0.000000	0.000000
Ne-20	0.000000	0.000000	0.000000	1.277352	0.000000	0.000000	0.000000
Ne-21	0.000000	0.000000	0.000000	0.004002	0.000000	0.000000	0.000000
Ne-22	0.000000	0.000000	0.000000	0.143646	0.000000	0.000000	0.000000
Na-23	0.009700	0.009700	0.040000	0.000874	0.000000	0.000000	0.000001
Mg-24	0.000000	0.000000	0.000000	0.025334	0.000000	0.000000	0.000000
Mg-25	0.000000	0.000000	0.000000	0.003341	0.000000	0.000000	0.000000
Mg-26	0.000000	0.000000	0.000000	0.003825	0.000000	0.000000	0.000000
Al-27	0.100000	0.100000	0.050000	0.495000	0.000000	0.000000	0.000007
Si-28	9.187333	5.879893	2.756200	0.863609	0.000000	0.000000	3.215567
Si-29	0.481808	0.308357	0.144542	0.045290	0.000000	0.000000	0.168633
Si-30	0.330858	0.211749	0.099258	0.031101	0.000000	0.000000	0.115800
P-31	0.450000	0.250000	3.500000	0.050000	0.000000	0.000000	0.000032
S-32	0.284238	0.180018	0.378984	0.007106	0.000000	0.000000	0.473731
S-33	0.002314	0.001465	0.003085	0.000058	0.000000	0.000000	0.003856
S-34	0.013381	0.008474	0.017841	0.000335	0.000000	0.000000	0.022301

APPENDIX A

	Concentration (g/kg)						
Isotope	304 SS	347 SS	SA-212 Grade B Steel	Be	Cd	Pb	Ni-200
S-35	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
S-36	0.000067	0.000043	0.000090	0.000002	0.000000	0.000000	0.000112
Cl-35	0.052315	0.052315	0.000000	0.037368	0.000000	0.000000	0.000004
Cl-36	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Cl-37	0.017685	0.017685	0.000000	0.012632	0.000000	0.000000	0.000001
Ar-36	0.000000	0.000000	0.000000	0.000019	0.000000	0.000000	0.000000
Ar-37	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Ar-38	0.000000	0.000000	0.000000	0.000004	0.000000	0.000000	0.000000
Ar-39	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Ar-40	0.000000	0.000000	0.000000	0.006347	0.000000	0.000000	0.000000
K-39	0.002788	0.002788	0.002788	0.012147	0.000000	0.000000	0.000000
K-40	0.000000	0.000000	0.000000	0.000002	0.000000	0.000000	0.000000
K-41	0.000212	0.000212	0.000212	0.000922	0.000000	0.000000	0.000000
Ca-40	0.018366	0.018366	0.013533	0.014499	0.000000	0.000000	0.000001
Ca-41	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Ca-42	0.000129	0.000129	0.000095	0.000102	0.000000	0.000000	0.000000
Ca-43	0.000027	0.000027	0.000020	0.000022	0.000000	0.000000	0.000000
Ca-44	0.000435	0.000435	0.000320	0.000343	0.000000	0.000000	0.000000
Ca-45	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Ca-46	0.000001	0.000001	0.000001	0.000001	0.000000	0.000000	0.000000
Ca-47	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Ca-48	0.000043	0.000043	0.000031	0.000034	0.000000	0.000000	0.000000
Sc-45	0.000030	0.000030	0.000000	0.002300	0.000000	0.000000	0.000000
Ti-46	0.046067	0.007678	0.000154	0.004735	0.000000	0.000000	0.000003
Ti-47	0.042950	0.007158	0.000143	0.004414	0.000000	0.000000	0.000003
Ti-48	0.443447	0.073908	0.001478	0.045576	0.000000	0.000000	0.000031
Ti-49	0.033737	0.005623	0.000112	0.003467	0.000000	0.000000	0.000002
Ti-50	0.033799	0.005633	0.000113	0.003474	0.000000	0.000000	0.000002
V-50	0.001226	0.000980	0.000074	0.000008	0.000000	0.000000	0.000000
V-51	0.498774	0.399020	0.029926	0.003415	0.000000	0.000000	0.000035
Cr-50	7.837717	7.386986	0.000003	0.005279	0.000000	0.000000	0.000556
Cr-51	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Cr-52	157.190152	148.150463	0.000050	0.105882	0.000000	0.000000	0.011148
Cr-53	18.164744	17.120126	0.000006	0.012236	0.000000	0.000000	0.001288
Cr-54	4.607387	4.342426	0.000001	0.003103	0.000000	0.000000	0.000327

APPENDIX A

	Concentration (g/kg)						
Isotope	**304 SS**	**347 SS**	**SA-212 Grade B Steel**	**Be**	**Cd**	**Pb**	**Ni-200**
Mn-55	14.100000	16.400000	9.000000	0.094000	0.000000	0.000000	3.500000
Fe-54	38.889965	43.220933	55.696735	0.053567	0.000000	0.001140	0.227943
Fe-55	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Fe-56	626.965796	696.787643	897.916676	0.863577	0.000000	0.018374	3.674798
Fe-57	14.611201	16.238373	20.925609	0.020125	0.000000	0.000428	0.085640
Fe-58	1.982338	2.203101	2.839030	0.002730	0.000000	0.000058	0.011619
Co-59	1.700000	1.000000	0.093000	0.001000	0.000000	0.000000	2.000000
Ni-58	62.204445	11.052577	0.000202	0.062339	0.000000	0.000000	662.134379
Ni-59	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Ni-60	24.601143	4.371167	0.000080	0.024654	0.000000	0.000000	261.866533
Ni-61	1.082859	0.192404	0.000004	0.001085	0.000000	0.000000	11.526475
Ni-62	3.496630	0.621286	0.000011	0.003504	0.000000	0.000000	37.219829
Ni-63	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Ni-64	0.914924	0.162565	0.000003	0.000917	0.000000	0.000000	9.738893
Cu-63	1.712489	0.958994	1.301492	0.036647	0.000000	0.547997	1.712489
Cu-64	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Cu-65	0.787511	0.441006	0.598508	0.016853	0.000000	0.252003	0.787511
Zn-64	0.047510	0.047510	0.010452	0.011877	0.000000	0.004751	0.000003
Zn-65	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Zn-66	0.028126	0.028126	0.006188	0.007032	0.000000	0.002813	0.000002
Zn-67	0.004196	0.004196	0.000923	0.001049	0.000000	0.000420	0.000000
Zn-68	0.019527	0.019527	0.004296	0.004882	0.000000	0.001953	0.000001
Zn-69	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Zn-70	0.000642	0.000642	0.000141	0.000160	0.000000	0.000064	0.000000
Ga69	0.076656	0.076656	0.011885	0.000511	0.000000	0.000000	0.000005
Ga-70	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Ga-71	0.052344	0.052344	0.008115	0.000349	0.000000	0.000000	0.000004
Ge-70	0.000000	0.000000	0.000000	0.000987	0.000000	0.000000	0.000000
Ge-71	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Ge-72	0.000000	0.000000	0.000000	0.001357	0.000000	0.000000	0.000000
Ge-73	0.000000	0.000000	0.000000	0.000392	0.000000	0.000000	0.000000
Ge-74	0.000000	0.000000	0.000000	0.001857	0.000000	0.000000	0.000000
Ge-75	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Ge-76	0.000000	0.000000	0.000000	0.000408	0.000000	0.000000	0.000000
As-75	0.100000	0.100000	0.160000	0.001782	0.000000	0.007000	0.000007

APPENDIX A

	Concentration (g/kg)						
Isotope	**304 SS**	**347 SS**	**SA-212 Grade B Steel**	**Be**	**Cd**	**Pb**	**Ni-200**
Se-74	0.001685	0.001685	0.000076	0.000020	0.000000	0.000000	0.000000
Se-75	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Se-76	0.017496	0.017496	0.000787	0.000208	0.000000	0.000000	0.000001
Se-77	0.014804	0.014804	0.000666	0.000176	0.000000	0.000000	0.000001
Se-78	0.046567	0.046567	0.002096	0.000555	0.000000	0.000000	0.000003
Se-79	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Se-80	0.100987	0.100987	0.004544	0.001203	0.000000	0.000000	0.000007
Se-81	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Se-82	0.018462	0.018462	0.000831	0.000220	0.000000	0.000000	0.000001
Br-79	0.001001	0.001001	0.001001	0.026034	0.000000	0.000000	0.000000
Br-80	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Br-81	0.000999	0.000999	0.000999	0.025966	0.000000	0.000000	0.000000
Kr-78	0.000000	0.000000	0.000000	0.000277	0.000000	0.000000	0.000000
Kr-79	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Kr-80	0.000000	0.000000	0.000000	0.001827	0.000000	0.000000	0.000000
Kr-81	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Kr-82	0.000000	0.000000	0.000000	0.009657	0.000000	0.000000	0.000000
Kr-83	0.000000	0.000000	0.000000	0.009690	0.000000	0.000000	0.000000
Kr-84	0.000000	0.000000	0.000000	0.048610	0.000000	0.000000	0.000000
Kr-85	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Kr-86	0.000000	0.000000	0.000000	0.015105	0.000000	0.000000	0.000000
Rb-85	0.007169	0.007169	0.051617	0.005568	0.000000	0.000000	0.000001
Rb-86	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Rb-87	0.002831	0.002831	0.020383	0.002199	0.000000	0.000000	0.000000
Sr-84	0.000001	0.000001	0.000001	0.000032	0.000000	0.000000	0.000000
Sr-85	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Sr-86	0.000019	0.000019	0.000015	0.000580	0.000000	0.000000	0.000000
Sr-87	0.000014	0.000014	0.000010	0.000417	0.000000	0.000000	0.000000
Sr-88	0.000166	0.000166	0.000124	0.004971	0.000000	0.000000	0.000000
Y8-9	0.005000	0.005000	0.004000	0.001000	0.000000	0.000000	0.000000
Zr-90	0.005071	0.005071	0.002028	0.019377	0.000000	0.000000	0.000000
Zr-91	0.001118	0.001118	0.000447	0.004273	0.000000	0.000000	0.000000
Zr-92	0.001728	0.001728	0.000691	0.006603	0.000000	0.000000	0.000000
Zr-93	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Zr-94	0.001789	0.001789	0.000716	0.006837	0.000000	0.000000	0.000000

APPENDIX A

	Concentration (g/kg)						
Isotope	**304 SS**	**347 SS**	**SA-212 Grade B Steel**	**Be**	**Cd**	**Pb**	**Ni-200**
Zr-95	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Zr-96	0.000294	0.000294	0.000118	0.001125	0.000000	0.000000	0.000000
Nb-93	0.120000	7.000000	0.040000	0.011700	0.000000	0.000000	0.000009
Mo-92	0.526062	0.540280	0.000064	0.001422	0.000000	0.000000	0.000037
Mo-93	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Mo-94	0.335031	0.344086	0.000041	0.000905	0.000000	0.000000	0.000024
Mo-95	0.582749	0.598499	0.000071	0.001575	0.000000	0.000000	0.000041
Mo-96	0.616996	0.633672	0.000075	0.001668	0.000000	0.000000	0.000044
Mo-97	0.356936	0.366583	0.000043	0.000965	0.000000	0.000000	0.000025
Mo-98	0.911168	0.935794	0.000111	0.002463	0.000000	0.000000	0.000065
Mo-99	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Mo-100	0.371058	0.381086	0.000045	0.001003	0.000000	0.000000	0.000026
Tc-99	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Ru-96	0.000000	0.000000	0.000000	0.000263	0.000000	0.000000	0.000000
Ru-97	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Ru-98	0.000000	0.000000	0.000000	0.000090	0.000000	0.000000	0.000000
Ru-99	0.000000	0.000000	0.000000	0.000621	0.000000	0.000000	0.000000
Ru-100	0.000000	0.000000	0.000000	0.000623	0.000000	0.000000	0.000000
Ru-101	0.000000	0.000000	0.000000	0.000854	0.000000	0.000000	0.000000
Ru-102	0.000000	0.000000	0.000000	0.001593	0.000000	0.000000	0.000000
Ru-103	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Ru-104	0.000000	0.000000	0.000000	0.000956	0.000000	0.000000	0.000000
Rh-103	0.000000	0.000000	0.000000	0.000994	0.000000	0.000000	0.000000
Pd-102	0.000000	0.000000	0.000000	0.000049	0.000000	0.000000	0.000000
Pd-103	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Pd-104	0.000000	0.000000	0.000000	0.000544	0.000000	0.000000	0.000000
Pd-105	0.000000	0.000000	0.000000	0.001101	0.000000	0.000000	0.000000
Pd-106	0.000000	0.000000	0.000000	0.001360	0.000000	0.000000	0.000000
Pd-107	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Pd-108	0.000000	0.000000	0.000000	0.001341	0.000000	0.000000	0.000000
Pd-109	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Pd-110	0.000000	0.000000	0.000000	0.000605	0.000000	0.000000	0.000000
Ag-107	0.001028	0.001028	0.001028	0.000514	0.000000	0.102753	0.000000
Ag-108	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Ag-109	0.000972	0.000972	0.000972	0.000486	0.000000	0.097247	0.000000

APPENDIX A

	Concentration (g/kg)						
Isotope	304 SS	347 SS	SA-212 Grade B Steel	Be	Cd	Pb	Ni-200
Cd-106	0.000000	0.000000	0.000000	0.000002	12.500000	0.000000	0.000000
Cd-107	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Cd-108	0.000000	0.000000	0.000000	0.000002	8.900000	0.000000	0.000000
Cd-109	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Cd-110	0.000000	0.000000	0.000000	0.000024	124.900000	0.000000	0.000000
Cd-111	0.000000	0.000000	0.000000	0.000025	128.000000	0.000000	0.000000
Cd-112	0.000000	0.000000	0.000000	0.000048	241.300000	0.000000	0.000000
Cd-113	0.000000	0.000000	0.000000	0.000025	122.200000	0.000000	0.000000
Cd-114	0.000000	0.000000	0.000000	0.000058	287.300000	0.000000	0.000000
Cd-115	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Cd-116	0.000000	0.000000	0.000000	0.000015	74.900000	0.000000	0.000000
In-113	0.000000	0.000000	0.000000	0.000003	0.000000	0.000000	0.000000
In-114	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
In-115	0.000000	0.000000	0.000000	0.000066	0.000000	0.000000	0.000000
Sn-112	0.000914	0.000914	0.000001	0.000027	0.000000	0.000064	0.000000
Sn-113	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Sn-114	0.000624	0.000624	0.000001	0.000019	0.000000	0.000044	0.000000
Sn-115	0.000348	0.000348	0.000000	0.000010	0.000000	0.000024	0.000000
Sn-116	0.014187	0.014187	0.000013	0.000426	0.000000	0.000993	0.000001
Sn-117	0.007563	0.007563	0.000007	0.000227	0.000000	0.000529	0.000001
Sn-118	0.024055	0.024055	0.000022	0.000722	0.000000	0.001684	0.000002
Sn-119	0.008594	0.008594	0.000008	0.000258	0.000000	0.000602	0.000001
Sn-120	0.032917	0.032917	0.000030	0.000988	0.000000	0.002304	0.000002
Sn-121	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Sn-122	0.004754	0.004754	0.000004	0.000143	0.000000	0.000333	0.000000
Sn-123	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Sn-124	0.006043	0.006043	0.000005	0.000181	0.000000	0.000423	0.000000
Sb-121	0.056999	0.056999	0.009120	0.000137	0.000000	0.003990	0.000004
Sb-122	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Sb-123	0.043001	0.043001	0.006880	0.000103	0.000000	0.003010	0.000003
Te-120	0.000000	0.000000	0.000000	0.000042	0.000000	0.000000	0.000000
Te-121	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Te-122	0.000000	0.000000	0.000000	0.001175	0.000000	0.000000	0.000000
Te-123	0.000000	0.000000	0.000000	0.000414	0.000000	0.000000	0.000000
Te-124	0.000000	0.000000	0.000000	0.002208	0.000000	0.000000	0.000000

APPENDIX A

	Concentration (g/kg)						
Isotope	**304 SS**	**347 SS**	**SA-212 Grade B Steel**	**Be**	**Cd**	**Pb**	**Ni-200**
Te-125	0.000000	0.000000	0.000000	0.003309	0.000000	0.000000	0.000000
Te-126	0.000000	0.000000	0.000000	0.008867	0.000000	0.000000	0.000000
Te-127	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Te-128	0.000000	0.000000	0.000000	0.015084	0.000000	0.000000	0.000000
Te-129	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Te-130	0.000000	0.000000	0.000000	0.016368	0.000000	0.000000	0.000000
I-127	0.000000	0.000000	0.000000	0.010000	0.000000	0.000000	0.000000
Xe-124	0.000000	0.000000	0.000000	0.000507	0.000000	0.000000	0.000000
Xe-125	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Xe-126	0.000000	0.000000	0.000000	0.000464	0.000000	0.000000	0.000000
Xe-127	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Xe-128	0.000000	0.000000	0.000000	0.009998	0.000000	0.000000	0.000000
Xe-129	0.000000	0.000000	0.000000	0.139278	0.000000	0.000000	0.000000
Xe-130	0.000000	0.000000	0.000000	0.021798	0.000000	0.000000	0.000000
Xe-131	0.000000	0.000000	0.000000	0.113578	0.000000	0.000000	0.000000
Xe-132	0.000000	0.000000	0.000000	0.145216	0.000000	0.000000	0.000000
Xe-133	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Xe-134	0.000000	0.000000	0.000000	0.056994	0.000000	0.000000	0.000000
Xe-135	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Xe-136	0.000000	0.000000	0.000000	0.049501	0.000000	0.000000	0.000000
Cs-133	0.000300	0.000300	0.000000	0.000201	0.000000	0.000000	0.000000
Ba-130	0.000501	0.000501	0.000802	0.000006	0.000000	0.000000	0.000000
Ba-131	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Ba-132	0.000485	0.000485	0.000776	0.000006	0.000000	0.000000	0.000000
Ba-133	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Ba-134	0.011799	0.011799	0.018878	0.000142	0.000000	0.000000	0.000001
Ba-135	0.032384	0.032384	0.051815	0.000389	0.000000	0.000000	0.000002
Ba-136	0.038844	0.038844	0.062150	0.000466	0.000000	0.000000	0.000003
Ba-137	0.055978	0.055978	0.089564	0.000672	0.000000	0.000000	0.000004
Ba-138	0.360009	0.360009	0.576014	0.004320	0.000000	0.000000	0.000026
La-138	0.000000	0.000000	0.000000	0.000001	0.000000	0.000000	0.000000
La-139	0.000200	0.000200	0.000200	0.000999	0.000000	0.000000	0.000000
Ce-136	0.000684	0.000684	0.000000	0.000002	0.000000	0.000000	0.000000
Ce-137	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Ce-138	0.000913	0.000913	0.000000	0.000002	0.000000	0.000000	0.000000

APPENDIX A

	Concentration (g/kg)						
Isotope	304 SS	347 SS	SA-212 Grade B Steel	Be	Cd	Pb	Ni-200
Ce-139	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Ce-140	0.327583	0.327583	0.000000	0.000883	0.000000	0.000000	0.000023
Ce-141	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Ce-142	0.041821	0.041821	0.000000	0.000113	0.000000	0.000000	0.000003
Pr-141	0.000000	0.000000	0.000000	0.001000	0.000000	0.000000	0.000000
Nd-142	0.000000	0.000000	0.000000	0.001335	0.000000	0.000000	0.000000
Nd-143	0.000000	0.000000	0.000000	0.000603	0.000000	0.000000	0.000000
Nd-144	0.000000	0.000000	0.000000	0.001187	0.000000	0.000000	0.000000
Nd-145	0.000000	0.000000	0.000000	0.000417	0.000000	0.000000	0.000000
Nd-146	0.000000	0.000000	0.000000	0.000869	0.000000	0.000000	0.000000
Nd-147	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Nd-148	0.000000	0.000000	0.000000	0.000295	0.000000	0.000000	0.000000
Nd-149	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Nd-150	0.000000	0.000000	0.000000	0.000293	0.000000	0.000000	0.000000
Pm-145	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Sm-144	0.000003	0.000003	0.000000	0.000015	0.000000	0.000000	0.000000
Sm-145	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Sm-146	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Sm-147	0.000015	0.000015	0.000000	0.000073	0.000000	0.000000	0.000000
Sm-148	0.000011	0.000011	0.000000	0.000056	0.000000	0.000000	0.000000
Sm-149	0.000014	0.000014	0.000000	0.000068	0.000000	0.000000	0.000000
Sm-150	0.000007	0.000007	0.000000	0.000037	0.000000	0.000000	0.000000
Sm-151	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Sm152	0.000027	0.000027	0.000000	0.000135	0.000000	0.000000	0.000000
Sm-153	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Sm-154	0.000023	0.000023	0.000000	0.000116	0.000000	0.000000	0.000000
Eu-151	0.000009	0.000009	0.000095	0.000237	0.000000	0.000000	0.000000
Eu-152	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Eu-153	0.000011	0.000011	0.000105	0.000263	0.000000	0.000000	0.000000
Gd-152	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Gd-153	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Gd-154	0.000000	0.000000	0.000000	0.000004	0.000000	0.000000	0.000000
Gd-155	0.000000	0.000000	0.000000	0.000029	0.000000	0.000000	0.000000
Gd-156	0.000000	0.000000	0.000000	0.000041	0.000000	0.000000	0.000000
Gd-157	0.000000	0.000000	0.000000	0.000031	0.000000	0.000000	0.000000

APPENDIX A

	Concentration (g/kg)						
Isotope	304 SS	347 SS	SA-212 Grade B Steel	Be	Cd	Pb	Ni-200
Gd-158	0.000000	0.000000	0.000000	0.000050	0.000000	0.000000	0.000000
Gd-159	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Gd-160	0.000000	0.000000	0.000000	0.000044	0.000000	0.000000	0.000000
Tb-159	0.000470	0.000470	0.000000	0.001000	0.000000	0.000000	0.000000
Dy-156	0.000001	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000
Dy-157	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Dy-158	0.000001	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000
Dy-159	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Dy-160	0.000023	0.000023	0.000000	0.000005	0.000000	0.000000	0.000000
Dy-161	0.000187	0.000187	0.000000	0.000037	0.000000	0.000000	0.000000
Dy-162	0.000254	0.000254	0.000000	0.000051	0.000000	0.000000	0.000000
Dy-163	0.000250	0.000250	0.000000	0.000050	0.000000	0.000000	0.000000
Dy-164	0.000284	0.000284	0.000000	0.000057	0.000000	0.000000	0.000000
Ho-165	0.001000	0.001000	0.000000	0.001000	0.000000	0.000000	0.000000
Er-162	0.000000	0.000000	0.000000	0.000001	0.000000	0.000000	0.000000
Er-163	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Er-164	0.000000	0.000000	0.000000	0.000008	0.000000	0.000000	0.000000
Er-165	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Er-166	0.000000	0.000000	0.000000	0.000167	0.000000	0.000000	0.000000
Er-167	0.000000	0.000000	0.000000	0.000115	0.000000	0.000000	0.000000
Er-168	0.000000	0.000000	0.000000	0.000135	0.000000	0.000000	0.000000
Er-169	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Er-170	0.000000	0.000000	0.000000	0.000076	0.000000	0.000000	0.000000
Tm-169	0.000000	0.000000	0.000000	0.000500	0.000000	0.000000	0.000000
Yb-168	0.000003	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000
Yb-169	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Yb-170	0.000060	0.000060	0.000030	0.000006	0.000000	0.000000	0.000000
Yb-171	0.000283	0.000283	0.000141	0.000028	0.000000	0.000000	0.000000
Yb-172	0.000435	0.000435	0.000218	0.000044	0.000000	0.000000	0.000000
Yb-173	0.000322	0.000322	0.000161	0.000032	0.000000	0.000000	0.000000
Yb-174	0.000639	0.000639	0.000320	0.000064	0.000000	0.000000	0.000000
Yb-175	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Yb-176	0.000258	0.000258	0.000129	0.000026	0.000000	0.000000	0.000000
Lu-175	0.000779	0.000779	0.000292	0.000649	0.000000	0.000000	0.000000
Lu-176	0.000021	0.000021	0.000008	0.000017	0.000000	0.000000	0.000000

APPENDIX A

	Concentration (g/kg)						
Isotope	304 SS	347 SS	SA-212 Grade B Steel	Be	Cd	Pb	Ni-200
Hf-174	0.000003	0.000003	0.000001	0.000001	0.000000	0.000000	0.000000
Hf-175	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Hf-176	0.000103	0.000103	0.000031	0.000022	0.000000	0.000000	0.000000
Hf-177	0.000369	0.000369	0.000111	0.000078	0.000000	0.000000	0.000000
Hf-178	0.000544	0.000544	0.000163	0.000115	0.000000	0.000000	0.000000
Hf-179	0.000273	0.000273	0.000082	0.000058	0.000000	0.000000	0.000000
Hf-180	0.000708	0.000708	0.000212	0.000150	0.000000	0.000000	0.000000
Ta-180M	0.000000	0.000955	0.000000	0.000000	0.000000	0.000000	0.000000
Ta-181	0.000750	7.999045	0.000300	0.000433	0.000000	0.000000	0.000000
W-180	0.000218	0.000218	0.000006	0.000090	0.000000	0.000000	0.000000
W-181	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
W-182	0.048413	0.048413	0.001301	0.019837	0.000000	0.000000	0.000003
W-183	0.026431	0.026431	0.000711	0.010830	0.000000	0.000000	0.000002
W-184	0.057134	0.057134	0.001536	0.023411	0.000000	0.000000	0.000004
W-185	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
W-186	0.053804	0.053804	0.001446	0.022046	0.000000	0.000000	0.000004
Re-185	0.000000	0.000000	0.000000	0.000239	0.000000	0.000000	0.000000
Re-186	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Re-187	0.000000	0.000000	0.000000	0.000405	0.000000	0.000000	0.000000
Os-184	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Os-185	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Os-186	0.000000	0.000000	0.000000	0.000010	0.000000	0.000000	0.000000
Os-187	0.000000	0.000000	0.000000	0.000010	0.000000	0.000000	0.000000
Os-188	0.000000	0.000000	0.000000	0.000084	0.000000	0.000000	0.000000
Os-189	0.000000	0.000000	0.000000	0.000102	0.000000	0.000000	0.000000
Os-190	0.000000	0.000000	0.000000	0.000168	0.000000	0.000000	0.000000
Os-191	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Os-192	0.000000	0.000000	0.000000	0.000264	0.000000	0.000000	0.000000
Ir-191	0.000000	0.000000	0.000000	0.000002	0.000000	0.000000	0.000000
Ir-192	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Ir-193	0.000000	0.000000	0.000000	0.000003	0.000000	0.000000	0.000000
Pt-190	0.000000	0.000000	0.000000	0.000010	0.000000	0.000000	0.000000
Pt-191	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Pt-192	0.000000	0.000000	0.000000	0.000792	0.000000	0.000000	0.000000
Pt-193	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000

APPENDIX A

	Concentration (g/kg)						
Isotope	304 SS	347 SS	SA-212 Grade B Steel	Be	Cd	Pb	Ni-200
Pt-194	0.000000	0.000000	0.000000	0.033323	0.000000	0.000000	0.000000
Pt-195	0.000000	0.000000	0.000000	0.034411	0.000000	0.000000	0.000000
Pt-196	0.000000	0.000000	0.000000	0.025889	0.000000	0.000000	0.000000
Pt-197	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Pt-198	0.000000	0.000000	0.000000	0.007443	0.000000	0.000000	0.000000
Au-197	0.000000	0.000000	0.000000	0.024800	0.000000	0.000000	0.000000
Hg-196	0.000000	0.000000	0.000000	0.000006	0.000000	0.000000	0.000000
Hg-197	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Hg-198	0.000000	0.000000	0.000000	0.000402	0.000000	0.000000	0.000000
Hg-199	0.000000	0.000000	0.000000	0.000683	0.000000	0.000000	0.000000
Hg-200	0.000000	0.000000	0.000000	0.000938	0.000000	0.000000	0.000000
Hg-201	0.000000	0.000000	0.000000	0.000539	0.000000	0.000000	0.000000
Hg-202	0.000000	0.000000	0.000000	0.001222	0.000000	0.000000	0.000000
Hg-203	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Hg-204	0.000000	0.000000	0.000000	0.000284	0.000000	0.000000	0.000000
Tl-203	0.000000	0.000000	0.000000	0.007329	0.000000	0.000000	0.000000
Tl-204	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Tl-205	0.000000	0.000000	0.000000	0.017671	0.000000	0.000000	0.000000
Pb-204	0.000276	0.000276	0.000551	0.000014	0.000000	13.765884	0.000000
Pb-205	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Pb-206	0.004791	0.004791	0.009582	0.000240	0.000000	239.293092	0.000000
Pb-207	0.004415	0.004415	0.008830	0.000221	0.000000	220.499962	0.000000
Pb-208	0.010518	0.010518	0.021037	0.000526	0.000000	525.340062	0.000001
Bi-209	0.000000	0.000000	0.000000	0.000000	0.000000	0.050000	0.000000
Th-232	0.001000	0.001000	0.004000	0.000438	0.000000	0.000000	0.000000
U-234	0.000000	0.000000	0.000000	0.000002	0.000000	0.000000	0.000000
U-235	0.000014	0.000014	0.000014	0.000213	0.000000	0.000000	0.000000
U-236	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
U-237	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
U-238	0.001986	0.001986	0.001986	0.029785	0.000000	0.000000	0.000000

APPENDIX A

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APPENDIX A

Table A-3. Isotope-specific activity contributions (Ci) of the various activated structures in ETR to the total radioactivity of the facility as of January 2005.

Isotope	Be Reflector (Be)	Grid Plate (304-SS)	I-Beams (all 6, 304-SS)	C-7 In-Pile Tube (304-SS)	F-10 In-Pile Tube (304-SS)	M-13 In-Pile Tube (304-SS)	N-14 In-Pile Tube (304-SS)	Upper Support Frame (304-SS)	Inner Tank (304-SS, Steel)	Internal Thermal Shields (304-SS)	External Thermal Shield (304-SS, Pb)	External Tank (304-SS, Steel)	Black Rod Poison & Shock Assys (Cd)	Gray Rod Poison & Shock Assys (Ni)	Total Activity
H-3	7.84E+04	1.13E+01	3.73E-06	3.51E-01	2.66E-01	2.67E-01	2.15E-01	9.12E-07	7.62E+00	2.26E-01	1.96E-03	4.54E-03	2.83E-01	3.32E-04	7.84E+04
Be-10	8.88E-01	2.04E-06	6.49E-13	7.19E-08	2.00E-07	9.02E-08	4.62E-08	1.59E-13	1.39E-06	3.92E-08	4.34E-10	1.00E-09	4.65E-07	2.98E-06	8.88E-01
C-14	7.06E+00	1.12E+01	3.11E-06	4.21E-01	1.29E+00	5.70E-01	2.79E-01	7.61E-07	7.57E+00	1.89E-01	1.71E-04	4.98E-04	2.98E+00	9.50E-04	3.16E+01
Cl-36	8.63E-02	1.15E-01	2.47E-08	3.30E-03	9.31E-03	4.34E-03	2.17E-03	6.05E-09	5.97E-02	1.50E-03	3.85E-07	1.76E-06	1.89E-02	3.19E-05	3.00E-01
Mn-54	2.18E-08	3.87E-06	7.39E-13	1.15E-07	3.90E-07	3.46E-07	1.50E-07	1.81E-13	1.80E-06	4.48E-08	2.45E-10	5.78E-10	8.89E-07	1.44E-08	7.64E-06
Ni-59	6.40E-02	1.32E+01	1.74E-05	2.15E+00	4.15E+00	2.47E+00	1.37E+00	4.26E-06	4.05E+01	1.06E+00	2.71E-04	1.24E-03	5.17E+00	2.45E+02	3.15E+02
Co-60	2.64E+00	1.31E+03	4.93E-04	7.10E+01	1.93E+02	1.38E+02	6.72E+01	1.21E-04	1.18E+03	2.99E+01	1.36E-02	4.85E-02	3.31E+02	1.37E+03	4.69E+03
Ni-63	9.23E+00	1.51E+03	1.84E-03	2.45E+02	6.58E+02	3.26E+02	1.65E+02	4.51E-04	4.43E+03	1.12E+02	3.01E-02	1.32E-01	1.21E+03	4.89E+04	5.76E+04
Zn-65	1.02E-10	9.15E-11	1.83E-17	3.12E-12	1.59E-11	1.10E-11	4.22E-12	4.46E-18	4.65E-11	1.11E-12	6.60E-15	3.29E-15	5.61E-11	7.66E-11	4.07E-10
Sr-90	1.79E+00	1.16E-01	8.16E-09	3.24E-03	1.48E-02	6.46E-03	2.60E-03	2.00E-09	4.24E-02	5.01E-04	1.99E-06	4.78E-06	3.09E-02	7.77E-06	2.01E+00
Nb-94	1.95E-02	1.13E+01	4.23E-08	5.60E-03	1.51E-02	7.25E-03	3.67E-03	1.03E-08	1.02E-01	2.56E-03	3.77E-06	1.00E-05	2.87E-02	7.72E-06	1.15E+01
Tc-99	1.31E-03	7.65E-03	1.68E-09	2.15E-04	5.36E-04	2.68E-04	1.40E-04	4.10E-10	3.93E-03	1.01E-04	2.68E-08	1.21E-07	9.05E-04	2.54E-07	1.51E-02
Ru-103	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ru-106	7.30E-07	9.17E-09	4.14E-17	2.88E-10	1.10E-09	1.10E-09	4.28E-10	1.01E-17	3.04E-09	3.43E-12	9.84E-15	2.37E-14	1.77E-09	3.98E-13	7.46E-07
Ag-108m	8.33E-02	1.55E-01	3.37E-08	4.49E-03	1.23E-02	5.97E-03	3.01E-03	8.24E-09	8.11E-02	2.04E-03	1.00E-02	1.91E-05	2.20E-01	6.29E-06	5.77E-01
Ag-110m	6.21E-11	2.92E-11	8.35E-18	9.95E-13	7.76E-13	1.82E-12	1.16E-12	2.04E-18	1.79E-11	5.06E-13	2.49E-12	4.74E-15	5.87E-11	9.30E-17	1.76E-10
Sb-125	1.64E-03	6.79E-03	1.44E-09	2.22E-04	7.80E-04	5.91E-04	2.58E-04	3.53E-10	3.49E-03	8.74E-05	3.23E-07	1.03E-07	1.87E-03	3.60E-07	1.57E-02
I-129	9.74E-06	2.26E-07	5.17E-15	6.11E-09	2.84E-08	1.20E-08	4.74E-09	1.27E-15	7.22E-08	3.28E-10	1.23E-12	2.96E-12	5.27E-08	1.45E-11	1.01E-05
Cs-134	5.55E-03	7.78E-04	1.80E-10	2.57E-05	5.93E-05	6.07E-05	3.03E-05	4.39E-11	4.19E-04	1.09E-05	2.79E-09	1.28E-08	7.68E-05	1.98E-08	7.01E-03
Cs-137	5.99E+00	2.40E-01	8.87E-09	6.64E-03	3.24E-02	1.41E-02	5.47E-03	2.17E-09	7.98E-02	5.53E-04	2.15E-06	5.16E-06	6.63E-02	1.68E-05	6.44E+00
Ce-144	5.23E-09	8.83E-11	3.38E-18	2.80E-12	1.04E-11	1.03E-11	4.07E-12	8.26E-19	3.23E-11	2.12E-13	8.25E-16	1.98E-15	1.75E-11	3.87E-15	5.39E-09
Eu-152	3.64E-02	8.91E-02	6.55E-07	3.73E-03	1.61E-05	2.25E-04	1.34E-03	1.60E-07	2.58E-01	3.90E-02	1.46E-03	3.30E-03	1.26E-05	4.18E-09	4.33E-01
Eu-154	2.14E+00	2.15E-01	3.74E-08	6.54E-03	4.97E-03	7.56E-03	5.07E-03	9.15E-09	1.05E-01	2.27E-03	8.31E-05	1.89E-04	2.35E-03	8.79E-07	2.49E+00
Pb-210	3.82E-11	3.96E-11	1.04E-13	9.83E-13	1.08E-11	2.21E-12	6.23E-13	2.10E-13	1.39E-11	8.01E-12	2.65E-12	5.28E-12	4.14E-11	9.00E-15	1.64E-10
Ra-226	5.34E-11	9.71E-11	3.00E-13	2.47E-12	9.33E-12	3.36E-12	1.43E-12	6.09E-13	3.71E-11	2.31E-11	7.66E-12	1.53E-11	1.44E-11	4.79E-15	2.65E-10
Ac-227	3.01E-07	1.21E-06	1.88E-12	3.53E-08	3.78E-08	3.03E-08	2.03E-08	3.22E-12	7.24E-07	2.03E-08	3.41E-10	7.70E-10	2.95E-08	1.10E-11	2.41E-06
Th-228	1.50E-04	1.51E-04	1.18E-08	3.96E-06	2.74E-05	1.08E-05	3.49E-06	2.39E-08	3.80E-05	9.06E-07	1.14E-06	2.17E-06	3.84E-05	1.21E-08	4.27E-04
Th-229	2.51E-07	1.45E-06	5.44E-13	4.26E-08	3.01E-08	2.71E-08	2.17E-08	1.33E-13	9.81E-07	3.04E-08	4.89E-10	1.12E-09	2.55E-08	9.28E-12	2.86E-06

APPENDIX A

Isotope	Be Reflector (Be)	Grid Plate (304-SS)	I-Beams (all 6, 304-SS)	C-7 In-Pile Tube (304-SS)	F-10 In-Pile Tube (304-SS)	M-13 In-Pile Tube (304-SS)	N-14 In-Pile Tube (304-SS)	Upper Support Frame (304-SS)	Inner Tank (304-SS, Steel)	Internal Thermal Shields (304-SS)	External Thermal Shield (304-SS, Pb)	External Tank (304-SS, Steel)	Black Rod Poison & Shock Assys (Cd)	Gray Rod Poison & Shock Assys (Ni)	Total Activity
Th-230	7.79E-09	9.01E-09	3.03E-11	2.35E-10	9.11E-10	3.87E-10	1.56E-10	6.15E-11	3.32E-09	2.32E-09	7.74E-10	1.54E-09	1.31E-09	4.20E-13	2.79E-08
Th-232	3.09E-08	2.42E-07	1.19E-08	7.88E-09	3.16E-09	3.49E-09	3.63E-09	2.41E-08	3.00E-07	9.05E-07	1.15E-06	2.19E-06	2.38E-09	8.70E-13	4.88E-06
Pa-231	4.80E-07	1.75E-06	3.73E-12	5.16E-08	5.70E-08	4.71E-08	3.12E-08	6.71E-12	1.04E-06	2.92E-08	5.16E-10	1.16E-09	4.61E-08	1.67E-11	3.53E-06
U-232	1.46E-04	1.46E-04	5.95E-16	3.85E-06	2.67E-05	1.05E-05	3.39E-06	1.07E-16	3.67E-05	8.51E-09	1.57E-12	4.32E-12	3.74E-05	1.18E-08	4.11E-04
U-233	8.31E-05	4.02E-04	1.52E-10	1.22E-05	8.41E-06	8.64E-06	6.89E-06	3.72E-11	2.74E-04	8.53E-06	1.37E-07	3.13E-07	6.63E-06	2.37E-09	8.11E-04
U-234	3.27E-05	1.71E-05	7.32E-08	4.61E-07	1.85E-06	1.01E-06	3.78E-07	1.49E-07	5.89E-06	5.57E-06	1.87E-06	3.73E-06	2.26E-06	6.86E-10	7.31E-05
U-235	9.08E-09	2.40E-08	3.33E-09	8.74E-10	1.45E-10	1.20E-10	2.80E-10	6.76E-09	5.37E-08	2.53E-07	8.50E-08	1.69E-07	2.02E-10	5.91E-14	6.05E-07
U-236	1.31E-06	2.24E-07	7.91E-14	6.78E-09	5.36E-09	4.55E-09	3.75E-09	1.93E-14	1.54E-07	4.78E-09	1.87E-11	4.49E-11	9.00E-09	2.32E-12	1.72E-06
U-238	5.72E-06	1.43E-06	7.23E-08	4.65E-08	1.58E-08	1.95E-08	2.12E-08	1.47E-07	1.80E-06	5.51E-06	1.85E-06	3.68E-06	9.01E-09	3.72E-12	2.03E-05
Np-237	4.49E-06	4.26E-07	1.44E-14	1.13E-08	1.69E-08	1.37E-08	7.88E-09	3.52E-15	1.23E-07	8.61E-10	3.40E-12	8.17E-12	2.05E-08	5.92E-12	5.11E-06
Pu-238	1.85E-01	1.03E-02	2.86E-16	2.21E-04	8.30E-04	4.88E-04	1.58E-04	8.44E-18	9.86E-04	1.32E-08	6.23E-13	1.81E-12	5.49E-04	2.07E-07	1.99E-01
Pu-239	3.01E-02	6.64E-03	3.84E-09	2.09E-04	8.36E-05	1.02E-04	1.04E-04	9.39E-10	5.75E-03	2.27E-04	9.06E-07	2.18E-06	4.78E-05	1.97E-08	4.32E-02
Pu240	4.31E-02	6.20E-03	2.31E-14	1.81E-04	1.57E-04	1.35E-04	1.10E-04	6.80E-16	2.86E-03	1.09E-06	5.04E-11	1.46E-10	1.98E-04	6.27E-08	5.30E-02
Pu-241	3.90E+00	3.06E-01	6.65E-18	8.37E-03	1.06E-02	1.15E-02	6.93E-03	2.36E-20	7.03E-02	2.51E-07	1.34E-13	4.70E-13	8.51E-03	2.95E-06	4.32E+00
Pu-242	6.57E-04	1.18E-05	8.63E-28	2.75E-07	3.10E-06	1.41E-06	3.36E-07	3.69E-31	9.83E-07	2.59E-14	1.61E-22	6.81E-22	2.88E-06	1.07E-09	6.77E-04
Pu-244	6.05E-10	2.25E-13	0.00E+00	4.35E-15	3.88E-12	4.44E-13	1.81E-14	0.00E+00	2.97E-15	4.97E-27	4.20E-39	2.58E-38	2.63E-11	4.15E-15	6.36E-10
Am-241	3.79E-01	3.92E-02	8.53E-19	1.04E-03	1.12E-03	1.22E-03	7.70E-04	3.03E-21	9.04E-03	3.21E-08	1.72E-14	6.03E-14	7.79E-04	2.91E-07	4.32E-01
Am-243	6.44E-03	3.61E-05	1.14E-32	7.38E-07	4.05E-05	1.07E-05	1.28E-06	5.84E-37	1.25E-06	2.71E-16	1.96E-26	1.00E-25	4.54E-05	1.64E-08	6.58E-03
CM-243	1.15E-03	3.37E-05	1.43E-32	7.10E-07	8.22E-06	3.99E-06	8.18E-07	7.37E-37	1.40E-06	3.41E-16	2.47E-26	1.26E-25	3.72E-06	1.84E-09	1.20E-03
CM-244	7.27E-01	7.77E-04	9.30E-37	1.40E-05	8.16E-03	7.83E-04	3.85E-05	0.00E+00	1.05E-05	1.77E-17	1.49E-29	9.18E-29	2.52E-02	6.49E-06	7.62E-01
CM-245	1.36E-04	8.26E-08	0.00E+00	1.36E-09	1.91E-06	1.37E-07	4.58E-09	0.00E+00	5.52E-10	8.83E-24	8.66E-38	6.42E-37	6.13E-06	1.62E-09	1.44E-04
CM-246	1.14E-04	1.33E-08	0.00E+00	1.90E-10	3.23E-06	7.40E-08	9.90E-10	0.00E+00	3.43E-11	4.27E-27	1.07E-43	3.71E-42	4.21E-05	6.82E-09	1.59E-04
CM-247	5.11E-10	1.55E-14	0.00E+00	1.95E-16	2.36E-11	2.37E-13	1.47E-15	0.00E+00	1.63E-17	1.64E-35	0.00E+00	0.00E+00	5.81E-10	7.98E-14	1.12E-09
CM-248	2.39E-09	1.69E-14	0.00E+00	1.86E-16	2.14E-10	7.59E-13	2.06E-15	0.00E+00	7.08E-18	5.70E-38	0.00E+00	0.00E+00	1.75E-08	1.61E-12	2.01E-08
Total	7.84E+04	2.87E+03	2.36E-03	3.19E+02	8.57E+02	4.67E+02	2.34E+02	5.78E-04	5.66E+03	1.43E+02	5.77E-02	1.90E-01	1.55E+03	5.05E+04	1.41E+05
TRU Fraction	9.045	0.274	0.000	0.224	0.653	0.569	0.333	0.000	0.067	0.000	0.000	0.000	0.448	0.000	0.127
Class C Fraction	74.322	134.223	0.001	43.629	247.979	123.992	63.183	0.000	15.226	0.175	0.000	0.000	424.186	4092.793	20.614

APPENDIX B
ETR FUEL FAILURE EXPERIENCE

The Engineering Test Reactor suffered a fission break event that required a manual scram on December 12, 1961. Primary coolant water flow had been restricted by remnants of a Lucite sight box that had lodged on top of the six affected fuel elements. The transparent sight box apparently sank in the reactor tank during the previous outage and was left inside. From one to eight fuel plates in six fuel elements melted, resulting in about 13 grams of enriched uranium release into the coolant (NS, 1962; Keller, 1962). After the scram, coolant continued to flow at the rated flow rate to help clean up the water, and two flushes of 60,000 gallons were carried out to remove contamination to the demineralizer. The primary coolant water read as high as 1 rem/hour on contact at that time. When the reactor head was opened after several hours of circulation into the demineralizer, the primary coolant read less than 1 mrem/h for a 100 ml sample, which was a very low reading. The vessel was vacuum cleaned with an underwater vacuum cleaner and pieces of Lucite were removed with finger tools. After the extent of the fuel element damage was understood, a second cleanup by manned entry was conducted later in the month to remove more contamination, fuel and Lucite debris, as well as bristles and other remnants of in-tank cleaning operations. Administrative controls were in place to keep radiation exposure levels low. Through December 27, 1961, the 90 cleanup personnel averaged 133 mrem each as a total from both sessions.[B-1]

Test coupons were placed in the reactor tank to determine what plate out of fission products could be expected. After four operating cycles, these are the results.[B-2]

	Counts per minute per square meter				
	Ru-103	Zr-95	Ce-141	I-131	Bo-140 – La-140
Stainless steel	3.51E+06	6.02E+06	1.46E+07	2.38E+06	1.03E+05
Aluminum	7.36E+06	1.33E+07	7.95E+06	3.33E+06	not detectable

From these coupon results, there was no reason to expect a serious buildup of fission product contamination on the reactor surfaces.

Most of the fission break contamination of the cooling water was handled by the ion-exchange demineralizer system; however, this operating experience shows that there is good reason to expect more contamination in the primary coolant system than mere fission product migration through the aluminum fuel cladding.

REFERENCES

B-1. "ETR Fission Break Incident," *Nuclear Safety, 3* (June 1962) pp. 93-95.

B-2. F. R. Keller,, May 10, 1962, *Fuel Element Flow Blockage in the Engineering Test Reactor*, IDO-16780, Phillips Petroleum Company, Atomic Energy Division, Idaho Falls, Idaho.

APPENDIX C
SURFACE ACTIVITY ESTIMATION DETAILS

Based on information in Ref. 30 in the main document, we assumed the activity on ETR surfaces in 1997 was a combination of C-14, Co-60, Ni-63, Sr-90, Tc-99, I-129, and Cs-137. Measurements in 1996 gave average values for various cubicles listed in Table 4 and repeated here for convenience as Table C-1.

Table C-1. Average 1996 activities of selected isotopes on smear samples from ETR cubicles.

Cubicle	Co-60 (pCi/100 cm^2)	Cs-137 (pCi/100 cm^2)	Sr-90 (pCi/100 cm^2)
C-7	701	21,975	12
F-10	320	6,500	13
J-10	139	433	18
L-10	445	5,643	25
L-12	420	3,790	38
M-3	194	2,306	99
M-7	458	1,051	148
P-7	164	246	148
Average	355	5,243	63

Scaling factors developed in Ref. 30 and presented in Table 6 of the main document, allow estimation of Ni-63 and C-14 from Co-60 activities and Tc-99 and I-129 activities from Cs-137 data. Those scaling factors were based on measurements made in 1996 and 1997.

Not all of the areas of interest are included in Table C-1. The Hazard Assessment Document (HAD-200) included total curies of activity in a number of areas, some of which are included in Table C-1, based on measurements made in 1982. Those activities are in Table C-2. The last column, Ci/m^2, in the table has been multiplied by a factor of 1000 to account for the assumed collection efficiency of the smear samples for surface contamination.

Table C-2. Measurements of surface activity from 1982 smear samples in various areas of the ETR reactor building from HAD-200.

Region	DPM/100 cm^2	Ci/m^2
Reactor nozzle trench	236	6.38E-04
Canal	35,209	9.52E-02
Main reactor floor area	742	2.01E-03
Reactor console floor and balcony	1,513	4.09E-03
Reactor building basement header*	2,113	5.71E-03
Warm and hot waste pits	4,183	1.13E-02
Annulus gas	13,500	3.65E-02

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Region		DPM/100 cm^2	Ci/m^2
M-3 and P-7 cubicle*		18,620	5.03E-02
J-10/L-10 cubicle*		313	8.46E-04
C7/M-13/N-14 cubicle*		61,755	1.67E-01
F-10/H-10 cubicle*		28,586	7.73E-02
L-12/M-7 Cubicle*		367,819	9.94E-01
C-13/G-16 cubicle		3,963	1.07E-02
Helium system cubicle		7,064	1.91E-02
Control access room*		938	2.54E-03
Sub-pile room		1,543	4.17E-03
	Average	34,256.06	9.26E-02

* Unused or other values used for these areas.

The method of obtaining isotopic activities was as follows.

- For areas identified in Table C-1, 1997 specific activities of Co-60, Sr-90, and Cs-137 from the table were used, and other isotopes were scaled from those using the scaling factors of Table 6.
- For areas not in Table C-1 but where local total specific activity was available in Table C-2, we estimated 1997 Co-60, Sr-90, and Cs-137 specific activities by
  - assuming that the isotopic distribution of activity on the surfaces was essentially the same as the average of a number of activated structures in the reactor core;
  - finding from ORIGEN2 results the average activity in 2005 of each of the isotopes of interest for each of the internal structures except the beryllium reflector and the control rod assemblies;
  - reverse-decaying each of the isotopes to find the activities those isotopes would have in 1982;
  - determining the isotopic activity fraction in 1982 of the Co-60 (0.863), Sr-90 (4.5E-06), and Cs-137 (9.01E-06);
  - multiplying the 1982 activity indicated for the various areas in Table C-2 by the 1982 isotopic activity fraction to get 1982 activities of Co-60, Sr-90, and Cs-137;
  - decaying those activities to 1997.

  Then, 1997 activities of other isotopes were scaled from the Co-60 and Cs-137 using the scaling factors of Table 6.
- For areas where no measurements were available, we used the same process as the previous one except that we used facility average activity in Table C-2 in place of the local room activity. We then applied the scaling factors of Table 6 to get the specific activities of the other isotopes.

Surface areas for the various regions in the buildings were estimated using graphical techniques. Numbers thus obtained are listed in Table C-3

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Table C-3. Estimated surface areas for regions of the ETR complex subject to surface contamination.

Zone	Floor (ft^2)	Wall (ft^2)	Ceiling (ft^2)	Total (ft^2)	Total (m^2)
Reactor Vessel					272.4
Nozzle Trench	136.6	547		684	63.5
Biological Shield (over cap)	490.9			491	45.6
Canal	972	4644		5616	521.7
Main Room	13525	28866	15232	69147	6423.4
Console Floor	9430	20357	9430	39217	3643.0
Balcony	3,270		3,270	6,540	607.5
Emergency Cooling Loop Cubicles	773	4901	773	6,448	598.9
PCS Pipe Tunnel	406	1261	406	2,072	192.5
Hot Waste Pit	300	951.3	300	1,551	144.1
P-7 Primary Cubicle	245		245	489	45.5
J-10/L-10 Primary Cubicle	214		214	429	39.9
C-7/M-13/N-14 Primary Cubicle	248		248	497	46.1
C-7/M-13/N-14 Secondary Cubicle	531		531	1,063	98.7
F-10/H-10 Primary Cubicle	270		270	541	50.3
F-10/H-10 Auxiliary Cubicle	139		139	278	25.8
F-10/H-10 Secondary Cubicle	212		212	424	39.4
Helium System Cubicle	445		445	890	82.6
L-12/M-7 Primary Cubicle	519		519	1,037	96.4
L-12/M-7 Secondary Cubicle	202		202	404	37.5
C-13/G-16 Primary Cubicle	237		237	474	44.0
C-13/G-16 Secondary Cubicle	224		224	448	41.7
Crud Generator Cubicle	51		51	102	9.4
Sub-pile Room Entryway	113		113	226	21.0
AGS Cubicle	70	314.5	70	455	42.3
GEEL Pipe Tunnel (HAD-200 p. A11)	240	480	240	960	89.2
M-3 Primary Cubicle	161		161	322	29.9
M-3/P-7 Secondary Cubicle	74		74	147	13.7
Warm Waste Pit	300	1165	300	1765	164.0
Sub-Pile Room	296		296	593	55.0
Rod Access Room	137		137	274	25.5
Other Basement Areas	6,891		6,891	13,782	1,280.2

The 1997 specific activities were decayed to January 2005 using a decay time of 6.917 years and multiplied by the respective areas to get the activities listed in Table 9.

APPENDIX D
PLACEMENT OF ITEMS ON ETR CORE

Following are copies of the sign-off sheets from D. W. Suthers, December 14, 1981 memorandum DWS-7-81 to D. L. French, detailing the placement of items from the ETR canal onto the top of the ETR core. It appears that for the most part, there are no highly activated stainless steel objects on the core top.

APPENDIX D

D. L. French
December 14, 1981
OWS-7-81
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STORAGE OF SPARE IRRADIATED CORE COMPONENTS IN THE ETR REACTOR TANK

The guide tubes will be used to store all the useable control rod components to allow future canal draining. To prevent damage to the dogs and/or inadvertant latch up, a spacer will be inserted on top of the shock sections inside the guide tube and again on top of the first poison section.

Load the following control rod components from the canal for storage. Remove and replace guide tube covers as necessary.

Rod	Position	Install Piece No.	From Canal Position	Completed by	Verified by
3	G-11	Spacer	N/A	[initials]	[initials]
3	G-11	B-51	P-3-1	[initials]	[initials]
3	G-11	Spacer	N/A	[initials]	[initials]
3	G-11	B-43	R-4-3	[initials]	[initials]
14	K-11	Spacer	N/A	[initials]	[initials]
14	K-11	G-33	P-3-2	[initials]	[initials]
14	K-11	Spacer	N/A	[initials]	[initials]
14	K-11	G-49	R-4-1	[initials]	[initials]
6	J-5	Spacer	N/A	[initials]	[initials]
6	J-5	G-50	P-3-3	[initials]	[initials]
6	J-5	Spacer	N/A	[initials]	[initials]
6	J-5	G-31	R-5-6	[initials]	[initials]
8	E-9	Spacer	N/A	[initials]	[initials]
8	E-9	G-43	P-3-4	[initials]	[initials]
8	E-9	Spacer	N/A	[initials]	[initials]
8	E-9	G-46	R-4-2	[initials]	[initials]
12	E-11	Spacer	N/A	[initials]	[initials]
12	E-11	G-30	P-3-5	[initials]	[initials]
12	E-11	Spacer	N/A	[initials]	[initials]
12	E-11	G-35	R-5-2	[initials]	[initials]
15	H-13	Spacer	N/A	DB	GT
15	H-13	G-39	P-36	DB	GT
15	H-13	Spacer	N/A	GT	~~GT~~ NB
15	H-13	G-34	R-5-4	GT	~~GT~~ NB

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Rod	Position	Install Piece No.	From Canal Position	Completed by	Verified by
1	H-7	Spacer	N/A	JT	DB
1	H-7	B-45	P-41	DB	JT
1	H-7	Spacer	N/A	DB	JT
1	H-7	B-36	R-5-1	JT	DB
10	I-9	Spacer	N/A	DB	JT
10	I-9	B-47	P-42	DB	JT
10	I-9	Spacer	N/A	DB	JT
10	I-9	B-41	R-5-3	DB	JT
2	K-9	Spacer	N/A	WFZ	JBK
2	K-9	B-44	O-4-3	WFZ	JBK
2 NA	K-9 NA	Spacer NA	N/A	[illegible]	[illegible]
2 NA	K-9 NA	G-34 NA	R-5-4 NA	[illegible]	[illegible]
11	M-9	Spacer	N/A	DB	JT
11	M-9	B-50	P-44	DB	JT
11	M-9	Spacer	N/A	DB	JT
11	M-9	G-36	R-5-5	JT	DB
9	G-9	Spacer	N/A	JT	DB
9	G-9	G-42	P-45	JT	DB
9	G-9	Spacer	N/A	JT	DB
9	G-9	G-32	X-1-1	JT	DB
13	I-11	Spacer	N/A	JT	DB
13	I-11	B-46	P-46	JT	DB
13	I-11	Spacer	N/A	JT	DB
13	I-11	G-40	X-1-2	JT	DB
4	M-11	Spacer	N/A	WFZ	JBK
4	M-11	B-48	P 5.1	WFZ	JBK
4	M-11	Spacer	N/A	WFZ	JBK
4	M-11	G-37	X-2-2	WFZ	JBK

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Rod	Position	Install Piece No.	From Canal Position	Completed by	Completed by
7	J-7	Spacer	N/A	WFZ	DGK
7	J-7	B-49	P5. 2	WFZ	DGK
7	J-7	Spacer	N/A	WFZ	DGK
7	J-7	G-47	P-5-3	WFZ	DGK
16	K-13	Spacer	N/A	GT	NB
16	K-13	Shock	R-6-6	GT	NB
5	H-5	Spacer	N/A	WFZ	DGK
5	H-5	G-45	P-5-4	WFZ	DGK

Verify all guide tube covers in place.

Plant inactivation information concerning the usable control rod components stored in the guide tubes.

G-46	bad rollers	(2 top, 1 bottom)
G-31	bad rollers	
G-34	bad rollers	
G-35	broken latch	
G-36	bad rollers	
G-37	bad	
G-40	bad	

Shock section from R-6-6 stored in J-7 has a bad roller.

Discharge the L-8 CFP cover plate and install the SLSF TOP mock up in the L-8 position.

Completed by ____________

Core inspected and cleaned of any extraneous material. Upper tank surfaces, flow distributor, etc., inspected and cleaned of foreign material.

Completed by LD Brooks

Vacuum the reactor core, reflector and all horizontal surfaces, as directed by the plant controller.

Completed by LD Brooks

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Visually check that experiment lead tubes are clamped.

Completed by [signature]

Guide tube arms down and latched.

Completed by [signature] 2-12-82

Notify the ETR Plant Schedules Controller to have photographs taken of the core area.

Photography completed by R.E. [signature]

Note: All usable SFR's, "X" baskets "S" baskets. Al slugs and SS slugs will be stored in tank on top of tha core in a vertical position between the hold down frames. The storage areas will be identified by "NSA" for between north short arms, "SSA" for between south short arms and "BLA' for between long arms.

Perform the following canal/reactor transfers:

Piece Identification	From Canal Position	To Tank Position	Completed by	Verified by
X-322/SS-322	S-1-3	NA	—	—
X-71/SS-71	S-1-8	NA	—	—
X-362/empty	S-2-2	NSA	[initials]	[initials]
X-66/SS-66	S-2-3	NA	—	—
X-178/SS-178	S-2-4	NA	—	—
X-263/SS-263	S-2-5	NA	—	—
X-65/SS-65	S-2-6	NA	—	—
~~X=~~ A piece liner	S-2-7	NA	—	—
X-257/SS-257	S-3-2	NA	—	—
X-355/SS-355	S-3-3	NA	—	—
X-332/SS-332	S-3-4	NA	—	—
X-328/SS-328	S-3-5	NA	—	—
X-330/SS-330	S-3-6	NA	—	—
X-67/SS-67	S-4-1	NA	—	—
X-359/empty	S-4-2	NSA	[initials]	[initials]
X-331/SS-331	S-4-3	NA	—	—
Special SFR	S-4-5	NSA	[initials]	[initials]

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Piece Identification	From Canal Position	To Tank Position	Completed by	Verified by
Special SFR (no flow hole)	S-4-9	NSA	DS	WS
X-370/empty	S-5-1	NSA	DS	WS
X-357/empty	S-5-2	NSA	DS	WS
X-360/empty	S-5-3	NSA	DS	WS
X-361/SS-361	S-5-4	NA	—	—
X-369/empty	S-5-6	NSA	DS	WS
X-368/empty	S-5-7	NSA	DS	WS
X-367/empty	S-5-9	NSA	DS	WS
X-336/~~empty~~ SS	S-6-1	NA	—	—
X-358/empty	S-6-2	NSA	DS	WS
Special SFR (No flow hole)	S-6-3	NSA	DS	WS
X-363/SS-363	S-6-4	NA	—	—
X-366/SS-366	S-6-9	NA	—	—
X-365/SS-365	S-7-7	NA	—	—
X-364/SS-364	S-7-8	NA	—	—
X-259/SS-259	S-7-9	NA	—	—
S-25/~~empty~~ damaged	T-1-1	NA	—	—
X-333/SS-333	T-1-8	NA	—	—
Special SFR (slit, section insert)	T-2-7	NSA	DS	WS
X-350/1x2 Al	T-4-6	SSA	DMH	[illegible]
X-353/1x2 Al	T-4-7	SSA	DMH	[illegible]
X-354/1x2 Al	T-5-5	SSA	DMH	[illegible]
X-349/1x2 Al	T-5-6	SSA	DMH	[illegible]
X-351/1x2 Al	T-5-8	SSA	DMH	[illegible]

Transfer the SFR's from the "R" grid to the reactor tank and store vertically between the hold down frames. There are approximately 16 SFR's in the "R" grid.

Completed by [signature]

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Transfer the SFR's from the "Z" grid to the reactor tank and store vertically between the hold down frames. There are approximately 42 SFR's in the "Z" grid.

Completed by [signature]

Transfer the SFR's from the "S" grid to the reactor tank and store vertically between the hold down frames. There are approximately 15 SFR's in the "S" grid.

Completed by [signature]

Transfer the SFR's from the "T" grid to the reactor tank and store vertically between the hold down frames. There are approximately 46 SFR's in the "T" grid.

Completed by [signature]

Note: All remaining usable core components will be stored in tank on top of the core, usually in a vertical position. To minimize handling problems and/ or component damage, piece storage areas have been designated. The south-east quadrant (designated TSE) will be used for the IPL filler pieces and SLSF hydraulic mock ups. The northeast quadrant (designated TNE) will be used for grid adapter pieces and shock section tail pieces. The northwest and southwest quadrants (designated TNW and TSW respectively) will be used for the remaining components. Storage area locations may be changed with approval of the plant scheduler controller.

Note: Use extreme care while handling the following core components to minimize damage.

Perform the following canal/reactor transfers:

Piece Identification	From Canal Position	To Tank Position	Completed by	Verified by
*SLSF FMM filler piece	Inspection Tray	TNW	[signature]	[signature]
M-7 filler piece	Working Canal	TNW	[signature]	[signature]
Remaining filler piece	Working Canal	TNW	[signature]	[signature]
**SLSF SPND Hydraulic mock up	Working Canal Floor	TNW	[signature]	[signature]

**Store SLSF SPND Hydraulic Mock up inside M-7 filler piece.
*Store vertically with tail pieces up.

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Note: Grid adapter pieces shall be handled only with grid adapter handling tools, or properly secured ropes [illegible]

Piece Identification	From Canal Position	To Tank Position	Completed by	Verified by
***SLSF FMM Hydraulic Mockup	Working Canal Mockup Stand	TNW	[illegible]	[illegible]
grid adapter (3x3)	Working Canal	NE	WFZ	[illegible]
grid adapter (3x6)	Working Canal	NE	[illegible]	[illegible]
grid adapter (3x6)	Working Canal	NE	[illegible]	[illegible]
grid adapter (6x6)	Working Canal	SE	[illegible]	[illegible]
grid adapter (6x6)	Working Canal	E	[illegible]	[illegible]
grid adapter (6x6)	Working Canal	E	[illegible]	[illegible]
grid adapter (6x9) (small holes)	Working Canal	SE	WFZ	DEK
grid adapter (6x9) (small holes)	Working Canal	SE	WFZ	DEK
grid adapter (6x9) (6" hole)	Working Canal	NE	[illegible]	DEK
grid adapter (6x9) (5" hole)	Working Canal	NE	[illegible]	DEK
grid adapter (3x9)	Working Canal	NE	[illegible]	[illegible]
grid adapter (3x9)	Working Canal	NE	[illegible]	[illegible]
grid adapter (9x9) (small holes)	Working Canal	NE	[illegible]	DEK
grid adapter (9x9) (SLSF FMM)	Working Canal	NE	[illegible]	[illegible]
shock receiver tail piece	Bucket #30	~~NE~~ NW	[illegible]	[illegible]
shock receiver tail piece	Bucket #39	~~NE~~ [illegible]	[illegible]	[illegible]
shock receiver tail piece	Bucket #39	~~NE~~ NW	[illegible]	[illegible]
C-4x-9/4SFR	~~R-1-7~~ R-2-[illegible]	TNW	[illegible]	[illegible]

***Store SLSF FMM Hydraulic Mockup inside the remaining filler piece.

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Piece Identification	From Canal Position	To Tank Position	Completed by	Verified by
two hole/2SFR R-2W-1	R-1-4	TNW	[signature]	[signature]
C-4X-124/4SFR	P-2-5	TNW	[signature]	[signature]
C-4x-22/4SFR	P-2-6	TNW	[signature]	[signature]
C-4x-15/4SFR	R-2-3	* TNW	[signature]	[signature]
one hole/empty	R-6-12	TNW	[signature]	[signature]
R4x-64/4SFR	P-1-3	TNW	[signature]	[signature]
C-4x-126/4SFR	P-1-6	TNW	[signature]	[signature]
C-4X-116/4SFR	P-1-1	TNW	[signature]	[signature]
R-4x-29/4SFR	P-2-1	TNW	[signature]	[signature]
C-4x-110(4SFR) [illegible]	P-1-4	TNW	[signature]	[signature]
C-4x-107/4SFR	P-1-2	TNW	[signature]	[signature]
C-4x-23/4SFR	P-1-5	TNW	[signature]	[signature]
R-4x-50/4SFR	P-2-2	TNW	[signature]	[signature]
C-4x-122/4SFR	P-2-3	TNW	[signature]	[signature]
A piece, No pin	R-4-12	TNW	[signature]	[signature]

Plant Inactivation information concerning the usable core components stored in tank.

C-4x-22	has special lifting bail
C-4x-116	has special lifting pin
R-4x-29	lifting pin missing - needs to be retapped
C-4x-110	broken lifting pin - needs drilled & tapped
C-4x-122	special lifting pin
C-4x-9	2 plugged FM holes

Notify the ETR Plant Scheduler Controller to have photographs taken of the core area.

Completed by [signature] 2-16-82

Install the discharge chute cover.

Completed by [signature] 2.17.82 [signature]