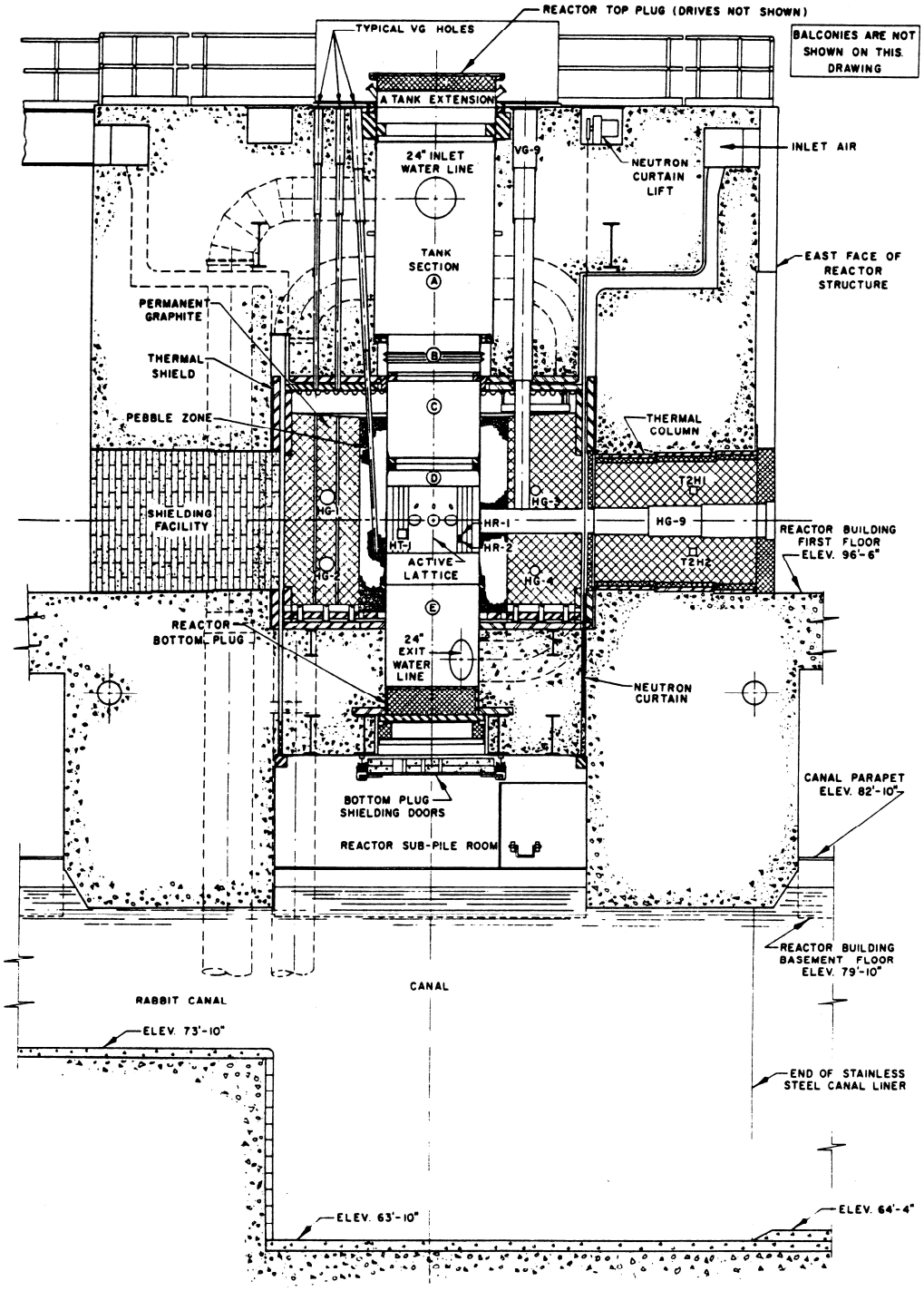

Figure 7. Vertical section of MTR from the south at the core center (note tank sections A through E that comprise the reactor vessel).

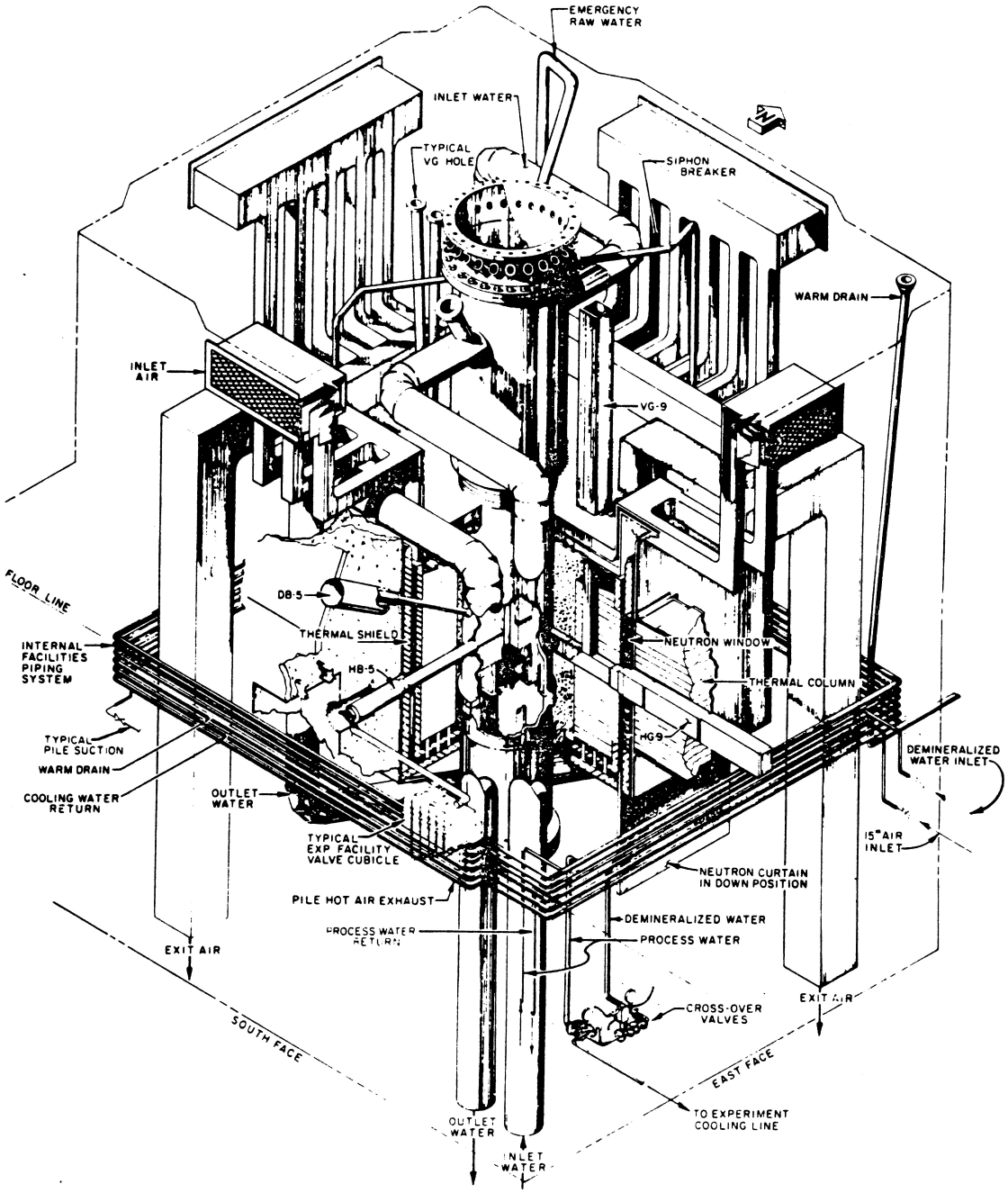

Figure 8. Cutaway view of the MTR structure revealing some of the ducts and piping

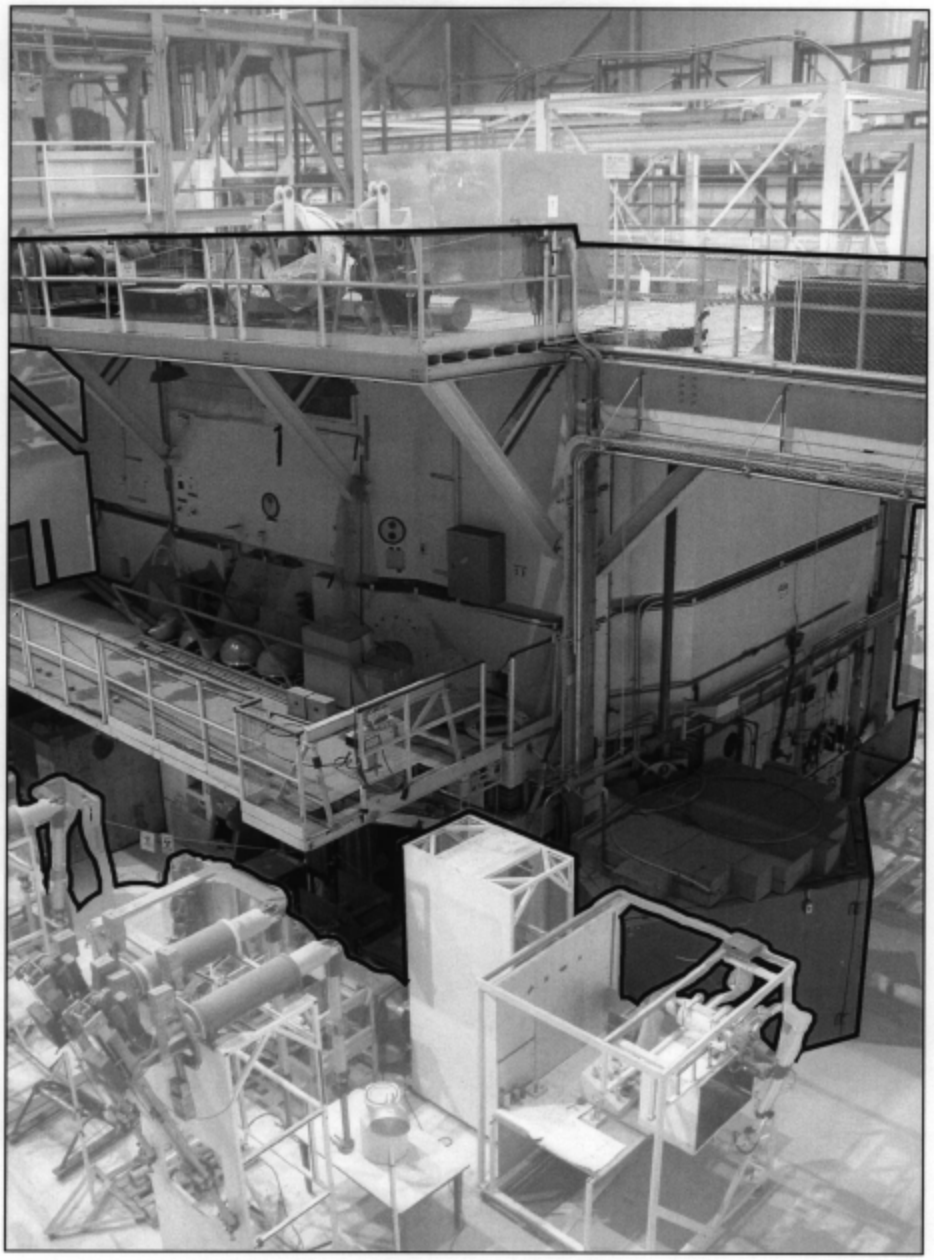

Figure 9. More recent view of the MTR from the northwest. The solid-walled rectangular structure on top is an aluminum housing that covers the top head of the reactor vessel.

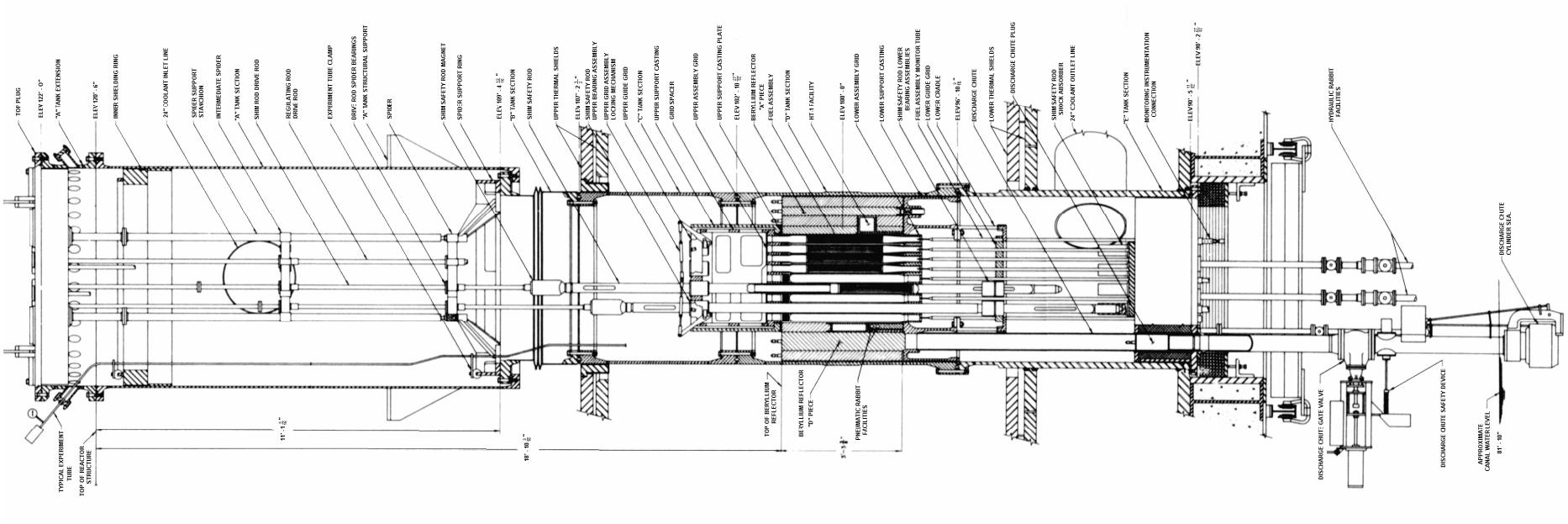

Figure 10. Details of MTR core tank structures.

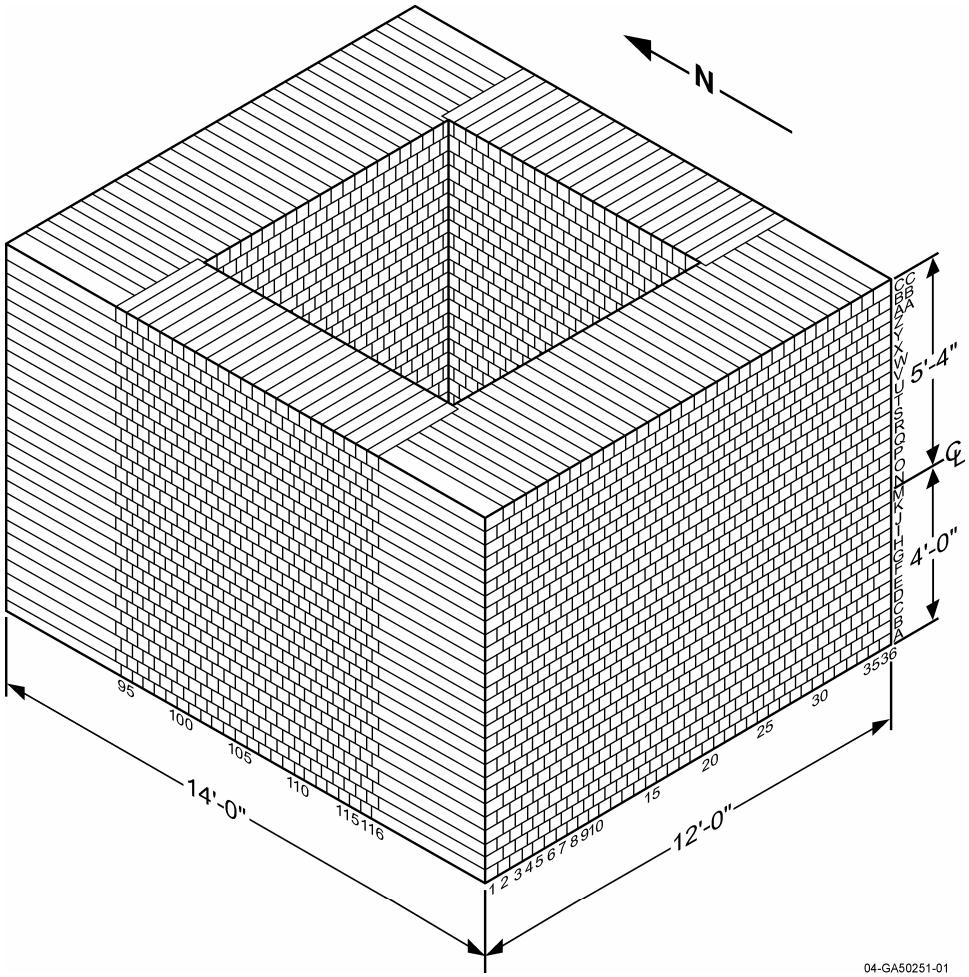

Figure 11. Arrangement of graphite blocks in the sold reflector in MTR.

Buildings

Buildings associated with the MTR complex which are scheduled for D&D include the following: TRA-603, TRA-604, TRA-610, TRA-626, TRA-630, TRA-635, TRA-654, TRA-657, TRA-661, TRA-665, TRA-668, TRA-709, TRA-710, TRA-730, & TRA-784. A brief description of each of these building is given below and is taken from Reference 1.

- TRA-603: Reactor building designed to enclose the reactor structure, canal, and to provide space for experimental facilities (both on the main floor and in the basement). The second and third floors of this building contained the control room, electrical equipment room, and office areas.
- TRA-604: Laboratory facility located to the west of the reactor building.
- TRA-610: Fan House located near the MTR stack which housed the blowers used to circulate air through the MTR and other facilities.
- TRA-626: Compressor Building located on the northeast corner of the reactor building.
- TRA-630: Catch Tank Pump Pit located to the south of building TRA-604. The pit contains pumps valves and piping associated with the TRA-730 hot waste catch tanks.
- TRA-635: Reactor Service Building located to the south of the reactor building. This building was used for warehousing and storage, quality inspections, and x-ray operations.
- TRA-654: ETRC building that was used to house the Engineering Test Reactor (ETR) Critical Facility.
- TRA-657: The Plug Storage Facility used to store the reactor beam port plugs and other radioactive materials.
- TRA-661: The radiochemical laboratory facility.
- TRA-665: Twenty-Meter Neutron Chopper House located on the east corner of the reactor building.
- TRA-668: Physics laboratory facility and clean room.
- TRA-709: Air intake shaft for the MTR reactor building.
- TRA-710: MTR exhaust stack and monitor building.
- TRA-730: Underground vault containing four hot waste catch tanks.
- TRA-784: Liquid nitrogen tank.

Source Term Information

The activity values used for the reactor and each building were determined as presented in the following Appendices:

- Appendix A – Activated materials in the reactor;
- Appendix B – Air contaminated surfaces associated with the reactor;
- Appendix C – Water contaminated surfaces associated with the reactor;
- Appendix D – Building contaminated surfaces.
- Appendix E – TRA-730 vault surfaces and tanks

TRA-603:

1. Reactor

    - **Activity Source:** Activated materials, air contaminated surfaces and water contaminated surfaces.
    - **Location Relative to Grade:** The locations of the reactor internal components, relative to grade, are approximated based on the information contained in Figure 7.
    - **Activity Distribution:** All of the reactor activity due to activation (with the exception of the "E" tank) is assigned to the above grade location based on the locations of the reactor components. The "E" tank is 6.38 ft tall with the top of the tank located at approximately the grade level. The percentage of the tank activity assigned to the 0 – 3 ft below location is based on the fraction of the volume of the tank existing in this location (47% of the total tank activity is assigned to the 0 – 3 ft region). All of the tank activity is included in the 0 – 10 ft below grade and the below grade locations.

2. Building Surfaces

    - **Activity Source:** Contaminated surface of the building including: the reactor top; the Sub-pile room; the Hot Waste Tank Pit; the Process Sump Pit; the Canal Sump Pit; Primary Pipe Tunnel.
    - **Location Relative to Grade:** The locations, relative to grade level, for the contaminated surfaces are taken from drawing 100005, *Reactor Bldg. Area 2 Transverse Section.*
    - **Activity Distribution:** Of the contaminated surfaces identified in this building, only the reactor top exists in the above grade location. All of the activity due to contamination on the reactor top is assigned to this location. All other contaminated surfaces are located at a depth deeper than 10 ft below grade.

3. Contaminated Piping

    - **Activity Source:** Contamination on the interior surfaces of piping and ductwork.
    - **Location Relative to Grade:** Information concerning locations relative to grade for the various piping systems were approximated based on the information in Figure 7 and drawing 100005, *Reactor Bldg. Area 2 Transverse Section.*
    - **Activity Distribution:** Of the contaminated water exposed surfaces, the majority exists in the above grade location. Only the bottom plug, E-tank, a section of the primary coolant outlet, and discharge chute contaminated surfaces are below grade. The area of these below grade surfaces is estimated to be 37.6 m^2 of which 6 m^2 are

estimated to be in the 0 – 3 ft below grade region and 37.6 m^2 are estimated to exist in the 0 – 10' below grade region. The majority of the contaminated air exposed surfaces are also above grade. The graphite reflector extends 6 in. below grade level and contaminated channels are located directly below the graphite reflector. An estimated 210.7 m^2 of air contaminated surface exists below grade level in the 0 – 3 ft below grade region. The activity on these surfaces is also included in the 0-10 ft and below grade regions.

TRA-604

1. Building Surfaces

   TRA-604 is currently in use with no known inventories of surface contamination. TRA-604 is not posted as either a Contamination Area or a Radiological Buffer Area for contamination control purposes. A review of contamination survey results for this building confirms that there is no detectable contamination on building surfaces.

2. Piping
   - **Activity Source:** One contaminated pipe exists in the overhead of the basement of TRA-604..
   - **Activity Distribution:** This pipe is located less than 3 ft below grade level. Activity in this pipe is included in the 0 – 3 ft, 0 – 10 ft, and below grade activity determinations.

TRA-610

1. Building Surfaces

   - **Activity Source:** Building surface contamination.
   - **Location Relative to Grade:** The locations, relative to grade level, for the various contaminated surfaces are taken from drawing 100020, *Fan House & Stack Layout Plan & Sections.*
   - **Activity Distribution:** All the activity in this building is located above grade level.

TRA-626

TRA-626 is not posted as either a Contamination Area or a Radiological Buffer Area for contamination control purposes.

TRA-630

- **Activity Source:** Surface contamination.
- **Location Relative to Grade:** Location relative to grade for TRA-630 is taken from drawing 100023, *Effluent Control, Area 13, Layout Plan & Sections.*
- **Activity Distribution:** This underground vault is located entirely within the 0 – 10 ft below grade region. Of the estimated total contaminated surface area of 152.2 m^2 for this building, approximately 50 m^2 is in the 0 – 3 ft below grade region, thus, 33% of the activity is assigned to the 0 – 3 ft below grade region. The hot spots located in TRA-630 are at a location deeper than 3 ft below grade level thus, the activity due to the hot spots is included in the 0 – 10 ft and below grade source terms.

TRA-635

- **Activity Source:** The only contaminated area associated with this building is the air duct pit under the north end of the building.
- **Location Relative to Grade:** Location relative to grade for TRA-635 contamination is taken from the description of the pit in Reference 1, Section 4.4.1.
- **Activity Distribution:** Contaminated surfaces and air ducts are located deeper than 10 ft below grade.

TRA-654

- **Activity Source:** Contaminated surfaces.
- **Location Relative to Grade:** Location relative to grade for TRA-654 is taken from drawing 101865, *Critical Facility Building Ground Floor Plan.*
- **Activity Distribution:** Contaminated surfaces are all located above grade level.

TRA-657

- **Activity Source:** Surface contamination on the plug storage tube surfaces.
- **Location Relative to Grade:** Location relative to grade for TRA-657 is taken from drawing 101875, *MTR Plug Storage facility.*
- **Activity Distribution:** Contaminated surfaces are all located above grade level.

TRA-661

TRA-661 is identified as a Radiological Buffer Area with Contamination Areas established on several bench tops and fume hoods. The bench tops and fume hoods will be removed prior to demolition and a review of the contamination surveys performed in the building confirms that building surfaces contain no detectable contamination.

TRA-665

The Twenty-Meter Neutron Chopper House held three small radioactive sources in 1984, but no other radioactivity levels above background were detected. Therefore, no source term calculations were performed for TRA-665.

TRA-668

The building is not posted for contamination control purposes and a review of the contamination surveys performed in the building confirms that building surfaces contain no detectable contamination.

TRA-709

TRA-709 is not posted for radiological control purposes. While no characterization data for TRA-709 could be readily located, it is assumed that the building surfaces contain no levels of contamination that would significantly contribute to the source term.

TRA-710

- **Activity Source:** Surface contamination.
- **Location Relative to Grade:** Location relative to grade for TRA-710 is taken from drawing 150645, *Arrgt. Of Stack Piping & Piping Details.*
- **Activity Distribution:** Contaminated surfaces of the MTR stack are located above grade level.

TRA-730

Vault Surfaces

- **Activity Source:** Surface contamination
- **Locations Relative to grade and surface areas:** Location relative to grade and surface areas are determined based on the information provided on drawing 165932, *TRA Catch Tank Upgrade, Tank Vault Details.*
- **Activity Distribution:** The total contaminated surface area of this room is approximately 190 m^2 and is all located deeper than 3 ft below grade. An estimated 95 m^2 of this contaminated surface exists in the 0 – 10 ft below grade region.

1. Catch Tanks

- **Activity Source:** Scale ring around the inside of the tank corresponding to the water level in the tank prior to draining.
- **Locations Relative to grade and tank dimensions:** Location of the tanks relative to grade level are taken from drawing number 165932, *TRA Catch Tank Upgrade, Tank Vault Details.* Tank dimensions were taken from drawing 165758, *TRA Catch Tanks Upgrade, Tank Elevation and Details.*
- **Activity Distribution:** All activity in the tanks is all estimated to be deeper than 10 ft below grade level.

TRA-784

No characterization data for TRA-784 could be readily located. The tank is not posted for either internal or external contamination. It is assumed that TRA-784 does not provide a significant contribution to the total MTR source term.

Results

Table 2. Summary of All MTR Above Grade Activity by Building and Nuclide

Location	Source	Ac-227 (Ci)	Ag-108m (Ci)	Ag-110m (Ci)	Am-241 (Ci)	Am-243 (Ci)	Be-10 (Ci)	C-14 (Ci)	Ce-144 (Ci)	Cl-36 (Ci)	CM-243 (Ci)
Reactor Building (TRA-603)	Reactor (Activation)	4.67E-07	1.60E-01	4.78E-15	7.45E-02	6.61E-05	5.59E-02	3.19E+00	1.67E-13	3.11E-02	4.64E-05
	Reactor Air Surfaces							2.40E-03			
	Reactor Water Surfaces							8.18E-03			
	Reactor Top External Contamination				2.37E-04			6.83E-05			
TRA-610	Surfaces				4.83E-06			2.84E-06			
	Duct & Fan Hotspots				3.94E-05			1.14E-05			
TRA-654	Surfaces				3.12E-04			1.84E-04			
TRA-657	Plug Storage Tubes				2.49E-04			1.47E-04			
TRA-710	Stack Surfaces							1.09E-03			
	Total =	4.67E-07	1.60E-01	4.78E-15	7.53E-02	6.61E-05	5.59E-02	3.20E+00	1.67E-13	3.11E-02	4.64E-05

		CM-244 (Ci)	CM-245 (Ci)	CM-246 (Ci)	CM-247 (Ci)	CM-248 (Ci)	Co-60 (Ci)	Cs-134 (Ci)	Cs-137 (Ci)	Eu-152 (Ci)	Eu-154 (Ci)
Reactor Building (TRA-603)	Reactor (Activation)	1.23E-03	1.77E-07	3.10E-08	3.99E-14	4.81E-14	5.23E+01	1.21E-03	4.48E-01	5.63E+00	1.02E+00
	Reactor Air Surfaces						2.33E-02		3.01E-03		
	Reactor Water Surfaces						1.01E-01		3.05E-02		
	Reactor Top External Contamination						6.46E-04		2.22E-02		
TRA-610	Surfaces						3.50E-05				
	Duct & Fan Hotspots						1.08E-04		3.69E-03		
TRA-654	Surfaces						2.26E-03				
TRA-657	Plug Storage Tubes						1.80E-03				
TRA-710	Stack Surfaces						1.63E-03				
	Total =	1.23E-03	1.77E-07	3.10E-08	3.99E-14	4.81E-14	5.25E+01	1.21E-03	5.08E-01	5.63E+00	1.02E+00

Table 2. Continued

		H-3 (Ci)	I-129 (Ci)	Mn-54 (Ci)	Nb-94 (Ci)	Ni-59 (Ci)	Ni-63 (Ci)	Np-237 (Ci)	Pa-231 (Ci)	Pb-210 (Ci)	Pu-238 (Ci)
Reactor Building (TRA-603)	Reactor (Activation)	2.22E+02	7.48E-07	1.85E-10	5.16E-02	3.89E+00	4.05E+02	1.03E-06	6.26E-07	1.88E-10	1.73E-02
	Reactor Air Surfaces		3.94E-07				1.02E-03				
	Reactor Water Surfaces		3.84E-06				3.54E-03				
	Reactor Top External Contamination		2.91E-06				2.92E-05				5.49E-05
TRA-610	Surfaces		1.21E-07				1.23E-06				1.12E-06
	Duct & Fan Hotspots		4.85E-07				4.86E-06				9.14E-06
TRA-654	Surfaces		7.81E-06				7.95E-05				7.25E-05
TRA-657	Plug Storage Tubes		6.24E-06				6.34E-05				5.79E-05
TRA-710	Stack Surfaces						2.03E-03				
	Total =	2.22E+02	2.25E-05	1.85E-10	5.16E-02	3.89E+00	4.05E+02	1.03E-06	6.26E-07	1.88E-10	1.75E-02

		Pu-239 (Ci)	Pu-240 (Ci)	Pu-241 (Ci)	Pu-242 (Ci)	Pu-244 (Ci)	Ra-226 (Ci)	Ru-106 (Ci)	Sb-125 (Ci)	Sr-90 (Ci)	Tc-99 (Ci)
Reactor Building (TRA-603)	Reactor (Activation)	3.79E-02	1.40E-02	4.12E-01	2.08E-05	3.76E-13	5.06E-10	9.57E-11	3.08E-04	1.95E-01	3.55E-03
	Reactor Air Surfaces									2.07E-04	
	Reactor Water Surfaces									2.10E-03	
	Reactor Top External Contamination	1.21E-04	4.45E-05							1.52E-03	
TRA-610	Surfaces	2.47E-06	9.08E-07							6.64E-05	
	Duct & Fan Hotspots	2.01E-05	7.40E-06							2.54E-04	
TRA-654	Surfaces	1.59E-04	5.87E-05							4.29E-03	
TRA-657	Plug Storage Tubes	1.27E-04	4.68E-05							3.42E-03	
TRA-710	Stack Surfaces									6.06E-04	
	Total =	3.83E-02	1.42E-02	4.12E-01	2.08E-05	3.76E-13	5.06E-10	9.57E-11	3.08E-04	2.07E-01	3.55E-03

Table 2 (Continued)

		Th-228 (Ci)	Th-229 (Ci)	Th-230 (Ci)	Th-232 (Ci)	U-232 (Ci)	U-233 (Ci)	U-234 (Ci)	U-235 (Ci)	U-236 (Ci)	U-238 (Ci)	Zn-65 (Ci)	**Total Activity (Ci)**
Reactor Building (TRA-603)	Reactor (Activation)	4.53E-05	6.98E-07	4.69E-08	3.29E-05	1.22E-05	1.71E-04	1.07E-04	4.54E-06	9.76E-07	1.03E-04	3.51E-14	6.94E+02
	Reactor Air Surfaces												2.12E-03
	Reactor Water Surfaces												1.45E-01
	Reactor Top External Contamination												2.49E-02
TRA-610	Surfaces												1.15E-04
	Duct & Fan Hotspots												4.14E-03
TRA-654	Surfaces												7.42E-03
TRA-657	Plug Storage Tubes												5.92E-03
TRA-710	Stack Surfaces												5.36E-03
	Total =	4.53E-05	6.98E-07	4.69E-08	3.29E-05	1.22E-05	1.71E-04	1.07E-04	4.54E-06	9.76E-07	1.03E-04	3.51E-14	6.94E+02

Table 3. Summary of All MTR 0 – 3 ft below Grade Activity by Building and Nuclide

		Ac-227 (Ci)	Ag-108m (Ci)	Ag-110m (Ci)	Am-241 (Ci)	Am-243 (Ci)	Be-10 (Ci)	C-14 (Ci)	Ce-144 (Ci)	Cl-36 (Ci)	Cm-243 (Ci)	Cm-244 (Ci)
Reactor Building (TRA-603)	Reactor (Activation)	6.21E-09	5.60E-04	1.02E-17	8.46E-08	6.02E-15	1.11E-08	5.36E-02	1.97E-17	4.26E-04	5.88E-15	9.26E-16
	Water Contaminated Surfaces							2.70E-04				
	Air Contaminated Surfaces							1.70E-04				
TRA-604	Hot Waste Line				8.91E-06			5.24E-06				
TRA-630	Surfaces				3.27E-05			1.92E-05				
	Total =	6.21E-09	5.60E-04	1.02E-17	4.17E-05	6.02E-15	1.11E-08	5.41E-02	1.97E-17	4.26E-04	5.88E-15	9.26E-16

		Cm-245 (Ci)	Cm-246 (Ci)	Cm-247 (Ci)	Cm-248 (Ci)	Co-60 (Ci)	Cs-134 (Ci)	Cs-137 (Ci)	Eu-152 (Ci)	Eu-154 (Ci)	H-3 (Ci)	I-129 (Ci)
Reactor Building (TRA-603)	Reactor (Activation)	1.75E-21	2.50E-24	2.87E-32	2.98E-34	3.79E+00	3.37E-07	1.44E-04	7.85E-03	3.94E-04	4.54E-02	1.03E-10
	Water Contaminated Surfaces					3.32E-03		1.01E-03				1.27E-07
	Air Contaminated Surfaces					1.65E-03		2.13E-04				2.79E-08
TRA-604	Hot Waste Line					6.44E-05						2.23E-07
TRA-630	Surfaces					2.37E-04						8.19E-07
	Total =	1.75E-21	2.50E-24	2.87E-32	2.98E-34	3.80E+00	3.37E-07	1.36E-03	7.85E-03	3.94E-04	4.54E-02	1.20E-06

Table 3 (Continued)

		Mn-54 (Ci)	Nb-94 (Ci)	Ni-59 (Ci)	Ni-63 (Ci)	Np-237 (Ci)	Pa-231 (Ci)	Pb-210 (Ci)	Pu-238 (Ci)	Pu-239 (Ci)	Pu240 (Ci)	Pu-241 (Ci)
Reactor Building (TRA-603)	Reactor (Activation)	1.02E-11	7.29E-04	3.00E-01	3.03E+01	2.49E-10	8.23E-09	1.13E-12	1.10E-08	6.39E-05	9.17E-07	4.67E-07
	Water Contaminated Surfaces				1.17E-04							
	Air Contaminated Surfaces				7.26E-05							
TRA-604	Hot Waste Line				2.27E-06				2.07E-06	4.55E-06	1.67E-06	
TRA-630	Surfaces				8.32E-06				7.60E-06	1.67E-05	6.15E-06	
	Total =	1.02E-11	7.29E-04	3.00E-01	3.03E+01	2.49E-10	8.23E-09	1.13E-12	9.68E-06	8.52E-05	8.74E-06	4.67E-07

		Pu-242 (Ci)	Pu-244 (Ci)	Ra-226 (Ci)	Ru-106 (Ci)	Sb-125 (Ci)	Sr-90 (Ci)	Tc-99 (Ci)	Th-228 (Ci)	Th-229 (Ci)	Th-230 (Ci)	Th-232 (Ci)
Reactor Building (TRA-603)	Reactor (Activation)	1.93E-13	2.73E-25	2.95E-12	4.80E-15	5.08E-06	1.26E-04	2.87E-05	9.31E-08	9.97E-09	2.57E-10	8.65E-08
	Water Contaminated Surfaces						6.93E-05					
	Air Contaminated Surfaces						1.47E-05					
TRA-604	Hot Waste Line						1.22E-04					
TRA-630	Surfaces						4.51E-04					
	Total =	1.93E-13	2.73E-25	2.95E-12	4.80E-15	5.08E-06	7.83E-04	2.87E-05	9.31E-08	9.97E-09	2.57E-10	8.65E-08

		U-232 (Ci)	U-233 (Ci)	U-234 (Ci)	U-235 (Ci)	U-236 (Ci)	U-238 (Ci)	Zn-65 (Ci)	**Total Activity (Ci)**
Reactor Building (TRA-603)	Reactor (Activation)	6.77E-09	2.41E-06	5.31E-07	2.39E-08	1.35E-09	5.27E-07	1.65E-17	3.48E+01
	Water Contaminated Surfaces								4.78E-03
	Air Contaminated Surfaces								2.12E-03
TRA-604	Hot Waste Line								2.11E-04
TRA-630	Surfaces								8.29E-02
	Total =	6.77E-09	2.41E-06	5.31E-07	2.39E-08	1.35E-09	5.27E-07	1.65E-17	3.48E+01

Table 4. Summary of All MTR 0 – 10 ft Below Grade Activity by Building and Nuclide.

		Ac-227 (Ci)	Ag-108m (Ci)	Ag-110m (Ci)	Am-241 (Ci)	Am-243 (Ci)	Be-10 (Ci)	C-14 (Ci)	Ce-144 (Ci)	Cf-252 (Ci)	Cl-36 (Ci)	Cm-242 (Ci)
Reactor Building (TRA-603)	Reactor (Activation)	1.32E-08	1.19E-03	2.16E-17	1.80E-07	1.28E-14	2.35E-08	1.14E-01	4.19E-17	9.06E-04	1.25E-14	
	Water Contaminated Surfaces							1.69E-03				
	Air Contaminated Surfaces							1.70E-04				
TRA-604	Pipe				8.91E-06			5.24E-06				
TRA-630	Surfaces				9.95E-05			5.85E-05				
	Hot Spots				1.22E-04			3.54E-05				
TRA-730	Vaults				1.45E-04							4.89E-07
	Total =	1.32E-08	1.19E-03	2.16E-17	3.76E-04	1.28E-14	2.35E-08	1.16E-01	4.19E-17	9.06E-04	1.25E-14	4.89E-07

		Cm-243 (Ci)	Cm-244 (Ci)	Cm-245 (Ci)	Cm-246 (Ci)	Cm-247 (Ci)	Cm-248 (Ci)	Co-60 (Ci)	Cs-134 (Ci)	Cs-137 (Ci)	Eu-152 (Ci)	Eu-154 (Ci)
Reactor Building (TRA-603)	Reactor (Activation)	1.25E-14	1.97E-15	3.72E-21	5.31E-24	6.10E-32	6.33E-34	8.06E+00	7.17E-07	3.07E-04	1.67E-02	8.38E-04
	Water Contaminated Surfaces							2.08E-02		6.30E-03		
	Air Contaminated Surfaces							1.65E-03		2.13E-04		
TRA-604	Pipe							6.44E-05				
TRA-630	Surfaces							7.20E-04				
	Hot Spots							3.36E-04		1.15E-02		
TRA-730	Vaults		9.61E-06					8.77E-05	8.44E-07	1.78E-03	1.55E-05	3.00E-05
	Total =	1.25E-14	9.61E-06	3.72E-21	5.31E-24	6.10E-32	6.33E-34	8.08E+00	1.56E-06	2.01E-02	1.67E-02	8.68E-04

		Eu-155 (Ci)	Fe-55 (Ci)	H-3 (Ci)	I-129 (Ci)	Mn-54 (Ci)	Nb-94 (Ci)	Nb-95 (Ci)	Ni-59 (Ci)	Ni-63 (Ci)	Np-237 (Ci)	Pa-231 (Ci)
Reactor Building (TRA-603)	Reactor (Activation)			9.65E-02	2.18E-10	2.17E-11	1.55E-03		6.38E-01	6.45E+01	5.30E-10	1.75E-08
	Water Contaminated Surfaces				7.94E-07					7.32E-04		
	Air Contaminated Surfaces				2.79E-08					7.26E-05		
TRA-604	Pipe				2.23E-07					2.27E-06		
TRA-630	Surfaces				2.49E-06					2.53E-05		
	Hot Spots				1.51E-06					1.51E-05		
TRA-730	Vaults	6.17E-06	3.01E-06						3.01E-07	1.90E-04		
	Total =	6.17E-06	3.01E-06	9.65E-02	5.04E-06	2.17E-11	1.55E-03		6.38E-01	6.45E+01	5.30E-10	1.75E-08

Table 4 (Continued)

		Pb-210 (Ci)	Pu-238 (Ci)	Pu-239 (Ci)	Pu-240 (Ci)	Pu-241 (Ci)	Pu-242 (Ci)	Pu-244 (Ci)	Ra-226 (Ci)	Ru-106 (Ci)	Sb-125 (Ci)	Sr-90 (Ci)
Reactor Building (TRA-603)	Reactor (Activation)	2.40E-12	2.33E-08	1.36E-04	1.95E-06	9.94E-07	4.10E-13	5.80E-25	6.27E-12	1.02E-14	1.08E-05	2.68E-04
	Water Contaminated Surfaces											4.34E-04
	Air Contaminated Surfaces											1.47E-05
TRA-604	Pipe		2.07E-06	4.55E-06	1.67E-06							1.22E-04
TRA-630	Surfaces		2.31E-05	5.07E-05	1.87E-05							1.37E-03
	Hot Spots		2.84E-05	6.24E-05	2.30E-05							7.90E-04
TRA-730	Vaults		1.15E-04	6.84E-05	6.84E-05							2.58E-03
	Total =	2.40E-12	1.69E-04	3.22E-04	1.14E-04	9.94E-07	4.10E-13	5.80E-25	6.27E-12	1.02E-14	1.08E-05	5.58E-03

		Tc-99 (Ci)	Th-228 (Ci)	Th-229 (Ci)	Th-230 (Ci)	Th-232 (Ci)	U-232 (Ci)	U-233 (Ci)	U-234 (Ci)	U-235 (Ci)	U-236 (Ci)	U-238 (Ci)
Reactor Building (TRA-603)	Reactor (Activation)	6.11E-05	1.98E-07	2.12E-08	5.47E-10	1.84E-07	1.44E-08	5.13E-06	1.13E-06	5.09E-08	2.88E-09	1.12E-06
	Water Contaminated Surfaces											
	Air Contaminated Surfaces											
TRA-604	Pipe											
TRA-630	Surfaces											
	Hot Spots											
TRA-730	Vaults								1.20E-06			
	Total =	6.11E-05	1.98E-07	2.12E-08	5.47E-10	1.84E-07	1.44E-08	5.13E-06	2.33E-06	5.09E-08	2.88E-09	1.12E-06

		Zn-65 (Ci)	Total Activity (Ci)
Reactor Building (TRA-603)	Reactor (Activation)	3.51E-17	7.34E+01
	Water Contaminated Surfaces		3.00E-02
	Air Contaminated Surfaces		2.12E-03
TRA-604	Pipe		2.11E-04
TRA-630	Surfaces		2.37E-03
	Hot Spots		1.29E-02
TRA-730	Vaults		5.10E-03
	Total =	3.51E-17	7.35E+01

Table 5. Summary of All MTR Below Grade Activity by Nuclide and Building.

		Ac-227 (Ci)	Ag-108m (Ci)	Ag-110m (Ci)	Am-241 (Ci)	Am-243 (Ci)	Be-10 (Ci)	C-14 (Ci)	Ce-144 (Ci)	Cf-252 (Ci)	Cl-36 (Ci)	Cm-242 (Ci)
Reactor Building (TRA-603)	Reactor (Activation)	1.32E-08	1.19E-03	2.16E-17	1.80E-07	1.28E-14	2.37E-08	1.14E-01	4.19E-17		9.06E-04	
	Water Contaminated Surfaces							1.69E-03				
	Air Contaminated Surfaces							1.70E-04				
	Surfaces				1.17E-02			6.23E-03				
TRA-604	Pipe				8.91E-06			5.24E-06				
TRA-630	Surfaces				9.95E-05			5.85E-05				
	Hot Spots				1.22E-04			3.54E-05				
TRA-635	Hot Spots & Surfaces				4.44E-03			2.60E-03				
TRA-730	Vaults				2.89E-04							9.78E-07
	Tanks				1.45E-04				5.69E-04	4.99E-06		
	Total =	1.32E-08	1.19E-03	2.16E-17	1.68E-02	1.28E-14	2.37E-08	1.25E-01	5.69E-04	4.99E-06	9.06E-04	9.78E-07

		Cm-243 (Ci)	Cm-244 (Ci)	Cm-245 (Ci)	Cm-246 (Ci)	Cm-247 (Ci)	Cm-248 (Ci)	Co-60 (Ci)	Cs-134 (Ci)	Cs-137 (Ci)	Eu-152 (Ci)	Eu-154 (Ci)
Reactor Building (TRA-603)	Reactor (Activation)	1.25E-14	1.97E-15	3.72E-21	5.31E-24	6.10E-32	6.33E-34	8.06E+00	7.17E-07	3.07E-04	1.67E-02	8.38E-04
	Water Contaminated Surfaces							2.08E-02		6.30E-03		
	Air Contaminated Surfaces							1.65E-03		2.13E-04		
	Surfaces							7.49E-02		1.96E-01		
TRA-604	Pipe							6.44E-05				
TRA-630	Surfaces							7.20E-04				
	Hot Spots							3.36E-04		1.15E-02		
TRA-635	Hot Spots & Surfaces							3.21E-02				
TRA-730	Vaults		1.92E-05					1.75E-04	1.69E-06	3.56E-03	3.09E-05	6.00E-05
	Tanks		4.31E-05					2.97E-04	1.15E-03	1.27E-02		1.46E-04
	Total =	1.25E-14	6.23E-05	3.72E-21	5.31E-24	6.10E-32	6.33E-34	8.19E+00	1.15E-03	2.31E-01	1.67E-02	1.04E-03

Table 5 (Continued)

		Eu-155 (Ci)	Fe-55 (Ci)	H-3 (Ci)	I-129 (Ci)	Mn-54 (Ci)	Nb-94 (Ci)	Nb-95 (Ci)	Ni-59 (Ci)	Ni-63 (Ci)	Np-237 (Ci)	Pa-231 (Ci)
Reactor Building (TRA-603)	Reactor (Activation)			9.65E-02	2.18E-10	2.17E-11	1.55E-03		6.38E-01	6.45E+01	5.30E-10	1.75E-08
	Water Contaminated Surfaces				7.94E-07					7.32E-04		
	Air Contaminated Surfaces				2.79E-08					7.26E-05		
	Surfaces				2.65E-04					2.69E-03		
TRA-604	Pipe				2.23E-07					2.27E-06		
TRA-630	Surfaces				2.49E-06					2.53E-05		
	Hot Spots				1.51E-06					1.51E-05		
TRA-635	Hot Spots & Surfaces				1.11E-04					1.13E-03		
TRA-730	Vaults	1.23E-05	6.02E-06						6.02E-07	3.79E-04		
	Tanks	8.27E-05						4.24E-06				
	Total =	9.50E-05	6.02E-06	9.65E-02	3.81E-04	2.17E-11	1.55E-03	4.24E-06	6.38E-01	6.45E+01	5.30E-10	1.75E-08

		Pb-210 (Ci)	Pu-238 (Ci)	Pu-239 (Ci)	Pu-240 (Ci)	Pu-241 (Ci)	Pu-242 (Ci)	Pu-244 (Ci)	Ra-226 (Ci)	Ru-106 (Ci)	Sb-125 (Ci)	Sr-90 (Ci)
Reactor Building (TRA-603)	Reactor (Activation)	2.40E-12	2.33E-08	1.36E-04	1.95E-06		4.10E-13	5.80E-25	6.27E-12	1.02E-14	1.08E-05	2.68E-04
	Water Contaminated Surfaces											4.34E-04
	Air Contaminated Surfaces											1.47E-05
	Surfaces		2.71E-03	5.95E-03	2.19E-03							1.45E-01
TRA-604	Pipe		2.07E-06	4.55E-06	1.67E-06							1.22E-04
TRA-630	Surfaces		2.31E-05	5.07E-05	1.87E-05							1.37E-03
	Hot Spots		2.84E-05	6.24E-05	2.30E-05							7.90E-04
TRA-635	Hot Spots & Surfaces		1.03E-03	2.26E-03	8.34E-04							6.09E-02
TRA-730	Vaults		2.31E-04	1.37E-04	1.37E-04							5.16E-03
	Tanks		1.65E-04	1.28E-04							5.60E-05	1.72E-02
	Total =	2.40E-12	4.19E-03	8.73E-03	3.21E-03		4.10E-13	5.80E-25	6.27E-12	1.02E-14	6.68E-05	2.31E-01

Table 5 (Continued)

		Tc-99 (Ci)	Th-228 (Ci)	Th-229 (Ci)	Th-230 (Ci)	Th-232 (Ci)	U-232 (Ci)	U-233 (Ci)	U-234 (Ci)	U-235 (Ci)	U-236 (Ci)	U-238 (Ci)
Reactor Building (TRA-603)	Reactor (Activation)	6.11E-05	1.98E-07	2.12E-08	5.47E-10	1.84E-07	1.44E-08	5.13E-06	1.13E-06	5.09E-08	2.88E-09	1.12E-06
	Water Contaminated Surfaces											
	Air Contaminated Surfaces											
	Surfaces											
TRA-604	Pipe											
TRA-630	Surfaces											
	Hot Spots											
TRA-635	Hot Spots & Surfaces											
TRA-730	Vaults								2.41E-06			
	Tanks						5.66E-07		1.07E-05	1.15E-07		3.55E-07
	Total =	6.11E-05	1.98E-07	2.12E-08	5.47E-10	1.84E-07	5.81E-07	5.13E-06	1.42E-05	1.66E-07	2.88E-09	1.48E-06

		Zn-65 (Ci)	Total Activity (Ci)
Reactor Building (TRA-603)	Reactor (Activation)	3.51E-17	7.34E+01
	Water Contaminated Surfaces		3.00E-02
	Air Contaminated Surfaces		2.12E-03
	Surfaces		4.47E-01
TRA-604	Pipe		2.11E-04
TRA-630	Surfaces		2.37E-03
	Hot Spots		1.29E-02
TRA-635	Hot Spots & Surfaces		1.05E-01
TRA-730	Vaults		1.02E-02
	Tanks	3.18E-06	3.27E-02
	Total =	3.18E-06	7.41E+01

Table 6. Summary of MTR Above and Below Grade Activity by Nuclide.

	Ac-227 (Ci)	Ag-108m (Ci)	Ag-110m (Ci)	Am-241 (Ci)	Am-243 (Ci)	Be-10 (Ci)	C-14 (Ci)	Ce-144 (Ci)	Cf-252 (Ci)	Cl-36 (Ci)	Cm-242 (Ci)	Cm-243 (Ci)	Cm-244 (Ci)
Above Grade Total =	4.64E-07	1.60E-01	4.78E-15	7.53E-02	6.61E-05	5.59E-02	3.20E+00	1.67E-13		3.11E-02		4.64E-05	1.23E-03
Below Grade Total =	1.32E-08	1.19E-03	2.16E-17	1.68E-02			1.25E-01	5.69E-04	4.99E-06	9.06E-04	9.78E-07	1.25E-14	6.23E-05
Total =	4.77E-07	1.61E-01	4.80E-15	9.21E-02	6.61E-05	5.59E-02	3.32E+00	5.69E-04	4.99E-06	3.20E-02	9.78E-07	4.64E-05	1.29E-03

	Cm-245 (Ci)	Cm-246 (Ci)	Cm-247 (Ci)	Cm-248 (Ci)	Co-60 (Ci)	Cs-134 (Ci)	Cs-137 (Ci)	Eu-152 (Ci)	Eu-154 (Ci)	Eu-155 (Ci)	Fe-55 (Ci)	H-3 (Ci)	I-129 (Ci)
Above Grade Total =	1.77E-07	3.10E-08	3.99E-14	4.81E-14	5.25E+01	1.21E-03	5.08E-01	5.63E+00	1.02E+00			2.22E+02	2.25E-05
Below Grade Total =	3.72E-21	5.31E-24			8.19E+00	1.15E-03	2.30E-01	1.67E-02	1.04E-03	9.50E-05	6.02E-06	6.65E-01	3.81E-04
Total =	1.77E-07	3.10E-08	3.99E-14	4.81E-14	6.07E+01	2.36E-03	7.38E-01	5.65E+00	1.02E+00	9.50E-05	6.02E-06	2.22E+02	4.03E-04

	Mn-54 (Ci)	Nb-94 (Ci)	Nb-95 (Ci)	Ni-59 (Ci)	Ni-63 (Ci)	Np-237 (Ci)	Pa-231 (Ci)	Pb-210 (Ci)	Pu-238 (Ci)	Pu-239 (Ci)	Pu-240 (Ci)	Pu-241 (Ci)	Pu-242 (Ci)
Above Grade Total =	1.85E-10	5.16E-02		3.89E+00	4.05E+02	1.03E-06	6.26E-07	1.88E-10	1.75E-02	3.83E-02	1.42E-02	4.12E-01	2.08E-05
Below Grade Total =	2.17E-11	1.55E-03	4.24E-06	6.38E-01	6.45E+01	5.30E-10	1.75E-08	2.40E-12	4.19E-03	8.73E-03	3.21E-03		4.10E-13
Total =	2.07E-10	5.31E-02	4.24E-06	4.53E+00	4.69E+02	1.03E-06	6.43E-07	1.90E-10	2.17E-02	4.70E-02	1.74E-02	4.12E-01	2.08E-05

	Pu-244 (Ci)	Ra-226 (Ci)	Ru-106 (Ci)	Sb-125 (Ci)	Sr-90 (Ci)	Tc-99 (Ci)	Th-228 (Ci)	Th-229 (Ci)	Th-230 (Ci)	Th-232 (Ci)	U-232 (Ci)	U-233 (Ci)	U-234 (Ci)
Above Grade Total =	3.76E-13	5.06E-10	9.57E-11	3.08E-04	2.07E-01	3.55E-03	4.53E-05	6.98E-07	4.69E-08	3.29E-05	1.22E-05	1.71E-04	1.07E-04
Below Grade Total =		6.27E-12	1.02E-14	6.68E-05	2.31E-01	6.11E-05	1.98E-07	2.12E-08	5.47E-10	1.84E-07	5.81E-07	5.13E-06	1.42E-05
Total =	3.76E-13	5.12E-10	9.57E-11	3.75E-04	4.38E-01	3.61E-03	4.55E-05	7.19E-07	4.74E-08	3.31E-05	1.28E-05	1.76E-04	1.21E-04

	U-235 (Ci)	U-236 (Ci)	U-238 (Ci)	Zn-65 (Ci)	Total Activity (Ci)
Above Grade Total =	4.54E-06	9.76E-07	1.03E-04	3.51E-14	6.94E+02
Below Grade Total =	1.66E-07	2.88E-09	1.48E-06	3.18E-06	7.41E+01
Total =	4.70E-06	9.79E-07	1.04E-04	3.18E-06	7.68E+02

Conclusion:

This EDF provides the estimated source term of the MTR complex above grade level, from grade level to 3 feet below grade, from grade level to 10 feet below grade, and the source term below grade level (to the bottom of the concrete slab of the lowest level for each building in the MTR complex).

These data will be used as input into three dose assessment scenarios as part of the required CERCLA risk assessment process for the MTR complex.

References:

1. R. L. Ralfe & E. L. Wills, 1984, WM-F1-83-016, Characterization of the Materials Testing Reactor, Idaho National Laboratory, Idaho Falls, Idaho.

2. R. S. McPherson et al., 1963, Fundamentals in the Operation of Nuclear Test Reactors Vol. 2, IDO-16871-2, Phillips Petroleum Company, Atomic Energy Division, Idaho Falls, Idaho..

3. Engineering drawings numbers 100005, 100020, 100023, 101865, 150645, 165932, & 165758.

Appendices:

Appendix A – Reactor Activated Materials

Appendix B – Air Contaminated Surface Activity

Appendix C – Water Contaminated Surface Activity

Appendix D – Building Contaminated Surfaces

Appendix E – TRA-730 Vault & Tank Activity Calculations

Appendix F – Fission Break Experience in MTR

Appendix G – Sample Calculations

Appendix A

Reactor Activated Materials

The following analysis, modeling, and calculations were performed by Glen R. Longhurst, James R. Parry, and Michael L. Carboneau.

Core Description

The core has 45 positions in a 5 by 9 rectangular lattice approximately 15.7 inches by 28.8 inches by 24 inches high (meat height). Of the 45 positions 8 were reserved for control rods though only seven positions were used for this purpose. The one control rod position not occupied by a control rod was used as an experiment location. The fuel portion of the lattice was the 3 northern rows by 9 positions minus 4 control rod positions for a total of 23 fuel assemblies. The 2 southern rows of 9 positions except for the 4 control rod positions were filled with beryllium "L" assemblies which had outer dimensions equivalent to the fuel assemblies. The beryllium "L" pieces had axial holes through the center of the elements for cooling water and experiment placement. The southwest control rod position is the one used for experiments.

The seven control rods, known as shim-safety rods, in the active lattice were used for coarse control of the reactor and fast shutdown. The control rods in the fuel portion of the core used cadmium for the poison and had fuel element followers. In the beryllium area of the core, the cadmium shim rods had beryllium followers. Just outside of the lattice in the reflector region were 4 locations (2 on the north and 2 on the south) for regulating rods used for fine control of the reactor. Only the two northern locations were used for regulating rods with the southern locations used for experiments. The regulating rods also used cadmium for the poison material.

The fuel assemblies consisted of 19 curved fuel plates attached to aluminum side plates. The fuel plates were manufactured by filling a 0.245-inch-thick aluminum "window frame" with the uranium-aluminum alloy fuel. The assembly was hot rolled to a thickness of 0.125 inches and then sandwiched between 0.125 inch thick aluminum cover sheets. The sandwiched assembly was then cold rolled to a target fuel (meat) thickness of 0.020 inches leaving enough aluminum material for milling to final dimensions. The milled pieces were then formed into the curved fuel plates using a 25-ton press to create a 5.5 inch radius. The outside fuel plates (numbers 1 and 19) were machined to a thickness of 0.065 inches while the inner 17 fuel plates were machined to a thickness of 0.050 inches. The 19 fuel plates were spaced in the aluminum side plates to provide a gap of approximately 0.116 inches for coolant water flow. The fuel assemblies were held in place by upper and lower assembly grids. The lower support casting was bolted to tank section D to support the lower assembly grid and the beryllium reflector. An upper support casting attached to the tank supported the upper grid assembly and the upper guide grid.

The beryllium reflector was composed of interlocking beryllium blocks forming a cylinder on the outside and matching the core shape on the inside with a height of 39 3/8 inches. The reflector extended from the active core to the tank walls and was constructed to accommodate the various beam tubes and other experimental facilities.

Activated Structures

For purposes of the analysis described here, only those components near the core of the reactor are important for activation. Contaminated duct-work within the biological shield is also considered. Figure A-1 shows fast and thermal flux profiles determined for the MTR core under normal operating conditions. Because the fuel and reflector loadings in the central core were not axially symmetric, the flux profiles are non-circular. The shallowest flux gradients in Figure A-1 are 31 cm/decade for thermal neutrons and 24.4 cm/decade for fast neutrons. Thus activation more than 1 m from the rectangular central core will be at

most 0.1% of that in the core itself. That allows limiting of the components of MTR that required activation analysis to the following:

- Graphite balls (Pebble Zone)
- Graphite blocks
- Heat shield plates
- Beryllium reflector
- Lower support casting
- Lower assembly grid
- Lower cradle
- Lower guide grid
- Upper support casting
- Upper grid assembly
- C to D tank adapters
- D to E tank adapters
- Fuel assembly monitor tubes
- C Tank
- D Tank
- E Tank
- Discharge Chute

Items known to have been removed from the reactor include the fuel, the cadmium safety shim rods, and the cadmium regulating rods (Reference 2). It is not known whether the beryllium "L" pieces interspersed with the fuel elements in the core were removed with the fuel. For conservatism, it was assumed they are still there.

C tank, D tank, and the core support structures were included even though they are made of aluminum alloy. Often, aluminum structures are overlooked in activation calculations because they contain no significant activation product precursors and their impurities are relatively benign. However, for completeness and because of the high neutron fluences, the two aluminum tank sections and other aluminum structures around the core are included in the calculations.

The beam port plugs, which were kept in the reactor when the ports were not in use, had beryllium in that part of the plug that passed through beryllium and graphite in sections that passed through graphite. Therefore, a reasonable approximation for activation analysis of the beryllium and graphite reflectors is to assume all the beam port plugs were in place and that the beryllium and graphite reflectors were continuous over their volumes, not interrupted by beam port holes. In that way, the beam port plugs are included in the inventory.

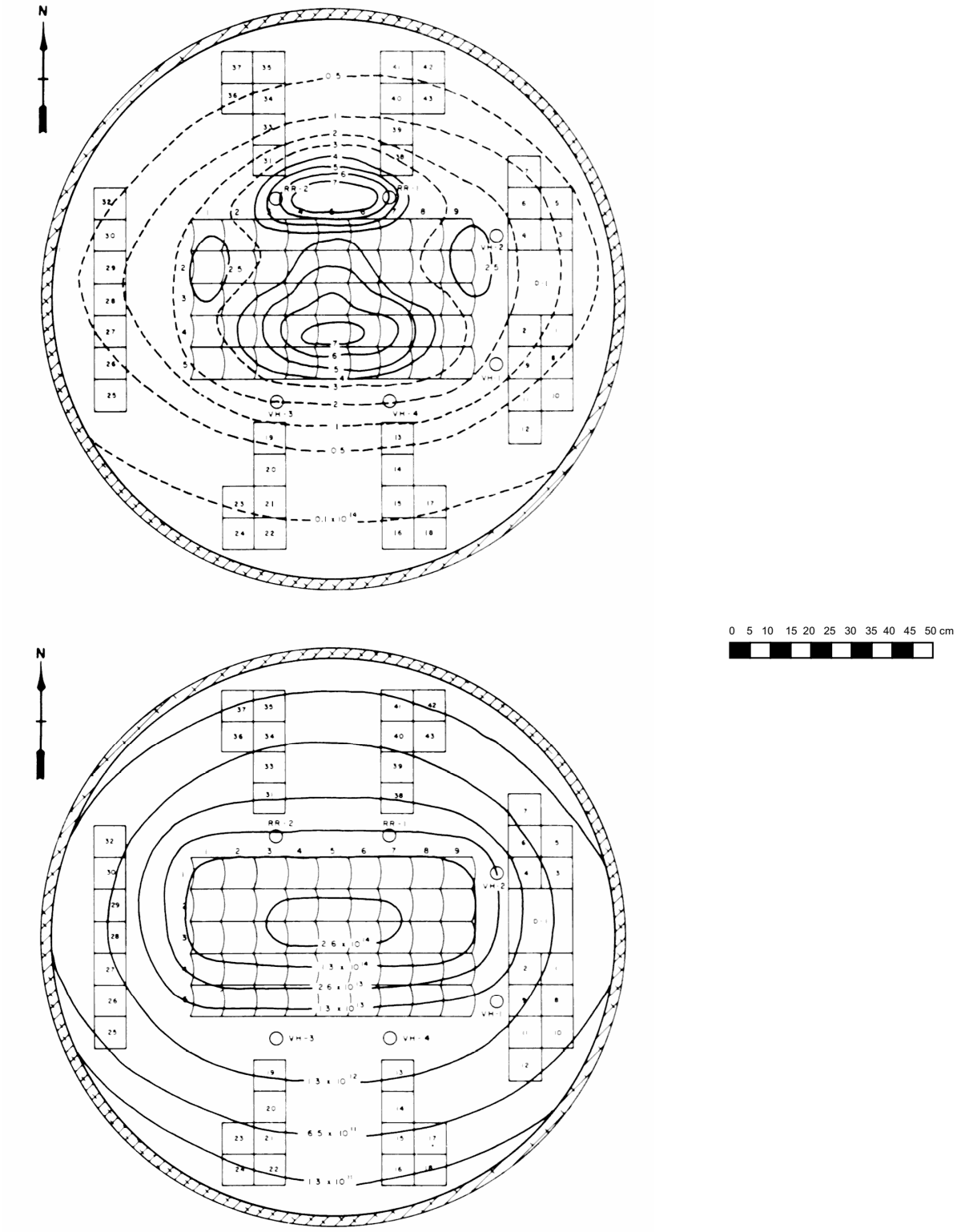

Figure A-1. Thermal (top) and fast (bottom) neutron flux profiles at the MTR core mid-plane for normal operating conditions.

Reactor Materials

- **Graphite Balls -** These 2.54-cm (1-inch) diameter spheres are made from AGOT graphite (Reference 3), which has a density of 1.6 to 1.7 g/cm^3 and is essentially isotropic. Its neutron capture cross section was 3.9 to 4.3 b (Reference 4). The aggregate mass of these balls is 16 tons.

  AGOT graphite was manufactured by the National Carbon Company using a process developed by Edward Acheson (Reference 5). The process begins with petroleum coke and coal tar pitch. The coke has typical impurities listed in Table A-1, taken from Reference 4. The coal tar pitch is produced from the distillation of coal tar from byproduct coke ovens. Its typical impurities are listed in Table A-2.

Table A-1. Metallic impurities in calcined petroleum coke.

Impurity	Usual range	Typical value
Total ash impurity, %	0.1 to 0.5	0.15
Silicon, mg/kg	30 to 300	50
Iron, mg/kg	30 to 1500	40
Vanadium, mg/kg	3 to 500	15
Titanium, mg/kg	1 to 10	10
Aluminum, mg/kg	15 to 300	30
Manganese, mg/kg	5 to 50	10
Nickel, mg/kg	25 to 100	40
Calcium, mg/kg	15 to 250	20
Magnesium, mg/kg	5 to 50	10
Boron, mg/kg	0.1 to 0.3	0.1

Table A-2. Chemical constituents in coal-tar pitch binders (by weight).

Total ash impurity, %	0.03 to 0.3
Carbon, %	92 to 93
Hydrogen, %	4.2 to 4.5
Sulfur, %	0.6
Nitrogen, %	1.1
Oxygen, %	1.0 to 2.0
Carbon/hydrogen ratio (atomic)	1.7 to 1.85

There is strong evidence for other contaminants in the AGOT graphite. Two other reactors that used this grade of material were the Chicago Pile (CP-1) at the University of Chicago and the Georgia Tech Research Reactor (GTRR). When the GTRR was being decommissioned, it was discovered that the graphite surrounding its 5-MW core contained up to 300,000 pCi/g Co-60 and measurable quantities of Eu-152, Eu-154, and Eu-155. Contact beta/gamma was 300 mR/h on the graphite. While Eu can be an impurity in the graphite, the presence of Eu-155 suggests some of the Eu they found may have come from U fission.

Some CP-1 AGOT graphite was secured that had been donated to the American Nuclear Society by Argonne National Laboratory. Confirmation that it was AGOT was provided by the stamped "T07" on the end of the block (Figure A-2). Additionally, the "Acheson" engraved on the side of the block (Figure A-3) confirms its association with the Acheson Graphite Company, acquired by National Carbon Company in 1928. This material was analyzed by the Southwest Research Institute of San Antonio, TX. Their findings appear in Table A-3. They were reviewed by Portage Environmental with no findings that data qualification was required (Reference 6).

Figure A-2. The "TO7" stamped on the graphite block confirms it is AGOT type

Figure A-3. The "ACHESON" name on the block indicates it came from the Acheson Graphite Company mill, which was part of National Carbon Company after 1928.

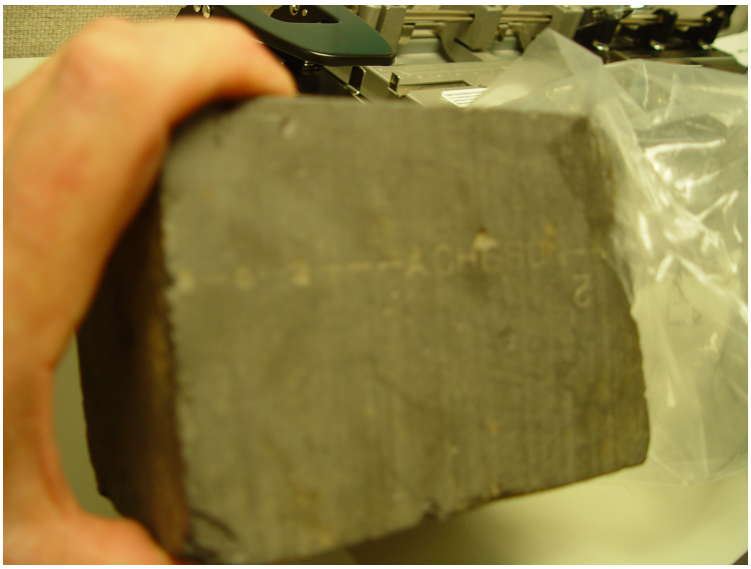

Table A-3. Summary of measurements made by Southwest Research Institute on AGOT graphite.

	Lab Sample Number				
Element	245229 (mg/kg)	245231 (mg/kg)	245233 (mg/kg)	**Average** (mg/kg)	MDA (mg/kg)
Ag	0.48	0.50	0.47	**0.48**	0.01
Cd	0.48	0.50	0.47	**0.48**	0.01
Cr	1.40	0.61	0.58	**0.86**	0.02
Co	0.48	0.50	0.47	**0.48**	0.10
Eu	0.01	0.01	0.01	**0.01**	0.01
Fe	9.70	15.70	13.00	**12.80**	0.20
Mn	0.48	0.50	0.47	**0.48**	0.03
Mo	0.96	1.00	0.94	**0.97**	0.40
N	<10.00	<10.00	<10.00	**<10.00**	10.00
Na	24.00	25.00	23.60	**24.20**	10.00
Ni	1.20	0.53	0.47	**0.73**	0.08
Pb	0.48	0.50	0.47	**0.48**	0.10
Sb	1.90	4.20	1.90	**2.67**	0.12
Sr	4.50	3.90	3.90	**4.10**	0.40
Th	0.05	0.05	0.05	**0.05**	0.01
Isotope	(ug/kg)	(ug/kg)	(ug/kg)	(ug/kg)	(ug/kg)
U-235	0.985	2.55	3.12	**2.22**	0.5
U-238	212	660	779	**550.33**	1.7

- **Graphite blocks -** Outside the graphite balls was a rectangular zone made of graphite blocks. A large fraction of this solid reflector, 64.3%, was made from AGOT graphite. Two other grades of graphite were also used there, AGHT and GBF, both also made by National Carbon Company. 1.57 tons of AGHT were used for the 4 x 6-inch corner pieces, and 25.06 tons of GBF were used. The total mass of the solid reflector is 74.58 tons.

  The AGHT and GBF graphites are virtually identical in composition to the AGOT. Only the manufacturing processes are slightly different. For example, AGOT comes from the central part of the graphitizing furnace and has a neutron absorption cross section from 3.9 to 4.3 mb while AGHT comes from the edge and uses larger molds (Reference 7). GBF, formerly known as TSGBF, was made from Texas-Lockport coke and Standard pitch. Its density is 1.65 g/cm^3, and its neutron capture cross section was 3.68 mb. Thus, GBF is slightly purer than AGOT graphite.

- **Heat Shield Plates -** ASTM A201 Grade "A" carbon steel (Reference 8).

- **Beryllium Reflector** - Composed of interlocking beryllium blocks. Note: the MTR reflector was replaced not long before MTR was shut down and had experienced less than 1,000 MWd of reactor operation.

- **Lower and Upper Support Casting, Lower and Upper Assembly Grid, Lower Cradle, & Lower Guide Grid -** ASTM 209-46T Alloy A2. Note: The only specifications for that alloy that could be located also included 6061 aluminum. Therefore, the detailed composition of 6061 Al in lieu of ASTM 209-46T Alloy A2 was used in the activation analysis.

- **C to D Tank and D to E Tank Adapters –** 303 Stainless Steel

- **Fuel Assembly Monitor Tubes –** 304 Stainless Steel

- **C Tank & D Tank –** 356 Aluminum Alloy. To determine the potential for uranium impurity in the "C" and "D" tanks, a sample was milled from the exterior of the D tank in March 2007, through one of the "beam hole" access points from outside of the bioshield. The sample was analyzed for total uranium and established an initial uranium concentration for the aluminum used to fabricate the "C" and "D" tanks of 0.44 mg/kg.

- **E Tank –** 304 Stainless Steel

- **Discharge Chute –** 304 Stainless Steel.

Radionuclides

The radioisotopes of concern for this analysis are listed in Table A-4.

Table A-4. Radioisotopes of concern for MTR 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

Isotope	Decay Product	Half Life (yr)	Isotope	Decay Product	Half Life (yr)
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.

Material Isotopic Composition

Table A-5 lists the detailed composition of the materials used in the activation analyses for the various structures. These data were obtained from manufacturers' specifications for the composition of the various materials, taking naturally occurring isotopic abundances and using the maximum permissible values for impurity concentrations when detailed analyses were not available.

Table A-5. Isotopic composition of the various materials the in MTR

	Concentration (g/kg)							
Isotope	**303 SS**	**304 SS**	**347 SS**	**A-201 Steel**	**Beryllium**	**AGOT Graphite**	**Aluminum 356**	**Aluminum 6061**
H-1	0.006998	0.006998	0.006998	0.000000	0.000000	0.000000	0.000010	0.000010
H-2	0.000002	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	0.000000
He-4	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Li-6	0.000008	0.000008	0.000008	0.000019	0.000000	0.000000	0.000000	0.000325
Li-7	0.000122	0.000122	0.000122	0.000281	0.000650	0.000005	0.001000	0.004675
Be-9	0.000000	0.000000	0.000000	0.000000	988.011752	0.000005	0.000110	0.000110
Be-10	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
B-10	0.000922	0.000922	0.000922	0.000000	0.000120	0.000442	0.000184	0.001843
B-11	0.004078	0.004078	0.004078	0.000000	0.000530	0.001958	0.000816	0.008157
C-12	1.482137	0.790473	0.632378	3.063083	0.790473	987.932541	0.494046	0.009881
C-13	0.017863	0.009527	0.007622	0.036917	0.009527	11.906877	0.005954	0.000119
N-14	0.468137	0.468137	0.358573	0.083667	0.204586	0.009960	0.004980	0.004980
N-15	0.001863	0.001863	0.001427	0.000333	0.000814	0.000040	0.000020	0.000020
O-16	0.149599	0.149599	0.149599	0.000000	5.345666	0.000000	0.498663	0.498663
O-17	0.000064	0.000064	0.000064	0.000000	0.002277	0.000000	0.000212	0.000212
O-18	0.000337	0.000337	0.000337	0.000000	0.012057	0.000000	0.001125	0.001125
F-19	0.000000	0.000000	0.000000	0.000000	0.069167	0.000000	0.000000	0.000000

	Concentration (g/kg)							
Isotope	303 SS	304 SS	347 SS	A-201 Steel	Beryllium	AGOT Graphite	Aluminum 356	Aluminum 6061
Ne-20	0.000000	0.000000	0.000000	0.000000	1.277352	0.000000	0.000000	0.000000
Ne-21	0.000000	0.000000	0.000000	0.000000	0.004002	0.000000	0.000000	0.000000
Ne-22	0.000000	0.000000	0.000000	0.000000	0.143646	0.000000	0.000000	0.000000
Na-23	0.009700	0.009700	0.009700	0.023400	0.000874	0.024200	0.060000	0.060000
Mg-24	0.000000	0.000000	0.000000	0.000000	0.025334	0.000780	3.507751	7.015502
Mg-25	0.000000	0.000000	0.000000	0.000000	0.003341	0.000103	0.462578	0.925157
Mg-26	0.000000	0.000000	0.000000	0.000000	0.003825	0.000118	0.529671	1.059342
Al-27	0.100000	0.100000	0.100000	0.085000	0.495000	0.004100	898.990075	976.799780
Si-28	9.187333	9.187333	5.879893	2.067150	0.863609	0.023887	68.905001	5.971767
Si-29	0.481808	0.481808	0.308357	0.108407	0.045290	0.001253	3.613561	0.313175
Si-30	0.330858	0.330858	0.211749	0.074443	0.031101	0.000860	2.481438	0.215058
P-31	2.000000	0.450000	0.250000	0.375000	0.050000	0.001000	0.010000	0.010000
S-32	0.284238	0.284238	0.180018	0.426358	0.007106	0.008906	0.018949	0.018949
S-33	0.002314	0.002314	0.001465	0.003470	0.000058	0.000072	0.000154	0.000154
S-34	0.013381	0.013381	0.008474	0.020071	0.000335	0.000419	0.000892	0.000892
S-35	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
S-36	0.000067	0.000067	0.000043	0.000101	0.000002	0.000002	0.000004	0.000004
Cl-35	0.052315	0.052315	0.052315	0.047083	0.037368	0.002242	0.000000	0.000000
Cl-36	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Cl-37	0.017685	0.017685	0.017685	0.015917	0.012632	0.000758	0.000000	0.000000
Ar-36	0.000000	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	0.000000
Ar-38	0.000000	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	0.000000
Ar-40	0.000000	0.000000	0.000000	0.000000	0.006347	0.000000	0.000000	0.000000
K-39	0.002788	0.002788	0.002788	0.002788	0.012147	0.000929	0.000000	0.000000
K-40	0.000000	0.000000	0.000000	0.000000	0.000002	0.000000	0.000000	0.000000
K-41	0.000212	0.000212	0.000212	0.000212	0.000922	0.000071	0.000000	0.000000
Ca-40	0.018366	0.018366	0.018366	0.013533	0.014499	0.000541	0.010633	0.010633
Ca-41	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Ca-42	0.000129	0.000129	0.000129	0.000095	0.000102	0.000004	0.000075	0.000075
Ca-43	0.000027	0.000027	0.000027	0.000020	0.000022	0.000001	0.000016	0.000016
Ca-44	0.000435	0.000435	0.000435	0.000320	0.000343	0.000013	0.000252	0.000252
Ca-45	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Ca-46	0.000001	0.000001	0.000001	0.000001	0.000001	0.000000	0.000001	0.000001
Ca-47	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Ca-48	0.000043	0.000043	0.000043	0.000031	0.000034	0.000001	0.000025	0.000025
Sc-45	0.000030	0.000030	0.000030	0.000000	0.002300	0.000010	0.000000	0.000000
Ti-46	0.046067	0.046067	0.007678	0.026565	0.004735	0.001228	0.191947	0.015356
Ti-47	0.042950	0.042950	0.007158	0.024768	0.004414	0.001145	0.178959	0.014317
Ti-48	0.443447	0.443447	0.073908	0.255721	0.045576	0.011825	1.847695	0.147816
Ti-49	0.033737	0.033737	0.005623	0.019455	0.003467	0.000900	0.140570	0.011246
Ti-50	0.033799	0.033799	0.005633	0.019491	0.003474	0.000901	0.140830	0.011266
V-50	0.001226	0.001226	0.000980	0.000185	0.000008	0.000046	0.000490	0.000490
V-51	0.498774	0.498774	0.399020	0.075315	0.003415	0.018854	0.199510	0.199510
Cr-50	7.512189	7.837717	7.386986	0.091816	0.005279	0.000036	0.020867	0.025041

	Concentration (g/kg)							
Isotope	**303 SS**	**304 SS**	**347 SS**	**A-201 Steel**	**Beryllium**	**AGOT Graphite**	**Aluminum 356**	**Aluminum 6061**
Cr-51	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Cr-52	150.661488	157.19015	148.15046	1.841418	0.105882	0.000720	0.418504	0.502205
Cr-53	17.410297	18.164744	17.120126	0.212793	0.012236	0.000083	0.048362	0.058034
Cr-54	4.416026	4.607387	4.342426	0.053974	0.003103	0.000021	0.012267	0.014720
Mn-55	20.000000	14.100000	16.400000	8.000000	0.094000	0.000480	3.500000	0.500000
Fe-54	33.952139	38.889965	43.220933	55.068614	0.053567	0.000729	0.341915	0.136766
Fe-55	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Fe-56	547.360488	626.96579	696.78764	887.790409	0.863577	0.011759	5.512197	2.204879
Fe-57	12.756030	14.611201	16.238373	20.689621	0.020125	0.000274	0.128460	0.051384
Fe-58	1.730643	1.982338	2.203101	2.807013	0.002730	0.000037	0.017428	0.006971
Co-59	1.700000	1.700000	1.000000	0.104000	0.001000	0.000480	0.001100	0.002000
Ni-58	62.204445	62.204445	11.052577	4.144717	0.062339	0.000492	0.011457	0.047176
Ni-59	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Ni-60	24.601143	24.601143	4.371167	1.639188	0.024654	0.000195	0.004531	0.018657
Ni-61	1.082859	1.082859	0.192404	0.072151	0.001085	0.000009	0.000199	0.000821
Ni-62	3.496630	3.496630	0.621286	0.232982	0.003504	0.000028	0.000644	0.002652
Ni-63	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Ni-64	0.914924	0.914924	0.162565	0.060962	0.000917	0.000007	0.000169	0.000694
Cu-63	1.712489	1.712489	0.958994	1.712489	0.036647	0.000322	1.712489	0.821995
Cu-64	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Cu-65	0.787511	0.787511	0.441006	0.787511	0.016853	0.000148	0.787511	0.378005
Zn-64	0.047510	0.047510	0.047510	0.007364	0.011877	0.000475	1.662833	0.095019
Zn-65	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Zn-66	0.028126	0.028126	0.028126	0.004360	0.007032	0.000281	0.984420	0.056253
Zn-67	0.004196	0.004196	0.004196	0.000650	0.001049	0.000042	0.146856	0.008392
Zn-68	0.019527	0.019527	0.019527	0.003027	0.004882	0.000195	0.683438	0.039054
Zn-69	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Zn-70	0.000642	0.000642	0.000642	0.000099	0.000160	0.000006	0.022453	0.001283
Ga69	0.076656	0.076656	0.076656	0.017827	0.000511	0.000000	0.118846	0.118846
Ga-70	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Ga-71	0.052344	0.052344	0.052344	0.012173	0.000349	0.000000	0.081154	0.081154
Ge-70	0.000000	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	0.000000
Ge-72	0.000000	0.000000	0.000000	0.000000	0.001357	0.000000	0.000000	0.000000
Ge-73	0.000000	0.000000	0.000000	0.000000	0.000392	0.000000	0.000000	0.000000
Ge-74	0.000000	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	0.000000
Ge-76	0.000000	0.000000	0.000000	0.000000	0.000408	0.000000	0.000000	0.000000
As-75	0.100000	0.100000	0.100000	0.128000	0.001782	0.000000	0.000000	0.000000
Se-74	0.001685	0.001685	0.001685	0.000042	0.000020	0.000000	0.000000	0.000000
Se-75	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Se-76	0.017496	0.017496	0.017496	0.000437	0.000208	0.000000	0.000000	0.000000
Se-77	0.014804	0.014804	0.014804	0.000370	0.000176	0.000000	0.000000	0.000000
Se-78	0.046567	0.046567	0.046567	0.001164	0.000555	0.000000	0.000000	0.000000
Se-79	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Se-80	0.100987	0.100987	0.100987	0.002525	0.001203	0.000000	0.000000	0.000000

	Concentration (g/kg)							
Isotope	303 SS	304 SS	347 SS	A-201 Steel	Beryllium	AGOT Graphite	Aluminum 356	Aluminum 6061
Se-81	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Se-82	0.018462	0.018462	0.018462	0.000462	0.000220	0.000000	0.000000	0.000000
Br-79	0.001001	0.001001	0.001001	0.004506	0.026034	0.000000	0.000000	0.000000
Br-80	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Br-81	0.000999	0.000999	0.000999	0.004494	0.025966	0.000000	0.000000	0.000000
Kr-78	0.000000	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	0.000000
Kr-80	0.000000	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	0.000000
Kr-82	0.000000	0.000000	0.000000	0.000000	0.009657	0.000000	0.000000	0.000000
Kr-83	0.000000	0.000000	0.000000	0.000000	0.009690	0.000000	0.000000	0.000000
Kr-84	0.000000	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	0.000000
Kr-86	0.000000	0.000000	0.000000	0.000000	0.015105	0.000000	0.000000	0.000000
Rb-85	0.007169	0.007169	0.007169	0.037279	0.005568	0.000717	0.000000	0.000000
Rb-86	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Rb-87	0.002831	0.002831	0.002831	0.014721	0.002199	0.000283	0.000000	0.000000
Sr-84	0.000001	0.000001	0.000001	0.000001	0.000032	0.000022	0.000001	0.000001
Sr-85	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Sr-86	0.000019	0.000019	0.000019	0.000015	0.000580	0.000396	0.000010	0.000010
Sr-87	0.000014	0.000014	0.000014	0.000010	0.000417	0.000285	0.000007	0.000007
Sr-88	0.000166	0.000166	0.000166	0.000124	0.004971	0.003397	0.000083	0.000083
Y8-9	0.005000	0.005000	0.005000	0.005500	0.001000	0.000000	0.000000	0.000000
Zr-90	0.005071	0.005071	0.005071	0.002789	0.019377	0.000254	0.101414	0.101414
Zr-91	0.001118	0.001118	0.001118	0.000615	0.004273	0.000056	0.022362	0.022362
Zr-92	0.001728	0.001728	0.001728	0.000950	0.006603	0.000086	0.034556	0.034556
Zr-93	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Zr-94	0.001789	0.001789	0.001789	0.000984	0.006837	0.000089	0.035781	0.035781
Zr-95	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Zr-96	0.000294	0.000294	0.000294	0.000162	0.001125	0.000015	0.005887	0.005887
Nb-93	0.120000	0.120000	7.000000	0.024000	0.011700	0.001740	0.000500	0.005000
Mo-92	12.796101	0.526062	0.540280	0.860182	0.001422	0.000138	0.000299	0.000142
Mo-93	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Mo-94	8.149398	0.335031	0.344086	0.547821	0.000905	0.000088	0.000190	0.000091
Mo-95	14.174985	0.582749	0.598499	0.952874	0.001575	0.000153	0.000331	0.000157
Mo-96	15.008013	0.616996	0.633672	1.008872	0.001668	0.000162	0.000350	0.000167
Mo-97	8.682225	0.356936	0.366583	0.583638	0.000965	0.000094	0.000203	0.000096
Mo-98	22.163550	0.911168	0.935794	1.489883	0.002463	0.000239	0.000517	0.000246
Mo-99	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Mo-100	9.025728	0.371058	0.381086	0.606729	0.001003	0.000097	0.000211	0.000100
Tc-99	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Ru-96	0.000000	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	0.000000
Ru-98	0.000000	0.000000	0.000000	0.000000	0.000090	0.000000	0.000000	0.000000
Ru-99	0.000000	0.000000	0.000000	0.000000	0.000621	0.000000	0.000000	0.000000
Ru-100	0.000000	0.000000	0.000000	0.000000	0.000623	0.000000	0.000000	0.000000

	Concentration (g/kg)							
Isotope	303 SS	304 SS	347 SS	A-201 Steel	Beryllium	AGOT Graphite	Aluminum 356	Aluminum 6061
Ru-101	0.000000	0.000000	0.000000	0.000000	0.000854	0.000000	0.000000	0.000000
Ru-102	0.000000	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	0.000000
Ru-104	0.000000	0.000000	0.000000	0.000000	0.000956	0.000000	0.000000	0.000000
Rh-103	0.000000	0.000000	0.000000	0.000000	0.000994	0.000000	0.000000	0.000000
Pd-102	0.000000	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	0.000000
Pd-104	0.000000	0.000000	0.000000	0.000000	0.000544	0.000000	0.000000	0.000000
Pd-105	0.000000	0.000000	0.000000	0.000000	0.001101	0.000000	0.000000	0.000000
Pd-106	0.000000	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	0.000000
Pd-108	0.000000	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	0.000000
Pd-110	0.000000	0.000000	0.000000	0.000000	0.000605	0.000000	0.000000	0.000000
Ag-107	0.001028	0.001028	0.001028	0.002055	0.000514	0.000247	0.000000	0.000000
Ag-108	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Ag-109	0.000972	0.000972	0.000972	0.001945	0.000486	0.000233	0.000000	0.000000
Cd-106	0.000000	0.000000	0.000000	0.000000	0.000002	0.000006	0.000012	0.000012
Cd-107	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Cd-108	0.000000	0.000000	0.000000	0.000000	0.000002	0.000004	0.000009	0.000009
Cd-109	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Cd-110	0.000000	0.000000	0.000000	0.000000	0.000024	0.000059	0.000122	0.000122
Cd-111	0.000000	0.000000	0.000000	0.000000	0.000025	0.000061	0.000126	0.000126
Cd-112	0.000000	0.000000	0.000000	0.000000	0.000048	0.000115	0.000240	0.000240
Cd-113	0.000000	0.000000	0.000000	0.000000	0.000025	0.000059	0.000123	0.000123
Cd-114	0.000000	0.000000	0.000000	0.000000	0.000058	0.000140	0.000291	0.000291
Cd-115	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Cd-116	0.000000	0.000000	0.000000	0.000000	0.000015	0.000037	0.000077	0.000077
In-113	0.000000	0.000000	0.000000	0.000000	0.000003	0.000042	0.000000	0.000000
In-114	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
In-115	0.000000	0.000000	0.000000	0.000000	0.000066	0.000958	0.000000	0.000000
Sn-112	0.000914	0.000914	0.000914	0.000001	0.000027	0.000009	0.000219	0.000219
Sn-113	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Sn-114	0.000624	0.000624	0.000624	0.000001	0.000019	0.000006	0.000150	0.000150
Sn-115	0.000348	0.000348	0.000348	0.000000	0.000010	0.000003	0.000084	0.000084
Sn-116	0.014187	0.014187	0.014187	0.000013	0.000426	0.000142	0.003405	0.003405
Sn-117	0.007563	0.007563	0.007563	0.000007	0.000227	0.000076	0.001815	0.001815
Sn-118	0.024055	0.024055	0.024055	0.000022	0.000722	0.000241	0.005773	0.005773
Sn-119	0.008594	0.008594	0.008594	0.000008	0.000258	0.000086	0.002063	0.002063
Sn-120	0.032917	0.032917	0.032917	0.000030	0.000988	0.000329	0.007900	0.007900
Sn-121	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Sn-122	0.004754	0.004754	0.004754	0.000004	0.000143	0.000048	0.001141	0.001141
Sn-123	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Sn-124	0.006043	0.006043	0.006043	0.000005	0.000181	0.000060	0.001450	0.001450
Sb-121	0.056999	0.056999	0.056999	0.465964	0.000137	0.001522	0.056999	0.056999
Sb-122	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000

	Concentration (g/kg)							
Isotope	303 SS	304 SS	347 SS	A-201 Steel	Beryllium	AGOT Graphite	Aluminum 356	Aluminum 6061
Sb-123	0.043001	0.043001	0.043001	0.351536	0.000103	0.001148	0.043001	0.043001
Te-120	0.000000	0.000000	0.000000	0.000027	0.000042	0.000000	0.000000	0.000000
Te-121	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Te-122	0.000000	0.000000	0.000000	0.000742	0.001175	0.000000	0.000000	0.000000
Te-123	0.000000	0.000000	0.000000	0.000262	0.000414	0.000000	0.000000	0.000000
Te-124	0.000000	0.000000	0.000000	0.001396	0.002208	0.000000	0.000000	0.000000
Te-125	0.000000	0.000000	0.000000	0.002091	0.003309	0.000000	0.000000	0.000000
Te-126	0.000000	0.000000	0.000000	0.005604	0.008867	0.000000	0.000000	0.000000
Te-127	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Te-128	0.000000	0.000000	0.000000	0.009533	0.015084	0.000000	0.000000	0.000000
Te-129	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Te-130	0.000000	0.000000	0.000000	0.010345	0.016368	0.000000	0.000000	0.000000
I-127	0.000000	0.000000	0.000000	0.000000	0.010000	0.000000	0.000000	0.000000
Xe-124	0.000000	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	0.000000
Xe-126	0.000000	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	0.000000
Xe-128	0.000000	0.000000	0.000000	0.000000	0.009998	0.000000	0.000000	0.000000
Xe-129	0.000000	0.000000	0.000000	0.000000	0.139278	0.000000	0.000000	0.000000
Xe-130	0.000000	0.000000	0.000000	0.000000	0.021798	0.000000	0.000000	0.000000
Xe-131	0.000000	0.000000	0.000000	0.000000	0.113578	0.000000	0.000000	0.000000
Xe-132	0.000000	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	0.000000
Xe-134	0.000000	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	0.000000
Xe-136	0.000000	0.000000	0.000000	0.000000	0.049501	0.000000	0.000000	0.000000
Cs-133	0.000300	0.000300	0.000300	0.000000	0.000201	0.001000	0.000000	0.000000
Ba-130	0.000501	0.000501	0.000501	0.000552	0.000006	0.000003	0.000000	0.000000
Ba-131	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Ba-132	0.000485	0.000485	0.000485	0.000534	0.000006	0.000003	0.000000	0.000000
Ba-133	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Ba-134	0.011799	0.011799	0.011799	0.012979	0.000142	0.000068	0.000000	0.000000
Ba-135	0.032384	0.032384	0.032384	0.035623	0.000389	0.000188	0.000000	0.000000
Ba-136	0.038844	0.038844	0.038844	0.042728	0.000466	0.000225	0.000000	0.000000
Ba-137	0.055978	0.055978	0.055978	0.061576	0.000672	0.000325	0.000000	0.000000
Ba-138	0.360009	0.360009	0.360009	0.396010	0.004320	0.002088	0.000000	0.000000
La-138	0.000000	0.000000	0.000000	0.000000	0.000001	0.000001	0.000000	0.000000
La-139	0.000200	0.000200	0.000200	0.000132	0.000999	0.001379	0.000000	0.000000
Ce-136	0.000684	0.000684	0.000684	0.000008	0.000002	0.000000	0.000000	0.000000
Ce-137	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Ce-138	0.000913	0.000913	0.000913	0.000010	0.000002	0.000000	0.000000	0.000000
Ce-139	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Ce-140	0.327583	0.327583	0.327583	0.003620	0.000883	0.000000	0.000000	0.000000
Ce-141	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Ce-142	0.041821	0.041821	0.041821	0.000462	0.000113	0.000000	0.000000	0.000000
Pr-141	0.000000	0.000000	0.000000	0.000000	0.001000	0.000640	0.000000	0.000000

	Concentration (g/kg)							
Isotope	303 SS	304 SS	347 SS	A-201 Steel	Beryllium	AGOT Graphite	Aluminum 356	Aluminum 6061
Nd-142	0.000000	0.000000	0.000000	0.000000	0.001335	0.000096	0.000000	0.000000
Nd-143	0.000000	0.000000	0.000000	0.000000	0.000603	0.000043	0.000000	0.000000
Nd-144	0.000000	0.000000	0.000000	0.000000	0.001187	0.000085	0.000000	0.000000
Nd-145	0.000000	0.000000	0.000000	0.000000	0.000417	0.000030	0.000000	0.000000
Nd-146	0.000000	0.000000	0.000000	0.000000	0.000869	0.000063	0.000000	0.000000
Nd-147	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Nd-148	0.000000	0.000000	0.000000	0.000000	0.000295	0.000021	0.000000	0.000000
Nd-149	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Nd-150	0.000000	0.000000	0.000000	0.000000	0.000293	0.000021	0.000000	0.000000
Pm-145	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Sm-144	0.000003	0.000003	0.000003	0.000006	0.000015	0.000018	0.000000	0.000000
Sm-145	0.000000	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	0.000000
Sm-147	0.000015	0.000015	0.000015	0.000029	0.000073	0.000089	0.000000	0.000000
Sm-148	0.000011	0.000011	0.000011	0.000022	0.000056	0.000068	0.000000	0.000000
Sm-149	0.000014	0.000014	0.000014	0.000027	0.000068	0.000083	0.000000	0.000000
Sm-150	0.000007	0.000007	0.000007	0.000015	0.000037	0.000045	0.000000	0.000000
Sm-151	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Sm152	0.000027	0.000027	0.000027	0.000054	0.000135	0.000165	0.000000	0.000000
Sm-153	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Sm-154	0.000023	0.000023	0.000023	0.000046	0.000116	0.000142	0.000000	0.000000
Eu-151	0.000009	0.000009	0.000009	0.000057	0.000237	0.000005	0.000000	0.000000
Eu-152	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Eu-153	0.000011	0.000011	0.000011	0.000064	0.000263	0.000005	0.000000	0.000000
Gd-152	0.000000	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	0.000000
Gd-154	0.000000	0.000000	0.000000	0.000000	0.000004	0.000002	0.000000	0.000000
Gd-155	0.000000	0.000000	0.000000	0.000000	0.000029	0.000012	0.000000	0.000000
Gd-156	0.000000	0.000000	0.000000	0.000000	0.000041	0.000016	0.000000	0.000000
Gd-157	0.000000	0.000000	0.000000	0.000000	0.000031	0.000012	0.000000	0.000000
Gd-158	0.000000	0.000000	0.000000	0.000000	0.000050	0.000020	0.000000	0.000000
Gd-159	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Gd-160	0.000000	0.000000	0.000000	0.000000	0.000044	0.000018	0.000000	0.000000
Tb-159	0.000470	0.000470	0.000470	0.000400	0.001000	0.000260	0.000000	0.000000
Dy-156	0.000001	0.000001	0.000001	0.000001	0.000000	0.000000	0.000000	0.000000
Dy-157	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Dy-158	0.000001	0.000001	0.000001	0.000001	0.000000	0.000000	0.000000	0.000000
Dy-159	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Dy-160	0.000023	0.000023	0.000023	0.000028	0.000005	0.000004	0.000000	0.000000
Dy-161	0.000187	0.000187	0.000187	0.000225	0.000037	0.000030	0.000000	0.000000
Dy-162	0.000254	0.000254	0.000254	0.000305	0.000051	0.000041	0.000000	0.000000
Dy-163	0.000250	0.000250	0.000250	0.000300	0.000050	0.000040	0.000000	0.000000
Dy-164	0.000284	0.000284	0.000284	0.000341	0.000057	0.000046	0.000000	0.000000
Ho-165	0.001000	0.001000	0.001000	0.000000	0.001000	0.000080	0.000000	0.000000
Er-162	0.000000	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	0.000000

	Concentration (g/kg)							
Isotope	303 SS	304 SS	347 SS	A-201 Steel	Beryllium	AGOT Graphite	Aluminum 356	Aluminum 6061
Er-164	0.000000	0.000000	0.000000	0.000000	0.000008	0.000001	0.000000	0.000000
Er-165	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Er-166	0.000000	0.000000	0.000000	0.000000	0.000167	0.000013	0.000000	0.000000
Er-167	0.000000	0.000000	0.000000	0.000000	0.000115	0.000009	0.000000	0.000000
Er-168	0.000000	0.000000	0.000000	0.000000	0.000135	0.000011	0.000000	0.000000
Er-169	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Er-170	0.000000	0.000000	0.000000	0.000000	0.000076	0.000006	0.000000	0.000000
Tm-169	0.000000	0.000000	0.000000	0.000000	0.000500	0.000040	0.000000	0.000000
Yb-168	0.000003	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	0.000000
Yb-170	0.000060	0.000060	0.000060	0.000025	0.000006	0.000002	0.000000	0.000000
Yb-171	0.000283	0.000283	0.000283	0.000120	0.000028	0.000008	0.000000	0.000000
Yb-172	0.000435	0.000435	0.000435	0.000185	0.000044	0.000013	0.000000	0.000000
Yb-173	0.000322	0.000322	0.000322	0.000137	0.000032	0.000010	0.000000	0.000000
Yb-174	0.000639	0.000639	0.000639	0.000272	0.000064	0.000019	0.000000	0.000000
Yb-175	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Yb-176	0.000258	0.000258	0.000258	0.000110	0.000026	0.000008	0.000000	0.000000
Lu-175	0.000779	0.000779	0.000779	0.000341	0.000649	0.000019	0.000000	0.000000
Lu-176	0.000021	0.000021	0.000021	0.000009	0.000017	0.000001	0.000000	0.000000
Hf-174	0.000003	0.000003	0.000003	0.000001	0.000001	0.000000	0.000789	0.000789
Hf-175	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Hf-176	0.000103	0.000103	0.000103	0.000028	0.000022	0.000009	0.025659	0.025659
Hf-177	0.000369	0.000369	0.000369	0.000101	0.000078	0.000031	0.092227	0.092227
Hf-178	0.000544	0.000544	0.000544	0.000150	0.000115	0.000046	0.136071	0.136071
Hf-179	0.000273	0.000273	0.000273	0.000075	0.000058	0.000023	0.068320	0.068320
Hf-180	0.000708	0.000708	0.000708	0.000195	0.000150	0.000060	0.176934	0.176934
Ta-180M	0.000000	0.000000	0.000955	0.000000	0.000000	0.000000	0.000060	0.000060
Ta-181	0.000750	0.000750	7.999045	0.000750	0.000433	0.000350	0.499940	0.499940
W-180	0.000218	0.000218	0.000218	0.000038	0.000090	0.000001	0.000176	0.000176
W-181	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
W-182	0.048413	0.048413	0.048413	0.008459	0.019837	0.000260	0.039043	0.039043
W-183	0.026431	0.026431	0.026431	0.004618	0.010830	0.000142	0.021315	0.021315
W-184	0.057134	0.057134	0.057134	0.009983	0.023411	0.000307	0.046075	0.046075
W-185	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
W-186	0.053804	0.053804	0.053804	0.009401	0.022046	0.000289	0.043390	0.043390
Re-185	0.000000	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	0.000000
Re-187	0.000000	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	0.000000
Os-185	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Os-186	0.000000	0.000000	0.000000	0.000000	0.000010	0.000000	0.000000	0.000000
Os-187	0.000000	0.000000	0.000000	0.000000	0.000010	0.000000	0.000000	0.000000
Os-188	0.000000	0.000000	0.000000	0.000000	0.000084	0.000000	0.000000	0.000000
Os-189	0.000000	0.000000	0.000000	0.000000	0.000102	0.000000	0.000000	0.000000
Os-190	0.000000	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	0.000000

	Concentration (g/kg)							
Isotope	**303 SS**	**304 SS**	**347 SS**	**A-201 Steel**	**Beryllium**	**AGOT Graphite**	**Aluminum 356**	**Aluminum 6061**
Os-192	0.000000	0.000000	0.000000	0.000000	0.000264	0.000000	0.000000	0.000000
Ir-191	0.000000	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	0.000000
Ir-193	0.000000	0.000000	0.000000	0.000000	0.000003	0.000000	0.000000	0.000000
Pt-190	0.000000	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	0.000000
Pt-192	0.000000	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	0.000000
Pt-194	0.000000	0.000000	0.000000	0.000000	0.033323	0.000000	0.000000	0.000000
Pt-195	0.000000	0.000000	0.000000	0.000000	0.034411	0.000000	0.000000	0.000000
Pt-196	0.000000	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	0.000000
Pt-198	0.000000	0.000000	0.000000	0.000000	0.007443	0.000000	0.000000	0.000000
Au-197	0.000000	0.000000	0.000000	0.000000	0.024800	0.000000	0.000000	0.000000
Hg-196	0.000000	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	0.000000
Hg-198	0.000000	0.000000	0.000000	0.000000	0.000402	0.000000	0.000000	0.000000
Hg-199	0.000000	0.000000	0.000000	0.000000	0.000683	0.000000	0.000000	0.000000
Hg-200	0.000000	0.000000	0.000000	0.000000	0.000938	0.000000	0.000000	0.000000
Hg-201	0.000000	0.000000	0.000000	0.000000	0.000539	0.000000	0.000000	0.000000
Hg-202	0.000000	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	0.000000
Hg-204	0.000000	0.000000	0.000000	0.000000	0.000284	0.000000	0.000000	0.000000
Tl-203	0.000000	0.000000	0.000000	0.000000	0.007329	0.000293	0.000000	0.000000
Tl-204	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Tl-205	0.000000	0.000000	0.000000	0.000000	0.017671	0.000707	0.000000	0.000000
Pb-204	0.000276	0.000276	0.000276	0.000689	0.000014	0.000007	0.000083	0.000083
Pb-205	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Pb-206	0.004791	0.004791	0.004791	0.011978	0.000240	0.000115	0.001437	0.001437
Pb-207	0.004415	0.004415	0.004415	0.011037	0.000221	0.000106	0.001324	0.001324
Pb-208	0.010518	0.010518	0.010518	0.026296	0.000526	0.000252	0.003156	0.003156
Bi-209	0.000000	0.000000	0.000000	0.000000	0.000000	0.001000	0.000000	0.000000
Th-232	0.001000	0.001000	0.001000	0.002250	0.000438	0.000050	0.000000	0.000000
U-234	0.000000	0.000000	0.000000	0.000000	0.000002	0.000000	0.000000	0.000001
U-235	0.000014	0.000014	0.000014	0.000011	0.000213	0.000004	0.000003	0.000071
U-236	0.000000	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	0.000000
U-238	0.001986	0.001986	0.001986	0.001489	0.029785	0.000549	0.000437	0.009928

Modeling

The model of the MTR was created for and run in MCNP4C (Reference 9). The model consists of explicitly modeled components and homogenous mixtures in areas deemed appropriate. Dimensions of the model were based on written descriptions as well as various drawings. The core configuration

modeled contained 23 fuel elements and 14 beryllium "L" pieces. The explicitly modeled components include:

- Fuel plates
- Beryllium "L" pieces
- Cd-Be Control Rod
- Cd-U Control Rod
- Beryllium reflector (simplified geometry)
- Aluminum tank (simplified geometry)
- Solid graphite zone (simplified geometry)
- Thermal shields (simplified geometry)
- Biological shield (simplified geometry)
- Thermal column (simplified geometry)
- Bulk shielding (simplified geometry)

The rest of the reactor components were modeled as homogenous mixtures of the major materials in the volume occupied by the component. Concerning the graphite pebble zone, the homogenization was determined by assuming a simple cubic structure for the packing fraction (52%). This ensures a conservative value for the flux in the pebble zone and beyond when considering activation. A cross sectional view of the whole reactor through the vertical core center can be seen in Figure A-4. A close up of the core can be seen in Figure A-5. A cross sectional view through the horizontal centerline is shown in Figure A-6.

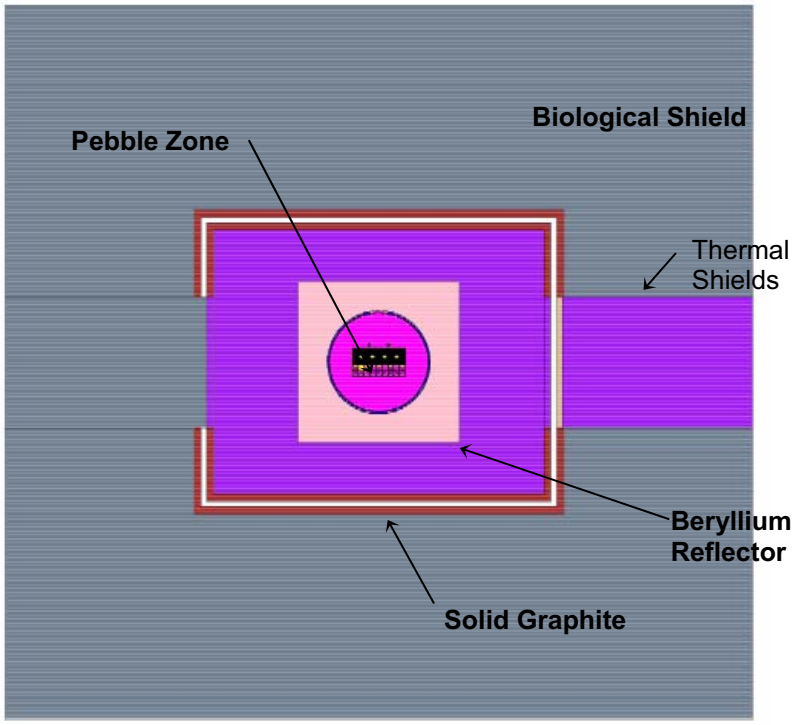

Figure A-4: Reactor cross section showing the biological shield, thermal shields, graphite, and the core internals.

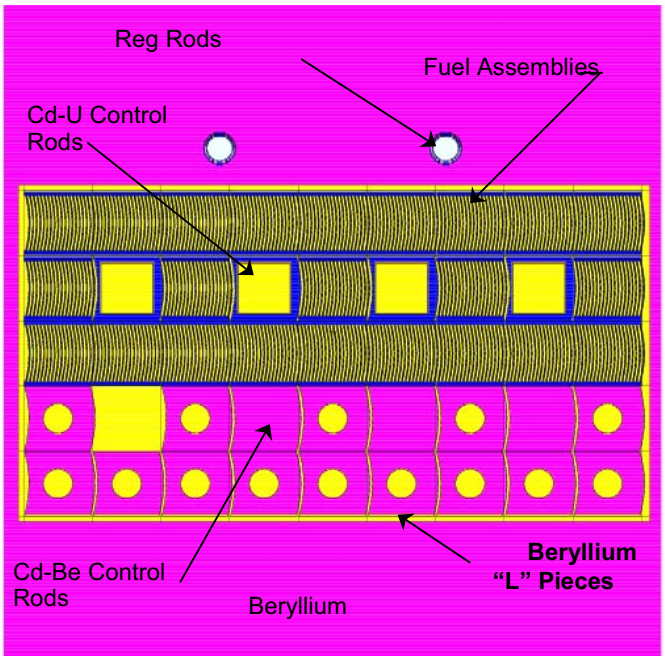

Figure A-5: Reactor cross section showing a close-up of the active core.

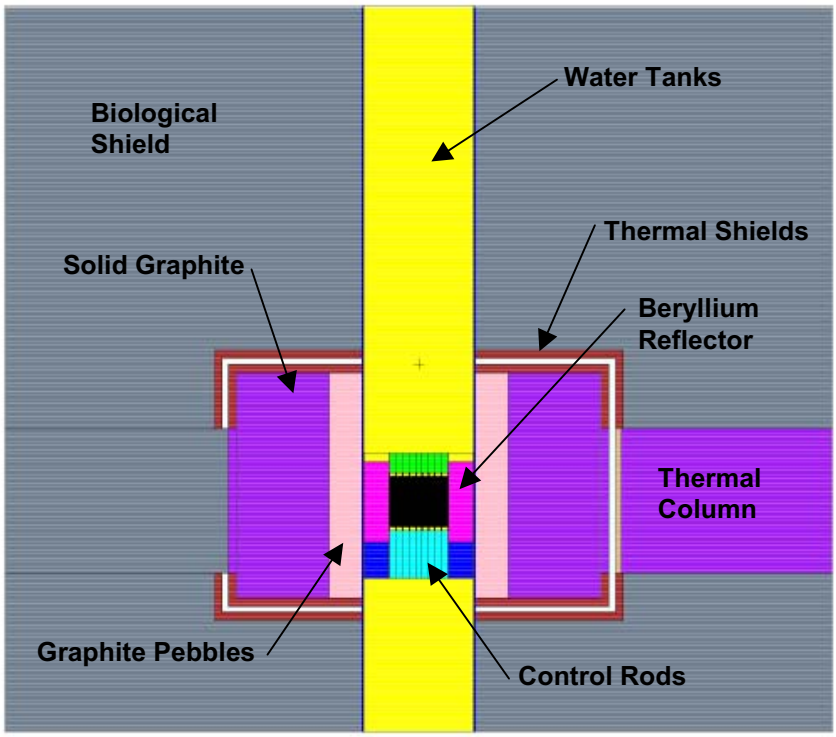

Figure A-6: Vertical cross section of the reactor showing the biological shield, thermal shields, graphite, and the core internals.

The MCNP results show that any significant distance through water decreases the neutron flux to extremely low levels as would be expected. Components at large distances from the core registered little to no flux in the MCNP calculation. Water is the major constituent above and below the core significantly reducing the neutron flux in a very short distance. Radially around the core there is less water, but beryllium is used as a neutron reflector to reflect many of the neutrons back to the core. This also decreases the flux significantly in the radial direction.

A comparison of MCNP results with published data can be made of the neutron flux in experimental facilities. Since an exact comparison cannot be made due to possible core loading differences and operational differences, the following data can only be used as a general comparison. Core loading as well as control rod position will affect the results significantly. It is assumed that the values in the reference are for full power (40 MW) operation. It is also assumed that the flux in the reference is considered representative and not absolute. It is possible that the reactor power in the reference document was only 30 MW and not 40 MW since the original design of the reactor was for 30 MW full power. For this reason the flux calculated by MCNP scaled to 30 MW is also included for reference. It is also possible that the flux value in the reference document is an average over a length of 45.72 cm in the horizontal through hole as compared to the 40.9 cm in the MCNP calculation. It can be seen from Table A-6 that the MCNP result are consistent with the published values in the reference. The thermal flux calculated by MCNP is very close to the value from the reference. It can be inferred from this comparison that the model is an accurate representation of the MTR reactor.

Table A-6: A flux comparison in the HT-1 experimental facility of the MTR.

Horizontal Through Facility Neutron Flux			
	Flux (nt/cm^2-s)		
	MCNP		IAEA
Neutron Energy	30 MW	40 MW	Reference
Thermal Flux (< 0.1 MeV)	2.2E+14	3.0E+14	2E+14
Fast Flux (> 1.0 MeV)	2.2E+13	2.9E+13	3E+13

Below are presented the details of activated structure configuration upon which the MCNP4C and ORIGEN2 modeling were based. These were derived from drawings and reports as part of this study. Table A-7 list the structures that would have been in neutron flux fields high enough to warrant concern.

Table A-7. Details of activated structures.

Graphite Pebble Zone			Average Flux	2.319E+11 nts/cm2-s/MW		
Packing Fraction	Volume (in^3)	Volume (cm^3)	Packing Arrangement	Material	Mass (lb)	Mass (gm)
52%	307565.1	5.040E+06	Simple Cubic	Graphite	18761.5	8.510E+06
64%	378541.6	6.203E+06	Random	Graphite	23091.0	1.047E+07
68%	402200.5	6.591E+06	BCC	Graphite	24534.2	1.113E+07
74%	437688.7	7.172E+06	FCC	Graphite	26699.0	1.211E+07
Doc CF-50-1-30	378404.5	6.201E+06		Graphite	23212.3	1.053E+07
Solid Graphite	Doc: CF-50-1-30		Average Flux	3.498E+10 nts/cm2-s/MW		
Volume (in^3)	1900672.0		Volume (cm^3)	3.115E+07		
Material	Graphite					
Mass (lb)	116592.1		Mass (gm)	5.289E+07		
Heat Shield			Average Flux	8.414E+07 nts/cm2-s/MW		
Volume (in^3)	1034863.9		Volume (cm^3)	1.696E+07		
Material	A201 Steel					
Mass (lb)	289761.9		Mass (gm)	1.314E+08		
Be Reflector			Average Flux	4.985E+12 nts/cm2-s/MW		
Volume (in^3)	71604.3		Volume (cm^3)	1.173E+06		
Material	Be					
Mass (lb)	4797.5		Mass (gm)	2.176E+06		
Lower Support Casting			Average Flux	2.258E+11 nts/cm2-s/MW		
Volume (in^3)	16990.0		Volume (cm^3)	2.784E+05		
Material	6061 Al					
Mass (lb)	1648.0		Mass (gm)	7.475E+05		
Lower Assembly Grid			Average Flux	8.093E+11 nts/cm2-s/MW		
Volume (in^3)	1100.5		Volume (cm^3)	1.803E+04		
Material	6061 Al					
Mass (lb)	106.7		Mass (gm)	4.842E+04		

Lower Cradle		Average Flux	1.079E+09 nts/cm2-s/MW
Volume (in^3)	1030.3	Volume (cm^3)	1.688E+04
Material	6061 Al		
Mass (lb)	99.9	Mass (gm)	4.533E+04
Lower Guide Grid		Average Flux	1.079E+09 nts/cm2-s/MW
Volume (in^3)	608.1	Volume (cm^3)	9.965E+03
Material	6061 Al		
Mass (lb)	59.0	Mass (gm)	2.675E+04
Upper Support Casting		Average Flux	2.168E+09 nts/cm2-s/MW
Volume (in^3)	3711.8	Volume (cm^3)	6.082E+04
Material	6061 Al		
Mass (lb)	360.0	Mass (gm)	1.633E+05

Upper Grid Assembly		Average Flux	2.168E+09 nts/cm2-s/MW
Volume (in^3)	2703.9	Volume (cm^3)	4.431E+04
Material	6061 Al		
Mass (lb)	262.3	Mass (gm)	1.190E+05
C to D Tank Adapters		Average Flux	2.145E+10 nts/cm2-s/MW
Volume (in^3)	418.8	Volume (cm^3)	6.863E+03
Material	SS 303		
Mass (lb)	121.5	Mass (gm)	5.509E+04
D to E Tank Adapters		Average Flux	2.457E+11 nts/cm2-s/MW
Volume (in^3)	522.5	Volume (cm^3)	8.562E+03
Material	SS 303		
Mass (lb)	151.5	Mass (gm)	6.873E+04
Monitor Tube		Average Flux	1.002E+11 nts/cm2-s/MW
Volume (in^3)	2550.4	Volume (cm^3)	4.179E+04
Material	SS 304		
Mass (lb)	739.6	Mass (gm)	3.355E+05

Discharge Chute		Average Flux	4.825E+10 nts/cm2-s/MW
Volume (in^3)	436.1	Volume (cm^3)	7.146E+03
Material	SS 304		
Mass (lb)	126.4	Mass (gm)	5.737E+04
"C" Tank		Average Flux	1.501E+10 nts/cm2-s/MW
Volume (in^3)	8939.0	Volume (cm^3)	1.465E+05
Material	356 Al		
Mass (lb)	867.1	Mass (gm)	3.933E+05
"D" Tank		Average Flux	5.254E+11 nts/cm2-s/MW
Volume (in^3)	13029.7	Volume (cm^3)	2.135E+05
Material	356 Al		
Mass (lb)	1263.9	Mass (gm)	5.733E+05
"E" Tank		Average Flux	5.059E+09 nts/cm2-s/MW
Volume (in^3)	12723.4	Volume (cm^3)	2.085E+05
Material	SS 304		
Mass (lb)	3689.8	Mass (gm)	1.674E+06

Results

Table A-8. Results (Ci) of activation calculations for various structures in the MTR as of January 2005.

Isotope	Be Reflector	"C" to "D" Tank Adapters	"D" to "E" Tank Adapters	"C" Tank	"D" Tank	"E" Tank	Graphite Balls	Graphite Blocks	Heat Shield Plates	Monitor Tubes	Non-Tank Aluminum Structures (all)	Discharge Chute
H-3	1.37E+02	1.33E-02	1.56E-01	2.57E+00	7.14E+01	9.65E-02	3.15E-03	1.09E-04	2.92E-01	3.56E-01	5.14E-04	2.79E-02
Be-10	4.51E-02	5.34E-09	7.07E-08	1.50E-06	1.73E-07	2.37E-08	6.16E-03	4.67E-03	8.64E-08	8.76E-08	3.00E-07	5.80E-09
C-14	3.60E-01	0.01591	0.2271	8.51E-04	4.33E-02	1.14E-01	1.14E+00	8.65E-01	2.66E-02	4.52E-01	3.01E-02	2.61E-02
Cl-36	4.66E-03	1.26E-04	1.79E-03	2.73E-11	4.81E-08	9.06E-04	1.11E-02	8.47E-03	1.06E-03	3.58E-03	1.16E-08	2.70E-04
Mn-54	4.45E-12	2.64E-12	3.76E-11	5.31E-14	4.42E-13	2.17E-11	1.17E-13	8.87E-14	4.00E-11	8.59E-11	4.68E-12	7.18E-12
Ni-59	4.58E-03	8.87E-02	1.21E+00	3.37E-04	1.54E-02	6.38E-01	1.38E-03	1.10E-03	5.55E-02	2.48E+00	2.79E-03	3.35E-02
Co-60	9.28E-02	1.12E+00	1.57E+01	6.62E-03	2.41E-02	8.06E+00	6.42E-01	4.95E-01	6.44E-01	3.17E+01	1.28E-01	1.41E+00
Ni-63	5.05E-01	8.99E+00	1.27E+02	4.87E-02	2.38E+00	6.45E+01	1.47E-01	1.13E-01	5.67E+00	2.55E+02	1.36E+00	3.42E+00
Zn-65	1.84E-15	4.91E-18	7.36E-17	4.89E-17	2.52E-16	3.51E-17	1.01E-16	7.66E-17	7.09E-18	1.42E-16	3.02E-14	1.05E-17
Sr-90	3.80E-02	4.16E-05	1.19E-03	9.51E-04	4.08E-03	2.68E-04	3.73E-02	1.81E-02	2.59E-04	1.68E-03	2.54E-05	1.03E-04
Nb-94	1.09E-03	2.18E-04	3.08E-03	4.50E-05	2.23E-03	1.55E-03	6.42E-03	4.90E-03	4.06E-04	6.12E-03	1.57E-04	2.69E-02
Tc-99	1.69E-05	2.03E-04	2.84E-03	4.55E-07	4.33E-06	6.11E-05	4.44E-06	1.28E-05	1.30E-04	2.37E-04	8.43E-07	1.84E-05
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
Ru-106	3.67E-11	3.65E-15	3.31E-13	6.92E-14	4.11E-13	1.02E-14	1.26E-11	2.30E-12	5.04E-15	3.53E-13	8.31E-15	1.49E-14
Ag-108m	4.51E-03	1.66E-04	2.35E-03	1.05E-10	1.81E-07	1.19E-03	8.17E-02	6.25E-02	3.12E-03	4.72E-03	4.43E-08	3.56E-04
Ag-110m	2.18E-15	2.98E-18	3.72E-17	7.34E-23	8.73E-21	2.16E-17	1.30E-15	1.11E-15	5.65E-17	8.09E-17	2.88E-21	6.28E-18
Sb-125	1.47E-05	1.50E-06	2.16E-05	1.82E-06	5.44E-05	1.08E-05	3.32E-05	2.40E-05	1.65E-08	4.28E-05	6.44E-05	3.22E-06
I-129	3.35E-07	4.34E-11	2.43E-09	9.10E-10	1.18E-08	2.18E-10	8.27E-08	2.16E-08	3.47E-08	2.77E-09	5.38E-11	1.35E-10
Cs-134	2.43E-05	9.97E-08	1.36E-06	1.47E-10	1.96E-08	7.17E-07	6.57E-04	5.19E-04	8.37E-13	2.79E-06	7.04E-11	2.12E-07
Cs-137	8.15E-02	5.38E-05	2.31E-03	1.19E-03	1.07E-02	3.07E-04	8.04E-02	2.57E-02	2.82E-04	2.83E-03	5.35E-05	1.51E-04
Ce-144	1.20E-13	7.54E-18	3.19E-16	1.64E-16	1.88E-16	4.19E-17	1.08E-14	3.58E-15	3.82E-17	4.04E-16	7.23E-18	2.15E-17
Eu-152	3.77E+00	1.97E-03	4.11E-03	1.68E-07	5.45E-06	1.67E-02	3.46E-01	1.35E+00	1.39E-01	2.63E-02	3.69E-08	3.22E-03
Eu-154	2.83E-01	1.18E-04	1.97E-03	1.19E-07	5.14E-05	8.38E-04	5.69E-01	1.57E-01	6.61E-03	3.57E-03	8.22E-08	2.57E-04
Pb-210	1.48E-11	9.00E-14	6.03E-13	2.70E-12	1.81E-13	2.40E-12	7.26E-12	2.11E-11	1.36E-10	1.09E-12	4.05E-15	1.08E-13
Ra-226	5.23E-11	2.31E-13	1.48E-12	7.09E-12	4.96E-13	6.27E-12	1.84E-11	5.51E-11	3.59E-10	2.72E-12	1.07E-14	2.74E-13

Isotope	Be Reflector	"C" to "D" Tank Adapters	"D" to "E" Tank Adapters	"C" Tank	"D" Tank	"E" Tank	Graphite Balls	Graphite Blocks	Heat Shield Plates	Monitor Tubes	Non-Tank Aluminum Structures (all)	Discharge Chute
Ac-227	3.68E-08	1.81E-09	2.29E-08	3.47E-11	2.49E-12	1.32E-08	1.67E-07	1.41E-07	4.06E-08	4.94E-08	5.24E-14	3.82E-09
Th-228	3.72E-07	1.47E-08	1.27E-06	5.64E-11	2.64E-10	1.98E-07	8.76E-06	1.39E-06	3.23E-05	1.14E-06	1.39E-12	4.69E-08
Th-229	5.21E-08	2.91E-09	3.28E-08	2.59E-15	1.26E-14	2.12E-08	2.40E-07	2.24E-07	6.27E-08	7.60E-08	6.40E-17	6.04E-09
Th-230	6.90E-09	1.95E-11	1.17E-10	6.26E-10	5.00E-11	5.47E-10	1.53E-09	4.78E-09	3.16E-08	2.13E-10	9.41E-13	2.21E-11
Th-232	1.04E-07	6.04E-09	7.43E-09	2.16E-17	3.07E-17	1.84E-07	5.69E-08	2.90E-07	3.24E-05	3.66E-08	3.19E-19	5.73E-09
Pa-231	5.51E-08	2.42E-09	3.06E-08	6.66E-11	3.73E-12	1.75E-08	2.23E-07	1.88E-07	5.52E-08	6.58E-08	9.08E-14	5.09E-09
U-232	2.64E-07	8.45E-09	1.23E-06	5.49E-11	2.57E-10	1.44E-08	8.47E-06	1.07E-06	7.25E-10	1.08E-06	1.35E-12	4.01E-08
U-233	1.59E-05	7.02E-07	7.87E-06	5.00E-13	3.67E-12	5.13E-06	5.77E-05	5.42E-05	1.52E-05	1.83E-05	1.61E-14	1.46E-06
U-234	2.18E-05	3.79E-08	1.89E-07	1.32E-06	1.56E-07	1.13E-06	2.90E-06	9.82E-06	6.66E-05	3.48E-07	2.02E-09	3.95E-08
U-235	9.42E-07	1.61E-09	1.21E-09	5.84E-08	1.20E-09	5.09E-08	5.29E-08	4.15E-07	3.03E-06	8.22E-09	5.85E-11	1.44E-09
U-236	3.04E-07	3.95E-10	4.44E-09	9.94E-09	1.32E-08	2.88E-09	1.80E-07	1.69E-07	2.84E-09	1.03E-08	1.47E-10	8.22E-10
U-238	2.17E-05	3.67E-08	4.44E-08	1.31E-06	7.89E-08	1.12E-06	1.88E-06	9.71E-06	6.58E-05	2.21E-07	1.87E-09	3.48E-08
Np-237	6.63E-08	8.26E-11	5.00E-09	1.97E-09	3.38E-08	5.30E-10	1.90E-07	3.99E-08	5.25E-10	4.59E-09	1.18E-10	2.22E-10
Pu-238	1.37E-05	1.79E-08	4.35E-05	2.76E-07	6.83E-04	2.33E-08	1.53E-03	1.71E-05	3.83E-10	1.08E-05	6.81E-07	1.57E-07
Pu-239	1.40E-02	1.83E-05	1.58E-04	4.64E-04	3.75E-04	1.36E-04	6.49E-03	7.65E-03	1.37E-04	4.31E-04	5.58E-06	3.66E-05
Pu240	1.07E-03	1.10E-06	9.20E-05	1.95E-05	3.69E-04	1.95E-06	3.61E-03	7.41E-04	3.27E-08	1.14E-04	2.52E-06	4.85E-06
Pu-241	3.71E-03	2.35E-06	2.00E-03	2.94E-05	1.30E-02	9.94E-07	7.46E-02	2.57E-03	2.78E-10	1.10E-03	4.20E-05	2.31E-05
Pu-242	7.48E-09	4.15E-12	4.64E-08	3.62E-11	8.42E-07	4.10E-13	1.62E-06	7.47E-09	1.90E-18	9.53E-09	6.92E-10	9.33E-11
Pu-244	1.22E-17	1.06E-22	1.74E-16	4.53E-22	1.64E-14	5.80E-25	5.38E-15	5.13E-19	7.40E-34	5.54E-18	1.37E-18	1.23E-20
Am-241	5.15E-04	4.26E-07	3.63E-04	5.33E-06	2.66E-03	1.80E-07	1.35E-02	4.66E-04	5.03E-11	1.99E-04	7.62E-06	4.19E-06
Am-243	1.23E-09	5.48E-13	7.15E-08	3.34E-12	2.81E-06	1.28E-14	2.35E-06	1.61E-09	9.81E-22	5.92E-09	7.83E-10	2.78E-11
CM-243	1.48E-10	5.32E-13	6.04E-08	3.26E-12	1.86E-06	1.25E-14	2.01E-06	1.55E-09	9.65E-22	5.49E-09	6.90E-10	2.66E-11
CM-244	1.16E-09	3.61E-13	5.82E-07	1.54E-12	4.90E-05	1.97E-15	1.80E-05	1.74E-09	2.52E-24	1.87E-08	4.61E-09	4.16E-11
CM-245	1.11E-14	2.86E-18	4.62E-11	8.56E-18	7.74E-09	3.72E-21	1.36E-09	2.23E-14	7.92E-32	6.60E-13	2.80E-13	7.29E-16
CM-246	8.86E-17	1.74E-20	3.48E-12	3.64E-20	1.37E-09	5.31E-24	9.61E-11	2.22E-16	1.88E-36	1.93E-14	1.53E-14	1.01E-17
CM-247	5.63E-24	8.49E-28	2.02E-18	1.24E-27	1.76E-15	6.10E-32	5.25E-17	1.77E-23	0.00E+00	4.46E-21	6.47E-21	1.11E-24
CM-248	3.23E-25	3.75E-29	1.07E-18	3.83E-29	2.13E-15	6.33E-34	2.63E-17	1.28E-24	0.00E+00	9.38E-22	2.51E-21	1.11E-25
Total	1.43E+02	1.02E+01	1.44E+02	2.63E+00	7.41E+01	7.35E+01	3.17E+00	3.12E+00	6.83E+00	2.90E+02	1.52E+00	4.94E+00

Code Usage

The two computer codes formed the basis for the activation calculations in the present work. These are MCNP4C and ORIGEN2 (Reference 10).

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.

Uncertainty

The total uncertainty associated with the estimated neutron activation product inventory for MTR 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).

The fundamental uncertainty in the ORIGEN2 code is at least 10%. For the MTR 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. 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.

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Appendix B

Air Contaminated Surface Activity

The following analysis was performed by Glen R. Longhurst:

Background

Air passing over the graphite balls was ultimately carried through a 4 ft diameter exhaust duct. That duct emptied into the Exhaust Air Duct Pit, located in TRA-635, and then continued to the Fan House (TRA-607). Smear samples were taken in the Exhaust Air Duct Pit after reactor shutdown in 1970 and prior to 1984. This sampling probably took place in 1979. Analysis of the smear samples revealed that (From Reference 1):

> Contamination levels of smears taken in the pit area were (a) 10,500 dpm near the pit floor, (b) 8,000 dpm at the pit sump, (c) 6,000 dpm inside the north air duct, (d) 1,790 1,390, and 1,000 dpm on the walls about halfway up, and (e) 820, 730, and 636 dpm near the top of the hatchway.
>
> "Contamination in the pit area was beta and gamma. No alpha contamination was found. Radioisotopic analysis of smears indicates that the nuclides remaining in the pit were cesium-137 and cobalt-60 and a minute trace (0.000048 microcuries) of cobalt-57.

Of these, one pertinent measurement was (c) 6,000 dpm inside the north air duct, air passing that point having just come from the reactor. The beta-gamma survey taken at that location indicated 70 mR/h.[i]

The presence of the Co-60 was surprising since the air did not encounter any significantly activated metals in its path through the MTR except the graphite. It had been speculated at the time that one source of Co-60 may have been (n,α) reactions on Cu-63 from bearings and other wearing surfaces (Reference 2). Another possible source is activation of trace Co-59 in the graphite itself, Co is naturally 100% Co-59, which activates with a 100-barn cross section to Co-60. Trace Co impurities have been reported for graphite. Research on two other graphite grades, H-451 and TS-1240, showed Co impurity levels could be as high as 4 mg/kg but are more typically less than 1 mg/kg (Reference 3). Measurements made on AGOT graphite believed to be identical with that used in the MTR showed Co impurity to be 0.48 mg/kg (Reference 4). Assuming the Co-59 concentration in MTR graphite of 0.48 mg/kg, MCNP4C and ORIGEN2 calculations indicated the expected Co-60 activity in 2005 in a 19-g graphite ball at the top of the pebble reflector would be 8.0 mCi. If all disintegrations on the air duct surface were Co-60 and all the material came from the top of the reflector, the graphite on the smear sample would correspond to a graphite coating of 1.5 $\mu g/cm^2$. Another possibility, however, is that the Co-60 came from water leakage from the reactor vessel tanks. Such could possibly have taken place through bolted flange joints between barrel sections or through cracks in the bellows connecting some barrel sections. During an attempt to remove the graphite balls from the reactor in early 2007, water was discovered in the graphite ball discharge chute.

The additional presence of Cs-137 on the air duct wall may indicate the existence of uranium impurity in the graphite. Another possibility, however, is that both the Co-60 and Cs-137 came from leakage of primary coolant water from the reactor vessel tanks into the graphite ball reflector region. Because measurements on the AGOT graphite determined that uranium contamination was only approximately 0.6 mg/kg and with the discovery of water in the graphite ball discharge chute, the leakage explanation seems more plausible.

The graphite balls and the graphite blocks are all considered to have surface contamination and are counted in the area exposed to air.

Methodology

Contamination on the internal surfaces of ducts and pipes was based on estimates of surface area and measurements taken previously. Surface gamma measurements and scaling factors developed were used to give inventories from gamma measurements. It was assumed that internal surface contamination was represented by a measurement inside the air tunnel, which was 6,000 dpm/100cm^2 in 1979 (6.0E06 dpm/100 cm^2 if an assumed

collection efficiency of 0.001 is used). Measurements made inside the MTR in March of 1983 (Reference 1) suggest a Co-60/Cs-137 ratio of 100 at that time. In 1979, that ratio would have been about 158, so nearly all the gamma signal would be from Co-60. In 1996, that ratio would have been about 20.1. The specific activity of Co-60 in 1996 is then estimated from its value in 1979 as follows:.

$$\frac{6\times10^{6}\ (dpm)}{100\left(cm^{2}\right)}\exp\left(-\frac{17\ln(2)}{5.271}\right)\times\frac{10^{4}\left(cm^{2}\right)}{\left(m^{2}\right)}\times\frac{1\,(Ci)}{2.22\times10^{12}\ (dpm)}=2.49\times10^{-5}\left(\frac{Ci}{m^{2}}\right)$$

The 1996 Cs-137 activity would have been that value divided by 20.1 or 1.24E-06 Ci/m^2".

Once the 1996 values for Co-60 and Cs-137 were determined, scaling factors (discussed below) were used to determine the activity values of the remaining radionuclides. The 1996 activity values were then decayed to 2005 for use in the calculations. These activity values are shown in Table B-1.

Table B-1. Specific activities (Ci/m^2 in 2005) assumed for air-exposed surfaces within the MTR reactor.

	C-14	Co-60	Ni-63	Sr-90	I-129	Cs-137
1996 Activity	8.07E-07	2.49E-05	3.66E-07	8.58E-08	1.33E-10	1.24E-06
2005 Activity	8.06E-07	7.83E-06	3.44E-07	6.96E-08	1.33E-10	1.01E-06

The collection efficiency referenced above is a ratio to convert loose surface contamination measurements to total surface contamination. The value (0.001) is based on work performed in developing EDF-4697 (Reference 5), *Radiological Characterization of the PBF Reactor for Disposal.* The authors of that EDF established this ratio based on a comparison of in-situ gamma spectroscopy measurements (total contamination) to swipe surveys (loose contamination) performed at the same location in the Power Burst Reactor Facility.

The scaling factors referenced above and used to calculate the radionuclide inventories based on gamma measurements were taken from EDF-TRA-ATR-1405-R1 (Reference 6) *Dose Rate To Curie Conversion Factors for Waste Generated at the Test Reactor Area (TRA)*,1998. These scaling factors are presented in Table B-2.

Table B-2 Radionuclide Scaling Factors

Radionuclide	Ratio	Scaling Factor
Ni-63	Ni-63/Co-60	1.47E-02
C-14	C-14/Co-60	3.24E-02
I-129	I-129/Cs-137	1.07E-04
Sr-90	Sr-90/Cs-137	6.93E-02
Gross alpha	Gross alpha/Cs-137	8.27E-03

Results

Table B-3 presents the estimated air-exposed contaminated surface area and the radionuclide activity calculated for these surfaces.

Table B-3. Air-Exposed Contaminated Surface Area and Radionuclide Activity

Air-Exposed Surfaces	Area (m^2)	C-14 (Ci)	Co-60 (Ci)	Ni-63 (Ci)	Sr-90 (Ci)	I-129 (Ci)	Cs-137 (Ci)	Total (Ci)
Air Duct Header Box (4)	18.7	1.50E-05	1.46E-04	6.43E-06	1.30E-06	2.47E-09	1.89E-05	1.94E-04
Air Duct Down-comer (22)	130.8	1.05E-04	1.02E-03	4.50E-05	9.11E-06	1.73E-08	1.32E-04	1.36E-03
Thermal Barrier Gaps (4)	128	1.03E-04	1.00E-03	4.41E-05	8.91E-06	1.70E-08	1.30E-04	1.33E-03
Sub-Graphite Channels	63.4	5.11E-05	4.97E-04	2.18E-05	4.42E-06	8.41E-09	6.42E-05	6.60E-04
Graphite Block Surface (3,248)	1284.3	1.04E-03	1.01E-02	4.42E-04	8.94E-05	1.70E-07	1.30E-03	1.34E-02
Graphite Pebble Surface (722K)	1464.6	1.18E-03	1.15E-02	5.04E-04	1.02E-04	1.94E-07	1.48E-03	1.52E-02
Above Graphite Space	15.9	1.28E-05	1.24E-04	5.46E-06	1.10E-06	2.10E-09	1.61E-05	1.65E-04
Air Ducts (2)	80.3	6.47E-05	6.28E-04	2.76E-05	5.59E-06	1.06E-08	8.12E-05	8.35E-04

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Appendix C

Water Contaminated Surface Activity

The following analysis was performed by Glen R. Longhurst:

Background

The main core tank assembly consists of tanks "A" through "E" and were filled with water during MTR operation. The internal surface area of those tanks is approximately 219 m^2 (2,362 ft^2). That number includes estimates for nozzles, protrusions, primary coolant pipes (inside the biological shield), process water lines, etc., but it does not include the surface area of the core itself or the reflector.

Two 24-inch diameter primary coolant pipes carried water between the reactor and the Process Water Building (TRA-605). Those lines have been drained for over 20 years, but they probably have some residual contamination on their surfaces. The parts of those pipes beyond the biological shield are not included in this analysis. Areas of those pipes within the perimeter are included in the surface area values.

Methodology

Surfaces inside the tank sections and the coolant ducts were exposed to primary-coolant water. These are probably relatively clean. However, for conservatism, it is assumed that the activity on those surfaces was the same as in the dry canal in the sub-pile room. It measured 230,000 dpm/100 cm^2 in 1983 (Reference 1). The major nuclides on this surface were Cs-137 and Co-60 with no alpha-emitters found. Gamma measurements on MTR canal water in 2004 showed (9.21 +/- .67)E-01 (pCi/mL) of Co-60, (4.26 +/- .39)E-01 (pCi/mL) of Cs-134, and (3.41 +/- .24)E+03 (pCi/mL) of Cs-137 (Reference 2). The Cs-137 in the water is orders of magnitude more, relative to Co-60, than is shown in Table B-1 for the air exposed surfaces. It is probable that it came from other sources, such as PBF test trains, where there were considerable inventories of fission fragments. Hence, a reasonable assumption for water-exposed surfaces in MTR follows the logic of Table B-1 but is scaled to the higher count rates in the canal in 1983. A count rate of 230,000 dpm/100 cm^2 equates to a surface activity of 1.036E-02 Ci/m^2 once the assumed collection efficiency of 0.001 is factored in.

The following summarizes the methodology that was used to determine the water exposed surface contamination levels:

- 2005 air exposed surface activity values for Co-60 and Cs-137 were reverse decayed to 1998 activity values.
- The 1998 activity values for Co-60 and Cs-137 were then multiplied by the scaling factors from EDF-TRA-ATR-1405-R1 (Reference 3), shown in Table B-2, to obtain 1998 activity values for the remaining radionuclides (C-14, Ni-63, Sr-90, & I-129).
- The 1998 activity value for each nuclide was then reverse decayed to produce 1983 activity values.
- The surface activity values for each radionuclide were then summed to give a total surface activity value. This calculated value is 1.66E-04 Ci/cm^2.
- The above "total surface activity value" represent the activity on an air contaminated surface. To correct the activity values to the higher activity water contaminated surfaces, the 1983 activity values are multiplied by the ratio of water contaminated surface activity, 230,000 dpm/100 cm^2 (1.036E-02 Ci/m^2) to the air contaminated surface activity, 1.66E-04.
- The activity values for each radionuclide were then decayed to 2005 values. The results of these calculations are shown in Table C-1.

Table C-1. Specific activities (Ci/m^2) for the water-exposed surfaces within the MTR reactor.

	C-14	Co-60	Ni-63	Sr-90	I-129	Cs-137	Total
1998	7.20E-07	2.22E-05	3.27E-07	2.18E-07	3.37E-10	3.15E-06	2.66E-05
1983 (Relative)	7.21E-07	1.60E-04	3.62E-07	3.12E-07	3.37E-10	4.44E-06	1.66E-04
2005 Activity	4.50E-05	5.54E-04	1.95E-05	1.16E-05	2.11E-08	1.68E-04	7.98E-04

- The 2005 values in Table C-1 are then multiplied by the calculated surface area of the water contaminated components to obtain a total activity value for each radionuclide.

Results

Table C-2 presents the water-exposed contaminated surface area and the associated radionuclide activity values

Table C-2. Water-Exposed Contaminated Surface Area and Radionuclide Activity

Water-Exposed Surfaces	Area (m^2)	C-14 (Ci)	Co-60 (Ci)	Ni-63 (Ci)	Sr-90 (Ci)	I-129 (Ci)	Cs-137 (Ci)	Total (Ci)
Tank A Extension	3.37	1.52E-04	1.86E-03	6.56E-05	3.89E-05	7.10E-08	5.65E-04	2.69E-03
Tank A	21.12	9.50E-04	1.17E-02	4.11E-04	2.44E-04	4.45E-07	3.54E-03	1.68E-02
Tank B	3.13	1.41E-04	1.73E-03	6.09E-05	3.62E-05	6.60E-08	5.25E-04	2.50E-03
Tank C	6.23	2.80E-04	3.45E-03	1.21E-04	7.20E-05	1.31E-07	1.04E-03	4.97E-03
Tank D	8.71	3.92E-04	4.82E-03	1.70E-04	1.01E-04	1.84E-07	1.46E-03	6.95E-03
Tank E	8.41	3.79E-04	4.66E-03	1.64E-04	9.72E-05	1.77E-07	1.41E-03	6.71E-03
Primary Coolant Inlet	58.72	2.64E-03	3.25E-02	1.14E-03	6.78E-04	1.24E-06	9.85E-03	4.68E-02
Primary Coolant Outlet	79.97	3.60E-03	4.43E-02	1.56E-03	9.24E-04	1.69E-06	1.34E-02	6.38E-02
Inlet Process Water Lines (2)	0.97	4.38E-05	5.39E-04	1.89E-05	1.12E-05	2.05E-08	1.63E-04	7.76E-04
HB-2, -5 Thimbles	0.21	9.67E-06	1.19E-04	4.18E-06	2.48E-06	4.53E-09	3.60E-05	1.71E-04
HB-1, -3, -4, -6 Thimbles	0.48	2.17E-05	2.67E-04	9.39E-06	5.57E-06	1.02E-08	8.09E-05	3.85E-04
DB-2, -5 Thimbles	0.10	4.63E-06	5.70E-05	2.00E-06	1.19E-06	2.17E-09	1.73E-05	8.21E-05
DB-1, -3, -4, -6 Thimbles	0.23	1.04E-05	1.28E-04	4.50E-06	2.67E-06	4.87E-09	3.87E-05	1.84E-04
Top Plug	2.55	1.15E-04	1.41E-03	4.97E-05	2.95E-05	5.38E-08	4.28E-04	2.04E-03
Bottom Plug	1.49	6.71E-05	8.26E-04	2.90E-05	1.72E-05	3.14E-08	2.50E-04	1.19E-03
Discharge Chute	3.20	1.44E-04	1.77E-03	6.23E-05	3.70E-05	6.75E-08	5.37E-04	2.55E-03
Lower Support Assembly	5.31	2.39E-04	2.94E-03	1.03E-04	6.13E-05	1.12E-07	8.90E-04	4.23E-03
Upper Support Assembly	5.31	2.39E-04	2.94E-03	1.03E-04	6.13E-05	1.12E-07	8.90E-04	4.23E-03
Spider Support Ring	8.51	3.83E-04	4.71E-03	1.66E-04	9.83E-05	1.79E-07	1.43E-03	6.79E-03
Shim Safety Rod Shock Absorbers	1.36	6.13E-05	7.54E-04	2.65E-05	1.57E-05	2.87E-08	2.28E-04	1.09E-03
							Total	1.75E-01

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Appendix D

Building Contaminated Surface Activity

The following analysis was performed by Glen R. Longhurst:

Background

Surfaces associated with the MTR facility were characterized in WM-Fl-33-016 (Reference 1), C*haracterization of the Materials Testing Reactor*. This documented identified the following contaminated areas:

- **TRA-603 -**The radiologically contaminated surface areas identified in building TRA-603 are , the reactor top, the Subpile Room, the Hot Waste Tank Pit, the Process Sump Pit, the Canal Sump Pit, and the Primary Pipe Tunnel. No other radiological contaminated areas were noted in building TRA-603 itself.
- **TRA-604 –** The only identified source of activity associated with this building is the Hot Waste pipe located in the overhead of the basement level
- **TRA-610** – Surveys reported general contamination
- **TRA-630** - There was no activity information available for the Catch Tank Pump Pit (TRA-630). It was not characterized in 1984 because it was in service. A conservative estimate is that it will be contaminated to the same degree as the hot waste storage pump pit (TRA-613A) where the general field reading was 30 mR/hr. There were hot spots up to 70 mR/hr. Two such hot spots were arbitrarily assumed TRA-630.
- **TRA-635** - The only contaminated area associated with this building is the air duct pit under the north end of the building.
- **TRA-657 -** The Plug Storage Facility was sampled by smear surveys inside the tubes used to store the MTR beam port plugs. Tubes were found to be intact, so any surface contamination should only be inside the tubes. No measurements were made in tubes 1,2, and 15. A conservative reading of 10,000 dpm/100 cm^2 was assumed for those tubes.
- **TRA-710** - This is the MTR stack. It is in continuous service and contains some residual radioactivity.

Methodology

The methodology used to determine the activity values in the surface contamination on surfaces outside of the reactor was as follows:

- Conversion factors (Ci/mR/hr) for waste in a 33” x 40” poly bag presented in TRA-ATR-1405 (Reference 2) were used as a starting point. Those conversion factors calculated for waste in a 33” x 40” poly bag, with an assumed proximity of ½ in. from the detector to the bag, most nearly represent readings taken through air near surfaces and hot spots in the facility.” These conversion factors are presented in Table D-1.

Table D-1. Scaling of dose to inventory in the MTR facility as of 1998.

Radionuclide	Scaling Factor (Ci/mR/hr)
Total gamma	2.21E-04
Ni-63	2.34E-07
C-14	5.15E-07
I-129	2.19E-08
Sr-90	1.42E-05
Gross alpha	1.69E-06
Co-60	1.59E-05
Cs-137	2.05E-04

- The conversion factors were developed in 1998 using 1996 data. The measurements in the characterization report were made in early 1984. By back decaying the Cs-137 and Co-60 activities to 1984 and making use of the known gamma energies, the total gamma level that would have been seen in 1984 and the corresponding activities of other isotopes as they would have been seen in 1984 per unit gamma flux in 1984 ca be determined. Those inventories can then be decayed to 2005 to show current inventories. The results of these calculations are shown in Table D-2.

Table D-2. Conversions in determining 2005 surface activities based on 1984 measurements

Radionuclide	1996 Activity (Ci/mR/hr in 96)	Gamma Energy (MeV)	Gamma Dose (MeV/s in 96 per mR/hr in 96)	Isotope Half Life (yr)	1984 Activity (Ci/mR/hr in 96)	Gamma Dose (MeV/s in 84 per mR/hr in 96)	Ci in 84 per mR/hr in 84	2005 Activity (Ci/mR/hr in 84)
Total gamma	2.21E-04		7.42E+06		3.47E-04	1.51E+07		8.44E-05
Ba-137m*	1.95E-04	0.661	4.77E+06		2.57E-04	6.28E+06	1.26E-04	7.80E-05
Ni-63	2.34E-07	no gamma		100	2.54E-07		1.25E-07	1.08E-07
C-14	5.15E-07	no gamma		5730	5.16E-07		2.54E-07	2.53E-07
I-129	2.19E-08	0.0396	3.21E+01	1.57E+07	2.19E-08	3.21E+01	1.08E-08	1.08E-08
Sr-90	1.42E-05	no gamma		29.1	1.89E-05		9.30E-06	5.64E-06
Y-90*	1.42E-05	2.1862	1.15E+06		1.89E-05	1.53E+06	9.30E-06	5.64E-06
Gross alpha	1.69E-06				1.69E-06		1.69E-06	1.69E-06
Co-60	1.59E-05	2.55	1.50E+06	5.271	7.70E-05	7.27E+06	3.79E-05	2.39E-06
Cs-137	2.05E-04	no gamma		30.17	2.70E-04		1.33E-04	8.20E-05

- The calculated Ci/mR/hr conversion factors were then normalized to the total gamma value to determine fractions of each radionuclide in the surface contamination measurements.
- Activity values for the nuclides in each area were then determined by multiplying the measured contamination level (dpm/100 cm^2) by the assumed swipe to total contamination conversion factor (1000), then multiplied by the normalized Ci/mR/hr value for the nuclide, and finally multiplied by the surface area of the location.
- Since low levels of alpha contamination have been identified on some MTR surfaces and since only a gross alpha value is presented in Table D-1, the following methodology was used to assign the gross alpha activity to the most abundant alpha emitters associated with the MTR:

  - The alpha emitting radionuclides in the MTR reactor with the highest activity determined in Appendix A are Am-241, Pu-238, Pu-239, & Pu-240. The activity of these four radionuclides in the MTR reactor are presented in Table D-3.

Table D-3. Most Abundant Alpha Emitting Radionuclides in the MTR Reactor

Nuclide	Activity (Ci)
Pu-238	1.73E-02
Pu-239	3.80E-02
Pu240	1.40E-02
Am-241	7.45E-02

- The gross alpha activity is assigned to the above four alpha emitting radionuclides based on the relative percentage of the activity of each of these radionuclides. The relative percentage of each of these nuclides is determined by dividing the activity of the nuclide by the total activity of these four nuclides. The relative percentage of Am-241 for example is determined as follows:

$$\%Am241 = \frac{Act_{Am241}}{Act_{Am241} + Act_{Pu239} + Act_{Pu240} + Act_{Pu241}} = \frac{7.45*10^{-2}\,Ci}{(7.45+1.73+3.80+1.40)*10^{-2}\,Ci} = 51.8\%$$

- The relative activity of the remaining three nuclides is determined to be the following:

  Pu-238 = 12.0%
  Pu-239 = 26.4%
  Pu-240 = 9.8%

- The methodology used to determine the activity values in the hot spots on surfaces outside of the reactor was similar to that used for the surface contamination. Once the Ci/mR/hr values were determined relating 2005 activity values to 1984 measurements, the Ci/mR/hr value was multiplied by the 1984 measurement and the activity determined.

Results

Table D-4 presents an estimate of the contaminated surface area and the calculated radionuclide activity values for the general surfaces of the MTR facility.

Table D-4. Contaminated Surface Area and Surface Radioactivity on General Surfaces Outside the Reactor in the MTR Facility.

	Surface Area (m^2)	Surface Activity Measured (dpm/100 cm2 in 1984)	Ni-63 (Ci)	C-14 (Ci)	I-129 (Ci)	Sr-90 (Ci)	Co-60 (Ci)	Gross alpha (Ci)	Pu-238 (Ci)	Pu-239 (Ci)	Pu-240 (Ci)	Am-241 (Ci)	Total (Ci)
North floor	22.3	3600	4.46E-06	1.03E-05	4.38E-07	2.40E-04	1.27E-04	3.38E-05	4.07E-06	8.93E-06	3.29E-06	1.75E-05	3.62E-03
North parapet wall	5.6	2040	6.31E-07	1.46E-06	6.20E-08	3.40E-05	1.79E-05	4.79E-06	5.76E-07	1.27E-06	4.66E-07	2.48E-06	5.12E-04
Wood planks across canal	6.7	3600	1.34E-06	3.09E-06	1.31E-07	7.21E-05	3.80E-05	1.01E-05	1.22E-06	2.67E-06	9.83E-07	5.23E-06	1.08E-03
Piping	9.3	4000	2.06E-06	4.76E-06	2.03E-07	1.11E-04	5.86E-05	1.56E-05	1.88E-06	4.12E-06	1.52E-06	8.08E-06	1.67E-03
Carriage	10.7	3120	1.85E-06	4.28E-06	1.82E-07	9.99E-05	5.27E-05	1.41E-05	1.70E-06	3.73E-06	1.37E-06	7.30E-06	1.50E-03
North floor	1.5	840	6.93E-08	1.60E-07	6.81E-09	3.74E-06	1.97E-06	5.25E-07	6.32E-08	1.39E-07	5.11E-08	2.72E-07	5.62E-05
Northeast wall	11.1	840	5.20E-07	1.20E-06	5.11E-08	2.80E-05	1.48E-05	3.94E-06	4.74E-07	1.04E-06	3.84E-07	2.04E-06	4.22E-04
Tool handles	0.3	10000	1.55E-07	3.57E-07	1.52E-08	8.34E-06	4.40E-06	1.17E-06	1.41E-07	3.09E-07	1.14E-07	6.06E-07	1.26E-04
Southeast wall	8.4	3100	1.44E-06	3.32E-06	1.41E-07	7.76E-05	4.09E-05	1.09E-05	1.31E-06	2.88E-06	1.06E-06	5.65E-06	1.17E-03
Canal	185.8	230000	2.37E-03	5.48E-03	2.33E-04	1.28E-01	6.74E-02	1.80E-02	2.17E-03	4.76E-03	1.75E-03	9.33E-03	1.92E+00
South Parapet	5.6	4000	1.24E-06	2.86E-06	1.22E-07	6.67E-05	3.52E-05	9.38E-06	1.13E-06	2.48E-06	9.13E-07	4.86E-06	1.00E-03
South floor	22.3	3000	3.71E-06	8.57E-06	3.65E-07	2.00E-04	1.05E-04	2.81E-05	3.38E-06	7.43E-06	2.74E-06	1.46E-05	3.01E-03
South Wall	36.2	2600	5.23E-06	1.21E-05	5.14E-07	2.82E-04	1.49E-04	3.96E-05	4.76E-06	1.05E-05	3.86E-06	2.05E-05	4.24E-03

	Surface Area (m^2)	Surface Activity Measured (dpm/100 cm2 in 1984)	Ni-63 (Ci)	C-14 (Ci)	I-129 (Ci)	Sr-90 (Ci)	Co-60 (Ci)	Gross alpha (Ci)	Pu-238 (Ci)	Pu-239 (Ci)	Pu-240 (Ci)	Am-241 (Ci)	Total (Ci)
Ceiling	66.9	3000	1.11E-05	2.57E-05	1.09E-06	6.01E-04	3.16E-04	8.44E-05	1.02E-05	2.23E-05	8.22E-06	4.37E-05	9.04E-03
Floor	11.1	1830	1.13E-06	2.61E-06	1.11E-07	6.11E-05	3.22E-05	8.59E-06	1.03E-06	2.27E-06	8.36E-07	4.45E-06	9.19E-04
Walls	51.3	1830	5.21E-06	1.20E-05	5.12E-07	2.81E-04	1.48E-04	3.95E-05	4.75E-06	1.04E-05	3.85E-06	2.05E-05	4.23E-03
Ceiling	11.1	1830	1.13E-06	2.61E-06	1.11E-07	6.11E-05	3.22E-05	8.59E-06	1.03E-06	2.27E-06	8.36E-07	4.45E-06	9.19E-04
Tank	11.7	9000	5.83E-06	1.35E-05	5.73E-07	3.14E-04	1.66E-04	4.42E-05	5.32E-06	1.17E-05	4.30E-06	2.29E-05	4.73E-03
Pipes & ducts	8.8	7000	3.40E-06	7.85E-06	3.34E-07	1.83E-04	9.67E-05	2.58E-05	3.10E-06	6.82E-06	2.51E-06	1.34E-05	2.76E-03
Floor	12.3	860	5.85E-07	1.35E-06	5.75E-08	3.16E-05	1.66E-05	4.44E-06	5.34E-07	1.17E-06	4.32E-07	2.30E-06	4.75E-04
Walls	40.1	860	1.92E-06	4.42E-06	1.88E-07	1.03E-04	5.44E-05	1.45E-05	1.74E-06	3.83E-06	1.41E-06	7.51E-06	1.55E-03
Ceiling	12.3	860	5.85E-07	1.35E-06	5.75E-08	3.16E-05	1.66E-05	4.44E-06	5.34E-07	1.17E-06	4.32E-07	2.30E-06	4.75E-04
Piping	4.9	780	2.12E-07	4.90E-07	2.09E-08	1.14E-05	6.03E-06	1.61E-06	1.94E-07	4.25E-07	1.57E-07	8.34E-07	1.72E-04
Floor	13.9	240	1.86E-07	4.29E-07	1.82E-08	1.00E-05	5.27E-06	1.41E-06	1.70E-07	3.73E-07	1.37E-07	7.30E-07	1.51E-04
Walls	41.8	200	4.64E-07	1.07E-06	4.56E-08	2.50E-05	1.32E-05	3.52E-06	4.23E-07	9.30E-07	3.43E-07	1.82E-06	3.77E-04
Ceiling	13.9	240	1.86E-07	4.29E-07	1.82E-08	1.00E-05	5.27E-06	1.41E-06	1.70E-07	3.73E-07	1.37E-07	7.30E-07	1.51E-04
Piping	86.8	385	1.86E-06	4.28E-06	1.82E-07	1.00E-04	5.27E-05	1.41E-05	1.70E-06	3.73E-06	1.37E-06	7.30E-06	1.51E-03
South end floor	3.7	800	1.65E-07	3.81E-07	1.62E-08	8.90E-06	4.69E-06	1.25E-06	1.50E-07	3.30E-07	1.22E-07	6.48E-07	1.34E-04
South causeway	13.9	1200	9.28E-07	2.14E-06	9.12E-08	5.00E-05	2.64E-05	7.04E-06	8.47E-07	1.86E-06	6.85E-07	3.65E-06	7.53E-04
West floor	4.6	500	1.29E-07	2.98E-07	1.27E-08	6.95E-06	3.66E-06	9.77E-07	1.18E-07	2.58E-07	9.51E-08	5.06E-07	1.05E-04
South 24-in pipe	5.8	500	1.62E-07	3.74E-07	1.59E-08	8.74E-06	4.60E-06	1.23E-06	1.48E-07	3.25E-07	1.20E-07	6.37E-07	1.31E-04
Southeast 24-in pipe	11.7	1200	7.78E-07	1.80E-06	7.64E-08	4.19E-05	2.21E-05	5.90E-06	7.10E-07	1.56E-06	5.74E-07	3.06E-06	6.31E-04
West 24-in pipe	7	200	7.78E-08	1.80E-07	7.64E-09	4.19E-06	2.21E-06	5.90E-07	7.10E-08	1.56E-07	5.74E-08	3.06E-07	6.31E-05
North central 24-in pipe	14.6	400	3.24E-07	7.48E-07	3.18E-08	1.75E-05	9.21E-06	2.46E-06	2.96E-07	6.50E-07	2.39E-07	1.27E-06	2.63E-04
South 36-in pipe	21.9	1700	2.07E-06	4.77E-06	2.03E-07	1.11E-04	5.87E-05	1.57E-05	1.89E-06	4.15E-06	1.53E-06	8.13E-06	1.68E-03

	Surface Area (m^2)	Surface Activity Measured (dpm/100 cm2 in 1984)	Ni-63 (Ci)	C-14 (Ci)	I-129 (Ci)	Sr-90 (Ci)	Co-60 (Ci)	Gross alpha (Ci)	Pu-238 (Ci)	Pu-239 (Ci)	Pu-240 (Ci)	Am-241 (Ci)	Total (Ci)
Central 36-in pipe	13.1	500	3.65E-07	8.41E-07	3.58E-08	1.97E-05	1.04E-05	2.76E-06	3.32E-07	7.29E-07	2.69E-07	1.43E-06	2.96E-04
Hot waste water pipe	20.4	2000	2.27E-06	5.24E-06	2.23E-07	1.22E-04	6.44E-05	1.72E-05	2.07E-06	4.55E-06	1.67E-06	8.91E-06	1.84E-03
Surface Areas	443.4	50	1.23E-06	2.84E-06	1.21E-07	6.64E-05	3.50E-05	9.33E-06	1.12E-06	2.47E-06	9.08E-07	4.83E-06	9.99E-04
Surface Areas	152.2	3000	2.53E-05	5.85E-05	2.49E-06	1.37E-03	7.20E-04	1.92E-04	2.31E-05	5.07E-05	1.87E-05	9.95E-05	2.06E-02
Air duct pit	1023.3	1400	7.95E-05	1.84E-04	7.81E-06	4.29E-03	2.26E-03	6.03E-04	7.25E-05	1.59E-04	5.87E-05	3.12E-04	6.45E-02
Air ducts	3151.8	6000	1.05E-03	2.42E-03	1.03E-04	5.66E-02	2.98E-02	7.96E-03	9.58E-04	2.10E-03	7.75E-04	4.12E-03	8.52E-01
ETRC	1023.3	1400	7.95E-05	1.84E-04	7.81E-06	4.29E-03	2.26E-03	6.03E-04	7.25E-05	1.59E-04	5.87E-05	3.12E-04	6.45E-02
Tube 1	16.2	10000	9.02E-06	2.08E-05	8.86E-07	4.86E-04	2.56E-04	6.83E-05	8.22E-06	1.80E-05	6.65E-06	3.54E-05	7.32E-03
Tube 2	14.4	10000	7.99E-06	1.85E-05	7.85E-07	4.31E-04	2.27E-04	6.06E-05	7.29E-06	1.60E-05	5.90E-06	3.14E-05	6.49E-03
Tube 3	7.1	10545	4.17E-06	9.63E-06	4.10E-07	2.25E-04	1.18E-04	3.16E-05	3.80E-06	8.35E-06	3.08E-06	1.64E-05	3.38E-03
Tube 4	7.1	88850	3.51E-05	8.11E-05	3.45E-06	1.89E-03	9.98E-04	2.66E-04	3.20E-05	7.03E-05	2.59E-05	1.38E-04	2.85E-02
Tube 5	7.1	0	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
Tube 6	7.1	2631	1.04E-06	2.40E-06	1.02E-07	5.61E-05	2.96E-05	7.89E-06	9.49E-07	2.08E-06	7.68E-07	4.09E-06	8.44E-04
Tube 7	7.1	521	2.06E-07	4.76E-07	2.02E-08	1.11E-05	5.85E-06	1.56E-06	1.88E-07	4.12E-07	1.52E-07	8.08E-07	1.67E-04
Tube 8	7.1	10	3.95E-09	9.13E-09	3.89E-10	2.13E-07	1.12E-07	3.00E-08	3.61E-09	7.93E-09	2.92E-09	1.55E-08	3.21E-06
Tube 9	7.1	0	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
Tube 10	7.1	0	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
Tube 11	7.1	100	3.95E-08	9.13E-08	3.89E-09	2.13E-06	1.12E-06	3.00E-07	3.61E-08	7.93E-08	2.92E-08	1.55E-07	3.21E-05
Tube 12	7.1	1863	7.37E-07	1.70E-06	7.24E-08	3.97E-05	2.09E-05	5.59E-06	6.73E-07	1.48E-06	5.44E-07	2.90E-06	5.98E-04
Tube 13	7.1	119	4.71E-08	1.09E-07	4.62E-09	2.54E-06	1.34E-06	3.57E-07	4.29E-08	9.43E-08	3.48E-08	1.85E-07	3.82E-05
Tube 14	7.1	925	3.66E-07	8.44E-07	3.59E-08	1.97E-05	1.04E-05	2.77E-06	3.33E-07	7.32E-07	2.70E-07	1.44E-06	2.97E-04
Tube 15	7.1	10000	3.95E-06	9.13E-06	3.89E-07	2.13E-04	1.12E-04	3.00E-05	3.61E-06	7.93E-06	2.92E-06	1.55E-05	3.21E-03
Tube 16	7.1	1214	4.80E-07	1.11E-06	4.72E-08	2.59E-05	1.36E-05	3.64E-06	4.38E-07	9.62E-07	3.54E-07	1.89E-06	3.90E-04
Tube 17	7.1	298	1.18E-07	2.72E-07	1.16E-08	6.35E-06	3.35E-06	8.93E-07	1.07E-07	2.36E-07	8.69E-08	4.63E-07	9.56E-05
Tube 18	7.1	13	5.14E-09	1.19E-08	5.05E-10	2.77E-07	1.46E-07	3.90E-08	4.69E-09	1.03E-08	3.80E-09	2.02E-08	4.17E-06
Tube 19	7.1	15	5.93E-09	1.37E-08	5.83E-10	3.20E-07	1.69E-07	4.50E-08	5.41E-09	1.19E-08	4.38E-09	2.33E-08	4.81E-06
Tube 20	7.1	30	1.19E-08	2.74E-08	1.17E-09	6.40E-07	3.37E-07	8.99E-08	1.08E-08	2.38E-08	8.75E-09	4.66E-08	9.63E-06

	Surface Area (m^2)	Surface Activity Measured (dpm/100 cm2 in 1984)	Ni-63 (Ci)	C-14 (Ci)	I-129 (Ci)	Sr-90 (Ci)	Co-60 (Ci)	Gross alpha (Ci)	Pu-238 (Ci)	Pu-239 (Ci)	Pu-240 (Ci)	Am-241 (Ci)	Total (Ci)
Tube 21	7.1	72	2.85E-08	6.57E-08	2.80E-09	1.54E-06	8.09E-07	2.16E-07	2.60E-08	5.71E-08	2.10E-08	1.12E-07	2.31E-05
Tube 22	7.1	19	7.51E-09	1.73E-08	7.38E-10	4.05E-07	2.13E-07	5.70E-08	6.86E-09	1.51E-08	5.55E-09	2.95E-08	6.10E-06
Tube 23	7.1	11	4.35E-09	1.00E-08	4.27E-10	2.35E-07	1.24E-07	3.30E-08	3.97E-09	8.72E-09	3.21E-09	1.71E-08	3.53E-06
Tube 24	7.1	10	3.95E-09	9.13E-09	3.89E-10	2.13E-07	1.12E-07	3.00E-08	3.61E-09	7.93E-09	2.92E-09	1.55E-08	3.21E-06
Tube 25	3.5	37	7.26E-09	1.68E-08	7.14E-10	3.92E-07	2.06E-07	5.51E-08	6.63E-09	1.46E-08	5.36E-09	2.85E-08	5.89E-06
Tube 26	0.1	109	7.25E-10	1.67E-09	7.13E-11	3.91E-08	2.06E-08	5.50E-09	6.62E-10	1.45E-09	5.35E-10	2.85E-09	5.89E-07
Tube 27	0.1	26	1.73E-10	3.99E-10	1.70E-11	9.33E-09	4.92E-09	1.31E-09	1.58E-10	3.46E-10	1.28E-10	6.79E-10	1.40E-07
Tube 28	0.1	0	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
Tube 29	0.1	0	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
Tube 30	0.1	18	1.20E-10	2.77E-10	1.18E-11	6.46E-09	3.40E-09	9.08E-10	1.09E-10	2.40E-10	8.84E-11	4.70E-10	9.72E-08
Tube 31	0.2	12	1.14E-10	2.64E-10	1.12E-11	6.16E-09	3.25E-09	8.67E-10	1.04E-10	2.29E-10	8.44E-11	4.49E-10	9.28E-08
Tube 32	0.2	0	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
Faceplate	11.7	160	1.04E-07	2.39E-07	1.02E-08	5.58E-06	2.94E-06	7.85E-07	9.44E-08	2.07E-07	7.64E-08	4.07E-07	8.40E-05
TRA Stack			2.03E-03	1.09E-03	0.00E+00	6.06E-04	1.63E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.98E-02
			5.77E-03	9.71E-03	3.67E-04	2.02E-01	1.08E-01	2.83E-02	3.40E-03	7.48E-03	2.76E-03	1.47E-02	6.26E+00

Table D-5 presents the 1984 dose rate measurements of the hot spots and the calculated radionuclide activity values for the hot spots of the MTR facility.

Table D-5. Hotspot dose Rate and Activity Levels for Surfaces Outside the Reactor in the MTR Facility.

Area	Spot	Dose Rate in 84 (mR/hr)	Total Activity in 2005 (Ci)	Ni-63 (Ci)	C-14 (Ci)	I-129 (Ci)	Sr-90 (Ci)	Co-60 (Ci)	Cs-137 (Ci)	Gross alpha (Ci)	Pu-238 (Ci)	Pu-239 (Ci)	Pu-240 (Ci)	Am-241 (Ci)
							TRA-603							
Reactor Top	Northeast	140	2.44E-02	1.51E-05	3.54E-05	1.51E-06	7.89E-04	3.35E-04	1.15E-02	2.37E-04	2.85E-05	6.26E-05	2.31E-05	1.23E-04
	East	40	6.96E-03	4.33E-06	1.01E-05	4.31E-07	2.25E-04	9.58E-05	3.28E-03	6.76E-05	8.13E-06	1.79E-05	6.58E-06	3.50E-05
	Northeast	30	5.22E-03	3.24E-06	7.59E-06	3.23E-07	1.69E-04	7.18E-05	2.46E-03	5.07E-05	6.10E-06	1.34E-05	4.94E-06	2.63E-05
	Southeast	30	5.22E-03	3.24E-06	7.59E-06	3.23E-07	1.69E-04	7.18E-05	2.46E-03	5.07E-05	6.10E-06	1.34E-05	4.94E-06	2.63E-05
	South	30	5.22E-03	3.24E-06	7.59E-06	3.23E-07	1.69E-04	7.18E-05	2.46E-03	5.07E-05	6.10E-06	1.34E-05	4.94E-06	2.63E-05
Subpile Room	North Floor Drain	30	5.22E-03	3.24E-06	7.59E-06	3.23E-07	1.69E-04	7.18E-05	2.46E-03	5.07E-05	6.10E-06	1.34E-05	4.94E-06	2.63E-05
	Northeast Canal	120	2.09E-02	1.30E-05	3.04E-05	1.29E-06	6.76E-04	2.87E-04	9.84E-03	2.03E-04	2.44E-05	5.36E-05	1.98E-05	1.05E-04
	West Canal	100	1.74E-02	1.08E-05	2.53E-05	1.08E-06	5.64E-04	2.39E-04	8.20E-03	1.69E-04	2.03E-05	4.47E-05	1.65E-05	8.76E-05
	Southwest Canal	200	3.48E-02	2.16E-05	5.06E-05	2.15E-06	1.13E-03	4.79E-04	1.64E-02	3.38E-04	4.07E-05	8.93E-05	3.29E-05	1.75E-04
	South Floor Drain	70	1.22E-02	7.57E-06	1.77E-05	7.54E-07	3.95E-04	1.68E-04	5.74E-03	1.18E-04	1.42E-05	3.12E-05	1.15E-05	6.11E-05
Canal Sump Pit	Northeast Valve	160	2.78E-02	1.73E-05	4.05E-05	1.72E-06	9.02E-04	3.83E-04	1.31E-02	2.70E-04	3.25E-05	7.13E-05	2.63E-05	1.40E-04
	East Sump	160	2.78E-02	1.73E-05	4.05E-05	1.72E-06	9.02E-04	3.83E-04	1.31E-02	2.70E-04	3.25E-05	7.13E-05	2.63E-05	1.40E-04
	West Sump	100	1.74E-02	1.08E-05	2.53E-05	1.08E-06	5.64E-04	2.39E-04	8.20E-03	1.69E-04	2.03E-05	4.47E-05	1.65E-05	8.76E-05
HB-2 Cubicle	North End	800	1.39E-01	8.65E-05	2.02E-04	8.62E-06	4.51E-03	1.92E-03	6.56E-02	1.35E-03	1.62E-04	3.57E-04	1.31E-04	6.99E-04
	Center 1	150	2.61E-02	1.62E-05	3.80E-05	1.62E-06	8.46E-04	3.59E-04	1.23E-02	2.54E-04	3.06E-05	6.71E-05	2.47E-05	1.32E-04
	Center 2	100	1.74E-02	1.08E-05	2.53E-05	1.08E-06	5.64E-04	2.39E-04	8.20E-03	1.69E-04	2.03E-05	4.47E-05	1.65E-05	8.76E-05
	East 1	80	1.39E-02	8.65E-06	2.02E-05	8.62E-07	4.51E-04	1.92E-04	6.56E-03	1.35E-04	1.62E-05	3.57E-05	1.31E-05	6.99E-05
	East 2	50	8.70E-03	5.41E-06	1.27E-05	5.39E-07	2.82E-04	1.20E-04	4.10E-03	8.45E-05	1.02E-05	2.23E-05	8.23E-06	4.38E-05

Area	Spot	Dose Rate in 84 (mR/hr)	Total Activity in 2005 (Ci)	Ni-63 (Ci)	C-14 (Ci)	I-129 (Ci)	Sr-90 (Ci)	Co-60 (Ci)	Cs-137 (Ci)	Gross alpha (Ci)	Pu-238 (Ci)	Pu-239 (Ci)	Pu-240 (Ci)	Am-241 (Ci)
							TRA-610							
	East Blower	8	1.39E-03	8.65E-07	2.02E-06	8.62E-08	4.51E-05	1.92E-05	6.56E-04	1.35E-05	1.62E-06	3.57E-06	1.31E-06	6.99E-06
	East Duct	8	1.39E-03	8.65E-07	2.02E-06	8.62E-08	4.51E-05	1.92E-05	6.56E-04	1.35E-05	1.62E-06	3.57E-06	1.31E-06	6.99E-06
	Central Blower	10	1.74E-03	1.08E-06	2.53E-06	1.08E-07	5.64E-05	2.39E-05	8.20E-04	1.69E-05	2.03E-06	4.47E-06	1.65E-06	8.76E-06
	Central Duct	4	6.96E-04	4.33E-07	1.01E-06	4.31E-08	2.25E-05	9.58E-06	3.28E-04	6.76E-06	8.13E-07	1.79E-06	6.58E-07	3.50E-06
	West Blower	10	1.74E-03	1.08E-06	2.53E-06	1.08E-07	5.64E-05	2.39E-05	8.20E-04	1.69E-05	2.03E-06	4.47E-06	1.65E-06	8.76E-06
	West Duct	5	8.70E-04	5.41E-07	1.27E-06	5.39E-08	2.82E-05	1.20E-05	4.10E-04	8.45E-06	1.02E-06	2.23E-06	8.23E-07	4.38E-06
							TRA-630							
	Hot Spot 1	70	1.22E-02	7.57E-06	1.77E-05	7.54E-07	3.95E-04	1.68E-04	5.74E-03	1.18E-04	1.42E-05	3.12E-05	1.15E-05	6.11E-05
	Hot Spot 2	70	1.22E-02	7.57E-06	1.77E-05	7.54E-07	3.95E-04	1.68E-04	5.74E-03	1.18E-04	1.42E-05	3.12E-05	1.15E-05	6.11E-05
	TOTALS		4.48E-01	2.78E-04	6.52E-04	2.77E-05	1.45E-02	6.17E-03	2.11E-01	4.35E-03	5.23E-04	1.15E-03	4.24E-04	2.25E-03

References

D-1 R. L. Rolfe and E. L. Wills, April 1984, Characterization of the Materials Testing Reactor, WM-Fl-33-016, EG&G Idaho, Inc., Idaho Falls, Idaho

D-2 J. J. Lopez, December 1998, *Dose Rate to Curie Conversion Factors for Waste Generated at the Test Reactor Area (TRA),* EDF TRA-ATR-1405, Idaho National Engineering and Environmental Laboratory, Idaho Falls, Idaho.

Appendix E

TRA-730 Vault Activity Calculations

TRA-730 Surface Activity Calculation

The TRA-730 tanks and vault have been turned over to the Voluntary Consent Order (VCO) program. Source terms for these areas are calculated based on VCO characterizations.

Vault Surfaces

Activity levels on the vault surfaces are determined based on the average of the 10 swipe surveys documented on the survey report (Reference 1) and the results of the rinsate samples removed from the tanks documented in EDF-5431 (Reference 2), *Radionuclide Concentrations of the Rinsate Samples from the Four TRA-730 Catch Tanks.* Table E-1 presents the EDF-5431 results

Table E-1, EDF-5431 Results

Radionuclide	Concentration (nCi/ml)			
	CT-1	**CT-2**	**CT-3**	**CT-4**
Am-241	1.26E+00	5.84E-01	2.04E-01	3.08E-02
Cm-242	2.12E-03	1.39E-03		
Cm-244	7.52E-02	4.54E-02	1.48E-02	2.55E-03
Co-60	8.42E-01	1.06E-01	2.09E-01	1.03E-01
Cs-134	2.79E-03	3.27E-03		
Cs-137	9.55E+00	6.96E+00	7.38E+00	1.67E+00
Eu-152	1.33E-01	5.34E-02	3.03E-02	5.37E-03
Eu-154	2.13E-01	7.76E-02	1.20E-01	2.06E-02
Eu-155	4.23E-02	2.18E-02	2.19E-02	2.54E-03
Fe-55	0.00E+00	3.38E-02	2.38E-03	7.02E-03
Ni-59		4.50E-04		1.71E-03
Ni-63	2.61E+00	4.15E-02	2.01E-02	5.28E-02
Pu-238	1.12E+00	3.67E-01	1.47E-01	2.47E-02
Pu-239	6.35E-01	2.52E-01	8.14E-02	1.39E-02
Pu-240	6.35E-01	2.52E-01	8.14E-02	1.39E-02
Sr-90	1.40E+01	1.77E+01	4.54E+00	7.94E-01
U-234	6.17E-03	3.30E-03	5.80E-03	2.00E-03

Normalized to Cs-137

The contamination on the vault surfaces is assumed to be a result of the spread of contamination from each of these tanks so an average of the above results is used to determine the activity of the radionuclides on the surfaces. The average results were then normalized to Cs-137 as shown in Table E-2 below:

Table E-2. Average and Normalized Results

Nuclide	Average (nCi/ml)	Normalized to Cs-137
Am-241	5.20E-01	8.13E-02
Cm-242	1.76E-03	2.75E-04
Cm-244	3.45E-02	5.40E-03
Co-60	3.15E-01	4.93E-02
Cs-134	3.03E-03	4.74E-04
Cs-137	6.39E+00	1.00E+00
Eu-152	5.55E-02	8.69E-03
Eu-154	1.08E-01	1.69E-02
Eu-155	2.21E-02	3.46E-03
Fe-55	1.08E-02	1.69E-03
Ni-59	1.08E-03	1.69E-04
Ni-63	6.81E-01	1.07E-01
Pu-238	4.15E-01	6.49E-02
Pu-239	2.46E-01	3.84E-02
Pu-240	2.46E-01	3.84E-02
Sr-90	9.26E+00	1.45E+00
U-234	4.32E-03	6.76E-04

With the assumption that only Co-60, Cs-137, and Sr-90 contribute to the results of the beta/gamma contamination survey and that these radionuclides are detected with approximately equal efficiency, the fraction of the results due to Cs-137 is determined as follows:

$$Cs137 = \frac{Act._{Cs137}}{Act._{Cs137} + Act._{Co60} + Act._{Sr90}} = \frac{6.39\mu Ci/ml}{(6.39 + .315 + 9.26)\mu Ci/ml} = 0.40$$

Next, an average of the contamination survey results was obtained using the data taken from the survey log sheet. The average result was multiplied by 10 (using the assumption that total activity is 10 times the removable activity). These results are presented in Table E-3.

Table E-3. Total Contamination Levels in the TRA-730 Vault

Survey Point	Result (dpm/100 cm^2)
1	14000
2	19000
3	23000
4	150000
5	490000
6	120000
7	38000
8	25000
9	120000
10	40000
Average =	103900
Total Contamination =	1039000

Total surface area of the tank vault located within the grade to 10' below grade region is estimated to by 95 m^2. The activity in this area due to Cs-137 is calculated by multiplying the total contamination value by both the surface area and the Cs-137 contribution to the survey result. This calculation is shown below:

$$Ci_{Cs137} = \frac{1039000 dpm}{100 cm^2} * \frac{10000 cm^2}{m^2} * 95 m^2 * \frac{Ci}{2.22*10^{12} dpm} *.40 = 1.78*10^{-3} Ci$$

The activities of the remaining nuclides are determined by multiplying the above result by the nuclide's normalized value. For example, the activity due to Am-241 is determined as follows:

$$Ci_{Am241} = 1.78*10^{-3} Ci*8.31*10^{-2} = 1.5*10^{-4} Ci$$

TRA-730 Tank Activity Determination

The VCO program supplied the results of the activity (in uCi/g) in sludge samples removed from the tanks (Reference 3). An average value for the results is then determined as presented in Table E-4.

Table E-4. TRA-730 Sludge Sample Results

Nuclide	Tank 1HC	Tank 2HC	Tank 3	Tank 4	Average uCi/g
Am-241	1.64E-01	2.94E-01	2.73E-02	2.00E-01	1.71E-01
Ce-144	1.40E+00	3.30E-01	3.20E-02	9.20E-01	6.71E-01
Cf-252	6.90E-04	1.30E-03	5.70E-04	2.10E-02	5.89E-03
Cm-244	4.27E-02	8.68E-02	9.28E-03	6.43E-02	5.08E-02
Co-60	5.90E-01	1.40E-01	1.80E-01	4.90E-01	3.50E-01
Cs-134	2.70E+00	3.00E-01	1.30E-01	2.30E+00	1.36E+00
Cs-137	2.90E+01	3.30E+00	4.40E+00	2.30E+01	1.49E+01
Eu-154	1.80E-01	5.20E-02	5.70E-02	4.00E-01	1.72E-01
Eu-155	1.10E-01	3.10E-02	1.90E-02	2.30E-01	9.75E-02
Nb-95	0.00E+00	0.00E+00	0.00E+00	2.00E-02	5.00E-03
Pu-238	1.43E-01	2.62E-01	5.95E-02	3.13E-01	1.94E-01
Pu-239	1.56E-01	2.62E-01	4.24E-02	1.41E-01	1.50E-01
Sb-125	7.20E-02	2.60E-02	1.60E-02	1.50E-01	6.60E-02
Sr-90	4.20E+01	2.80E+01	3.60E+00	7.60E+00	2.03E+01
U-232	1.50E-04	6.40E-05	2.02E-03	4.37E-04	6.68E-04
U-234	5.10E-03	7.95E-03	2.41E-02	1.31E-02	1.26E-02
U-235	4.10E-04	1.32E-04	0.00E+00	0.00E+00	1.36E-04
U-238	6.30E-04	8.70E-04	0.00E+00	1.75E-04	4.19E-04
Zr-95	0.00E+00	0.00E+00	0.00E+00	1.50E-02	3.75E-03

The VCO Project Engineer (Reference 3) described the scale remaining in the tank as being a very thin ring ~1" wide around the inside of each tank corresponding to the level of the liquids that were removed from the tank. The tank dimensions are 120" long by 60" in diameter. A scale thickness of 1/64" (0.016") is assumed based on the description as being "very thin". The tanks are right circular cylinders with the 120" axis parallel to the ground surface. Each tank has a ring 360" in length by 1" wide by .016" thick. The scale volume per tank is determined by multiplying the scale area (determined using the tank dimensions and the width of the scale) by the scale thickness as follows:

$$Volume = 360"*1"*.016"\,in = 5.6in^3 = 92.2cm^3$$

The total scale volume for all four tanks is 368.7 cm^3. The density of the scale is assumed to be equal to the density of concrete (2.35 g/cm^3). The total mass of the tank scale is determined by multiplying the volume by the density. The total activity for each radionuclide is determined by multiplying the nuclides specific activity by the total mass of the sludge. For example, the activity in the tanks due to Am-241 is determined as follows:

$$Act_{Am241} = 368.7cm^3 * \frac{2.35g}{cm^3} * \frac{1.71*10^{-1} uCi}{g} = 1.48*10^{-4} Ci$$

References

E-1 Form 441.45 Radiological Survey Report, TRA 730 Catch Tanks, 1/27/05 Log #2.
E-2 D. L. Georgeson, 11/2004, EDF-5431, Radionuclide Concentration of the Rinsate Samples from the Four TRA-730 Catch Tanks, Idaho National Laboratory, Idaho Falls, Idaho.
E-3 Brett D. Welty, personal communication, 11/2/05

Appendix F

FISSION BREAK EXPERIENCES IN MTR

Rainwater discussed the fact that there had been several MTR fuel element ruptures in October 1954, until the fuel was redesigned to handle the thermal stresses. These fission breaks also contaminated the reactor tank and piping with fission products and U-235. Activity readings on contact with the outside of the pipe walls of the primary coolant system before the fission breaks was 50 to 100 mR/h, and after it was as high as 3 R/h. Over time, the activity was removed from the system. Rainwater also pointed out that any uranium plating out in the core or on the aluminum vessel walls or on the steel piping close to the vessel could fission due to the neutron flux present during operations. Rainwater gave the following table:

Sample description	Uranium plate out (grams/cm^2)
Stainless coupon from active lattice	3E-08
Aluminum coupon from active lattice	6E-07
Beryllium coupon from active lattice	1.5E-07
Stainless steel tubing from reactor tank	2.0E-10
Aluminum tubing from reactor tank	1.7E-09

The MTR also experienced a so-called "fission break" event in 1962. The reactor had been operating at 40 MWth since November 2, 1962. A piece of a gasket from the floating roof seal tank (the 17,000 gallon water supply tank to the primary coolant system) came loose and entered the primary coolant. The piece of black rubber gasket material lodged against a fuel element and part of a plate in element J-385 melted. The reactor scrammed from the N-16 instrument on November 13, 1962. Following the scram, the seal tank activity increased from 100 mrem/h to 9.8 rem/h. The primary coolant system (PCS) was maintained at the normal rate to reduce deposition of fission products on the PCS surfaces. The fuel element breach allowed a conservative estimate of 0.7 gram of U-235 to enter the coolant. After refueling and operation in the next cycle, the reactor coolant water radioactivity decreased until it read the more typical 100 mrem/h value.

Most of the 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

F-1. J. H. Rainwater, February 21, 1957, *Maintenance of Primary Coolant Water Quality in the Materials Testing Reactor*, IDO-16322, Phillips Petroleum Company, Atomic Energy Division, Idaho Falls, Idaho.

F-2. R. A. Costner, Jr., June 1963, "MTR Fission-Break Incident," *Nuclear Safety, 4*, pp. 144-147.

F-3. J. W. Dykes, J. D. Ford, K. R. Hoopingarner, 1965, *A Summary of the 1962 Fuel Element Fission Break in the MTR*, IDO-17064, Idaho Nuclear Corporation, Idaho Falls, Idaho.

Appendix G

Sample Calculations

The following examples demonstrate how the Co-60 activity was assigned to the various locations relative to grade. The other radionuclide activity values were assigned through similar calculations:

1. Reactor Activation:

Appendix A present the following Co-60 activity values for the various components in the reactor:

Isotope	Be Reflector	"C" to "D" Tank Adapters	"D" to "E" Tank Adapters	"C" Tank	"D" Tank	"E" Tank	Graphite Balls	Graphite Blocks	Heat Shield Plates	Monitor Tubes	Non-Tank Aluminum Structures (all)	Discharge Chute	Total Activity
Co-60	9.28E-02	1.12E+00	1.57E+01	6.62E-03	3.23E-01	8.06E+00	6.42E-01	4.95E-01	6.44E-01	3.17E+01	1.28E-01	1.41E+00	6.04E+01

As stated previously, all of the reactor activity, with the exception of the "E" tank, is in the above grade location. Thus, the above grade Co-60 value is determined as follows:

$$6.04*10^{1}\,Ci - 8.06*10^{0}\,Ci = 5.23*10^{1}\,Ci$$

The "E" tank is 6.38' tall with the top of the tank located at approximately the grade level. The entire tank is located in the 0 to 10' below grade region. The percentage of the tank within the 0 to 3' below grade region is determined as follows:

$$\% = \frac{3\,ft}{6.38\,ft} = 47\%$$

Since the entire tank is in the 0 – 10' below grade region, the activity due to activation of Co-60 in this region is equal to the Co-60 activity in the "E" tank or 8.06 Ci. The activity in the 0 to 3' below grade region is 47% of the total "E" tank value or 3.79 Ci.

2. Air Contaminated Surfaces:

Of the 3186 m^2 of air contaminated surface in the reactor, it is estimated that only 210.7 m^2 exists in the below grade region and all of it exists at a depth shallower than 3' below grade. The Co-60 contamination per square meter value determined in Appendix B is 7.83E-6 Ci/m^2 so the activity above grade is determined as follows:

$$Above_Grade = (3186 - 210.7)m^2 * \frac{7.83*10^{-6}\,Ci}{m^2} = 2.33*10^{-2}\,Ci$$

Since none of this activity exists at a depth greater than 3', the activity level in the 0 – 3' below grade region equals the activity in both the 0 – 10' below grade and the below grade regions. This activity value is determined as follows:

$$Below_Grade = 210.7m^2 * \frac{7.83*10^{-6}\,Ci}{m^2} = 1.65*10^{-3}\,Ci$$

3. Water Contaminated Surfaces:

Of the 219.38 m^2 of water contaminated surface, 37.6 m^2 exists below grade at a depth shallower than 10' below grade. 6 m^2 of the 37.6 m^2 below grade surface exists in the 0 – 3' below grade region. The activity per

square meter value for Co-60 determined in Appendix 5 is 5.54E-4 Ci/m^2. The above grade Co-60 activity is determined as follows:

$$Above_Grade = (219.38 - 37.6)m^2 * \frac{5.54*10^{-4}\,Ci}{m^2} = 1.01*10^{-1}\,Ci$$

The 0 – 3' below grade Co-60 activity is determined as follows:

$$3'_Below_Grade = 6m^2 * \frac{5.54*10^{-4}\,Ci}{m^2} = 3.32*10^{-3}\,Ci$$

And the 0 – 10' below grade and below grade Co-60 activity is determined as follows:

$$Below_Grade = 37.6m^2 * \frac{5.54*10^{-4}\,Ci}{m^2} = 2.08*10^{-2}\,Ci$$

4. TRA-603 Surfaces

Appendix D presents the following Co-60 activity values in the general area contamination in TRA-603:

	Co-60 (Ci)
TRA-603	
Subpile Room	
North floor	1.27E-04
North parapet wall	1.79E-05
Wood planks across canal	3.80E-05
Piping	5.86E-05
Carriage	5.27E-05
North floor	1.97E-06
Northeast wall	1.48E-05
Tool handles	4.40E-06
Southeast wall	4.09E-05
Canal	6.74E-02
South Parapet	3.52E-05
South floor	1.05E-04
South Wall	1.49E-04
Ceiling	3.16E-04
Hot Waste Tank Pit	
Floor	3.22E-05
Walls	1.48E-04
Ceiling	3.22E-05
Tank	1.66E-04
Pipes & ducts	9.67E-05
Process Sump Pit	
Floor	1.66E-05
Walls	5.44E-05
Ceiling	1.66E-05
Piping	6.03E-06
Canal Sump Pit	
Floor	5.27E-06

	Co-60 (Ci)
Walls	1.32E-05
Ceiling	5.27E-06
Piping	5.27E-05
Primary Pipe Tunnel	
South end floor	4.69E-06
South causeway	2.64E-05
West floor	3.66E-06
South 24-in pipe	4.60E-06
Southeast 24-in pipe	2.21E-05
West 24-in pipe	2.21E-06
North central 24-in pipe	9.21E-06
South 36-in pipe	5.87E-05
Central 36-in pipe	1.04E-05

And the following values for the Co-60 activity in the hotspots in TRA-603:

	Co-60 (Ci)
Area	
Reactor Top	3.35E-04
	9.58E-05
	7.18E-05
	7.18E-05
	7.18E-05
Subpile Room	7.18E-05
	2.87E-04
	2.39E-04
	4.79E-04
	1.68E-04
Canal Sump Pit	3.83E-04
	3.83E-04
	2.39E-04
HB-2 Cubicle	1.92E-03
	3.59E-04
	2.39E-04
	1.92E-04
	1.20E-04

With the exception of the Reactor Top, all of this activity exists at a depth deeper than 10’ below grade. Therefore, the Co-60 activity above grade is that due to the hotspots on the reactor top and is equal to 6.46E-4 Ci and the below grade activity is equal to 7.42E-2 Ci.

5. TRA-604

The Co-60 activity present in TRA-604 is located in a pipe placed shallower than 3’ below grade. There is no activity value in EDF-4989 for the above grade location. Since the pipe is less than 3’ below grade, the 0 – 3’, 0 – 10’ and below grade values are equal. The Co-60 value presented in Appendix D is 6.44E-05 Ci.

6. TRA-610

All contaminated surfaces and equipment for this building are above grade. The general area Co-60 contamination value presented in Appendix D is 3.50E-5 Ci and the sum of the Co-60 hotspot activity from EDF-4989 is 1.08E-4 Ci.

7. TRA-630

The contaminated surfaces in this vault are entirely below grade, in the 0 – 10' below grade region. Of the 152.2 m^2 contaminated surface area, ~50 m^2 (or 33%) is located in the 0 – 3' below grade region. The Co-60 activity due to hotspots is located deeper than 3' below grade but less than 10' below grade. The Co-60 activity values due to general area contamination presented in Appendix D are as follows:

TRA-630	Co-60
Surface Areas	7.20E-04

And the Co-60 hotspot activity from Appendix D is as follows:

		Co-60
TRA-630	Hot Spot 1	1.68E-04
	Hot Spot 2	1.68E-04

Thus, the Co-60 activity in the 0 – 3' below grade region is determined as follows:

$$0-3'_Below_Grade = \frac{50m^2}{152.2m^2} * 7.20*10^{-4}\,Ci = 2.37*10^{-4}\,Ci$$

And the 0 – 10' below grade and below grade Co-60 activity is determined as follows:

$$Below_Grade = 7.20*10^{-4}\,Ci + 2*1.68*10^{-4}\,Ci = 1.06*10^{-3}\,Ci$$

8. TRA-635

The contaminated surfaces and ducts in this building are all located at a depth deeper than 10' below grade. The data presented in Appendix D for Co-60 in the contamination are as follows:

TRA-635	Co-60
Air duct pit	2.26E-03
Air ducts	2.98E-02

Thus, the below grade Co-60 below grade activity is 3.21E-2 Ci

9. TRA-654

The contaminated surfaces in this building are all located above grade. The Co-60 activity value presented in Appendix D is as follows:

TRA-654	Co-60
ETRC	2.26E-03

10. TRA-657

The activity in this building is all due to the contamination inside of the tubes used to store the MTR beam port plugs. All of these tubes are located above grade. The Co-60 activity values presented in Appendix D area as follows:

TRA-657	Co-60
Tube 1	2.56E-04
Tube 2	2.27E-04
Tube 3	1.18E-04
Tube 4	9.98E-04
Tube 5	0.00E+00
Tube 6	2.96E-05
Tube 7	5.85E-06
Tube 8	1.12E-07
Tube 9	0.00E+00
Tube 10	0.00E+00
Tube 11	1.12E-06
Tube 12	2.09E-05
Tube 13	1.34E-06
Tube 14	1.04E-05
Tube 15	1.12E-04
Tube 16	1.36E-05
Tube 17	3.35E-06
Tube 18	1.46E-07
Tube 19	1.69E-07
Tube 20	3.37E-07
Tube 21	8.09E-07
Tube 22	2.13E-07
Tube 23	1.24E-07
Tube 24	1.12E-07
Tube 25	2.06E-07
Tube 26	2.06E-08
Tube 27	4.92E-09
Tube 28	0.00E+00
Tube 29	0.00E+00
Tube 30	3.40E-09
Tube 31	3.25E-09
Tube 32	0.00E+00
Faceplate	2.94E-06

Thus, the total Co-60 above grade source term is 1.80E-3 Ci.

11. TRA-710

All contaminated surfaces in this building are located above grade. The Co-60 activity presented in Appendix D is as follows:

TRA-710	Co-60
TRA Stack	1.63E-03

12. TRA-730

See Appendix E for calculations.

Results:

After completing the above calculations, the activity values are summed for the above grade, below grade, 0 – 3' below grade and 0 – 10' below grade locations

_____

Nesshoefer, Craig A

From: Hutchison, David P
Sent: Monday, June 18, 2007 7:05 AM
To: Nesshoefer, Craig A
Cc: Reno, Scott L; Floerke, James P
Subject: RE: EDF-6381 Rev01

Great summary EDF. This presents lots of data in a logical and concise manner. No specific comments - thanks for the opportunity to review.

From: Nesshoefer, Craig A
Sent: Monday, June 11, 2007 2:48 PM
To: Hutchison, David P
Subject: EDF-6381 Rev01

Scott Reno requested that I add you as a reviewer to the attached EDF for MTR.

Craig A. Nesshoefer
D&D Rad Engineering
Phone: 533-0553
Cell: 360-0399

Nesshoefer, Craig A

From: James R Parry [James.Parry@inl.gov]
Sent: Tuesday, June 12, 2007 5:08 PM
To: Nesshoefer, Craig A
Subject: Re: EDF-6381

Craig,

I read through the document and everything seems fine. The one change I would request is to change the spelling of my name to Parry from Perry.

Thanks,

Jim

"Nesshoefer, Craig A" <Craig.Nesshoefer@icp.doe.gov>

06/11/2007 03:16 PM

To "Parry, James R" <James.Parry@inl.gov>
cc
Subject EDF-6381

We are trying to close EDF-4989 (the characterization document for MTR) so I have included all of the MTR activation information into Appendix A of my EDF. Would you please review this Appendix to insure that I have included all of the necessary information. I tried to send you the whole EDF but the document is too big to e-mail.

Craig A. Nesshoefer
D&D Rad Engineering
Phone: 533-0553
Cell: 360-0399

[attachment "Appendix A to EDF6381 Rev01.doc" deleted by James R

Nesshoefer, Craig A

From: Stewart, Dean A
Sent: Tuesday, June 12, 2007 6:25 AM
To: Nesshoefer, Craig A
Subject: RE: EDF-6381 Rev01
Attachments: image001.png; oledata.mso

I've reviewed and concur with Rev.1 to EDF-6381.

Dean Stewart
INTEC D&D
Radiological
Engineering
O: 6-9329
C: 521-2697
MS 5232
CPP-663 1SA144

From: Nesshoefer, Craig A
Sent: Monday, June 11, 2007 2:02 PM
To: Stewart, Dean A
Subject: EDF-6381 Rev01

Dean, you reviewed this EDF previously (several times in fact because of the highly valuable Joe Ross input). All of the calculated values remain the same. The only change is that the source term calculations performed by Longhurst are now included in the document. This was done so that EDF-4989 could be closed. Would you please review.

Craig A. Nesshoefer
D&D Rad Engineering
Phone: 533-0553
Cell: 360-0399