ATTACHMENT M

Radiological Dose Calculations

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1.0 DOSE CALCULATIONS

A radiological dose assessment was performed to evaluate scenarios where members of the general public could receive exposure from residual radioactivity associated with remaining drainpipes. Dose calculations were performed for individual exposure pathways and summed to provide an estimate of total dose for each scenario evaluated.

Five different exposure scenarios were considered:

6. Pipe removal,
7. Residual dust,
8. Recycle,
9. Disposal, and
10. Truck driver.

1.1 Exposure Pathways

The exposure pathways included in the dose assessment were inhalation of resuspended contaminated pipe scale and ingestion of pipe scale. The external exposure pathway was not included as part of the pipe removal or residual dust scenarios because the radionuclides decay by alpha particle emission with few photon emissions, the scale is on the inside surfaces of the pipe providing shielding from photons, and the field measurements performed when the pipes were removed from the 4th Floor did not detect any external exposure above background. The dose from external exposure for the recycle, disposal, and truck driver scenarios was based on the calculations of external exposure provided in the 2012 dose assessment (Cabrera 2012).

Dose conversion factors for radionuclides of concern were obtained from Federal Guidance Report No. 11 (EPA 1988). The committed effective dose equivalent for the inhalation and ingestion pathways were calculated by multiplying the nuclide-specific dose conversion factor by the radionuclide concentration.

1.1.1 Dust Inhalation

The CEDE from inhalation of contaminated dust was calculated based on the radionuclide concentrations measured in pipe scale samples collected from pipes associated with a specific riser.

The equation used to calculate dose from inhalation was adapted from EPA Risk Assessment Guidance for Superfund, Human Health Evaluation Manual Part B (RAGS/HHEM, EPA 1991):

$$CEDE_{Inh} = R_C \times DCF_{Inh} \times C_{Dust} \times IR_{Air} \times ED$$

Where:

$CEDE_{Inh}$	=	Inhalation dose (mrem)
R_C	=	radionuclide concentration in pipe scale (pCi/g)
DCF_{Inh}	=	dose conversion factor for inhalation (mrem/pCi)
C_{Dust}	=	mass loading for inhalation (g/m^3)
IR_{Air}	=	air inhalation rate (m^3/hr)
ED	=	exposure duration (hours)

The radionuclide concentration in pipe scale, R_C, is the maximum concentration reported in samples collected from the piping removed from the 4th floor and is discussed for each riser for each scenario. Radionuclides of concern for each riser are discussed in Section 4.2.2 of the report.

The mass loading for inhalation, C_{Dust}, is the concentration of respirable particles in air. The value selected for pipe removal is the time-weighted average nuisance level for dust during an 8-hour workday from 29 CFR 1910.1000, 0.015 grams per cubic meter (g/m^3). Concentrations greater than this limit would be mitigated using respiratory protection, engineering controls, or administrative controls and this is considered the maximum potential value for this parameter. The C_{Dust} value for the residual dust scenario was selected based on guidance in the RESRAD Data Collection Handbook (ANL 2015). The value of 0.0001 g/m^3 represents the 98th percentile concentration of respirable particles less than or equal to 2.5 micrometers in diameter and is the recommended value used for predictive purposes in dose modeling. The C_{Dust} value for the recycle scenario uses the recommended value of 0.001 g/m^3 for smelter workers from the RESRAD-Recycle manual (ANL 2000). As a conservative measure all respirable particles in air are assumed to be contaminated pipe scale generated during pipe cutting.

The air inhalation rate, IR_{Air}, is the volume of air inhaled over a specified time. The IR_{Air} value of 1.5 cubic meters per hour (m^3/hr) represents the average inhalation rate for all adults performing moderate activities (EPA, 2011) and the moderate breathing rate for construction workers (NRC, 1999).

The exposure duration, ED, is the time someone is exposed to the contaminated material. For the inhalation pathway the ED is expressed in hours. The value of ED used for the pipe removal scenario is based on the length of pipe removed and the number of cuts made to reduce the pipe to manageable length. The ED for each riser is discussed as part of the pipe removal scenario. The ED for the residual dust scenario is based on a maintenance worker performing light cleaning or other tasks in the area where contaminated dust settled on surfaces, and was assigned a value of 8 hours, or one workday. The ED value for the recycle scenario was selected based on guidance in the RESRAD-Recycle manual (ANL 2000) that describes a crew of 10 people working with the scrap metal over a period of two weeks, or a total of 800 hours. The ingestion pathway was not included in the dose calculations for the disposal and truck driver scenarios.

1.1.2 Dust Ingestion

The CEDE from ingestion of contaminated dust was calculated based on the radionuclide concentrations measured in pipe scale samples collected from pipes associated with a specific riser. The equation used to calculate dose from ingestion was adapted from EPA RAGS/HHEM (EPA 1991):

$$CEDE_{Ing} = R_C \times DCF_{Ing} \times IR_{Dust} \times ED$$

Where:

$CEDE_{Ing}$	=	Ingestion dose (mrem)
R_C	=	radionuclide concentration in pipe scale (pCi/g)
DCF_{Inh}	=	dose conversion factor for ingestion (mrem/pCi)
IR_{Dust}	=	ingestion rate for dust (g/day)
ED	=	exposure duration (days)

The dust ingestion rate, IR_{Dust}, is the amount of dust inadvertently ingested during a day. The IR_{Dust} value of 0.1 grams per day (g/day) represents the average of the 95th percentile values from multiple studies and is the upper percentile for the general population (EPA, 2011) and the maximum dust ingestion rate (NRC, 1999). As a conservative measure, all ingested dust is assumed to be contaminated pipe scale.

The ED value is expressed in terms of days for the ingestion pathway and includes the assumption a workday lasts 8 hours. The value of ED used for the pipe removal scenario is based on the length

of pipe removed and the number of cuts made to reduce the pipe to manageable length. The ED for each riser is discussed as part of the pipe removal scenario. The ED for the residual dust scenario is based on a maintenance worker performing light cleaning or other tasks in the area where contaminated dust settled on surfaces, and was assigned a value of 8 hours, or one workday. The ingestion pathway was not included in the dose calculations for the disposal and truck driver scenarios.

1.2 Pipe Removal Scenario

The pipe removal scenario describes potential exposure to a worker involved in removing or repairing pipes at 201 Varick Street containing pipe scale contaminated with radioactivity from the 5th floor laboratories. Samples of pipe scale representing individual risers were collected from pipe segments removed from the 4th floor. The radionuclide concentrations measured in the samples of pipe scale were used as the concentrations in pipe scale for all downstream pipes associated with that riser. The amount of time required to remove the pipe associated with a specific riser was related to the length of pipe remaining at 201 Varick Street. The removal of pipe from the 4th Floor required 8 workdays, or 64 hours, to remove approximately 2,000 linear feet of pipe. The time required to remove the remaining pipe associated with each riser was calculated based on the ratio of 0.032 hours per foot. The values were rounded up for conservatism.

Riser 50

All piping associated with Riser 50 was removed from the 4th floor and the riser was removed down to the 3rd Floor. The length of remaining downstream piping is 180 feet including 20 feet of vertical pipe to reach the basement, 20 feet of horizontal pipe on the 2nd floor to move from Riser 50 to Riser 69, and 140 feet of horizontal pipe in the basement connecting Riser 69 to the sewer. The number of hours estimated to remove 180 feet of piping at 0.032 hours per foot is 5.8 hours, which was rounded up to 6 hours or one workday.

The radionuclides included as part of the dose assessment for Riser 50 were all radionuclides reported above the detection limit by the analytical laboratory in the scale sample collected from the removed sections of vertical pipe from the 3rd Floor to the 5th Floor. The two radionuclides of concern for Riser 50 are uranium-234 (U-234) and uranium-238 (U-238). The concentrations reported in Table 4-7 of the main report are 0.0681 pCi/g for U-234 and 0.0556 pCi/g for U-238.

The results of the dose calculations for the inhalation and ingestion exposure pathways for removal of the remaining pipes associated with Riser 50 are provided in Table M-1.

Table M-1. Calculation of TEDE for Riser 50 Pipe Removal

Inhalation

Radionuclide	Concentration (pCi/g)	Inhalation Rate (m^3/h)	Respirable Particulates (g/m^3)	Exposure Time (hour)	Inhalation DCF (mrem/pCi)	CEDE (mrem)
Uranium-234	0.0681	1.5	0.015	6	0.132	1.2E-03
Uranium-238	0.0556	1.5	0.015	6	0.118	8.9E-04

Ingestion

Radionuclide	Concentration (pCi/g)	Ingestion Rate (grams/day)	Exposure Time (day)	Ingestion DCF (mrem/pCi)	CEDE (mrem)
Uranium-234	0.0681	0.1	1	2.83E-04	1.9E-06
Uranium-238	0.0556	0.1	1	2.55E-04	1.5E-06
				TEDE (mrem)	2.1E-03

Notes:
CEDE = Committed Effective Dose Equivalent
DCF = Dose Conversion Factor
g/m^3 = grams per cubic meter
m^3/hr = cubic meters per hour
mrem = milli Roentgen Equivalent Man
mrem/pCi = milli Roentgen Equivalent Man per picocurie
pCi/g = picocurie(s) per gram

Riser 51

All piping associated with Riser 51 was removed from the 4th floor and the riser was removed down to the 3rd Floor. The length of remaining downstream piping is 60 feet including 20 feet of vertical pipe to reach the basement, 20 feet of horizontal pipe on the 2nd floor to move from Riser 51 to Riser 70, and 20 feet of horizontal pipe in the basement connecting Riser 70 to piping removed for Riser 50. The number of hours estimated to remove 60 feet of piping at 0.032 hours per foot is 1.9 hours, which was rounded up to 2 hours or one workday.

The radionuclides included as part of the dose assessment for Riser 51 were all radionuclides

reported above the detection limit by the analytical laboratory in the scale sample collected from the sections of horizontal pipe removed from the 4th Floor. There are five radionuclides of concern for Riser 51. The radionuclides and concentrations listed in Table 4-6 of the main report are U-234 at 0.555 pCi/g, U-238 at 0.402 pCi/g, Th-228 at 0.730 pCi/g, Th-232 at 0.315 pCi/g, and Pu-238 at 1.15 pCi/g.

The results of the dose calculations for the inhalation and ingestion exposure pathways for removal of the remaining pipes associated with Riser 51 are provided in Table M-2.

Table M-2. Calculation of TEDE for Riser 51 Pipe Removal

Inhalation

Radionuclide	Concentration (pCi/g)	Inhalation Rate (m^3/h)	Respirable Particulates (g/m^3)	Exposure Time (hour)	Inhalation DCF (mrem/pCi)	CEDE (mrem)
Uranium-234	0.555	1.5	0.015	2	0.132	3.3E-03
Uranium-238	0.402	1.5	0.015	2	0.118	2.1E-03
Plutonium-238	1.15	1.5	0.015	2	0.392	2.0E-02
Thorium-228	0.73	1.5	0.015	2	0.345	1.1E-02
Thorium-232	0.315	1.5	0.015	2	1.64	2.3E-02

Ingestion

Radionuclide	Concentration (pCi/g)	Ingestion Rate (grams/day)	Exposure Time (day)	Ingestion DCF (mrem/pCi)	CEDE (mrem)
Uranium-234	0.555	0.1	1	2.83E-04	1.6E-05
Uranium-238	0.402	0.1	1	2.68E-04	1.1E-05
Plutonium-238	1.15	0.1	1	3.20E-03	3.7E-04
Thorium-228	0.730	0.1	1	8.09E-04	5.9E-05
Thorium-232	0.315	0.1	1	2.73E-03	8.6E-05
				TEDE (mrem)	6.1E-02

Notes:
CEDE = Committed Effective Dose Equivalent
DCF = Dose Conversion Factor
g/m^3 = grams per cubic meter
m^3/hr = cubic meters per hour
mrem = milli Roentgen Equivalent Man
mrem/pCi = milli Roentgen Equivalent Man per picocurie
pCi/g = picocurie(s) per gram

Riser 64

All piping associated with Riser 64 was removed from the 4th floor and the riser was removed down to the 3rd Floor. The length of remaining downstream piping is 90 feet including 20 feet of vertical pipe to reach the basement, 60 feet of horizontal pipe in the basement connecting Riser 64 to 10 feet of vertical pipe connected to the sewer. The number of hours estimated to remove 90 feet of piping at 0.032 hours per foot is 2.9 hours, which was rounded up to 3 hours or one workday.

The radionuclides included as part of the dose assessment for Riser 64 were all radionuclides reported above the detection limit by the analytical laboratory in the scale sample collected from the sections of horizontal pipe removed from the 4th Floor. Uranium-234 is the only radionuclide of concern for Riser 64. The radionuclide concentration listed in Table 4-5 of the main report is 0.0792 pCi/g for U-234.

The results of the dose calculations for the inhalation and ingestion exposure pathways for removal of the remaining pipes associated with Riser 64 are provided in Table M-3.

Table M-3. Calculation of TEDE for Riser 64 Pipe Removal

Inhalation

Radionuclide	Concentration (pCi/g)	Inhalation Rate (m^3/h)	Respirable Particulates (g/m^3)	Exposure Time (hour)	Inhalation DCF (mrem/pCi)	CEDE (mrem)
Uranium-234	0.0792	1.5	0.015	2	0.132	4.7E-04

Ingestion

Radionuclide	Concentration (pCi/g)	Ingestion Rate (grams/day)	Exposure Time (day)	Ingestion DCF (mrem/pCi)	CEDE (mrem)
Uranium-234	0.0792	0.1	1	2.83E-04	2.2E-06
				TEDE (mrem)	4.7E-04

Notes:
CEDE = Committed Effective Dose Equivalent
DCF = Dose Conversion Factor
g/m^3 = grams per cubic meter
m^3/hr = cubic meters per hour
mrem = milli Roentgen Equivalent Man
mrem/pCi = milli Roentgen Equivalent Man per picocurie
pCi/g = picocurie(s) per gram

Riser 76

The length of remaining downstream piping associated with Riser 76 is 140 feet including 20 feet of vertical pipe to reach the basement, and 120 feet of horizontal pipe in the basement connecting Riser 76 to the sewer. The number of hours estimated to remove 140 feet of piping at 0.032 hours per foot is 4.5 hours, which was rounded up to 5 hours or 1 workday.

The radionuclides included as part of the dose assessment for Riser 76 were all radionuclides reported above the detection limit by the analytical laboratory in the scale sample collected from the removed sections of vertical pipe from the 3rd Floor to the 5th Floor. The three radionuclides of concern for Riser 76 are U-234, U-238, and plutonium-238 (Pu-238). The concentrations reported in Table 4-7 of the main report are 6.65 pCi/g for U-234, 6.43 pCi/g for U-238, and 4.60 for Pu-238.

The results of the dose calculations for the inhalation and ingestion exposure pathways for removal of the remaining pipes associated with Riser 76 on the 4th floor are provided in Table M-4.

Table M-4. Calculation of TEDE for Riser 76 Pipe Removal

Inhalation						
Radionuclide	**Concentration (pCi/g)**	**Inhalation Rate (m^3/h)**	**Respirable Particulates (g/m^3)**	**Exposure Time (hour)**	**Inhalation DCF (mrem/pCi)**	**CEDE (mrem)**
Uranium-234	0.838	1.5	0.015	5	0.132	1.2E-02
Uranium-238	0.807	1.5	0.015	5	0.118	1.1E-02
Ingestion						
Radionuclide	**Concentration (pCi/g)**	**Ingestion Rate (grams/day)**	**Exposure Time (day)**	**Ingestion DCF (mrem/pCi)**		**CEDE (mrem)**
Uranium-234	0.838	0.1	1	2.83E-04		2.4E-05
Uranium-238	0.807	0.1	1	2.55E-04		2.2E-05
				TEDE (mrem)		2.3E-02

Notes:
CEDE = Committed Effective Dose Equivalent
DCF = Dose Conversion Factor
g/m^3 = grams per cubic meter
m^3/hr = cubic meters per hour
mrem = milli Roentgen Equivalent Man

mrem/pCi = milli Roentgen Equivalent Man per picocurie
pCi/g = picocurie(s) per gram

Riser 128

All piping associated with Riser 128 was removed from the 4th floor and the riser was removed down to the 3rd Floor. The length of remaining downstream piping is 150 feet including 20 feet of vertical pipe to reach the basement, and 130 feet of horizontal pipe in the basement connecting Riser 128 to the sewer. The number of hours estimated to remove 150 feet of piping at 0.032 hours per foot is 4.8 hours, which was rounded up to 5 hours or one workday.

The radionuclides included as part of the dose assessment for Riser 128 were all radionuclides reported above the detection limit by the analytical laboratory in the three scale samples collected from the sections of horizontal pipe removed from the 4th Floor. There are nine radionuclides of concern for Riser 128. The radionuclides and concentrations listed in Table 4-5 and Table 4-6 of the main report are U-234 at 0.706 pCi/g, U-235 at 0.426 pCi/g, U-238 at 0.605 pCi/g, Pu-238 at 0.480 pCi/g, Th-228 at 0.688 pCi/g, Th-230 at 0.699 pCi/g, Th-232 at 0.864 pCi/g, Ra-226 at 0.241 pCi/g, and Sr-90 at 0.299 pCi/g.

The results of the dose calculations for the inhalation and ingestion exposure pathways for removal of the remaining pipes associated with Riser 128 are provided in Table M-5.

Table M-5. Calculation of TEDE for Riser 128 Pipe Removal

Inhalation						
Radionuclide	**Concentration (pCi/g)**	**Inhalation Rate (m^3/h)**	**Respirable Particulates (g/m^3)**	**Exposure Time (hour)**	**Inhalation DCF (mrem/pCi)**	**CEDE (mrem)**
Uranium-234	0.706	1.5	0.015	5	1.32E-01	1.0E-02
Uranium-235	0.426	1.5	0.015	5	1.23E-01	5.9E-03
Uranium-238	0.605	1.5	0.015	5	1.18E-01	8.0E-03
Plutonium-238	0.480	1.5	0.015	5	3.92E-01	2.1E-02
Thorium-228	0.688	1.5	0.015	5	3.45E-01	2.7E-02
Thorium-230	0.699	1.5	0.015	5	3.26E-01	2.6E-02

Thorium-232	0.864	1.5	0.015	5	1.64E+00	1.6E-01
Radium-226	0.241	1.5	0.015	5	8.59E-03	2.3E-04
Strontium-90	0.299	1.5	0.015	5	1.31E-03	4.4E-05

Ingestion

Radionuclide	Concentration (pCi/g)	Ingestion Rate (grams/day)	Exposure Time (day)	Ingestion DCF (mrem/pCi)	CEDE (mrem)
Uranium-234	0.261	0.1	1	2.83E-04	7.4E-06
Uranium-235	0.426	0.1	1	2.67E-04	1.1E-05
Uranium-238	0.395	0.1	1	2.68E-04	1.1E-05
Plutonium-238	0.48	0.1	1	3.20E-03	1.5E-04
Thorium-228	0.688	0.1	1	8.09E-04	5.6E-05
Thorium-230	0.699	0.1	1	5.48E-04	3.8E-05
Thorium-232	0.864	0.1	1	2.73E-03	2.4E-04
Radium-226	0.241	0.1	1	1.32E-03	3.2E-05
Strontium-90	0.299	0.1	1	1.53E-04	4.6E-06
				TEDE (mrem)	2.6E-01

Notes:
CEDE = Committed Effective Dose Equivalent
DCF = Dose Conversion Factor
g/m^3 = grams per cubic meter
m^3/hr = cubic meters per hour
mrem = milli Roentgen Equivalent Man
mrem/pCi = milli Roentgen Equivalent Man per picocurie
pCi/g = picocurie(s) per gram

Riser 131

All piping associated with Riser 131 was removed from the 4th floor but the riser remains in place. The length of remaining downstream piping is 80 feet including 50 feet of vertical pipe to reach the basement, and 30 feet of horizontal pipe in the basement connecting Riser 131 to piping removed for Riser 128. The number of hours estimated to remove 80 feet of piping at 0.032 hours per foot is 2.6 hours, which was rounded up to 3 hours or one workday.

The radionuclides included as part of the dose assessment for Riser 131 were all radionuclides reported above the detection limit by the analytical laboratory in the scale sample collected from

the sections of horizontal pipe removed from the 4th Floor. There are eight radionuclides of concern for Riser 131. The radionuclides and concentrations listed in Table 4-6 of the main report are U-234 at 1.01 pCi/g, U-238 at 1.68 pCi/g, Pu-238 at 0.706 pCi/g, Th-230 at 1.24 pCi/g, Th-232 at 0.516 pCi/g, Ra-226 at 1.16 pCi/g, Cs-137 at 0.227 pCi/g, and Ni-63 at 4.99 pCi/g.

The results of the dose calculations for the inhalation and ingestion exposure pathways for removal of the remaining pipes associated with Riser 131 are provided in Table M-6.

Table M-6. Calculation of TEDE for Riser 131 Pipe Removal

Inhalation

Radionuclide	Concentration (pCi/g)	Inhalation Rate (m^3/h)	Respirable Particulates (g/m^3)	Exposure Time (hour)	Inhalation DCF (mrem/pCi)	CEDE (mrem)
Uranium-234	1.01	1.5	0.015	3	1.32E-01	9.0E-03
Uranium-238	1.68	1.5	0.015	3	1.18E-01	1.3E-02
Plutonium-238	0.706	1.5	0.015	3	3.92E-01	1.9E-02
Thorium-230	1.24	1.5	0.015	3	3.26E-01	2.7E-02
Thorium-232	0.516	1.5	0.015	3	1.64E+00	5.7E-02
Radium-226	1.16	1.5	0.015	3	8.59E-03	6.7E-04
Cesium-137	0.227	1.5	0.015	3	3.19E-05	4.9E-07
Nickel-63	4.99	1.5	0.015	3	6.29E-06	2.1E-06

Ingestion

Radionuclide	Concentration (pCi/g)	Ingestion Rate (grams/day)	Exposure Time (day)	Ingestion DCF (mrem/pCi)	CEDE (mrem)
Uranium-234	1.01	0.1	1	2.83E-04	2.9E-05
Uranium-238	1.68	0.1	1	2.68E-04	4.5E-05
Plutonium-238	0.706	0.1	1	3.20E-03	2.3E-04
Thorium-230	1.24	0.1	1	5.48E-04	6.8E-05
Thorium-232	0.516	0.1	1	2.73E-03	1.4E-04
Radium-226	1.16	0.1	1	1.32E-03	1.5E-04
Cesium-137	0.227	0.1		5.00E-05	1.1E-06
Nickel-63	4.99	0.1	1	5.77E-07	2.9E-07
				TEDE (mrem)	1.3E-01

Notes:
CEDE = Committed Effective Dose Equivalent

DCF = Dose Conversion Factor
g/m^3 = grams per cubic meter
m^3/hr = cubic meters per hour
mrem = milli Roentgen Equivalent Man
mrem/pCi = milli Roentgen Equivalent Man per picocurie
pCi/g = picocurie(s) per gram

Riser 144

All piping associated with Riser 144 was removed from the 4th floor and the riser was removed down to the 3rd Floor. The length of remaining downstream piping is 80 feet including 20 feet of vertical pipe to reach the basement, 20 feet of horizontal pipe on the 2nd Floor to move from Riser 144 to Riser 145, 40 feet of horizontal pipe on the 1st Floor to move from Riser 145 to Riser 127, and 20 feet of horizontal pipe in the basement connecting Riser 127 to piping removed for Riser 128. The number of hours estimated to remove 80 feet of piping at 0.032 hours per foot is 2.6 hours, which was rounded up to 3 hours or one workday.

The radionuclides included as part of the dose assessment for Riser 144 were all radionuclides reported above the detection limit by the analytical laboratory in the scale sample collected from the sections of horizontal pipe removed from the 4th Floor. There are seven radionuclides of concern for Riser 144. The radionuclides and concentrations listed in Table 4-5 of the main report are U-234 at 0.719 pCi/g, U-238 at 0.920 pCi/g, Th-228 at 0.222 pCi/g, Th-230 at 0.563 pCi/g, Th-232 at 0.337 pCi/g, Ra-226 at 0.373 pCi/g, and Cs-137 at 0.253 pCi/g.

The results of the dose calculations for the inhalation and ingestion exposure pathways for removal of the remaining pipes associated with Riser 144 are provided in Table M-7.

Table M-7. Calculation of TEDE for Riser 144 Pipe Removal

Inhalation

Radionuclide	Concentration (pCi/g)	Inhalation Rate (m^3/h)	Respirable Particulates (g/m^3)	Exposure Time (hour)	Inhalation DCF (mrem/pCi)	CEDE (mrem)
Uranium-234	0.719	1.5	0.015	3	1.32E-01	6.4E-03
Uranium-238	0.920	1.5	0.015	3	1.18E-01	7.3E-03
Thorium-228	0.222	1.5	0.015	3	3.45E-01	5.2E-03

Thorium-230	0.563	1.5	0.015	3	3.26E-01	1.2E-02
Thorium-232	0.337	1.5	0.015	3	1.64E+00	3.7E-02
Radium-226	0.373	1.5	0.015	3	8.59E-03	2.2E-04
Cesium-137	0.253	1.5	0.015	3	3.19E-05	5.4E-07

Ingestion

Radionuclide	Concentration (pCi/g)	Ingestion Rate (grams/day)	Exposure Time (day)	Ingestion DCF (mrem/pCi)	CEDE (mrem)
Uranium-234	0.719	0.1	1	2.83E-04	2.0E-05
Uranium-238	0.920	0.1	1	2.68E-04	2.5E-05
Thorium-228	0.222	0.1	1	8.09E-04	1.8E-05
Thorium-230	0.563	0.1	1	5.48E-04	3.1E-05
Thorium-232	0.337	0.1	1	2.73E-03	9.2E-05
Radium-226	0.373	0.1	1	1.32E-03	4.9E-05
Cesium-137	0.253	0.1		5.00E-05	1.3E-06
				TEDE (mrem)	6.9E-02

Notes:
CEDE = Committed Effective Dose Equivalent
DCF = Dose Conversion Factor
g/m^3 = grams per cubic meter
m^3/hr = cubic meters per hour
mrem = milli Roentgen Equivalent Man
mrem/pCi = milli Roentgen Equivalent Man per picocurie
pCi/g = picocurie(s) per gram

Riser 145

All piping associated with Riser 145 was removed from the 4th floor and the riser was removed down to the 3rd Floor. The length of remaining downstream piping is 170 feet including 20 feet of vertical pipe to reach the basement, 20 feet of horizontal pipe on the 2nd Floor to move from Riser 145 to Riser 126, and an estimated 130 feet of inaccessible horizontal pipe in the unexcavated portion of the basement connecting Riser 126 to piping removed for Riser 168. The number of hours estimated to remove 170 feet of piping at 0.032 hours per foot is 5.4 hours, which was rounded up to 6 hours or one workday.

The radionuclides included as part of the dose assessment for Riser 145 were all radionuclides

reported above the detection limit by the analytical laboratory in the scale sample collected from the sections of horizontal pipe removed from the 4th Floor. There are seven radionuclides of concern for Riser 145. The radionuclides and concentrations listed in Table 4-5 of the main report are U-234 at 0.331 pCi/g, U-238 at 0.516 pCi/g, Pu-238 at 0.164 pCi/g, Th-228 at 0.541 pCi/g, Th-230 at 0.680 pCi/g, Th-232 at 0.534 pCi/g, and Ra-226 at 0.461 pCi/g.

The results of the dose calculations for the inhalation and ingestion exposure pathways for removal of the remaining pipes associated with Riser 145 are provided in Table M-8.

Table M-8. Calculation of TEDE for Riser 145 Pipe Removal

Inhalation

Radionuclide	Concentration (pCi/g)	Inhalation Rate (m^3/h)	Respirable Particulates (g/m^3)	Exposure Time (hour)	Inhalation DCF (mrem/pCi)	CEDE (mrem)
Uranium-234	0.331	1.5	0.015	6	1.32E-01	5.9E-03
Uranium-238	0.516	1.5	0.015	6	1.18E-01	8.2E-03
Plutonium-238	0.164	1.5	0.015	6	3.92E-01	8.7E-03
Thorium-228	0.541	1.5	0.015	6	3.45E-01	2.5E-02
Thorium-230	0.680	1.5	0.015	6	3.26E-01	3.0E-02
Thorium-232	0.534	1.5	0.015	6	1.64E+00	1.2E-01
Radium-226	0.461	1.5	0.015	6	8.59E-03	5.3E-04

Ingestion

Radionuclide	Concentration (pCi/g)	Ingestion Rate (grams/day)	Exposure Time (day)	Ingestion DCF (mrem/pCi)	CEDE (mrem)
Uranium-234	0.331	0.1	1	2.83E-04	9.4E-06
Uranium-238	0.516	0.1	1	2.68E-04	1.4E-05
Plutonium-238	0.164	0.1	1	3.20E-03	5.2E-05
Thorium-228	0.541	0.1	1	8.09E-04	4.4E-05
Thorium-230	0.680	0.1	1	5.48E-04	3.7E-05
Thorium-232	0.534	0.1	1	2.73E-03	1.5E-04
Radium-226	0.461	0.1	1	1.32E-03	6.1E-05
				TEDE (mrem)	2.0E-01

Notes:
CEDE = Committed Effective Dose Equivalent
DCF = Dose Conversion Factor

g/m^3 = grams per cubic meter
m^3/hr = cubic meters per hour
mrem = milli Roentgen Equivalent Man
mrem/pCi = milli Roentgen Equivalent Man per picocurie
pCi/g = picocurie(s) per gram

Riser 168

The length of remaining downstream piping associated with Riser 168 is 50 feet including 20 feet of vertical pipe to reach the basement and 30 feet of horizontal pipe in the basement connecting Riser 168 to the sewer. The number of hours estimated to remove 50 feet of piping at 0.032 hours per foot is 1.6 hours, which was rounded up to 2 hours for inhalation and 1 workday for ingestion.

The radionuclides included as part of the dose assessment for Riser 168 were all radionuclides reported above the detection limit by the analytical laboratory in the scale sample collected from the removed sections of vertical pipe from the 3rd Floor to the 5th Floor. The 3 radionuclides of concern for Riser 168 are U-234, U-238, and Pu-238. The radionuclide concentrations reported in Table 4-7 of the main report are 7.07 pCi/g for U-234, 2.03 pCi/g for U-238, and 19.5 for Pu-238.

The results of the dose calculations for the inhalation and ingestion exposure pathways for removal of the remaining pipes associated with Riser 168 on the 4th floor are provided in Table M-9.

Table M-9. Calculation of TEDE for Riser 168 Pipe Removal

Inhalation						
Radionuclide	**Concentration (pCi/g)**	**Inhalation Rate (m^3/h)**	**Respirable Particulates (g/m^3)**	**Exposure Time (hour)**	**Inhalation DCF (mrem/pCi)**	**CEDE (mrem)**
Plutonium-238	0.514	1.5	0.015	2	0.392	9.1E-03
Uranium-234	0.0953	1.5	0.015	2	0.132	5.7E-04
Uranium-238	0.0843	1.5	0.015	2	0.118	4.5E-04
Ingestion						
Radionuclide	**Concentration (pCi/g)**	**Ingestion Rate (grams/day)**	**Exposure Time (day)**	**Ingestion DCF (mrem/pCi)**	**CEDE (mrem)**	
Plutonium-238	0.514	0.1	1	3.20E-03	1.6E-04	

Uranium-234	0.0953	0.1	1	2.83E-04	2.7E-06
Uranium-238	0.0843	0.1	1	2.55E-04	2.3E-06
				TEDE (mrem)	**1.6**

Notes:
CEDE = Committed Effective Dose Equivalent
DCF = Dose Conversion Factor
g/m^3 = grams per cubic meter
m^3/hr = cubic meters per hour
mrem = milli Roentgen Equivalent Man
mrem/pCi = milli Roentgen Equivalent Man per picocurie
pCi/g = picocurie(s) per gram

Riser 111

The length of remaining downstream piping associated with Riser 111 is 150 feet including 50 feet of vertical pipe to reach the basement and 100 feet of horizontal pipe in the basement connecting Riser 111 to the sewer. The number of hours estimated to remove 150 feet of piping at 0.032 hours per foot is 4.8 hours, which was rounded up to 6 hours for inhalation and 1 workday for ingestion. The increased time to remove this pipe is based on the inaccessibility of the pipe and expected issues with removing this pipe..

The radionuclides included as part of the dose assessment for Riser 111 were radionuclides identified in the 2012 dose assessment (Cabrera 2012) that contribute at least 1% to the TEDE for alpha emitting radionuclides or contribute significantly to the total activity for beta emitting radionuclides. The radionuclide concentrations are based on the total activity for individual radionuclides provided in Attachment 3 to the 2012 dose assessment (Cabrera 2012). The volume of pipe scale in the remaining 10 feet of pipe was calculated assuming the pipes were 4-inch diameter 25% filled with scale. The estimate of the total amount of scale was 140,000 grams spread evenly over 150 feet of pipe. Each radionuclide concentration was calculated as the total activity in picocuries (pCi) divided by the total volume in grams to provide the pCi/g values listed in Table M-4.

The results of the dose calculations for the inhalation and ingestion exposure pathways for removal of the remaining pipes associated with Riser 111 on the 4th floor are provided in Table M-10.

Table M-10. Calculation of TEDE for Riser 111 Pipe Removal

Inhalation

Radionuclide	Concentration (pCi/g)	Inhalation Rate (m^3/h)	Respirable Particulates (g/m^3)	Exposure Time (hour)	Inhalation DCF (mrem/pCi)	CEDE (mrem)
Am-241	0.708	1.5	0.015	6	0.444	0.042
Am-243	1.02	1.5	0.015	6	4.40E-01	0.061
Cm-243/244	1.72	1.5	0.015	6	0.307	0.071
Ni-63	18.3	1.5	0.015	6	6.29E-06	1.6E-05
Pu-238	12.2	1.5	0.015	6	0.392	0.65
Pu-239/240	1.06	1.5	0.015	6	4.29E-01	0.061
Pu-242	1.14	1.5	0.015	6	0.411	0.063
Ra-226	4.1	1.5	0.015	6	8.59E-03	4.8E-03
Tc-99	6.89	1.5	0.015	6	8.32E-06	7.7E-06
Th-230	62.2	1.5	0.015	6	3.26E-01	2.7
U-234	2.24	1.5	0.015	6	1.32E-01	0.040
U-238	0.216	1.5	0.015	6	1.18E-01	3.4E-03

Ingestion

Radionuclide	Concentration (pCi/g)	Ingestion Rate (grams/day)	Exposure Time (day)	Ingestion DCF (mrem/pCi)	CEDE (mrem)
Am-241	0.708	0.1	1	3.64E-03	2.6E-04
Am-243	1.02	0.1	1	3.62E-03	3.7E-04
Cm-243/244	1.72	0.1	1	2.51E-03	4.3E-04
Ni-63	18.3	0.1	1	5.77E-07	1.1E-06
Pu-238	12.2	0.1	1	3.20E-03	3.9E-03
Pu-239/240	1.06	0.1	1	3.54E-03	3.8E-04
Pu-242	1.14	0.1	1	3.36E-03	3.8E-04
Ra-226	4.1	0.1	1	1.32E-03	5.4E-04
Tc-99	6.89	0.1	1	1.46E-06	1.0E-06
Th-230	62.2	0.1	1	5.48E-04	3.4E-03
U-234	2.24	0.1	1	2.83E-04	6.3E-05
U-238	0.216	0.1	1	2.68E-04	5.8E-06
				TEDE (mrem)	**3.7**

Notes:
CEDE = Committed Effective Dose Equivalent
DCF = Dose Conversion Factor
g/m^3 = grams per cubic meter

m^3/hr = cubic meters per hour
mrem = milli Roentgen Equivalent Man
mrem/pCi = milli Roentgen Equivalent Man per picocurie
pCi/g = picocurie(s) per gram

1.3 Residual Dust Scenario

The residual dust scenario assumes the pipe scale particles released during pipe removal and cutting would settle on building surfaces in the area where the work was performed. These particles could then be ingested or resuspended in air and inhaled as a result of other activities performed in that area. The basis for the dose calculations uses a scenario where the area is cleaned following completion of pipe removal activities. Maintenance personnel would perform cleaning activities to remove the residual dust from the area, potentially being exposed to radiological contamination.

The radionuclide concentrations are based on the scale for pipes downstream of Riser 111. These are the highest concentrations for many radionuclides and include more radionuclides of concern resulting in the greatest potential for exposure. The duration of cleaning activities was et at 8 hours, or one workday. Both assumptions provide conservative estimates of dose.

The results of the dose calculations for the inhalation and ingestion exposure pathways for the residual dust scenario are provided in Table M-11.

Table M-11. Calculation of TEDE for the Residual Dust Scenario

Inhalation						
Radionuclide	**Concentration (pCi/g)**	**Inhalation Rate (m^3/h)**	**Respirable Particulates (g/m^3)**	**Exposure Time (hour)**	**Inhalation DCF (mrem/pCi)**	**CEDE (mrem)**
Am-241	0.708	1.5	1.0E-04	8	0.444	3.8E-04
Am-243	1.02	1.5	1.0E-04	8	4.40E-01	5.4E-04
Cm-243/244	1.72	1.5	1.0E-04	8	0.307	6.3E-04
Ni-63	18.3	1.5	1.0E-04	8	6.29E-06	1.4E-07
Pu-238	12.2	1.5	1.0E-04	8	0.392	5.7E-03
Pu-239/240	1.06	1.5	1.0E-04	8	4.29E-01	5.5E-04
Pu-242	1.14	1.5	1.0E-04	8	0.411	5.6E-04
Ra-226	4.1	1.5	1.0E-04	8	8.59E-03	4.2E-05

Tc-99	6.89	1.5	1.0E-04	8	8.32E-06	6.9E-08
Th-230	62.2	1.5	1.0E-04	8	3.26E-01	2.4E-02
U-234	2.24	1.5	1.0E-04	8	1.32E-01	3.5E-04
U-238	0.216	1.5	1.0E-04	8	1.18E-01	3.1E-05

Ingestion

Radionuclide	**Concentration (pCi/g)**	**Ingestion Rate (grams/day)**	**Exposure Time (day)**	**Ingestion DCF (mrem/pCi)**	**CEDE (mrem)**
Am-241	0.708	0.1	1	3.64E-03	7.7E-05
Am-243	1.02	0.1	1	3.62E-03	1.1E-04
Cm-243/244	1.72	0.1	1	2.51E-03	1.3E-04
Ni-63	18.3	0.1	1	5.77E-07	3.2E-07
Pu-238	12.2	0.1	1	3.20E-03	1.2E-03
Pu-239/240	1.06	0.1	1	3.54E-03	1.1E-04
Pu-242	1.14	0.1	1	3.36E-03	1.1E-04
Ra-226	4.1	0.1	1	1.32E-03	1.6E-04
Tc-99	6.89	0.1	1	1.46E-06	3.0E-07
Th-230	62.2	0.1	1	5.48E-04	1.0E-03
U-234	2.24	0.1	1	2.83E-04	1.9E-05
U-238	0.216	0.1	1	2.68E-04	1.7E-06
				TEDE (mrem)	**3.6E-02**

Notes:
CEDE = Committed Effective Dose Equivalent
DCF = Dose Conversion Factor
g/m^3 = grams per cubic meter
m^3/hr = cubic meters per hour
mrem = milli Roentgen Equivalent Man
mrem/pCi = milli Roentgen Equivalent Man per picocurie
pCi/g = picocurie(s) per gram

1.4 Recycle Scenario

The recycle scenario is based on melting the pipes to recover and reuse the component metal. The pipes would be processed at a smelting facility where the pipes would be shredded and placed in a furnace to melt the pipes and recover the metal. Radionuclides could end up in the reprocessed metal, released as vapors or particulates and captured in the baghouse filters, or be disposed of as

slag or waste at the end of the process. The basis for this scenario is taken from guidance in the RESRAD-Recycle manual (ANL 2000).

The recycle scenario assumed a crew of 10 people work at the smelter and could be exposed over a two-week period while the pipes are processed. The exposure duration was set at 800 hours assuming 10 people working 8 hours per day for 10 days.

Radionuclide concentrations were based on uniform distribution of the total activity for the same radionuclides used for removal of pipe downstream of Riser 111 from the 2012 dose assessment (Cabrera 2012). The total volume of metal recycled in one batch was set at 100 tons based on guidance from the RESRAD-Recycle manual (ANL 2000).

The contribution to total dose for external exposure was incorporated in the recycle scenario. The external dose to a landfill worker presented in the 2012 dose assessment (Cabrera 2012) was adjusted to account for the increased exposure duration and the increased distance between the workers and the contaminated pipe (10 meters instead of 1 meter).

The results of the dose calculation for the recycle scenario for pipes removed from 201 Varick Street are provided in Table M-12.

Table M-12. Calculation of TEDE for the Recycle Scenario

Inhalation						
Radionuclide	**Concentration (pCi/g)**	**Inhalation Rate (m^3/h)**	**Respirable Particulates (g/m^3)**	**Exposure Time (hour)**	**Inhalation DCF (mrem/pCi)**	**CEDE (mrem)**
Am-241	1.09E-10	1.5	1.0E-03	800	0.444	5.8E-11
Am-243	1.58E-10	1.5	1.0E-03	800	4.40E-01	8.3E-11
Cm-243/244	2.66E-10	1.5	1.0E-03	800	0.307	9.8E-11
Ni-63	2.82E-09	1.5	1.0E-03	800	6.29E-06	2.1E-14
Pu-238	1.89E-09	1.5	1.0E-03	800	0.392	8.9E-10
Pu-239/240	1.63E-10	1.5	1.0E-03	800	4.29E-01	8.4E-11
Pu-242	1.76E-10	1.5	1.0E-03	800	0.411	8.7E-11
Ra-226	6.33E-10	1.5	1.0E-03	800	8.59E-03	6.5E-12
Tc-99	1.06E-09	1.5	1.0E-03	800	8.32E-06	1.1E-14
Th-230	9.60E-09	1.5	1.0E-03	800	3.26E-01	3.8E-09

U-234	3.46E-10	1.5	1.0E-03	800	1.32E-01	5.5E-11
U-238	3.33E-11	1.5	0.015	800	1.18E-01	4.7E-12
Ingestion						
Radionuclide	**Concentration (pCi/g)**	**Ingestion Rate (grams/day)**	**Exposure Time (day)**	**Ingestion DCF (mrem/pCi)**		**CEDE (mrem)**
Am-241	1.09E-10	0.1	100	3.64E-03		4.0E-12
Am-243	1.58E-10	0.1	100	3.62E-03		5.7E-12
Cm-243/244	2.66E-10	0.1	100	2.51E-03		6.7E-12
Ni-63	2.82E-09	0.1	100	5.77E-07		1.6E-14
Pu-238	1.89E-09	0.1	100	3.20E-03		6.0E-11
Pu-239/240	1.63E-10	0.1	100	3.54E-03		5.8E-12
Pu-242	1.76E-10	0.1	100	3.36E-03		5.9E-12
Ra-226	6.33E-10	0.1	100	1.32E-03		8.4E-12
Tc-99	1.06E-09	0.1	100	1.46E-06		1.6E-14
Th-230	9.60E-09	0.1	100	5.48E-04		5.3E-11
U-234	3.46E-10	0.1	100	2.83E-04		9.8E-13
U-238	3.33E-11	0.1	100	2.68E-04		8.9E-14
External						
						External (mrem)
Total						0.059
					TEDE (mrem)	**5.9E-02**

Notes:
CEDE = Committed Effective Dose Equivalent
DCF = Dose Conversion Factor
g/m^3 = grams per cubic meter
m^3/hr = cubic meters per hour
mrem = milli Roentgen Equivalent Man
mrem/pCi = milli Roentgen Equivalent Man per picocurie
pCi/g = picocurie(s) per gram

1.5 Disposal Scenario

The disposal scenario was described in detail in the 2012 dose assessment (Cabrera 2012). This scenario assumes the pipe sections and contaminated scale have been transported to a landfill. The resulting exposure rate was modeled at a range of one meter from the contaminated material.

The person exposed in this scenario is a landfill worker (non-radiation trained worker using no radiological controls) who stood in the middle of this uncovered source term for a total maximum estimate of eight hours before the pipe sections and contaminated contents were covered by other landfill materials. Direct external exposure from radionuclides was the only exposure pathway considered for this scenario.

The calculation of dose from external exposure included all radionuclides of concern presented in the 2012 dose assessment (Cabrera 2012) and also included photons from unidentified peaks to ensure all potential sources of external exposure were included. The dose from external exposure presented in the 2012 dose assessment was 0.47 mrem.

1.6 Truck Driver Scenario

The truck driver scenario considered the potential exposure to personnel transporting pipes removed from 201 Varick Street. The pipes could be transported to a recycle facility or to a landfill for disposal. Direct external exposure from radionuclides was the only exposure pathway considered for this scenario.

For consistency with the disposal scenario the truck drive was assumed to be sitting one meter from the center of the contaminated pipes and scale. The exposure duration was set at 4 hours based on guidance in the RESRAD-Recycle manual (ANL 2000). Since the exposure duration is half what was used for the disposal scenario, the dose from external exposure for the truck driver scenario would be half the disposal scenario dose. Therefore, the truck driver dose would be 0.23 mrem.

2.0 CONCLUSIONS

The exposure scenario resulting in the highest potential dose is the pipe removal scenario. The dose calculated for the removal of all remaining radiologically impacted piping at 201 Varick Street could result in a dose of 4.5 mrem to the reasonable maximally exposed individual. This is below the 25 mrem dose limit from 10 CFR 20.1402.

Dose calculations were performed for remaining piping associated with individual risers. The riser with the highest potential dose during removal was Riser 111. Approximately 50 feet of acid waste line containing elevated concentrations of residual radioactivity associated with

Column 111 were removed from the 4th floor in 2012. The current dose calculations evaluate the potential for residual radioactivity to have migrated downstream from the pipes removed from the 4th floor based on the results of characterization and investigations performed at 201 Varick Street.

Additional scenarios were evaluated to ensure the estimates of dose were comprehensive. A residual dust scenario covering cleanup and exposures to personnel working in areas where pipes were removed was evaluated with a dose approximately 10% of the dose calculated for the removal scenario. Scenarios covering transport of removed pipe, recycling od removed pipe, and disposal of removed pipe were also evaluated and the calculated doses were less than the dose from the pipe removal scenario.

The pipe removal scenario includes conservative assumptions to ensure the dose is not underestimated. The maximum radionuclide concentrations in scale collected from removed pipes was used as the radionuclide concentration for scale in all downstream pipes. The mass loading factor used for calculation inhalation dose was the time weighted limit for nuisance dust and assumed all respirable particles were contaminated scale. Higher concentrations of particulates in air would result in protective measures being implemented that would reduce the calculated dose. The ingestion rate for dust was selected as an upper limit for the general population and assumes all of the ingested dust is contaminated scale.

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