Technical Support Document

TSD 14-015

Buried Pipe Dose Modeling & DCGLs

Revision 3

Originator: ________________________________ Date: 02/23/2017

David Fauver

Reviewer: ________________________________ Date: 02/23/2017

David Wojtkowiak (Revision 3 Changes Only)

Approval: ________________________________ Date: 02/23/17

Robert F. Yetter

Summary of Changes in this Revision:

- Revision 3 – Incorporated TSD 14-016 reference as document for buried pipe inventory and deleted Attachment 1 inventory list.

Table of Contents

List of Tables

1. PURPOSE

The purpose of this Technical Support Document (TSD) is to establish the Derived Concentration Guideline Levels (DCGLs), in units of disintegrations per minute per one hundred square centimeters (dpm/100 cm^2), for the internal surfaces of buried piping at Zion. Buried piping is defined as piping contained in soil as opposed to embedded piping which is contained within concrete floors of structures.

2. DISCUSSION

The Zion Site Restoration Project (ZSRP), Exhibit C, Lease Agreement, section 8.5 titled "Removal of Improvements; Site Restoration" integral to the *"Zion Nuclear Power Station, Units 1 and 2 Asset Sale Agreement"* requires the demolition and removal of all on-site buildings, structures, and components to a depth of at least three feet below grade. Several minor structures such as the Switchyard, the ISFSI warehouse, the microwave tower, and the Sewage Lift Station, as well as all roadways and rail lines, will remain at license termination as requested by Exelon. The major structures that will remain at license termination are the basements of the Unit 1 Containment Building, Unit 2 Containment Building, Auxiliary Building, Turbine Building, Waste Water Treatment Facility (WWTF), the lower portion of the Spent Fuel Pool (SFP), the Fuel Transfer Canal, Crib House and Forebay, Unit 1 and Unit 2 Steam Tunnels and the Circulating Water Intake and Discharge Piping below the 588 foot elevation. All systems, components as well as all structures above the 588 foot elevation (with the exception of the minor structures previously noted) will be removed during the decommissioning process and disposed of as a waste stream.

A range of below ground piping will also remain at license termination. The piping will fall into one of three categories: buried, embedded and penetrations. Buried piping is below ground pipe located outside of structures and basements and buried in soil. Embedded piping is defined as piping that is located, or embedded, in the concrete basement floors. Penetrations are the portions of various systems piping remaining within building walls, floors, and ceilings after all systems and piping are removed from building interiors.

This TSD provides the method for calculating the dose to the Average Member of the Critical Group (AMCG) from any remaining buried piping associated with the ZSRP and the corresponding DCGLs to demonstrate compliance with 10 CFR 20 Subpart E, (1). TSD 14-010, *RESRAD Modeling for Basement Fill Model and Soil DCGL and Calculation of Basement Fill Model Dose Factors and DCGLs,* calculates site-specific DCGLs for soils, (2). The list of radionuclides of concern (ROC) was evaluated using Reactor Buildings (Units 1 and 2), Auxiliary Building, and Turbine Building concrete core analysis data by evaluating the dose significance of each radionuclide in the end state model. The list of ROCs was evaluated in TSD 14-019, *Radionuclides of Concern for Basement Fill Model Source Term and Surrogate Ratios*, (3).

2.1. Buried Piping Radionuclides of Concern

The results of surface and subsurface soil characterization in the impacted area surrounding ZNPS indicate that there is minimal residual radioactivity in soil. Based on the characterization survey results to date, ZSRP does not anticipate the presence of significant soil contamination in any remaining subsurface soil that has not yet been characterized. In addition, based on process knowledge, minimal contamination is expected in any of the buried piping that ZSRP plans to abandon in place. Consequently, due to the absence of any significant source term in soil or in buried piping, the suite of ROC and radionuclide mixture derived for the Auxiliary Building concrete was considered to be a reasonably conservative mixture to apply to soils and buried piping for FSS planning and implementation.

To date, with the exception of some Turbine Building basement drains, samples from site piping systems have not been collected. The buried piping that is intended to remain is from support systems where process knowledge and historical operation surveys indicate an extremely low probability of residual contamination. ZSRP is currently using activity from Auxiliary Building structural concrete core samples to represent the radionuclide mixture that will remain within buried piping. These cores were obtained at locations with high contact dose rates and/or evidence of leaks/spills. They are therefore heavily biased toward locations with high concentrations of radionuclides in the concrete. Based upon the analysis, as described in TSD 14-019, it was determined that Co-60, Ni-63, Sr-90, Cs-134 and Cs-137 accounted for 99.4% of all dose in the contaminated concrete mixes, (3) The remaining radionuclides of concern from the original radionuclide suite were eliminated due to insignificant dose consequence.

2.2. End State Buried Piping

Buried piping, with internal diameters ranging from one-inch to 42 inches (not including the Circulating Water Intakes and Discharge Pipes from Units 1 and 2 and 48 inch Service Water Headers), are expected to remain on site. The current buried piping inventory is provided as Attachment 1. The inventory will be updated, as necessary, with future findings. None of the buried piping listed in Attachment 1 is associated with systems involving reactor coolant and therefore, based on process knowledge, are not expected to be significantly contaminated, containing trivial or no residual radioactive material.

Embedded conduit is also listed in Attachment 1 for completeness. The conduit was installed during initial construction prior to the internal contamination of systems; therefore, the interior surface of conduit is not expected to be contaminated unless installation occurred after ZNPS startup. The same applies to the interior and exterior of duct boxes. Underground electrical equipment vaults, electrical manholes, and associated components will be evaluated on a case by case basis with consideration given for contamination potential due to flooding or other mechanisms where contamination could have been introduced into the vault. Storm drains will also be evaluated considering runoff flow paths and regional topography relative to the contamination potential of the immediate area that could influence the drainage.

3. CALCULATIONS

The buried pipe DCGL is determined for two scenarios; assuming that all pipe is excavated and assuming that all pipe remains insitu. Although unrealistic, for the purpose of the bounding modeling approach used, the dose from the two scenarios is summed to determine the Buried Pipe DCGL.

The excavation scenario assumes that all buried pipe is excavated and all activity on the internal surfaces of the pipes instantly released and mixed with surface soil. The insitu scenario assumes that all of the buried piping remains insitu and all activity is instantly released to adjacent soil. Two separate insitu calculations were performed. The first assumes that all pipes are located at 1 m below the ground surface and the second assumes that all pipes are located in the saturated zone.

The final Buried Pipe DCGLs is calculated by adding the Excavation Scenario Dose to Source Ratio (DSR) to the Insitu Scenario DSR. To ensure conservatism, the maximum insitu dose from the two scenarios, saturated and unsaturated, is used in the final buried pipe DCGL calculation

3.1. Buried Pipe RESRAD Model for Excavation Scenario

The Excavation scenario assumes that all of the buried piping is excavated, brought to the surface and spread over a contiguous area equal to the internal surface area of the pipe. After being brought to the surface all of the activity on the internal surfaces of the pipe is assumed to instantly release and mix in a 0.15 m depth of surface soil.

RESRAD modeling is used to determine the dose from excavated buried pipe in units of mrem/yr per pCi/g. The RESRAD parameters used are the same as those used for surface soil DCGLs (see LTP Chapter 6, Attachment 4) with the following exceptions:

- Area of Contaminated Zone 2153 m^2
- Length Parallel to Flow 46 m
- Cover Depth 0 m
- Unsaturated Zone Thickness 3.45 m

The Area of Contaminated Zone parameter is equal to the total internal surface are of all buried pipe as shown in Attachment 1. The length parallel to flow is the square root of the contaminated area under a nominal assumption that the shape of the contaminated area is square. The bases for the remaining parameters are self-explanatory. Note that the buried pipe list was revised after the RESRAD runs were made. The total internal surface area was reduced from 2153 m^2 to 1942 m^2 as documented in ZionSolutions TSD 14-016, “Description of Embedded Piping, Penetrations and Buried Piping to Remain in Zion End State” (4). The reduced area results in lower dose to source ratios (DSRs) (mrem/yr per pCi/g) and therefore the DSRs using 2153 m^2 were retained and used to calculate the Buried Pipe DCGLs which is conservative. The area revision (and associated conservatism) also applies to the Insitu Saturated and Insitu Unsaturated scenarios RESRAD runs described below in section 3.2.

3.2. Buried Pipe RESRAD Model for Insitu Scenarios

The Buried Pipe Insitu scenarios assume that the pipe remains in place. Two insitu geometries are evaluated. One scenario assumes that the buried pipe is in the unsaturated zone and a second scenario assumes that the pipe is in the saturated zone.

For the Insitu Unsaturated Zone scenario, the pipes are assumed to be located 1 m below the ground surface. The ZSRP decommissioning approach calls for removal of all material, including piping, to 3 feet below grade. Note that portions of the storm drain system that will remain in place and functional after license termination are closer to the surface than 1 m but this minor exception is considered insignificant. Assuming that the pipe is within 1m of the surface allows the roots to penetrate the 0.15 m thick insitu source which maximizes dose.

The RESRAD parameters used for the Buried Pipe Unsaturated Zone Insitu scenario are the same as those used for surface soil DCGLs (see LTP Chapter 6, Attachment 4) with the following exceptions:

- Area of Contaminated Zone 2153 m^2
- Length Parallel to Flow 46 m
- Cover Depth 1 m
- Unsaturated Zone Thickness 2.45

The second insitu scenario evaluated assumed that all buried pipe is in the saturated zone. This scenario is intended to conservatively address the possibility that GW could possibly enter some portions of the buried piping.

The RESRAD parameters used for the Buried Pipe Saturated Zone Insitu scenario are the same as those used for surface soil DCGLs (see LTP Chapter 6, Attachment 4) with the following exceptions:

- Area of Contaminated Zone 2153 m^2
- Length Parallel to Flow 46 m
- Cover Depth 3.6 m
- Unsaturated Zone Thickness 0 m
- Contaminated Fraction Below the Water Table 1
- All Kds set to minimum site-specific value since dose is 100% from water pathways

3.3. Buried Pipe Uncertainty Analysis

An uncertainty analysis was performed for the three Buried Pipe dose scenarios to identify any parameters, if any, that are sensitive in the Buried Pipe scenarios that were not identified as sensitive in the soil dose modeling uncertainty analysis. The process and criteria used to identify sensitive parameters and select conservative deterministic parameters were the same as that describe in TSD 14-010, Figure 1.

The RESRAD parameters assigned for the uncertainty analysis are the same as those used for the soil uncertainty analysis listed in TSD 14-010, Attachment 7 with a few exceptions:

- The Buried Pipe scenario parameters listed in section 3.2 were used as opposed to the corresponding soil parameters.
- Kd distributions were included to represent the range of site-specific sand Kd values determined by laboratory analysis
- To allow the dose from plant ingestion to vary with contaminated zone area, the two plant ingestion rate parameters were doubled to account for the fact that RESRAD automatically divides the entered ingestion rates by a factor of 2 when a value of -1 is used for the "Contaminated Fraction of Plant Food" parameter. The modified parameters are:
  - Fruits, non-leafy vegetables, grain consumption (kg/y) = 224
  - Leafy vegetable consumption (kg/y) = 42.8

The file names of the three RESRAD Uncertainty Reports are listed below (one for each of the Buried Pipe scenarios). The full reports are stored electronically.

- Buried Pipe Excavation RESRAD Uncertainty Report 5_22_16.pdf

- Buried Pipe Insitu Unsat RESRAD Uncertainty Report 5_22_16.pdf
- Buried Pipe Insitu Sat RESRAD Uncertainty Report 5_22_16.pdf

The parameters identified as sensitive, i.e., those with a Partial Rank Correlation Coefficient (PRCC) greater than the absolute value of 0.25 (|0.25|) are listed in Table 2. The 75th percentile of the parameter distribution was selected as the deterministic value for parameters with positive correlation and the 25th percentile selected for negatively correlated parameters. The percentiles and selected deterministic parameters are listed in Table 2.

Table 1 - Sensitive Parameters for the Three Buried Pipe Scenarios

Parameter Name	BP Excavation		BP Insitu Unsaturated		Bp Insitu Saturated	
	Percentile	Parameter	Percentile	Parameter	Percentile	Parameter
Plant Transfer Factor for Sr-90	75th	0.59	75th	0.59	NS	
Plant Transfer Factor for Cs-137	75th	0.078	NS[1]		NS	
External Gamma Shielding Factor	75th	0.4	NS		NS	
Depth of Roots	25th	1.22	75th	1.15[5]	NS	
Saturated Zone Hydraulic Gradient	NS		NS		25th	0.0022[2]
Weathering Removal Constant of all Vegetables	NS		NS		25th	21.50
Well Pump Intake Depth	NS		NS		25th	3.3[3]
Kd of Sr-90 in Contaminated Zone	NS[6]		NS		25th	2.3[4]

Note 1: NS = Not Sensitive

Note 2: Saturated Zone Hydraulic Gradient was slightly negatively correlated. The 25th percentile value of the NUREG-6697 recommended distribution is 0.00185. However, the lowest site-specific value is 0.0022 as reported in "Zion*Solutions* TSD 14-006 "Conestoga Rovers & Associates (CRA) Report, Evaluation of Hydrological Parameters in Support of Zion Restoration Project" October 2014" which was used as opposed to the generic 25th percentile value.

Note 3: The 25th percentile value of the NUREG-6697 recommended distribution is11.02 m. However, the selected well depth parameter for soil (and applied to Buried Pipe) is the average depth of the Upper Sand Unit which is 3.3 m. Because 3.3 m is site-specific as well as being less than the NUREG-6697 25th percentile 3.3 m was used.

Note 4: the minimum site-specific soil Kd of 2.3 was used.

Note 5: The dose from root depth in the Insitu Unsaturated scenario is a step function with zero plant dose up to a 1 m depth, maximum dose at 1.15 m depth and decreasing dose with depth > 1.15 m. Therefore, a 1.15 m root depth was used to maximize dose.

Note 6: Maximum site-specific Sr-90 Kd of 3.4 cm^3/g was shown to result in slightly increased dose for surface soil in TSD 14-010 therefore 3.4 cm^3/g was used.

The final deterministic parameter set used to calculate buried pipe dose conversion factors for the Buried Pipe scenarios was the surface soil parameter with modifications described in section 3.2 and any changes to parameters considered sensitive by the uncertainty analysis (see Table 2).

Table 2 - RESRAD DSR Results for Buried Pipe Dose Assessment to Support DCGL Development

Radionuclide	Excavation (mrem/yr per pCi/g)	Insitu Unsaturated (mrem/yr per pCi/g)	Insitu Saturated (mrem/yr per pCi/g)
Co-60	4.975E+00	7.298E-02	5.710E-04
Cs-134	2.836E+00	1.070E-01	2.881E-03
Cs-137	1.238E+00	8.491E-02	2.287E-03
Ni-63	1.445E-03	1.285E-03	2.745E-04
Sr-90	1.489E+00	1.384E+00	1.480E+00

Note 1: The Sr-90 DSRs for Excavation and Insitu Saturated were multiplied by a factors of 1.13 and 1.08, respectively, to adjust for potentially higher dose from thicker source terms

The only parameters that required change as a result of the uncertainty analysis were the Saturated Zone Hydraulic Gradient for the Insitu Saturated scenario and the Depth of Roots for the Insitu Unsaturated scenario. All of the remaining parameters identified as sensitive in Table 2 were already identified as sensitive, with the same correlation, in the soil DCGL sensitivity analyses. The corresponding parameters, either 25^{th} or 75^{th} percentile, were included in the baseline surface soil DCGL deterministic parameter sets used for the Buried Pipe RESRAD runs.

The sensitivity of the assumed source term thickness required a separate analysis. The buried pipe scenarios assume that residual radioactivity is released from the pipes into adjacent soil. The thickness of soil into which the released activity was assumed to mix was 0.15 m which is considered the minimum reasonable mixing depth, particularly for the excavation scenario. As the "Thickness of Contaminated Zone" parameter is increased, assuming a unit concentration for all radionuclides, the dose increases. However, as the contaminated zone thickness increases the source term concentration decreases as an inverse linear function of the mixing depth. To determine the effect of these conflicting effects of increasing the Thickness of Contaminated Zone a separate sensitivity analysis was performed that accounts for both effects for source term thicknesses of 0.15 m and 1.0 m.

Attachment 3 provides the results of the sensitivity analysis. Note that for all scenarios and all radionuclides except Sr-90 increasing the Thickness of Contaminated Zone either has no effect on dose (indicated by a value of 1 in the column labeled "DSR Ratio*Source Term Decrease" in Attachment 3 Tables) or causes the dose to decrease (indicated by a fraction in the column labeled "DSR Ratio*Source Term Decrease" in Attachment 3 Tables). The one exception, i.e., Sr-90, showed an 8% increase in dose at a 1 m source term depth for the Insitu Saturated scenario and a 13% increase at 1 m depth for the Excavation Scenario.

For the Insitu Saturated Scenario, increasing the source term thickness had no effect on dose for any radionuclides other than Sr-90. Note that the actual dose impact from the slightly increased Sr-90 dose for a 1 m thick source, as opposed to 0.15 m, is much lower than the values calculated

individually for Sr-90 when the mixture percentages are considered. As shown in LTP Chapter 5, Table 5-2, the mixture fraction for Cs-137 is 75.32% while the mixture fraction for Sr-90 is 0.05%. Therefore, the actual fractional dose attributable to the 8% and 20% increased values can be approximated as the ratio of percentages times the percentage increase, i.e., 1.08*0.05/75.32 and 1.13 *0.05/75.32, or 0.07% and 0.08% of the final compliance dose which is insignificant.
For the excavation scenario there are conflicting results for Sr-90 and the gamma emitters. While the Sr-90 dose shows an increase of 13% for the 1 m depth the Cs-137 dose decreases by 79%. When the mixture fractions are considered it is clear that the decrease in Cs-137 dose at 1 m source term depth would be orders of magnitude greater than the slight Sr-90 increase which would result in a non-conservative dose calculation.

In conclusion, the Thickness of Contaminated Zone parameter will be set to 0.15 for all scenarios. However, to account for the indicated dose increase for Sr-90 at 1m depth DSRs for Sr-90 will be increased by factors of 1.08 and 1.13 for the Insitu Saturated and Excavation scenarios, respectively.

3.4. Buried Pipe RESRAD Results

Three RESRAD runs were performed for Buried Pipe; Excavation Scenario, Insitu Unsaturated Scenario, and Insitu Saturated Scenario. The RESRAD Summary Report file names are listed below. The full reports are stored electronically.

- Zion Buried Pipe Excavation RESRAD Summary Report 5_23_16.pdf
- Zion Buried Pipe Insitu Unsaturated RESRAD Summary Report 5_23_16.pdf
- Zion Buried Pipe Insitu Saturated RESRAD Summary Report 5_23_16.pdf

The RESRAD Dose to Source Ratio (DSR) results are summarized in Table 3.

Table 3 - Maximum Summed RESRAD DSRs from Excavation and Insitu Scenarios

Radionuclide	Maximum Summed DSR Excavation + Insitu (mrem/yr per pCi/g)
Co-60	5.048E+00
Cs-134	2.943E+00
Cs-137	1.323E+00
Ni-63	2.730E-03
Sr-90	2.969E+00

3.5. Buried Pipe DCGLs

The Buried Pipe DCGL is determined by first calculating the pCi/g concentration in the 0.15 m soil mixing layer that corresponds to a unit concentration, 1 dpm/100 cm^2, on the pipe surface. The second input to the DCGL calculation is the sum of the DSR for Excavation and the maximum DSR for the Insitu Scenarios. As seen in Table 2, the maximum Insitu DSR is from the Unsaturated Scenario for all radionuclides except Sr-90. Therefore, the DSR summation used in the Buried Pipe DCGL calculation is comprised of the Excavation and Insitu Unsaturated Scenario DSRs for all radionuclides except Sr-90 which is based on the summation of the Excavation and Insitu Saturated Scenario DSRs. The summed DSRs are shown in Table 4.

Table 4 - Buried Pipe DCGLs

Radionuclide	Buried Pipe DCGL (dpm/100 cm^2)
Co-60	2.942E+04
Cs-134	5.046E+04
Cs-137	1.123E+05
Ni-63	5.440E+07
Sr-90	5.002E+04

The dpm/100 cm^2 per pCi/g conversion factor is used with the maximum summation DSR in Table 3 to calculate the Buried Pipe DCGL as shown in Equation 1.

Equation 1

BP DCGL = 1/Max Summed DSR * [(dpm/100 cm^2) / (pCi/g)] * 25 mrem/yr

where:

BP DCGL = Buried Pipe DCGL (dpm/100 cm^2)
Max Summed DSR = Maximum Summed DSR values from Table 3 (pCi/g per mrem/yr)
[(dpm/100 cm^2)/pCi/g] = dpm/100 cm^2 in pipe per pCi/g in soil

The spreadsheet calculation of Buried Pipe DCGLs is shown in Attachment 2. Table 5 provides the resulting Buried Pipe DCGLs.

3.6. Adjustment for Dose from Insignificant Contributors

The Buried Pipe DCGLs must be adjusted to account for the radionuclides in the initial suite that were removed due to insignificant dose contribution. The buried pipe Insitu scenarios, particularly the Insitu Saturated, have a greater potential groundwater dose contribution than the soil DCGL scenario. Therefore, the insignificant dose contribution fraction calculated for the Basement Fill Model (BFM) is considered more applicable than the soil value.

To check that the BFM insignificant fraction is applicable a simple assessment was performed based on the ratio of maximum summed DSRs for Sr-90/Cs-137 for the Insitu Saturated and Excavation scenarios. The Sr-90 dose is predominantly due to groundwater and plant/meat/milk pathways and therefore represents the radionuclides in the initial suite with the same characteristics. The ratio of Sr-90 to Cs-137 maximum DSRs from Table 4 is 2.969/1.323 = 2.2. The ratio of Sr-90 to Cs-137 BFM Dose Factors for the Auxiliary Basement from (Reference 2) is 3.38E-01/3.04E-02 = 11.1.

The ratio of Sr-90/Cs-137 for the BFM is more than 4 times higher than the corresponding ratio using the Buried Pipe DSRs. Therefore, the relative contribution of Sr-90, and by inference, all other initial suite radionuclides that have a significant groundwater dose contribution, was much higher for the BFM insignificant contribution calculation. Therefore, the insignificant dose fraction would be less for buried pipe than was calculated for the BFM and the application of the BFM insignificant dose fraction is conservative. As stated in Zion LTP, Revision 1, Chapter 6, section 6.12.8, the activity in buried pipes originate in one of the basements and the activity is assumed to mix with basements as well as mix with soil. Therefore, the insignificant dose contribution percentage assigned for the Buried Pipe DCGL adjustment was the maximum for either soil or the BFM. The maximum IC dose percentage was 10% for both soil and the BFM (Containment) and was the value used for Buried Pipe DCGL adjustment.

The Adjusted Buried Pipe DCGLs are provided in Table 5. Note that the DCGL values in Table 5 are truncated as opposed to rounded to ensure conservatism.

Table 5 – Buried Pipe DCGLs Adjusted for Insignificant Contributor Dose Fraction

Radionuclide	Buried Pipe DCGL (dpm/100 cm^2)
Co-60	2.648E+04
Cs-134	4.541E+04
Cs-137	1.010E+05
Ni-63	4.896E+07
Sr-90	4.502E+04

4. CONCLUSION

Buried Pipe DCGLs in units of dpm/100 cm^2 were calculated for two scenarios; Excavation and Insitu. The calculation included all buried pipe on the Zion site. The DCGLs were conservatively based on the summation of dose from the Excavation and Insitu scenarios.

5. REFERENCES

1. 10 CFR 20 Standards for Protection Against Radiation, Subpart E—Radiological Criteria for License Termination http://www.nrc.gov/reading-rm/doc-collections/cfr/part020/.
2. *TSD 14-010, RESRAD Dose Assessment for Basement Fill Model Dose Factors and Soil DCGL and Calculation of Basement Fill Model Dose Factors and DCGLs. Zion, Illinois : ZionSolutions, LLC, 2014.*
3. *TSD 14-019, Radionuclides of Concern for Basement Fill Model Source Term and Surrogate Ratios. Zion, Illinois : ZionSolutions, LLC, 2014.*
4. ZionSolutions TSD 14-016, "Description of Embedded Piping, Penetrations and Buried Piping to Remain in Zion End State".

6. ATTACHMENTS

6.1. Attachment 1 – Buried Pipe DCGL Calculation

6.2. Attachment 2 - Buried Pipe Thickness of Contaminated Zone Sensitivity Analysis

Calculation of Buried Pipe DCGL

Assumptions

Total Buried Pipe Internal Surface Area	2153	m2
Soil Mixing After Release from Pipe	0.15	m

RESRAD Parameters

All parameters same as for surface soil DCGL with following exceptions

Area of Contamnated Zone	2153	m2
Contaminated Zone Thickness Insitu	0.15	m
Length Parrallel to Flow	46	m2
Cover Depth Insitu Unsat Zone	1	m
Unsaturated Zone Thickness Insitu Unsat Zone	2.45	m
Cover Depth Insitu Sat Zone	3.6	m
Unsaturated Zone Thickness Insitu Sat Zone	NA	
Cover Depth Excavation	0	m
Contaminated Zone Thickness (Excavation and Insitu Unsaturated)	15	cm
Unsaturated Zone Thickness Excavation	3.45	m

Conversion of dpm/100 cm^2 to pCi/g after mixing with 15 cm depth of soil

1	dpm/100 cm2
2.2	dpm/pCi
4.55E-01	pCi/100 cm^2 on pipe surface at 1 dpm/100 cm2
4.55E-03	pCi/cm2 on pipe surface at 1 dpm/100 cm2
1.8	g/cm3 soil density
15	cm mixing depth in soil
1.68E-04	pCi/g in soil per dpm/100 cm2 in pipe (Excavation and Insitu Unsaturated)

Buried Pipe Dose to Source Ratios and DCGL Including All Pipe and Summation of Maximum Insitu and Excavation Dose

Radionuclide	Excavation (mrem/yr per pCi/g)	Insitu Unsaturated (mrem/yr per pCi/g)	Insitu Saturated (mrem/yr per pCi/g)	Summation Saturated + Maximum Insitu	Excavation plus Max Insitu mrem/yr @ 1 dpm/100 cm2	Buried Pipe DCGL (dpm/100 cm^2)
Co-60	4.975E+00	7.298E-02	5.710E-04	5.048E+00	8.498E-04	2.942E+04
Cs-134	2.836E+00	1.070E-01	2.881E-03	2.943E+00	4.955E-04	5.046E+04
Cs-137	1.238E+00	8.491E-02	2.287E-03	1.323E+00	2.227E-04	1.123E+05
Ni-63	1.445E-03	1.285E-03	2.745E-04	2.730E-03	4.596E-07	5.440E+07
Sr-90[1]	1.489E+00	1.384E+00	1.480E+00	2.969E+00	4.998E-04	5.002E+04

Note 1: The Sr-90 DSRs for Excavation and Insitu Saturated were multiplied by a factors of 1.13 and 1.08 , respectively , to adjust for potentailly higher dose from thicker source terms

Buried Pipe DCGLs Adjusted for Insignificant Contributor Dose Fraction

Insignificant Dose Fraction 10.00% Reference TSD 14-010 value for Basement Fill Model Auxiliary Building Basment

Insignificant Dose Fraction Adustment Factor 0.90

Radionuclide	**Adjusted Buried Pipe DCGL (dpm/100 cm2)**
Co-60	2.648E+04
Cs-134	4.541E+04
Cs-137	1.010E+05
Ni-63	4.896E+07
Sr-90	4.502E+04

Table 1 Buried Pipe Insitu Saturated Scenario Thickness of Contaminated Zone

Radionuclide	**DSR (mrem/yr per pCi/g)**		**DSR Ratio**	**DSR Ratio * Source Term Decrease**
Contaminated Zone Thickness (m)	**0.15**	**1**	**1/.15**	**.15/1**
Co-60	5.7100E-04	3.807E-03	6.667E+00	1.00
Cs-134	2.8810E-03	1.922E-02	6.671E+00	1.00
Cs-137	2.2870E-03	1.525E-02	6.668E+00	1.00
Ni-63	2.7450E-04	1.837E-03	6.692E+00	1.00
Sr-90	1.3700E+00	9.908E+00	7.232E+00	1.08

Table 2 Buried Pipe Excavation Scenario Thickness of Contaminated Zone

Radionuclide	**DSR (mrem/yr per pCi/g)**		**DSR Ratio**	**DSR Ratio * Source Term Decrease**
Contaminated Zone Thickness (m)	**0.15**	**1.00**	**1/.15**	**.15/1**
Co-60	4.975E+00	5.753E+00	1.16E+00	1.73E-01
Cs-134	2.836E+00	3.476E+00	1.23E+00	1.84E-01
Cs-137	1.238E+00	1.717E+00	1.39E+00	2.08E-01
Ni-63	1.445E-03	8.338E-03	5.77E+00	8.66E-01
Sr-90	1.318E+00	9.950E+00	7.55E+00	1.13E+00

Table 3 Buried Pipe Insitu Unsaturated Scenario Thickness of Contaminated Zone Sensitivity

Radionuclide	**DSR (mrem/yr per pCi/g)**			**DSR Ratio**		**DSR Ratio * Source Term Decrease**	
Contaminated Zone Thickness (m)	0.15	1	1	1/0.15	1/.15	.15/1	.15/1
Co-60	7.298E-02	1.012E-01	2.798E-01	1.39E+00	3.83E+00	2.08E-01	5.75E-01
Cs-134	1.070E-01	1.484E-01	4.103E-01	1.39E+00	3.83E+00	2.08E-01	5.75E-01
Cs-137	8.491E-02	1.178E-01	3.257E-01	1.39E+00	3.84E+00	2.08E-01	5.75E-01
Ni-63	1.285E-03	1.784E-03	4.932E-03	1.39E+00	3.84E+00	2.08E-01	5.76E-01
Sr-90	1.384E+00	2.190E+00	6.053E+00	1.58E+00	4.37E+00	2.37E-01	6.56E-01
		1.22 m root	2 m root	1.22 m root	2 m root	1.22 m root	2 m root