CHAPTER 2

SUBSECTION 2.4.13 ACCIDENTAL RELEASES OF LIQUID EFFLUENTS INTO GROUND AND SURFACE WATERS

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2.4.13 ACCIDENTAL RELEASES OF LIQUID EFFLUENTS INTO GROUND AND SURFACE WATERS

This section describes the hypothetical accidental liquid release scenario for the various areas where liquid radwaste might occur within the nuclear island (NI): Fuel Handling Annex Building (FHAB), Canister Processing Facility (CPF), Helium Services Facility (HSF), Inter-Unit Access Tunnel (IUAT), Reactor Building (RB), and Radwaste Building (RWB). Not all design parameters have been determined at this time, but some bounding assumptions are used in this evaluation. These assumptions are described below.

LME estimates the liquid waste generation rate as 1.23 cubic meters per day or approximately 9500 gallons per month . ~~(1180 liters per day); th~~ This waste will be containerized and shipped offsite for disposal. The A Sand water-bearing zone is overlain with low permeability clays, and if a release reaches the A Sand water-bearing zone, it would migrate eastward at a relatively slow rate (see Section 2.4.13.1) and would allow the groundwater monitoring program to detect any release prior to migrating off the Long Mott Generating Station (LMGS) site, enabling the required remedial measures, if necessary, to be put into place long before it could reach any potential receptor.

Radioactive ~~wastes~~waste will be handled by the Radioactive Waste Management System (RWMS). Final design details of this system are still pending.

The following bounding volumetric estimates of waste material for potential accidental release apply: worst failure case tank volume is 75 cubic meters (75,000 liters or 19,815 gallons) ~~120 m3 in the Radioactive Waste Building (RWB), 1436 m3 in the RB and Reactor Cavity Cooling System (RCCS), and 10 m3 in the SFISF. Of the 1436 m3 in the RB and RCCS, 1421 m3 is in the RCCS and contains only tritium at 370 Becquerels/cubic centimeter (Bq/cc).~~

NRC (NRC 10 CFR Part 20, Appendix B, Table 2 (there are individual tables for each isotope~~)~~) sets Effluent Concentration Limits (ECLs) for various isotopes.

Estimated specific activities for expected nuclides are provided in Table 2.4.13-1~~. This composition excludes the potential 1421~~ ~~m^3~~ ~~of tritium containing fluids in the RCCS~~. All the individual isotopes initially exceed their respective ECLs. In addition, using the NRC unity rule (sum of ratios), the initial assemblage of isotopes exceeds unity (i.e., 1.0).

The sum of ratios is calculated:

$$\sum_{1}^{n}\left[\frac{R_1}{ECLR_1}+\frac{R_2}{ECLR_2}+\frac{R_n}{ECLR_n}+\right]\geq 1.0$$

Equation 2.4.13-1

Where:

R_1 = total activity concentration for radionuclide 1

R_2 = total activity concentration for radionuclide 2

R_n = total activity concentration for radionuclide n

$ECLR_1$ = Effluent concentration limit (ECL) threshold for radionuclide 1

$ECLR_2$ = ECL threshold for radionuclide 2

$ECLR_n$ = ECL threshold for radionuclide n

Results of using the unity rule on the initial individual isotope concentrations are included in Table 2.4.13-2. The sum of the ratios is greater than 1, which indicates that attenuating factors (e.g., retardation, radioactive decay, dispersion, or dilution) need to be considered, since a release would not meet the ECLs pending their inclusion. Further information regarding a potential accidental release is provided below.

Potential receptor location(s) have not yet been fully identified. There ~~have been~~are 18 potential receptors (users of groundwater) identified ranging from 0.87 mi. (1.40 km) to 36.44 mi. (58.64 km) ~~–~~ from the center of the site. It is unlikely that any of these potential receptors would use A Sand water bearing zone groundwater because it is not likely present at these distances nor is it an aquifer that could sustain a consistent yield. As a conservative estimate, anything approaching the current groundwater flow model domain limit (such as entering a drain or a constant head boundary cell) is considered a potential release exposure point in this or in any future modeling.

The envisioned accidental release scenario includes the following assumptions:

- A worst-case release of liquid waste of ~~145~~75 cubic meters (19,815 gallons) with composition as listed in Table 2.4.13-1 at or near land~~ surface (the tritium waste has lower activity and is considered a lesser case)~~.

- The release would occur somewhere within the Nuclear/Conventional Island area.
- The liquid would make its way through the overlying low-permeability clays to enter the A Sand water-bearing zone. Conservatively, no dilution of the release with groundwater is assumed.
- The released isotopes move relatively slowly eastward with the general groundwater flow in the A Sand water bearing zone.~~.~~
- Attenuation due to adsorptive retardation and radioactive decay are not initially considered. These factors would slow migration rates and reduce total activity of the isotopes identified in Table 2.4.13-1 at potential receptor locations. Mitigating factors will be considered in a later step of this analysis (section 2.4.13.4).

2.4.13.1 Initial Assessment Using Seepage Velocities.

The groundwater flow system downgradient of the point of release was evaluated to identify potential exposure points from an accidental release of radionuclides to groundwater. First, estimates of seepage velocities, based on hydraulic gradient, hydraulic conductivity, and effective porosity were determined. For the A Sand water bearing zone, this resulted in an average groundwater seepage velocity of 0.069~~3~~ ft/day (21~~9~~ mm/day) and a maximum seepage velocity of 0.53~~18~~ ft/day~~-~~ (~~55~~ 162 mm/day). These correspond to seepage velocities of 25~~11~~ and 193~~66~~ ft/yr (7.67~~3.3~~ and 59~~20.0~~ m/yr),~~-~~ respectively.

Given the direct distance to the creek is approximately 1000 ft (305 m), the simplistic unattenuated straight-line travel time is estimated to be between ~~1~~5 and 40~~91~~ years. Ignoring both the attenuation of dissolved radionuclides by adsorption to aquifer solids and radioactive decay as well as a more indirect path to the creek, this conservative~~ly~~ (fast) estimate of travel time (~~1~~5 years) cannot rule out plausible transport and potential for exposure within realistic time periods. These bounding estimates are simplistic and do not necessarily reflect true travel paths and velocities. A more accurate method using particle tracking is presented in Section 2.4.13.2, and is used as the basis for conclusions~~need tousing particle tracking presented~~

2.4.13.2 Assessment Using Particle Tracking

Based on the ~~indeterminant~~uncertainty in the results of the simplistic assessment using straight-line path assumptions and the potential range of seepage velocities, a more detailed analysis was warranted using particle tracking that considered groundwater flow to determine if they reach potential receptors, and if so, when. The basis for this analysis was the groundwater flow model developed for the site as described in section 2.4.12~~2~~.3.1.1~~x.~~

The release was simulated by placing a particle in every model grid block within the vicinity of the Nuclear and Conventional Plant Facilities area and tracking their movement for various time periods through the modelled groundwater flow regime to see where they go, if they reach potential receptors, and if so, when. The movement of these particles through time was calculated using MODPATH, which is a companion program to MODFLOW, and which uses MODFLOW output to perform the particle tracking. While a steady-state groundwater flow simulation does not require specifying a porosity, an effective porosity is needed in MODPATH to compute particle velocities and estimate travel times between release and receptor locations. The value of effective porosity specified for this model simulation was 0.25 which is somewhat more conservative that the average value of 0.2 and the model was run for varying lengths of time from 1 to 106 years.

In ~~The release was simulated by placing a particle in every model grid block within the vicinity of the Nuclear/Conventional Island and tracking their movement for various periods through the modeled groundwater flow regime, if they reach potential receptors, and if so, when. The movement of these particles through time was calculated using MODPATH, which is a companion program to MODFLOW that uses its output to track the particles. While a steady-state simulation does not require specifying a porosity, an effective porosity is needed in MODPATH to estimate travel times. The value of effective porosity specified for this model simulation was 0.22~~ 25 ~~(22~~ 25 ~~percent), and the model was run for varying lengths of time from 1 year to 100 years.~~addition to the arrival of the first particle, the arrival of o~~O~~ther notable particles ~~tracking simulations t~~were identified. These included ~~racked~~ the earliest particles released at the center of the project site to West Coloma Creek while the median time for particles released at this location was also determined.

According to the MODFLOW/MODPATH simulation, it takes approximately ~~22~~ 11.6 years for the first of the unattenuated particles to reach the vicinity of the creek drain cells representing West Coloma Creek ("creek"). The particles from the eastern corners reach the creek drain more quickly than the western corners' particles, which are still essentially within or near the boundaries of the Nuclear/Conventional Island by the time the eastern corners' particles have reached the creek drain. Travel times for the other two scenarios were ~~approximately 61~~approximately 61 and 106 years, respectively.

It is worth reiterating that the particle tracking is done without considering attenuation factors such as radioactive decay and adsorptive retardation onto the aquifer materials. Thus, travel times are conservative, and real travel times would be longer due to these other factors.

Results of the particle tracking are depicted ~~o~~in~~n~~ Figure 2.4.13-1.

2.4.13.3 Sensitivity Analysis

A ~~more formal~~ sensitivity study on the response of the particle tracking analysis included rerunning the tracking simulation with ~~nine~~ particles seeded all across~~at each of the the four corner locations of~~ the Nuclear/Conventional Island area~~,~~ and then tracking and noting the location of potential receptors at the creek and their fastest and median travel times. In addition, a hypothetical ½ shortest travel time was calculated and a unity rule value calculated as an additional sensitivity analysis. This was for sensitivity analysis only and does not represent a plausible travel time in this analysis.

Reviewing the particle tracks suggests the particles in the corners closest to the creek drain move quickly and would arrive before particles from the two more distant corners. Results of the particle tracking sensitivity analysis (including the additional particle initiation locations) are depicted on Figure 2.4.13-1.~~2.~~ As noted above, major changes in the initial positions of potential release points affect travel time and can affect the exact location of discharge into the creek. More specific location(s) for potential release would refine estimates of travel and discharge point(s) into the creek.

2.4.13.4 Attenuation Factors

Two particular attenuation factors considered here can significantly affect the transport of released isotopes - radioactive decay and retardation of advective transport due to interaction of the dissolved isotope with the water bearing zone~~unit~~'s solid matrix.

Radioactive Decay

Each identified isotope that may be potentially released has a distinct decay constant that describes how quickly that isotope's nuclei decay by a certain radioactive decay process. One of the common measures of this is an isotope’s half-life. This is the time needed for half of a given number of atoms to undergo a radioactive decay process and is a constant value under all practical conditions.

As noted above, a half-life’s value depends on the isotope. An extensive, authoritative list of isotopes’ half-lives is available from Brookhaven National Laboratories (https://www.nndc.bnl.gov/walletcards). The half-lives used in this calculation were taken from this source where possible. For Ag-110m, I-131, and Ba-137m half-lives from MIRDSOFT MIRDspecs were used.

Advective Retardation (Sorption)

Sorption is a process where the dissolved constituent in groundwater interacts with the solid phase through which it is flowing, retarding its movement relative to the groundwater flow velocity. As described in Kresic (2023):

> “Sorption results in distribution of a solute between the solution (groundwater, where it is dissolved) and the solid phase (where it is held by the solids of the aquifer). This distribution is called partitioning, and it is quantitatively described with the term distribution coefficient (or sorption coefficient, or partitioning coefficient~~), and~~) and denoted with K_d. Importantly, K_d is a generic term devoid of any inferred mechanism. It is used to describe the general partitioning of aqueous phase constituents to a solid phase due to sorption.”
>
> “Because of sorption, the contaminant movement in groundwater is slowed down relative to the average groundwater velocity. This effect of sorption is called retardation and the affinity of different solutes (chemicals dissolved in groundwater) to be retarded is quantified with a parameter called the retardation factor, denoted with R. The overall effect of sorption is a decrease in dissolved contaminant concentrations.”

Sorption potential varies only minimally among isotopes of an element, especially for the heavier elements where the difference in mass is minimal among isotopes of the same element. Isotope-specific K_d values are not generally cataloged, especially for the heavier elements. For this reason, partitioning coefficients for isotopes of interest in these calculations will be considered the same across all isotopes for a given element. K_d values are available from a number of sources. One frequently used source is the following:

The Atomic Energy of Canada, Limited (AECL) has published “A Critical Compilation and Review of Default Soil Solid/Liquid Partition Coefficients, K_d, For Use in Environmental Assessments, AECL-10125” which includes an extensive list of elemental K_d values for sand, silt and clay.

Partition coefficients are dependent on both the constituent being partitioned and the solid material participating in the partitioning. Generally, sand has less interaction with dissolved constituents and causes the least retardation, leading to conservative (shorter) estimates of travel time and (greater) estimates of concentration downgradient of the release. To be conservative, attenuated flow will use the least retarded transport material (sand) while using elemental K_d values from Table 8 of AECL-10125.

A more comprehensive analysis considers the attenuation factors affecting the potential release to receptor locations. As noted above, both sorptive retardation and radioactive decay attenuate the potential exposure. Retardation slows the travel time allowing greater decay and spreads out the contaminant mass along the flow path, leading to a smaller peak exposure while radioactive decay removes activity from the system, lessening the total amount of contaminant available and slowing arrival times and lowering concentrations.

Sorption

Using the retardation factors derived from the element-specific K_d values for sand (as described above in subsection 2.2.5), the various retarded travel times for constituents listed in Table 2.4.13-1 are shown in Table 2.4.13-3. These retarded travel times are the conservative estimates of when the peak concentration of contaminant will arrive at the potential receptor location. Because of isotope-specific variable spreading of the mass of contaminants in the flow path due to sorption, some of the contaminants will arrive earlier than this (but no quicker than the unretarded groundwater flow time described above). Also, some of the contaminants will arrive later than the peak. The larger the retardation factor, the more the contaminant mass will be spread along the flow ~~path~~path, and the peak concentration will be relatively lessened.

A linear retardation factor is related to K_d and aquifer properties using the following equation (13.8 from Kresic (2023)):

$$R = 1 + \frac{\rho_b * K_d}{n}$$

Equation 2.4.13-2

Where:

R = retardation factor (dimensionless)

ρ_b = bulk density (grams per cubic centimeter) of the aquifer porous media (assumed quartz mineral 2.65 *(1-n) = 1.9875)

K_d = distribution coefficient (cubic centimeters per gram)

n = porosity of the media at saturation (assumed to be 0.25)

Radioactive Decay

Using the isotope-specific half-lives previously described and the retarded travel times just described, total numbers of half-lives elapsed during the retarded travel have been calculated and are included in Table 2.4.13-3. In addition, using the following equations for remaining mass or activity after a set time has elapsed for an isotope with a given half-life (from European Organization for Nuclear Research (CERN, Radioactive Decay: An Introduction”, Chris Cassel

2013)):

$$\lambda = {}^{ln(2)}/_{T}$$
$$N = N_0 * e\ (-\lambda * t)$$

Equations 2.4.13-3 and 2.4.13-4

Where:

λ = decay constant (1/day)

ln(2) = natural logarithm of 2

T = half-life (days)

N = Number of atoms (or activity) at time t

N_0 = Initial number of atoms (or activity) at time = 0

e = base of natural logarithm (Euler’s number)

t = time of interest (days)

If a partition coefficient was not available, the retardation factor was set to 1, i.e., no retardation as a conservative assumption.

Table 2.4.13-4 presents the results after calculating each of these quantities for all isotopes of interest~~After calculating each of these quantities for all isotopes of interest the results are shown in Table 2.4.13-4~~.(Note that the ½ travel time scenario is included for sensitivity analysis only and does not represent an actual travel time ~~prediction~~estimate.)

Unity Rule calculations were performed on the resulting maximum concentrations at the point of potential exposure (after radioactive decay and retarded travel). All isotopes would be expected to be below ECLs, and a composite of all maximum concentrations' Unity Rule does not exceed 1 (Note - All of the isotopes emerging at the point of potential exposure is not likely due to variable retardation (different K_d) for each isotope, so a combination of all maximums arriving at the receptor at the same time is a very conservative estimate). See Table 2.4.13-4 for details of expected maximum concentrations after retarded travel and decay.

Sensitivity analysis (taken as 1/2 shortest expected travel time) still has an acceptable unity value, so minor overestimates of shortest travel time will not lead to erroneous conclusions for unity values. Underestimates of travel time would lead to even longer travel times and more attenuation than the shortest travel time – which already has an acceptable unity value.

2.4.13.5 Findings

Based on NRC ECLs and unity rule calculations, the composition of the initial potential release material exceeds ECLs both individually and in combination. Due to retardation and radioactive decay during travel, activities of the specific isotopes listed in initial potential release material are expected to decrease to below ECLs individually and in combination before reaching the conservative exposure point location in the creek.

Specific findings of the particle modeling effort include:

- Particle tracking suggests that for the closest receptor for an accidental release, the shortest travel time is approximately ~~22~~11.6~~11.6~~ years for an unattenuated particle to arrive at the creek drain (for a release along the eastern edge of the Nuclear/Conventional Island).
- Travel times from central or western parts of Nuclear/Conventional Island are much longer.
- ~~These estimated travel times are for unattenuated radioisotopes.~~ In an actual release,
- attenuation due to adsorptive retardation and loss of activity to radioactive decay would, in the first factor, in some cases greatly increase travel times, (from 1 to over 2200 times the unattenuated travel time, depending

on the isotope) and in the second factor, reduce radioactivity due to the decay of the isotopes.

- Sensitivity analysis (taken as 1/2 shortest expected travel time) still has an acceptable unity value. Minor overestimates of shortest travel time will not lead to erroneous conclusions for unity values.

~~Use of particle tracking from the Nuclear/Conventional Island provides a conservative estimate of travel time that does not consider adsorptive retardation and radioactive decay. Such particle tracking is independent of actual radioisotope(s) released. Expected~~
~~retardation increases the travel time, while decay reduces the amounts of remaining radionuclides. Thus, actual releases result in longer travel time and reduced quantities delivered to a point of exposure.~~

References

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2.4.13-010 MIRDSOFT MIRDspecs

https://mirdsoft.org/resources/mirdspecs (accessed 20 August 2025)

~~2.4.13-011 X-Energy, 2022. Technical Note: Xe-100 Radwaste Generation Calculation, Service Receipt Inspection Report~~.

~~Table 2.4.13-1. Estimated Liquid Radwaste Specific Activities~~

~~X-Energy~~			
~~Isotope~~	~~X Energy activity concentration Bq/ml~~	~~X Energy activity Bq~~	~~X Energy activity Ci~~
~~Ag-110m~~	~~3.60E+03~~	~~5.22E+11~~	~~1.41E+01~~
~~Ba-137m~~	~~2.78E+03~~	~~4.03E+11~~	~~1.09E+01~~
~~Ba-140~~	~~9.73E+01~~	~~1.41E+10~~	~~3.81E-01~~
~~Cs-134~~	~~4.76E+03~~	~~6.90E+11~~	~~1.87E+01~~
~~Cs-137~~	~~2.99E+03~~	~~4.34E+11~~	~~1.17E+01~~
~~I-131~~	~~4.27E+02~~	~~6.19E+10~~	~~1.67E+00~~
~~La-140~~	~~9.73E+01~~	~~1.41E+10~~	~~3.81E-01~~
~~Xe-133~~	~~2.89E-01~~	~~4.19E+07~~	~~1.13E-03~~

~~Key: Bq = Becquerel, Ci = Curie; Ag = silver; m = metastable isotope;~~

~~I – iodine; Cs = cesium; Ba = barium; La = lanthanum, Xe=xenon~~

~~From: X-Energy, 2022. Technical Note: Xe-100 Radwaste Generation Calculation, Service Receipt Inspection Report.~~

Table 2.4.13-1
Estimated Liquid Radwaste Specific Activities

X-Energy				
Isotope	**Activity concentration Bq/ml**	**Activity Bq**	**Activity Ci**	**Activity concentration µ~~u~~Ci/ml**
Ag-110m	3.60E+03	2.70E+11	7.30E+00	9.73E-02
Ba-137m	2.78E+03	2.09E+11	5.64E+00	7.51E-02
Ba-140	9.73E+01	7.30E+09	1.97E-01	2.63E-03
Cs-134	4.76E+03	3.57E+11	9.65E+00	1.29E-01
Cs-137	2.99E+03	2.24E+11	6.06E+00	8.08E-02
I-131	4.27E+02	3.20E+10	8.66E-01	1.15E-02
La-140	9.73E+01	7.30E+09	1.97E-01	2.63E-03
Xe-133	2.89E-01	2.17E+07	5.86E-04	7.81E-06
H-3	4.93E+01	3.70E+09	9.99E-02	1.33E-03

Key: Bq = Becquerel, Ci = Curie; µCi = microcurie; µCi/ml = microCuries per milliliter; Ag = silver; m = metastable isotope; I – iodine; Cs = cesium; Ba = barium; La = lanthanum, Xe=xenon, H-3 = tritium

~~*Table 2.4.13-2: Unity Rule Calculations - Initial Composition*~~

~~**Isotope**~~	~~**Element**~~	~~**X-Energy effluent concentration uCi/ml (Release)**~~	~~**10CFR20 App B Table 2 Effluent limit**~~	~~**Ratio Concentration to Effluent Limit (Initial)**~~
~~Ag-110m~~	~~Ag~~	~~9.73E-02~~	~~6.0E-06~~	~~16216.22~~
~~Ba-137m~~	~~Ba~~	~~7.51E-02~~	~~2.0E-08~~	~~3756756.76~~
~~Ba-140~~	~~Ba~~	~~2.63E-03~~	~~8.0E-06~~	~~328.72~~
~~Cs-134~~	~~Cs~~	~~1.29E-01~~	~~9.0E-07~~	~~142942.94~~
~~Cs-137~~	~~Cs~~	~~8.08E-02~~	~~1.0E-06~~	~~80810.81~~
~~I-131~~	~~I~~	~~1.15E-02~~	~~1.0E-06~~	~~11540.54~~
~~La-140~~	~~La~~	~~2.63E-03~~	~~9.0E-06~~	~~292.19~~
~~Xe-133~~	~~Xe~~	~~7.81E-06~~	~~2.0E-08~~	~~390.54~~

~~Sum Release Ratios (Unity Rule): 4009278.72~~

~~Key: NRC = Nuclear Regulatory Commission; Ag = silver; m = metastable isotope; I – iodine; Cs = cesium; Ba = barium; La = lanthanum; Xe = xenon.~~
~~Ba-137m, Xe-133 have no Table 2 entry – using most conservative unknown isotope limit~~

Table 2.4.13-2
Unity Rule Calculations - Initial Composition

Isotope	X-Energy effluent concentration µCi/ml (Release)	NCR 10CFR20 App B Table 2 Effluent limit µCi/ml	Ratio Concentration to Effluent Limit (Initial)
Ag-110m	9.73E-02	6.0E-06	1.62E+04
Ba-137m	7.51E-02	2.0E-08	3.76E+06
Ba-140	2.63E-03	8.0E-06	3.29E+02
Cs-134	1.29E-01	9.0E-07	1.43E+05
Cs-137	8.08E-02	1.0E-06	8.08E+04
I-131	1.15E-02	1.0E-06	1.15E+04
La-140	2.63E-03	9.0E-06	2.92E+02
Xe-133	7.81E-06	2.0E-08	3.91E+02
H-3	1.33E-03	1.0E-03	1.33E+00

Key: NRC = Nuclear Regulatory Commission; Ag = silver; m = metastable isotope; I – iodine; Cs = cesium; Ba = barium; La = lanthanum; Xe = xenon. H-3 = tritium Ba-137m, Xe-133 have no Table 2 entry – using most conservative unknown isotope limit µCi/ml = microCuries per milliliter

~~*Table 2.4.13-3: Isotope Half-Lives and Retarded Travel Times*~~

~~**Isotope**~~	~~**Element**~~	~~**Effluent concentration uCi/ml**~~	~~**Activity Ci**~~	~~**half-life (days)**~~	~~**Kd (sand)**~~	~~**Retardation Factor**~~	~~**Retarded Travel Time Days**~~	~~**Number of Half-lives**~~	~~**Percent of Original Activity Remaining**~~
~~Ag-110m~~	~~Ag~~	~~9.73E-02~~	~~1.41E+01~~	~~249.86~~	~~90~~	~~716.5~~	~~5753495~~	~~23026.9~~	~~0.0%~~
~~Ba-137m~~	~~Ba~~	~~7.51E-02~~	~~1.09E+01~~	~~0.001772222~~	~~Missing~~	~~1~~	~~8030~~	~~4531034.5~~	~~0.0%~~
~~Ba-140~~	~~Ba~~	~~2.63E-03~~	~~3.81E-01~~	~~12.751~~	~~Missing~~	~~1~~	~~8030~~	~~629.8~~	~~0.0%~~
~~Cs-134~~	~~Cs~~	~~1.29E-01~~	~~1.87E+01~~	~~754.2981889~~	~~280~~	~~2227~~	~~17882810~~	~~23707.9~~	~~0.0%~~
~~Cs-137~~	~~Cs~~	~~8.08E-02~~	~~1.17E+01~~	~~10986.48534~~	~~280~~	~~2227~~	~~17882810~~	~~1627.7~~	~~0.0%~~
~~I-131~~	~~I~~	~~1.15E-02~~	~~1.67E+00~~	~~8.0252~~	~~1~~	~~8.95~~	~~71869~~	~~8955.4~~	~~0.0%~~
~~La-140~~	~~La~~	~~2.63E-03~~	~~3.81E-01~~	~~1.67858~~	~~Missing~~	~~1~~	~~8030~~	~~4783.8~~	~~0.0%~~
~~Xe-133~~	~~Xe~~	~~7.81E-06~~	~~1.13E-03~~	~~5.2475~~	~~Missing~~	~~1~~	~~8030~~	~~1530.3~~	~~0.0%~~

~~Key: Ag = silver; m = metastable isotope; I – iodine; Cs = cesium; Ba = barium; La = lanthanum; Xe = xenon.~~

Table 2.4.13-3

Isotope Half-Lives and Retarded Travel Times

(1 of 2)

Nearest Perimeter

Isotope	X Energy activity Ci	half-life (days)	Kd (sand)	Retardation Factor	Retarded Travel Time Days	Number of Half-lives	Activity Remaining Ci	Percent of Original Activity Remaining
Ag-110m	7.30E+00	249.86	90	716.5	3033661	12141.4	0.00E+00	0.0%
Ba-137m	5.64E+00	0.001772222	Missing	1	4234	2389090.9	0.00E+00	0.0%
Ba-140	1.97E-01	12.751	Missing	1	4234	332.1	2.17E-101	0.0%
Cs-134	9.65E+00	754.2981889	280	2227	9429118	12500.5	0.00E+00	0.0%
Cs-137	6.06E+00	10986.48534	280	2227	9429118	858.2	2.66E-258	0.0%
I-131	8.66E-01	8.0252	1	8.95	37894	4721.9	0.00E+00	0.0%
La-140	1.97E-01	1.67858	Missing	1	4234	2522.4	0.00E+00	0.0%
Xe-133	5.86E-04	5.2475	Missing	1	4234	806.9	7.56E-247	0.0%
H-3	9.99E-02	4499.783889	0.1	1.795	7600	1.7	3.10E-02	31.0%

Nearest Center

Isotope	X Energy activity Ci	half-life (days)	Kd (sand)	Retardation Factor	Retarded Travel Time Days	Number of Half-lives	Activity Remaining Ci	Percent of Original Activity Remaining
Ag-110m	7.30E+00	249.86	90	716.5	15952873	63847.2	0.00E+00	0.0%
Ba-137m	5.64E+00	0.001772222	Missing	1	22265	12563322.9	0.00E+00	0.0%
Ba-140	1.97E-01	12.751	Missing	1	22265	1746.1	0.00E+00	0.0%
Cs-134	9.65E+00	754.2981889	280	2227	49584155	65735.5	0.00E+00	0.0%
Cs-137	6.06E+00	10986.48534	280	2227	49584155	4513.2	0.00E+00	0.0%
I-131	8.66E-01	8.0252	1	8.95	199272	24830.8	0.00E+00	0.0%
La-140	1.97E-01	1.67858	Missing	1	22265	13264.2	0.00E+00	0.0%
Xe-133	5.86E-04	5.2475	Missing	1	22265	4243.0	0.00E+00	0.0%
H-3	9.99E-02	4499.783889	0.1	1.795	39966	8.9	2.12E-04	0.2%

Table 2.4.13-3
Isotope Half-Lives and Retarded Travel Times
(2 of 2)

Median Center

Isotope	X Energy activity Ci	half-life (days)	Kd (sand)	Retardation Factor	Retarded Travel Time Days	Number of Half-lives	Activity Remaining Ci	Percent of Original Activity Remaining
Ag-110m	7.30E+00	249.86	90	716.5	27721385	110947.7	0.00E+00	0.0%
Ba-137m	5.64E+00	0.001772222	Missing	1	38690	21831348.0	0.00E+00	0.0%
Ba-140	1.97E-01	12.751	Missing	1	38690	3034.3	0.00E+00	0.0%
Cs-134	9.65E+00	754.2981889	280	2227	86162630	114228.9	0.00E+00	0.0%
Cs-137	6.06E+00	10986.48534	280	2227	86162630	7842.6	0.00E+00	0.0%
I-131	8.66E-01	8.0252	1	8.95	346276	43148.5	0.00E+00	0.0%
La-140	1.97E-01	1.67858	Missing	1	38690	23049.2	0.00E+00	0.0%
Xe-133	5.86E-04	5.2475	Missing	1	38690	7373.0	0.00E+00	0.0%
H-3	9.99E-02	4499.783889	0.1	1.795	69449	15.4	2.26E-06	0.0%

½ Nearest Perimeter (Sensitivity Analysis Only)

Isotope	X Energy activity Ci	half-life (days)	Kd (sand)	Retardation Factor	Retarded Travel Time Days	Number of Half-lives	Activity Remaining Ci	Percent of Original Activity Remaining
Ag-110m	7.30E+00	249.86	90	716.5	1516831	6070.7	0.00E+00	0.0%
Ba-137m	5.64E+00	0.001772222	Missing	1	2117	1194545.5	0.00E+00	0.0%
Ba-140	1.97E-01	12.751	Missing	1	2117	166.0	2.07E-51	0.0%
Cs-134	9.65E+00	754.2981889	280	2227	4714559	6250.3	0.00E+00	0.0%
Cs-137	6.06E+00	10986.48534	280	2227	4714559	429.1	4.01E-129	0.0%
I-131	8.66E-01	8.0252	1	8.95	18947	2361.0	0.00E+00	0.0%
La-140	1.97E-01	1.67858	Missing	1	2117	1261.2	0.00E+00	0.0%
Xe-133	5.86E-04	5.2475	Missing	1	2117	403.4	2.10E-125	0.0%
H-3	9.99E-02	4499.783889	0.1	1.795	3800	0.8	5.57E-02	55.7%

~~*Table 2.4.13-4: Unity Rule Calculations – Retarded Travel Time Composition*~~

~~**Isotope**~~	~~**Element**~~	~~**Effluent concentration uCi/ml (After Travel to Exposure Point)**~~	~~**10CFR20 App B Table 2 Effluent limit**~~	~~**Ratio Concentration to Effluent Limit (Exposure Point after Travel)**~~
~~Ag-110m~~	~~Ag~~	~~0.00E+00~~	~~6.0E-06~~	~~0.00~~
~~Ba-137m~~	~~Ba~~	~~0.00E+00~~	~~2.0E-08~~	~~0.00~~
~~Ba-140~~	~~Ba~~	~~1.01E-190~~	~~8.0E-06~~	~~0.00~~
~~Cs-134~~	~~Cs~~	~~0.00E+00~~	~~9.0E-07~~	~~0.00~~
~~Cs-137~~	~~Cs~~	~~0.00E+00~~	~~1.0E-06~~	~~0.00~~
~~I-131~~	~~I~~	~~0.00E+00~~	~~1.0E-06~~	~~0.00~~
~~La-140~~	~~La~~	~~0.00E+00~~	~~9.0E-06~~	~~0.00~~
~~Xe-133~~	~~Xe~~	~~0.00E+00~~	~~2.0E-08~~	~~0.00~~

~~Sum Exposure Point Ratios (Unity Rule): 0.00~~

~~Key: NRC = Nuclear Regulatory Commission; Ag = silver; m = metastable isotope; I – iodine; Cs = cesium; Ba = barium; La = lanthanum; Xe = xenon. Ba-137m, Xe-133 have no Table 2 entry – using most conservative unknown isotope limit~~

Table 2.4.13-4
Unity Rule Calculations – Retarded Travel Time Composition
(1 of 2)

Nearest Perimeter

Isotope	X-Energy effluent concentration μCi/ml (Release)	X-Energy effluent concentration μCi/ml (After Travel to Exposure Point)	10CFR20 App B Table 2 Effluent limit μCi/ml	Ratio Concentration to Effluent Limit (Initial)	Ratio Concentration to Effluent Limit (Exposure Point after Travel)
Ag-110m	9.73E-02	0.00E+00	6.0E-06	1.62E+04	0.00E+00
Ba-137m	7.51E-02	0.00E+00	2.0E-08	3.76E+06	0.00E+00
Ba-140	2.63E-03	2.90E-103	8.0E-06	3.29E+02	3.62E-98
Cs-134	1.29E-01	0.00E+00	9.0E-07	1.43E+05	0.00E+00
Cs-137	8.08E-02	3.54E-260	1.0E-06	8.08E+04	3.54E-254
I-131	1.15E-02	0.00E+00	1.0E-06	1.15E+04	0.00E+00
La-140	2.63E-03	0.00E+00	9.0E-06	2.92E+02	0.00E+00
Xe-133	7.81E-06	1.01E-248	2.0E-08	3.91E+02	5.04E-241
H-3	1.33E-03	4.13E-04	1.0E-03	1.33E+00	4.13E-01

Sum Exposure Point Ratios (Unity Rule):	4.13E-01

Nearest Center

Isotope	X-Energy effluent concentration μCi/ml (Release)	X-Energy effluent concentration uCi/ml (After Travel to Exposure Point)	10CFR20 App B Table 2 Effluent limit μCi/ml	Ratio Concentration to Effluent Limit (Initial)	Ratio Concentration to Effluent Limit (Exposure Point after Travel)
Ag-110m	9.73E-02	0.00E+00	6.0E-06	1.62E+04	0.00E+00
Ba-137m	7.51E-02	0.00E+00	2.0E-08	3.76E+06	0.00E+00
Ba-140	2.63E-03	0.00E+00	8.0E-06	3.29E+02	0.00E+00
Cs-134	1.29E-01	0.00E+00	9.0E-07	1.43E+05	0.00E+00
Cs-137	8.08E-02	0.00E+00	1.0E-06	8.08E+04	0.00E+00
I-131	1.15E-02	0.00E+00	1.0E-06	1.15E+04	0.00E+00
La-140	2.63E-03	0.00E+00	9.0E-06	2.92E+02	0.00E+00
Xe-133	7.81E-06	0.00E+00	2.0E-08	3.91E+02	0.00E+00
H-3	1.33E-03	2.82E-06	1.0E-03	1.33E+00	2.82E-03

Sum Exposure Point Ratios (Unity Rule):	2.82E-03

Table 2.4.13-4
Unity Rule Calculations – Retarded Travel Time Composition
(2 of 2)

Median Center

Isotope	X-Energy effluent concentration µCi/ml (Release)	X-Energy effluent concentration uCi/ml (After Travel to Exposure Point)	10CFR20 App B Table 2 Effluent limit µCi/ml	Ratio Concentration to Effluent Limit (Initial)	Ratio Concentration to Effluent Limit (Exposure Point after Travel)
Ag-110m	9.73E-02	0.00E+00	6.0E-06	1.62E+04	0.00E+00
Ba-137m	7.51E-02	0.00E+00	2.0E-08	3.76E+06	0.00E+00
Ba-140	2.63E-03	0.00E+00	8.0E-06	3.29E+02	0.00E+00
Cs-134	1.29E-01	0.00E+00	9.0E-07	1.43E+05	0.00E+00
Cs-137	8.08E-02	0.00E+00	1.0E-06	8.08E+04	0.00E+00
I-131	1.15E-02	0.00E+00	1.0E-06	1.15E+04	0.00E+00
La-140	2.63E-03	0.00E+00	9.0E-06	2.92E+02	0.00E+00
Xe-133	7.81E-06	0.00E+00	2.0E-08	3.91E+02	0.00E+00
H-3	1.33E-03	3.01E-08	1.0E-03	1.33E+00	3.01E-05

Sum Exposure Point Ratios (Unity Rule):	3.01E-05

½ Nearest Perimeter (Sensitivity Analysis Only)

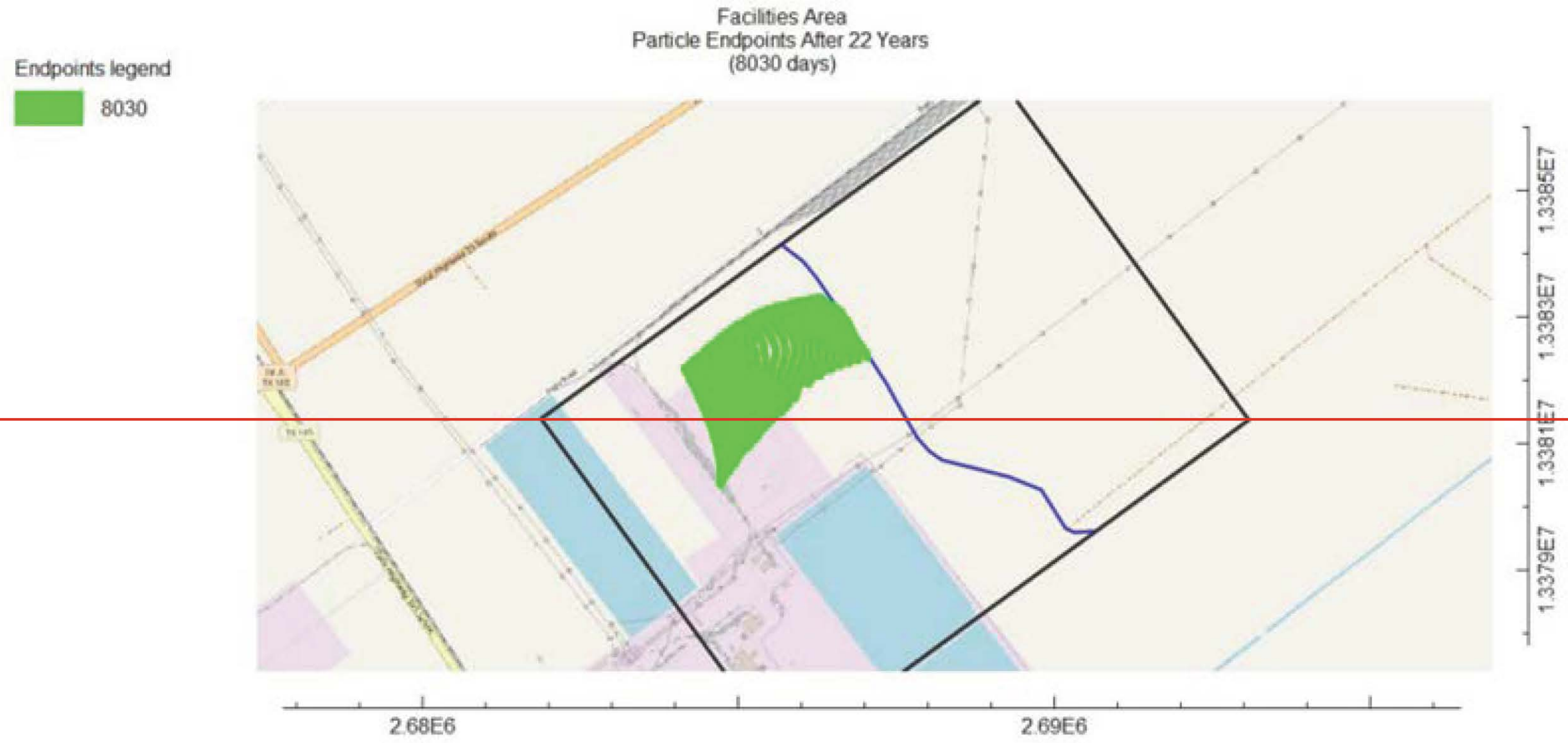
Isotope	X-Energy effluent concentration µCi/ml (Release)	X-Energy effluent concentration uCi/ml (After Travel to Exposure Point)	10CFR20 App B Table 2 Effluent limit µCi/ml	Ratio Concentration to Effluent Limit (Initial)	Ratio Concentration to Effluent Limit (Exposure Point after Travel)
Ag-110m	9.73E-02	0.00E+00	6.0E-06	1.62E+04	0.00E+00
Ba-137m	7.51E-02	0.00E+00	2.0E-08	3.76E+06	0.00E+00
Ba-140	2.63E-03	2.76E-53	8.0E-06	3.29E+02	3.45E-48
Cs-134	1.29E-01	0.00E+00	9.0E-07	1.43E+05	0.00E+00
Cs-137	8.08E-02	5.35E-131	1.0E-06	8.08E+04	5.35E-125
I-131	1.15E-02	0.00E+00	1.0E-06	1.15E+04	0.00E+00
La-140	2.63E-03	0.00E+00	9.0E-06	2.92E+02	0.00E+00
Xe-133	7.81E-06	2.81E-127	2.0E-08	3.91E+02	1.40E-119
H-3	1.33E-03	7.42E-04	1.0E-03	1.33E+00	7.42E-01

Sum Exposure Point Ratios (Unity Rule):	7.42E-01

Key: NRC = Nuclear Regulatory Commission; Ag = silver; m = metastable isotope; I – iodine; Cs = cesium; Ba = barium; La = lanthanum; Xe = xenon; H-3 = tritium. Ba-137m, Xe-133 have no Table 2 entry – using most conservative unknown isotope limit; µCi/ml = microCuries per milliliter

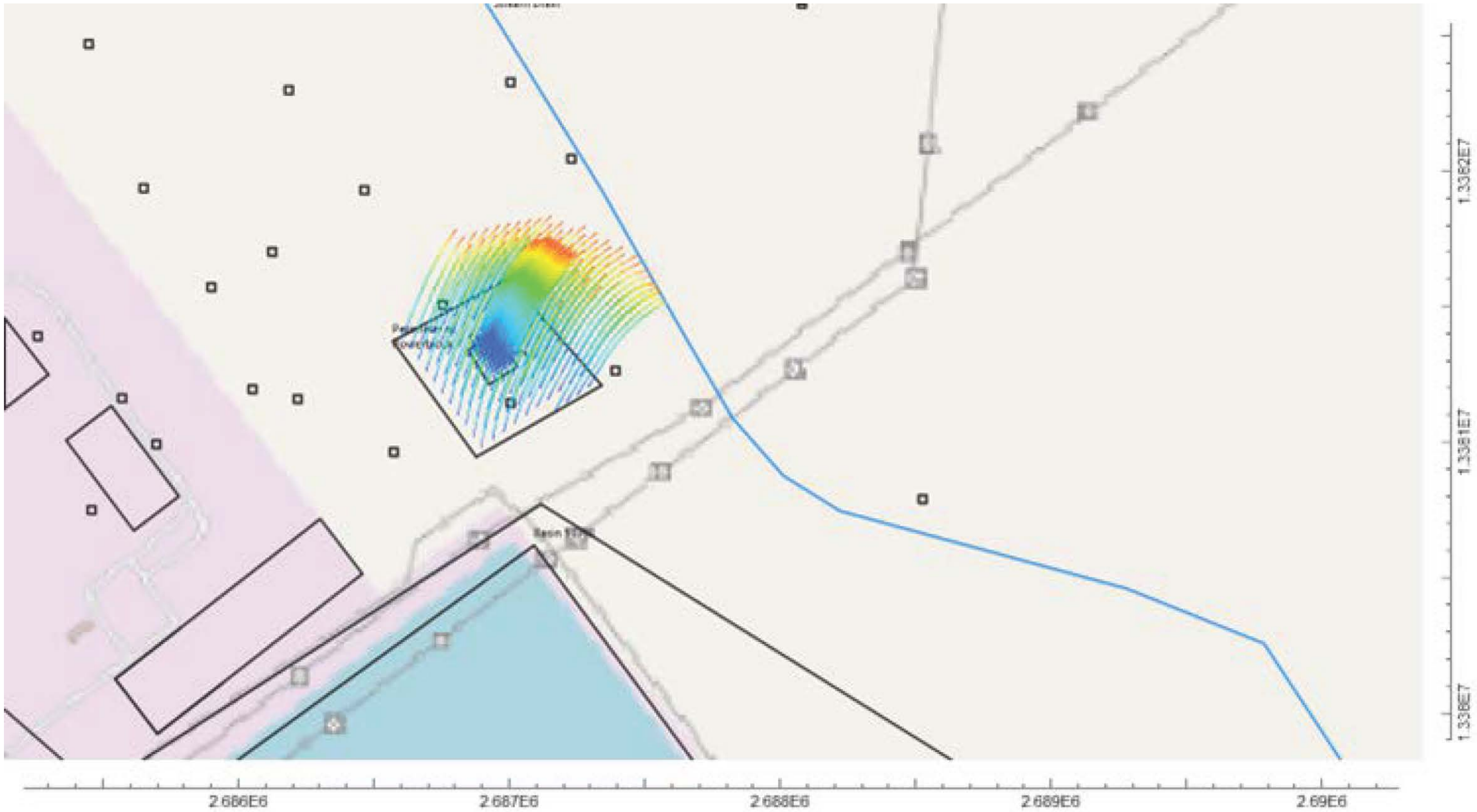
~~Figure 2.4.13-1~~

~~Facilities Particle Track After 22 Years~~



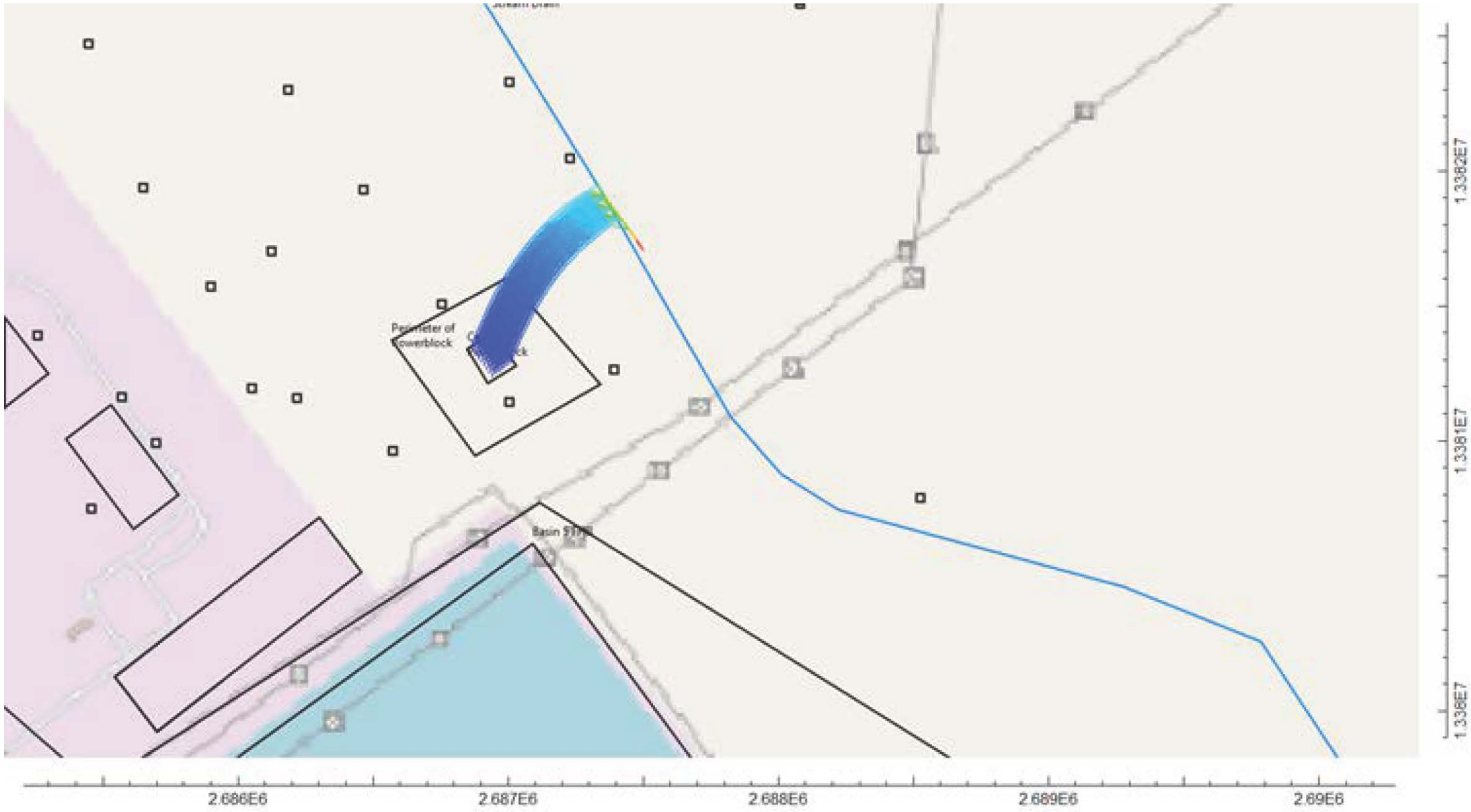
(Axes are Easting and Northing coordinates in NAD 1983 State Plane Texas South Central grid, US Feet)

Figure 2.4.13-1
Facilities Particle Tracks (Sheet 1 of 3)



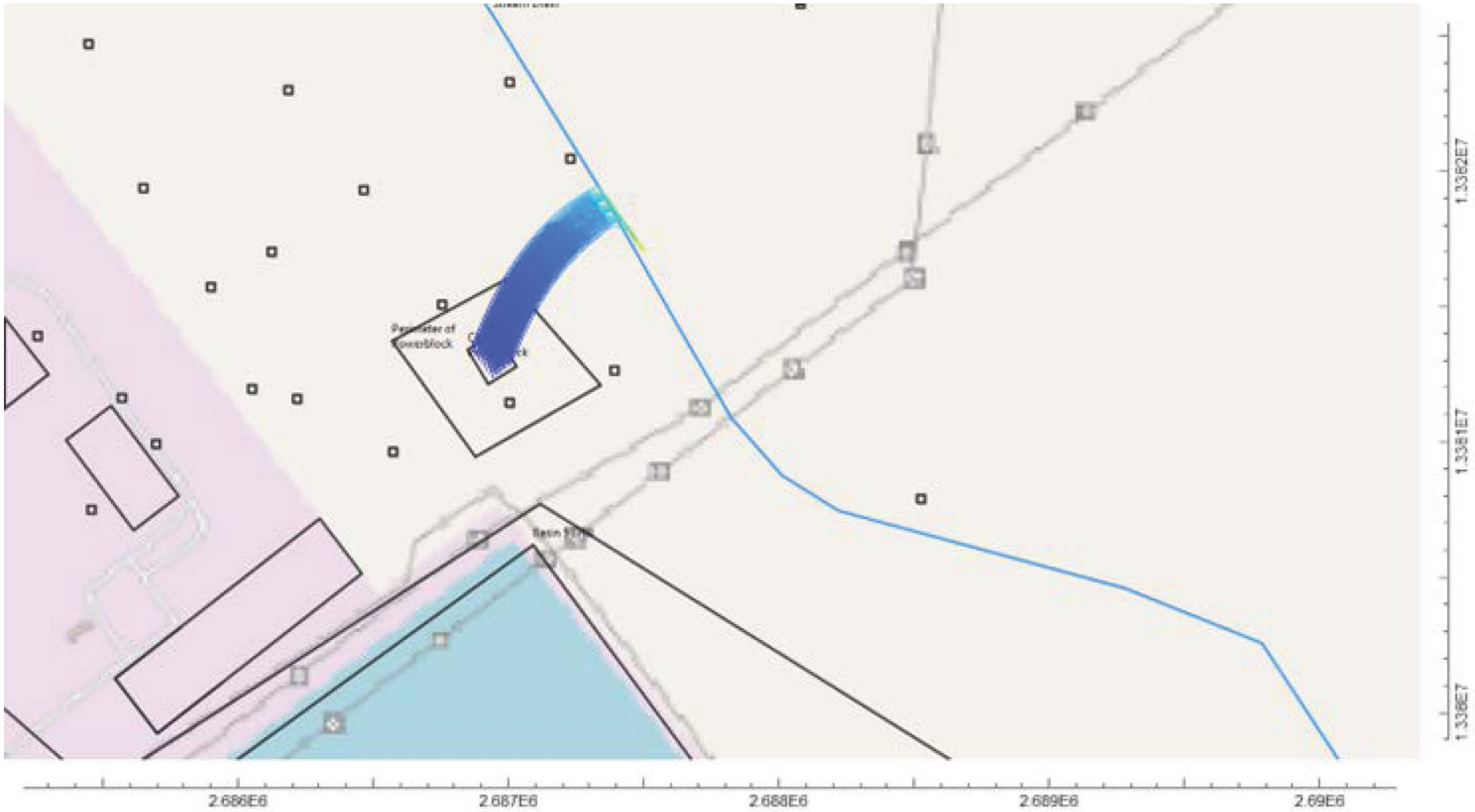
4234 days – First particle from perimeter

Figure 2.4.13-1 Facilities Particle Tracks (Sheet 2 of 3)



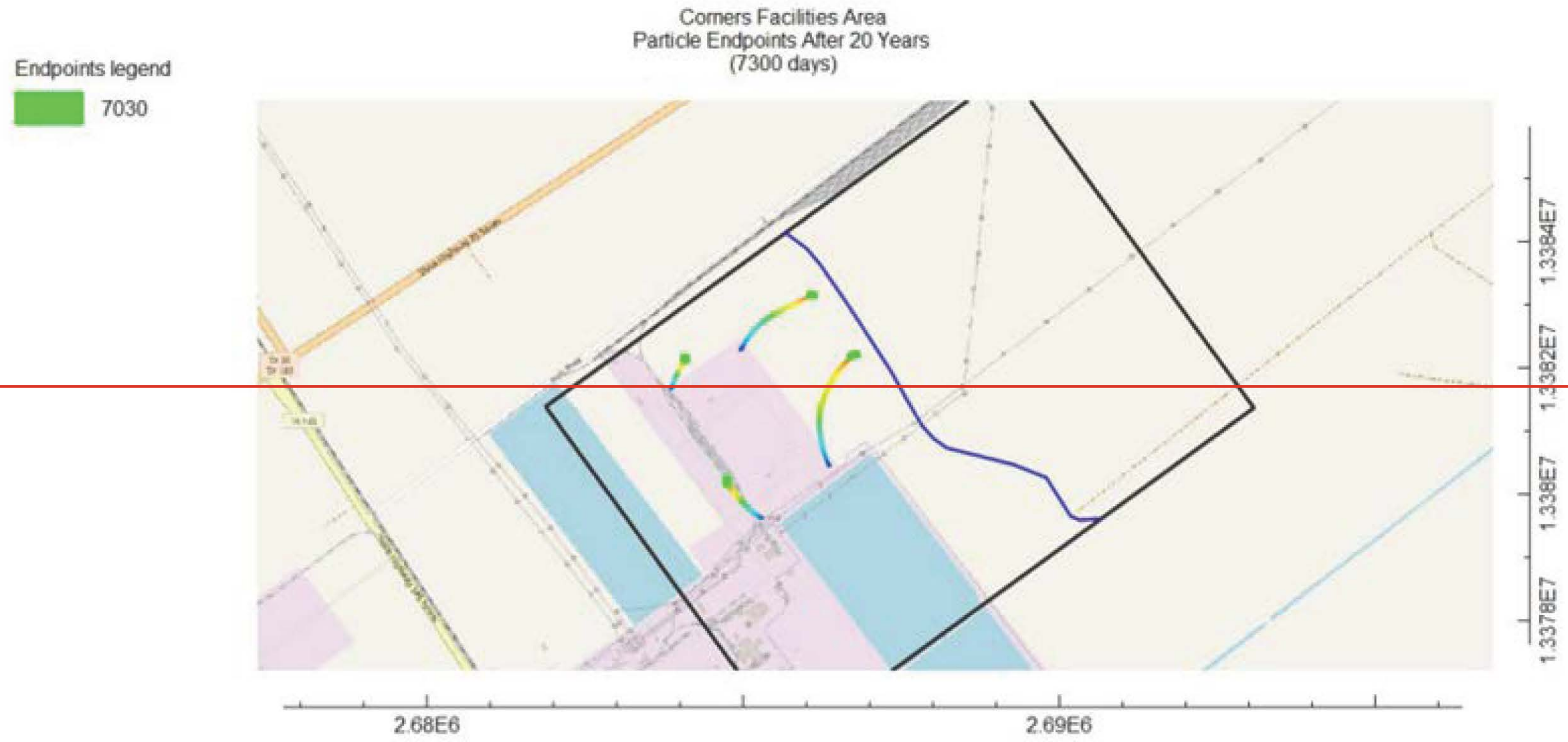
22265 days - First particle from center

Figure 2.4.13-1 Facilities
Particle Tracks
(Sheet 3 of 3)



38690 days – Median particle from center

~~Figure 2.4.13-2~~
~~Facilities Corners Particle Track After 20 Years~~



(Axes are Easting and Northing coordinates in NAD 1983 State Plane Texas South Central grid, US Feet)