Evaluation of the Need for Three-Dimensional Contaminant Transport Modeling of the Hanford Plateau Vadose Zone

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Hanford Site Composite Analysis

- The recently approved updated Hanford Site Composite Analysis (CA) is required to provide a reasonable expectation that U.S. Department of Energy low-level waste disposal, high-level waste tank closure, and transuranic waste disposal at the Central Plateau ensure radiological protection of the public.

- The CA includes a site-specific dose projection to a hypothetical future member of the public at points of assessment over a minimum 1,000-year compliance period (2070-3070) following the anticipated end of DOE site operations in 2070.

- The CA also provides a comparison with the performance measures during the post-compliance period (3070-12070) to address potential peaks beyond the compliance period.

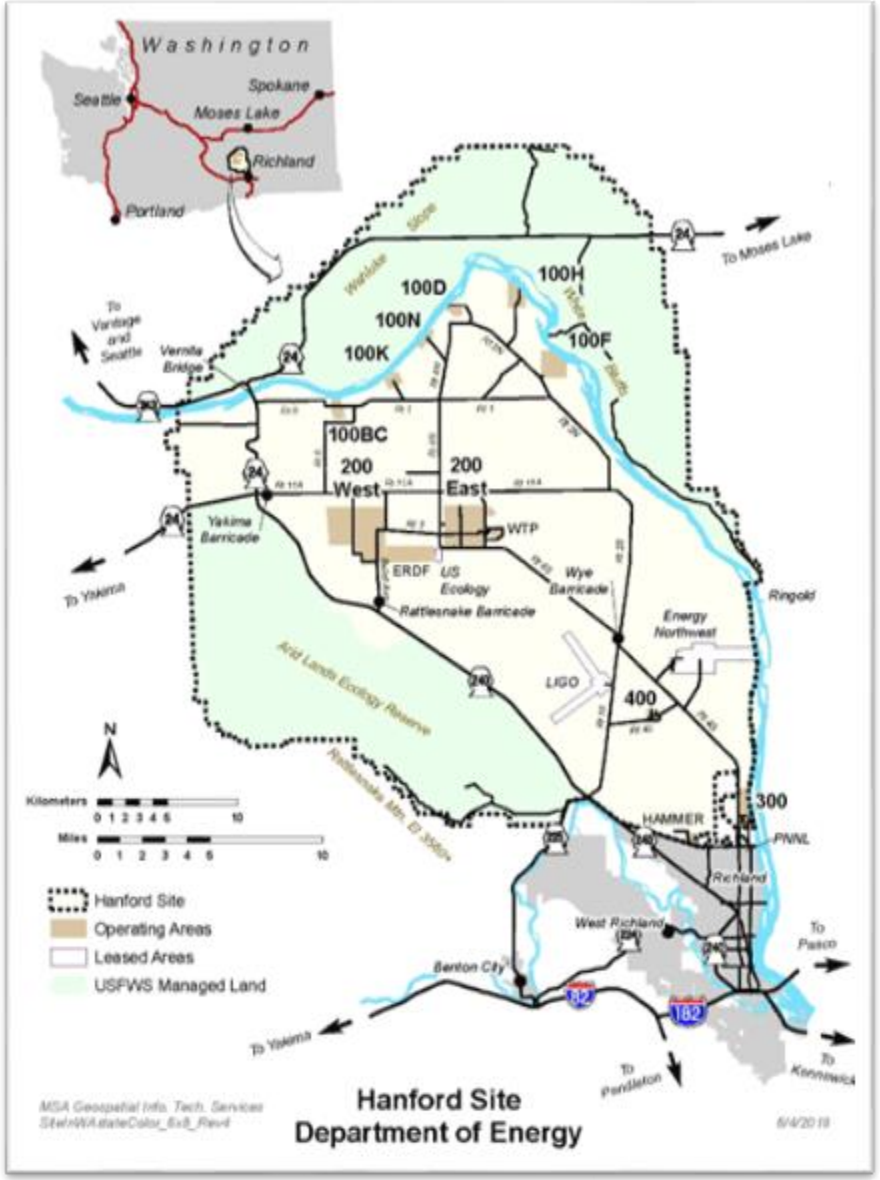
- The CA has been organized using technical facets of inventory, waste form release, vadose zone (VZ), saturated zone, and dose.

Composite Analysis Large Scale Vadose Zone Modeling

- Operational Era 1943-1988 for plutonium production

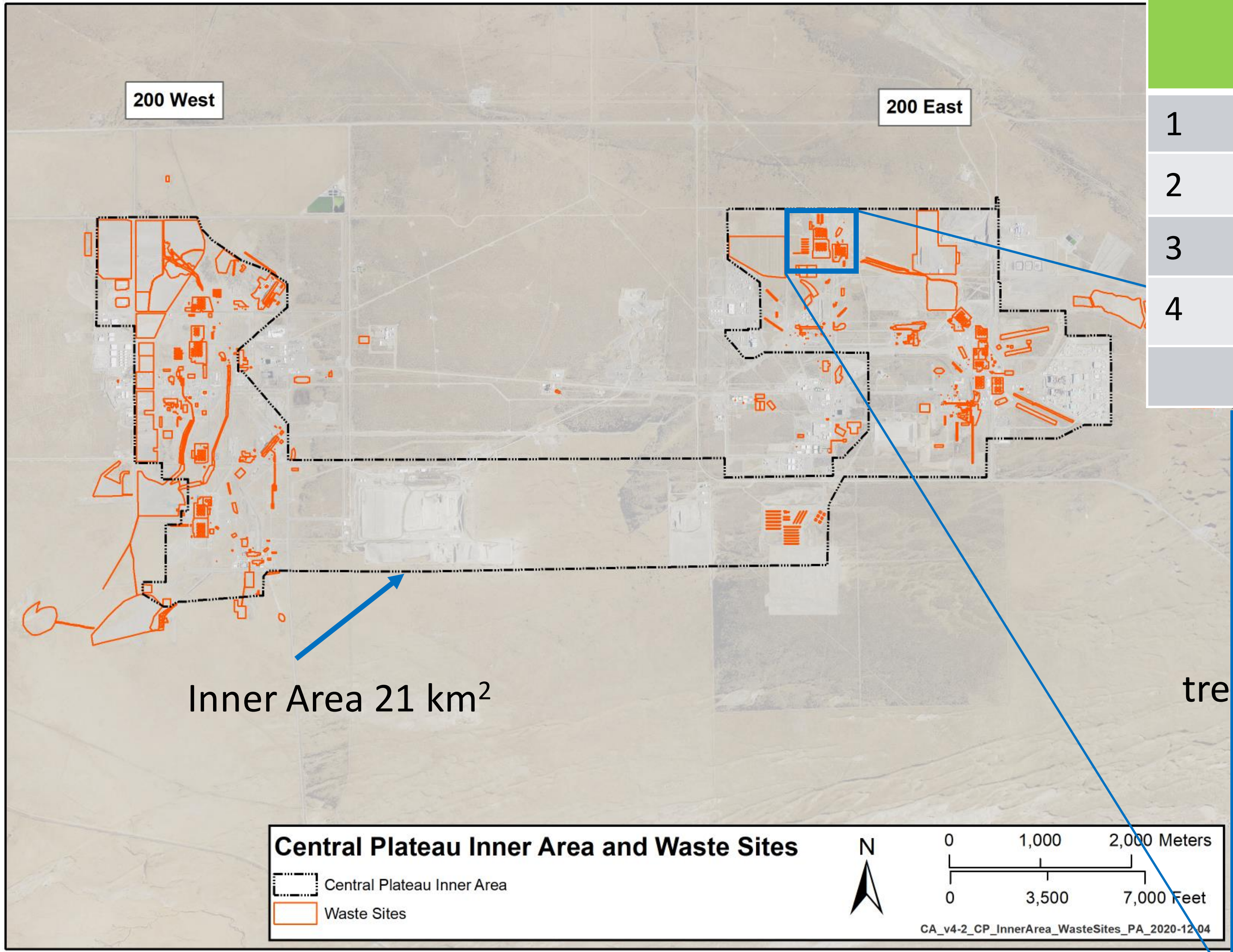
- Major operational areas:
  - 300 Area – uranium fuel rod production
  - 100 Areas – reactors
  - 200 Areas – chemical separations

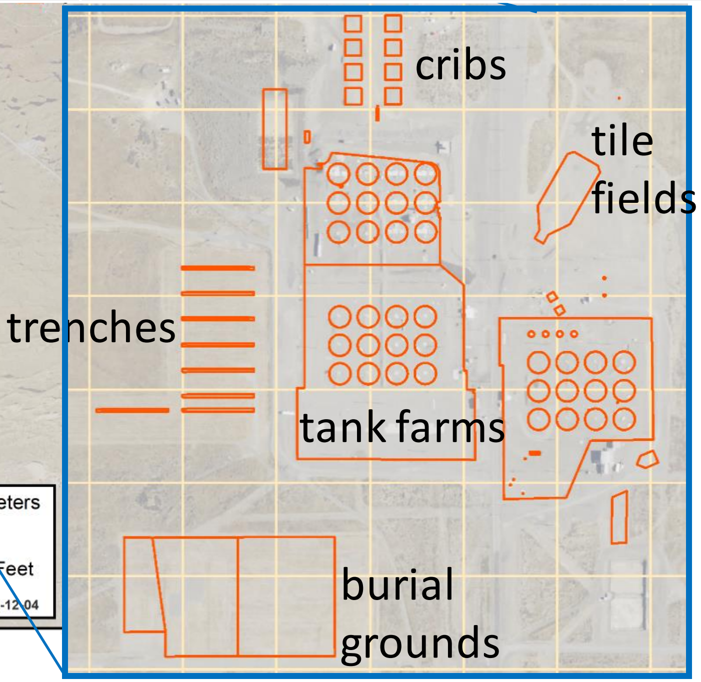
- Focus of the Composite Analysis is the 200 Areas, in support of low-level waste disposal Performance Assessments



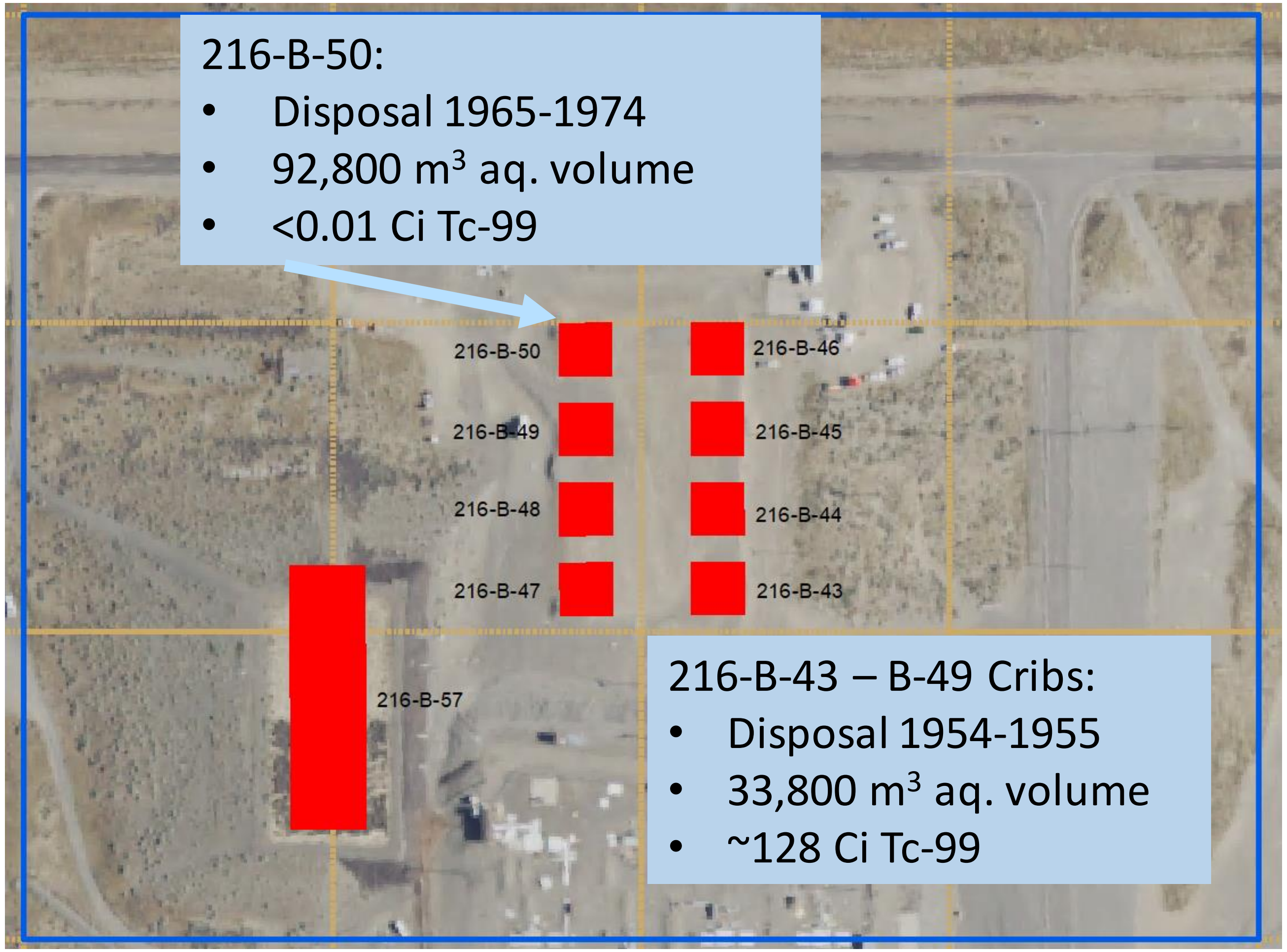
Modeling Challenges:
Large Number and Proximity of Waste Sites

	Sites	200 West	200 East	Total
1	Liquid Rad Sites	152	191	343
2	Liquid Non-Rad Sites	24	20	44
3	Solid Waste Sites	128	107	235
4	Tank Leaks/Overfill Events	27	10	37
	Total # Sites (1+2+3-4)	277	308	585





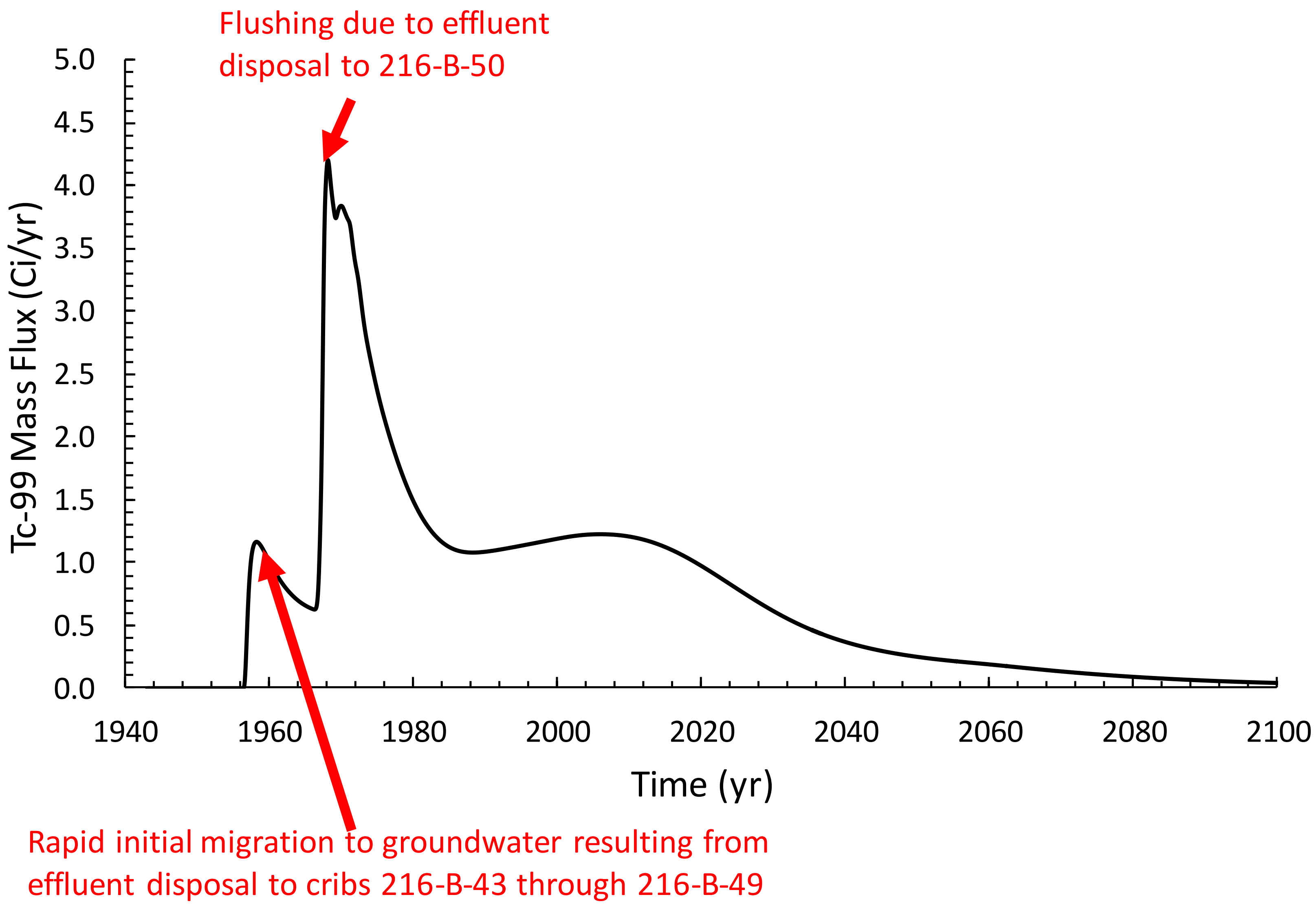
Modeling Challenges:
Vadose Zone Plume Commingling



Commingling is related to:

- Disposal characteristics (e.g., volumes, duration, rate, and time period)
- Hydraulic properties
- Distance between waste sites

Modeling Challenges: Vadose Zone Plume Commingling



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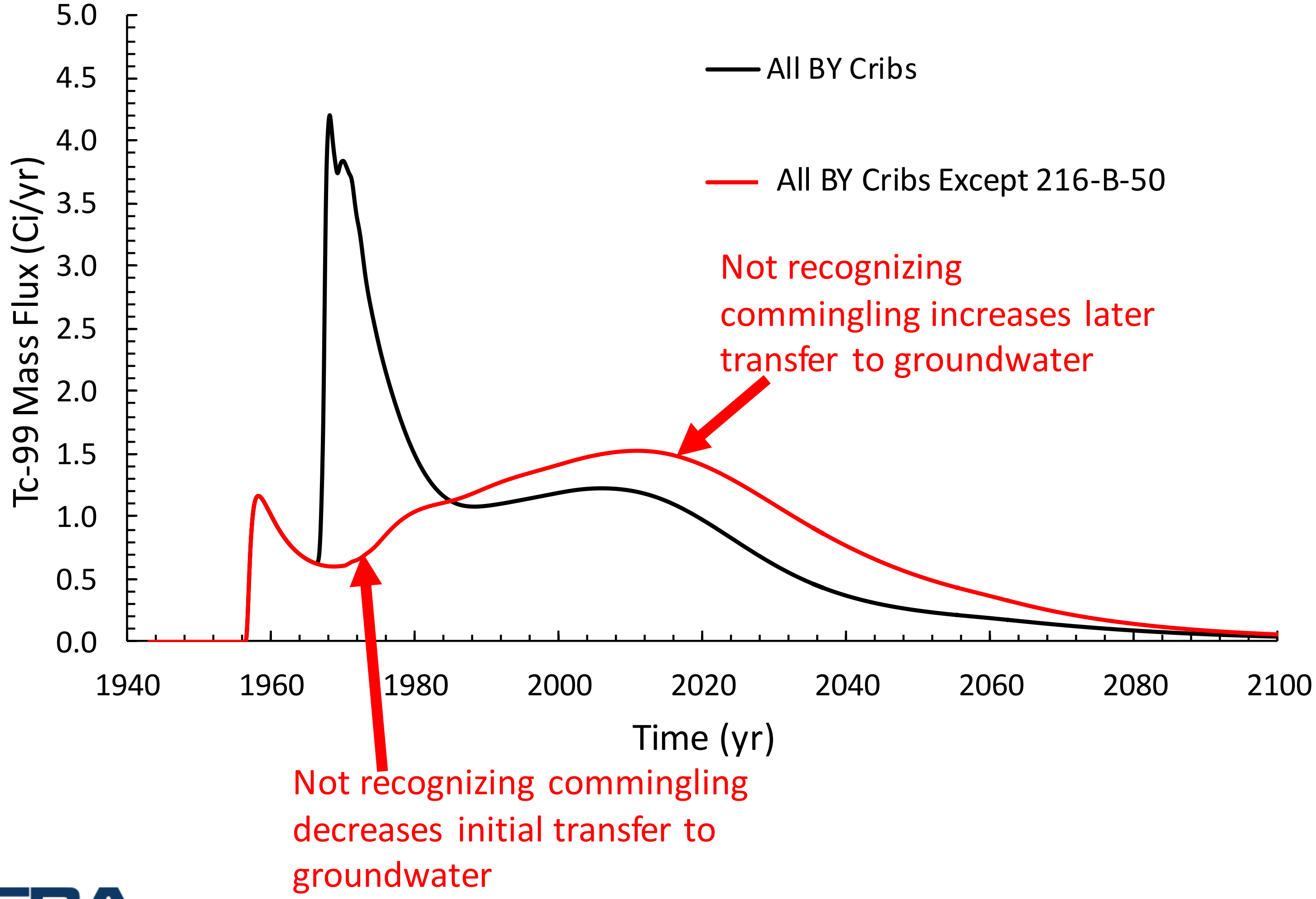
Modeling Challenges:
Vadose Zone Plume Commingling



The commingling effect of adjacent waste sites on subsurface transport cannot be captured using models

- representing a single waste site
- simulating flow and transport using a 1D approach

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GAIA Computational Cluster

- 12 Dell R740 (2U) Servers, each with:
  - Two Xeon Platinum 28-core processors @ 2.5 GHz
  - 768 GBytes RAM
  - 1 TByte SSD disk
  - Quad 10 Gbps, Base-T Ethernet ports
  - Dual, Hot-plug, Redundant Power Supply (1100W)

- Head node has an additional 10 TB hard disk.

- Two 10Gb Cisco Nexus 9300s switches to support intensive I/O communication between nodes.

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Modeling Considerations and General Approach

- Waste-site proximity and vadose zone plume commingling rule out a single waste site per model approach.
- Computational limitations rule out a single vadose zone model for the entire Inner Area.
- Based on scoping simulations, 4-5 million-node three-dimensional (3D) models, covering a domain area of about 1 km^2, would need a run time of up to 1 week on GAIA for the Hanford operations period.
- Approximately 25 vadose zone models would capture all waste sites.

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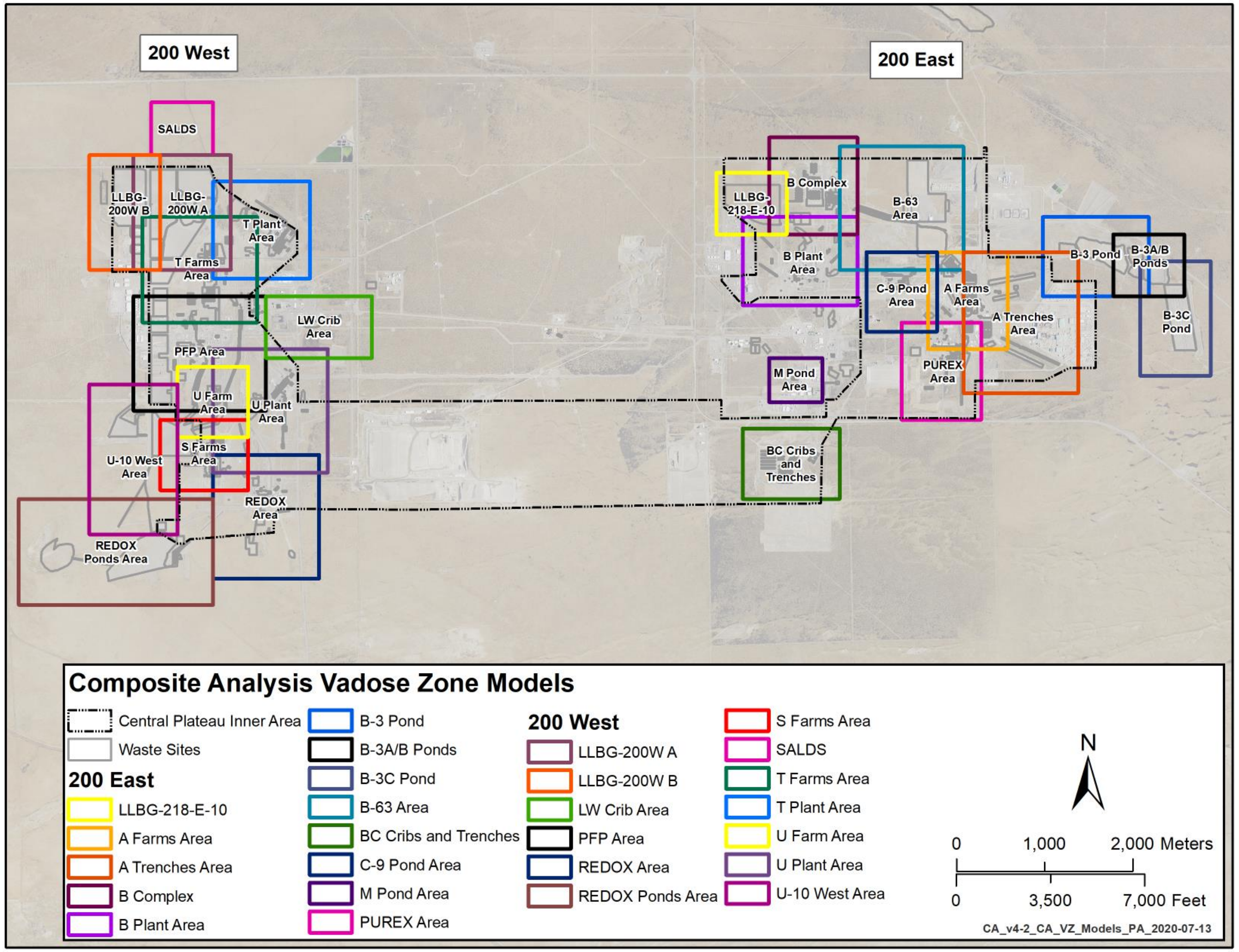
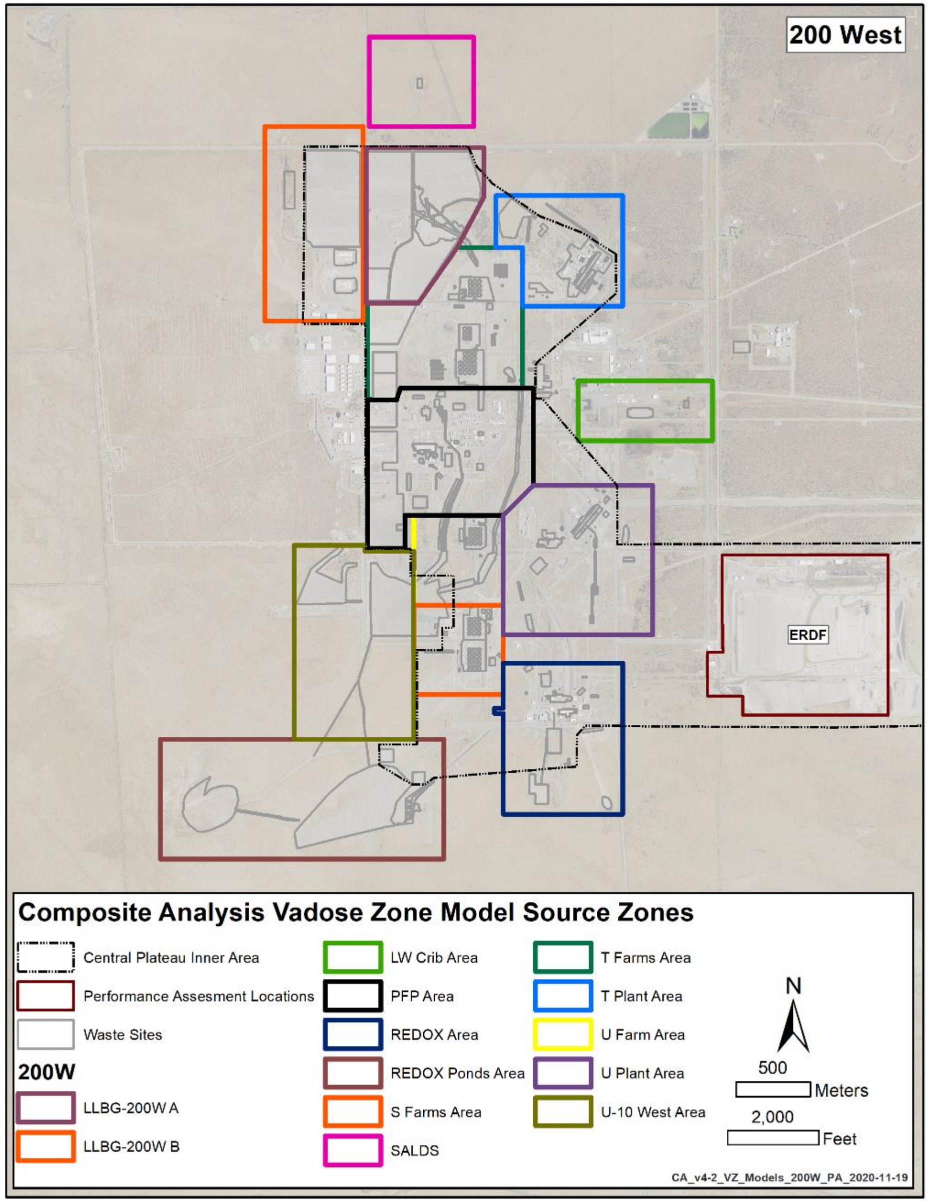
Model Domains of 26 Vadose Zone Models



- 13 vadose zone models each in 200 West and 200 East area.
- Models have source zones and buffer zones.
- To avoid double counting of inventory, contaminant releases are considered only in the source zones. In buffer zones, only water releases are used.

Example: 200 West Model Source Zones



- Model source zones do not overlap

Waste site radionuclide releases are only used in a single vadose zone model.

3D versus 1D Vadose Zone Simulations

- The computational demands of the 3D VZ simulation suite are considerable, with a typical run time of several days per VZ model using a high-performance computer and parallelization.
- The intensive nature of the simulations complicates execution of extensive sensitivity and uncertainty analyses.
- One dimensional (1D) simulations have much smaller run times and are therefore more suitable for sensitivity and uncertainty analyses. Regulators and peer-review panels have been pushing to use 1D simulations primarily for this reason.
- An alternative approach using 1D Tc-99 simulations of VZ transport below selected waste sites is applied, to the CA 3D simulation results, and evaluated for representativeness.
- The 1D simulations honor the leak/disposal characteristics and site footprint.

Disposal and Leak Volumes and Release Pore Volumes

- Tank leaks or overfill events are in the order of tens to hundreds of m^3.

- Waste site disposal volumes range from a few m^3 to ~10^8 m^3.

- To estimate potential near-term contaminant impact to groundwater due to waste sites releases, volumes have limited value. Instead, the term Release Pore Volume (RSP) is preferred:

  RSP = Disposal Volume / Waste Site Pore Volume

  (Waste Site Pore Volume = Pore space between the waste site footprint and the water table)

- If the RSP > 1, near-term (~within years/decades after release) waste site groundwater effects could be possible

- If the RSP < 1, near-term waste site groundwater effects are less likely

Site Selection

- To investigate how the model dimensionality affects VZ transport and transfer rate to groundwater, several example waste sites and tank leaks were selected for analysis.

- In this presentation, the results of four of these are presented:

  - The 241-A-105 tank leak represents tanks with leak/overfill events without the presence of adjacent fluid disposal sites causing commingling.

  - The 241-SX-115 tank leak represents tanks with similar events, but with adjacent aqueous volume releases.

  - The 216-B-18 site is an example of a crib without adjacent sites that could cause substantial commingling.

  - The 216-B-49 site is a crib located in an area with another high-volume crib that could lead to considerable mixing.

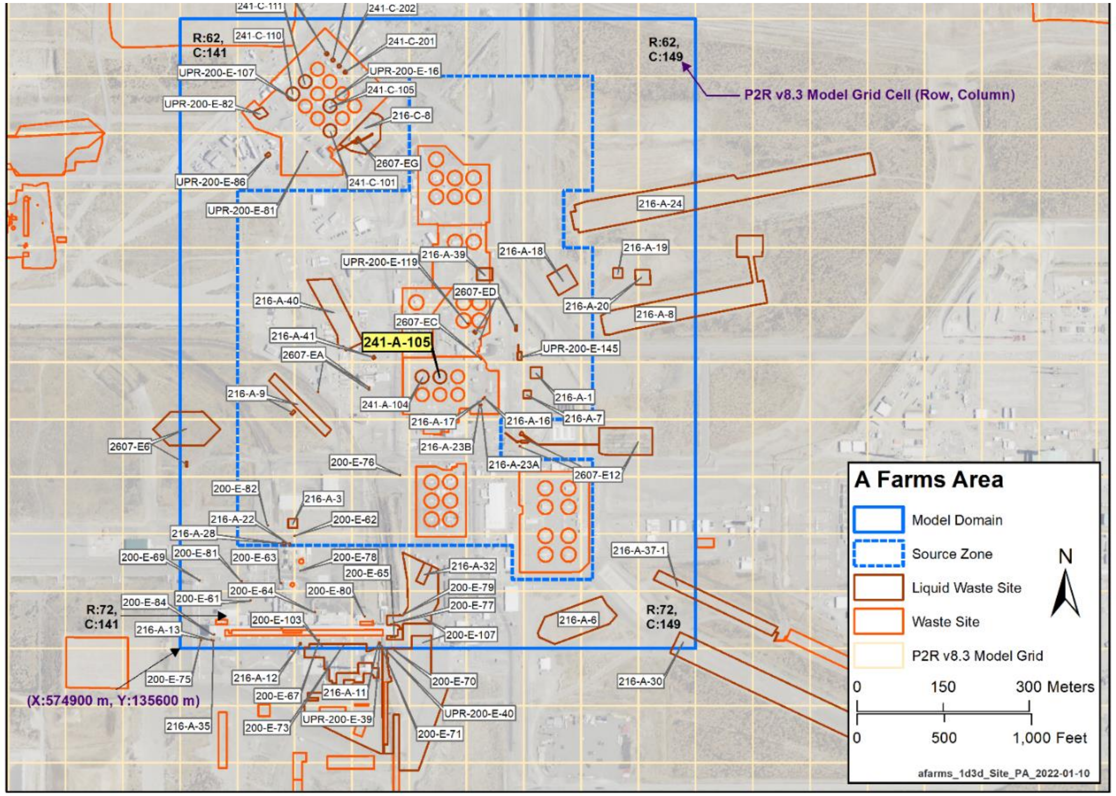
241-A-105 Tank Leak

Release Data

Period	Volume (m^3)	Release Pore Volume	Tc-99
1965	72	0.01	9.6
1970-1978	878	0.08	0

(0.73 Ci Solid Waste Release after 2043)

No 216-A-105-related Tc-99 contaminant plume has been generated in the saturated zone yet.



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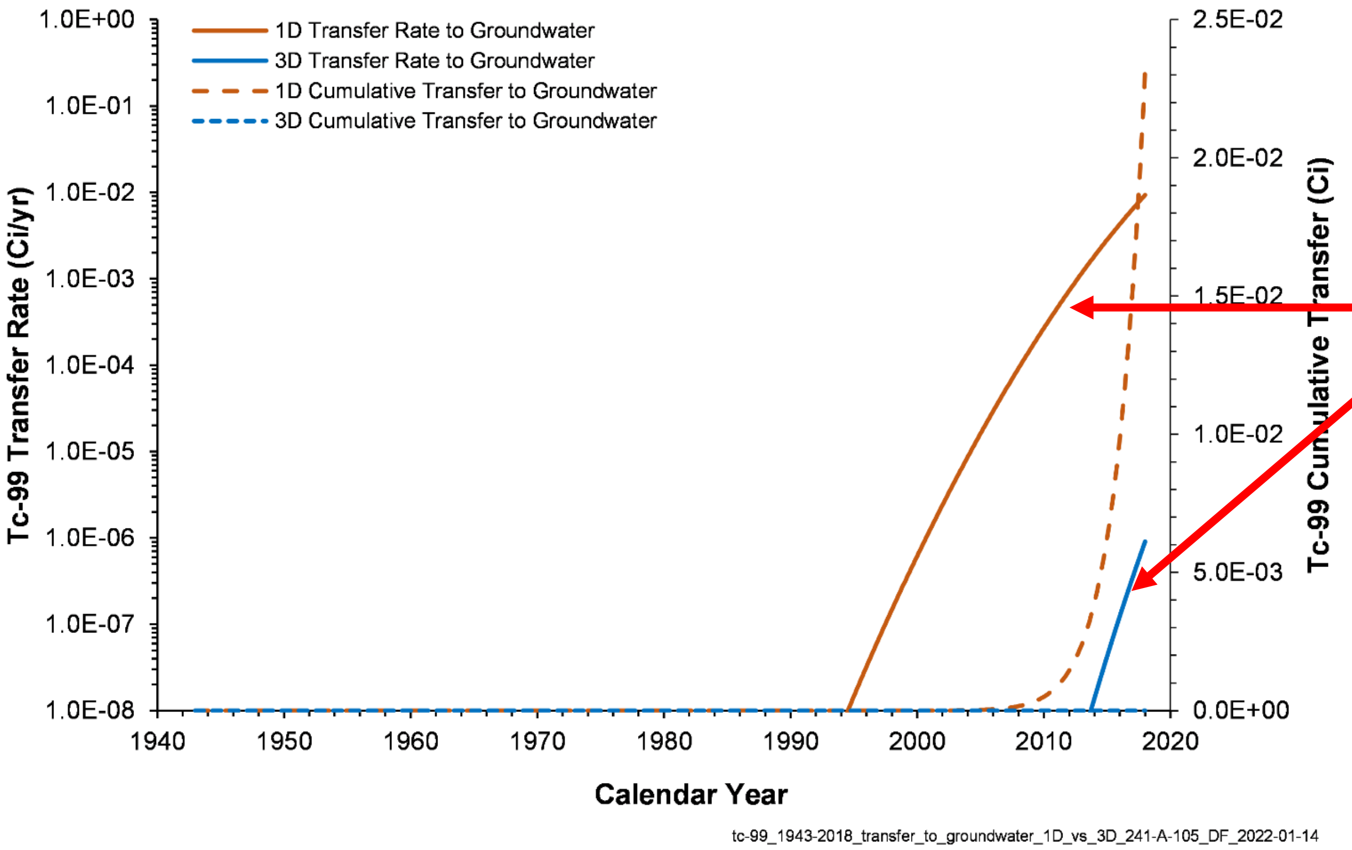
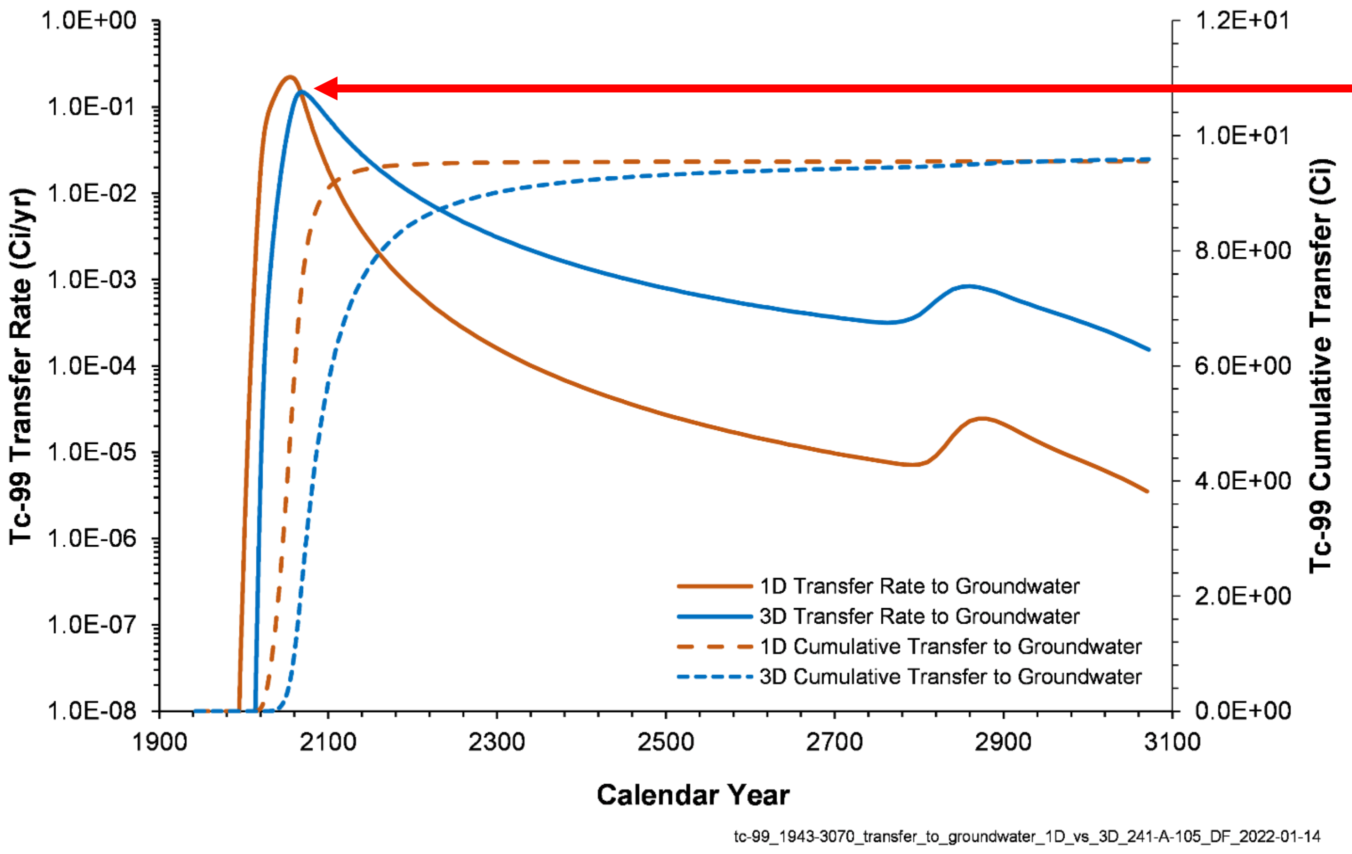
241-A-105 Tank Leak



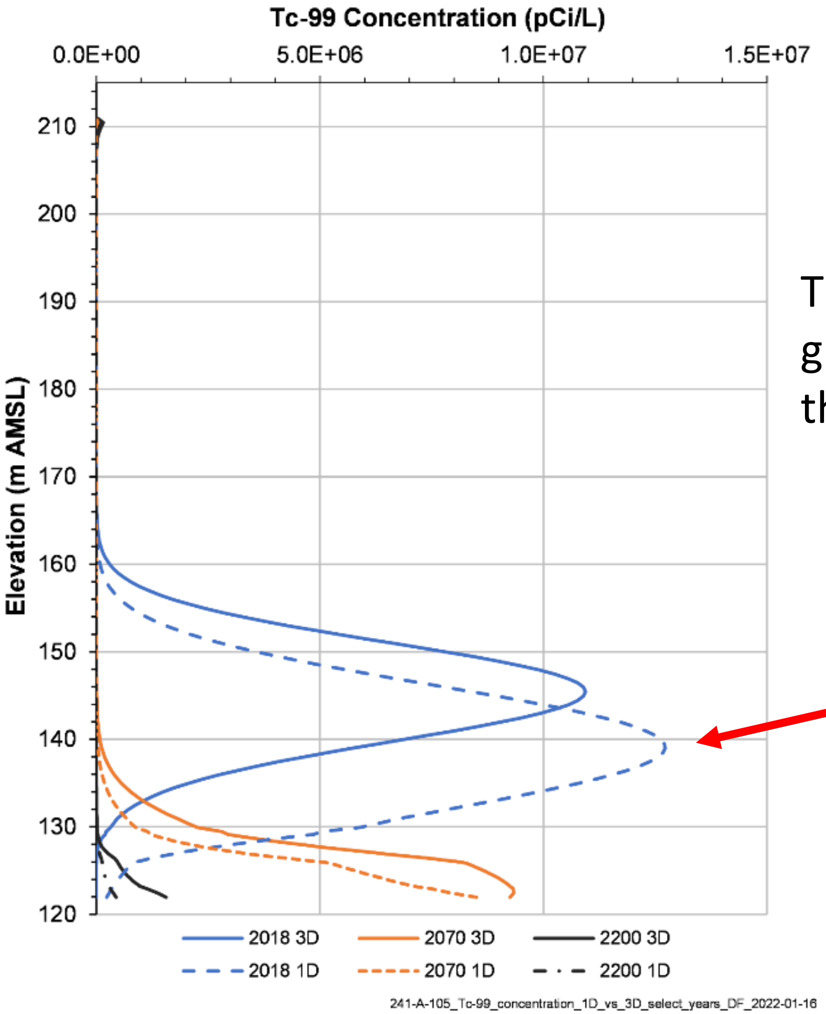
For both the 1D and 3D simulation, the transfer rates before the current time are too small to generate a groundwater plume.

241-A-105 Tank Leak



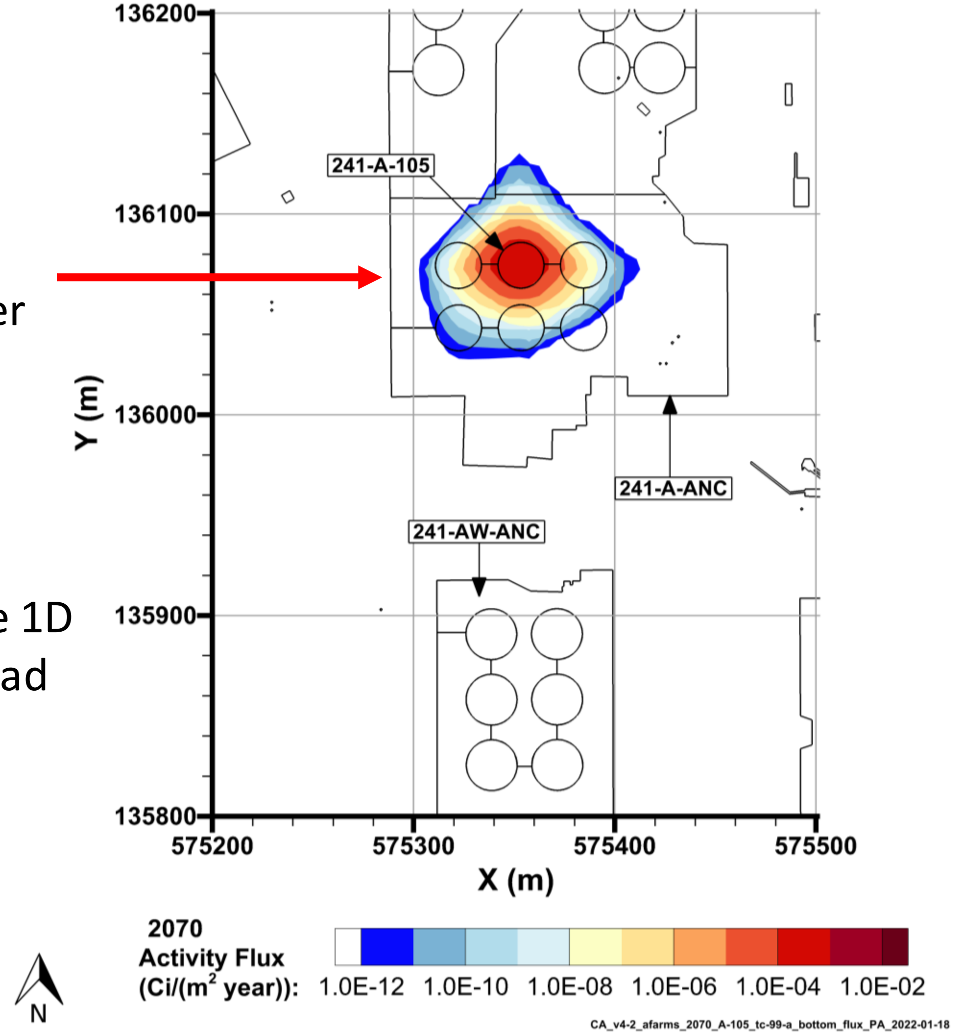
Although transport for the 1D simulation is faster than for the 3D simulation, peak arrivals are within a few decades, and overall, differences in rates are relatively minor.

241-A-105 Tank Leak



At the present time, the 1D VZ plume is slightly ahead of the 3D plume.

The transfer area to groundwater is much larger than the tank footprint.



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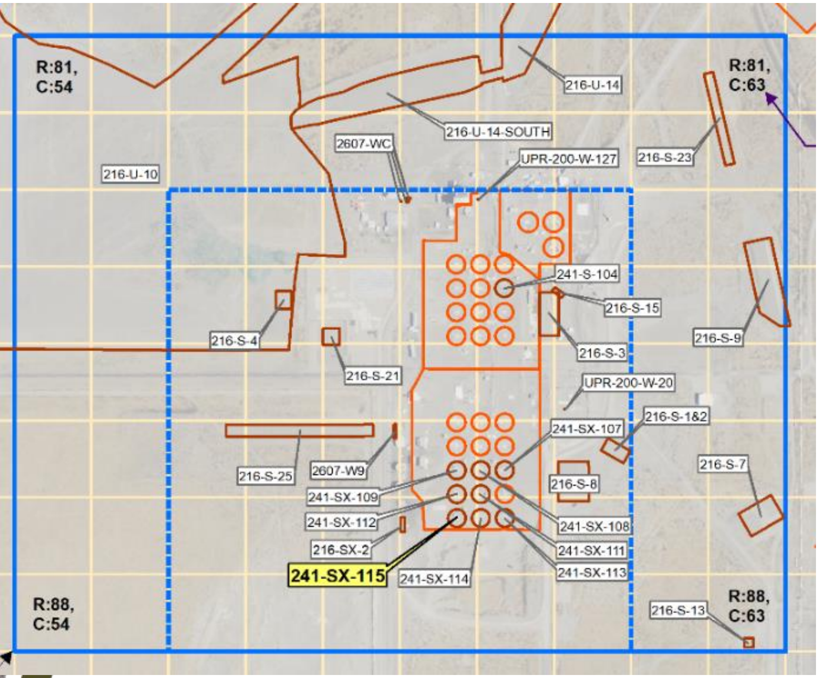
241-SX-115 Tank Leak

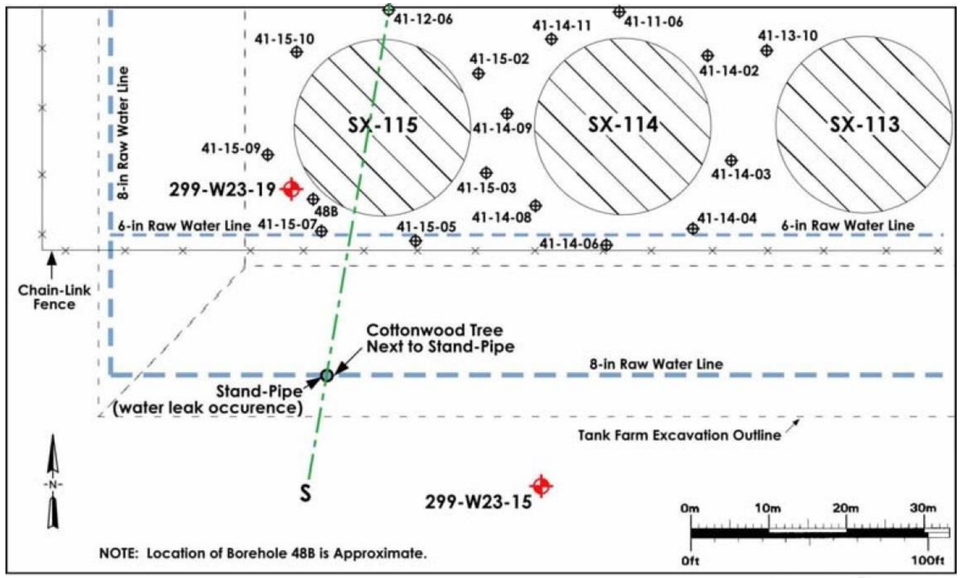
Release Data

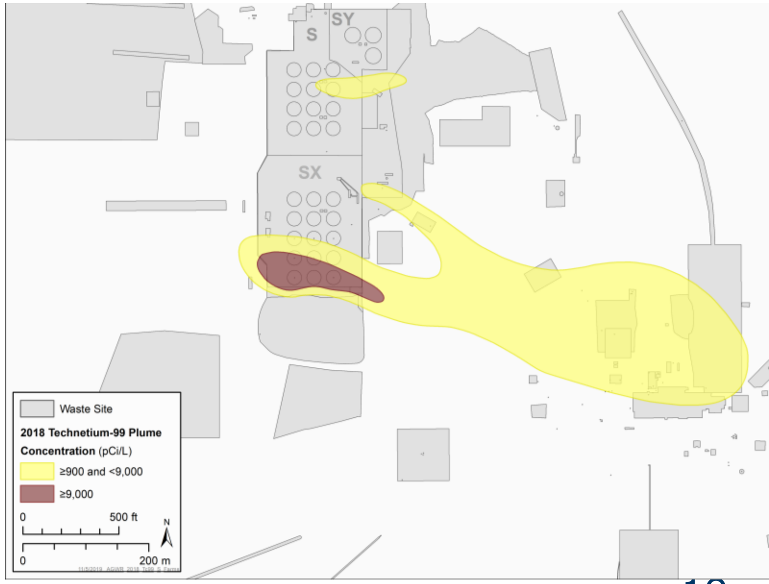
Period	Volume (m^3)	Release Pore Volume	Tc-99
1965	114	0.02	3.0

(0.753 Ci Solid Waste Release after 2043)

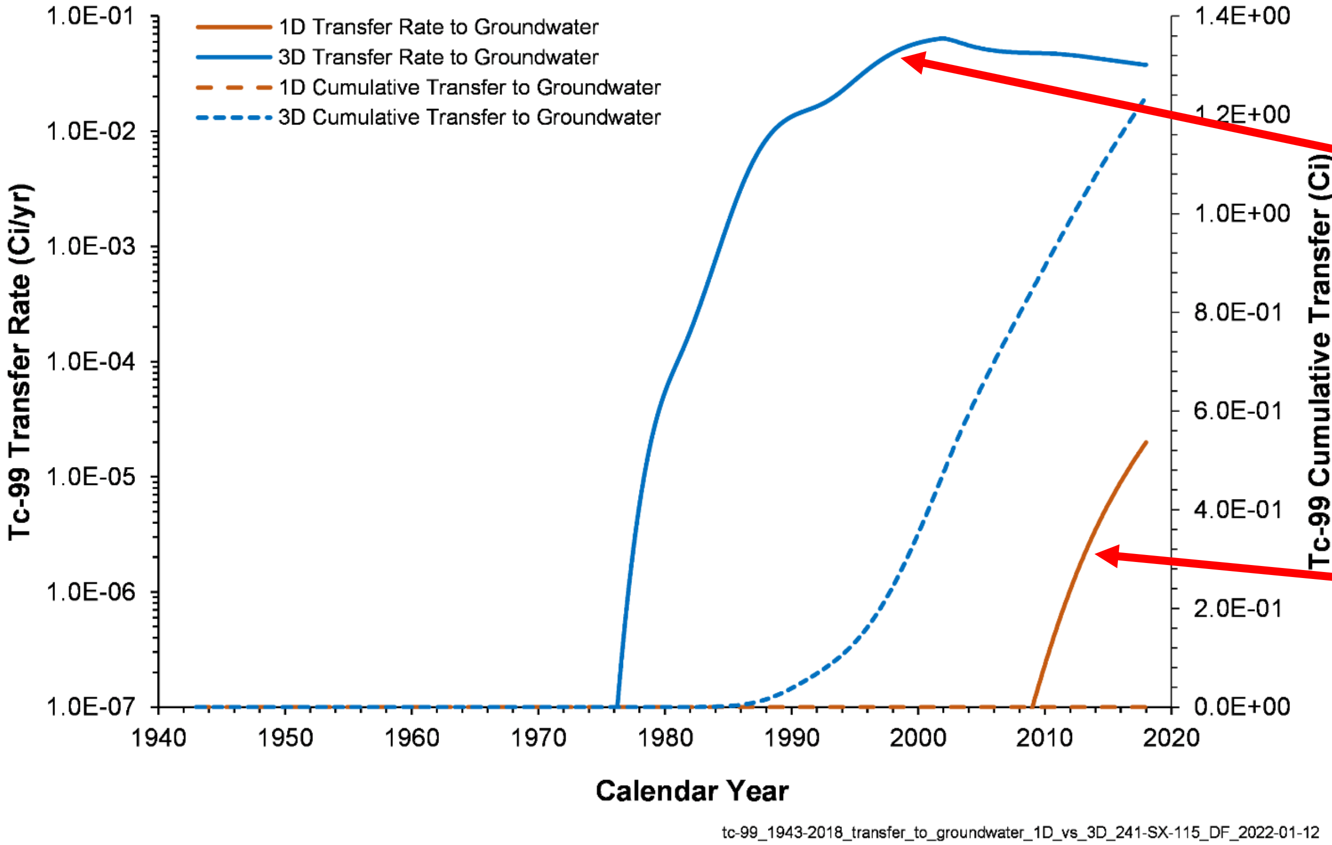
A saturated zone Tc-99 contaminant plume has been developed and sustained for several decades and has been linked to a water line leak south of SX-115.







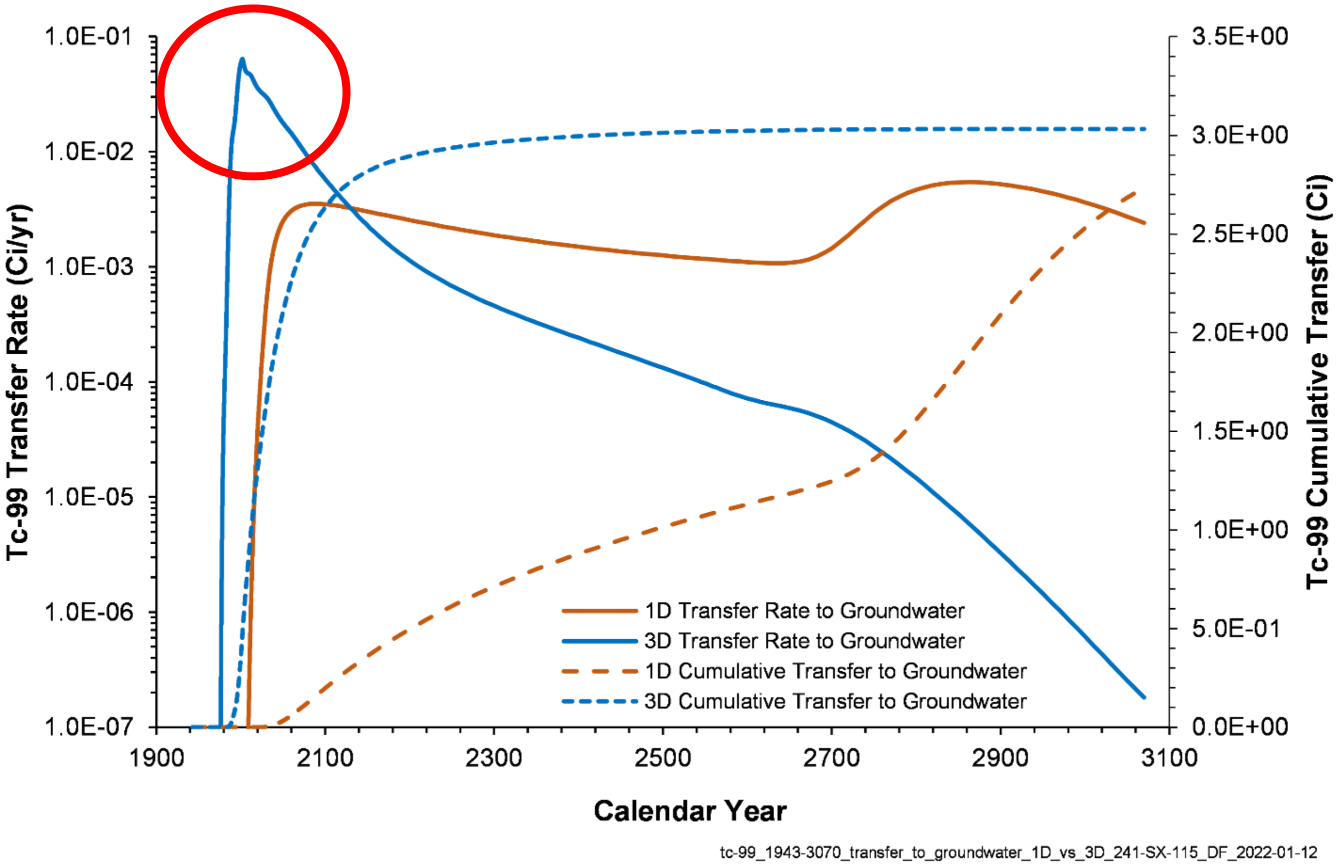
241-SX-115 Tank Leak



The transfer rate for the 3D simulation, enhanced by the calibrated water line leak, is sufficient to generate and sustain a groundwater plume.

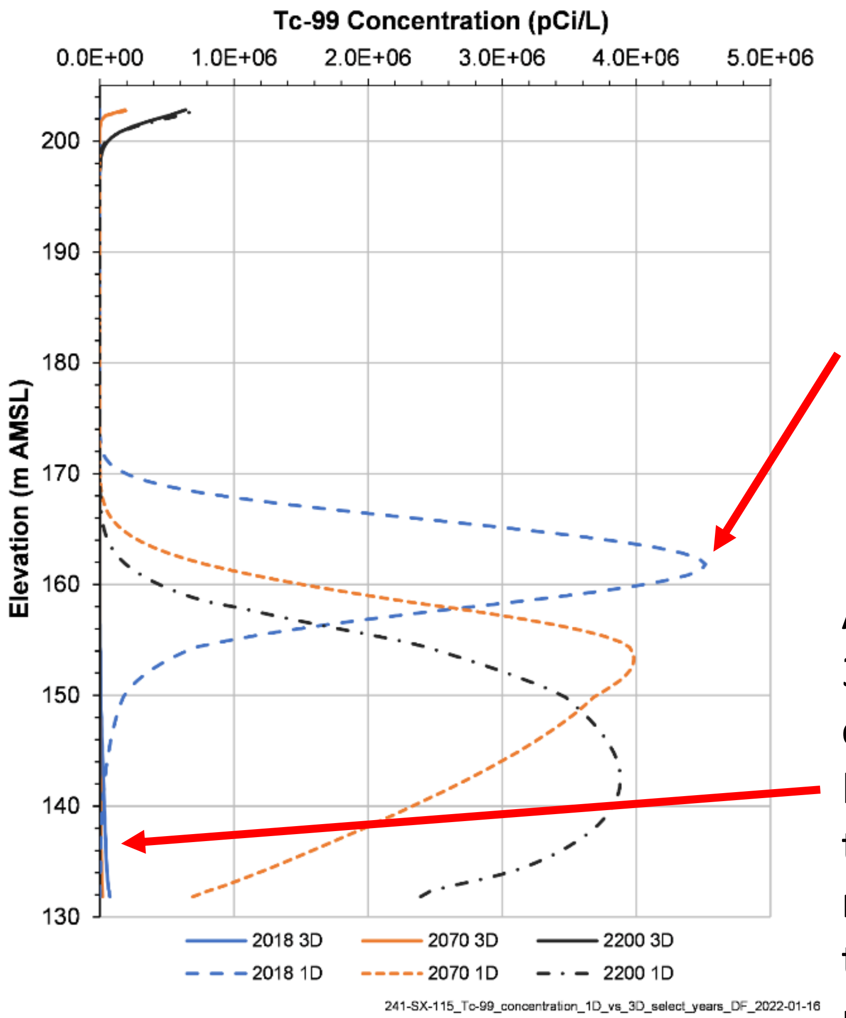
That is not the case for the 1D simulation.

241-SX-115 Tank Leak



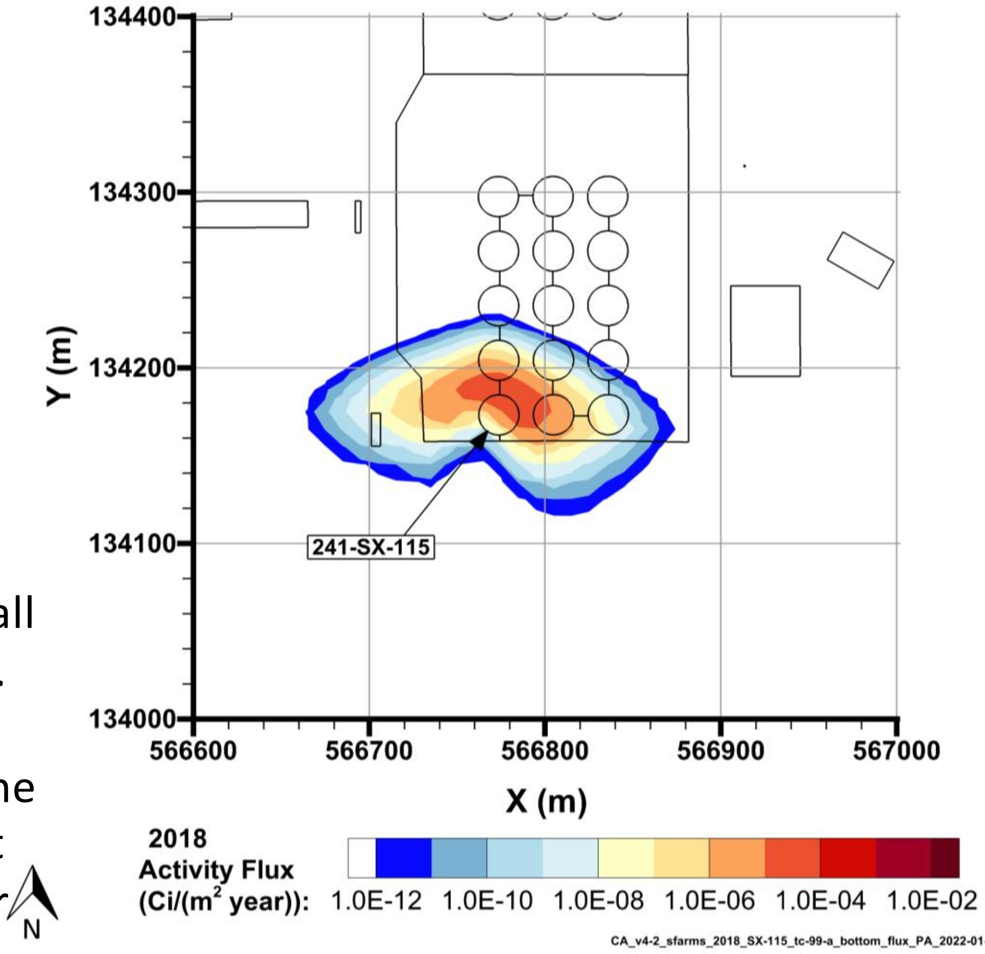
- The 3D simulation transfer rate is predicted to be sufficient to sustain the plume for a few more decades (until ~2040).
- The 1D transfer rate will never be enough to generate a plume.

241-SX-115 Tank Leak



The 1D simulation contaminant migrates relatively slowly through the VZ.

At the present time, the 3D simulation shows small concentrations in the VZ. However, multiplied by the aqueous flow rate, the resulting flux is sufficient to sustain a groundwater plume.

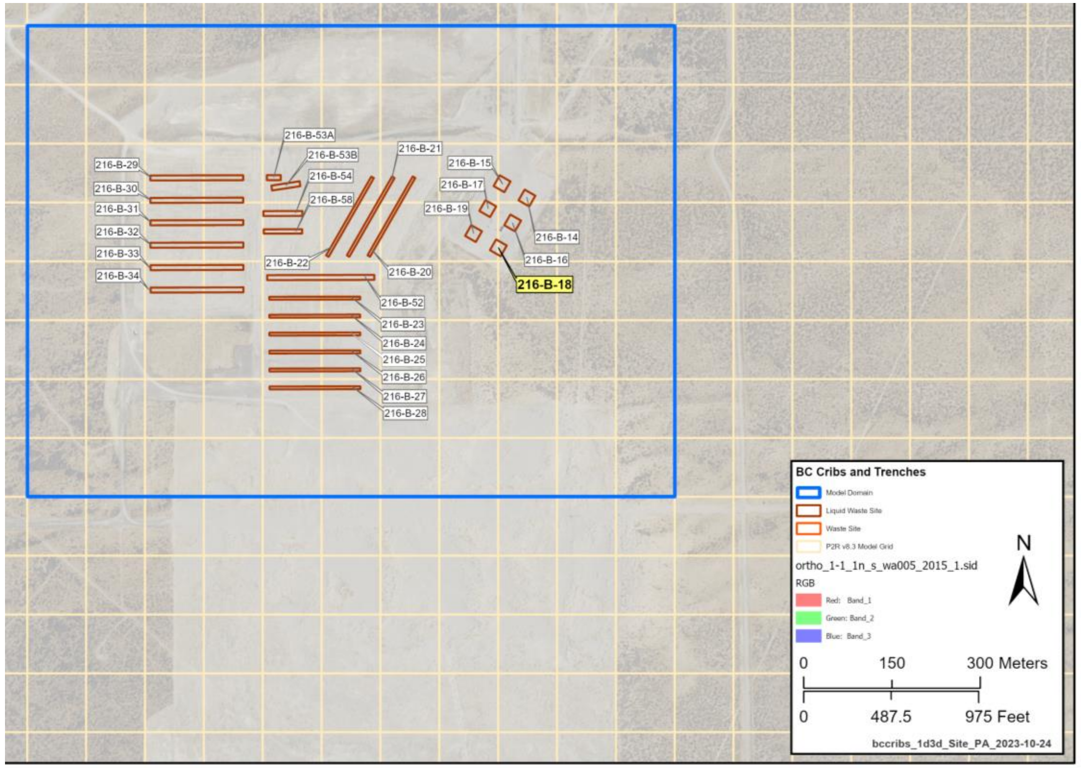


216-B-18 Crib Disposal

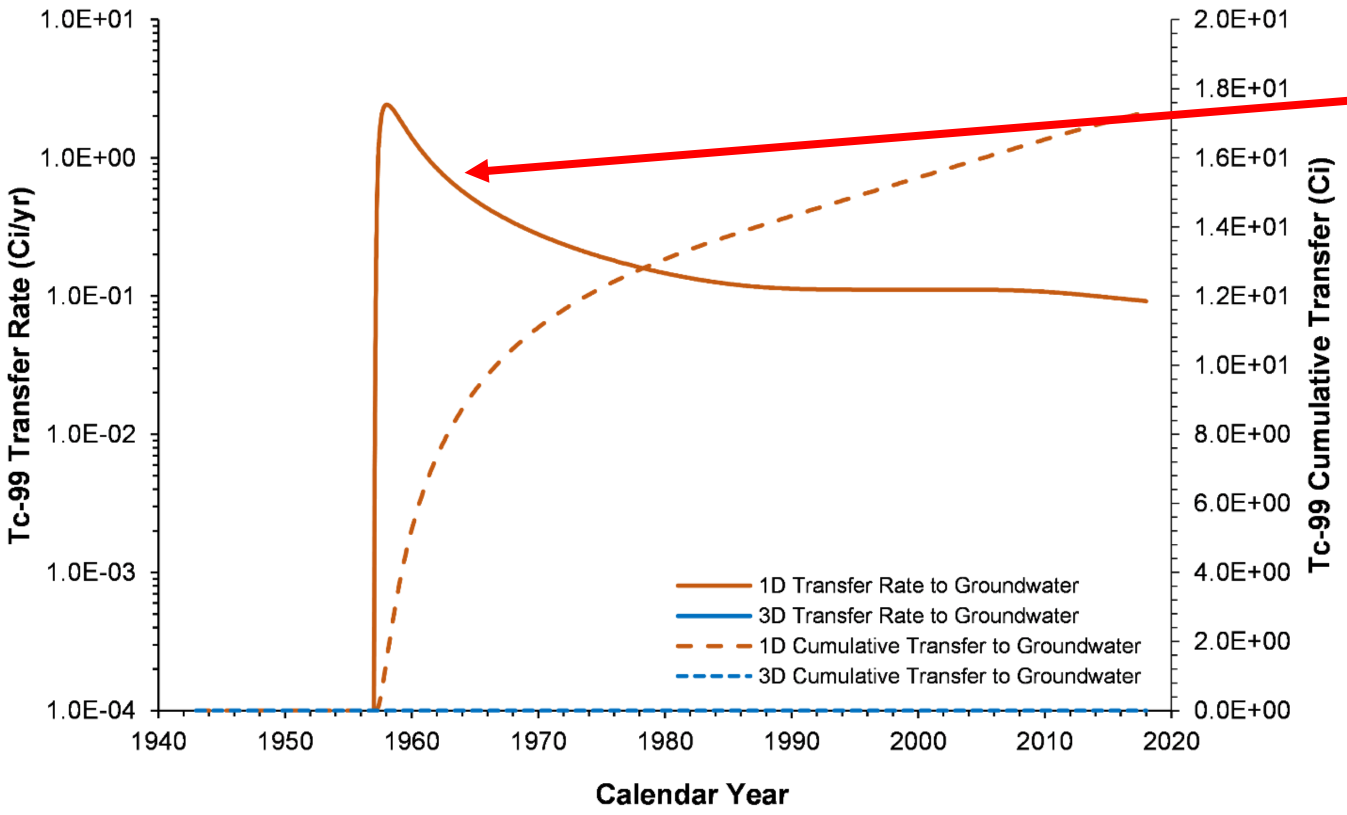
Release Data

Period	Volume (m^3)	Release Pore Volume	Tc-99
1956	8,520	0.59	34.4

No saturated zone Tc-99 contaminant plume has been developed below the BC Cribs and Trenches Area.



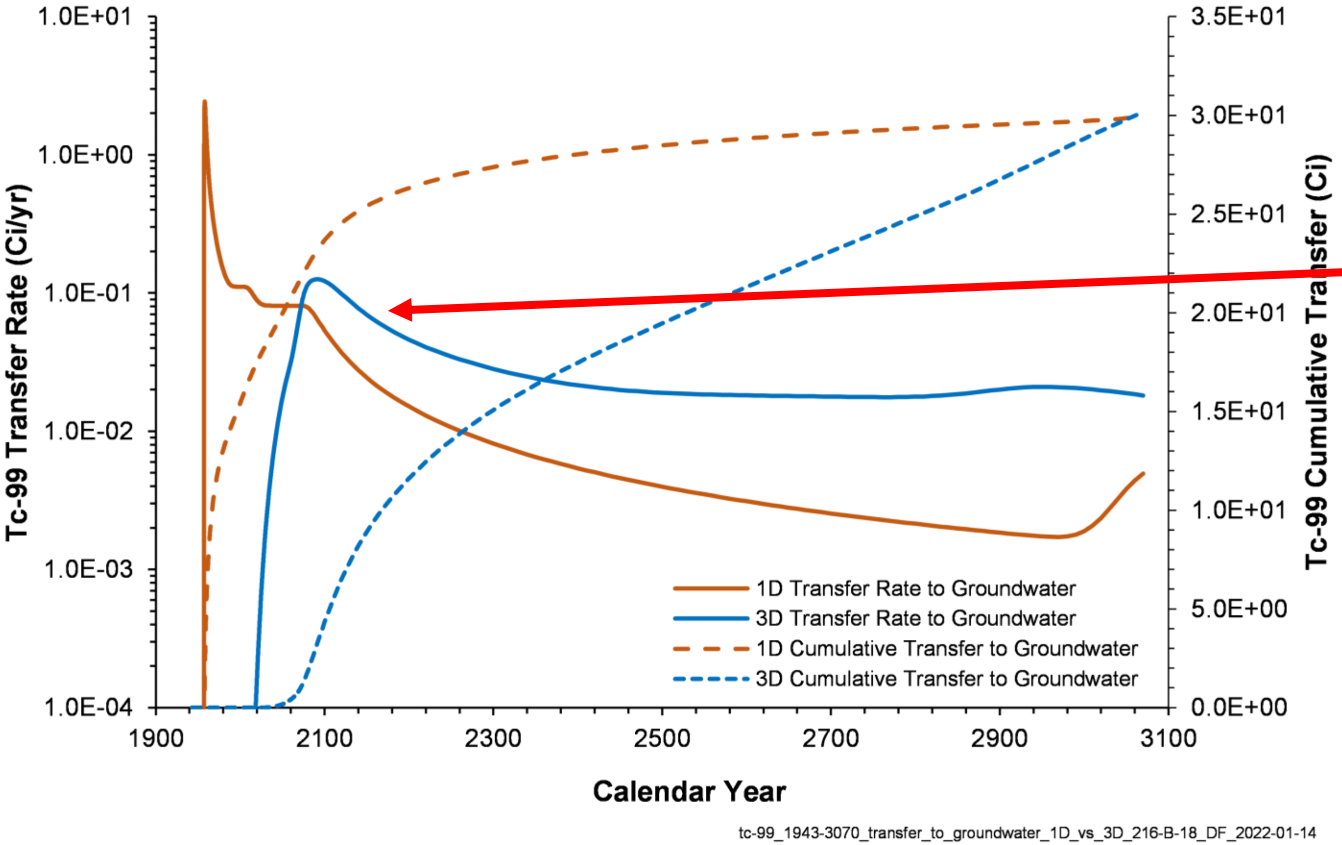
216-B-18 Crib Disposal



tc-99_1943-2018_transfer_to_groundwater_1D_vs_3D_216-B-18_DF_2022-01-14

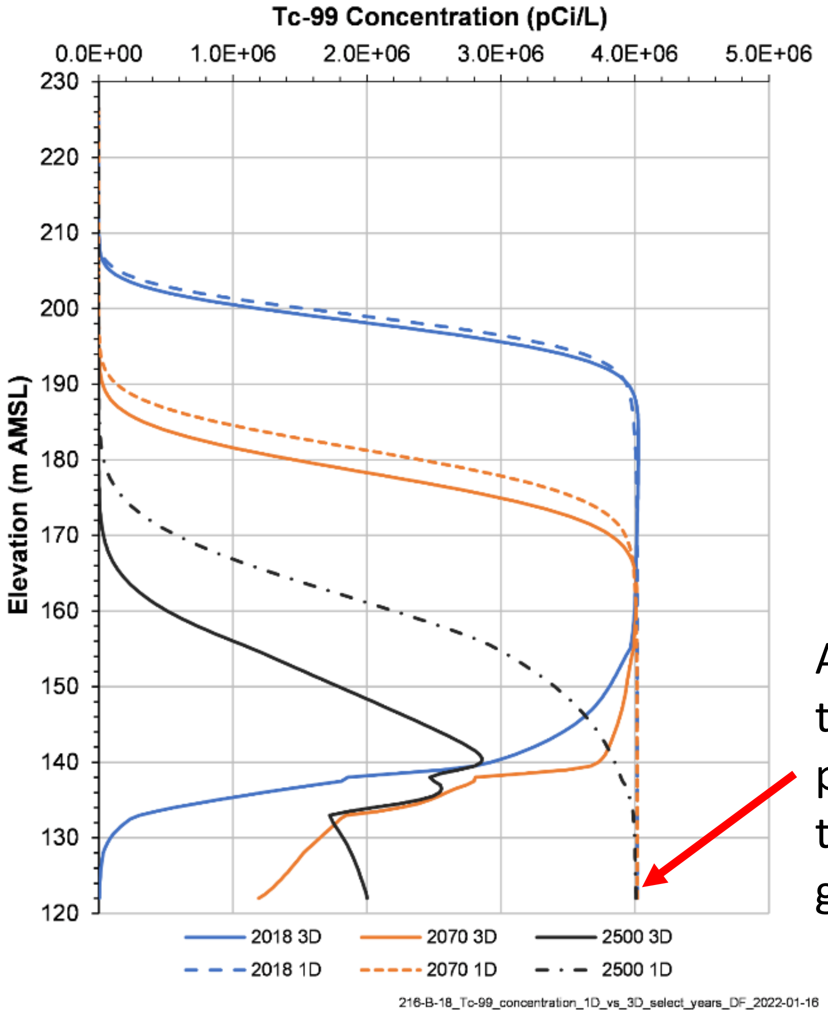
The 1D simulation predicts large transfer rates to the saturated zone and plume generation. No transfer is predicted for the 3D simulation.

216-B-18 Crib Disposal



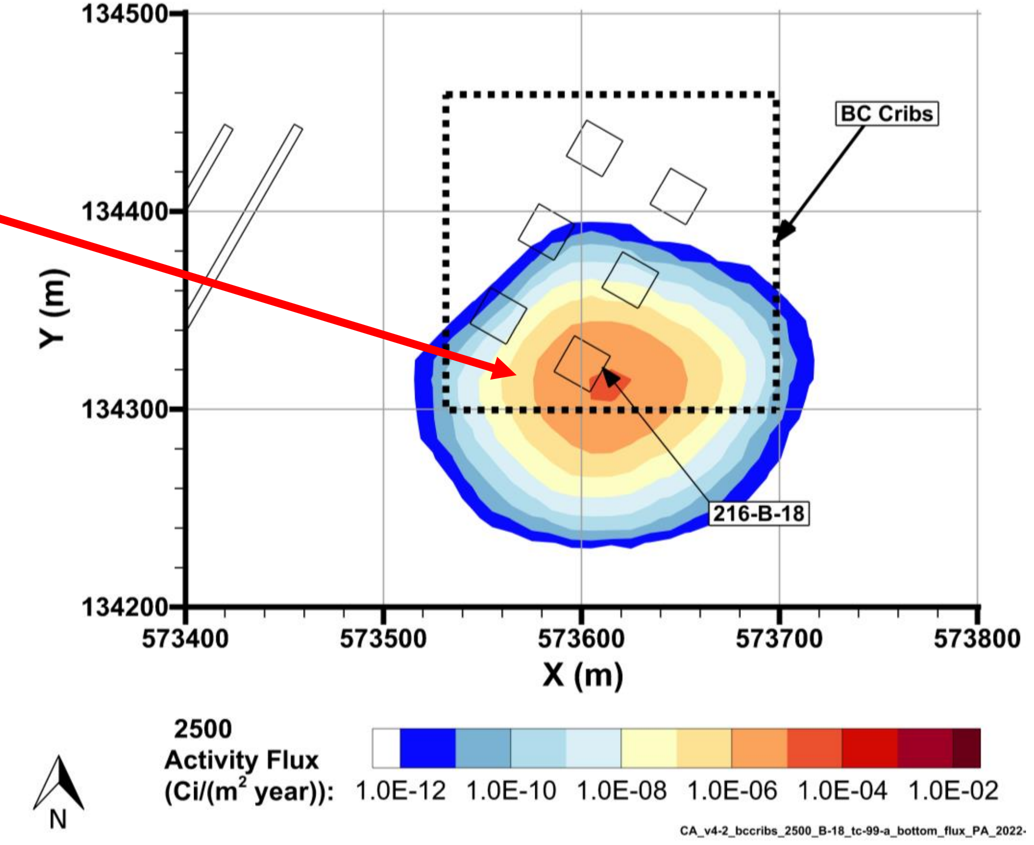
The 3D simulation predicts arrival at the groundwater in the future, consistent with the current lack of a plume underneath the BC Cribs and Trenches.

216-B-18 Crib Disposal



The transfer area to groundwater is much larger than the tank footprint.

At the present time, the 1D simulation predicts considerable transfer to the groundwater.

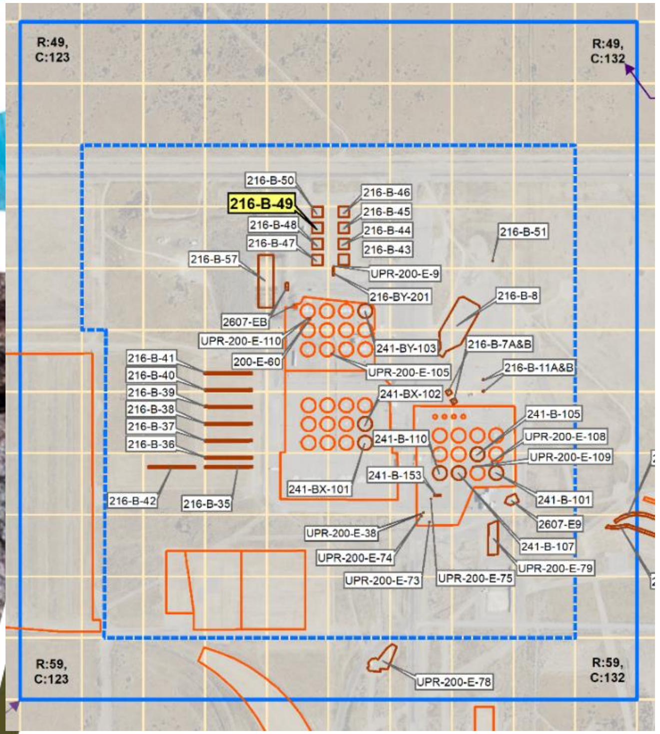


216-B-49 Crib Disposal

Release Data

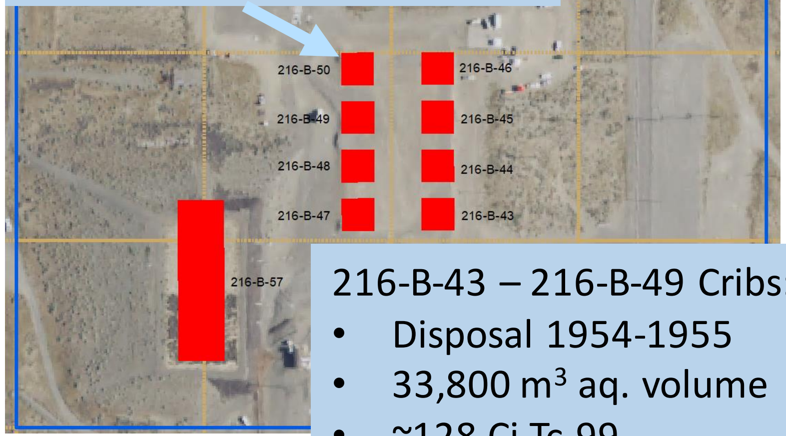
Period	Volume (m^3)	Release Pore Volume	Tc-99
1955	6,700	1.18	23.1

A saturated zone Tc-99 contaminant plume has been developed and sustained for several decades.



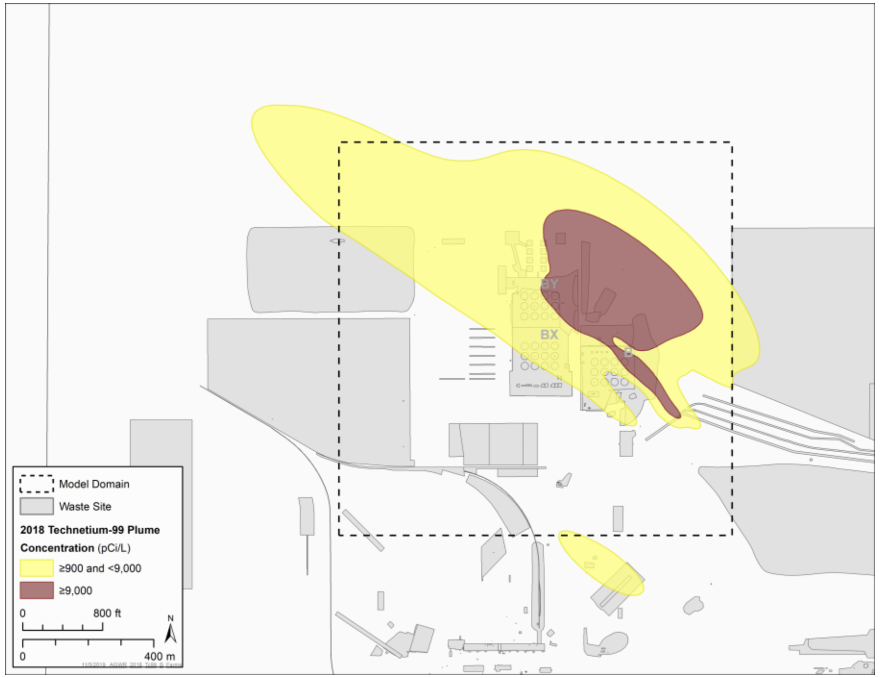
216-B-50 Crib:

- Disposal 1965-1974
- 92,800 m^3 aq. volume
- <0.01 Ci Tc-99

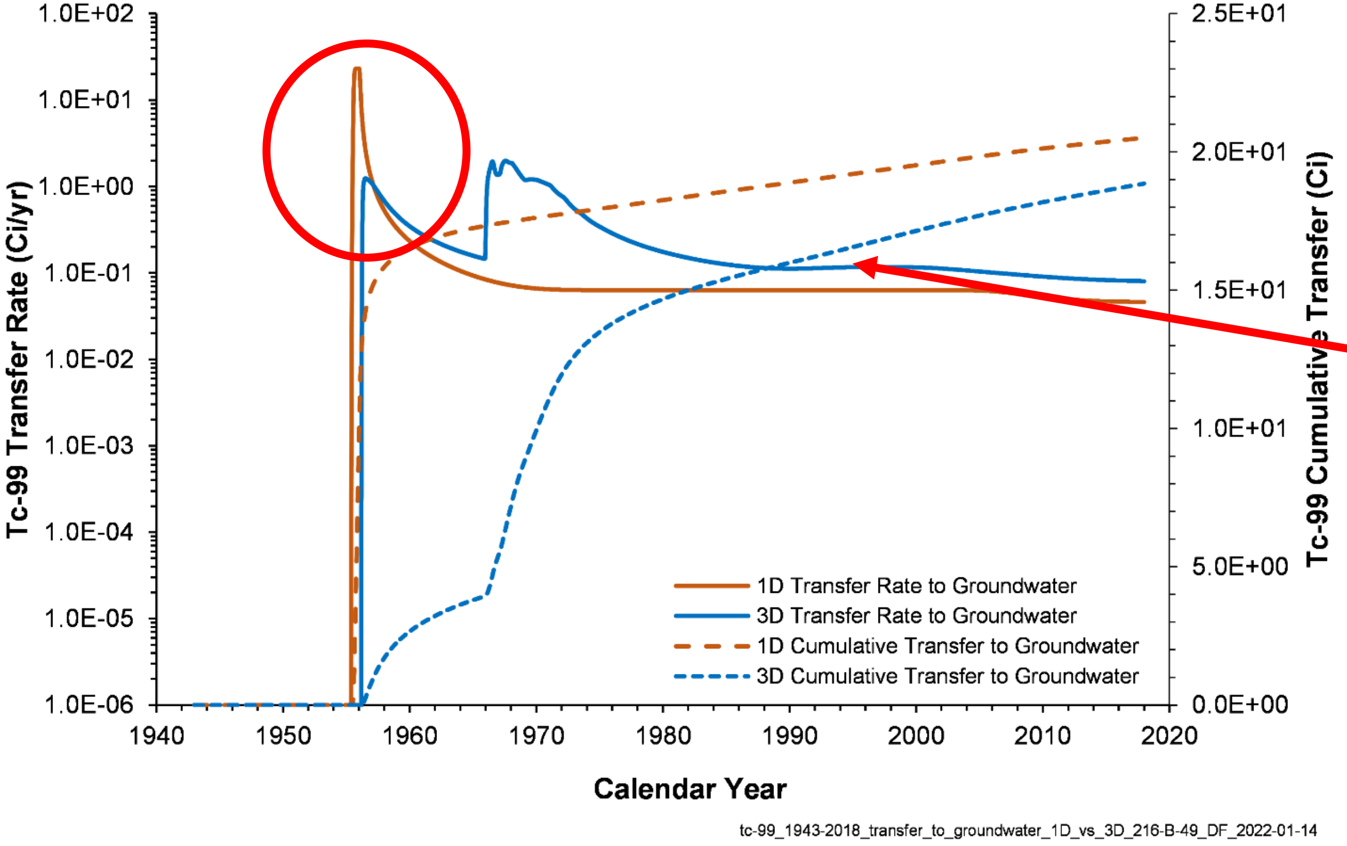


216-B-43 – 216-B-49 Cribs:

- Disposal 1954-1955
- 33,800 m^3 aq. volume
- ~128 Ci Tc-99



216-B-49 Crib Disposal



The 1D simulation transfer rates are only predicted to be sufficient to sustain a plume for up to 10 years.

The 3D simulation transfer rate produce rates that are double the 1D rates and stay above the plume-generating threshold through the present day.

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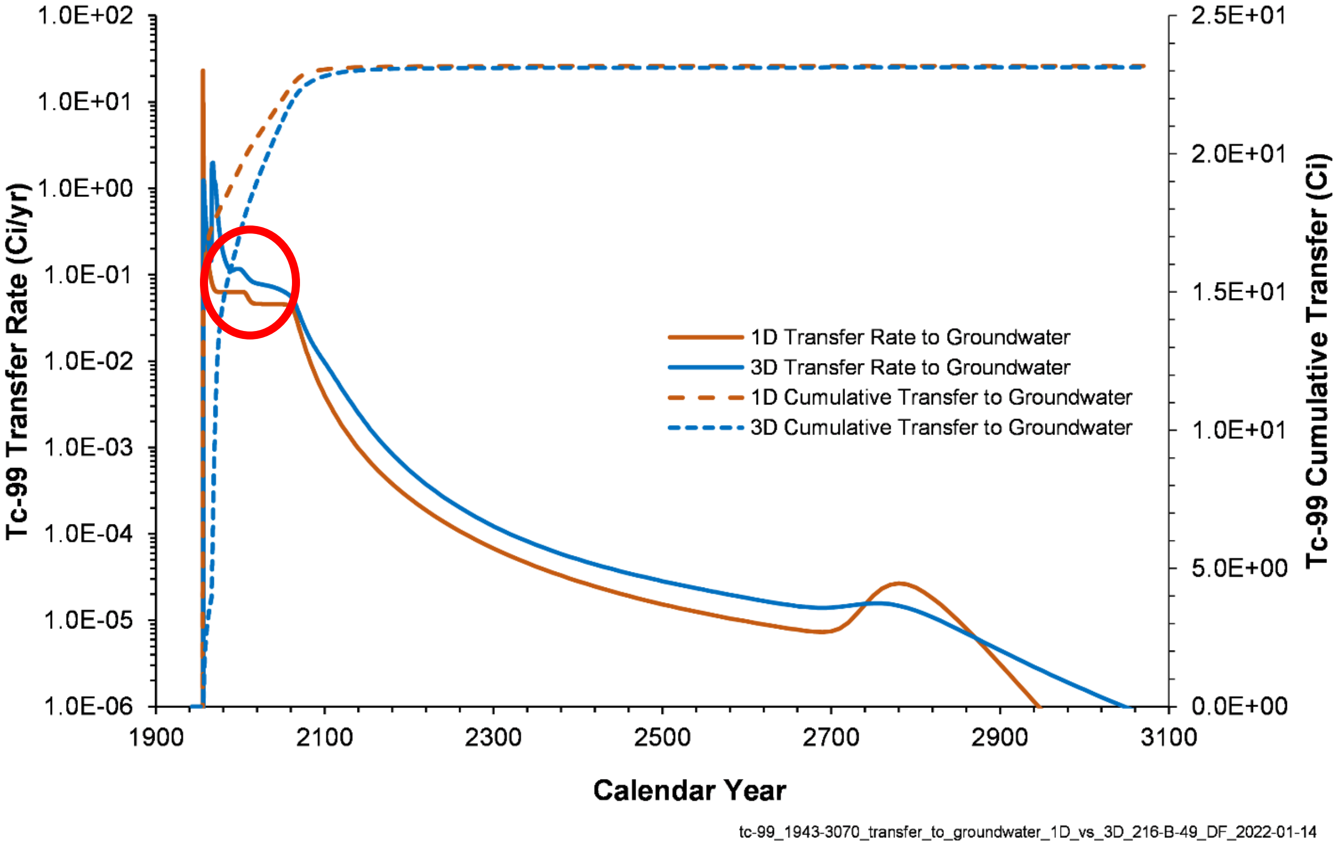
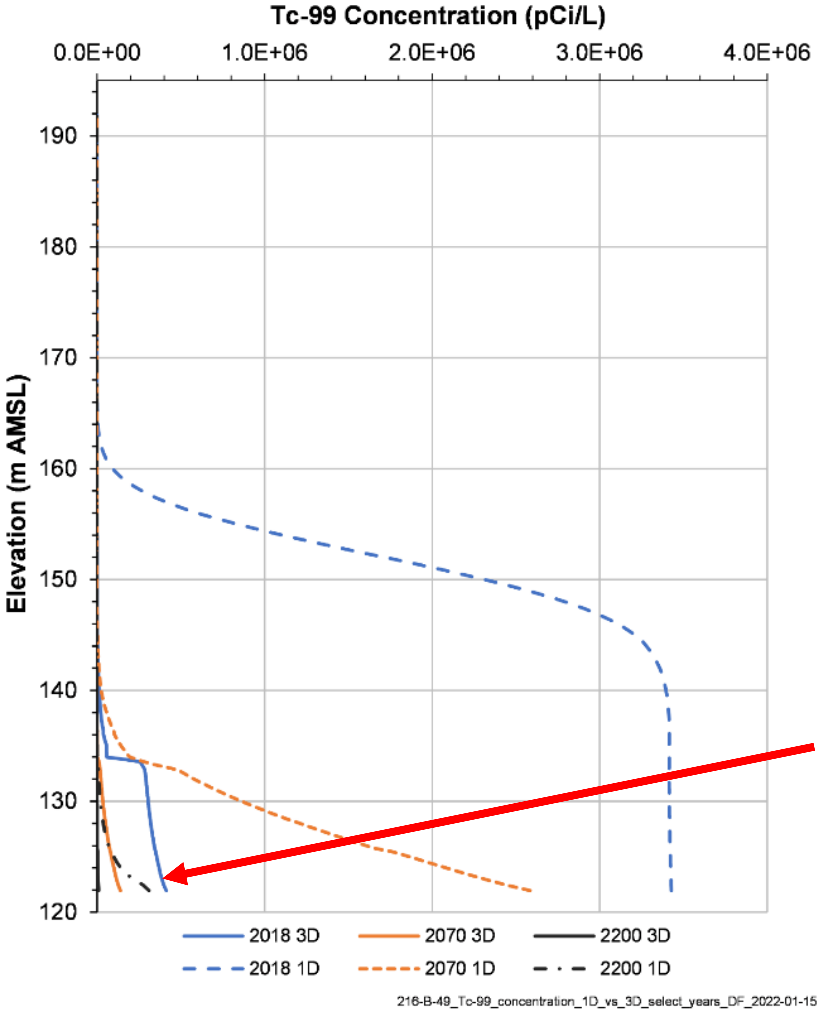
216-B-49 Crib Disposal



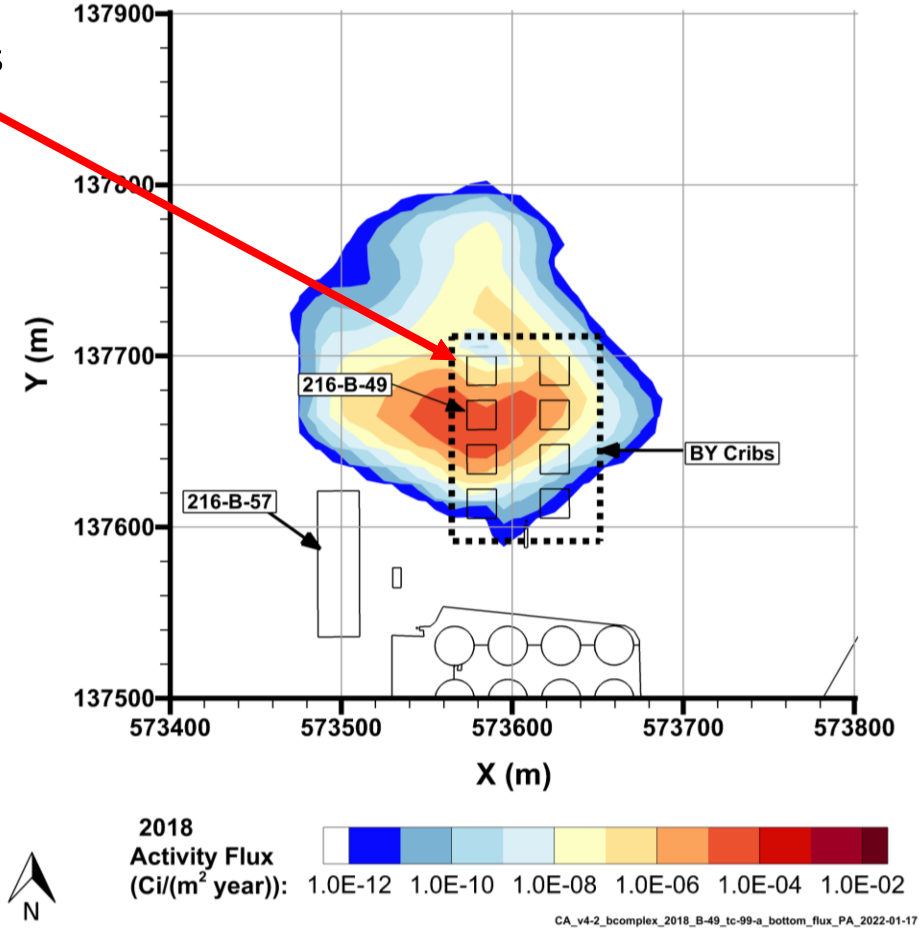
After ~2050, the 3D transfer rates are also not sufficient anymore to sustain the groundwater plume.

216-B-49 Crib Disposal



Flushing due to the 216-B-50 disposal is apparent at the present time.

The 3D simulation predicts lower concentrations but higher fluxes in the near future.



Summary

- The CA VZ simulations were completed using 26 large 3D VZ models to capture plume commingling.
- An alternative 1D approach was suggested by regulators and peer reviews to allow for more effective sensitivity and uncertainty analyses.
- A 3D-1D comparison has been completed for several selected sites, with a focus on representativeness.

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Conclusions

- For waste sites without adjacent liquid sources, VZ transport is faster in 1D simulations.
- For waste sites with adjacent liquid sources, VZ transport is faster in 3D simulations.
- For tank leaks without commingling with adjacent liquid sources, both 3D and 1D simulations do not produce fluxes to groundwater sufficient for plume generation at the present time (241-A-105 example).
- For tank leaks with commingling with adjacent liquid sources, 1D simulations do not produce fluxes to groundwater sufficient for plume generation at the present time. The results are non-representative (241-SX-115 example).

Conclusions (continued)

- For waste site disposals without commingling with adjacent liquid sources, 1D simulations produce fluxes to groundwater sufficient for plume generation, although no plumes are currently present. The results are non-representative (216-B-18 example).

- For waste site disposals with commingling with adjacent liquid sources, 1D simulations typically only produce sufficient transfer rates to generate groundwater plumes for a short period of time. The 1D transfer rates are not representative for sustaining longer-term plumes (216-B-49 example).

- Overall, most 1D waste site simulations yield unrepresentative results, making this modeling approach inappropriate for sensitivity and uncertainty analyses.