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Revision 0

**Conceptualization of Potential Leak Paths
Associated with Saltstone Disposal Unit 6 (SDU 6)**

April 2023

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ACRONYMS/ABBREVIATIONS

CRESP	Consortium for Risk Evaluation with Stakeholder Participation
DOE	U.S. Department of Energy
DSS	Decontaminated Salt Solution
GCL	Geosynthetic Clay Liner
gpm	Gallons Per Minute
HDPE	High Density Polyethylene
LTLS	Leak-Tight Liner System
Mgal	Million Gallons
MOP	Members of the Public
NRC	U.S. Nuclear Regulatory Commission
OOV	Onsite Observation Visit
PA	Performance Assessment
psi	Pounds per Square Inch
SDF	Saltstone Disposal Facility
SDS	Saltstone Disposal Structure (NRC term for SDU)
SDU	Saltstone Disposal Unit
SPF	Saltstone Production Facility
SRS	Savannah River Site
SRA	Shrinkage-Reducing Admixture
STAR	Site Tracking, Analysis, and Reporting (SRS issue tracking system)
UWMQE	Unreviewed Waste Management Question Evaluation

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1.0 INTRODUCTION

During an Onsite Observation Visit (OOV) on February 1, 2023, staff from the U.S. Nuclear Regulatory Commission (NRC) requested that the U.S. Department of Energy (DOE) “provides the NRC with the conceptual model of water source and path for SDS 6 [Saltstone Disposal Structure (SDS) 6 or Saltstone Disposal Unit (SDU) 6] leak detection sump contents and to provide discussion on the comparison and relevance to future disposal structure designs after SDS 6 [SDU 6].”

The purpose of this memorandum is to provide background information, conceptualize potential leak path(s) for SDU 6, and to discuss the relevance of the conceptualizations relative to other SDU designs. Additional context is also provided relative to the possibility of potential leaks forming at other SDUs.

1.1 Background

Construction of Saltstone Disposal Unit 6 (SDU 6) began in 2014 and was completed in 2015. A first leak tightness test was performed in late October to early November 2015. For this test, SDU 6 was filled with water (with a dye additive) to a height of 41 feet (estimated to be 32.8 million gallons (SRR-SDU-2017-00003)). Once filled with water, the SDU was observed for evidence of leaks. Even though there was no measurable loss in the height of the water during the observation period, this initial test failed because dyed water was observed along the floor-to-upper mud mat interface (SRMC-CWDA-2022-00025).

After the initially failed leak tightness test, remediation actions were taken which included sealing observed cracks in the SDU 6 floor and applying impermeable liners to the interior of the SDU. A second leak tightness test was successfully performed in December 2016 as there were no observed leak sites and no measurable loss of water height.

The *Performance Assessment for the Saltstone Disposal Facility at the Savannah River Site* (SRR-CWDA-2019-00001) (hereafter referred to as the SDF PA) was issued in March 2020. The SDF PA documents models and analyses used to demonstrate compliance to performance objectives prescribed by DOE Manual 435.1-1, *Radioactive Waste Management Manual*, Chapter IV.P according to guidance provided in DOE-STD-5002-2017, *Disposal Authorization Statement and Tank Closure Documentation*.

Despite the remediation actions for SDU 6 and despite passing the second leak tightness test, the SDF PA models assumed that: (1) there was no interior liner in SDU 6 (or in any of the 375-foot diameter SDUs), (2) the SDU 6 floor concrete would continue to leak, and (3) the liner containment of the SDU 6 leak detection system did not exist beyond the lateral extent of the SDU walls (i.e., there would be no barrier to prevent contaminants that leak into the floor or upper mud mat from then exiting from the outer perimeter of the SDU and entering the surrounding sediments or backfill material). These assumptions were applied to ensure maximum defensibility of the SDF PA model results. Even given these assumptions, the model results in the SDF PA demonstrate compliance to the required performance objectives (SRR-CWDA-2019-00001).

Disposal of saltstone into SDU 6 began in August 2018. In March 2022, contamination was observed in a leak detection sump indicating that waste had a leak path out of interior of SDU 6 (SRMC-CWDA-2022-00025). Despite contaminants being detected within the sump, there is no

evidence that the contaminants have migrated beyond the sump, or beyond the liner containment of the SDU 6 leak detection system, and into the local sediments or underlying groundwater (based on groundwater monitoring data through June 2022 per *Z-Area Saltstone Disposal Facility Groundwater Monitoring Midyear Report for 2022* (SRNS-TR-2022-00338)).

An Unreviewed Waste Management Question Evaluation (UWMQE) was prepared in June 2022 (SRMC-UWMQE-2022-00001) to evaluate the leak relative to the SDF PA. Supported by considerations laid out in *Leak Rate Considerations Related to SDU 6 Sumps* (SRMC-CWDA-2022-00025), the UWMQE concluded that the observed leak was consistent with the SDF PA modeling assumptions.

As of the March 2023, no additional waste has been disposed of within SDU 6; however, it is available to receive waste and is expected to be eventually filled to its operational capacity to support continuing waste disposal operations.

1.2 Outline

Section 2.0 describes the design and construction of SDU 6. Section 3.0 describes the start of disposal operations and the leak history for SDU 6. Section 4.0 proposes a number of potential leak paths. Section 5.0 describes the differences between SDU 6 and other 375-foot diameter SDUs relative to these potential leak paths. Finally, Section 6.0 describes new models that were used to provide insights relative to the potential impacts if new leak sites are discovered at SDUs 7 through 12.

2.0 SDU 6 DESIGN AND CONSTRUCTION

At a high level, SDU 6 may be described as a 43-foot-tall concrete cylindrical shell that is 375-feet in diameter.

2.1 Design Drawings for SDU 6

Multiple drawings were prepared to detail the design of SDU 6. Table 2.1-1 provides a summary of some of the key drawings. For a complete listing, refer to the Procurement Specifications document for SDU 6 (C-SPP-Z-00008).

Table 2.1-1: List of Selected SDU 6 Design Drawings

Drawing ID	Title
C-CC-Z-00039	Foundation Plan
C-CC-Z-00040	Overall Roof Plan and Partial Plan
C-CC-Z-00041	Partial Roof Plan
C-CC-Z-00042	Wall and Column Section and Details
C-CC-Z-00043	Typical Roof Sections
C-CC-Z-00044	Concrete Section and Details
C-CG-Z-00041	Overall Site Plan
C-CY-Z-00005	HDPE/GCL, Leakage Detection and Settlement Monitoring Plan
C-CY-Z-00006	Leakage Detection System Sections and Details
C-CY-Z-00007	Leakage Detection and Settlement Monitoring Sections and Details

These design drawings are not reproduced within this report. However, many of the conceptual illustrations provided throughout were developed to represent the key features of SDU 6 based on these design drawings.

Figure 2.1-1 provides a conceptual illustration of a portion of SDU 6 in “plan view.” Aside from the SDU sumps, each of the relevant features form concentric circles when observed from above. From the interior to the exterior, these features include the SDU interior (gray), the SDU walls (orange), the SDU floor (yellow), and the upper and lower mud mats (light blue). The red dot represents the location of an exterior sump, which is part of the SDU 6 leak detection system. There are four of these sumps (North, South, East, and West).

Next, Figure 2.1-2 illustrates the lower corner of SDU 6 in a “cross section view,” depicting a vertical “slice” through the SDU. The cross section includes the SDU floor, walls, mud mats, and a sump.

2.2 Construction of SDU 6

As previously mentioned, the construction of SDU 6 began in 2014 and was completed in 2015.

Prior to construction of SDU 6, the ground surface was graded and compacted, and a 4-inch-thick concrete lower mud mat was poured. Once the lower mud mat was cured, it was covered with a composite barrier (a geosynthetic clay liner (GCL) covered with an impermeable high density polyethylene (HDPE) geomembrane). After the composite barrier was installed, a second 6-inch-thick concrete upper mud mat was poured. SDU 6 was constructed on this upper mud mat.

Nominally, SDU 6 has an internal diameter of 375 feet. This is a nominal value because the walls are tapered (at the top, the walls are 10-inches thick and at the base the walls are 24-inches thick). The SDU 6 floor and roof are both sloped (1.5% downward from the center towards the walls). The roof and floor of SDU 6 are both made of concrete that is at least 12-inch-thick. The roof is supported by 208 roof-support columns, which are each 24-inches in diameter and stand on pedestals that are each 5-feet long, 5-feet wide, and 18-inches thick.

Accounting for internal structures (e.g., roof-support columns), and assuming an operational fill height of 41 feet, the internal volume of SDU 6 is 3.28E+07 gal (SRR-SDU-2017-00003).

Figure 2.2-1 through Figure 2.2-3 show photographs of SDU 6 at different stages of construction.

Figure 2.2-1: Construction of SDU 6, October 2014



Figure 2.2-2: Construction of SDU 6, April 2015



Figure 2.2-3: Construction of SDU 6, August 2015



2.3 Leak Tightness Testing and Interior Liner Installation for SDU 6

For the first leak tightness test of SDU 6, the disposal unit was filled with water up to its operational height of 41 feet. Filling started on October 12, 2015 and finished on November 4, 2015. Once filling was complete the fill level was measured and no measurable loss of water was detected.

Red dye was added to the water (C-SPP-Z-00008) on the morning of November 5, 2015. Adding this dye allows for the identification of water coming from inside the SDU during the filling process (as opposed to water coming from other sources). However, in the afternoon of November 5, 2015, dyed water was already observed coming out of the bottom of SDU 6 at the interface between the floor and the upper mud mat. Based on observations, it was estimated that less than 4 liters per minute (or approximately 1,500 gal/day) was leaking from the SDU after it was filled to 41 feet (SRR-SDU-2017-00004).

The presence of dye at the SDU floor-to-upper mud mat interface resulted in a failed leak tightness test for SDU 6. Additional testing continued until November 11, 2015, at which point the dyed water within the SDU was pumped out. Figure 2.3-1 through Figure 2.3-6 show the leaks at the base of the SDU 6 floor. In each of these figures, the concrete structure with the black stripe is the outside edge of the SDU floor (the black stripe is the HDPE embed to be used for enclosing the SDU 6 leak detection system upon successful completion of leak testing). Most of these figures show water seeping from the side-face of the floor, indicating that the leak is coming from within the concrete of the SDU 6 floor.

**Figure 2.3-1: Observed Leak from First Leak Tightness Test of SDU 6, November 2015
(1 of 6)**



Figure 2.3-2: Observed Leak from First Leak Tightness Test of SDU 6, November 2015
(2 of 6)

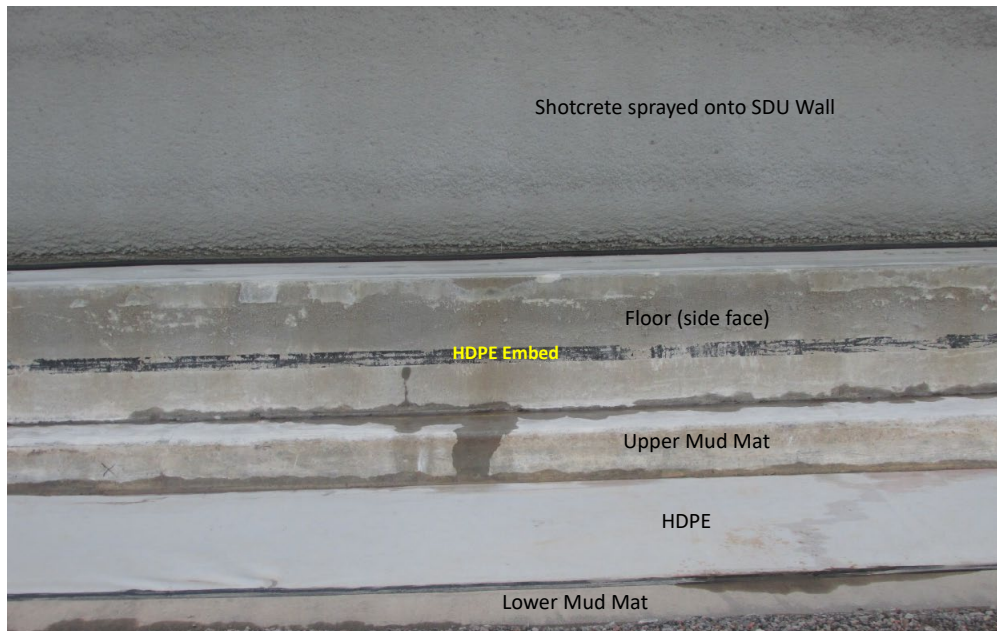


Figure 2.3-3: Observed Leak from First Leak Tightness Test of SDU 6, November 2015
(3 of 6)

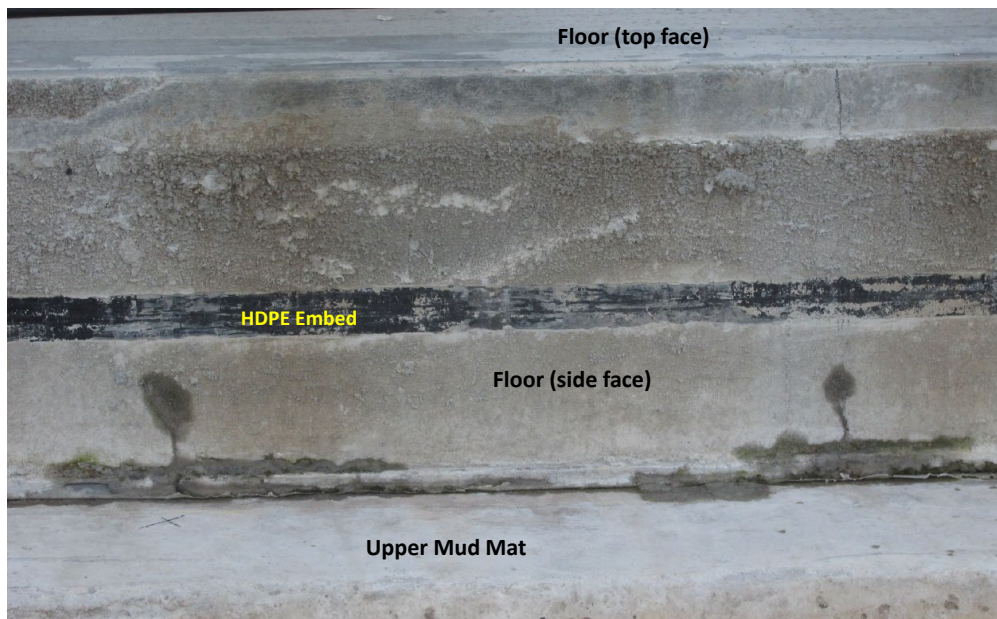
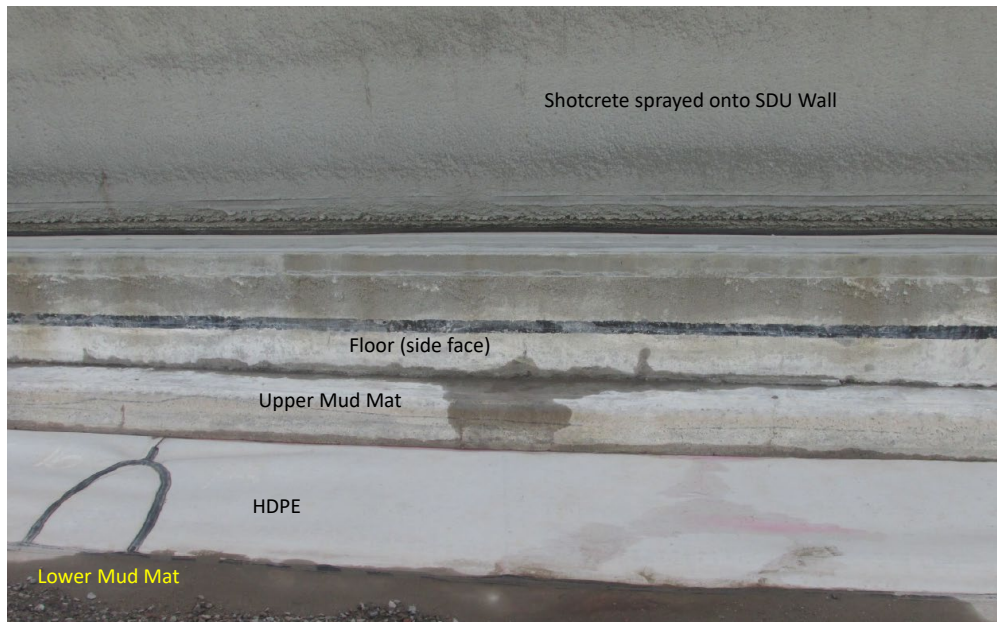


Figure 2.3-4: Observed Leak from First Leak Tightness Test of SDU 6, November 2015
(4 of 6)



Figure 2.3-5: Observed Leak from First Leak Tightness Test of SDU 6, November 2015
(5 of 6)



**Figure 2.3-6: Observed Leak from First Leak Tightness Test of SDU 6, November 2015
(6 of 6)**



After the first leak tightness test failed, a synthetic liner was installed inside SDU 6 (C-SPP-Z-00013). The liner material was a 3-mm-thick vulcanized rubber which was attached to the interior concrete surfaces of the SDU using an epoxy adhesive. Figure 2.3-7 shows the interior of SDU 6 after the liner installation. The liners are visible as black panels on the walls and floors.

For the second leak tightness test of SDU 6, the disposal unit was again filled with water to a height of 41 feet. Filling started on December 15, 2016 and finished on December 27, 2016. Based on lessons learned from the first leak tightness test, dye was added to the water while the SDU was being filled to ensure that any water coming from inside the SDU during the filling process could be isolated from other water sources. Once filling was complete, the fill level was measured. No measurable loss of water was detected. Inspections were performed periodically through December 28, 2016. No dye was detected.

Because there was no measurable loss of water and because no dye was detected, SDU 6 successfully passed leak tightness testing on December 29, 2016 at which point the dyed water was pumped out of the SDU.

After the second leak tightness test, the SDU 6 leak detection system was enclosed beneath an additional layer of HDPE as shown in Figure 2.3-8 and Figure 2.3-9. The black lines between the different sheets of HDPE and around the sump piping are HDPE extrusion welds.

Figure 2.3-7: Interior of SDU 6 After Liner Installation (Fall 2016)



[Source: SRR-SDU-2017-00004]

Figure 2.3-8: Installation of HDPE Over the Mud Mats



[Source: SRMC-CWDA-2022-00025, Fig. 2.3-6]

Figure 2.3-9: Installation of HDPE Over the Mud Mats at East Sump



[Source: SRMC-CWDA-2022-00025, Fig. 2.3-7]

3.0 SDU 6 DISPOSAL OPERATIONS AND LEAK HISTORY

This section provides information related to disposal operations and known leaks for SDU 6.

3.1 Saltstone Disposal Into SDU 6

SDUs are designed to store saltstone, a radioactive waste form that is made by mixing decontaminated salt solution (DSS) with dry feeds to form a flowable grout. The radioactive grout is mixed at the Saltstone Production Facility (SPF) and then pumped out to the nearby SDUs. Once it is poured into the SDUs, the radioactive grout cures into the final concrete-like waste form.

Prior to starting the disposal of radioactive material into SDU 6, and as part of the startup testing, an initial clean cap (i.e., grout prepared without radioactive DSS) was poured into SDU 6. The initial pours included approximately 3,000 gallons of clean cap grout on March 22, 2018 and approximately 2,200 gallons of clean cap grout on March 28, 2018 (X-CLC-Z-00085, Appendix C). The startup sequence used clean water, followed by clean grout, then transitioned to radioactive grout. This sequence also included additions of clean flush water that is used to keep the grout lines clear. Therefore, some amount of water is also included as part of the startup process.

On August 28, 2018, SDU 6 received its first pour of radioactive waste when approximately 8,500 gallons of DSS from the saltstone feed tank (Tank 50 in the H-Area Tank Farm) was transferred to the SPF and the resulting grout was pumped into SDU 6 (X-CLC-Z-00086, Table 1). Note that when the dry feeds are added to the DSS, the volume of the material generally increases by a factor of approximately 1.76 (SRR-LWP-2009-00001), so this first transfer was equivalent to approximately 15,000 gallons of saltstone.

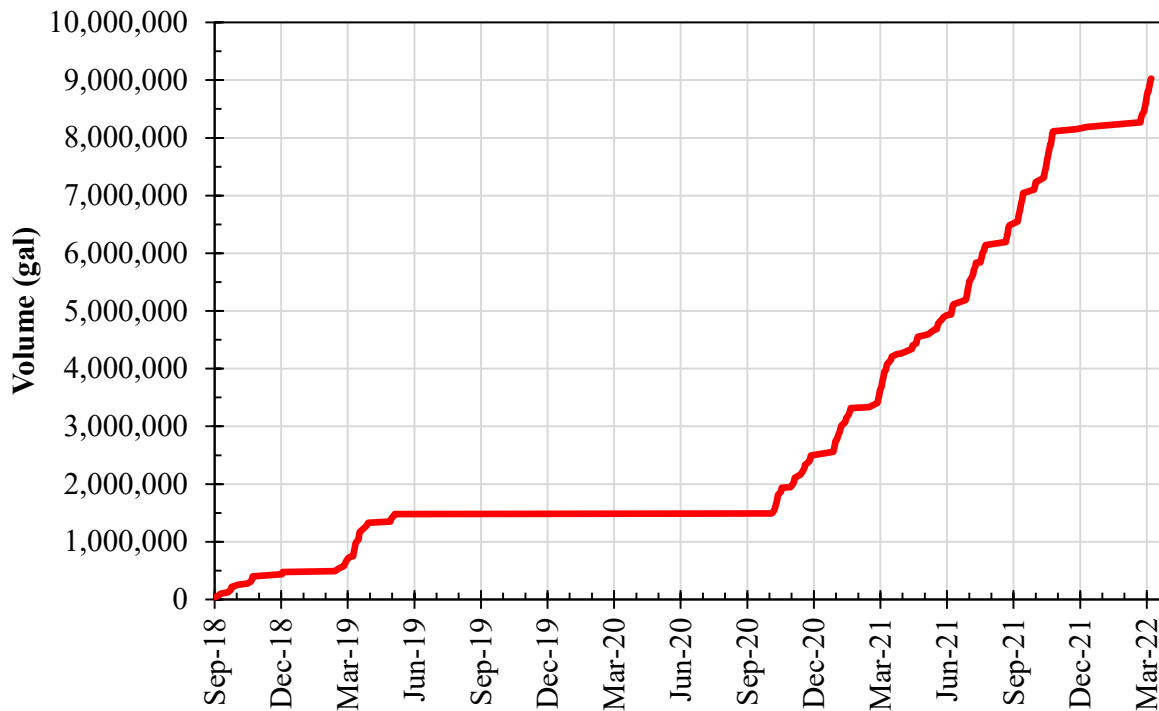
Disposal operations continued until March of 2022 when contamination was detected in the East Sump of SDU 6. As of March 2022, SDU 6 had already been filled with approximately 9M gallons of saltstone (Figure 3.1-1), with a maximum fill height of approximately 13.25 feet.

After each transfer, flush water was also passed through the transfer line from the SPF to the SDU to prevent accumulation of material within the transfer line. Assuming approximately 900 gallons of water is used to flush the line after each day when transfers occurred, and assuming that none of this water has been consumed by the saltstone during hydration and/or curing processes, there is approximately 150,000 gallons of flush water inside SDU 6.

Additionally, in July 2021, the recipe for saltstone was modified (SRMC-STI-2022-00601). Previously, the dry feeds used for mixing saltstone was 45 weight percent (wt%) blast furnace slag, 45 wt% fly ash, and 10 wt% cement. The new mix is 60 wt% blast furnace slag and 40 wt% fly ash and is known as “cement free” saltstone since it has no cement in the mix. While the final cured properties of both mixes are identical, the fresh properties have some notable differences. Specifically, the relative amount of bleed water (i.e., the amount of liquid not absorbed by the mix) increased from 0.7% to 1.2%. With the large volume of saltstone produced and given the high production rates throughout 2021, the increased bleed water also contributed to the total volume of excess liquid within SDU 6.

The excess flush water and excess bleed water is periodically drained from SDU 6 and is added to the DSS feed to be reprocessed through the SPF.

Figure 3.1-1: Fill Volume History for SDU 6 (Based on DSS Transfers)



[Source: SRMC-CWDA-2022-00025, Figure 3.4-1]

3.2 SDU 6 Leak Observations

In March 2017, SDU 6 was transferred from the SDU 6 Project Team (construction) to the SDF Operations. It was immediately noted that the East Sump alarm was actuated almost continuously (Riley, 2022). When the sump was pumped and the alarm cleared, it would re-actuate within an hour (Riley, 2022). Since this was prior to the start of disposal operations, it was assumed that the water in the sump was due to remnant construction water trapped within the leak detection system or due to rainwater that had been received while the HDPE liner around the perimeter of the SDU was being welded. It may be noted that the soils surrounding the HDPE appear to be damp in Figure 2.3-8, supporting this hypothesis.

Given the combined area of the upper and lower mud mats beyond the lateral extent of the SDU floor (approximately 8,000 ft²), hypothetically if only 2 inches of water had accumulated over the mud mats prior to the installation of the HDPE, then up to 10,000 gallons could have been trapped within the leak detection system.

The four SDU 6 sumps are each 16 inches in diameter and 12 inches deep, resulting in a volume of approximately 10 gallons each. The actual capacity of each sump is less than 10 gallons, because the void space within the sumps were filled with #57 stone (i.e., gravel) prior to backfilling (C-CY-Z-00007) as this helps to prevent the sumps from collapsing under the weight of the fill material. Ignoring the volume displaced by this gravel, the four sumps offer a combined capacity of approximately 40 gallons. So, if the hypothetical 2 inches of water were trapped within the leak detection system, the sumps would each have to be emptied more than 200 times to remove the

entire 10,000-gallon volume. While these values are merely hypothetical, they help to illustrate the problem. It remains unknown how much water was initially trapped within the system.

Given that annual rainfall at the Savannah River Site is approximately 48 to 50 inches per year (SRR-CWDA-2021-00036) and given that the SDU 6 roof covers an area of more than 110,000 square feet, a significant amount of rainwater can shed from the roof to the perimeter of the SDU each year. If there are any leaks in the extrusion welds of the HDPE in the leak detection system, rainwater could account for thousands of gallons of in-leakage each year. Regardless, the sumps would be pumped dry, and the alarm would be cleared.

In July 2018, a temporary modification SSF-TMC-18-003 was installed at the East Sump to reduce the effort required for dewatering the sump (shown in Figure 3.2-1). In January 2022, the temporary modification was converted into permanent modification M-DCP-Z-20001 (shown in Figure 3.2-2). After contamination was detected in March 2022, pumping ceased. In August 2022, temporary modification M-TMOD-Z-00002 was installed, which feeds the sump water directly back to the primary containment system inside SDU 6.

Figure 3.2-1: SSF-TMC-18-003, De-Watering Pump at the East Sump of SDU 6



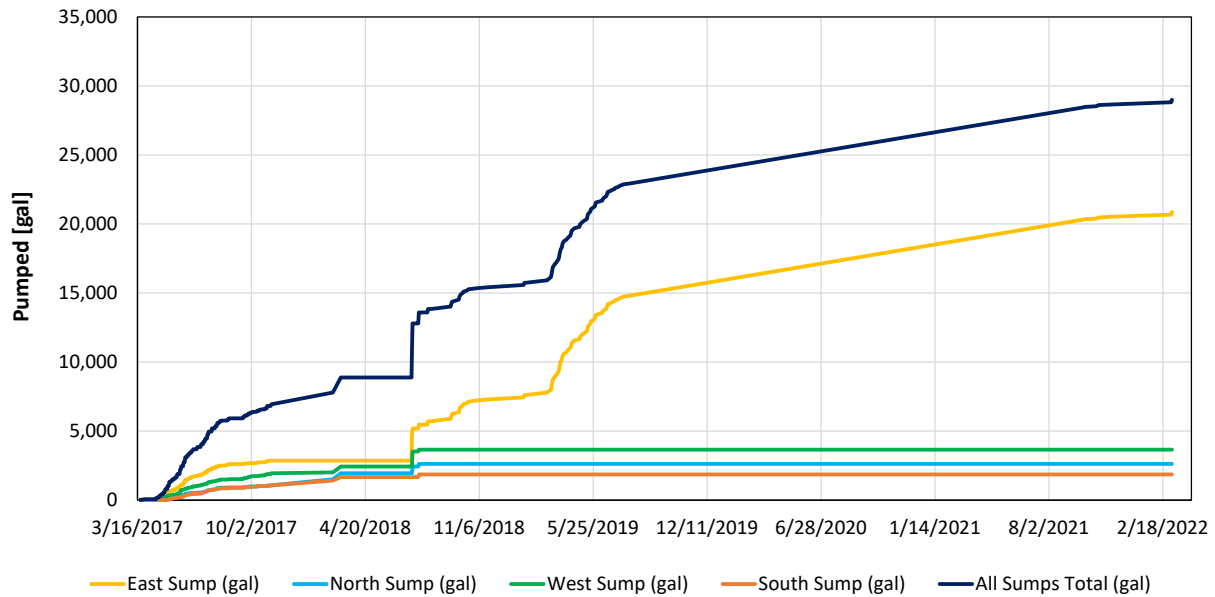
Figure 3.2-2: M-DCP-Z-20001 De-Watering Pump at the East Sump of SDU 6



Additionally, after disposal of saltstone began, samples of the sump water would routinely be tested per the alarm response procedure (ARP-LAH-6100) to ensure the water was not contaminated. The tests consistently indicated the water was free of contamination until March 2022, when the test indicated that contamination in the East Sump. Additional analyses were performed on the sump water to characterize the nature of this contamination (SRNL-STI-2022-00216) and although contaminated, the concentrations were relatively low.

When the contamination of the East Sump occurred, an investigation was performed to better understand how the water became contaminated. As part of the investigation, the cumulative volume of water pumped out of the SDU 6 sumps was estimated (Figure 3.2-3) (SRMC-2022-WSE-0010). Based on pump data it was estimated that a maximum of 29,000 gallons had been pumped out over the 5-year period.

Figure 3.2-3: Cumulative Volume of Water Pumped from SDU 6 Sumps through March 2022



[Source: SRMC-2022-WSE-0010]

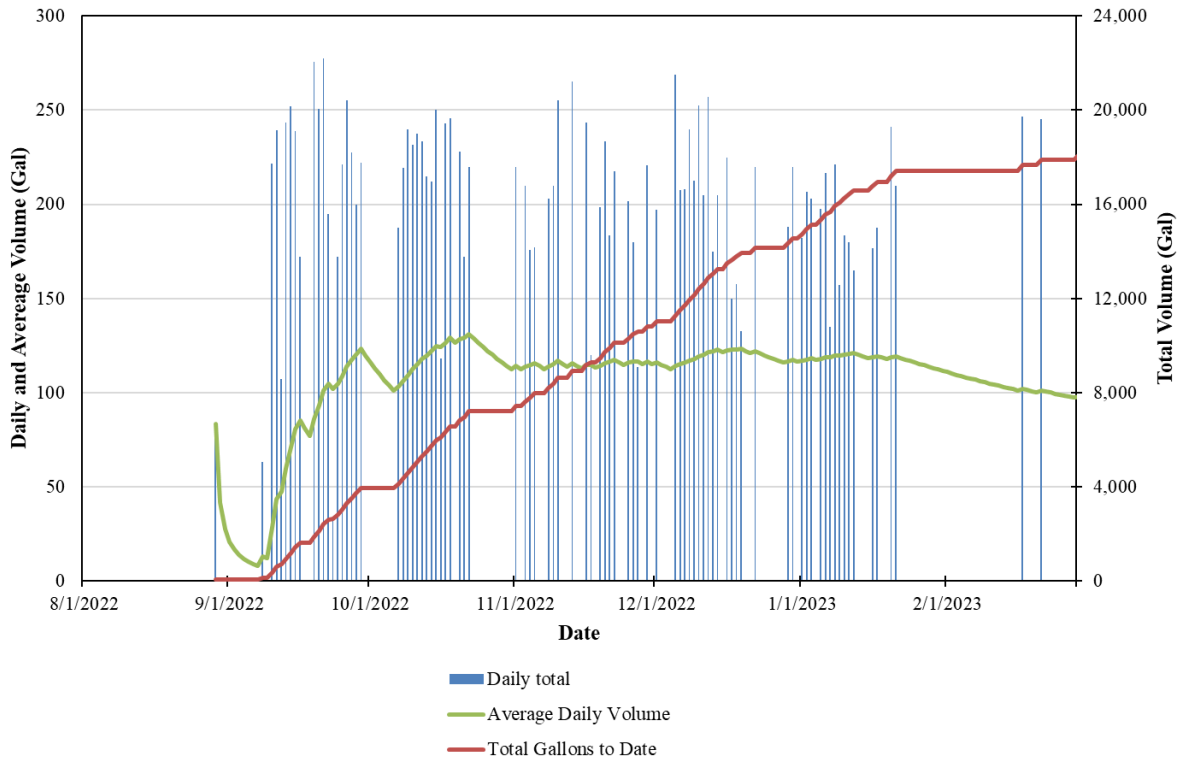
Note, however, that this estimate was not based on measuring the actual volumes but, instead, was based on the number of minutes that the pumps were run for, then multiplied by the flow rate of each pump (11 gallons per minute (gpm)) (McCoy, 2022). If the pumps were run continuously, even after the sump ran dry, then these estimates have the potential to be high. For example, it was noted that one day from this data set reported 5,480 gallons pumped out of the East Sump in a single day; coincidentally, this is approximately equal to the volume that could be pumped over an 8-hour shift at the set rate of 11 gpm. However, this volume is much higher than the approximately 10-gallon capacity of the sump. With this insight, the 29,000-gallon estimate over this five-year period is expected to be a bounding estimate. It is very likely that a smaller volume than this has actually been removed from the sumps.

Starting in late August, the temporary modification (M-TMOD-Z-00002) was deployed and drain water from the East Sump was pumped back into SDU 6 per procedure WS-Z-1055: *Pumping SDU 6 East Sump into SDU 6*. This modification provides a reliable method for removing water from the sump and sending it to SDU 6, consistent with the recommendations of the Site Tracking, Analysis, and Reporting (STAR) issue: 2022-CTS-004583. Sending the liquid back to the SDU will maintain the contamination in the system while allowing ongoing processing.

As shown in Figure 3.2-4, from late August 2022 through February 2023, approximately 18,000 gallons has been pumped into SDU 6 via this design modification (Riley, 2023). Over this period,

the largest volume ever pumped in a single day was approximately 275 gallons; however, on more than half of the days no water was pumped. The average over this period was approximately 100 gallons a day.

Figure 3.2-4: Cumulative Volume of Water Pumped from the SDU 6 East Sump Back into SDU 6 since August 2022



It is likely that the sump water has multiple sources: pre-existing construction water trapped when the system was initially enclosed, rainwater from the SDU roof and the soils external to the HDPE entering through a potential leak site, or from inside the SDU itself. In the absence of reliable flow totalizer data from the sump transfers, material balance around the system cannot be accurately determined. If only a portion of the water is from the inside of SDU 6 (which seems almost certain given the process history prior to the disposal of radioactive materials), then assuming that the estimated volume of 29,000 gallons comes entirely from inside of SDU 6 is likely to be an overestimate.

Using the bounding volume of 29,000 gallons over the 5-year period (from March 2017 to March 2022) along with the approximately 18,000-gallon volume (from late August 2022 through February 2023), the long-term average pump rate (from March 2017 through February 2023) is estimated to be less than 22 gal/day pumped from the leak detection system. This value is less than the approximately 100 gal/day shown by the green curve on Figure 3.2-4; however, because no water was pumped out of the sump while the modification was being deployed, there were approximately 5 months with no pumping. Figure 3.2-4 also shows that in February 2023, water was only pumped out twice (for a total of less than 500 gallons), suggesting that the leak rate might now be slowing down, which should be expected as the saltstone within SDU 6 cures and as excess

drainwater is removed from inside the SDU. Regardless, these estimates are significantly less than the approximately 1,500 gal/day leak rate estimated during the first leak tightness test.

Water that gets pumped from the sump to the interior of SDU 6 is assumed to be mixed with the other process water that may be present inside SDU 6. Periodically, this water is pumped back to the SPF where it is mixed with the DSS feed that is used to produce the saltstone grout. As of December 2022, over 125,000 gallons had been pumped from inside SDU 6 back to the SPF and there was “no visible standing water on the grout surface” (2022-CTS-004583). The 18,000 gallons from the SDU 6 sump represents less than 15% of the 125,000 gallons removed from the interior of SDU 6.

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4.0 POTENTIAL SDU 6 LEAK PATHS

In general, there are two potential sources for liquid in the SDU 6 sump: uncontaminated rainwater and contaminated saltstone process water (which may include DSS, flush water, and bleed water). Section 3.0 also assumes that some uncontaminated water may have been trapped within the SDU 6 leak detection system during construction activities.

Depending on the liquid source, different potential leak paths could contribute to the liquid accumulation within the SDU 6 sumps. Most (maybe all) of these leak paths are impossible to verify or confirm without a risk of damaging or destroying parts of the SDU or the SDU leak detection system. Further, doing so would likely increase the dose risk to workers. As such, while these different potential leak paths are being conceptually described herein, there is no assertion as to which of these potential leak path(s) actually contributed to the overall accumulation of liquid in the SDU 6 sumps.

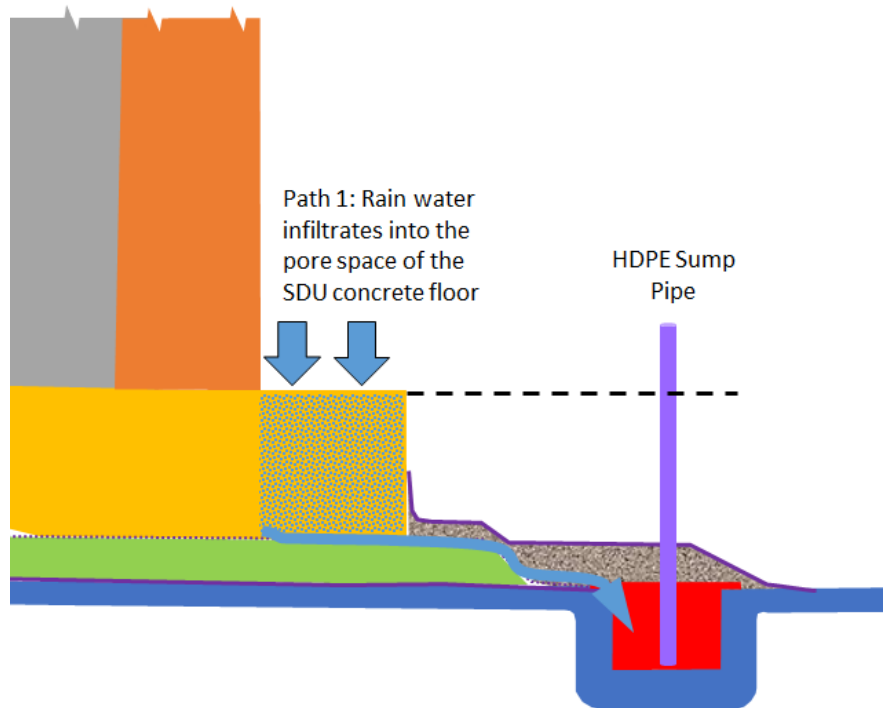
The following describes ten potential leak paths. These are identified as Leak Paths 1 through 10. The first four leak paths represent paths through which uncontaminated water may reach the sump while the last six leak paths represent paths through which contaminated water may reach the sump.

4.1 Leak Path 1

Figure 4.1-1 illustrates Leak Path 1. In this conceptualization, rainwater collects on the top surface of the exposed SDU concrete floor. This water then infiltrates through the surface and into the concrete; this may be through cracks or through interconnected pore spaces within the matrix of the concrete. Once the water reaches the bottom of the floor, the 10-mil liner then diverts the water laterally towards the outside edges of the SDU where the water can then collect into the sump.

This leak path is considered plausible because a portion of the top surface of the floor remains exposed (for example, refer to the base of SDU 6 depicted in Figure 3.2-1).

Figure 4.1-1: Leak Path 1



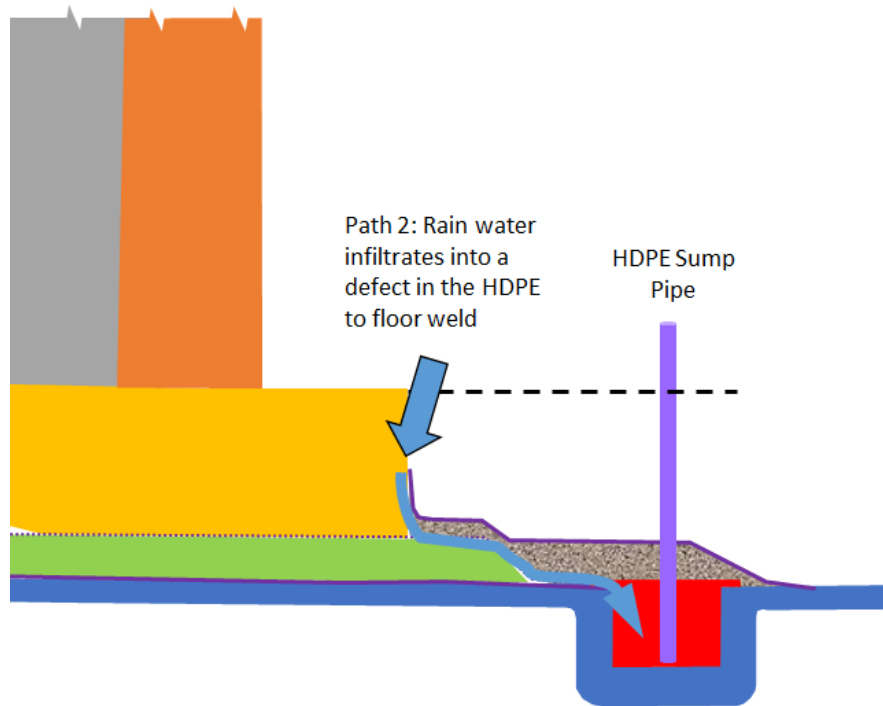
[This figure is not to scale.]

4.2 Leak Path 2

Figure 4.2-1 illustrates Leak Path 2. In this conceptualization, it is assumed that a portion of HDPE-to-floor weld has become defective, leaving an opening for rainwater ingress. This water then moves down the side of the floor to the top of the upper mud mat. The upper mud mat then diverts the water laterally towards the outside edges of the SDU where the water can then collect into the sump.

Leak Path 2 is considered plausible because the HDPE-to-floor welds are extrusion welds that must be installed vertically; this means that gravity is always working against the weld. Figure 2.3-8 and Figure 2.3-9 showed the HDPE during this installation. Once this installation was completed, this HDPE was buried beneath a layer of backfill to bring the grade up to be level with the top surface of the SDU floor. It is possible that the added weight of the backfill material over the top of the HDPE could have been sufficient to potentially separate some of these welds in isolated locations.

Figure 4.2-1: Leak Path 2

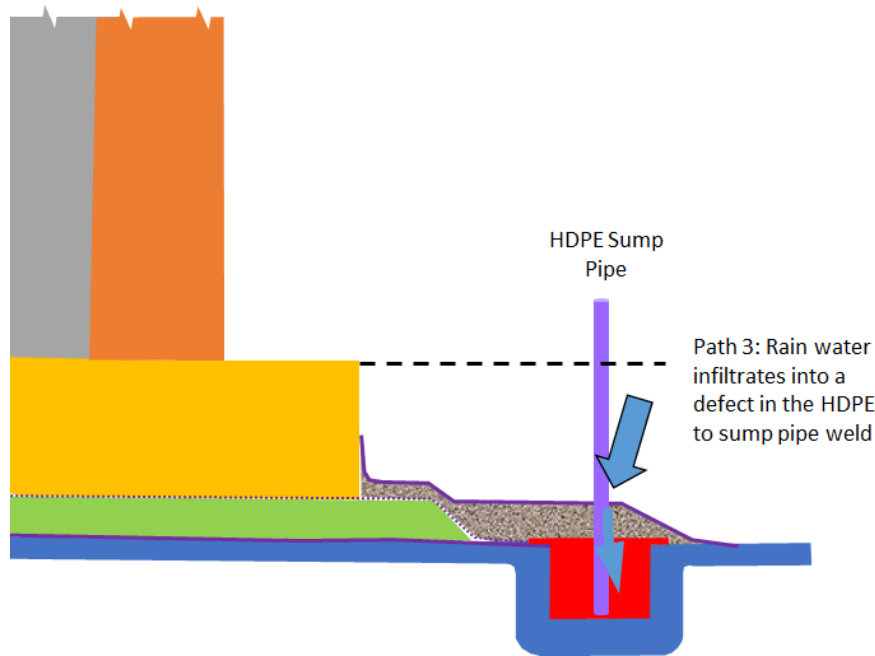


[This figure is not to scale.]

4.3 Leak Path 3

Figure 4.3-1 illustrates Leak Path 3. In this conceptualization, it is assumed that a portion of HDPE weld around the HDPE sump pipe (or any other part of the HDPE not already addressed via Leak Paths 1 and 2) has become defective, leaving an opening for rainwater ingress. In the case of the HDPE sump pipe, the water then moves down the pipe and directly into the sump. HDPE defects at other locations would require some transport for the water to reach the sump. Figure 2.3-9 showed an example of these extrusion welds, which visually appear to be complete and robust extrusion welds. Regardless, because this has the potential to be the most direct path for water to reach the sump, it is included as a potential path.

Figure 4.3-1: Leak Path 3

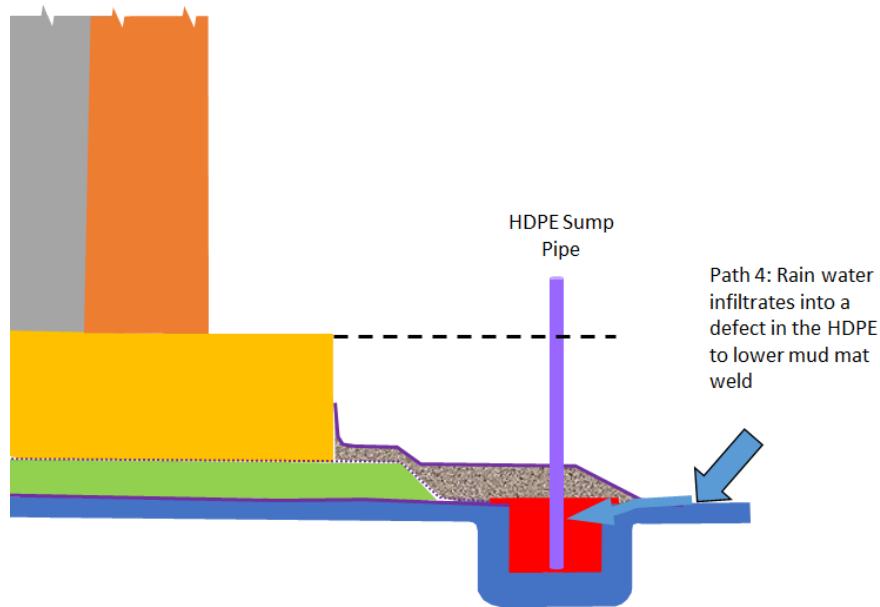


[This figure is not to scale.]

4.4 Leak Path 4

Figure 4.4-1 illustrates Leak Path 4. In this conceptualization, it is assumed that a portion of HDPE-to-lower mud mat weld has become defective, leaving an opening for rainwater ingress. This water then moves inward (towards the SDU), where the water can then collect into the sump. This leak path is considered less likely than Leak Paths 2 and 3 because this leak path does not rely on vertical welds. Along the HDPE-to-lower mud mat weld, the HDPE is expected to lay relatively flat against the lower mud mat; this means that the extrusion welds (as shown in the lower portion of Figure 2.3-9) are less likely to undergo strain that could damage the weld.

Figure 4.4-1: Leak Path 4



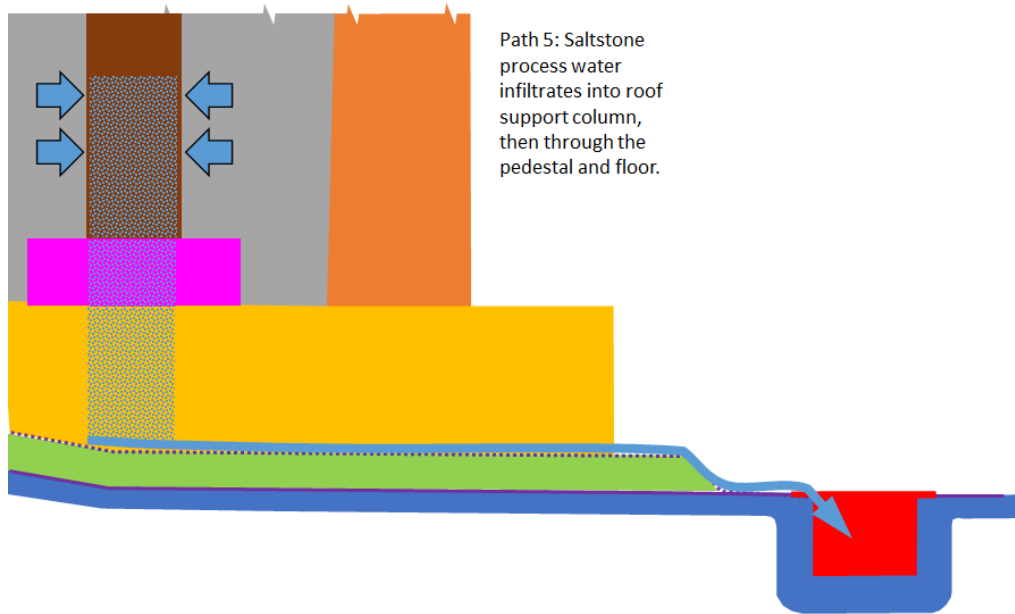
[This figure is not to scale.]

4.5 Leak Paths 5 and 6

Leak Paths 5 and 6 are nearly identical to one another. These leak paths are illustrated by Figure 4.5-1 and Figure 4.5-2, respectively. In these conceptualizations, saltstone process water infiltrates through the vertical surface of the roof-support columns (shown as the brown feature in Figure 4.5-1 and Figure 4.5-2). This water then percolates down, through the column pedestals (the pink feature) and into the SDU floor. For Leak Path 5, it is assumed that the saltstone process water reaches the top of the 10-mil liner where it is diverted laterally towards the outside edges of the SDU, where the water can then collect into the sump. For Leak Path 6, it is assumed that the 10-mil liner has defects that allows the water to penetrate the upper mud mat. It is then assumed that the saltstone process water reaches the top of the HDPE where it is diverted laterally towards the outside edges of the SDU, where the water can then collect into the sump.

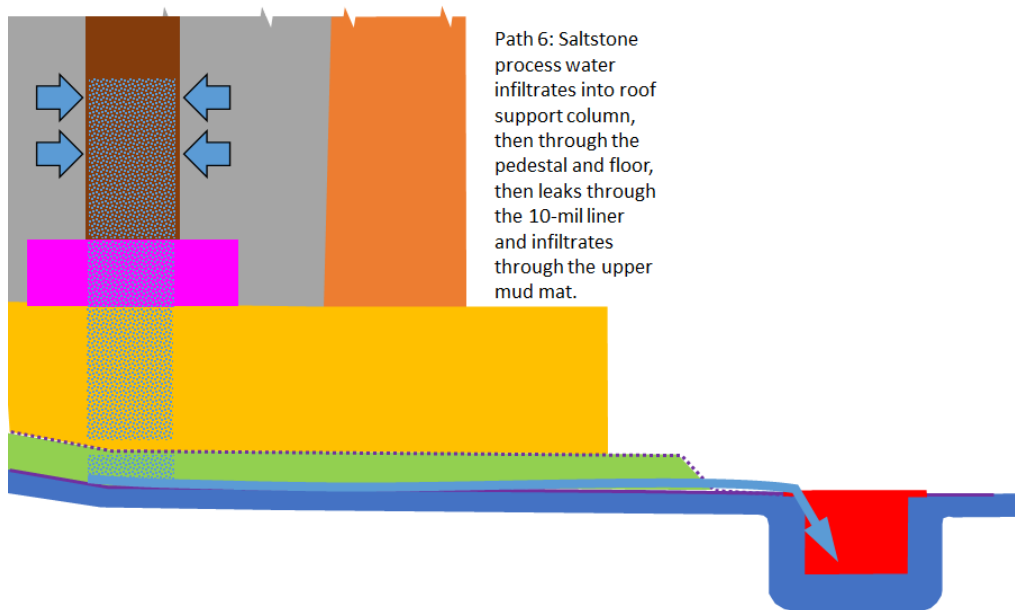
Leak Paths 5 and 6 are considered plausible because, unlike the walls and floor, the roof support columns inside SDU 6 are not protected by the interior liner system (as shown in Figure 2.3-7).

Figure 4.5-1: Leak Path 5



[This figure is not to scale.]

Figure 4.5-2: Leak Path 6



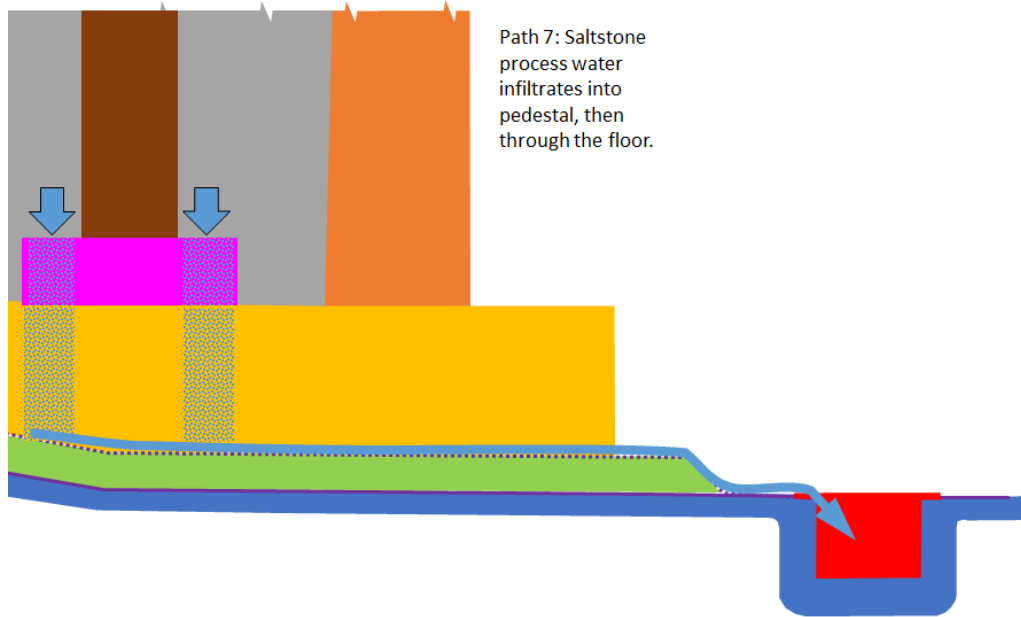
[This figure is not to scale.]

4.6 Leak Paths 7 and 8

Leak Paths 7 and 8 are nearly identical to one another. These leak paths are illustrated by Figure 4.6-1 and Figure 4.6-2, respectively. In these conceptualizations, saltstone process water infiltrates through the top surface of the column pedestals (shown as the pink feature in Figure 4.6-1 and

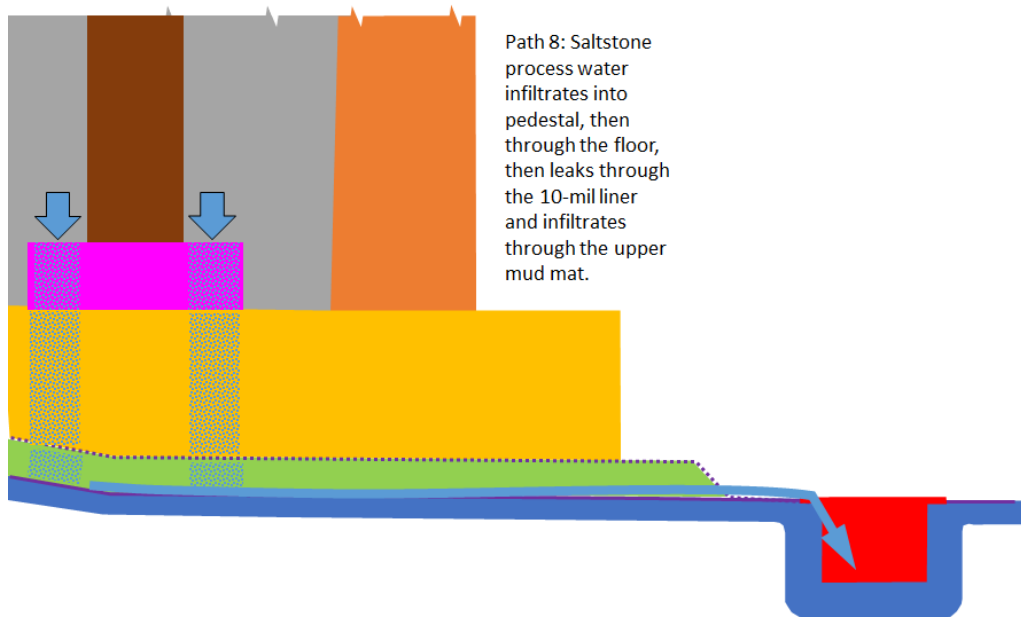
Figure 4.6-2), then percolates down, through the column pedestals (the pink feature) and into the SDU floor.

Figure 4.6-1: Leak Path 7



[This figure is not to scale.]

Figure 4.6-2: Leak Path 8



[This figure is not to scale.]

For Leak Path 7, it is assumed that the saltstone process water reaches the top of the 10-mil liner where it is diverted laterally towards the outside edges of the SDU, where the water can then collect

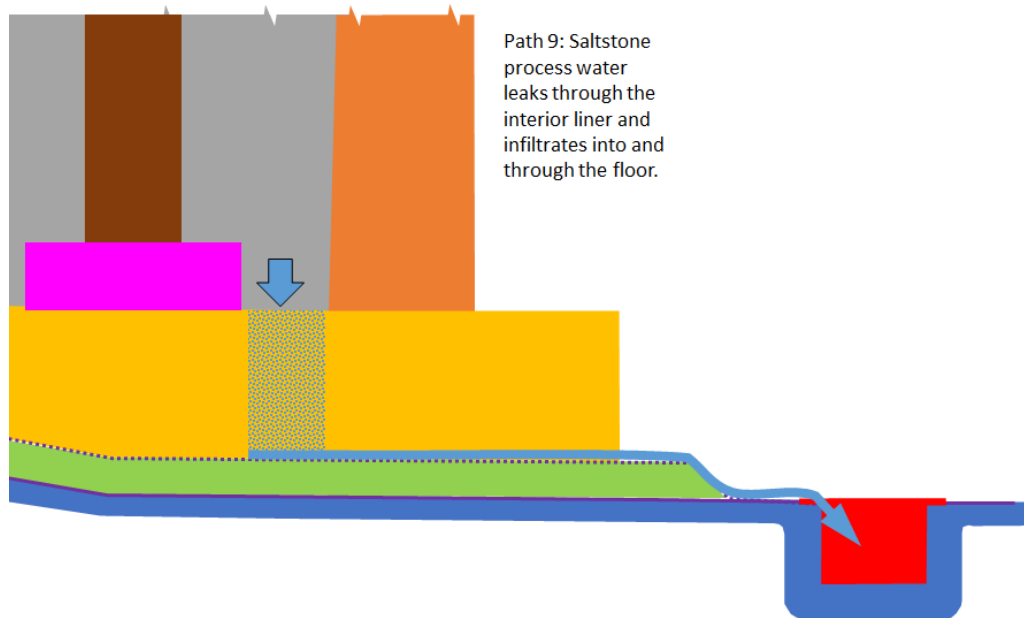
into the sump. For Leak Path 8, it is assumed that the 10-mil liner has defects that allows the water to penetrate the upper mud mat. It is then assumed that the saltstone process water reaches the top of the HDPE where it is diverted laterally towards the outside edges of the SDU, where the water can then collect into the sump.

Leak Paths 7 and 8 are considered plausible because, unlike the walls and floor, the top surface of the column pedestals inside SDU 6 are not protected by the interior liner system (as shown in Figure 2.3-7).

4.7 Leak Paths 9 and 10

Leak Paths 9 and 10 are nearly identical to one another. These leak paths are illustrated by Figure 4.7-1 and Figure 4.7-2, respectively. In these conceptualizations, it is assumed that there is a defect (or defects) in the interior liner system. The saltstone process water leaks through the defect(s) then infiltrates through the top surface of the SDU floor and percolates down. For Leak Path 9, it is assumed that the saltstone process water reaches the top of the 10-mil liner where it is diverted laterally towards the outside edges of the SDU, where the water can then collect into the sump. For Leak Path 10, it is assumed that the 10-mil liner has defects that allows the water to penetrate the upper mud mat. It is then assumed that the saltstone process water reaches the top of the HDPE where it is diverted laterally towards the outside edges of the SDU, where the water can then collect into the sump.

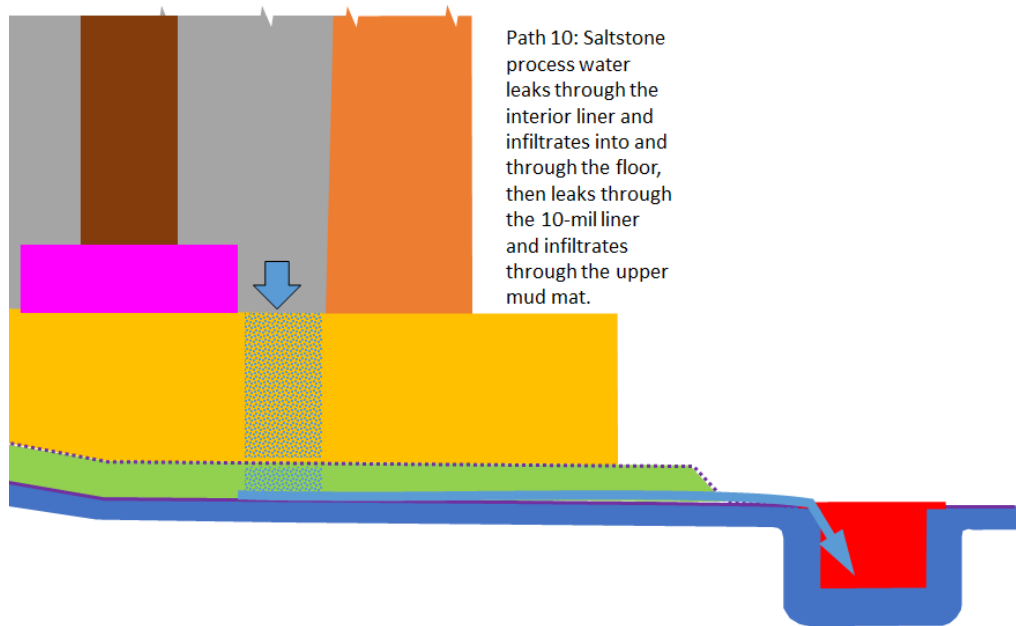
Figure 4.7-1: Leak Path 9



Path 9: Saltstone process water leaks through the interior liner and infiltrates into and through the floor.

[This figure is not to scale.]

Figure 4.7-2: Leak Path 10



[This figure is not to scale.]

4.8 Additional Leak Path Discussion

Since SDU 6 passed the second leak tightness test, it is proposed that while Leak Paths 9 and 10 are possible, they are probably less likely than the other leak paths.

One hypothesis is that under the hydraulic head of the first leak tightness test, the exposed interior concrete (columns, pedestals, and floors) might have become saturated or partially saturated. Because the floors were cracked, this saturating water may have been able to advance faster and further through the floor (compared to the other concrete features), resulting in the failed test.

Then, after the first test failed, and after the installation of the interior liner, the second test passed because the water did not have a direct path to the cracked floor. However, there were still exposed interior concrete surfaces (columns and pedestals). So, it remained possible that these exposed surfaces may have once again become saturated or partially saturated during the second leak tightness test.

Then, the SDU was emptied, and disposal operations began. As the SDU was filled with saltstone grout, some of the process water might also have penetrated these exposed concrete surfaces. Over time (from August 2018 to March 2022), it is possible that a small amount of this contaminated water may have migrated (via a combination of advective transport and diffusion) via Leak Path 5, 6, 7, or 8.

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5.0 COMPARISON OF SDU 6 TO OTHER SDUs

Engineers involved in the design and construction of SDUs are continuously applying lessons learned. As a result, SDUs constructed after SDU 6 have been slightly modified. Many of these modifications are described in the *System Description for SDU 6-Type Structures & Process Systems* (G-SD-Z-00009).

The following studies and testing were done to support these changes:

- *SDU 6 Tank Cracking SME Reports* (SRR-SDU-2016-00006)
- *Concrete Lessons Learned – Implementation Work Plan* (SRR-SDU-2016-00010)
- *Concrete Placement Options Study for Saltstone Disposal Unit (SDU) 7* (SRR-SDU-2016-00025)
- *Shrinkage Evaluation of SDU 7 Type V Concrete Mixtures* (SRR-SDU-2016-00027)
- *Constructability Evaluation of SDU 7 Concrete Placement – Options Team Charter* (SRR-SDU-2016-00030)
- *Application of SDU 6 Lessons Learned for SDU 7 Project* (SRR-SDU-2017-00007)
- *Constructability Evaluation of SDU 7 Concrete Placement* (SRR-SDU-2017-00013)
- *The Application of SDU 6 Lessons Learned for SDU 7* (SRR-SDU-2017-00043)

Relative to the cracking of the SDU 6 floor and to the potential leak paths for SDU 6, the most notable of these changes were changes to the floor design, changes to the concrete mix, and changes to the approach for pouring and curing the floor concrete. These changes, along with selected other changes are described below.

5.1 Changes to the SDU Floor Design

For SDU 6:

“The 12-inch-thick concrete floor is sloped at 1.5 percent radially (like the roof for SDU 6 only) from the center to the inside of the wall. The SDU 6 floor slab is thickened to approximately 2 feet at the perimeter beneath the wall” (G-SD-Z-00009).

For SDU 7 and future SDUs (referred to as “SDU 6-Type Structures” in G-SD-Z-00009), the design was changed:

“SDU 6-type structures have no floor slope with a uniform 24-inch-thick floor slab to minimize shrinkage cracking. The inclined change in the SDU 6 floor slab created a restrained edge against the upper mud mat which results in drying shrinkage cracking in the SDU 6 floor slab” (G-SD-Z-00009).

This means that the 1.5% floor slope has been eliminated (the floor is now flat), and that the thickness of the floor has been increased from one to two feet. It is expected that some of the cracking that was observed in the SDU 6 floor will be mitigated by these changes.

5.2 Changes to the SDU Concrete Mix

The first concrete mix changes that were made from SDU 6 to SDU 7 were changes to the mix used for the upper and lower mud mats. Specifically, the mud mat concrete was required to “have a 28-day minimum design compressive strength of 2,000 pounds per square inch (psi) for SDU 6 and 4,000 psi for SDU 7 and future SDUs” (G-SD-Z-00009). The primary reason for this change is that the 2,000 psi limit for SDU 6 “was deemed insufficient to allow heavy equipment traffic” so various construction aids “were used to mobilize equipment without damaging the [SDU 6] mud mat. The increase in compressive strength on SDU 7 and future SDUs to 4,000 psi eliminated the need for construction aids.” While this change wasn’t directly in response to the SDU 6 leaks, it is expected that stronger mud mats will provide a better foundation for the constructability of the SDU floors and reduce the potential for leak paths to form through the mud mat concrete.

The second concrete mix changes were for the SDU concrete (used for floors, walls, and roof). The SDU 6 concrete specification (C-SPP-Z-00008) specified an allowable concrete shrinkage limit of 0.048 percent. “However, shrinkage testing of SDU 6 concrete mix recorded shrinkage as high as 0.069 percent. Subsequently, the SDU 7 & 8 concrete specification (C-SPP-Z-00015) for concrete shrinkage has been reduced to 0.038 percent” (G-SD-Z-00009). This was achieved by increasing the mass of the sand and stone aggregate, slightly decreasing the volume of water in the mix, and by introducing a shrinkage-reducing admixture (SRA) to the mix.

By reducing the risk of shrinkage in the concrete mix, it is expected that some of the cracking that was observed in the SDU 6 floor will be mitigated.

5.3 Changes to the Approach for Pouring and Curing SDU Concrete Floors

Concrete Placement Options Study for Saltstone Disposal Unit 7 (SRR-SDU-2016-00025) informed changes to the pouring approach for the SDU 7 floor. As a result of this study, the placement (or pouring) of the floor concrete is now completed in 14 sections (per C-CC-Z-00059) rather than in 10 sections (per C-CC-Z-00059). The increased number of sections and revised concrete placement plan was designed to reduce the maximum stresses applied at the restrained edges (M-TC-Z-00009), which is expected to mitigate some of the cracking that was observed for SDU 6.

5.4 Other Notable Changes to the SDU Design

Another notable change to the SDU design from SDU 6 to SDU 7 is the increase in the wall thicknesses. While the thickness at the base of the tapered wall remains 24-inches-thick, the thickness at the top of the tapered wall has been increased from 10 inches to 12 inches. The thickness of the roof itself was also increased from 10 inches to 12 inches.

The tops of the roof-support columns now include drop panels “to distribute roof loads and minimize roof concrete cracking” (G-SD-Z-00009). The drop panels are each 8 feet square by 6.25 inches thick.

Finally, an interior leak-tight liner system (LTLS) that is equivalent to the LTLS that was installed inside SDU 6 (after the first leak tightness test failed) has now been included in the initial design of SDU 7 (C-SPP-Z-00015).

5.5 Change to the SDU 6 Drainwater Control

In addition to the design changes, an operations change has also been applied because of lessons learned from the water accumulation in the SDU 6 leak detection system. Specifically, the *Saltstone Control Room Operator Rounds* procedure (200-Z(E)-0002) has been revised. In earlier revisions of this procedure, the drainwater inside SDU 6 would be pumped to the SPF when the drainwater pump sump levels were greater than 15 feet; this has now been revised to 8 feet. This change ensured flush water would not accumulate on the grout surface and only be retained in the drainwells. This change is expected to decrease the hydraulic head acting on any potential leak paths. For SDU 7, the current threshold (5 feet per 200-Z(E)-0002) is even lower than SDU 6; this is due to the current lower grout height. Similar thresholds are expected to be placed on future SDUs.

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6.0 EVALUATION OF POTENTIAL LEAKS IN SDUs 7 THROUGH 12

Despite the significant design and construction changes described throughout Section 5.0, it remains possible that new leak sites may form at SDUs 7 through 12. This section has been prepared to provide an additional risk-informed evaluation of such potential leaks.

6.1 Modeling Approach

In the SDF PA (SRR-CWDA-2019-00001), the modeling of SDU 6 accounted for the first (failed) leak tightness test by making a conservative assumption about the initial condition of the roof and floor concrete. Specifically, a much higher initial saturated hydraulic conductivity was assumed (6.2E-06 cm/s versus 7.8E-10 cm/s use in other SDUs). This 6.2E-06 cm/s value was selected based on model calibration informed by the failed leak tightness test (per SRNL-STI-2016-00534), along with some bounding assumptions.

To evaluate the potential impacts should other SDUs leak, a set of sensitivity modeling cases have been developed. In each of these modeling cases, the floors and roofs of SDUs 7 through 12 have all been modified to apply the same high value for the initial saturated hydraulic conductivity (6.2E-06 cm/s). For this roof, this change significantly increases the ability for water to reach the saltstone waste form and for the floor, this change significantly increases the potential for contaminated water to permeate through the floor and be released from the SDU.

Since the impact of the increased initial saturated hydraulic conductivity may be sensitive to higher infiltration rates, modeling cases were developed that used both the Compliance Case infiltration rate (see Section 4.4.1 of the SDF PA (SRR-CWDA-2019-00001)) as well as a higher infiltration rate (based on modeling described in SRR-CWDA-2021-00076).

Also, because it is possible that leaks from SDU 6 may have passed through an interior liner system (per Section 4.7), a modeling case that also assumes leaks through the exterior liner system (HDPE and GCL) was also developed. This was modeled by replacing the material properties of the HDPE and GCL layers in the PORFLOW models with the properties of backfill material.

A final modeling case was developed that combines the initially degraded floor and roof concrete with the higher infiltration rate and the initially degraded HDPE and GCL. This final modeling case is a bounding case and is not expected to represent actual field conditions but is included to inform on potential risks.

These modeling cases are summarized as follows:

- Case2023.1 = Roof and Floor concrete initially degraded like SDU 6
- Case2023.2 = Roof and Floor concrete initially degraded like SDU 6 with increased infiltration
- Case2023.3 = Roof and Floor concrete initially degraded like SDU 6 with initially degraded HDPE and GCL
- Case2023.4 = Roof and Floor concrete initially degraded like SDU 6 with initially degraded HDPE and GCL and with increased infiltration

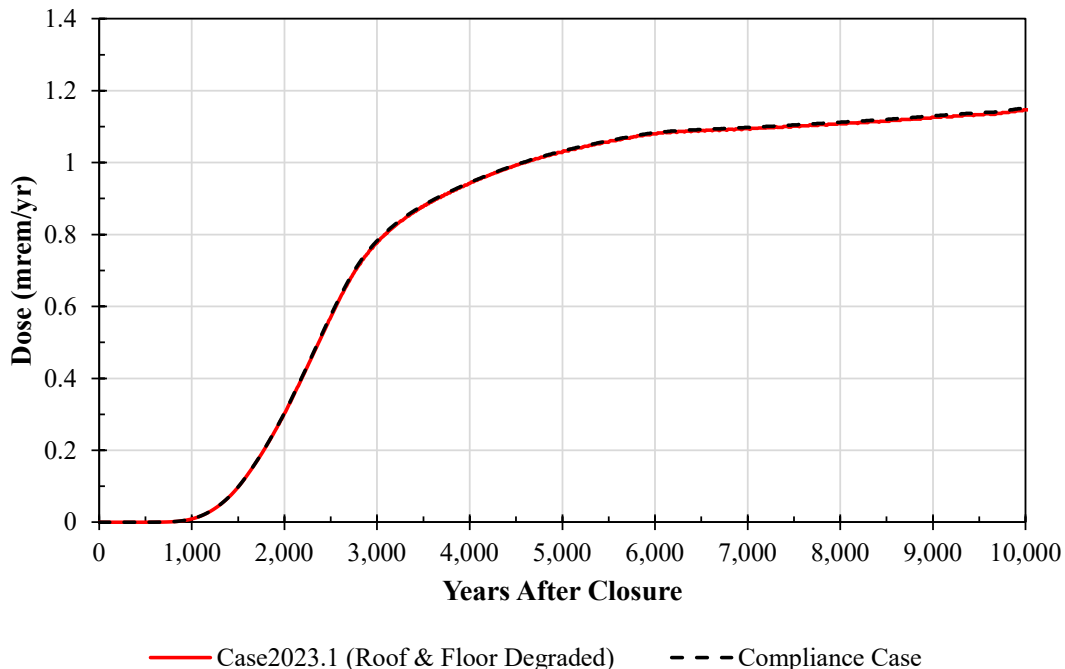
Within each modeling case, the changes were applied to SDUs 7 through 12.

6.2 Case2023.1 Result

Section 5.8.3.3 of the SDF PA (SRR-CWDA-2019-00001) already established that the SDF doses are not sensitive to the performance of the SDU concrete. This section of the SDF PA evaluated the doses when different initial saturated hydraulic conductivities are assumed for the SDU concrete (6.4E-11 cm/s, 9.1E-10 cm/s, 6.4E-10 cm/s, 1.0E-07 cm/s, and 6.4E-09 cm/s). The result of this previous analysis indicated that the SDU concrete performance had a negligible impact on modeling results (see Figure 5.8-24 of SRR-CWDA-2019-00001). However, since the SDU 6 concrete had an initial value (6.2E-06 cm/s) that was higher than any of these previously considered values, it is still beneficial to explore the potential impacts from applying this higher initial value.

As expected, the impact was still negligible (see Figure 6.2-1). This is because the SDU concrete is only a secondary containment system. The primary containment of the waste in the SDUs is the saltstone waste form itself, which was intentionally designed to immobilize the waste.

Figure 6.2-1: Dose Results Comparing the Compliance Case Against Case2023.1



6.3 Case2023.2 Result

Next, Case2023.2 was developed by modifying Case2023.1 to use a significantly higher infiltration rate, as shown in Figure 6.3-1. Because dose results are sensitive to infiltration rates, these dose results were significantly higher than the Compliance Case. Figure 6.3-2 shows that Case2023.2 had a peak of approximately 6.3 mrem/yr at approximately 3,300 years after closure. Within the 1,000-year Compliance Period, the doses remained very low (less than 0.05 mrem/yr).

Figure 6.3-1: Comparison of Infiltration Rates: Compliance Case Versus Case2023.2

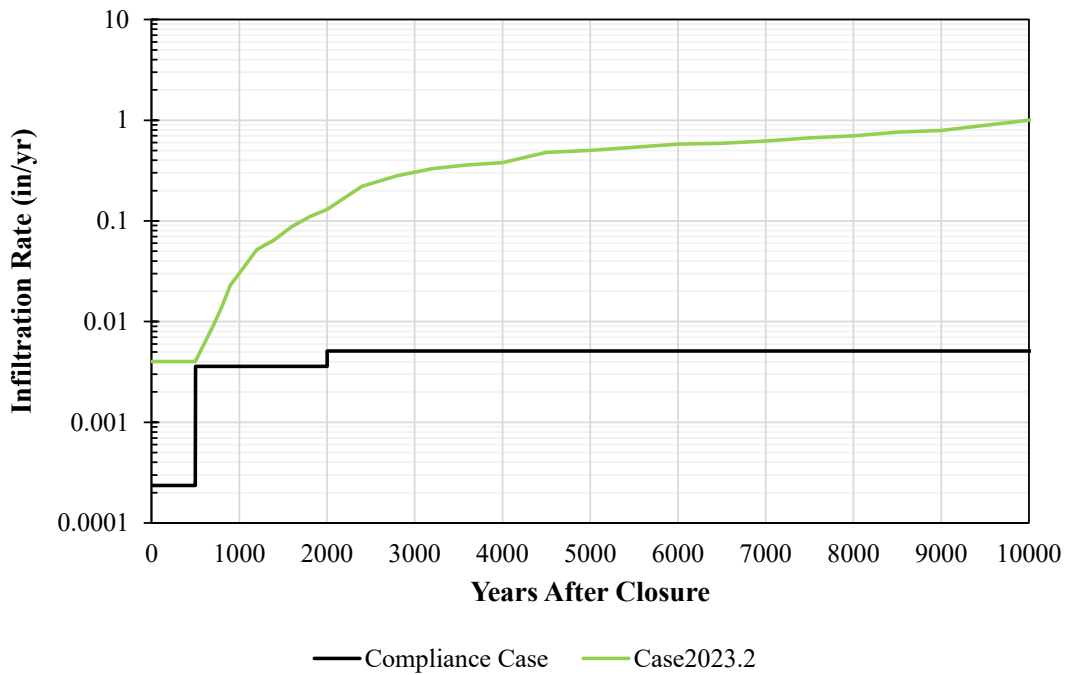
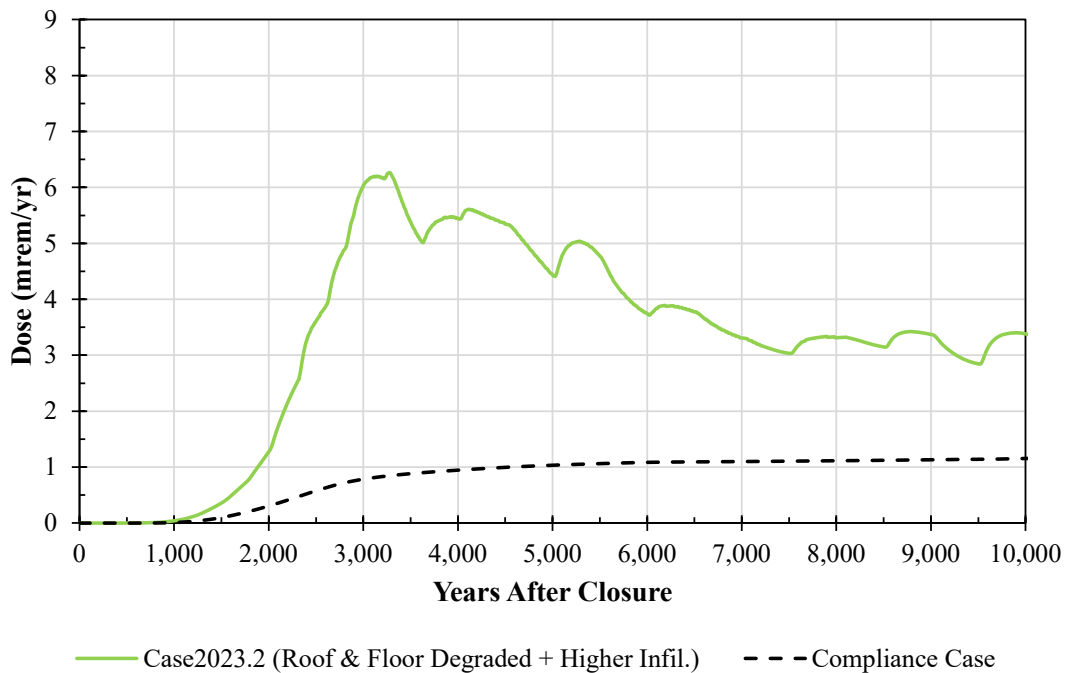


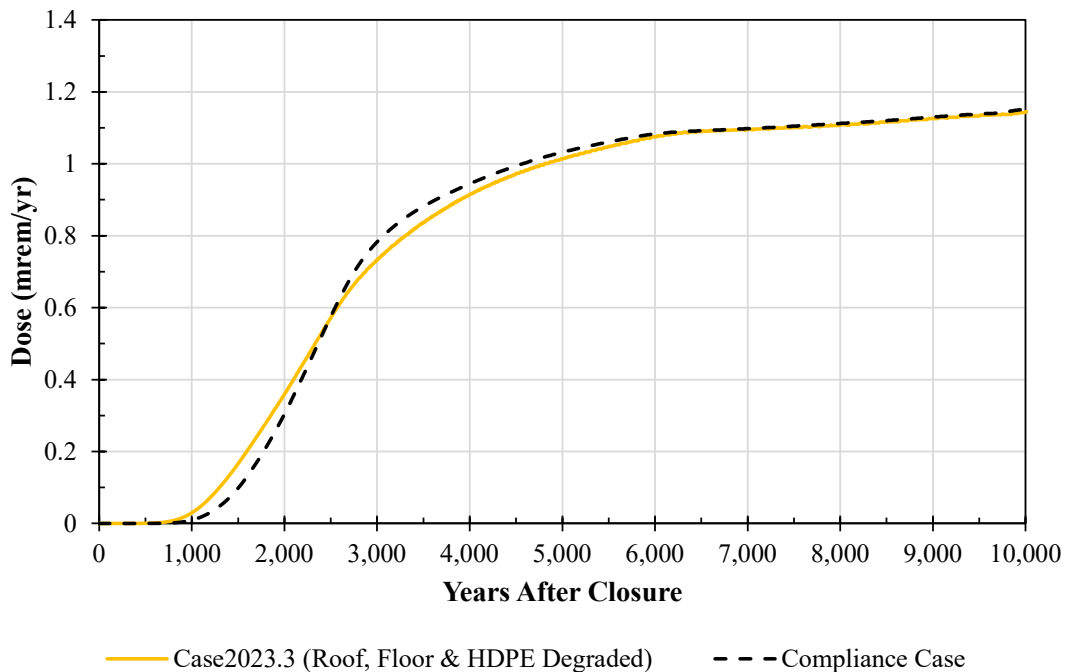
Figure 6.3-2: Dose Results Comparing the Compliance Case Against Case2023.2



6.4 Case2023.3 Result

Next, Case2023.2 was developed by modifying Case2023.1 to assign initially degraded properties to the HDPE and GCL of the exterior liner system (i.e., backfill properties were assigned to these materials). Figure 6.4-1 shows that this change had a minor impact on the dose result. The doses were slightly higher than the Compliance Case within the first 2,500 years and then from approximately 2,500 years to almost 6,000 years, the doses were slightly lower than the Compliance Case. However, there was not a significant impact on the magnitude or timing of the peak dose within the first 10,000 years.

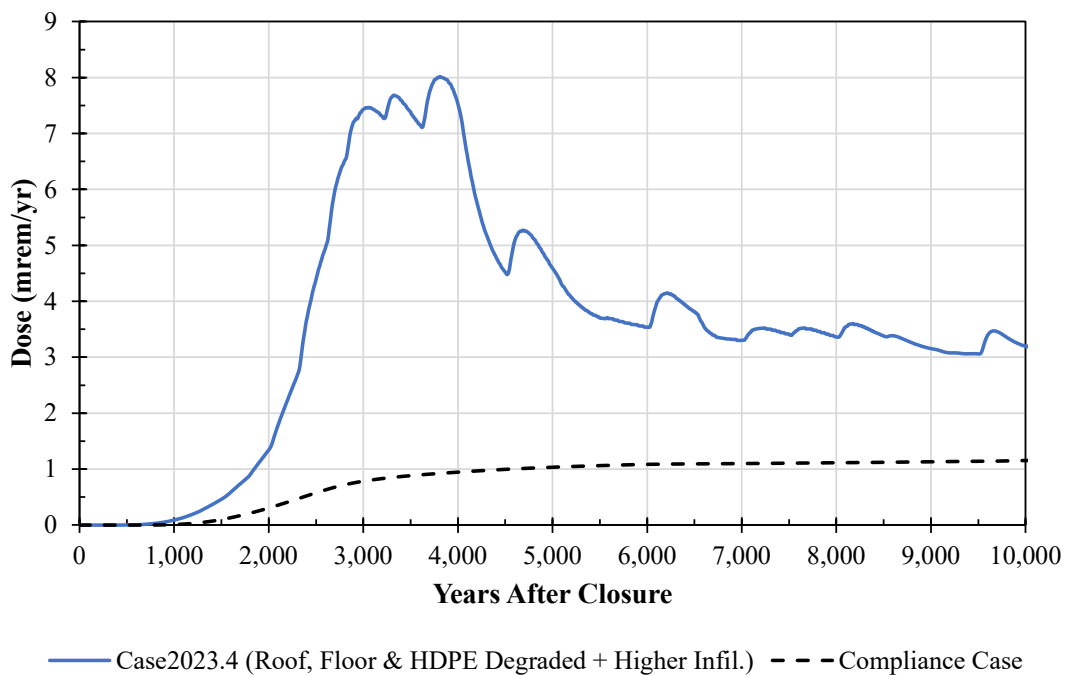
Figure 6.4-1: Dose Results Comparing the Compliance Case Against Case2023.3



6.5 Case2023.4 Result

Finally, Case2023.4 combines the increased infiltration rate from Case 2023.2 with the initially degraded HDPE and GCL from Case 2023.3. As expected, the combined affects from all of these conditions resulted in the highest peak dose among the sensitivity cases considered within this report. The peak dose in Figure 6.5-1 is approximately 8 mrem/yr at approximately 3,800 years after closure. While this peak dose is nearly seven times higher than the Compliance Case dose, it is still a factor of three lower than the 25 mrem/yr performance objective. Further, within the 1,000-year Compliance Period, the dose remains less than 0.1 mrem/yr, which may be considered a negligible dose.

Figure 6.5-1: Dose Results Comparing the Compliance Case Against Case2023.4



6.6 Analysis of Model Results

The dose results presented in Sections 6.2 through 6.5 show the potential impacts for various leak scenarios for the 375-foot diameter SDUs. While the doses in leak scenarios Case2023.2 and Case2023.4 may be higher than the doses estimated from the SDF PA Compliance Case, the doses within the 1,000-year Compliance Period remained negligible, and the doses within the 10,000-year Performance Period remained below the performance objectives. Since these leak scenarios were developed from bounding assumptions and since none of the models credit any interior liner systems, these results are expected to overpredict the actual dose risk. Further, the only cases that resulted in doses that were significantly higher than the Compliance Case doses were those cases that assumed significantly higher infiltration rates. This suggests that leaky conditions are not significant to dose results; instead, it is the higher infiltration rates that are significant, which was already acknowledged within the SDF PA.

Recent studies (SRMC-CWDA-2023-00018 and SRMC-CWDA-2023-00022) have established additional support for the infiltration rates used in the SDF PA Compliance Case. This support indicates that the much higher infiltration rates assumed for Case2023.2 and Case2023.4 are highly unlikely based on the current closure cap design.

These dose results demonstrate that the different leak scenarios do not pose a significant risk to future members of the public.

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7.0 SUMMARY

While the exact leak path(s) that contributed to liquid accumulation within the SDU 6 sumps remain(s) unknown, multiple possible leak paths have been identified and described within this report. The floor of SDU 6 is known to be cracked, so a common factor among many of the potential leak paths is that water can move through the floor of SDU 6, which likely resulted in the contamination of the sump liquid.

For SDUs 7 through 12, lessons learned from the construction of SDU 6 have been applied. As part of these lessons learned, the SDU floor has been modified to mitigate the risk of cracking. Regardless, it remains possible that leak paths may form through the floors of these SDUs. Additional modeling was developed to demonstrate the potential dose risk from such leak paths. The results from these analyses show that while doses may be higher than those represented by the SDF PA Compliance Case, the doses do not challenge the performance objectives. Further, the higher doses were mainly driven by increased infiltration rates and not by the leaky conditions applied to the SDUs. As such, if future leak sites are discovered for these SDUs, it is unlikely that such leaks would significantly impact the long-term performance of the SDF or challenge the conclusions of the SDF PA.

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8.0 REFERENCES

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