

Appendix R

Background Water Quality Data

This appendix addresses the potential for acid deposition resulting from the hydrogen chloride (HCl) contained in the exhaust cloud from the solid rocket boosters. For the proposed Evolved Expendable Launch Vehicles (EELVs), appreciable amounts of acid deposition are possible only if rain occurred during or just after a launch. While it is not impossible that an EELV would be launched during rain, other launch commit criteria (such as those designed to protect the launch vehicle and its payload against lightning strikes) make the likelihood for a launch during the rain very low.

Acid Deposition Runs

The following table summarizes the results of running the Rocket Exhaust Effluent Diffusion Model (REEDM) to assess the potential for acid deposition. This model was run for Cape Canaveral Air Force Station (CCAFS) using four different meteorological cases (CCAFS1, CCAFS2, CCAFS3, and CCAFS4) with precipitation rates of 0.1 inch per hour (in/hr) and 0.3 in/hr. Two launch scenarios, a nominal launch and a launch failure, were investigated for each vehicle for each meteorological case. Also, the model was run for Vandenberg Air Force Base (VAFB) using three different meteorological cases (VAFB1, VAFB2, and VAFB3) with precipitation rates of 0.05 in/hr and 0.1 in/hr. Two launch scenarios, a nominal launch and a failed launch, were investigated for each vehicle for each meteorological case. All other parameters are the same as those used in REEDM runs for the air quality analysis (see Appendix T).

It is important to note two key features of the REEDM rain washout modeling: the results do not provide information for locations near the launch sites and the results are indicative of the upper portion of the range of potential acid deposition amounts.

Two phases of the REEDM calculations are first the rise, and eventual stabilization, of the ground cloud of the exhaust from the launch vehicle and second the transport and diffusion of the stabilized cloud downwind. The rain washout (i.e., precipitation scavenging) module of REEDM models the removal of hydrogen chloride gas from the exhaust cloud during this second phase, the transport and diffusion of the stabilized ground cloud. As a consequence, there are no REEDM calculations for acid deposition for locations closer to the launch site than the distance at which the ground cloud reaches its stabilization height. For the cases presented here, stabilization occurs at distances between 1,000 meters and 3 kilometers. Furthermore, following the procedure in Appendix T, REEDM results closer than 1 kilometer were not calculated. Consequently, for the cases presented here, the REEDM rain washout results that could occur nearest to the launch sites are at distances of from 1,000 meters to 3 kilometers.

TABLE R-1
REEDM Acid Deposition Run Summary

Vehicle	Precipitation (in/hr)	Meteorological Case	Launch Site	Duration (min)	Al ₂ O ₃ (mg/m ²)	pH	HCl deposited (mg/m ²)	CaCO ₃ consumed (mg/L)
Normal Launches								
Atlas V Medium w/ solids	0.1	CCAFS1	CCAFS	6.4	2,067	0.158	6,862	94
	0.1	CCAFS2	CCAFS	10.1	3,891	0.364	6,730	92
	0.1	CCAFS3	CCAFS	5.4	1,965	0.311	4,053	56
	0.1	CCAFS4	CCAFS	5.2	2,282	0.498	2,552	35
	0.3	CCAFS1	CCAFS	6.4	3,942	0.355	13,080	179
	0.3	CCAFS2	CCAFS	10.1	7,265	0.568	12,622	173
	0.3	CCAFS3	CCAFS	5.4	3,731	0.508	7,725	106
	0.3	CCAFS4	CCAFS	5.2	4,279	0.696	4,854	67
Delta IV Medium w/ 4 solids	0.1	CCAFS1	CCAFS	7.8	1,410	0.22	7,276	100
	0.1	CCAFS2	CCAFS	9.7	2,414	0.54	4,323	59
	0.1	CCAFS3	CCAFS	4.4	1,537	0.32	3,221	44
	0.1	CCAFS4	CCAFS	5.8	1,264	0.74	1,638	22
	0.3	CCAFS1	CCAFS	7.8	2,687	0.41	14,094	193
	0.3	CCAFS2	CCAFS	9.7	4,525	0.75	7,996	110
	0.3	CCAFS3	CCAFS	4.4	2,927	0.51	6,240	86
	0.3	CCAFS4	CCAFS	5.8	2,377	0.94	3,101	43

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Vehicle	Precipitation (in/hr)	Meteorological Case	Launch Site	Duration (min)	Al ₂ O ₃ (mg/m ²)	pH	HCl deposited (mg/m ²)	CaCO ₃ consumed (mg/L)
Atlas V Medium w/ solids	0.05	VAFB1	VAFB	1.7	957	0.003	1,316	18
	0.05	VAFB2	VAFB	2.9	3,677	0.021	2,150	29
	0.05	VAFB3	VAFB	7.2	3,170	0.015	5,376	74
	0.1	VAFB1	VAFB	1.7	1,442	0.033	2,455	34
	0.1	VAFB2	VAFB	3.9	5,520	0.027	5,683	78
	0.1	VAFB3	VAFB	7.2	4,774	0.138	8,100	111
Delta IV Medium w/ 4 solids	0.05	VAFB1	VAFB	2.4	580	0.207	1,168	16
	0.05	VAFB2	VAFB	2.0	2,863	0.018	1,495	21
	0.05	VAFB3	VAFB	5.3	2,559	0.055	3,615	50
	0.1	VAFB1	VAFB	2.4	875	0.329	1,764	24
	0.1	VAFB2	VAFB	2.0	4,300	0.142	2,247	31
	0.1	VAFB3	VAFB	5.3	3,853	0.179	5,434	75
Launch Failures								
Atlas V Medium w/ solids	0.1	CCAFS1	CCAFS	2.4	2,565	0.893	464	6
	0.1	CCAFS2	CCAFS	6.0	4,684	0.968	993	14
	0.1	CCAFS3	CCAFS	12.5	2,380	1.011	1,883	26
	0.1	CCAFS4	CCAFS	12.0	3,065	1.038	1,697	23
	0.3	CCAFS1	CCAFS	2.4	4,737	1.104	857	12
	0.3	CCAFS2	CCAFS	6.0	8,161	1.199	1,750	24
	0.3	CCAFS3	CCAFS	12.5	4,356	1.226	3,444	47
	0.3	CCAFS4	CCAFS	12.0	5,512	1.260	3,054	42

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Vehicle	Precipitation (in/hr)	Meteorological Case	Launch Site	Duration (min)	Al ₂ O ₃ (mg/m ²)	pH	HCl deposited (mg/m ²)	CaCO ₃ consumed (mg/L)
Delta IV Medium w/ 4 solids	0.1	CCAFS1	CCAFS	1.9	1,248	1.67	63	1
	0.1	CCAFS2	CCAFS	6.3	2,257	0.94	1,124	15
	0.1	CCAFS3	CCAFS	6.5	1,509	1.13	747	10
	0.1	CCAFS4	CCAFS	5.2	2,567	0.86	1,099	15
	0.3	CCAFS1	CCAFS	1.9	2,315	1.38	369	5
	0.3	CCAFS2	CCAFS	6.3	4,173	1.16	2,031	28
	0.3	CCAFS3	CCAFS	6.5	2,784	1.34	1,381	19
	0.3	CCAFS4	CCAFS	5.2	4,756	1.07	2,033	28
Atlas V Medium w/ solids	0.05	VAFB1	VAFB	5.9	1,056	0.829	674	9
	0.05	VAFB2	VAFB	8.1	2,882	0.618	1,512	21
	0.05	VAFB3	VAFB	5.3	4,122	0.318	1,950	27
	0.1	VAFB1	VAFB	5.9	1,579	0.955	1,008	14
	0.1	VAFB2	VAFB	8.1	4,278	0.740	2,283	31
	0.1	VAFB3	VAFB	5.3	6,150	0.445	2,912	40
Delta IV Medium w/ 4 solids	0.05	VAFB1	VAFB	5.1	556	1.087	324	4
	0.05	VAFB2	VAFB	7.7	2,551	0.672	1,257	17
	0.05	VAFB3	VAFB	4.5	2,830	0.404	1,382	19
	0.1	VAFB1	VAFB	5.1	831	1.213	484	7
	0.1	VAFB2	VAFB	7.7	3,786	0.801	1,867	26
	0.1	VAFB3	VAFB	4.5	4,230	0.531	2,063	28

Because of the methodology used, the REEDM rain washout results should be indicative of an upper bound of the amount of hydrogen chloride that could be deposited. As shown in Appendix T, REEDM results were calculated for 1-kilometer intervals from 1 to 40 kilometers. The REEDM rain washout results at each of these locations is independent of all other calculations. The calculation at each point assumes that rain occurs only when the stabilized ground cloud is above the point for which the calculations are being made. So, for example, the REEDM rain washout value at a distance of 4 kilometers assume no rain fell until the cloud reached a distance of 4 kilometers, and, similarly, the value at a distance of 5 kilometers assume no rain fell until the cloud reached a distance of 5 kilometers. Because of this approach, it is expected that the REEDM results represent an upper bound on the amounts of hydrogen chloride that could be deposited by rain washout at distances beginning at 1,000 to 3,000 meters downwind from the launch sites.

Monitoring of launches of Delta, Atlas, and Titan at CCAFS (Schmalzer, et al., 1998) provides an indication of possible deposition of acid and aluminum oxide in the immediate vicinity of the launch sites. If the near-ground exhaust cloud contained excess moisture, or if rain fell through the cloud, acid and aluminum oxide were deposited near the launch sites. The pH of deposited acid could be as low as one or less. Quantities of acid deposited were not determined by Schmalzer, et al. (1998), but for larger vehicles (Titan IV and the Space Shuttle), acid deposition has at times been sufficient to cause fish kills in nearby waters because of temporary reductions in pH. It was noted that acid deposition decreased with distance, but some occurrences of deposition at distance (as indicated by the REEDM results). For the Atlas IAS, most of the deposition is likely to occur near the launch facility ("within several hundred feet"). During fourteen launches of Delta II acid deposition occurred at least once over an area of 70,807 square meters, with a maximum distance of 648 meters from the launch pad. Deposition of acid during 20 launches of Atlas IAS did not cause acid deposition.

Maximum amounts of acid produced per launch by the vehicles evaluated in this report are similar to or slightly greater than the maximum amounts evaluated by Schmalzer, et al. (1998). Therefore acid deposition is expected to be similar to, or somewhat greater than that evaluated by them.

Light rains after launches can scavenge Al_2O_3 and HCl from the propellant exhaust cloud. These would be rare events because of the combination of meteorological conditions required. Depending on vehicle and launch location, deposition modeling using REEDM (summarized above in Table R-1) indicates a maximum of 14,094 milligram per square meter of HCl for nominal launches and a maximum of 3,444 milligram per square meter of HCl for launch failures that would be deposited as droplets up to 1,000 to 4,000 meters from the launch site. That amount of HCl for nominal launches equates to 386.55 milliequivalents of hydrogen ion and for launch failures it equates to 94.46 milliequivalents of hydrogen ion. As a hypothetical example, if those amounts of acid were deposited on an unbuffered water body with a depth of 10 centimeters (about 4 inches), there would be 100 liters of water per square meter, and the acid concentrations for nominal launches would be 3.86 milliequivalents per liter and for launch failures would be 0.94 milliequivalents per liter. Without buffering, the resultant pH for nominal launches would be 2.68 and for launch failures would be 3.03. Because approximately 50 milligrams of CaCO_3 would be required to neutralize each milliequivalent of acid, the deposition of 14,094 milligrams of HCl per square meter for

nominal launches and 3,444 milligrams of HCl per square meter for launch failures would consume a total alkalinity of approximately 193 milligram per liter for nominal launches and 47 milligram per liter for launch failures in this example. The deposition modeling indicates that the amount of acid deposited decreases exponentially downwind from the point of maximum deposition, with an initial reduction of about one-half approximately 4,000 meters downwind from the area of maximum deposition. Surface waters at both CCAFS and Vandenberg AFB have ample alkalinity to neutralize the maximum acid deposition, but short-term reductions in pH could occur.

Background Water Quality Data

The tables in this appendix describe acid deposition runs and surface water quality monitoring data from waters near launch facilities at Vandenberg AFB. The information in Table R-2 supports the analysis of the potential for acid deposition at Vandenberg AFB, presented in the Water Quality section of this document (Section 4.9).

TABLE R-2
Surface Water Quality Monitoring Data from Waters Near Launch Facilities at Vandenberg AFB, California

Location/Date	Hardness (mg/L as CaCO ₃)	Alkalinity (mg/L as CaCO ₃)	Acid	pH	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/ L)	Sodium (mg/ L)
Santa Ynez Creek								
3/1/94	540	253	<1	7.5	120	94	59	95
9/1/94	754 ^a	789	49	7.9	170	789	80	140
5/1/95	880	252	15	7.4	170	120	110	120
9/1/95	410	394	9	7.6	116	144	56.6	128
Cañada Honda Creek								
3/1/94	603	309	<1	8.1	110	180	60	150
6/1/94	603	349	<1	7.8	116	250	76	180
9/1/94	749 ^a	0 ^b	<1	8.7	150	240	91	210
12/1/94 ^c	3720 ^a	240	26	8.4	324	12,000	707	5,230
3/1/95	620	240	11	7.6	120	160	78	100
6/1/95	430 ^a	350	<1	7.2	103	250	42	331
9/1/95	1069	352	<1	7.3	166	<1	159	1103
12/1/95 ^c	2805 ^a	250	<1		251	<1	529	3,771
4/1/96	456 ^a	350	<2		87	350	58	170
6/1/96		340	<5			240	70	170
12/1/96		264	<1			1,840	211	1,204
Bear Creek								
3/1/94	440	251	6	0.7 ^d	85	360	55	200
9/1/94	351 ^a			8.6	70	330	43	180
3/1/95	340			7.9	65	220	44	130
9/1/95	449	332	<1	7.2	86		56	175
Spring Canyon								
3/1/95	150			7.7	25	130	21	130