The Space Congress® Proceedings

1997 (34th) Our Space Future - Uniting For Success

May 1st, 1:00 PM

Paper Session III-D - The Environmental Impact of Space Shuttle Exhaust, Year Three

Philip Dooley
(Student)

The Environmental Impact of Space Shuttle Exhaust: (Year 3)

Philip Dooley
Sophomore
Rockledge High School
220 Raider Road
Rockledge, FL 32955
(407) 636-3711

Problem:

Will space shuttle exhaust have a detrimental effect on the ecosystem surrounding the Kennedy Space Center launch pads?

Purpose:

The space shuttle's solid rocket boosters create a large exhaust plume upon ignition. This exhaust plume contains hydrochloric acid, aluminum oxide, along with various other gases and particulates including carbon monoxide, carbon dioxide, and silicon dioxide. The exhaust plume may have detrimental impact on the ecosystem surrounding the Kennedy Space Center launch pads.

Hypothesis:

The space shuttle exhaust will have a detrimental impact on the ecosystem surrounding the Kennedy Space Center launch pads.

Introduction:

Exhaust Plume

The launch of the Space Shuttle creates two large exhaust plumes. They are commonly called the ground cloud, or ground plumes. One plume is created by the Space Shuttle Main Engines (SSMEs). The SSMEs are powered by liquid hydrogen and liquid oxygen so the ground cloud created by the SSMEs is basically a large steam cloud which does not have a very big impact on the plants. The other plume, the one my study focuses on is produced by the twin Solid Rocket Boosters (SRBs). This plume has the potential for much more environmental damage than the other.

Each SRB contains 498,950 kilograms (1,100,185 lbs.) of solid propellant. The composition of the propellant is as follows 16% aluminum powder fuel, 69.9% ammonium perchlorate as an oxidizer, 0.07% iron oxidizer powder, 12.04% rubber based binder of polybutadiene acrylic acid acrlonitrate, 1.96% epoxy curing agent. There are a couple of things, other than just the firing of the SRBs, that creates the ground cloud. One more thing that helps create the ground cloud is the sound suppression water system. This system dumps a large amount of water into the flame trench, an area under the pad which directs the exhaust away from the launch structure. The water absorbs acoustical energy created by the ignition of the SRBs and SSMEs. When the water absorbs the energy, the energy cannot be reflected off the bottom of the flame trench. The acoustical energy created is so great that even after being reflected it could damage the space shuttle and its payload.

The main component of the system is a 530,000 gallon tank. At T-12 seconds, 12 seconds before the time of launch, the system is engaged and water begins to pour and accumulate in the flame trench. The SSMEs engage at T-9 seconds and the SRBs ignite at T+2.8 seconds. By T+18 seconds, 25-30 seconds after the system is engaged the entire 530,000 gallon tank is empty. When the initial blast from the SRBs hits the accumulating water, the water is instantly ionized and vaporized. The exhaust explodes out of the flame trench at 80-110 miles per hour.

When the cloud explodes out of the flame trench and tears along the ground it picks up sand, grasses and shells, that are on the ground in the area of the launch pad. The exhaust plume consists, mainly, of the following four chemicals aluminum oxide Al2O3, accounting for 30.2036% of all deposition, carbon monoxide CO, accounting for 22.8433% of all deposition, hydrochloric acid, HCl, accounting for 21.6872% of all deposition, and water, H2O, accounting for 10.4875% of all deposition. Other particulates in the cloud include coarse sand, fine sand, fire brick, gravel, shell, and any other things that are picked up in the initial ignition of the SRBs. The ground cloud has an approximate total volume of 1.4 x 106 cubic meters or 1,400,000 cubic meters.

Chlorophyll

All green plants contain chlorophyll, a pigment which gives them their color. Chlorophyll is also an essential part of photosynthesis, the process that plants use to manufacture food. In a chemical comparison, chlorophyll is similar to hemoglobin, the red pigment present in blood. Chlorophyll is found in small granules in plant cells called, chloroplasts. Every part of a plant contains chlorophyll, but the leaves are especially rich in chlorophyll because they are specialized for photosynthesis. The chloroplasts also contain other pigments, called cartenoids, which can be yellow, orange, and occasionally red. These cartenoids can sometimes mask the green of the chlorophyll.

There are several types of chlorophyll that occur in plants capable of photosynthesis. The first chlorophyll a, is the most common. Chlorophyll a is distributed throughout almost all green plants. The chemical formula of chlorophyll a is C55H72MgN4O5. Chlorophyll b is the second most widely distributed. Chlorophyll b is found in all higher plants and some algae. The chemical formula of chlorophyll b is C55H70MgN4O6. Bacteria capable of photosynthesis contain yet other types of chlorophyll.

The photosynthesis equation is 6CO2 + 12H20 --in the presence of light and in a green plant--> C6H12O6 + 6H20 + 6O2. In photosynthesis, chlorophyll provides the needed energy. Chlorophyll traps the energy of sunlight and uses it in photosynthesis. When a chlorophyll molecule absorbs a single photon, the smallest unit of light, the energy from that photon is transferred to one of the 752 highly mobile electrons. The electron is thereby raised to a higher energy state. That additional energy is used to break down water into oxygen and hydrogen. The oxygen is then released and the hydrogen is used to convert the carbon dioxide into sugars and starches that the plant can use.

Experimentation Procedure:

1. Select 30 plants to sample. 25 of these plants, 12 brazilian pepper, 8 saw palmetto, and 5 sea myrtle should be in the immediate area around the perimeter of the launch pad. The other 5 plants should be control plants about 5 miles from the launch pad, in an area that has not been affected by the exhaust plume.

2. Select 12 sites around the launch pad to collect soil samples.

3. Select 9 sites around the launch pad to collect water samples.

4. Samples should be collected 4 times. The first one week before a launch, the second one week after that launch. The third should about a week before a second launch at the same launch pad as the first about two months later. The last sampling time should be about a week after the third launch.

5. Collect 75 square cm of leaf material from each plant. A 20 cm deep core sample should be taken at each soil sampling site. Collect 6 ounces of water from each water sampling site.

6. Analyze the samples.

7. Extract the chlorophyll from the plants by boiling them in ethanol for about 10 minutes. Mea sure the amount of chlorophyll using a spectrophotometer.

8. Culture the bacteria from 10 g of the soil first in luria broth for 4 days, then transfer 1 mL to a petri dish for 11 days. Measure and compare the bacterial growth of each of the plates.

9. Using the LaMotte Water Pollution Detection Outfit, Model AM-21, analyze the Alkalinity, Chlo ride, Iron, Nitrates, Phosphates, and pH levels of each sample.

10. Repeat steps 1-6 for each of the 4 sampling times.

11. After all the samples have been collected and analyzed, record the data and analyze the results.

Data:

Plant Samples:
Chlorophyll Levels and Changes:

Control Plants								
	Visit 1	Visit 2	Change v1-v2	% Change 1-2	Visit 3	Visit 4	Change v3-v4	% Change 3-4
CBP 1	1.40	1.20	-0.20	-14.29%	1.10	1.04	-0.06	-5.45%
CBP 2	1.50	1.20	-0.30	-20.00%	1.15	1.10	-0.05	-4.35%
CSP 1	1.10	0.95	-0.15	-13.64%	0.90	0.86	-0.04	-4.44%
CSP 2	0.95	0.80	-0.15	-15.79%	0.75	0.71	-0.04	-5.33%
CSM	1.20	0.95	-0.25	-20.83%	0.90	0.87	-0.03	-3.33%
Experimental Plants								
	Visit 1	Visit 2	Change	% Change	Visit 3	Visit 4	Change v3-v4	% Change 3-4
EBP 1	0.95	0.85	-0.10	-10.53%	0.80	0.75	-0.05	-6.25%
EBP 2	0.85	0.66	-0.19	-22.35%	0.64	0.50	-0.14	-21.88%
EBP 3	0.83	0.51	-0.32	-38.92%	0.48	0.37	-0.11	-22.92%
EBP 4	0.94	0.55	-0.39	-41.49%	0.52	0.40	-0.12	-23.08%
EBP 5	1.00	0.80	-0.20	-20.00%	0.76	0.74	-0.02	-2.63%
EBP 6	0.94	0.85	-0.09	-9.57%	0.82	0.78	-0.04	-4.88%
EBP 7	0.91	0.55	-0.36	-39.56%	0.51	0.38	-0.13	-25.49%
EBP 8	0.85	0.25	-0.60	-70.59%	0.23	0.10	-0.13	-56.52%
EBP 9	1.10	0.80	-0.30	-27.27%	0.74	0.72	-0.02	-2.70%
EBP 10	1.10	0.80	-0.30	-27.27%	0.76	0.70	-0.06	-7.89%
EBP 11	0.95	0.80	-0.15	-15.79%	0.75	0.71	-0.04	-5.33%
EBP 12	1.00	0.80	-0.20	-20.00%	0.78	0.75	-0.03	-3.85%
ESP 1	1.50	1.25	-0.25	-16.67%	1.16	1.10	-0.06	-5.17%
ESP 2	1.80	0.95	-0.85	-47.22%	0.90	0.62	-0.28	-31.11%
ESP 3	1.70	1.10	-0.60	-35.29%	1.05	1.00	-0.05	-4.76%
ESP 4	2.00	1.50	-0.50	-25.00%	1.42	1.35	-0.07	-4.93%
ESP 5	3.00	1.25	-1.75	-58.33%	1.14	0.85	-0.29	-25.44%
ESP 6	2.50	1.00	-1.50	-60.00%	0.91	0.62	-0.29	-31.87%
ESP 7	2.10	1.85	-0.25	-11.90%	1.74	1.65	-0.09	-5.17%
ESP 8	2.00	1.75	-0.25	-12.50%	1.65	1.55	-0.10	-6.06%
ESM 1	1.80	1.50	-0.30	-16.67%	1.37	1.27	-0.10	-7.30%
ESM 2	1.30	0.75	-0.55	-42.31%	0.71	0.50	-0.21	-29.58%
ESM 3	0.95	0.64	-0.31	-32.63%	0.60	0.41	-0.19	-31.67%
ESM 4	1.75	1.30	-0.45	-25.71%	1.20	1.15	-0.05	-4.17%
ESM 5	1.60	1.30	-0.30	-18.75%	1.25	1.17	-0.08	-6.40%

Soil Samples:
Bacterial Growth:

Number	V1 mm	V1 %	V2 mm	V2 %	Ch. V1-V2 mm	Ch. V1-V2 %
S1	6211.4	98.10%	5494.5	86.77%	-716.9	-11.32%
S2	5786.0	91.38%	5594.5	88.35%	-191.5	-3.02%
S3	6006.2	94.85%	5732.0	90.52%	-274.2	-4.33%
S4	5765.1	91.05%	5294.5	83.61%	-470.6	-7.43%
S5	6278.0	99.15%	5675.7	89.64%	-602.3	-9.51%
S6	6220.0	98.23%	5909.5	93.33%	-310.5	-4.90%
S7	6309.5	99.64%	6094.5	96.25%	-215.0	-3.40%
S8	6326.0	99.91%	5894.5	93.09%	-431.5	-6.81%
S9	5757.7	90.93%	5463.5	86.28%	-294.2	-4.65%
S10	6204.0	97.98%	5507.0	86.97%	-697.0	-11.01%
S11	6108.5	96.47%	5119.5	80.85%	-989.0	-15.62%
S12	6211.5	98.10%	5182.0	81.84%	-1029.5	-16.26%

Number	V3 mm	V3 %	V4 mm	V4 %	Ch. V3-V4 mm	Ch. V3-V4 %
S1	5542.3	87.53%	5288.5	83.52%	-253.8	-4.01%
S2	5628.9	88.90%	5490.9	86.72%	-138.0	-2.18%
S3	5780.4	91.29%	5574.8	88.04%	-205.6	-3.25%
S4	5409.6	85.43%	5112.1	80.73%	-297.5	-4.70%
S5	5807.1	91.71%	5545.7	87.58%	-261.4	-4.13%
S6	5928.8	93.63%	5777.2	91.24%	-151.6	-2.39%
S7	6138.5	96.94%	6029.6	95.22%	-108.9	-1.72%
S8	5908.6	93.31%	5757.4	90.93%	-151.2	-2.39%
S9	5545.7	87.58%	5444.9	85.99%	-100.8	-1.59%
S10	5611.2	88.62%	5263.4	83.12%	-347.8	-5.49%
S11	5344.1	84.40%	5072.0	80.10%	-272.1	-4.30%
S12	5411.7	85.47%	4920.8	77.71%	-490.9	-7.75%

Note: "mm" means square millimeters of growth on the petridish; "%" means the percentage of the petridish covered by growth.

Water Samples:

Alkalinity				
Number	Visit 1 (ppm)	Visit 2 (ppm)	Visit 3 (ppm)	Visit 4 (ppm)
W1	350	340	370	360
W2	240	215	220	184
W3	310	300	320	315
W4	220	190	202	160
W5	160	0	38	0
W6	340	280	314	220
W7	370	290	304	200
W8	590	435	462	315
W9	135	130	145	140
Chloride				
Number	Visit 1 (ppm)	Visit 2 (ppm)	Visit 3 (ppm)	Visit 4 (ppm)
W1	2000	1900	2000	2025
W2	800	1000	1150	1600
W3	1000	975	1000	1020
W4	2800	5400	4400	6000
W5	3200	8400	6400	9800
W6	2750	3825	3750	4850
W7	2700	3850	3600	5000
W8	2550	4150	4000	5750
W9	3600	3550	3450	3650
Iron				
Number	Visit 1 (ppm)	Visit 2 (ppm)	Visit 3 (ppm)	Visit 4 (ppm)
W1	0	0	0.5	0.0
W2	0	1	0.5	4.0
W3	0	0	0.0	0.0
W4	0	1	0.0	0.5
W5	0	10	1.5	1.0
W6	0	1	0.0	0.5
W7	0	2	0.0	1.0
W8	4	8	0.0	3.0
W9	0	0	0.0	0.0
pH				
Number	Visit 1	Visit 2	Visit 3	Visit 4
W1	7.5	7.5	7.5	8.0
W2	7.0	7.0	7.5	7.0
W3	7.5	7.5	7.5	7.5
W4	7.5	7.0	7.0	6.5
W5	7.0	4.0	6.0	4.5
W6	7.5	7.0	7.0	6.5
W7	8.0	7.0	7.5	7.0
W8	8.0	7.0	8.0	7.0
W9	7.0	7.5	8.0	8.5

Water Samples:

Phosphates				
Number	Visit 1 (ppm)	Visit 2 (ppm)	Visit 3 (ppm)	Visit 4 (ppm)
W1	0.00	0.00	0.00	3.50
W2	0.00	0.00	0.50	4.50
W3	0.50	3.00	7.00	2.00
W4	0.00	0.75	5.00	0.50
W5	0.00	7.00	0.50	7.50
W6	0.00	1.00	1.50	1.00
W7	0.00	0.50	0.00	0.50
W8	2.00	9.00	0.25	0.00
W9	0.00	0.00	0.50	0.00
Nitrates				
Number	Visit 1 (ppm)	Visit 2 (ppm)	Visit 3 (ppm)	Visit 4 (ppm)
W1	1.0	3.5	0.5	0.5
W2	0.5	1.0	0.0	0.5
W3	0.5	9.0	10.0	1.0
W4	1.5	0.5	0.0	0.0
W5	0.5	0.0	9.5	6.0
W6	0.5	10.0	0.5	0.5
W7	2.0	1.5	1.0	0.0
W8	0.0	0.0	0.5	0.0
W9	0.5	2.0	1.0	0.5

Results:

The results are as follows: the control plants experienced an average drop in chlorophyll of 16.91% from visit 1 to visit 2. They experienced an average drop in chlorophyll of 5.85% from visit 2 to visit 3, and an average drop in chlorophyll of 4.58% from visit 3 to visit 4. This is a total average drop in chlorophyll of 25.39% from visit 1 to visit 4. This loss of chlorophyll can be attributed to seasonal changes associated with cooler weather from November to January.

The experimental brazilain pepper that were not affected by space shuttle exhaust experienced an average drop in chlorophyll of 19.09% from visit 1 to visit 2. They experienced an average drop in chlorophyll of 4.84% from visit 2 to visit 3, and an average drop in chlorophyll of 4.79% from visit 3 to visit 4. This is a total average drop in chlorophyll of 26.46% from visit 1 to visit 4. These drops are almost identical to those of the control plants for the same time periods.

The experimental brazilain pepper that were affected by space shuttle exhaust experienced an average drop in chlorophyll of 47.64% from visit 1 to visit 2. They experienced an average drop in chlorophyll of 6.65% from visit 2 to visit 3, and an average drop in chlorophyll of 29.92% from visit 3 to visit 4. This is a total average drop in chlorophyll of 60.16% from visit 1 to visit 4. The drops

for the periods of exposure, from visit 1 to visit 2 and visit 3 to visit 4, are much higher in the exposed plants than the unexposed plants or the control plants.
The experimental saw palmetto that were not affected by space shuttle exhaust experienced an average drop in chlorophyll of 20.27% from visit 1 to visit 2. They experienced an average drop in chlorophyll of 5.75% from visit 2 to visit 3, and an average drop in chlorophyll of 5.22% from visit 3 to visit 4. This is a total average drop in chlorophyll of 28.86% from visit 1 to visit 4. These drops are almost identical to those of the control plants for the same time periods.

The experimental saw palmetto that were affected by space shuttle exhaust experienced an average drop in chlorophyll of 55.18% from visit 1 to visit 2. They experienced an average drop in chlorophyll of 7.69% from visit 2 to visit 3, and an average drop in chlorophyll of 29.47% from visit 3 to visit 4. This is a total average drop in chlorophyll of 70.81% from visit 1 to visit 4. Notice how like the brazilian pepper there is over a 50% loss of chlorophyll in exposed plants.

The experimental sea myrtle that were not affected by space shuttle exhaust experienced an average drop in chlorophyll of 20.38% from visit 1 to visit 2. They experienced an average drop in chlorophyll of 6.74% from visit 2 to visit 3, and an average drop in chlorophyll of 5.96% from visit 3 to visit 4. This is a total average drop in chlorophyll of 30.20% from visit 1 to visit 4. These drops are little more extreme than those of the control plants, but this can be explained by the fact that of the control plants the sea myrtle did experience the largest loss.

The experimental sea myrtle that were affected by space shuttle exhaust experienced an average drop in chlorophyll of 37.47% from visit 1 to visit 2. They experienced an average drop in chlorophyll of 5.79% from visit 2 to visit 3, and an average drop in chlorophyll of 30.63% from visit 3 to visit 4. This is a total average drop in chlorophyll of 59.19% from visit 1 to visit 4. Once again, the exposed plants experienced a drop in chlorophyll greater than 50%.

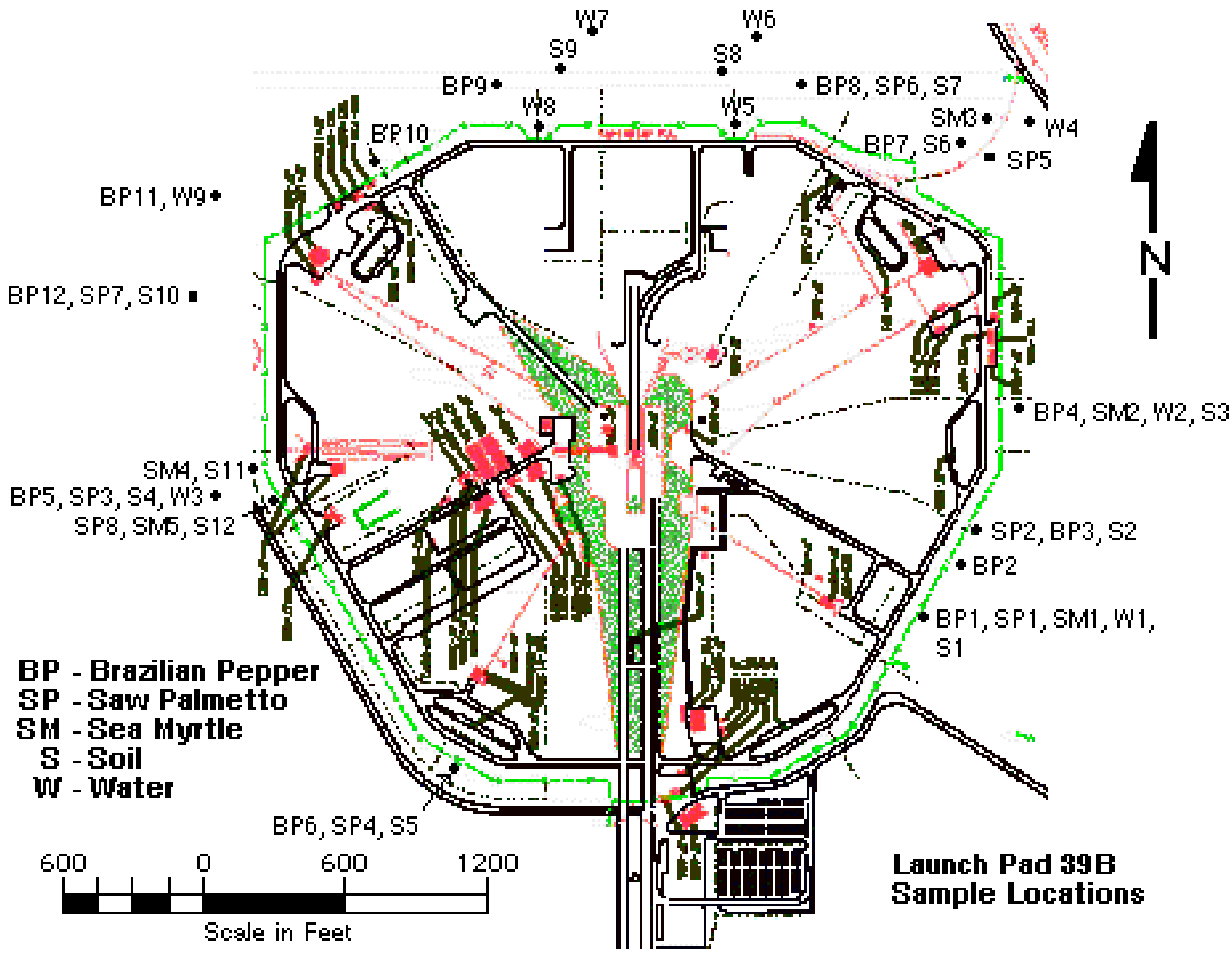
Soil samples that were not exposed to space shuttle exhaust experienced an average drop in bacteria of 11.86% from visit 1 to visit 2. They experienced an average drop in bacteria of 2.25% from visit 2 to visit 3, and a drop in bacteria of 5.06% from visit 3 to visit 4. This is an overall drop in bacteria of 14.68% from visit 1 to visit 4.

Soil samples that were exposed to space shuttle exhaust experienced an average drop in bacteria of 4.52% from visit 1 to visit 2. They experienced an average drop in bacteria of 0.64% from visit 2 to visit 3, and a drop in bacteria of 2.25% from visit 3 to visit 4. This is an overall drop in bacteria of 6.13% from visit 1 to visit 4. The exposed soil samples experienced 8.55% less of a loss in soil bacteria than the unexposed samples.

The unexposed water samples experienced an average drop in alkalinity of 2.65% from visit 1 to visit 4. This is mirrored by a gain in chloride of 2.94% for the same time period. These samples experienced an average gain in pH of 4.04%. The unexposed water samples, from visit 1 to visit 4, stayed at 0 ppm iron. From visit 2 to visit 3, there was a slight trace of iron in W1 but by visit 4 there was once again no trace of iron. There is no clear patter in the phosphate and nitrate data. Two water samples that had no trace of phosphates gained 4 ppm, while another stayed at 0. In regard to nitrates W1 dropped 0.5 ppm, W3 and W9 experienced no change.

The exposed water samples experienced an average drop in alkalinity of 65.80% from visit 1 to visit 4. This is mirrored by a gain in chloride of 63.35% for the same time period. These samples experienced an average drop in pH of 19.15%. The iron levels of exposed water samples rose an average of 1 ppm. There are large fluctuations in the phosphate and nitrate levels of the water samples. Due to a large range in these levels averages cannot be used because they are misleading and statistically invalid.

Following STS-80 the following samples were affected by the exhaust plume: BP3, BP4, BP7, BP8, SP2, SP5, SP6, SM2, SM3, S2, S3, S6, S7, S8, S9, W2, W4, W5, W6, W7, and W8. Following STS-81 the following samples were affected by the exhaust plume: BP2, BP3, BP4, BP7, BP8, SP2, SP5, SP6, SM2, SM3, S2, S3, S6, S7, S8, S9, W2, W4, W5, W6, W7, and W8.



Conclusion:

This project concludes that space shuttle exhaust has a detrimental impact on plants, and reduces the water quality somewhat, although the impact on the soil appears to be minimal.

Future Studies:

This project could be expanded in the following ways: check the plants or the bacteria in the soil for genetic mutations, a long term study could be set up where the same plants are monitored for a year to see if time of day, time of year, or air temperature have any effect on the impact of the exhaust plume.

Bibliography:

Anderson, B.J., and V.W. Keller. Space Shuttle Exhaust Cloud Properties. NASA Technical Paper 2258. Alabama: John C. Marshall Space Flight Center, 1983.

Dreschel, Thomas W., and Carlton R. Hall. Near-field Deposition Patters Resulting from Launches of the Space Transportation System at the John F. Kennedy Space Center, Florida. NASA Technical Memorandum 93104. Florida: John F. Kennedy Space Center, 1985.

Schmalzer, Paul A., et al. Environmental Monitoring of Space Shuttle Launches at Kennedy Space Center: The First Ten Years. AIAA93-0303. Washington D.C.: American Institute of Aeronautics and Astronautics, 1993.