APPENDIX A: EMISSIONS AFTERBURNING LOADS FOR PROGRAMMATIC AND NON-PROGRAMMATIC LAUNCHES

This appendix identifies the emissions/afterburning products from various propellants used in launch vehicle (LV) activities. It also discusses a methodology for determining the loads of these emissions in the various atmospheric layers and provides a table of these loads by layer. Finally, the appendix describes how the methodology can be linked with the categorization of LVs (e.g., payload capacity, launch method) proposed in the PEIS and how the programmatic and non-programmatic load of these emissions is calculated.

Emissions/Afterburning Products

The emissions/afterburning products from LV activities depend on the types of propellants used. Table A-1 provides the main emissions/afterburning products from various propellants that are currently used in spaceflight or are under development.[a,b,c,d,e,f]

TABLE A-1
MAIN EXHAUST PRODUCTS

Solid	Liquid Hydrocarbon	Hypergolic	Cryogenic	Hybrid Propellant
HCl, Al_2O_3, CO, CO_2, NO_x, Cl, H_2O	CO_2, CO, H_2, H_2O, OH, NO_x	CO_2, CO, NO_x, H_2O, H_2	H_2O, H_2	CO, CO_2, H_2, H_2O, NO_x, OH

Methodology for Determining Emissions Loads in Various Atmospheric Layers

This methodology was developed to apply to categories and specific types of LVs as identified in the proposed action of the PEIS. However, to create a generalized method applicable to any LV, specific LV data (e.g., propellant type and quantity) were used and then the method was validated against emissions load data in existing EA/EIS studies of specific LV launch activities. Consequently, the specific data presented in the development of this methodology are meant to be illustrative only. Later in this appendix, the application of the methodology to the categories of LVs discussed in the PEIS will be explained.

There are four principal layers in the Earth's atmosphere: the troposphere, stratosphere, mesosphere, and ionosphere. They are generally defined by temperature, structure, density, composition and degree of ionization.[g] The approximate altitude of these layers is provided in Table A-2. The troposphere is the turbulent and weather region containing 75 percent of the total mass of the Earth's atmosphere. The troposphere is critical because any LV emissions can potentially increase ambient pollution in the air or can fall back or be rained back to Earth. The stratosphere contains a critical ozone layer for protection from ultraviolet radiation. Both the stratosphere and the troposphere are of most concern when considering greenhouse gases and global warming.

TABLE A-2
ALTITUDE RANGE FOR VARIOUS ATMOSPHERIC LAYERS

	Troposphere	Stratosphere	Mesosphere	Ionosphere
Altitude Range	Surface to 10 km	10 to 50 km	50 to 80 km	80 to 1,000 km

LVs used to transport payloads into orbit will be propelled through several layers of the atmosphere including the troposphere, stratosphere, mesosphere, and ionosphere. The load of the emissions in each of these atmospheric layers depends on the stage firing, the type of propellant, the burn rate of propellant, and the residence time in the atmospheric layer. In developing the following methodology, the initial focus was on the tropospheric and the stratospheric layers that are generally viewed with greater concern environmentally. Also, the methodology was tested using solid propellant because most programmatic launches employ LVs that use solid rocket motors from launch through both the troposphere and stratosphere. It was assumed that the solid propellant was hydroxy-terminated polybutadiene, ammonium perchlorate and aluminum powder. HCl emissions were also a focus because of concerns for both ground exposure and ozone depletion. Using various reference sources,[h,i,j] a residence time of between 120 and 140 seconds was found to be typical for a variety of LVs to go from launch through the stratosphere (50 km). This residence time range was used as the basis for determining the emissions loads in the troposphere and stratosphere. Using the information from Table 5-2 in Section 5 of the PEIS, the quantity of SRM propellant expended during the first 120 seconds of the flight for any vehicle was first determined. Then, this quantity was multiplied by a weight fraction of HCl produced from a quantity of propellant burned. The weight fraction for HCl varied only narrowly from 17 to 21 percent in six different studies covering six different LVs as shown in Table A-3.[k,l,m,n,o,p] To be conservative, 21 percent was used.

TABLE A-3
HCl WEIGHT FRACTION EMISSIONS

HCl Weight Fraction	Endnote Reference
0.207	m
0.17	n
0.17	l
0.2	o
0.206	k
0.206	p

Table A-4 presents the calculated HCl load to the troposphere and the stratosphere for a variety of LVs. The calculated HCl load was then further validated against three EA/EIS studies that provided the quantity of HCl that could impact ozone depletion and the environment. In these studies, the HCl evaluated for ozone depletion was the quantity of HCl emissions released to both the troposphere and stratosphere. The results obtained using this methodology generally were more conservative yet still correlated with the data in the EA/EISs.

TABLE A-4
LOAD OF HCl TO TROPOSPHERE AND STRATOSPHERE COMBINED

Vehicle	Solid Propellant Burned (kg) in Troposphere and Stratosphere *	Calculated HCl Load (kg) in Troposphere and Stratosphere **	HCl Load (kg) in EA/EISs
Taurus	56,500	11,900	--
Athena	70,800	14,900	--
LLV2	74,500	15,600	14,300 - endnote l
Delta 7925	105,300	22,100	--
Atlas IIAS	40,800	8,600	7,200 - endnote n
Delta III	153,000	32,000	--
Delta IV M+	119,225	25,037	--
Titan III	420,000	88,200	--
Titan IV	540,000	113,000	110,000 - endnote m

* Quantities based on various documents [q]
** Calculated based on equation (Quantity of solid rocket propellant)(0.21) = Quantity of HCl

This method could be easily applied to the other emissions because weight fraction information is available. The following weight fractions for emissions in Table A-5 are based on various studies.[r,s,t,u,v] There was generally a narrow range for Al_20_3, HCl, and Cl. To be conservative, the highest percentages for Al_2O_3, HCl, and Cl were selected. In most studies, the weight fraction information for CO, CO_2, and H_2 pertains to the exhaust directly from the nozzle and not after the exhaust could react with the air. However, most studies acknowledge that in the troposphere and stratosphere, the CO will almost completely react to CO_2 in the high temperatures of the exhaust plume. Likewise, H_2 and N_2 in the exhaust plume will almost completely react to form H_2O and NO_x. Consequently, the CO, CO_2, H_2O, and NO_x in Table A-5 have been calculated based on the assumption that all of the CO goes to CO_2, all of the H_2 goes to H_2O, and all of the N_2 goes to NO_x.

TABLE A-5
WEIGHT FRACTION OF OTHER SOLID PROPELLANT EMISSIONS

HCl	Al_2O_3	Cl	CO_2	CO	NO_2	N_2	H_20
0.21	0.38	0.0028	0.46	-	0.27	-	0.27

In the mesosphere, where the oxidation reaction is less likely to occur because of the lack of oxygen, the weight fractions at the exhaust nozzle are 0.23 for CO and 0.03 for CO_2. Likewise, in the mesosphere, the weight fractions at the exhaust nozzle are 0.063 for H_2O, 0.0247 for H_2, zero for NO_x, and 0.083 for N_2.

To determine loads to the troposphere, stratosphere, and mesosphere individually, individual residence times for the LVs were needed. From a few select EA/EISs,[w,x] it was determined that generally the residence time in the troposphere, stratosphere and mesosphere was approximately 60 seconds, 60 seconds, and 50 seconds, respectively. The approach to determine the residence time for the stratosphere was validated by comparing the calculation of the chlorine emissions to the stratosphere from LV exhaust with a report by Prather (1990) that asserted that the Titan IV vehicle contributed 32 tons of Cl to the stratosphere.[y] Using the assumptions that the stratosphere begins above 15 kilometers, the Cl input from the Titan IV was calculated as 37 tons. Because the same launch vehicle stages typically travel through

both the troposphere and stratosphere and because the residence time in both atmospheric layers are the same, it was assumed that the type and quantity of propellant emissions in the troposphere would be the same as the stratosphere.

Using Above Methodology with LV Categories in Proposed Action

Most programmatic launches use solid propellant to propel the vehicle through the troposphere and stratosphere although other propellants such as liquid oxygen (LO_x) and kerosene (RP1) are used. In fact, several propellants in different launch vehicle stages may burn at the same time. Generally, the total quantity of propellant used is related to the payload capacity sizes (small, medium, intermediate, and high) although other factors play a role. Table A-6 shows that payload capacity is related to the total propellant quantity. The programmatic loads for years 2000-2010 were calculated based on specific vehicles anticipated to be used during this time period. For example, to determine programmatic load for hydrogen chloride, the number of projected programmatic launches (from the proposed action) involving vehicles (e.g., Delta 2) that have the propellants (e.g., solid rocket propellant) that emit hydrogen chloride was identified. The quantity of hydrogen chloride could be estimated from the total amount of solid propellant associated with these vehicles. In this same way, the total load of other propellant emissions to the troposphere and stratosphere could then be estimated.

TABLE A-6
RELATIONSHIP BETWEEN PAYLOAD CAPACITY AND PROPELLANT QUANTITY USED IN THE TROPOSPHERE AND STRATOSPHERE

Payload Capacity	Launch Vehicle	Solid Propellant Quantity (kg)	LO_x-RP1 Propellant Quantity (kg)	Hypergol Propellant Quantity (kg)	LO_x-LH_2 Propellant Quantity (kg)	Total Propellant (kg)
Small	Athena	48,000	-	-	-	48,000
	Taurus	56,500	-	-	-	56,500
	Titan 2	100,000	-	-	-	100,000
Medium	Delta 2	105,000	44,000	-	-	149,000
Intermediate	Atlas IISA	40,000	114,000	-	-	154,000
	Delta 3	153,000	44,000	-	-	197,000
High	Sea Launch	-	280,000	-	-	280,000
	Titan 4b	626,000	-	126,000	-	752,000
	Space Shuttle	1,000,000	-	-	172,000	1,172,000

Application of Method to Liquid, Liquid/Solid, and Hybrid Propellant Launch Vehicles

The approach can be used with liquid LO_x-RP1, hypergol, LOx-H_2 and hybrid LVs. The residence time, burn rate of the propellant, and if the propellant was ignited at launch or after the LV exits the stratosphere would be used. The weighted emission values for the liquids hydrocarbon (LO_x-RP1) and liquid hydrazine are presented below in Tables A-7 and A-8, respectively. Because hybrid propellant LVs are under development, literature references detailing the emission weighted fractions of emissions from these LV propulsion systems are not available. Therefore, the reaction product quantities could be estimated based on reaction kinetics of LO_x and solid propellant (i.e., hydroxy-terminated polybutadiene). It was assumed that the emission-weighted fractions are similar to the weighted fractions for the LO_x/RP1 propellants.

TABLE A-7
WEIGHT FRACTION OF LIQUID HYDROCARBON (LO_x-RP1) EMISSIONS

CO_2	CO	OH	H_2	H_2O
0.931	--	0.035	0.0	0.34

In the mesosphere, where the oxidation reaction is less likely to occur because of the lack of oxygen, the weight fractions at the exhaust nozzle are 0.44 for CO and 0.24 for CO_2. Likewise, in the mesosphere, the weight fractions at the exhaust nozzle are 0.27 for H_2O and 0.0099 for H_2.

TABLE A-8
WEIGHT FRACTION OF LIQUID HYPERGOL (N_2O_4-AEROZINE 50) EMISSIONS

CO_2	CO	NO_2	N_2	H_20
0.22	--	1.36	--	0.35

In the mesosphere, where the oxidation reaction is less likely to occur because of the lack of oxygen, the weight fractions at the exhaust nozzle are 0.03 for CO and 0.18 for CO_2. Likewise, in the mesosphere, the weight fractions at the exhaust nozzle are 0.019 for NO_x, and 0.41 for N_2.

Some LVs use two different types of propellants simultaneously (i.e., Atlas IIAS solid/liquid) at launch. The emissions would be some combination of the propellant emissions. For LVs that burn different propellants in different engine systems at lift-off in relatively equal quantities (e.g., 50% liquid hydrocarbon and 50% solid propellant, a combined weight fraction of liquid hydrocarbon and solid propellant was used (Table A-9). In cases where vastly different proportions of different propellants are used, the combined fractions were weighted differently.

TABLE A-9
COMBINED WEIGHT FRACTION OF LIQUID HYDROCARBON (LO_x-RP1)/SOLID PROPELLANT EMISSIONS (DUAL USE; ATLAS)*

HCl	Al_2O_3	Cl	CO_2	CO	NO_2	N_2	H_20	OH	H_2
0.105	0.185	0.0014	0.69	-	0.13	-	0.31	0.017	0.017

*Assumes 50% liquid hydrocarbon and 50% solid propellant.

In the mesosphere, where the oxidation reaction is less likely to occur because of the lack of oxygen, the weight fractions at the exhaust nozzle are 0.34 for CO and 0.13 for CO_2. Because other launch vehicles use different combinations of propellants other than solid and LO_x-RP1, other combined weight fractions were calculated and used.

Calculation of Emission Loads for Programmatic Activities

Programmatic activities include anticipated U.S. licensed launches. Table A-10 provides information and estimates used to make calculations of emissions load to the troposphere and stratosphere. Table A-10 estimates the number of programmatic launches in the U.S. from 2000-2010 by payload capacity and the propellant system(s) used. The estimates are based on several market projections including the Commercial Spacecraft Mission Model Update[z] and the 2000 Commercial Space Transportation Forecasts.[aa] The number of launches includes U.S. licensed launches from government launch facilities on both coasts. The table also presents estimates of the percent expenditure

of different propellants used in the troposphere/stratosphere based on the payload capacity and propellant system(s) used. The number of launches of each payload capacity vehicle is then multiplied by the percentages to give the number of LVs using certain propellant types within each payload capacity. The same information is provided for the mesosphere.

TABLE A-10
ESTIMATED NUMBER OF LICENSED (PROGRAMMATIC) U.S. LAUNCHES 2000-2010 BY PAYLOAD AND PROPELLANT TYPE

Payload Capacity	Estimated Launches	Percent Launch Vehicles using Various Propellant Types Used During Flight through Troposphere/ Stratosphere	Number of Flights Using Propellant Type in Troposphere/ Stratosphere	Propellant Types Used During Flight through Mesosphere	Number of Flights Using Propellant Type in Mesosphere
Small	72	100% Solid	72	100% Solid	72
Medium	22	100% Solid/LO_x-RP1	22	100% LO_x-RP1	22
Intermediate	75	75% Solid/LO_x-RP1 25% Hybrid	56 19	75% Solid/LO_x-RP1 25% Hybrid	56 19
High	92	50% LO_x-RP1 25% Solid-LO_x-RP1 25% Solid-LO_x-H_2	46 23 23	75% LO_x-RP1 25% LO_x-LH_2	69 23

Table A-11 presents the estimated load to the troposphere from programmatic U.S. launches from 2000-2010. The table uses information from many of the previous tables in this Appendix. The load to the stratosphere will be the same as the load to the troposphere because the residence time is the same (60 seconds) and the propellant type used is the same. However the load to the mesosphere is calculated using a 50-second residence time and the types of propellant listed in Table A-10. Table A-12 provides the loads to the mesosphere. The propellant quantities associated with the flight in the troposphere/stratosphere and mesosphere were based on quantities used in current programmatic launch activities and based on an AIAA document.[bb]

Table A-11
ESTIMATED EMISSION LOADS TO TROPOSPHERE FROM PROGRAMMATIC U.S. LICENSED LAUNCHES FROM 2000-2010

Payload Capacity	Percent Launch Vehicles using Various Propellant Types During Flight through Troposphere	Example of Launch Vehicle Type	Number of Flights in Troposphere	Propellant Quantity in Troposphere	Emission Loads (kg x 10^3)**					
					Al_2O_3	Cl	CO_2	H_2O	HCl	NO_2
Small	100% Solid	Taurus/Athena	72	30,000	821	6	994	583	454	583
Medium	100% LO_x-RP1/Solid	Delta 2	22	75,000	314	2	1,148	503	173	223
Intermediate	75% Solid/LO_x-RP1	Delta 3, Atlas IIAS	56	100,000	1,055	8	3,860	1,693	583	749
	25% Hybrid	to be developed	19	100,000	-	-	1,722	629	-	-
High	25% Solid-LO_x-LH_2	Delta 4H commercial	23	110,000	481	4	582	1,607	266	342
	50% LO_x-RP1	Zenit Sea Launch/BA-2	46	250,000	-	-	10,707	3,910	-	-
	25% Solid/LO_x-RP1	Atlas 5 Commercial	23	250,000	1,093	8	3,999	1,754	604	776
Total (10^3 kg)					3,762	28	23,011	10,679	2,079	2,673
Total (tons)*					4,147	31	25,365	11,771	2,292	2,946

* Ton equals 2,000 pounds

** Calculations subject to rounding

Table A-12
ESTIMATED EMISSION LOADS TO MESOSPHERE FROM PROGRAMMATIC U.S. LICENSED LAUNCHES FROM 2000-2010

Payload Capacity	Percent Launch Vehicles using Various Propellant Types During Flight through Mesosphere	Example of Launch Vehicle Type	Number of Flights Using Propellant Type	Propellant Quantity in Troposphere	Emission Loads (kg x 10^3)**									
					Al_2O_3	Cl	CO_2	CO	H_2	H_2O	HCl	OH	NO_2	N_2
Small	100% Solid	Taurus/Athena	72	5,000	137	1	11	83	9	23	76	-	-	30
Medium	100% LO_x-RP1	Delta 2	22	20,000	-	-	106	194	4	110	-	15	-	-
Intermediate	75% LO_x-RP1	Delta 3, Atlas IIAS	56	40,000	-	-	533	977	22	555	-	78	-	-
	25% Hybrid	to be developed	19	40,000	-	-	178	326	7	185	-	26	-	-
High	50% LO_x-RP1	Zenit Sea Launch/BA-1 Atlas V Commercial	69	50,000	-	-	828	1,518	34	863	-	121	-	-
	25% LO_x-LH2	Delta 4 Commercial	23	40,000	-	-	-	-	-	920	-	-	-	-
	137	1	1,655	3,097	76	2,655	76	240	-	30				
Total (10^3 kg)					151	1	1,824	3,414	84	2,927	83	264	-	33

* Ton equals 2,000 pounds
** Calculation subject to rounding

Calculation of Emission Loads for Non-Programmatic Activities

Non-programmatic activities include anticipated U.S. Government space activities (non-licensed e.g., NASA, USAF), foreign government (e.g., Russia, Europe, China, Japan, etc.) space activities, non-U.S. commercial (e.g., Ariane) activities and civil aviation industry, and all other industrial activities. Table A-13 estimates the number of non-programmatic launches from 2000-2010 by payload capacity. The basis for the estimates is provided in the table.

TABLE A-13
ESTIMATED NUMBER OF NON-PROGRAMMATIC LAUNCHES 2000-2010 BY PAYLOAD AND PROPELLANT TYPE*

Non-Programmatic Subcategory	Estimated Launches from 2000-2010	Payload Capacity	Number of Flights
U.S. Government	354	Small	62
		Medium	121
		Intermediate	56
		High	115
Foreign Government	326	Small	32
		Medium	66
		Intermediate	136
		High	92
Non-U.S. Commercial	220	Small	58
		Medium	18
		Intermediate	106
		High	38

*U.S. launches based on total estimates from the Air Force Launch Forecast[cc], DOD launch rates for the Evolved Expendable Launch Vehicle Program[dd], and 8 Space Shuttle Flights per year. Foreign Government launches include launches from Russia, ESA, China, India, and Japan. The estimates are based on information in STAR and historical launch trends. For non-U.S. commercial launches, the number of flights was the worldwide estimate of commercial launches[ee] minus the U.S. licensed launches. Because the worldwide estimates do not include 26 licensed launches at U.S. government facilities, these 26 launches were first subtracted from the U.S. licensed estimate before calculating the non-U.S. commercial launches. In terms of the distribution of the non-U.S. commercial launches in the various payload capacity categories, it was assumed that the profile of LVs for the non-U.S. commercial was the same as the foreign government launches.

Table A-14 presents the load to the troposphere from non-programmatic U.S. Government launches from 2000-2010. The table uses information from many of the previous tables in this Appendix. For the small payloads, the propellant quantities and propellant types were based on small payload capacity launch vehicles historically used by the U.S. government. For the high payloads, the propellant quantities and propellant types were based on the Titan IV and the Shuttle rather than the high capacity payload launch vehicles expected to be used commercially.[ff] The propellant quantities associated with the flight in the troposphere/stratosphere were based on quantities used in current programmatic launch activities and based on an AIAA document.[gg] Note that the load to the troposphere will be the same as the load to the stratosphere because the residence time is the same (60 seconds) and the propellant type used is the same. However, the load to the mesosphere is presented in Table 15 and is calculated using a 50-second residence time. The choice of propellant quantities and propellant types used in Table 15 is based on the same logic and data sources used in the above analysis of load to the troposphere from U.S. Licensed launches.[hh]

Table A-14
ESTIMATED EMISSION LOADS TO TROPOSPHERE FROM NON-PROGRAMMATIC U.S. GOVERNMENT LAUNCHES FROM 2000-2010

Payload Capacity	Percent Launch Vehicles using Various Propellant Types During Flight through Troposphere	Example of Launch Vehicle Type	Number of Flights Using Propellant Type	Propellant Quantity in Troposphere	Emission Loads (kg x 10^3)**					
					Al_2O_3	Cl	CO_2	H_2O	HCl	NO_2
Small	90% Solid	Pegasus/Taurus	56	30,000	636	5	770	452	352	452
	10% Hypergol	Titan 2	6	50,000	-	-	68	109	-	422
Medium	10% Solid	medium launch	12	75,000	345	3	417	245	191	245
	40% Solid/LO_x-RP1	Delta 2	48	75,000	690	5	2,525	1,107	381	490
	25% Solid/LO_x-LH2	Delta 4-Medium	30	75,000	431	3	522	1,441	238	306
	25% LOx-RP1	Atlas 5 medium	30	75,000	-	-	2,112	771	-	-
Intermediate	20% Solid	intermediate	11	100,000	426	3	515	302	235	302
	55% Solid/LO_x-RP1	Atlas2/Delta 3	31	100,000	585	4	2,142	939	323	416
	5% LOx-RP1	Atlas 3, Atlas V intermediate	3	150,000	-	-	391	143	-	-
	20% Solid/LO_x-LH_2	Delta 4-Intermediate	11	150,000	319	2	386	1,067	176	227
High	75% Solid/LO_x-LH_2	Space Shuttle	86	586,000	16,325	120	19,762	19,181	9,022	11,600
	5% LO_x-RP1	Atlas 5 Government	6	400,000	-	-	2,141	782	-	-
	15% Solid/hypergol	Titan 4b	17	315,000	1,714	13	2,278	1,541	947	2,474
	5% LO_x-LH_2	Delta 4-Government	6	205,000	-	-	-	1,179	-	-
Total (10^3 kg)					21,471	158	34,030	29,259	11,865	16,933
Total (tons)*					23,667	174	37,512	32,252	13,079	18,666

* Ton equals 2,000 pounds

** Calculation subject to rounding

TABLE A-15
ESTIMATED EMISSION LOADS TO MESOSPHERE FROM NON-PROGRAMMATIC U.S. GOVERNMENT LAUNCHES FROM 2000-2010

Payload Capacity	Percent Launch Vehicles using Various Propellant Types During Flight through Mesosphere	Example of Launch Vehicle Type	Number of Flights Using Propellant Type	Propellant Quantity in Troposphere	Emission Loads (kg x 10^3)**									
					Al_2O_3	Cl	CO_2	CO	H_2	H_2O	HCl	OH	NO_2	N_2
Small	90% Solid	Pegasus/Taurus	56	5,000	106	1	8	64	7	18	59	-	-	23
	10% Hypergol	Titan 2	6	25,000	-	-	28	5	-	54	-	-	3	64
Medium	10% Solid	medium vehicle	12	20,000	92	1	7	56	6	15	51	-	-	20
	25% LO_x-LH_2	Delta 4 medium	30	20,000	-	-	-	-	-	605	-	-	-	-
	65% LO_x-RP1	Delta 2, Atlas 5 medium	79	20,000	-	-	378	692	16	393	-	55	-	-
Intermediate	20% Solid	intermediate vehicle	11	25,000	106	1	8	64	7	18	59	-	-	23
	60% LO_x-RP1	Atlas 2/3/Delta3	34	40,000	-	-	323	591	13	336	-	47	-	-
	20% LO_x-LH_2	Delta 4 intermediate	11	40,000	-	-	-	-	-	448	-	-	-	-
High	5% LO_x-RPI	Atlas 5 government	6	60,000	-	-	83	152	3	86	-	12	-	-
	15% Hypergol	Titan 4b	17	50,000	-	-	155	26	-	302	-	-	16	354
	80% LO_x-LH_2	Space Shuttle, Delta 4 government	92	70,000	-	-	-	-	-	6,440	-	-	-	-
Total (10^3 kg)					304	2	990	1,650	52	8,715	168	114	19	484
Total (tons)*					336	2	1,091	1,819	57	9,607	185	126	21	533

* Ton equals 2,000 pounds
** Calculation subject to rounding

To estimate the load from non-U.S. commercial and foreign governments, specific international vehicles that are being used or are being developed were examined. These included the following vehicles Zenit (Russia), Proton (Russia), Ariane IV and V (ESA), Long March (China), H2 (Japan), GSLV (India), PSLV (India), and M-V (Japan). The propellant quantities and propellant types were determined from several sources [ii] as well as which propellant types would be used in the various layers of the Earth's atmosphere. The estimate of the number of non-U.S. commercial launches and foreign government launches are provided in Table A-13. An estimated 220 non-U.S. commercial launches are expected from 2000-2010. The estimated emissions load to the troposphere from non-U.S. commercial launches is provided in Table A-16 and the estimated load to the mesosphere from these same launches are presented in Table A-17. The load to the stratosphere is the same as the load to the troposphere because the residence time and the propellant types used in both these atmospheric layers is basically the same.

The estimated emissions load to the troposphere from foreign government launches is provided in Table A-18 and the load to the mesosphere is presented in Table A-19. The load to the stratosphere is the same as the load to the troposphere because the residence time and the propellant types used in both atmospheric layers is basically the same.

Table A-16
ESTIMATED EMISSION LOADS TO TROPOSPHERE FROM NON-PROGRAMMATIC NON-U.S. COMMERCIAL LAUNCHES FROM 2000-2010

Payload Capacity	Percent Launch Vehicles using Various Propellant Types During Flight through Troposphere	Example of Launch Vehicle Type	Number of Flights Using Propellant Type	Propellant Quantity in Troposphere	Emission Loads (kg x 10^3)**					
					Al_2O_3	Cl	CO_2	H_2O	HCl	NO_2
Small	35% Solid	Leolink/Shavit/M5	20	40,000	309	2	374	219	171	219
	65% Hypergol	Kosmos/Rokot	38	40,000	-	-	332	528	-	2,050
Medium	30% Solid	PSLV, VLS	5	100,000	205	2	248	146	113	146
	55% Hypergol	Tsyklon/Long March 2c	10	70,000	-	-	152	243	-	942
	15% Solid/Hypergol	GSLV	3	100,000	51	0.4	92	84	28	220
Intermediate	40% Hypergol	Long March 3b/Ariane 4	42	100,000	-	-	933	1,480	-	5,770
	10% Solid/LO_x-LH_2	H-2A	11	85,000	291	2	352	342	161	207
	50% LO_x-RP1	Soyuz	53	100,000	-	-	4,930	1,800	-	-
High	60% Hypergol	Proton	23	210,000	-	-	1,050	1,680	-	6,510
	25% LO_x-RP1	Zenit	10	140,000	-	-	1,240	452	-	-
	15% Solid	Ariane5	6	237,000	513	4	621	365	284	365
Total (10^3 kg)					1,369	10.1	10,324	7,339	757	16,429
Total (tons)*					1,509	11.5	11,380	8,090	834	18,109

* Ton equals 2,000 pounds
** Calculation subject to rounding

Table A-17
ESTIMATED EMISSION LOADS TO MESOSPHERE FROM NON-PROGRAMMATIC NON-U.S. COMMERCIAL LAUNCHES FROM 2000-2010

Payload Capacity	Percent Launch Vehicles using Various Propellant Types During Flight through Mesosphere	Example of Launch Vehicle Type	Number of Flights Using Propellant Type	Propellant Quantity in Troposphere	Emission Loads (kg x 10^3)**									
					Al_2O_3	Cl	CO_2	CO	H_2	H_2O	HCl	OH	NO_2	N_2
Small	35% Solid	Leolink/Shavit/M5	20	5,000	39	.3	3	23	2	6	21	-	-	8
	65% Hypergol	Kosmos/Rokot	38	4,000	-	-	27	5	-	53	-	-	3	62
Medium	15% Solid	VLS	3	4,000	4	.03	.3	2	.3	.7	2	-	-	.9
	55% Hypergol	Tsyklon	10	40,000	-	-	71	12	-	139	-	-	8	162
	15% Hypergol	GSLV	3	40,000	-	-	19	3	-	38	-	-	2	44
	15% Hypergol	PSLV, Long March 2c	3	15,000	-	-	7	1	-	14	-	-	.8	17
Intermediate	10% LO_x-LH_2	H-2A	11	10,000	-	-	-	-	-	106	-	-	-	-
	50% LO_x-RP1	Soyuz	53	20,000	-	-	254	466	11	265	-	37	-	-
	40% Hypergol	Long March 3b, Ariane 4	42	40,000	-	-	305	51	-	594	-	-	32	695
High	25% LO_x-RP1	Zenit	10	50,000	-	-	114	209	5	119	-	17	-	-
	60% Hypergol	Proton	23	37,000	-	-	152	25	-	295	-	-	16	346
	15% LO_x-LH_2	Ariane 5	6	13,000	-	-	-	-	-	74	-	-	-	-
Total (10^3 kg)					43	.33	952	799	18.3	1,704	23	54	61.8	1,335
Total (tons)*					47	.36	1049	880	20.2	1,878	25	60	68.1	1,471

* Ton equals 2,000 pounds

** Calculation subject to rounding

Table A-18
ESTIMATED EMISSION LOADS TO TROPOSPHERE FROM NON-PROGRAMMATIC FOREIGN GOVERNMENT LAUNCHES FROM 2000-2010

Payload Capacity	Percent Launch Vehicles using Various Propellant Types During Flight through Troposphere	Example of Launch Vehicle Type	Number of Flights Using Propellant Type	Propellant Quantity in Troposphere	Emission Loads (kg x 10^3)**					
					Al_2O_3	Cl	CO_2	H_2O	HCl	NO_2
Small	35% Solid	Leolink/Shavit/M5	11	40,000	170	1	206	121	94	121
	65% Hypergol	Kosmos/Rokot	21	40,000	0	0	183	291	0	1,132
Medium	30% Solid	PSLV, VLS	20	100,000	752	6	911	535	416	535
	55% Hypergol	Tsyklon/Long March 2c	36	70,000	0	0	559	889	0	3,456
	15% Solid/Hypergol	GSLV	10	100,000	188	1	337	307	104	807
Intermediate	40% Hypergol	Long March 3b, Ariane 4	54	100,000	0	0	1,197	1,904	0	7,398
	10% Solid/LO_x-LH_2	H-2A	14	85,000	373	3	452	439	206	265
	50% LO_x-RP1	Soyuz	68	100,000	0	0	6,331	2,312	0	0
High	60% Hypergol	Proton	55	210,000	0	0	2,550	4,057	0	15,765
	25% LO_x-RP1	Zenit	23	140,000	0	0	2,998	1,095	0	0
	15% Solid	Ariane5	14	237,000	1,243	9	1,504	883	687	883
Total (10^3 kg)					2,727	20	17,228	12,833	1,507	30,362
Total (tons)*					3,006	22	18,990	14,146	1,661	33,468

* Ton equals 2,000 pounds

** Calculation subject to rounding

Table A-19
ESTIMATED EMISSION LOADS TO MESOSPHERE FROM NON-PROGRAMMATIC FOREIGN GOVERNMENT LAUNCHES FROM 2000-2010

Payload Capacity	Percent Launch Vehicles using Various Propellant Types During Flight through Mesosphere	Example of Launch Vehicle Type	Number of Flights Using Propellant Type	Propellant Quantity in Troposphere	Emission Loads (kg x 10^3)**									
					Al_2O_3	Cl	CO_2	CO	H_2	H_2O	HCl	OH	NO_2	N_2
Small	35% Solid	Leolink/Shavit/M5	11	5,000	21	-	2	13	1	4	12	-	-	5
	65% Hypergol	Kosmos/Rokot	21	4,000	-	-	15	2	-	29	-	-	2	34
Medium	15% Solid	VLS	10	4,000	15	-	1	9	1	2	8	-	-	3
	55% Hypergol	Tsyklon	36	40,000	-	-	261	44	-	508	-	-	28	595
	15% Hypergol	GSLV	10	40,000	-	-	71	12	-	139	-	-	8	162
	15% Hypergol	PSLV, Long March 2c	10	15,000	-	-	27	4	-	52	-	-	3	61
Intermediate	10% LO_x-LH_2	H-2A	14	10,000	-	-	-	-	-	136	-	-	-	-
	50% LO_x-RP1	Soyuz	68	20,000	-	-	326	598	13	340	-	48	-	-
	40% Hypergol	Long March 3b, Ariane 4	54	40,000	-	-	392	65	-	762	-	-	41	892
High	25% LO_x-RP1	Zenit	23	50,000	-	-	276	506	11	288	-	40	-	-
	60% Hypergol	Proton	55	37,000	-	-	368	61	-	715	-	-	39	837
	15% LO_x-LH_2	Ariane 5	14	13,000	-	-	-	-	-	179	-	-	-	-
Total (10^3 kg)					36	-	1,739	1,315	27	3,153	20	88	120	2,590
Total (tons)*					40	-	1,917	1,450	30	3,476	22	97	132	2,855

* Ton equals 2,000 pounds

** Calculation subject to rounding

Summary Comparison of Programmatic and Non-Programmatic Loads

A summary of emission loads from programmatic and non-programmatic launch activities is provided in Table A-20. The largest emission load for programmatic launches is from CO_2 whereas the largest emission loads for non-programmatic launches are from both CO_2 and NO_x. In both the troposphere and stratosphere, the programmatic emission loads for NO_x, are as little as 4% of the non-programmatic emissions loads for NO_x. The largest proportion of programmatic to non-programmatic emission loads (37%) is for CO_2. In the mesosphere, the programmatic loads for HCl, Al_2O_3**,** and Cl are approximately 37% of the non-programmatic loads. For combined CO/CO_2, the programmatic load is approximately 64% of the non-programmatic load.

TABLE A-20
SUMMARY OF PROGRAMMATIC AND NON-PROGRAMMATIC EMISSION LOADS TO EARTH'S ATMOSPHERE FROM LAUNCHES FROM 2000-2010

Atmospheric Layer	Programmatic Non-Programmatic	Al_2O_3 Load (tons)	Cl Load (tons)	CO_2 Load (tons)	CO Load (tons)	H_2O Load (tons)	HCl Load (tons)	NO_x Load (tons)	N_2 Load (tons)
Troposphere	Programmatic	4,147	31	25,365	-	11,771	2,292	2,946	-
	Non-Programmatic	28,182	207	67,882	-	54,488	15,575	70,244	-
Stratosphere	Programmatic	4,147	31	25,365	-	11,771	2,292	2,946	-
	Non-Programmatic	28,182	207	67,882	-	54,488	15,575	70,244	-
Mesosphere	Programmatic	151	1.1	1,824	3,414	2,927	83	-	33
	Non-Programmatic	424	3.0	4,059	4,147	14,961	233	220	4,859

Ton equals 2,000 lb

APPENDIX A ENDNOTES

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[a] Department of the Air Force. Draft Programmatic Environmental Assessment Medium Launch Vehicle III Program. June 1991.

[b] Department of the Air Force. Environmental Assessment Lockheed Launch Vehicles, Vandenberg Air Force Base, CA. April 1994.

[c] Department of the Air Force. Environmental Assessment Titan IV/Solid Rocket Motor Upgrade Program, Cape Canaveral Air Force Station, FL, Vandenberg Air Force Base, CA. February 1990.

[d] Versar, Inc. Final Environmental Assessment Vandenberg Air Force Base Atlas II Program. August 1991.

[e] NSWC Indian Head Division. Combustion Products of Solid Rocket Motors. August 1996.

[f] Environmental Assessment for Complementary Expendable Launch Vehicle. June 1986.

[g] Department of Transportation. Environmental Impact Statement for Commercial Reentry Vehicles. Washington, May 1992.

[h] Department of the Air Force. Environmental Assessment Lockheed Launch Vehicles, Vandenberg Air Force Base, CA. April 1994.

[i] Department of the Air Force. Environmental Assessment Titan IV/Solid Rocket Motor Upgrade Program, Cape Canaveral Air Force Station, FL, Vandenberg Air Force Base, CA. February 1990.

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[k] Department of the Air Force. Draft Programmatic Environmental Assessment Medium Launch Vehicle III Program. June 1991.

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[q] Isakowitz, Steven J. International Reference Guide to Space Launch Systems. 3rd ed. Washington: American Institute of Aeronautics and Astronautics, 1999.

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[y] Versar, Inc. Final Environmental Assessment Vandenberg Air Force Base Atlas II Program. August 1991.

[z] Commercial Spacecraft Mission Model Update, Commercial Space Transportation Advisory Committee (COMSTAC), FAA, US.DOT, 2000.

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[cc] Air Force National Launch Forecast, July 2000.

[dd] Final Environmental Impact Statement for Evolved Expendable Launch Vehicle Program, April 1998.

[ee] 2000 Commercial Space Transportation Forecasts, Associate Administrator for Commercial Space Transportation and COMSTAC, May 2000.

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[ii] Isakowitz, Steven J. International Reference Guide to Space Launch Systems. 3rd ed. Washington: American Institute of Aeronautics and Astronautics, 1999.