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GROUND CLOUD AIR QUALITY EFFECTS

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The effects on air quality of the launching of a large rocket such as the HLLV are all expected to be restricted to the vicinity of the launch site, and are all associated with the development and subsequent evolution of the ground cloud. No detectable air quality effects are expected from the thin column of exhaust generated as the rocket rises rapidly through the troposphere.

The ground cloud consists of the exhaust emitted by the rocket during the first 15-25 seconds following ignition and liftoff, together with a large quantity of entrained air, cooling water, dust and other debris.

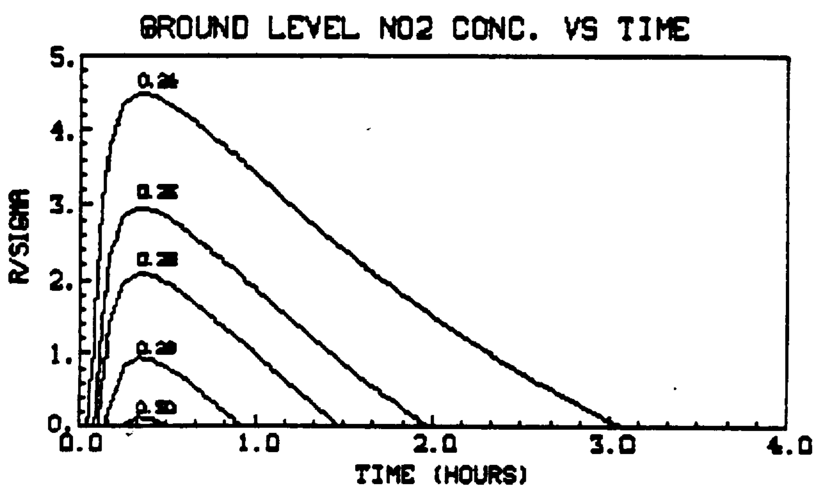
Immediately after formation, the ground cloud rises in the air due to the buoyant effect of its high thermal energy content. Eventually, at an altitude typically between 0.7 and 3 km, the cloud stabilizes and is carried along by the prevailing wind at that altitude. As the cloud rises, much of the surface dust and debris falls out, the distance over which the fallout occurs being determined by the wind speed, by the nature of the turbulence within the cloud, and by the size of the particles. This distance may be as great as a few kilometers.

The ground cloud represents a source of air pollution and associated effects. The cloud disperses over a period of time, the rate of dispersion being determined by the level of turbulence both in the cloud itself and in the ambient atmosphere. Depending on the ambient conditions, adverse environmental effects may be produced at ground level. Due to the use of liquid methane as fuel, any air quality effects must arise from substances present in relatively small amounts. The major exhaust products of the HLLV booster will be carbon dioxide and water. No effects are expected from these substances. Smaller quantities of nitrogen oxides, primarily nitric oxide and nitrogen dioxide, are expected to be produced from a possible molecular nitrogen impurity in the fuel or liquid oxygen, or from entainment and heating of ambient air in the hot rocket exhaust. In addition, possible impurities such as sulfur in the fuel would give rise to a corresponding amount of oxidation products such as sulfur dioxide.

The only substances which are potentially significant from an air quality point of view are the nitrogen oxides; any sulfur dioxide will be present at so low a level as to be unimportant, based upon actual measurements on an Atlas/Centaur ground cloud. It is estimated that an HLLV ground cloud will contain approximately 1.0×10^4 kg of nitrogen dioxide (NO_2) and 8.5×10^3 kg of nitric oxide (NO), with the peak cloud concentrations estimated at 0.50 and 0.64 ppmV, respectively. By way of comparison, the total peak NO_x ($NO + NO_2$) concentration of 1.14 ppmV is 3 to 4 times larger than NO_x concentrations measured in typical power plant plumes at distances on the order of 1 km from the stack.

Two different effects arising from the presence of nitrogen oxides in the ground cloud must be considered. The first is an enhanced ground-level concentration of NO_2 for a period of up to a few hours following a launch. It is likely that within a year or two, a one-hour national ambient air quality standard for NO_2 of about 0.25 ppmV will be promulgated. The state of California already has such a standard. Modeling studies indicate that in meteorological conditions typical of the Cape Kennedy area, ground-level NO_2 concentrations in the vicinity of the cloud on the order of 0.10 ppmV may be produced following a launch. Thus, the launch by itself is unlikely to cause a violation of a 0.25 ppmV standard, but may be sufficient to cause a violation if ambient concentrations are already close to the standard. Under more adverse meteorological conditions, the contribution of the ground cloud may be even higher and further work is required to adequately investigate this possibility.

Figure 1 shows the results of one calculation of the NO_2 concentration at ground level as a function of time after launch and of the radial distance from the point just below the ground cloud center. The distance has been normalized by the standard deviation σ of the (horizontal) Ganssian distribution assumed for the ground cloud contribution to the NO_x concentration. The estimated initial value of σ was 2200 meters, and 3220 meters after one hour. The cloud stabilization height was 1300 m. Ambient concentrations were: ozone = 0.12 ppmV, NO_x = 0.25 ppmV (NO_2 = 0.23, NO = 0.02). Contour values are given in ppmV. A region in which the NO_2 concentration is greater than 0.25 ppmV clearly exists and persists for approximately two hours.



The second effect that must be considered is a possible enhancement of acid rain in the vicinity of the launch site. When dissolved in water, NO_2 forms a mixture of nitric and nitrous acids. Rainfall through the ground cloud (or rising from within) will therefore be more acidic than would otherwise be the case. By making the unphysical assumptions that dissolved NO_2 is instantly and completely converted to acid and ignoring the fact that cloud NO_2 will be depleted by the washout process, an estimate of the pH of rain (rainfall rate= 10 mm/hour) of 3.5 is obtained. This should be regarded as an unrealistically low value; a more realistic estimate would lie in the range 4.0 - 5.5. This is not considered excessively acidic, and no significant effects are expected especially when the highly localized and transient nature of the precipitation is taken into account.