RESPONSE OF SELECTED PLANT AND INSECT SPECIES TO SIMULATED SRM EXHAUST MIXTURES AND TO EXHAUST COMPONENTS FROM SRM FUELS

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INTRODUCTION

This research was developed to determine possible biologic effects of exhaust products from solid rocket motor (SRM) burns associated with the Space Shuttle. The major components of the exhaust that might have an adverse effect on vegetation are HCl and Al_2O_3. It is possible that Cl_2 and NO_2 may be sufficiently important to deserve study.

The basic objective of this research is to determine dose-response curves for native and cultivated plants and selected insects exposed to simulated exhaust and component chemicals from SRM exhaust. Specific objectives are (1) to develop a system for dispensing and monitoring component chemicals of SRM exhaust (HCl and Al_2O_3); (2) to develop a system for exposing test plants to simulated SRM exhaust (controlled fuel burns); (3) to determine dose-response curves for single and multiple acute exposures of selected plant species to HCl, Al_2O_3, mixtures of the two, and simulated exhaust; (4) to work closely with the NASA John F. Kennedy Space Center and the staff of the Florida Technological University in Orlando, Florida, in the development of native and cultivated plant species for use in exposures and for possible later use in vegetation monitoring systems; (5) to determine the effects of HCl, Al_2O_3, and mixtures of the two on the honeybee, the corn earworm, and the common lacewing; and (6) to determine the effects of simulated exhaust on the honeybee.

Personnel involved in the study included the following senior staff members.

1. Dr. John T. Ambrose, entomologist and bee specialist of North Carolina State University (NCSU), who is serving as a consultant and organized the study on the honeybee, the corn earworm, and the common lacewing

2. Dr. A. S. Heagle, plant pathologist with the U.S. Department of Agriculture, who is primarily responsible for the field program and is the project officer for the precipitation project that started in February 1978

3. Dr. W. M. Knott, ecologist and plant physiologist with NCSU, who was primarily responsible for the work on the effects of the gases and particulates on vegetation

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4. Dr. E. P. Stahel, chemical engineer with NCSU, who was the principal consultant in the development of the facilities presently in use

Four graduate students worked on this project.

1. Louise A. Romanow, working toward a Master of Science degree in entomology, who was responsible for the insect studies

2. Alan G. Sawyer, working toward a Master of Science degree in chemical engineering, who was primarily responsible for working with Dr. Stahel in the original development of the facilities

3. James D. Tyson, working toward a Master of Science degree in chemical engineering, who studied the chemical characterization of the test chambers

4. Madeleine Engel, working toward a Master of Science degree in plant pathology, who characterized the uptake and localization of chlorine in plant tissues

FACILITIES DEVELOPMENT

The primary objective of the facilities development phase of the project was to develop systems for dispensing and monitoring HCl and the Al_2O_3 particulates and for dispensing and monitoring the exhaust products from a solid propellant burn. The three facilities include the HCl exposure system, the Al_2O_3 particle system, and the exhaust system. Figure 1 is a schematic of the four greenhouse chambers used for HCl and particulate exposures, and figure 2 shows details of a single chamber. Charcoal filtration of the air occurs upstream of the inlet manifold. The gases are injected into each chamber's inlet duct. The impeller stirs the air within the reactor; the impeller permits variation of airflow into the chamber without changing the rate of air movement within the chamber. High-intensity lamps are used over each chamber because the plants have a minimum light intensity threshold for response to pollutants; the plants are insensitive in the dark. With the high-intensity lamps, research in the greenhouse can continue all 12 months of the year. The gas is exhausted through the outlet manifold and through a charcoal filter before being exhausted outside the greenhouse. The chambers are 42 inches in diameter and 48 inches high. These have been tested using ozone and sulfur dioxide along with a continuous monitoring system.

Figure 3 depicts the particulate system. A small, motor-driven variable-speed syringe pump drives this system. The Al_2O_3 is placed in the Teflon cylinder and slowly pushed into the airstream using a Teflon-tipped plunger. The system has been modified since this schematic was prepared to include a Teflon holder filled with Al_2O_3 that is pushed into the airstream. This device permits better mixing and the breakup of the particulate. Efforts have been made with the NASA Langley Research Center and the NASA George C. Marshall Space Flight Center to define the aluminum oxide particulates used. Two sizes of particulates are used: an alpha particle of about 2 micrometers diameter and a gamma alumina that is less than 0.5 micrometer in size. Under the microscope, the large-sized particulates look similar, with the small often adhering to the larger.

The burn system consists of a control system (fig. 4) and an exposure system (fig. 5). The control system has an airflow rate comparable to that through the exposure chambers, but the air contains no propellant exhaust. The exposure chambers will have various propellant exhaust concentrations in the air passing through them.

The control system consists of a variable-flow blower connected to a closed-top field chamber. The variable-flow blower is equipped with a control converting alternating current (ac) to direct current (dc). The control is connected to a dc motor to regulate the dc motor speed from 125 to 2500 rpm. The dc motor is connected to a high-volume, direct-drive blower with a wheel diameter of 10-5/8 inches. The variable-flow blower system has a maximum airflow of approximately 2000 cfm. However, an airflow of 1350 cfm will be the maximum needed for the controlled-burn system. The closed-top field chamber is 8 feet high and 10 feet in diameter, and the pressure drop through it is assumed to be negligible because it acts as a constant-volume reservoir. The connecting line between blower and chamber and the exhaust line are 1-foot-diameter plastic lines.

The polybutadieneacrylonitrile (PBAN) propellant controlled-burn system has a constant-flow blower producing 3000 cfm. The blower is equipped with a 2-horsepower ac motor (single phase) connected to a radial blade blower. The constant-flow blower is connected to the burn chamber by a 3-foot galvanized tin duct (10-3/4 by 14-5/8 inches). The galvanized duct is painted with epoxy resin on the inside to prevent corrosion.

The burn chamber is a 3-foot cube constructed of galvanized tin and painted with epoxy resin on the inside to prevent corrosion. The blower duct is centered on one side of the burn chamber. Two epoxy-painted galvanized baffles, located immediately inside the burn chamber, are equally spaced in the inlet duct to disperse the airflow through the burn chamber. The baffles are oriented 45° upward and 45° downward from an imaginary horizontal plane passing through the center of the blower duct. On the side opposite the blower duct inlet, a 2-foot-diameter hole is centered with a 6-inch epoxy-painted galvanized sleeve protruding from the burn chamber. On one of the sides adjacent to the blower duct inlet, a 30-inch-square epoxy-painted galvanized door is hinged to the burn chamber for replenishing the system with PBAN propellant. Inside the burn chamber, three 1/4-inch-thick copper plates (24 by 24 inches) rest on epoxy-painted angle irons that provide equal spacing between the plates and perfect symmetry about the center of the burn chamber. The three copper plates are grooved to accommodate 30 feet of propellant strand - 10 feet per plate. Therefore, each plate is grooved 1/8 inch deep by 7/16 inch wide in a geometry that gives a length of 10 feet. The temperature rise around the burn chamber is about 2° C for a 30-foot strand of 7/16-inch-square propellant, based on a value of 1596.4 calories evolved per gram of PBAN propellant burned. Each strand of propellant is coated with a restrictor formulation to ensure a uniform burn front.

From the galvanized sleeve of the burn chamber, 3 feet of 2-foot-diameter plastic line extends to a 3-foot-diameter tetrahedron. The tetrahedron is constructed of epoxy-painted galvanized tin with a constant angle of 109.5° between the 2-foot-diameter inlet plastic line and the three 1-foot-diameter outlet plastic lines. The tetrahedron is assumed to achieve equal splitting of the 3000-cfm air/HCl/Al_2O_3 stream into three 1000-cfm air/HCl/Al_2O_3 streams.

From the tetrahedron, the three 1-foot-diameter plastic lines extend 10 feet to three closed-top field chambers. Halfway between the tetrahedron and the field chambers, a dilution system is attached that is identical to the variable-flow blower of the control system (fig. 5). The dilution system is connected to the 1-foot-diameter plastic line by a 4-foot epoxy-painted rectangular duct (8 by 11-3/4 inches).

The air/HCl/Al_2O_3 streams leave the three field chambers through 1-foot-diameter plastic lines. The lines extend 10 feet to another tetrahedron configuration. At this point, the air/HCl/Al_2O_3 streams combine into one stream that leaves the tetrahedron through a 2-foot-diameter plastic line that extends 10 feet to a scrubber. The scrubber is a closed-top field chamber with five spray nozzles mounted in the top that mist water into the chamber. The water mist removes the HCl and Al_2O_3 from the stream, so that only air leaves the scrubber and disperses into the environment.

INSECT STUDIES

Honeybees were exposed to concentrations ranging from 4 to 160 parts per million (ppm) of HCl in air over a period of 1 to 4 hours. The response of various groups of bees varied considerably. In initial experiments, many bees died because of the mechanics of transfer and handling. These problems were corrected, and later work produced less control death. Results suggest that bees are not sensitive to expected exhaust concentrations of HCl and/or Al_2O_3. Preliminary data on the effects of HCl on honeybees are available. The behavioral effects of HCl on the honeybee will be studied in the spring of 1978.

A study of corn earworms has been initiated. In preliminary exposures, the larval stages of corn earworms were placed in small plastic containers and exposed to HCl in the air (from 4 to 160 ppm). The high HCl concentrations liquefied the early plastic cages without injury to the larvae. New cages were designed, but the larvae were not injured.

PLANT STUDIES

The plant study concentrated on eight species: citrus, soybeans, tobacco, radishes, morning glories, ivy, wax myrtle, and sunflowers. Citrus and other woody plants are reused after exposure by cutting them back and allowing them to regrow.

The humidity is usually monitored but not controlled. The plants are much more sensitive to HCl when humidity is high or when the leaves are moist. After a rainstorm or early in the morning while dew is still on the plants, the plants would be much more sensitive.

Plants were not affected by Al_2O_3. If the plants are dry, the particulates settle on the leaves with no injury. When the plants are moved out of the chambers, the particulates fall off. Adding moisture or wetting plant leaves did not damage plants. Mixtures of HCl plus Al_2O_3 were no more effective in injuring plants than HCl alone.

Two varieties of soybeans and radishes and three of tobacco were used. The radish was one of the most sensitive plants tested; very little effect on citrus was noted, except at high concentrations of HCl.

When considerable injury occurred, a significant growth reduction was found at about 30-percent visual injury. No growth reductions were found without visible injury. Plants recovered after exposure except when injury was severe (about 60 percent).

Figures 6 to 9 and tables I to IV show sample results of exposures of test plants to HCl.

BIBLIOGRAPHY

Heck, W. W.; Knott, W. M.; Stahel, E. P.; Sawyer, A.; Engel, M.; and Shaw, G. G.: Response of Selected Plant and Insect Species to Simulated SRM Exhaust Mixtures and to Exhaust Components From Solid Rocket Fuels. Interim Report to NASA KSC, 1977.

Heck, W. W.; Knott, W. M.; Stahel, E. P.; Sawyer, A.; Engel, M.; and Shaw, G. G.: Response of Selected Plant and Insect Species to Simulated SRM Exhaust Mixtures and to Exhaust Components From Solid Rocket Fuels. JANNAF Working Group on Safety and Environmental Protection (Apr. 1977), pp. 1-19.

Knott, W. M.; Heck, W. W.; Stahel, E. P.; Ambrose, J. T.; Engel, M.; Romanow, L.; and Tyson, J.: Response of Selected Plant and Insect Species to Simulated SRM Exhaust Mixtures and to Exhaust Components From Solid Rocket Fuels. Progress Report. Agricultural Research Service, USDA, and North Carolina State University (Raleigh, N.C.), 1978.

TABLE I.- INJURY TO COMET VARIETY RADISH FROM EXPOSURE TO HCl[a]

Exposure time, min	Percent injury from HCl concentration, ppm,[b] of -			
	0	5	10	20
15	0	1	1	3
30	0	1	3	15
60	0	3	6	52
120	0	3	9	85

[a]Two-leaf average; six plants/value not analyzed.
[b]1 ppm ≃ 1.5 mg/m^3.

TABLE II.- INJURY TO COKER 16 VARIETY CORN FROM EXPOSURE TO HCl[a]

Exposure time, min	Percent injury from HCl concentration, ppm,[b] of -			
	0	10	20	40
15	0	1	1	36
30	0	1	2	67
60	0	1	2	74
120	0	1	2	84

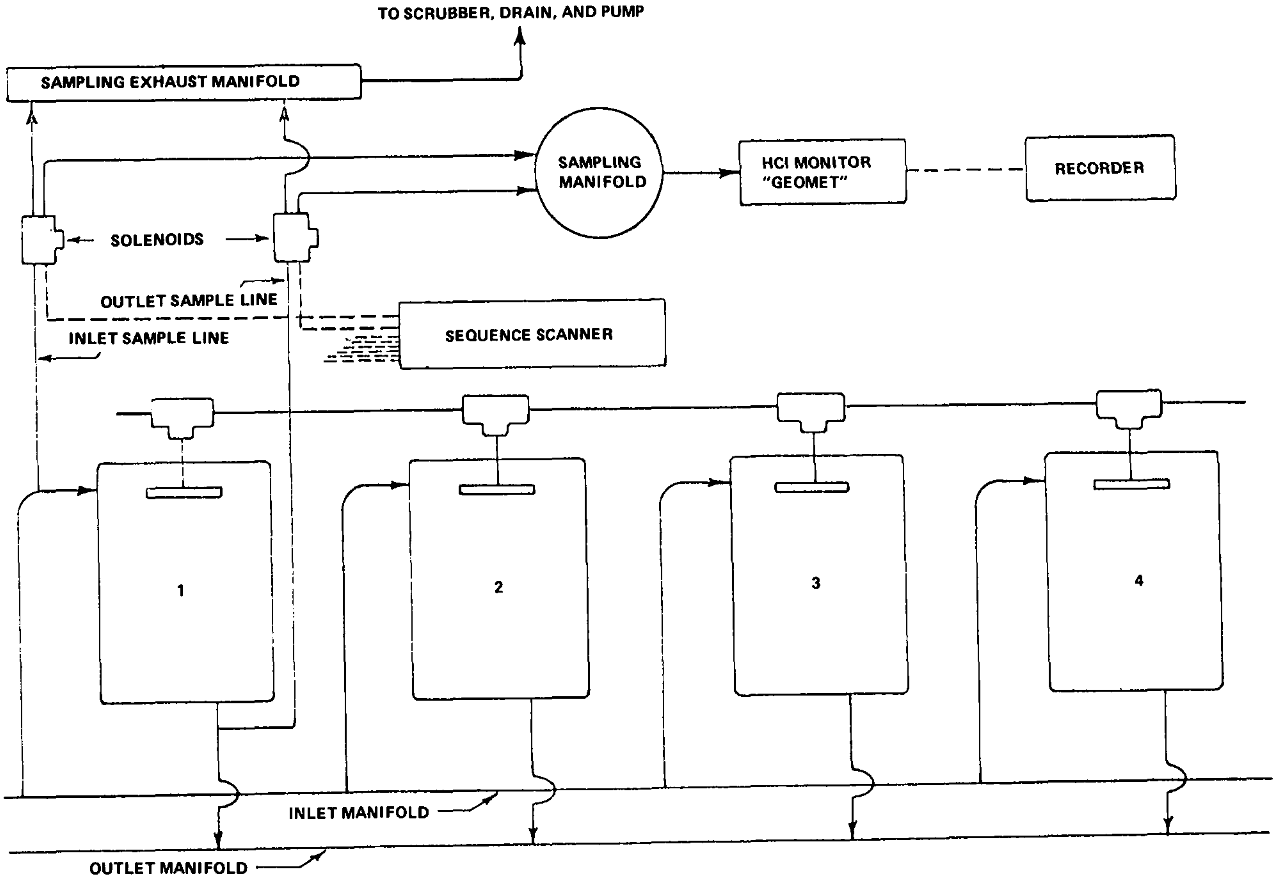
[a]Three-leaf average; six plants/value not analyzed.
[b]1 ppm ≃ 1.5 mg/m^3.

TABLE III.- INJURY TO TINY TIM VARIETY TOMATO FROM EXPOSURE TO HCl

Parameter	Value for HCl concentration, ppm, of -			
	0	10	20	40
Injury, percent	0	9	30	69
Control top dry weight (TDW), g	2.98	--	--	--
Change from control TDW, percent	0	1	-24	-53

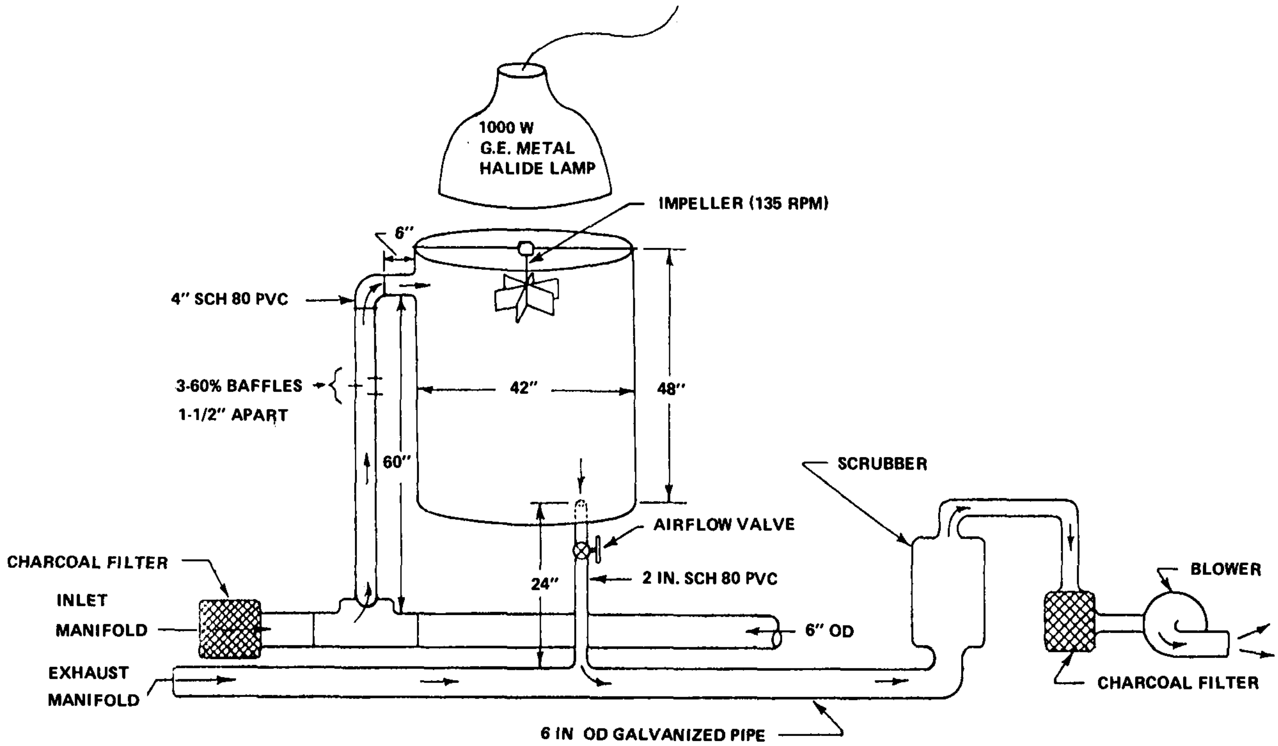
TABLE IV.- EFFECT ON DARE VARIETY SOYBEAN OF EXPOSURE TO HCl

Parameter	Value for HCl concentration, ppm, of -			
	0	4	8	16
Control TDW, g				
0 days after exposure	1.31	--	--	--
3 days after exposure	2.22	--	--	--
7 days after exposure	4.20	--	--	--
21 days after exposure . . .	7.96	--	--	--
Change from control TDW, percent				
0 days after exposure	0	1	10	-6
3 days after exposure	0	-6	0	-31
7 days after exposure	0	-2	-11	-43
21 days after exposure . . .	0	12	13	-12



NOTE: 1) ALL SAMPLE LINES ARE 1/4 IN. OUTER DIAMETER TEFLON
2) SOLID-STATE SCANNER ALLOWS INDEPENDENT OR SEQUENTIAL OPERATION OF ARBITRARY NUMBER OF CHAMBERS

Figure 1.- Schematic of sampling system.



NOTE: CHAMBER IS CIRCULAR, ~ 1000 LITERS

Figure 2.- Schematic of one exposure chamber.

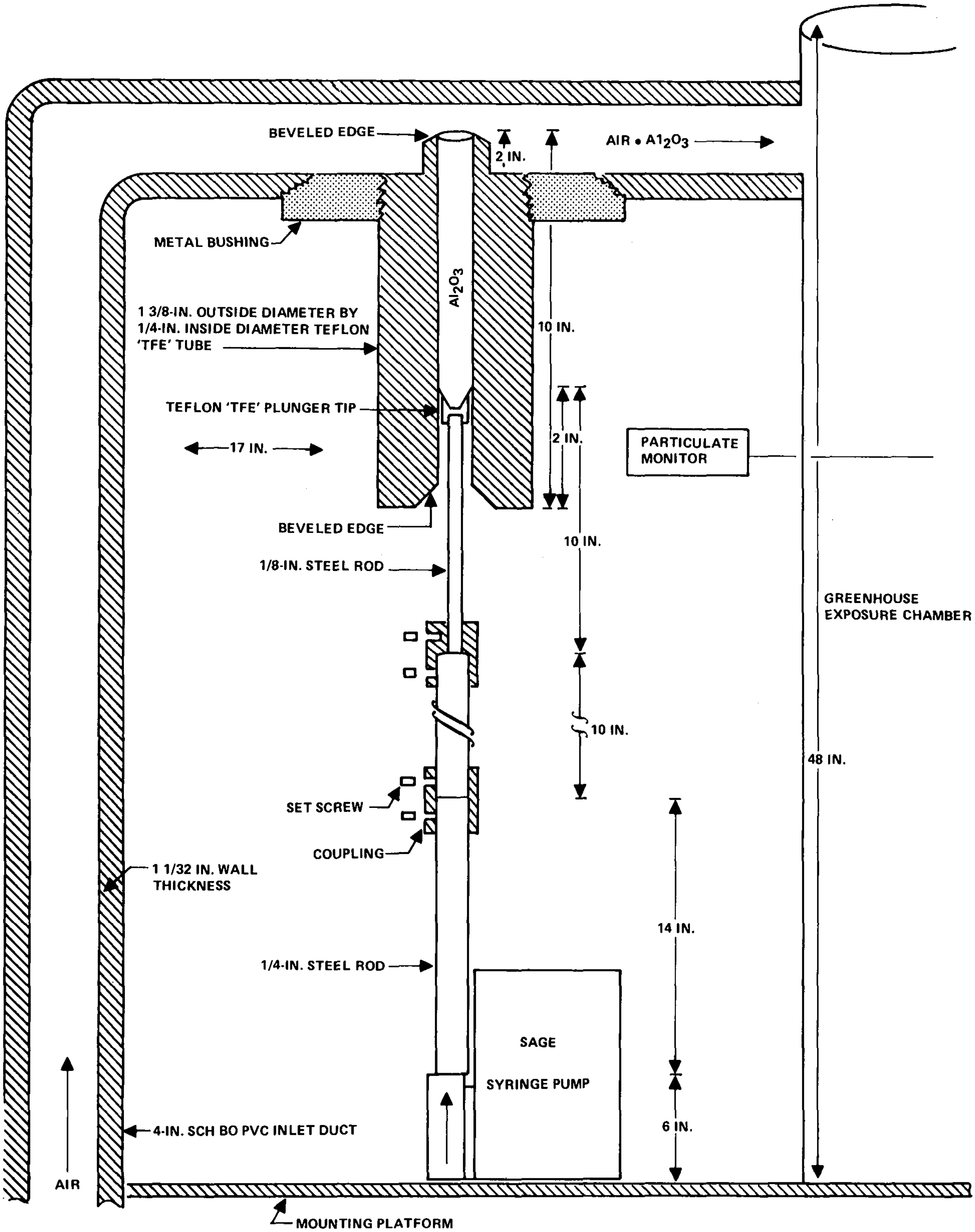


Figure 3.- Schematic of Al_2O_3 particulate exposure system.

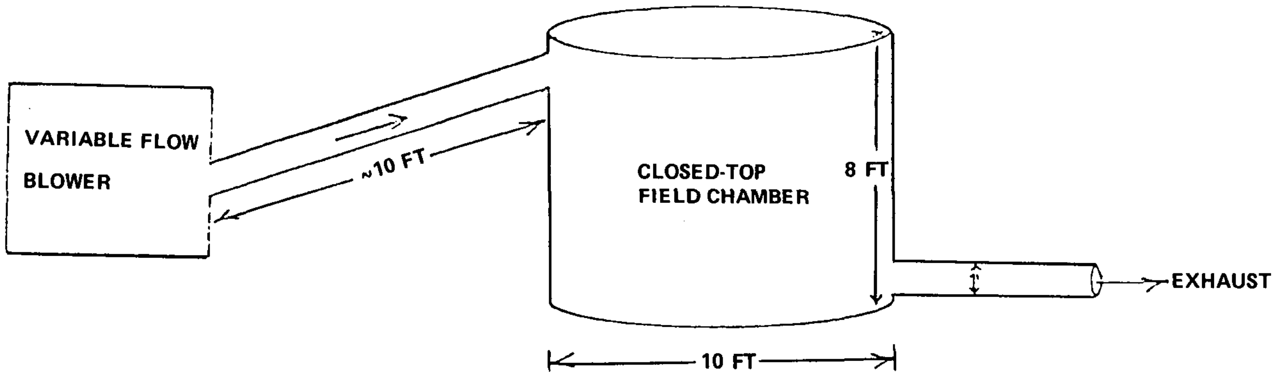


Figure 4.- Schematic of control system.

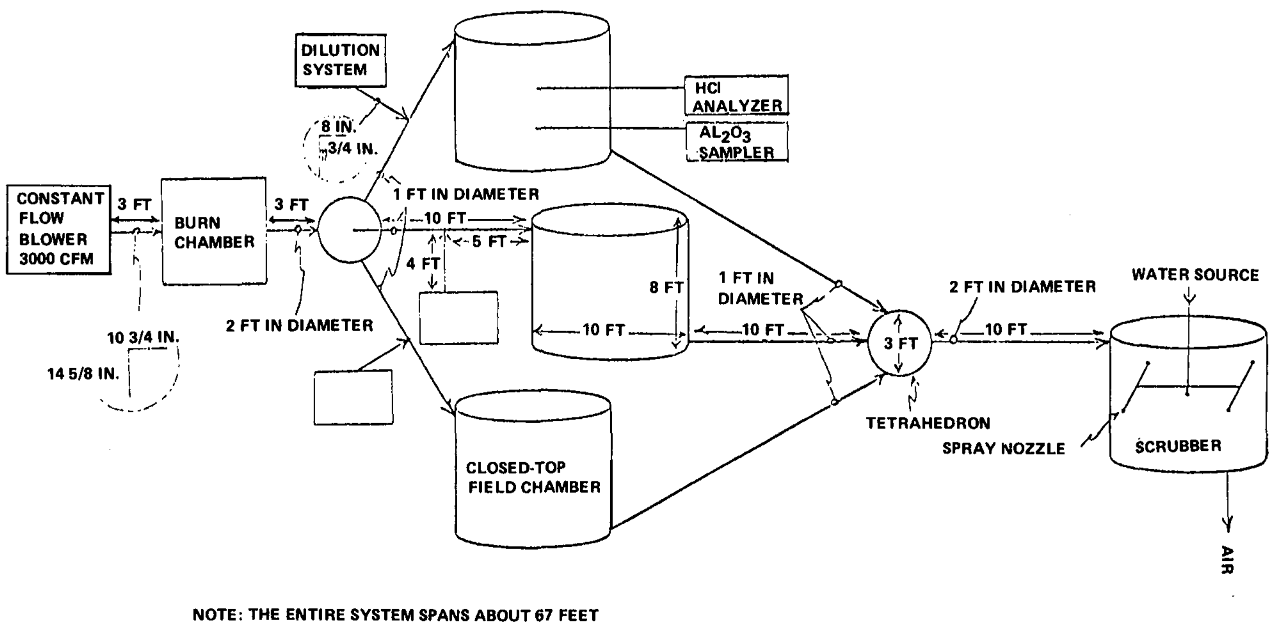


Figure 5.- Schematic of polybutadieneacrylonitrile propellant controlled-burn system.

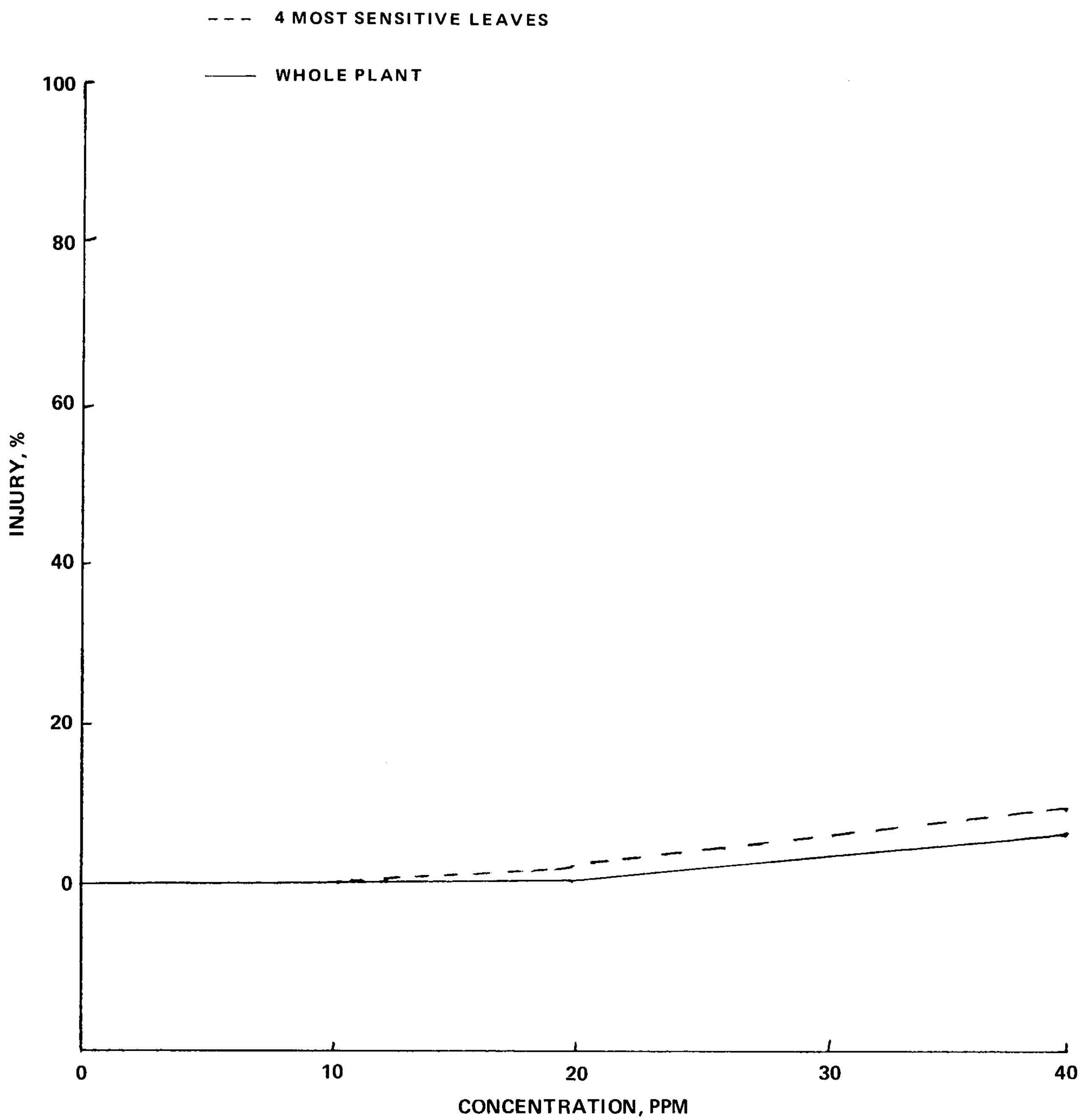


Figure 6.- Morning glory sensitivity screen to HCl.

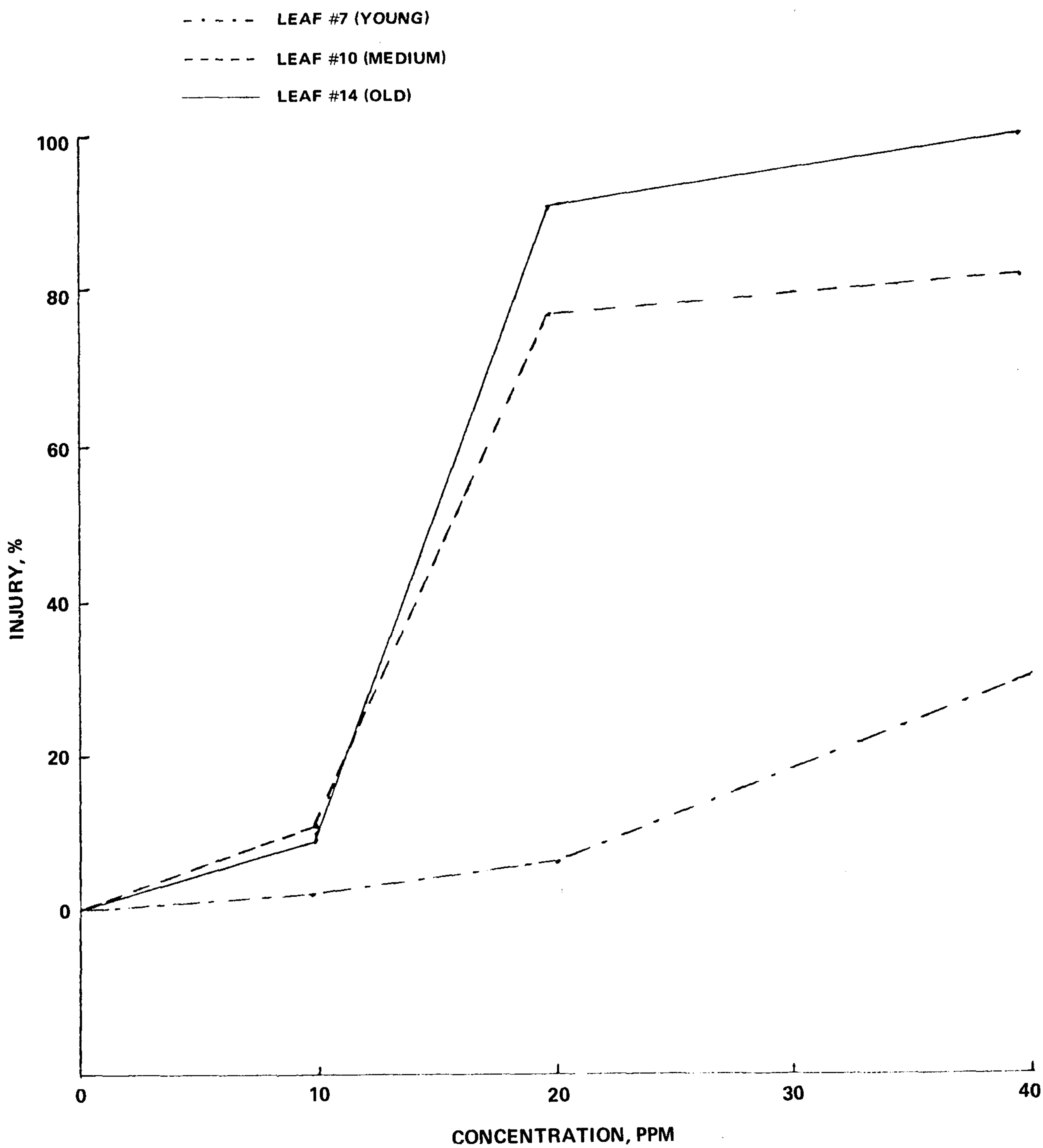


Figure 7.- Ivy sensitivity screen to HCl.

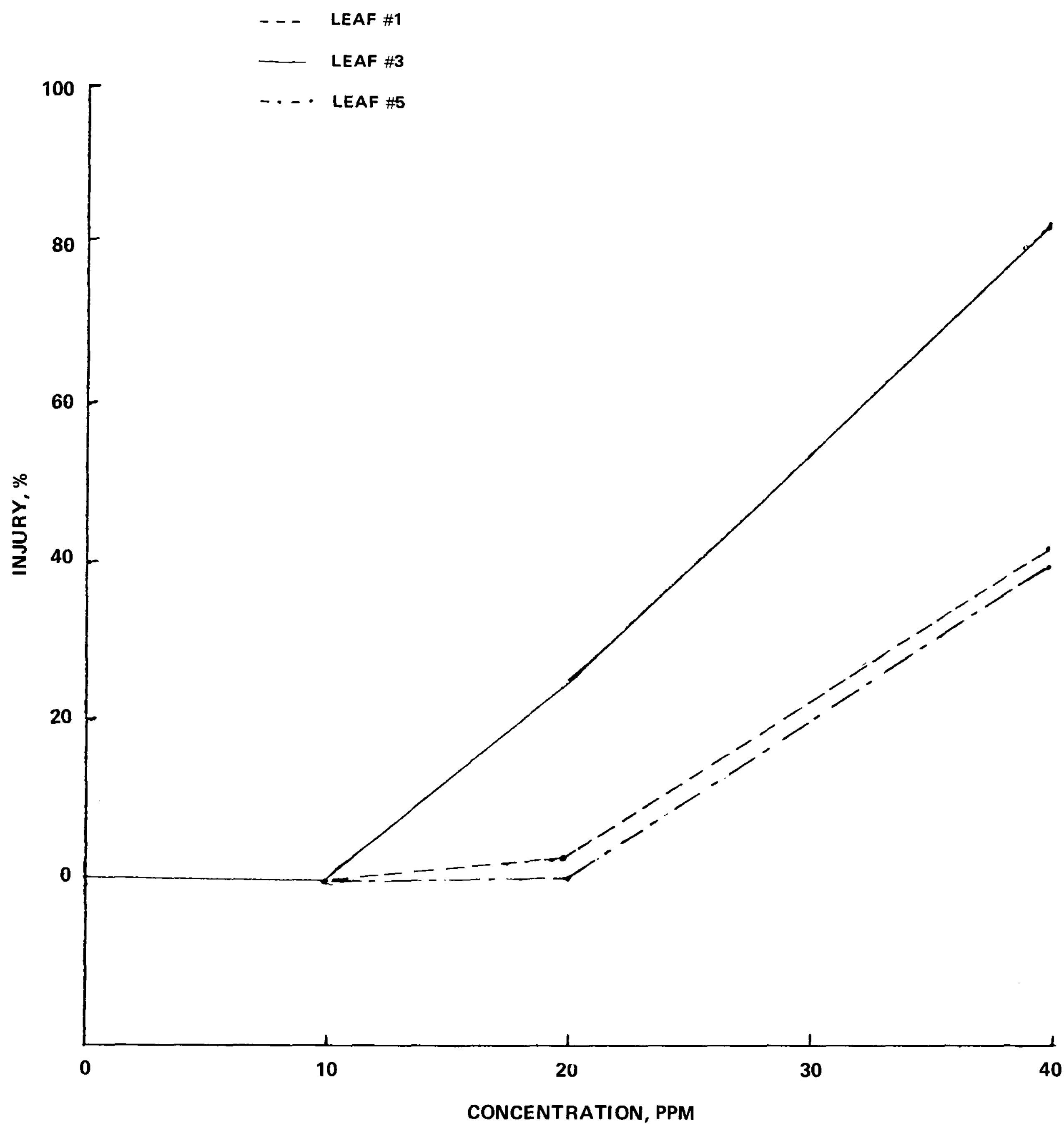


Figure 8.- Corn (Coker 16) sensitivity screen to HCl.

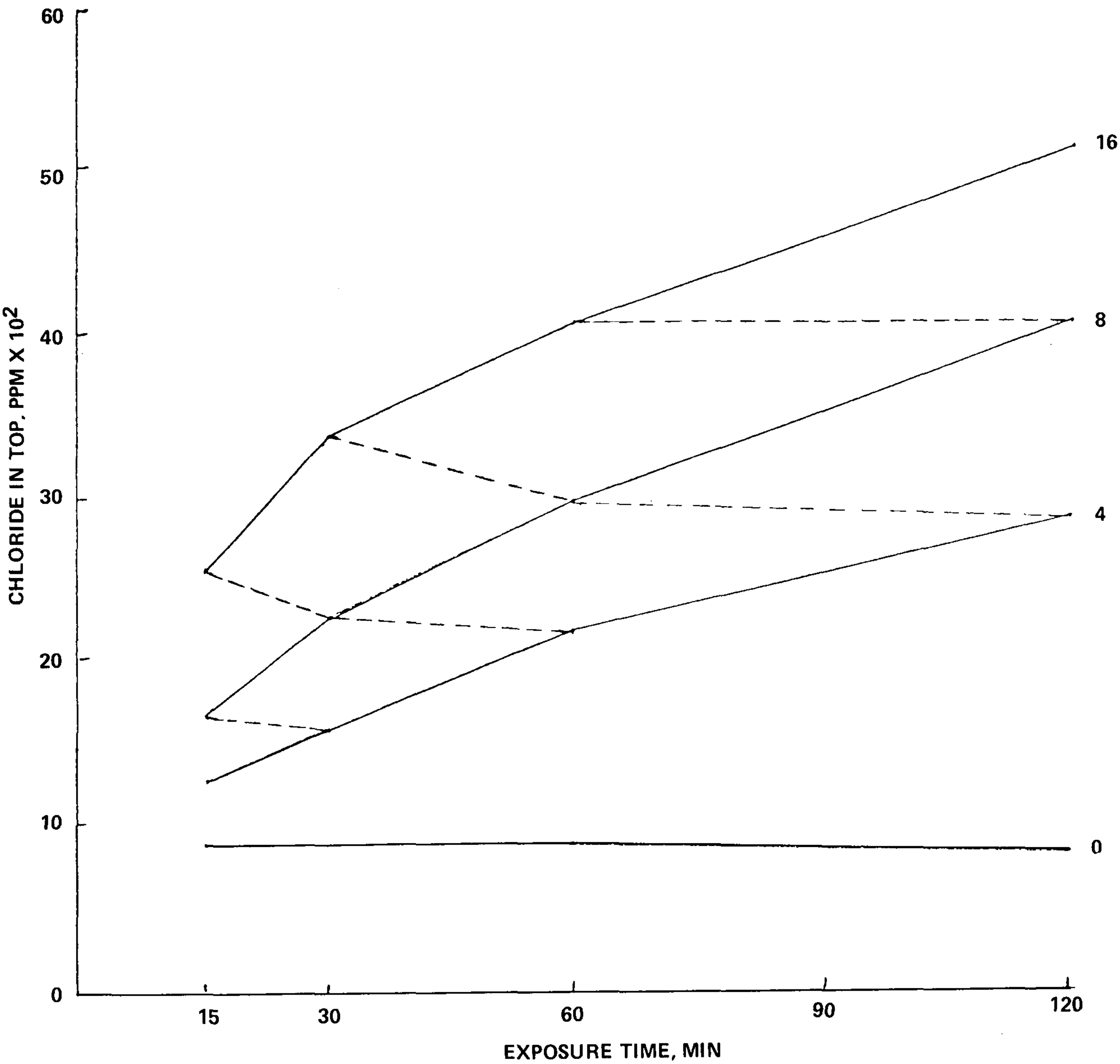


Figure 9.- Soybean chloride accumulation as related to duration of exposure and concentration of HCl.