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D. E. RANDALL

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SPECIAL TASK REPORT FOR CONCEPTUAL DESIGN OF AUTOMATIC CLEANING SYSTEM FOR SOLAR PANEL GLAZING - SOLAR DRYING OF SOYBEANS

October 31, 1978

TELEDYNE BROWN ENGINEERING

Cummings Research Park • Huntsville, Alabama 35807

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Prepared For

U.S. DEPARTMENT OF ENERGY

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Prepared By

SYSTEMS DIVISION
TELEDYNE BROWN ENGINEERING
HUNTSVILLE, ALABAMA

ABSTRACT

During the installation and checkout portion of the Department of Energy's program on the Application of Solar Energy to Industrial Drying of Soybeans, it became evident that a significant solar panel cleaning problem existed. The problem stems from soybean oil droplets and particles in the environment of the plant site. A conceptual design has been prepared for an automatic cleaning system for the solar panels.

Investigations into the nature of the contaminant revealed that the soybean oil polymerizes with extended exposure to ultraviolet rays. This polymerization is accelerated by the presence of ozone. It was concluded that the most practical method of panel cleaning would involve daily removal of deposits before significant polymerization could occur.

Several cleaning system concepts were studied. An oscillating spray bar promised the optimum cleaning action/initial investment ratio. A 48-ft-long prototype of this type was constructed and a test program initiated. This test program will continue throughout Phase III. To date, the prototype has operated daily without incident and has performed a credible cleaning job.

A preliminary design of a control system is presented. This system is completely automatic and incorporates freeze protection.

Excluding final design cost, the cleaning system cost will be between \$1.00 and \$1.59/ft^2, depending on whether Gold Kist labor is used. The economic improvement in system operation is anticipated to be \$2,790 annually. This includes the reduction in labor now used for manual cleaning and a 15% estimated performance improvement.

Recommendations include continuation of testing on the prototype and a final design-and-build program with emphasis on using Gold Kist labor to a maximum extent.

APPROVED:

B. R. Hall
Program Manager

R. A. Rieth
Vice President
Systems Division

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1. INTRODUCTION

1.1 BACKGROUND AND OBJECTIVES

A major objective of the Department of Energy's (DOE's) Industrial Processing Heat Program is to verify and evaluate the technical and operational performance of solar thermal energy systems for process drying. For this purpose, a demonstration system using air collectors has been constructed at the Gold Kist Soy plant in Decatur, Alabama. The system is designed to temper the combustion air of conventional dryers used to dry soybeans prior to storage and as a first step in the extraction process.

Construction of the solar facility and data acquisition have been completed and operational status has been achieved. The system will be operated and maintained for 1 year by Gold Kist as a part of its drying operations. Operational and technical data will be acquired, analyzed, evaluated, and reported by Teledyne Brown Engineering (TBE).

The environmental conditions at Gold Kist have presented a significant problem in maintaining clean glazings on the collectors. As a result, DOE has authorized a task to perform a conceptual design of a cleaning system for the solar array. This report, prepared under Contract No. EY-76-C-05-5122, presents the results of this conceptual design effort.

1.2 SUMMARY

This report encompasses a definition of the cleaning problem, conceptual approaches to automated cleaning systems, results of a prototype cleaning system test, and recommendations for the design of a full-scale automatic cleaning system.

2. PROBLEM DEFINITION

2.1 SOLAR ARRAY DESCRIPTION

The solar array in the Gold Kist project consists of 672 single, glazed Solaron collectors. The arrangement of the 114.5-by-144-ft array is shown in Figure 2-1. The entire array is tilted 15 deg from horizontal and is supported on a steel structure. The low end of the array is 16.5 ft from ground elevation.

There are seven double rows of collectors, with each double row containing 96 collectors. A walkway and handrail are provided at the bottom and between every other double row.

2.2 NATURE OF CONTAMINATION

Samples of the contaminated glazings have been examined by personnel in the Chemistry Department at the University of Alabama in Huntsville (UAH) to determine their nature and to obtain recommendations for cleaning solutions. UAH has determined that the contamination begins as a coating of soybean oil settling on the glazing. This oil polymerizes when exposed to ultraviolet and ozone and hardens very much like a varnish. During the process, soybean husks and flakes are deposited on and then bonded to the surface by the partially polymerized soybean oil.

2.3 CURRENT CLEANING TECHNIQUES

The current cleaning technique requires three men working 6 hours to clean the entire array. The first man uses a hand wand to apply a detergent solution (concentrated carwash solution) under 600-psi pressure. This is followed immediately with scrubbing using a long handled brush. The third man uses a hose to apply rinse water.

This cleaning process is accomplished on approximately a 40-day schedule. From the performance data obtained through August 1978, the efficiency improvement following cleaning is approximately 10 to 15%

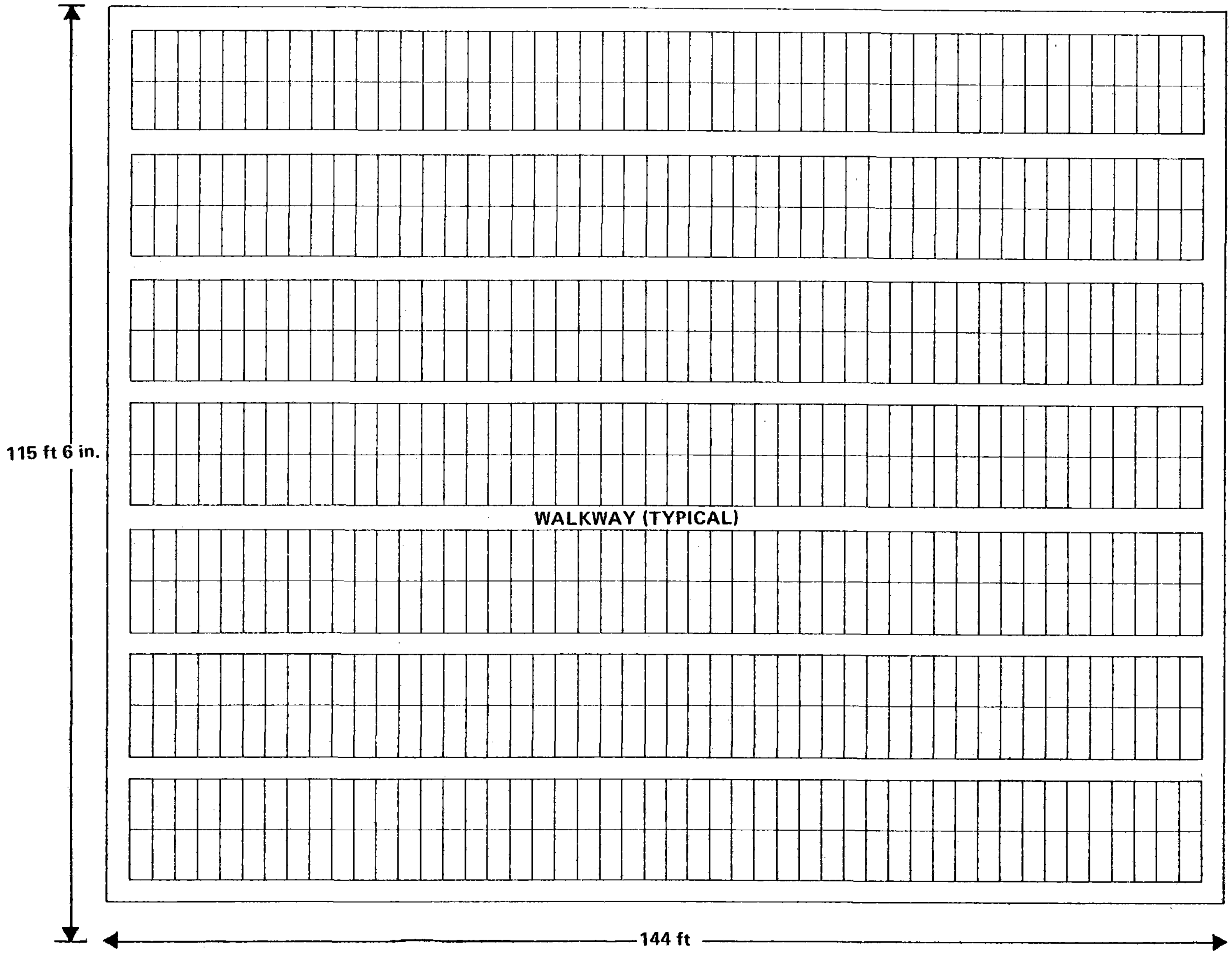


FIGURE 2-1. SOLAR ARRAY ARRANGEMENT

(Figure 2-2). Plans are underway to perform comparison testing of contaminated versus clean glazings. These tests will be performed by UAH. Results will be included in the monthly progress report following test completion.

The cost of the current cleaning technique is approximately $1,800 annually including labor and materials.

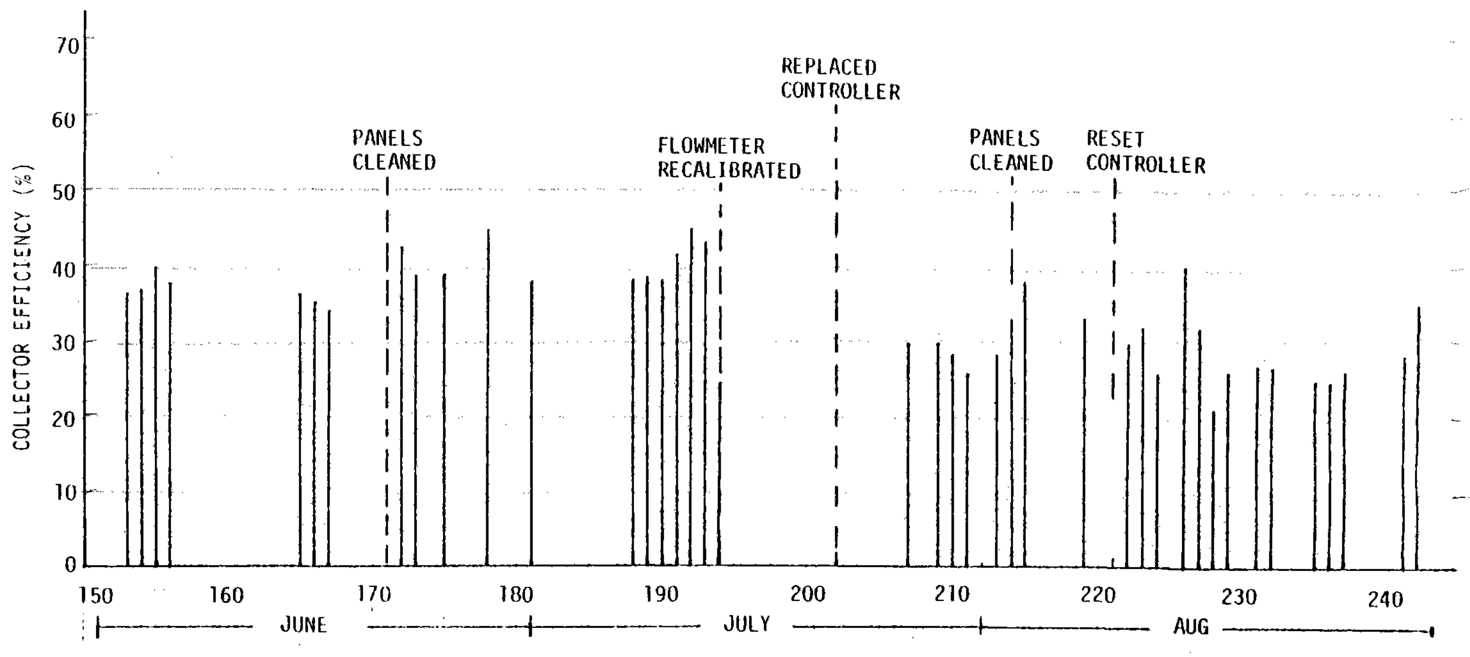


FIGURE 2-2. EFFECTS OF CLEANING GLAZING

3. CLEANING SYSTEM CRITERIA

The objective of the cleaning system design is to minimize recurring panel cleaning costs while meeting an acceptable compromise between capital cost, reliability, degraded performance, and maintainability. To meet this objective, the cleaning system must incorporate the following features:

- Minimum shading by the cleaning mechanism
- Automatic control system to cycle the cleaning action with a frequency sufficient to prevent excessive polymerization and deposit
- Freeze protection
- Minimum moving parts and adjustment or alignment
- Minimum consumption of water, detergent, and electricity.

Since the optimum cleaning frequency and detergent concentration requirements must be determined over a long period of operation, these functions should have a wide latitude for experimentation.

4. DESIGN CONCEPTS CONSIDERED

Using the criteria presented in Section 3, TBE studied several cleaning system concepts. During these studies, cleaning equipment vendors and specialists were contacted in an effort to establish a data base to use in evaluating various concepts. Because of the unique nature of the contaminant and the physical layout and size of the solar array, no significant data base was established. As a result, the evaluation of each concept had to be subjected and on a relative basis rather than absolute. ?

Figure 4-1 presents a sketch and comparison of the major cleaning concepts considered. A brief discussion of each follows.

4.1 FIXED SPRAY (FLOOD)

This system is simply a fixed piping system that directs a spray at the upper edge of each collector row. Because of its attractive low cost and simplicity, a simple prototype was constructed. The performance was poor because of splitting of the flooding into small streams, resulting in dry areas.

4.2 OSCILLATING SPRAY

This system incorporates a pipe (with a row of small orifices) supported a few feet over the collector and an actuator to provide rotation. This system appeared to be the most promising of all concepts studied. Therefore, two prototypes were constructed and tested. A detailed description of this system and the test results are presented in Sections 5 and 6.

4.3 MOVING SQUEEGY WITH SPRAY

This system consists of a flexible squeegy and spray bar that translate the length of a collector. The effectiveness of this type of system was considered good because of the mechanical action of the squeegy. However, it was considered impractical because of the complexity and consequent poor reliability.

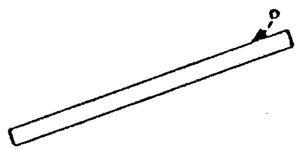
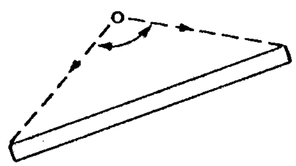
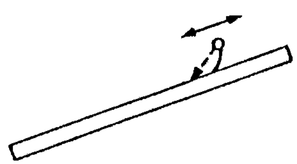
CONCEPT	PROBABLE CLEANING EFFECTIVENESS	RELATIVE COST	MAINTENANCE REQUIREMENTS
 FIXED SPRAY (FLOOD)	POOR - DIRECT IMPINGEMENT AT UPPER EDGE ONLY. FLOODING STREAMS SPLIT AS WATER PROGRESSES OVER GLAZING, LEAVING DRY AREAS.	VERY LOW - SIMPLE FIXED PIPING SYSTEM	VERY LOW - NO MOVING PARTS
 OSCILLATING SPRAY	GOOD - DIRECT IMPINGEMENT AND FLOODING ALONG FULL LENGTH OF GLAZING	LOW - MINIMAL MOVING PARTS	LOW - FEW SLOW MOVING PARTS. NO CRITICAL ALIGNMENT REQUIRED
 MOVING SQUEEGY WITH SPRAY	GOOD - DIRECT IMPINGEMENT AND SQUEEGY ACTION ALONG FULL LENGTH OF GLAZING	HIGH - COMPLEX ROLLERS, GUIDE RAILS AND DRIVE MECHANISM	HIGH - NUMEROUS MOVING PARTS; CRITICAL ALIGNMENT; SENSITIVE TO FREEZING CONDITIONS ON RAILS. SQUEEGY REPLACEMENT DUE TO WEAR AND BRITTLENESS.

FIGURE 4-1. CLEANING CONCEPT COMPARISON

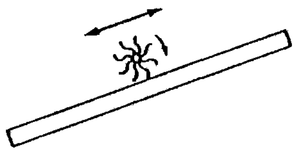
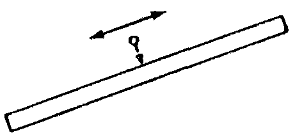
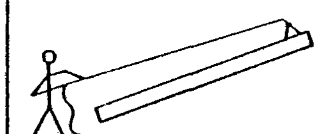
CONCEPT	PROBABLE CLEANING EFFECTIVENESS	RELATIVE COST	MAINTENANCE REQUIREMENTS
 ROTATING/MOVING BRUSH WITH SPRAY	EXCELLENT - BRUSHING ACTION OVER ENTIRE GLAZING	VERY HIGH - COMPLEX TRANSLATION AND ROTATION MECHANISM. DYNAMIC WATER SEALS REQUIRED	VERY HIGH - MOTION LIMIT ADJUSTMENTS CRITICAL; FREEZING OF BRUSH ELEMENTS; BRUSH WEAR AND REPLACEMENT; BRUSH PRESSURE ADJUSTMENTS
 MOVING SPRAY	GOOD - DIRECT WATER IMPINGEMENT OVER ENTIRE GLAZING SURFACE	HIGH - COMPLEX TRANSLATION MECHANISM. LONG, FLEXIBLE FEEDER TUBES	HIGH - MOTION LIMIT ADJUSTMENTS; CRITICAL ALIGNMENT: FREEZING OF WATER ON RAILS AND MECHANISM
 IMPROVED MANUAL (LONG SPRAY/BRUSH)	GOOD - BRUSH/SPRAY ACTION OVER ENTIRE GLAZING SURFACE	LOW INITIAL COST - SIMPLE FIXED PIPING SYSTEM HIGH LABOR COST - REQUIRES APPROXIMATELY 12 TO 14 MAN-HOURS EACH CLEANING	LOW - OCCASIONAL BRUSH REPLACEMENT

FIGURE 4-1 - Concluded

4.4 ROTATING/MOVING BRUSH WITH SPRAY

This system bears a resemblance to equipment used in the carwash industry. It would certainly offer a better cleaning effectiveness than all methods considered. However, the initial cost and maintenance penalties were too severe for further serious consideration.

4.5 MOVING SPRAY

This system consists of a spray bar that translates the length of the collector. It offers very little performance improvement over the oscillating spray and has the same disadvantage of the other systems incorporating translation.

4.6 IMPROVED MANUAL METHOD

The current manual cleaning technique involves a separate spray and brushing operation. A high-flow, long-handled, spray/brush was found in the market survey. This method offers the same cleaning effectiveness as the method now employed and the initial cost is low. However, it is estimated that it would take 12 to 14 man-hours per cleaning as compared to the 18 man-hours now required. As a result, the concept was not given further consideration.

5. PROTOTYPE SYSTEMS

Before final selection of a concept, two test setups were made and a prototype cleaning system was constructed and tested. One test setup was used to examine the effectiveness of the fixed spaybar concept. The other test setup and prototype were used to determine the effectiveness of the oscillating spray concept.

5.1 FIXED SPRAY TEST SETUP

The low initial cost and reliability of this concept prompted the construction of the test setup shown in Figure 5-1. The testing of this system revealed good cleaning effectiveness only in the area of direct water impingement. Below this area, the water formed a random pattern and offered no cleaning effectiveness.

5.2 OSCILLATING SPRAY TEST SETUP

A simple test setup using an inverted standard lawn sprinkler was installed to verify the cleaning effectiveness of the oscillating spray concept. This setup is shown in Figures 5-2 and 5-3. This system was installed on August 4 and tested until August 31. The system was operated once in the morning and once in the late afternoon. Each cycle consisted of 1 min of cleaning with detergent injection and 1 min of rinse. This system incorporated an inexpensive syphon-type soap injector with no accurate method of determining concentration. The system covered four panels and had a flow rate of approximately 5 gpm (0.063 gpm/ft^2).

Although no specific performance testing was performed, the cleaning effectiveness appeared excellent. As a result, it was decided to prepare a more elaborate system incorporating controlled soap injection and various hole spacings and sizes to determine the best combinations of each of these variables.

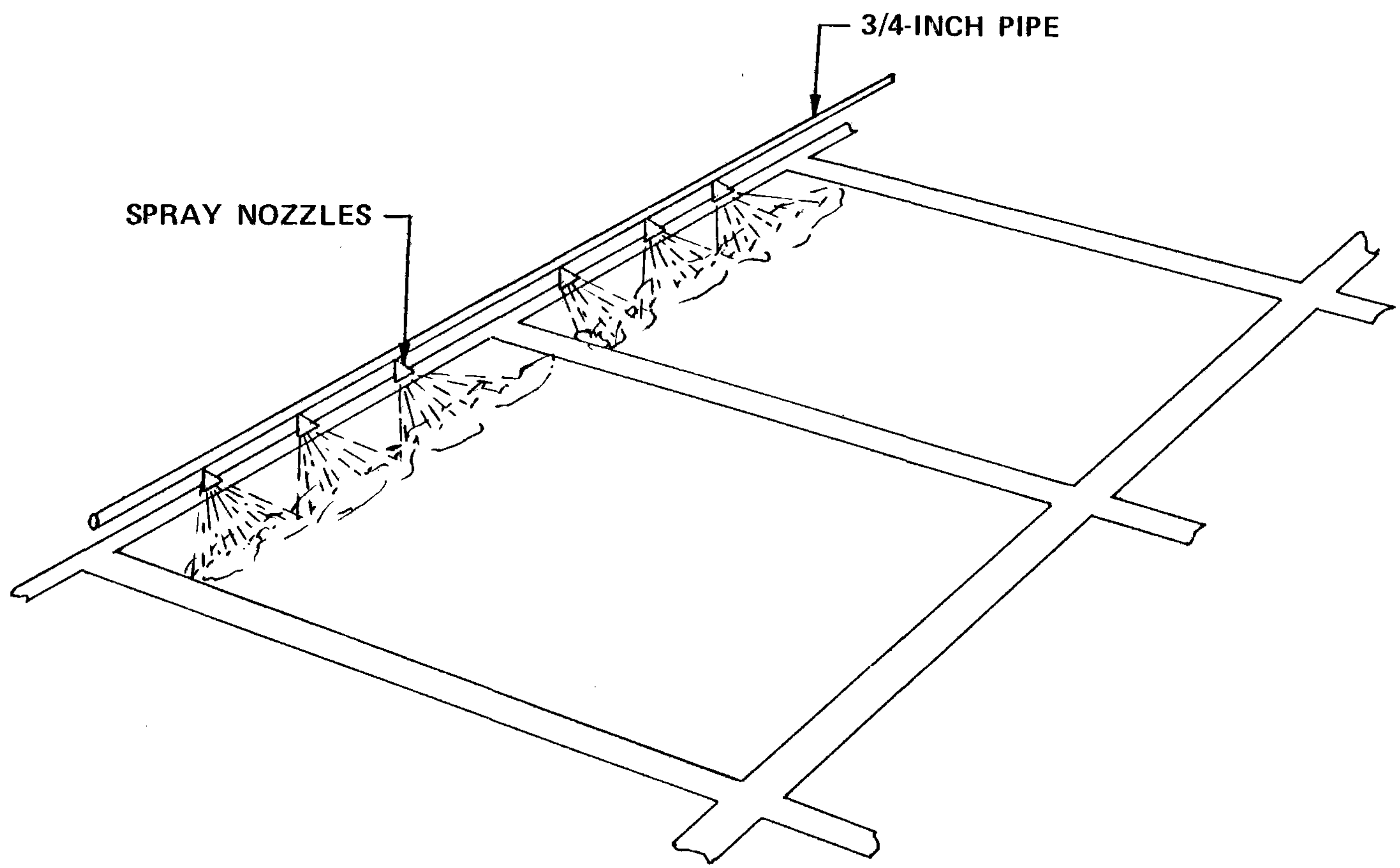


FIGURE 5-1. FIXED SPRAY TEST SETUP

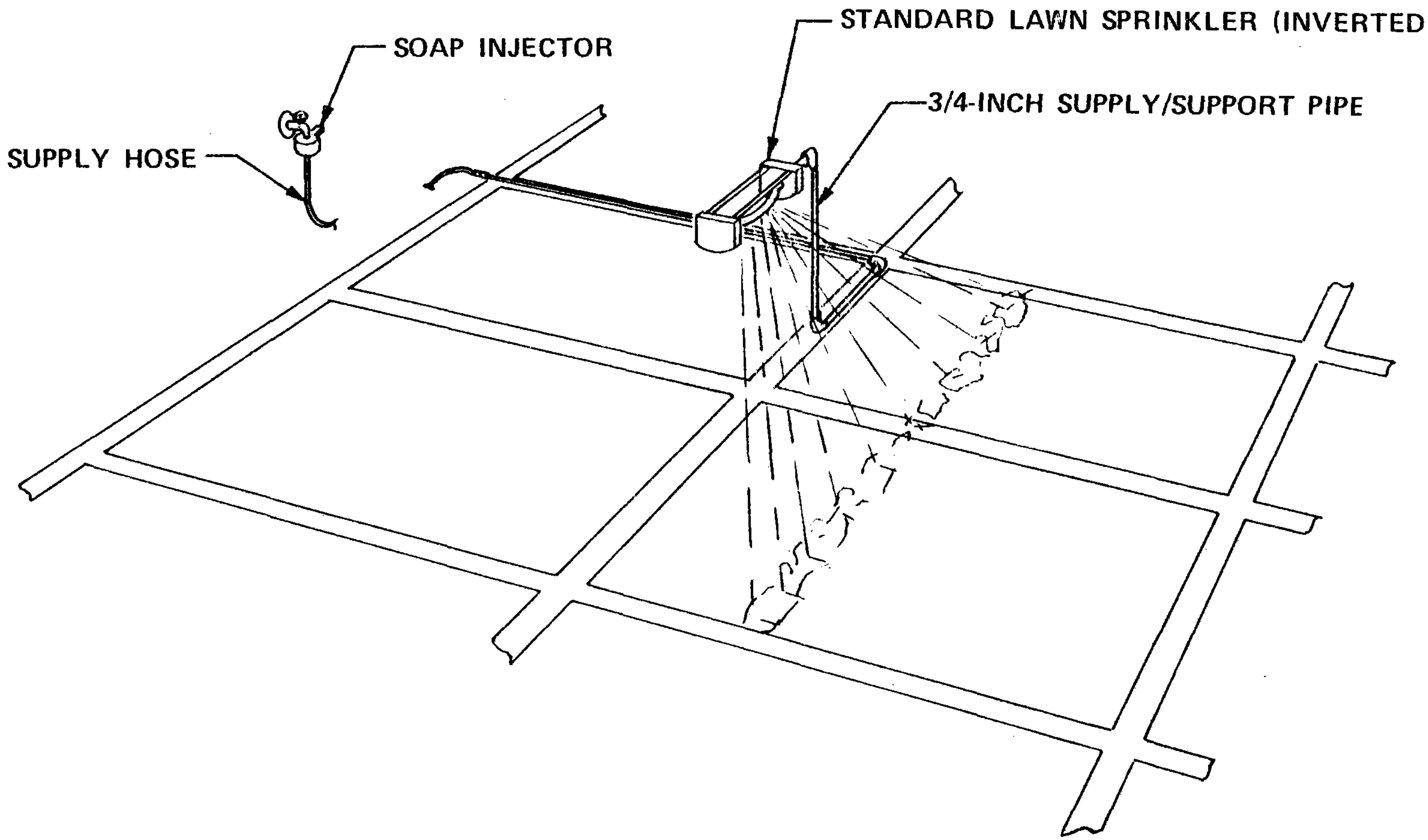


FIGURE 5-2. OSCILLATING SPRAY TEST SETUP

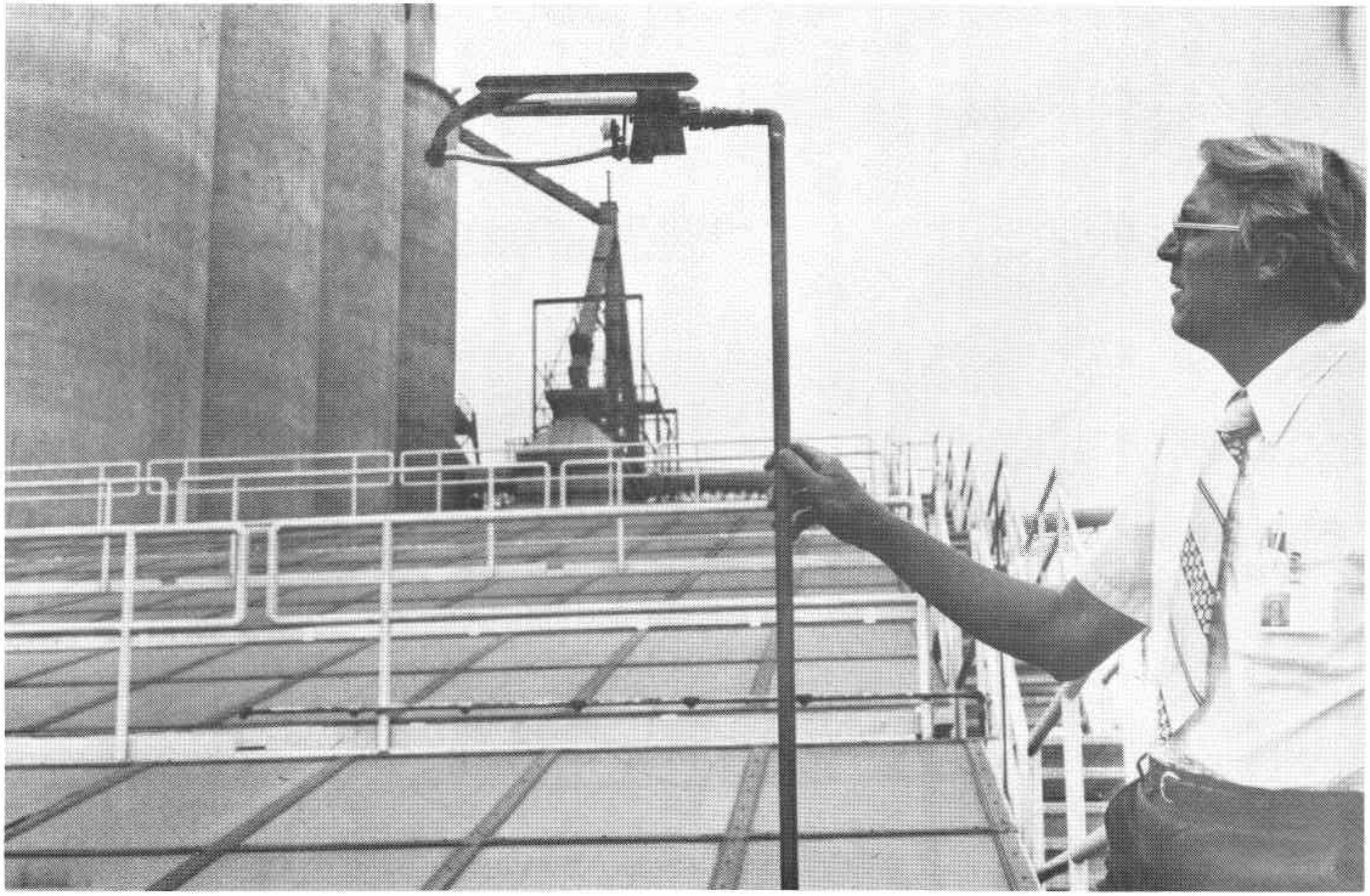


FIGURE 5-3. OSCILLATING SPRAY TEST SETUP

5.3 OSCILLATING SPRAY PROTOTYPE

A 48-ft-long oscillating spray prototype has been installed and partially tested. The testing of this system in continuing. Figures 5-4 and 5-5 present an overall view and photograph of the system.

5.3.1 Prototype System Design

The basic design criteria used in this system were as follows:

- Several test sections to evaluate different hole spacings and diameters
- An actuator with an adjustable stroke
- An accurate, variable soap feed system
- Sufficient line sizing to provide at least 65-psi pressure at a delivery rate of 25 gpm
- Manual control system without freeze protection
- Expandable to a full-scale system
- Minimum system cost.

The prototype system that was designed is a 48-ft oscillating spray bar. The system covers 32 collectors (16 pairs). A discussion of the design follows.

To ensure adequate delivery and to incorporate sufficient structural rigidity, a 0.75-in, type K, rigid copper pipe was chosen as the spray bar. Through experimentation, it was determined that this pipe required support at least every 12 ft. This led to the four-section, 48-ft spray bar shown in Figure 5-6. The spray bar is fed from both ends. The various hole sizing and spacing will allow evaluation of these parameters through testing. These are critical parameters since they are directly associated with the total water consumption required for each cleaning.

Each spray bar support is made up of inexpensive, off-the-shelf hardware. Figure 5-7 shows details of the supports.

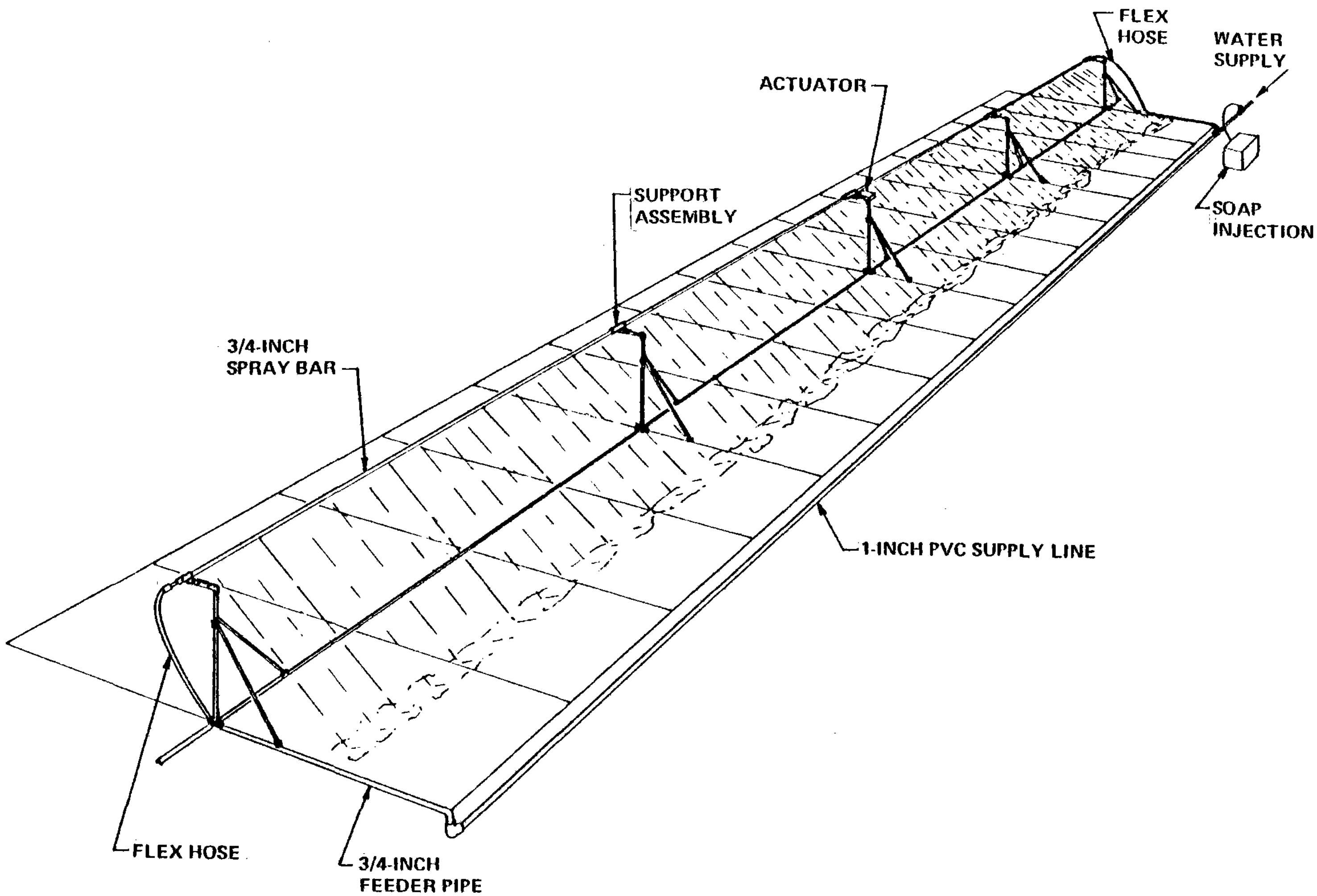


FIGURE 5-4. PROTOTYPE CLEANING SYSTEM

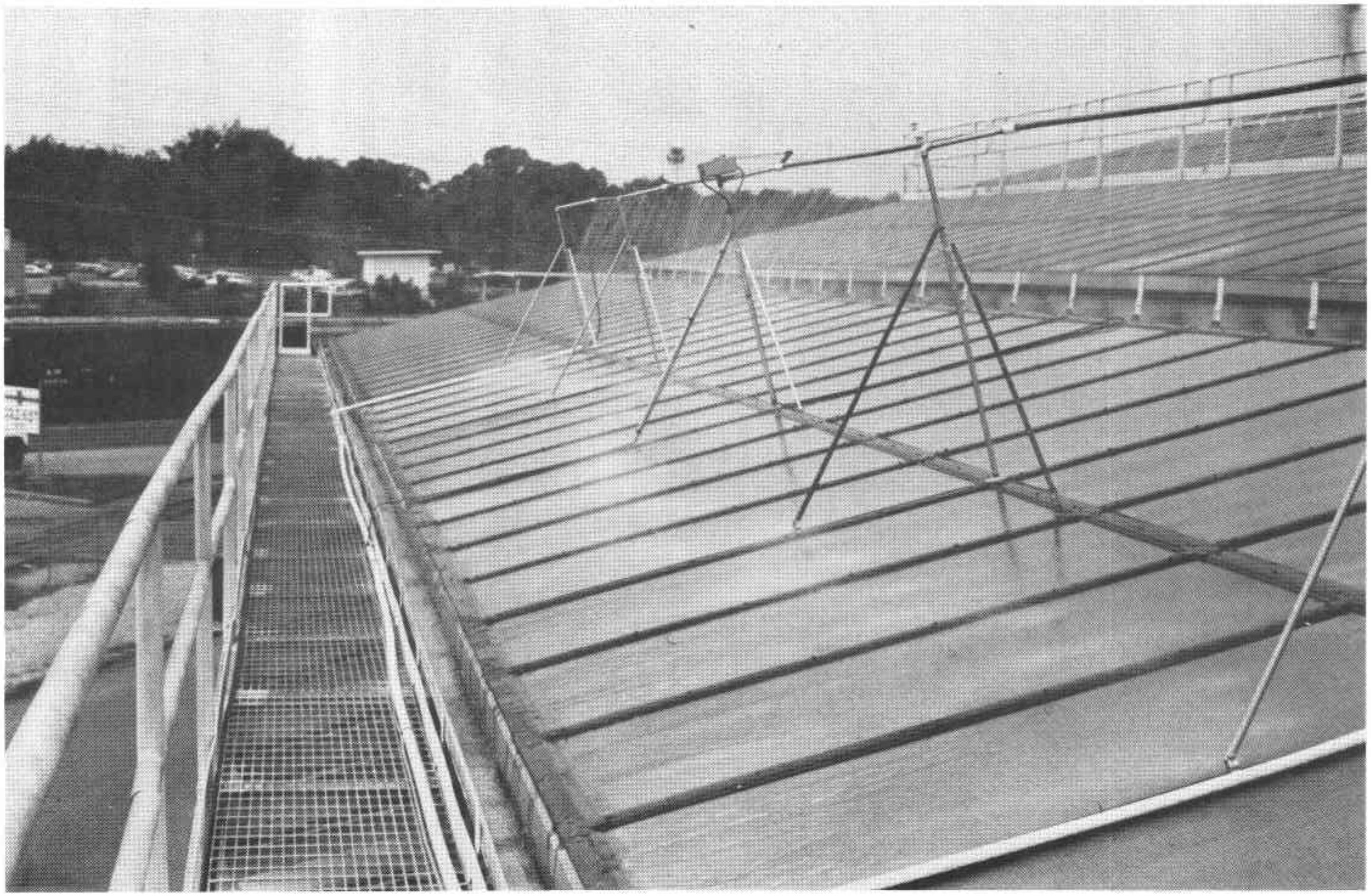


FIGURE 5-5. 48-ft PROTOTYPE CLEANING SYSTEM

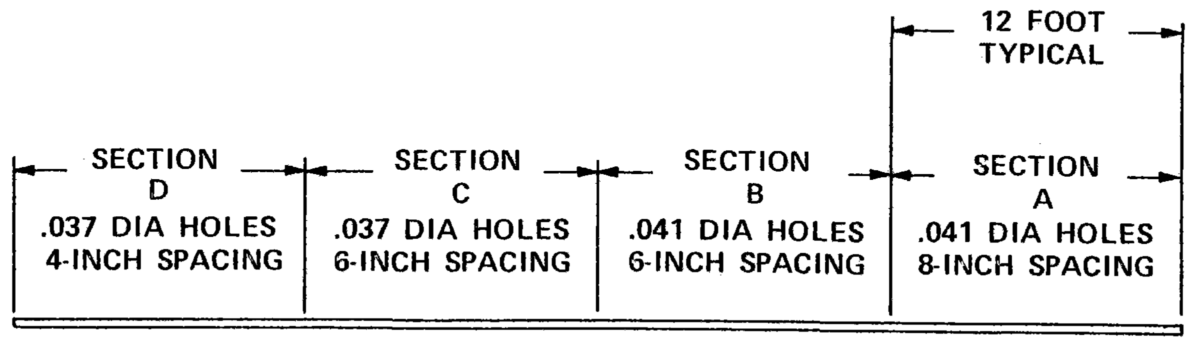


FIGURE 5-6. SPRAY TUBE HOLE PATTERN

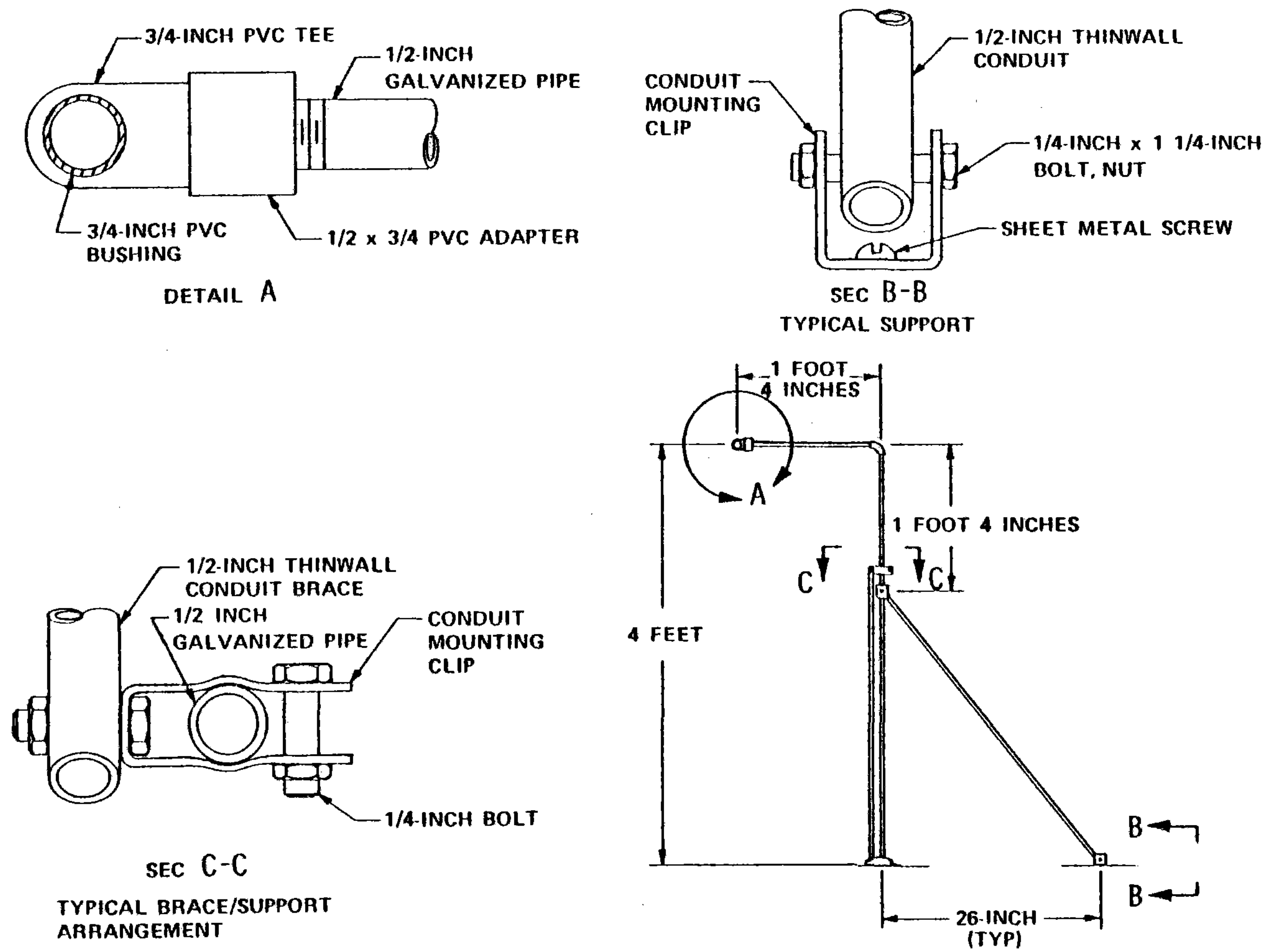


FIGURE 5-7. SPRAY TUBE SUPPORT ASSEMBLY

The actuator assembly is shown in the drawing and photograph of Figure 5-8. The motor is a standard 2-rpm, 25-in.-lb gearmotor. For rigidity, a cast aluminum box was chosen to house the motor. The linkage system consists of crank arms and a push rod that are standard in the heating, ventillation, and air conditioning industry.

The detergent injection system (Figure 5-9) was chosen to provide a variable injection rate of various chemicals. It is located in the supply line immediately upstream of the first spray tube supply feeder. This system is capable of injecting 0.008 gpm of detergent at a line pressure of 70 psig.

5.3.2 Prototype System Testing

To have a realistic test, all panels should be thoroughly cleaned initially. The prototype became operational (with the exception of the soap injector) on August 31, at the midpoint of a routine manual cleaning cycle. However, it was operated for 2 min. twice daily until the next scheduled panel cleaning. The accumulation of contamination at startup was heavy and its effectiveness was difficult to evaluate during this preliminary test phase.

The entire array was cleaned on September 20, at which time a test program was started without the use of a detergent. Figure 5-10 presents a comparison of panels with and without daily rinsing with the prototype cleaning system. This comparison is more vivid in the overall view shown in Figure 5-11.

After approximately 2 weeks of testing a number of the orifices were plugged by debris. It is suspected that this debris came from a repair operation by Gold Kist on a nearby water main. It does establish the need for a filter in the final design system.

It is still too early in testing to properly evaluate the effects of different detergents and concentrations. This testing will continue beyond this writing until freezing conditions dictate draining. Results of this further testing will be contained in monthly and quarterly contract status reports.

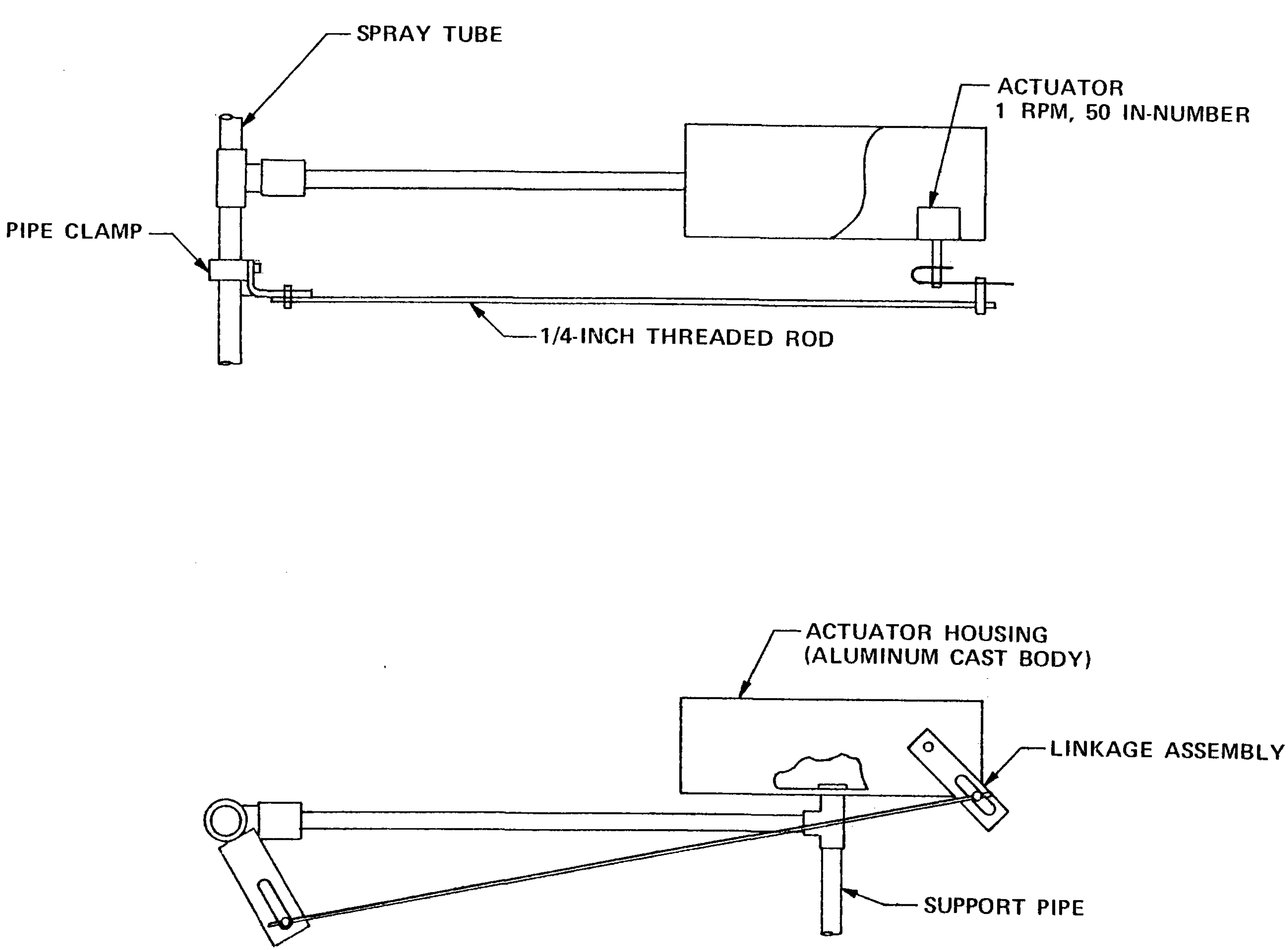


FIGURE 5-8. ACTUATOR ARRANGEMENT

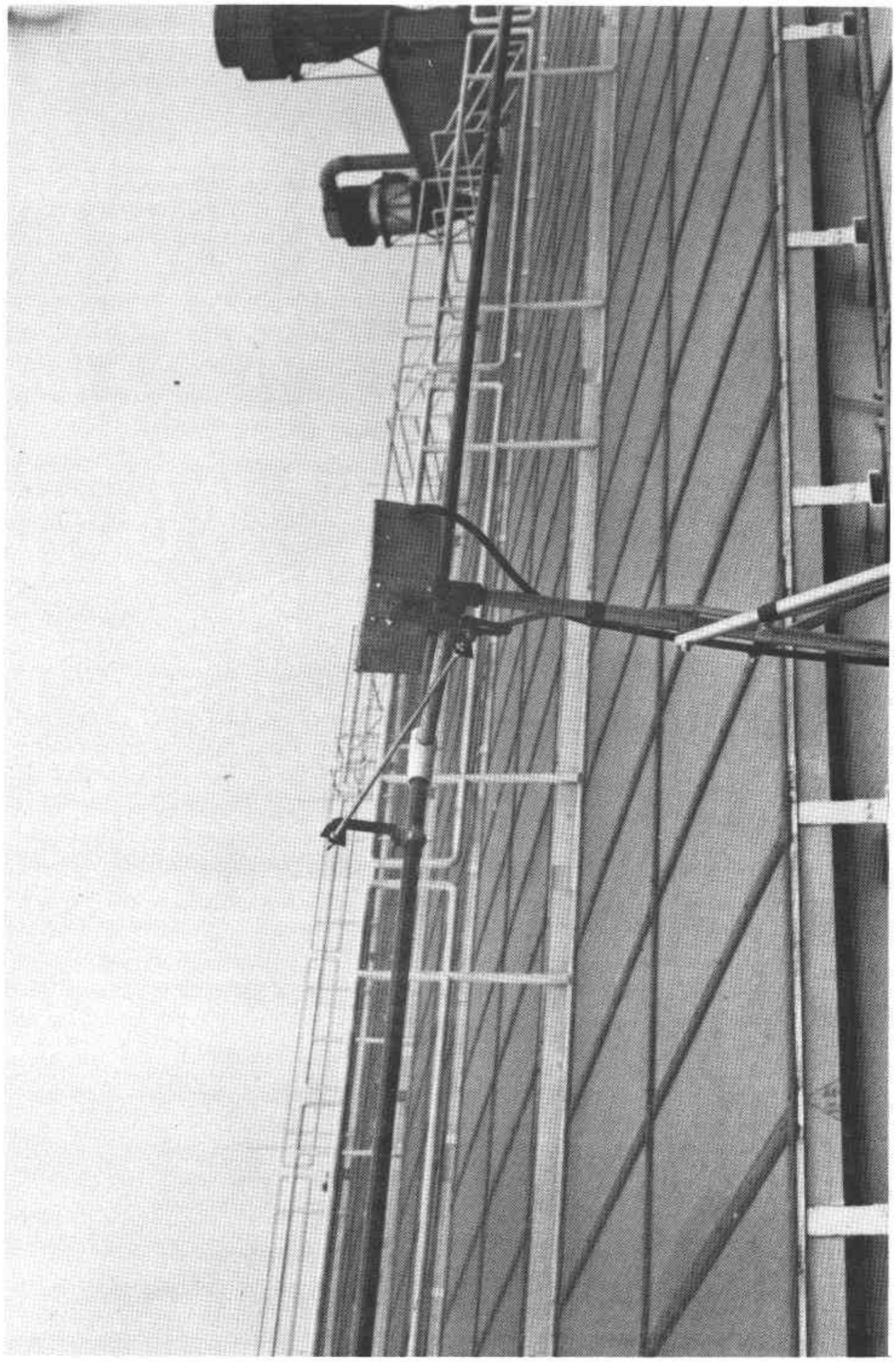


FIGURE 5-8 - Concluded

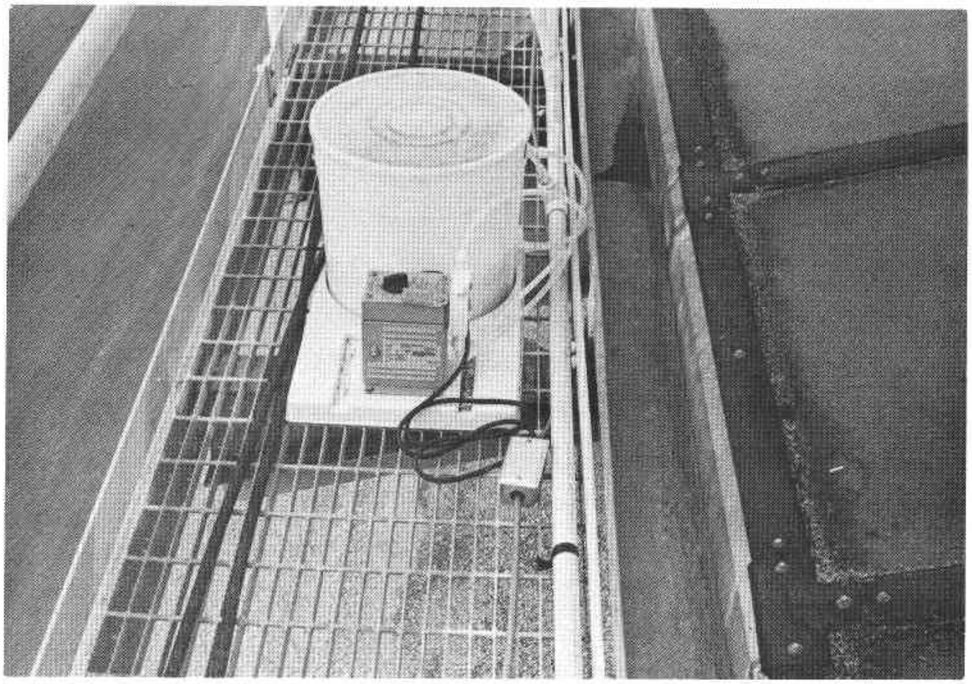
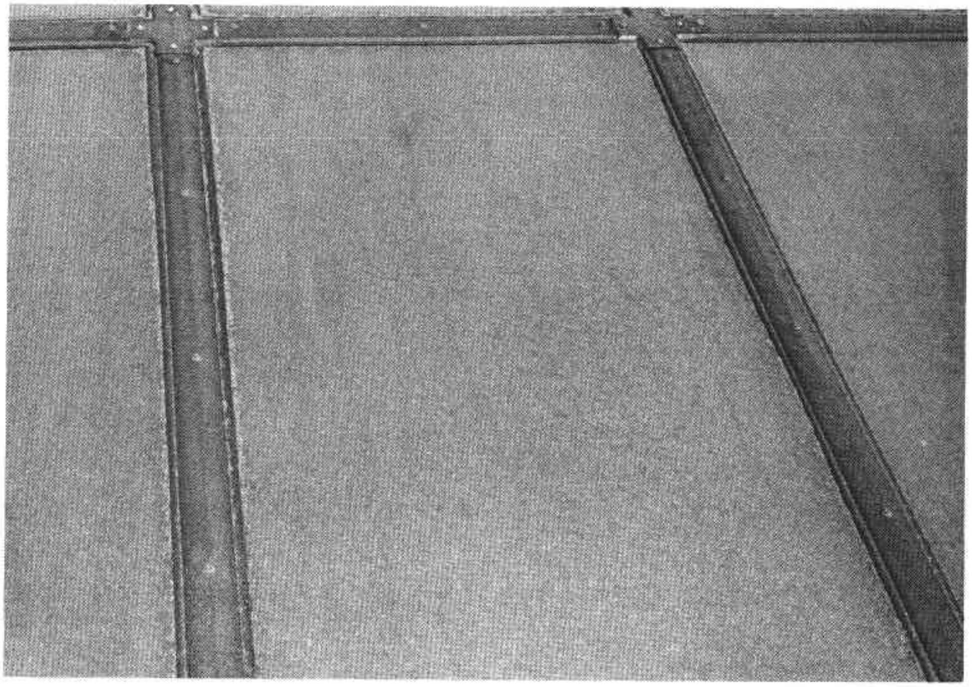
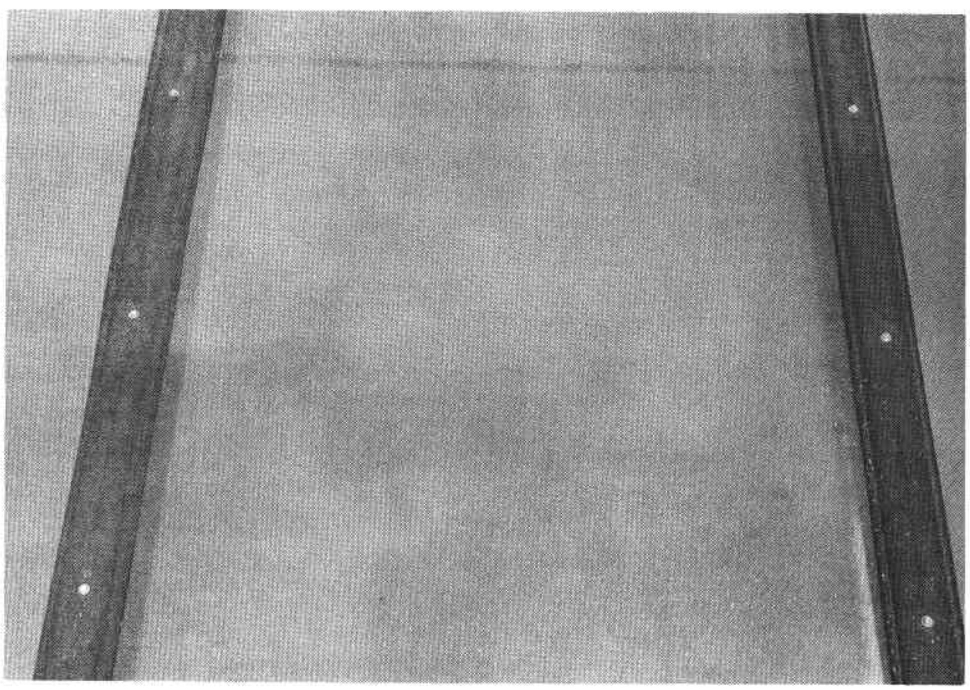


FIGURE 5-9. DETERGENT INJECTION SYSTEM



a. PANELS WITHOUT PROTOTYPE CLEANING SYSTEM



b. PANELS WITH PROTOTYPE CLEANING SYSTEM

FIGURE 5-10. COMPARISON OF PANELS

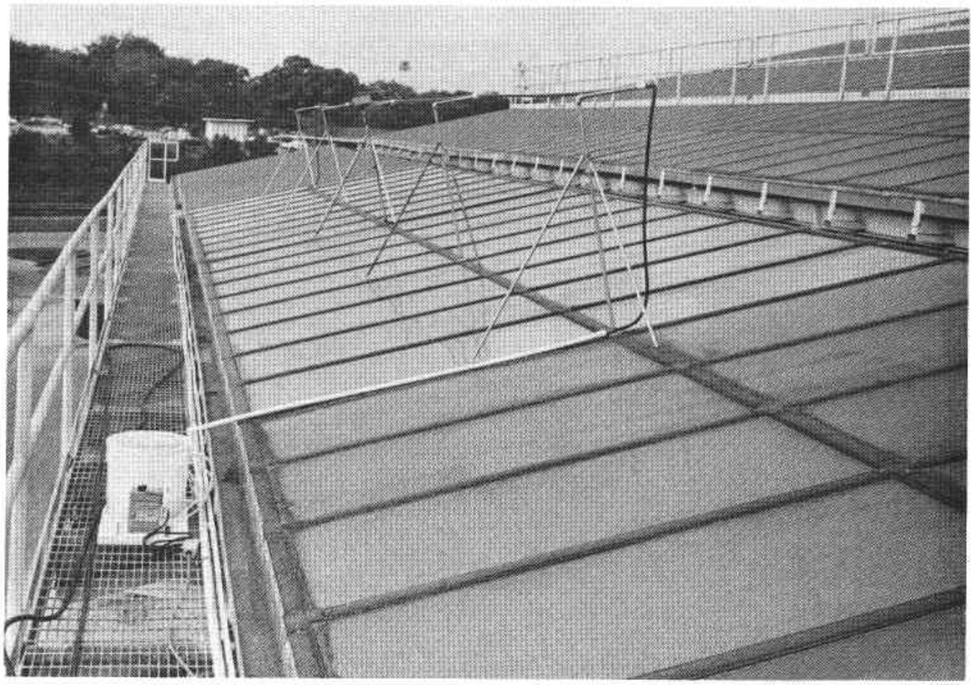


FIGURE 5-11. CLEANING SYSTEM EFFECTIVENESS

6. SYSTEM DESIGN CONCEPT

6.1 SPRAY BAR ARRANGEMENT

The spray bar syetem is conceived as being 21 modules, 48 ft long. Each module would be similar to the prototype described in Section 5. The support system will require some modification to accommodate the intersection of each module. A design concept of this modification is shown in Figure 6-1.

As in the prototype, standard materials may be used throughout the spray bar system. The actuator assemblies are conceived as being identical to the prototype, requiring one per module.

Each module is fed from both ends. This ensures maximum delivery pressure for good water impingement cleaning action.

Although not yet conclusive, testing to date indicates optimum hole sizing to be 0.037 in., spaced at 4-in. intervals. This provides a flow of 0.055 gpm/ft^2. Therefore, flow of 34 gpm is anticipated.

6.2 PLUMBING

A study of optimum pipe size has resulted in the choice of 1-in. PVC main runs and 0.75-in. feeder runs. To minimize total flow, each module is isolated with a solenoid valve and will be operated in series by an automatic control system.

Figure 6-2 presents a layout of the typical plumbing proposed. Careful design and installation will be necessary to ensure proper gravity draining for freeze protection.

6.3 DETERGENT INJECTION

The detergent injection system used in the prototype is sufficient for use in the full-scale system since only one module will be operated at any one time.

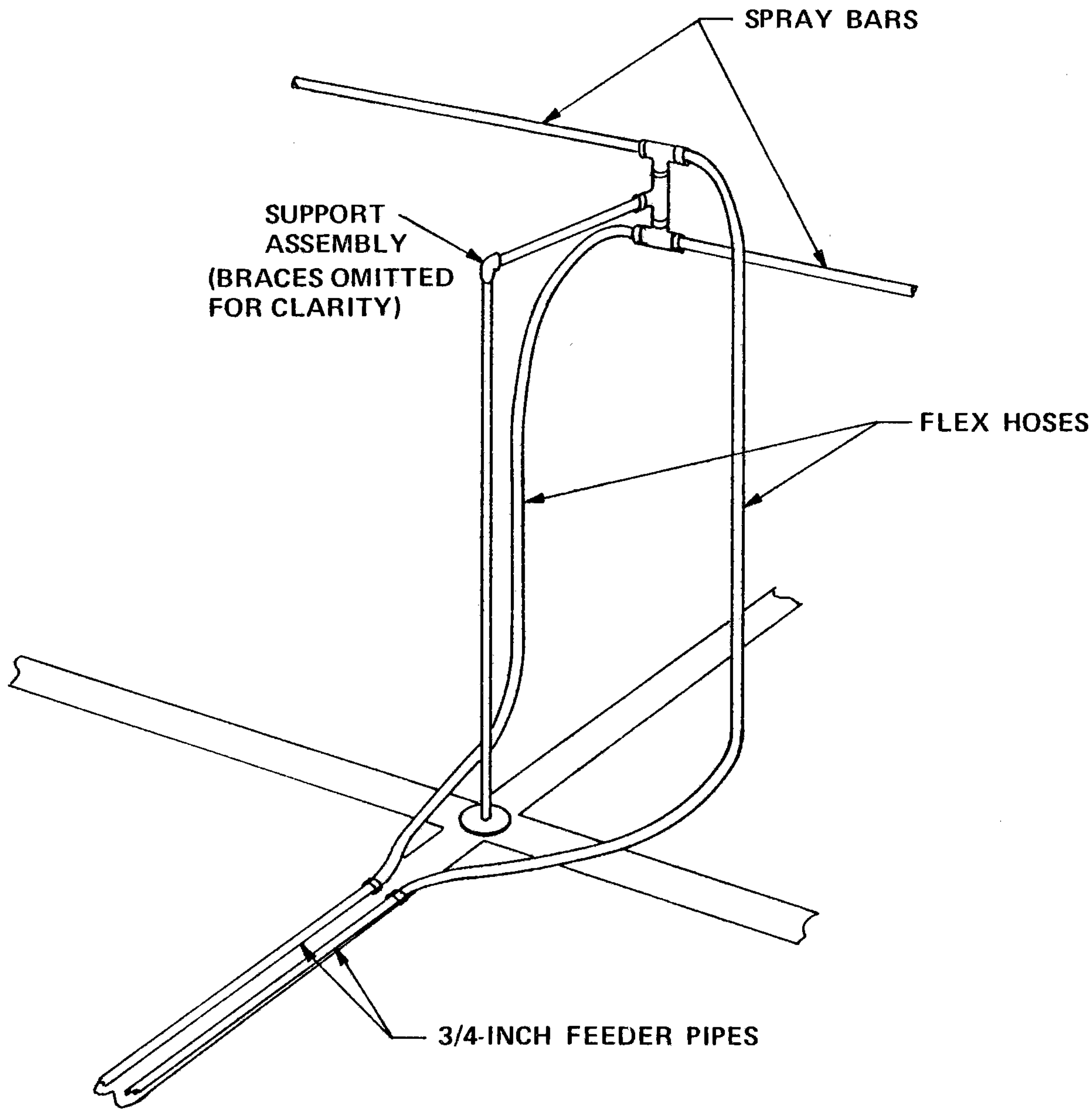


FIGURE 6-1. SUPPORT SYSTEM AT MODULE INTERFACES

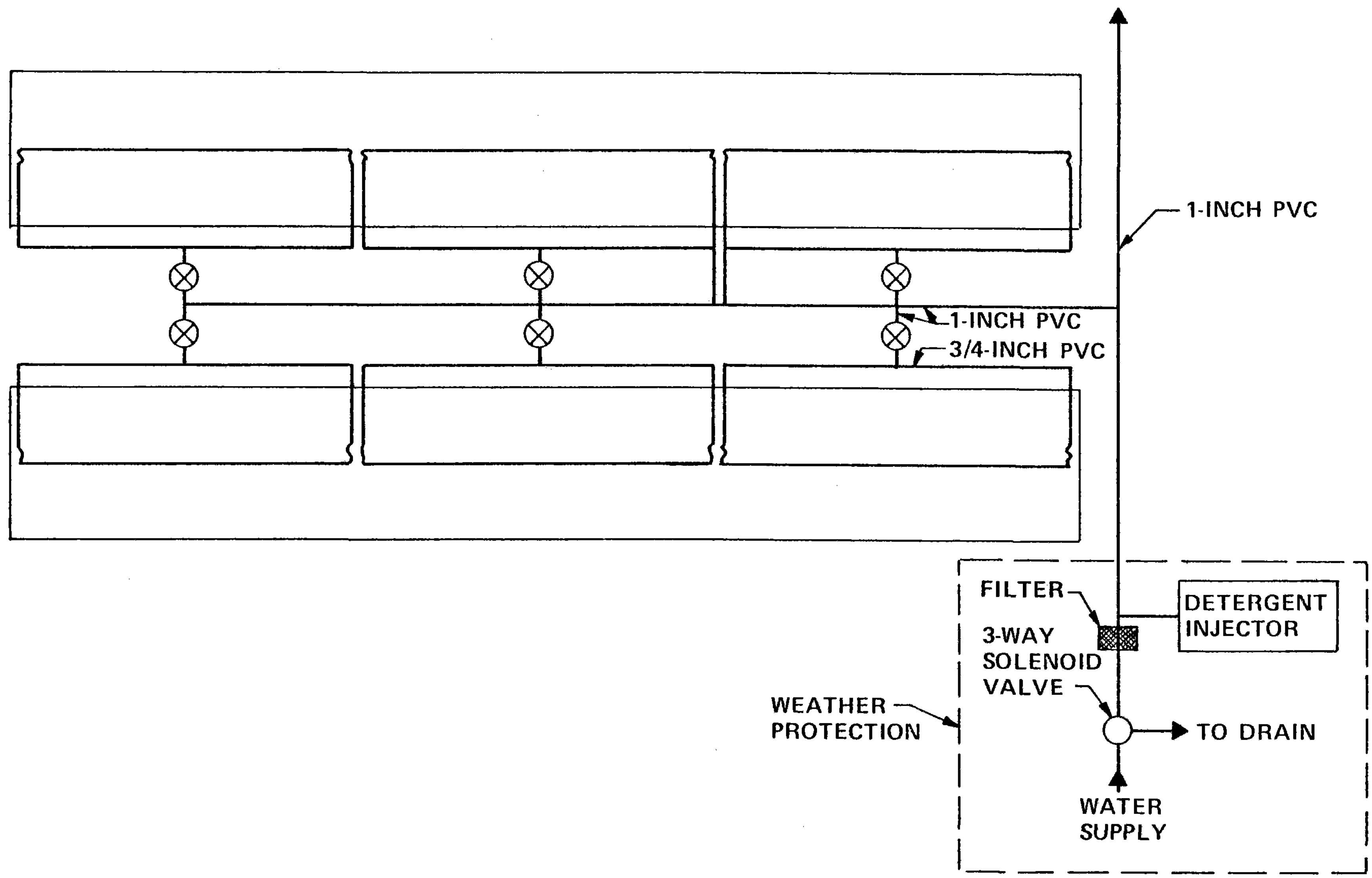


FIGURE 6-2. TYPICAL WATER DISTRIBUTION LAYOUT

6.4 CONTROL SYSTEM

The control system will manipulate the system to apply a detergent solution to each module for a duration of 1 min. each. With 21 modules, this will allow a 20-min. "soak" with the detergent solution. The soap injector would then be turned off and a 1 min. rinse applied to each module.

The control logic, shown in Figure 6-3, also provides for freeze protection. If, at the end of each rinse cycle, the temperature is below 33°F, the main water supply valve is positioned to "drain" and all control valves are positioned to "on" to allow the system to drain.

The system will be designed to use relay logic, a time clock, and a thermostat. System packaging will consist of a power panel and a control panel housing the relays and the time clock. A block diagram of the control system is presented in Figure 6-4.

6.5 SYSTEM LAYOUT

For weather protection, the control system, main water valve, and soap injector will be located in the building adjacent to the solar array. This location has the necessary water and power requirements and offers full-time freeze protection for this part of the system.

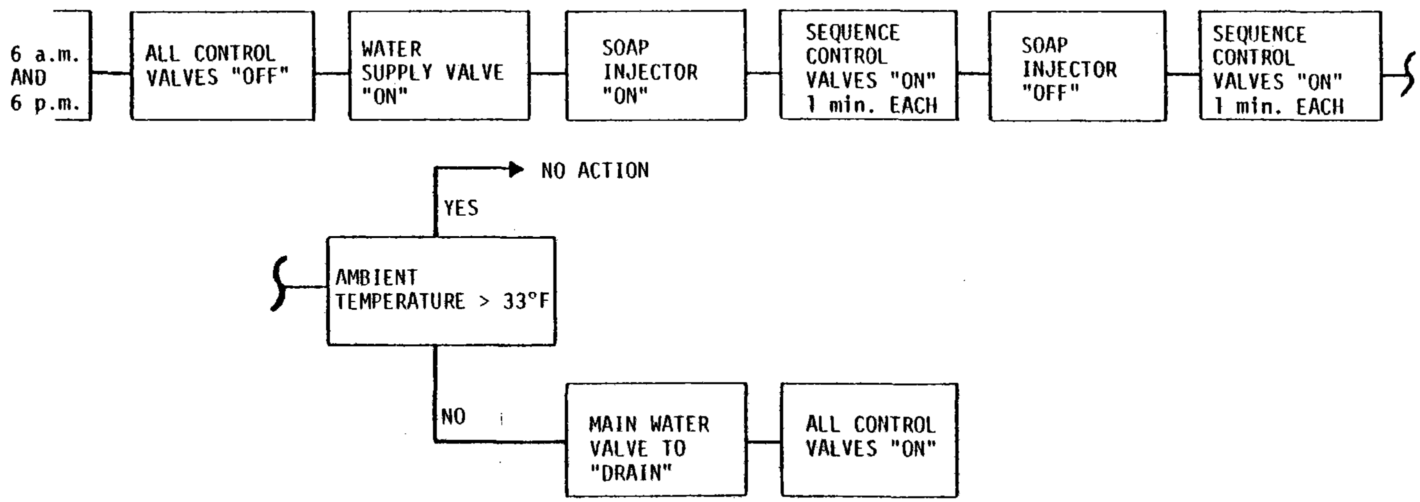


FIGURE 6-3. CONTROL LOGIC

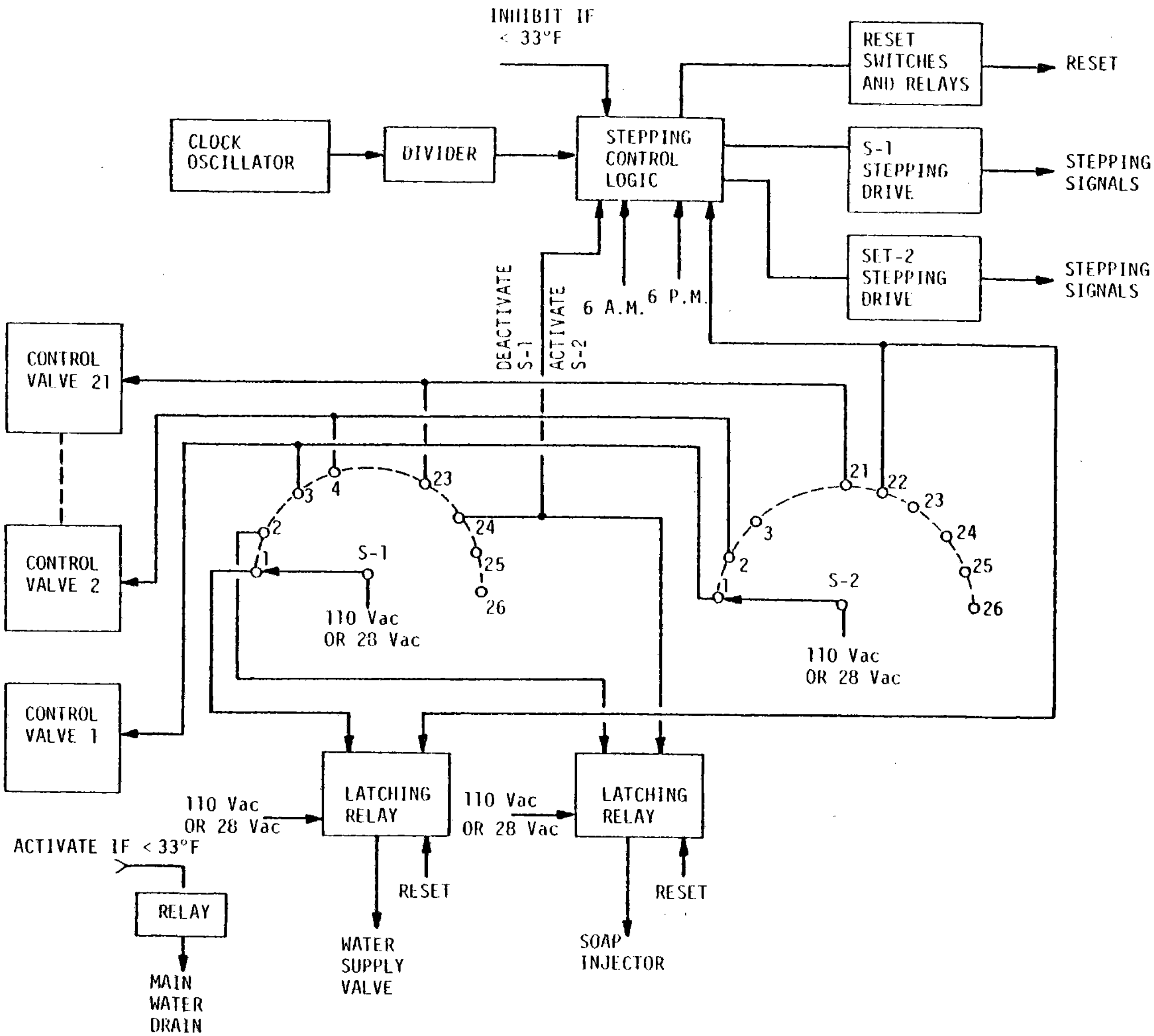


FIGURE 6-4. CONTROL SYSTEM BLOCK DIAGRAM

7. SYSTEM BUDGETARY COST

Based on experience gained during the fabrication and installation of the prototype cleaning system, a budgetary estimate has been prepared for the full-scale cleaning system. The results of this estimate are in Table 7-1. Engineering estimates shown are based on minimum engineering documentation.

TABLE 7-1. BUDGETARY COST ESTIMATE

ENGINEERING		
Mechanical	$5,000	
Electrical/Electronic	5,000	
		$10,000
FABRICATION LABOR		
Mechanical	$3,700	
Electronic	2,600	
		$ 6,300
MATERIAL		
Mechanical	$5,400	
Electrical/Electronic	1,500	
		$ 6,900
INSTALLATION		
Mechanical	$5,500	
Electrical/Electronic	2,200	
		$ 7,700
	TOTAL	$30,900

It should be noted that the mechanical fabrication and installation could be accomplished by Gold Kist personnel at significant savings.

Based on a 15% overall performance improvement, the cleaning system would increase annual fuel savings by $992 (based on June - August 1978 data). The manual cleaning cost, based on the first three months of operation, is projected to be $1,800 per year. The combination of these two is an estimated $2,792 annual economic improvement, assuming approximately equal quantities of water and detergent are consumed by either method of cleaning.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 CONCLUSIONS

The following conclusions are drawn from this conceptual design study:

- For this application, no translation or direct mechanical cleaning action is practical.
- Good cleaning action results from a direct water/detergent impingement on the face of collector glazings.
- The mechanical portions of such a system can be constructed using standard off-the-shelf hardware.
- An accurate economic assessment of an automatic cleaning system can be made only after specific performance testing on identical collectors in the contaminated condition and then in the cleaned condition.

8.2 RECOMMENDATIONS

The following recommendations are offered as a result of this study:

- Testing of the prototype system should continue (except during freezing weather) to determine the optimum cleaning agent and concentration and the best nozzle size and spacing.
- Tests should be performed to accurately determine the performance degradation as a result of the contamination.
- Based on results of the above, it is recommended that the system be designed and constructed in the following manner:
  - ▲ Design - TBE
  - ▲ Fabrication
    - Control System - TBE
    - Mechanical - Gold Kist

▲ Installation

- Control System - TBE
- Mechanical - Gold Kist
- Electrical - Gold Kist.