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VENTILATION EQUIPMENT ANALYSIS FOR BASEMENT SHELTERS

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General American Transportation Corporation
Niles, Illinois

February 1968

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GENERAL AMERICAN TRANSPORTATION CORPORATION

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GARD Final Report 1278 February 1968

GENERAL AMERICAN RESEARCH DIVISION

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REVIEW NOTICE

This report has been reviewed in the Office of Civil Defense and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Office of Civil Defense.

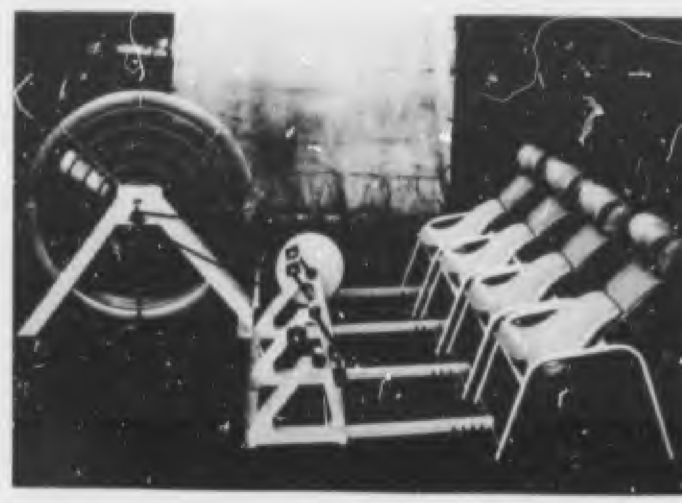
GENERAL AMERICAN RESEARCH DIVISION

FOREWORD

The ventilation equipment optimization study reported herein was conducted by the General American Research Division (GARD) of the General American Transportation Corporation, Niles, Illinois. The objective of this program was to identify the best ventilation equipment for use in the identified NFSS (National Fallout Shelter Survey) basement shelters based on an analysis of representative sample shelters, equipment performance, equipment designs, cost and physiological factors. The methodology was initially developed during the period of March, 1965 to October 1965 under Stanford Research Institute (SRI) Subcontract No. B-70925(4949A-28)-US, and the results presented herein were accomplished under a continuation of this contract during the period of January 1966 to February 1967. During the past twelve months, the results have been reviewed extensively by the Shelter Research Division of the Office of Civil Defense. Mr. C. A. Grubb of SRI monitored the project for the Office of Civil Defense under Work Unit 1423A.

The authors wish to acknowledge the assistance of Mr. David F. Liddell of Northwestern University. He was primarily responsible for the analysis of the shelter characteristics and preparation of the illustrations. The ventilator designs and cost analysis were prepared by Messrs. Basil A. Libovicz and Robert B. Neveril of GARD.

UNITARY VENTILATOR



MODULAR UNIT

POWER UNIT

ABSTRACT

Shelter and ventilator equipment analyses were performed to determine the best ventilator kits for the 138,000 below-grade fallout shelters identified during the second phase of the National Fallout Shelter Survey (NFSS). The basis for the study was a random sampling of 160 facilities. Sketches of these shelters were analyzed for basic characteristics that define the ventilation requirements, and by matching the performance of over 600 fans to the shelter requirements the best seven kits were chosen based on a least-cost ventilation system. The final selection of kits to be stocked depends on considerations other than engineering, primarily human factors.

Based on shelter conditions not exceeding a daily average effective temperature of 82°F for all but 10 percent of the days of the year, the best three ventilators, when power is available, are as illustrated on the facing page. The Unitary Ventilator is driven by one man and is packaged completely assembled in one container. The Modular Unit requires four operators, and the Power Unit is driven by a 5-horsepower motor. The kit for the electric motor-driven ventilator includes an engine-generator set. These units will provide adequate ventilation for 98.6 percent of the basement shelter-parts identified in the NFSS at an average per-capita cost of $0.56.

For an exclusively manual system, the best two kits are the Unitary and the four-man Modular Units, both of which are again shown on the facing page. The best three kits would be these same two units plus the one-man, 20-inch diameter unit described by Specification MIL-V-40645. With this equipment, 93.5 percent of the shelter-parts accommodating 65,353,075 people can be adequately ventilated. These shelters accommodate 81.9 percent of the total shelter spaces available, as compared to 90.2 percent when the Power Unit is used.

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SECTION 1

INTRODUCTION

In January 1963 an OCD Task Group conducted a one-week study to consider the feasibility of using ventilation and/or cooling units in spaces identified under the Shelter Survey Program for the purpose of maintaining a habitable shelter environment during emergency conditions. As a result of this study, the following recommendations were made (Ref. 1):

I. "That decision be made to stockpile packaged ventilation units in selected identified shelter spaces".

II. "An immediate development and testing program be initiated covering the mounting, manual drive and other necessary components for best utilization of currently available ventilation fans".

III. "A study-development program be initiated at the earliest possible date to (1) survey available components, (2) test prototype units, (3) perform cost-effectiveness analyses to select optimum designs to meet OCD requirements, (4) prepare detailed purchase specifications, and (5) study and review typical types of shelters and prepare necessary instructions for the use of packaged ventilation units".

IV. "Further study of the ventilation capabilities of identified shelter spaces be made to determine what capacity must be added to insure a habitable environment. If existing survey data do not provide such information, additional surveys will be required".

V. "A study of the availability of well water for possible use in cooling shelter areas*, as well as furnishing drinking water and meeting sanitary requirements, be instituted".

*According to Stanford Research Institute (Ref. 2), post-attack, in-shelter well construction is not feasible.

Items II and III.2 resulted in the development and testing of a one-man and a two-man pedal-driven ventilator kit (Refs. 3, 4, and 5) as shown in Figure 1 and described by Specification MIL-V-40645, "Package Ventilation Kit, 20-Inch Fan, Modular Drive (Civil Defense)", dated 16 August 1965. This unit can be readily operated by most adult shelterees for periods of at least three hours each day with 7-1/2 minutes rest each half-hour at pedal speeds from 45 to 62 rpm. The optimum power input was found to be .10 horsepower per operator. The instructions for this unit and other Civil Defense equipment is being studied and reviewed under another program by GARD (Ref. 6). This preliminary hardware development effort has proven the feasibility of the pedal-driven ventilator to exhaust air from shelters.

The exhaust method of ventilation, as opposed to the supply method, was adopted for use in the mass shelter program because the least cost ventilation system could be designed. In this type of system, rigid ductwork and filters are not necessary since interior stairwells and elevators are used as the air source, and consequently, the stories of the building above the basement act as a settling chamber for fallout. When air is introduced by necessity directly into the shelter through exterior windows and doors, the velocity of the incoming air stream reduces immediately after it passes through the opening, and the particles tend to drop-out in the vicinity of the aperture. The vicinity of the aperture, an area of roughly 22 square feet, has a considerable reduction in protection for either air introduced naturally or air introduced at velocities up to 425 feet per minute, and therefore should not be used as a shelter area (Ref. 7).

To develop confidence in a ventilating system for the NFSS basement shelters, and to minimize the cost for the system, an analysis of shelter characteristics, impeller performance, and design costs is required to determine the best kits and their capability. Our approach to gain this

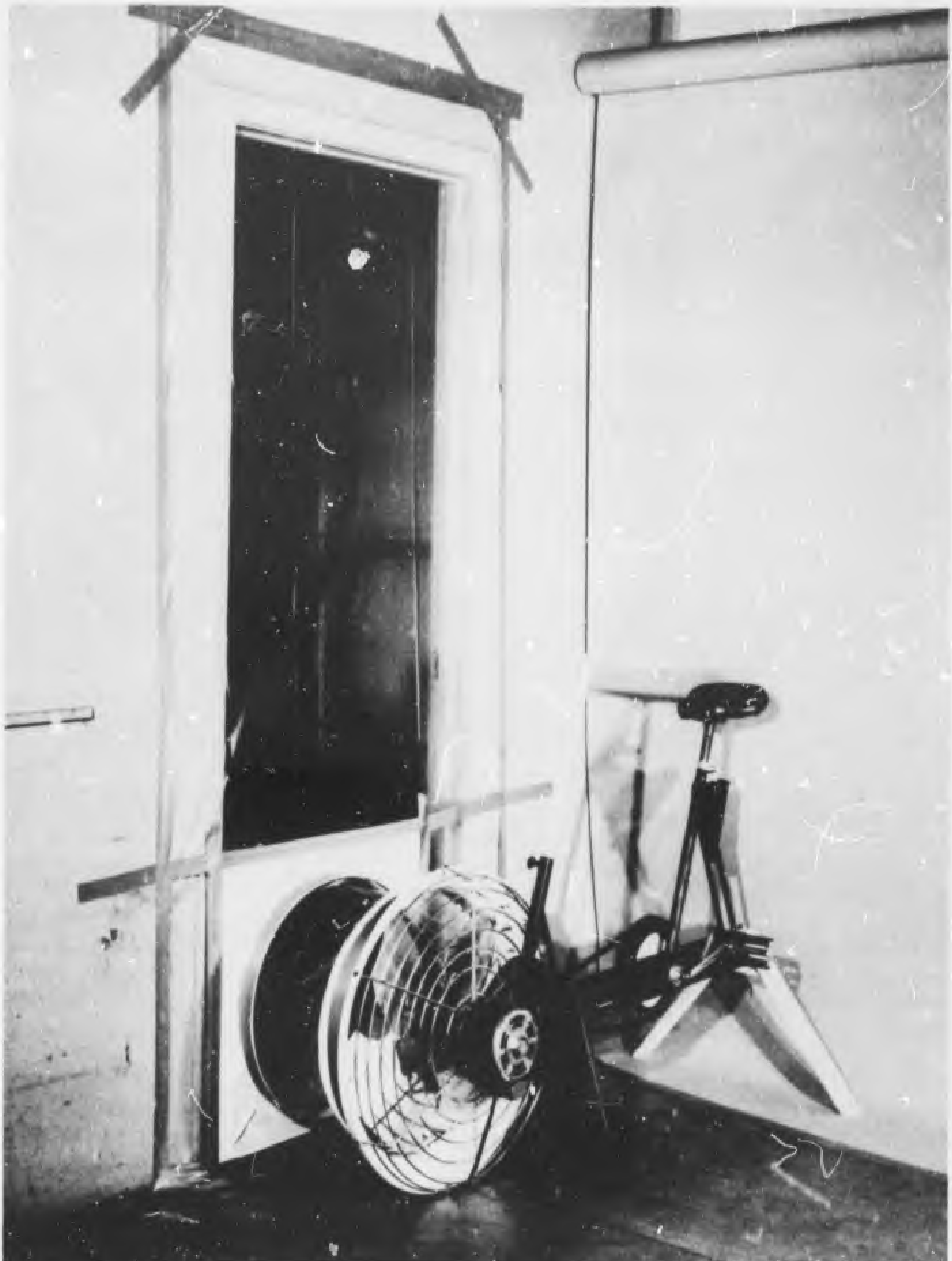

Figure 1 MIL-V-40645 "PACKAGE VENTILATION KIT"

confidence, and to identify the best ventilators, is shown by the program flow diagram, Figure 2. Simply, the characteristics of a random sample of shelters were matched to the performance of the family of ventilators considered, and by a process of elimination, the number of ventilators was reduced from the 636 units considered to a maximum of 28 units. Based upon purely engineering considerations, there should be as many different ventilation systems as there are different shelters, in order that each unit will operate at maximum efficiency and the overall cost of the system minimized. From inventory and human factors considerations, there should be as few types as possible. The number of kits to be stocked depends on considerations other than engineering, primarily human factors. These considerations are as follows:

- What is the maximum diameter of the duct system allowable in shelters?
- What is the maximum number of operators that can be utilized efficiently with each candidate ventilator?
- What is the allowable complexity of the equipment?
- What is the necessary instructional detail required to assure adequate deployment of the units, assembly of the hardware, fabrication of the duct system, and operation of the equipment?

The selection of the shelter characteristics is discussed in Section 2, and a design, performance and cost analysis of the 636 ventilation units considered is presented in Section 3. The screening procedure and selection of the best ventilators, based on engineering considerations only, is discussed in Section 4. Also in Section 4, predictions are presented for the National coverage, the number of kits required, and the cost for any combination of units up to seven, including the Package Ventilation Kit described by Specification MIL-V-40645. The coverage predictions, both shelter-parts and shelter spaces, were generated by applying the results of the sample shelter analysis to the actual distribution of the NFSS facilities throughout the isoventilation zones for the 50 states.

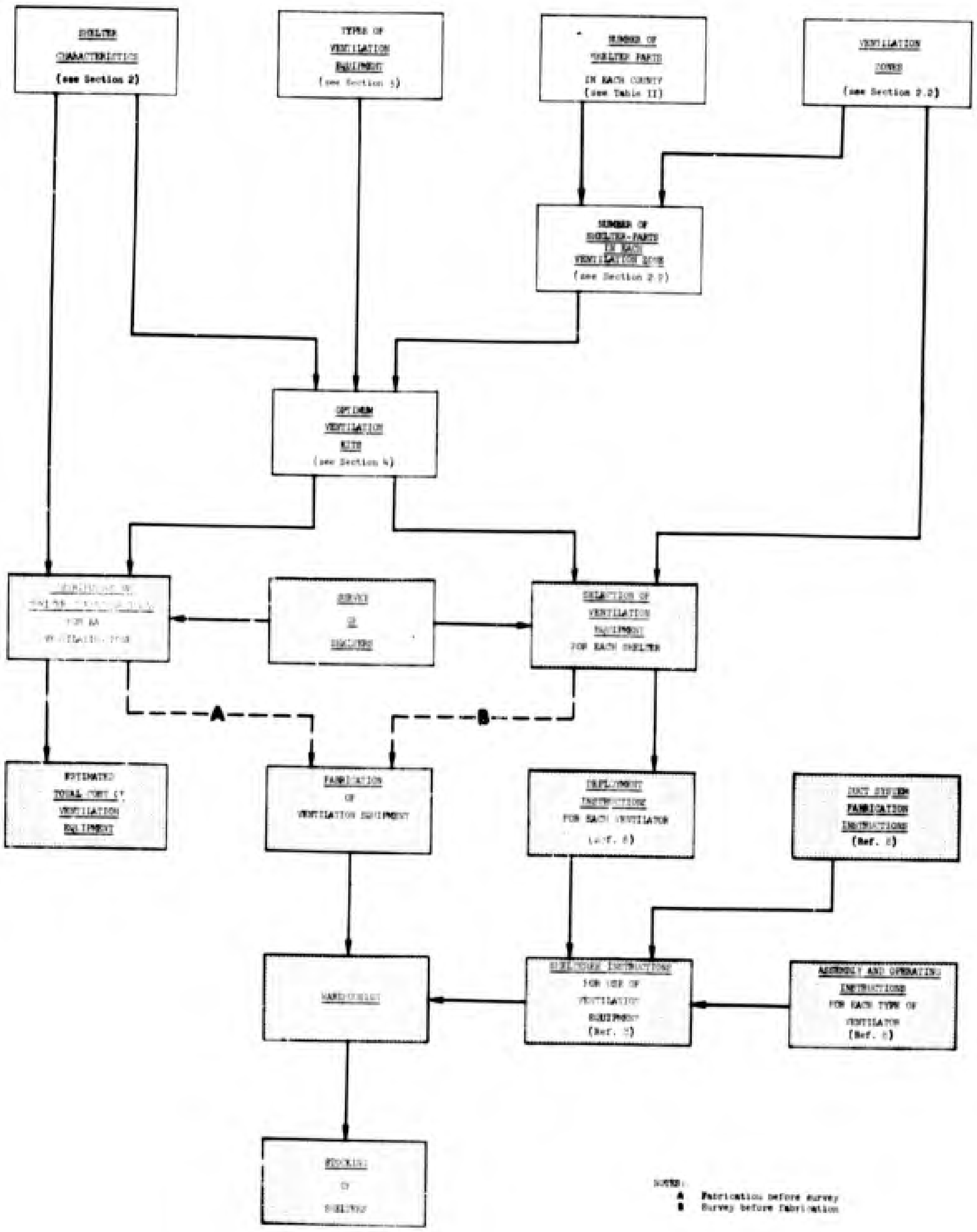

Figure 2 APPROACH FOR THE OPTIMIZATION ANALYSIS STUDY AND AN OPERATIONAL SYSTEM FOR VENTILATING THE NFSS BASEMENT SHELTERS

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SECTION 2

SHELTER CHARACTERISTICS

In order to provide ventilation for identified fallout shelters throughout the country, a random sample of basement shelters was analyzed to determine the basic descriptors necessary to adequately describe the NFSS shelters. With the shelter descriptors and the performance characteristics of ventilators, the equipment was screened and the best units identified for further design analysis and human factors evaluation. The selection of the shelter characteristics is discussed in this section, and an engineering and cost analysis of the ventilator units are presented in Section 3. The screening procedure and selection of the best ventilators is discussed in Section 4.

2.1 National Fallout Shelter Survey

The Office of Civil Defense called on the Bureau of Census, the National Bureau of Standards, the Army Corps of Engineers, and the Navy Bureau of Yards and Docks to locate fallout shelter space in existing structures. The latter two groups, in turn, contracted with consulting engineers throughout the country to conduct the field work. The survey methods ranged from visual inspection to detailed examinations of building plans. A facility was considered elegible to be surveyed if it was estimated to provide a protection factor (PF) of at least 20 (i.e., capable of reducing radiation intensity inside the shelter to 1/20 of that outside).

The survey developed into Phase 1 and 2. The basic function of the first phase was to identify and classify potential shelter spaces as they currently existed. In Phase 2, feasibility and cost estimates were made both for ventilation improvements and shielding modifications to increase the total number of spaces available. In addition, special shelters such as mines, caverns, caves, tunnels, subways, and underpasses were surveyed, and some of the qualified buildings were marked and stocked with food, sanitation kits and water containers (Refs. 9 and 10), medical supplies, and radiological equipment (Refs. 11 and 12), if a licence was obtained from the owner by the Government. A summary on the National level of all the NFSS facilities surveyed is presented in Table I (Ref. 13). Data recorded in the second National Fallout Shelter Survey are presented on DD Form 1356-1, dated 1 February 1962 (see Figure 3).

2.2 Ventilation Requirements

In the "pilot-lot" distribution of the MIL-V-40645 Ventilation kits it was specified that the quantity of ambient air shall be sufficient to limit the daily average effective temperature to 82°F for all but 10 percent of the days of the year (90 percent adequacy). A comparison of the experimentally determined environmental data for below-grade shelters and the analytical prediction of these environmental data for a shelter model with adiabatic-boundary surfaces showed that the effective temperature for the analytical results are about 1°F higher than the experimental results, hence the environment for below-grade shelter can be analytically predicted by considering the results for 83°F effective temperature. Combining the analytical shelter model with climatological studies (Ref. 15) has produced county tabulations and maps for the National ventilation air requirements (see Figure 4) which we have adopted for this study. These county tabulations and maps have some few minor variations from the Corps of Engineers Regulation No. 1190-1-2, dated 18 March 1966, for the Packaged Ventilation Kit Surveys.

Using the 83°F ET, 90 percent adequacy factor, air flow-county tabulations from the weather analysis-adiabatic model report (Ref. 16), and the county listing of facilities for the below-grade shelters, the distribution of shelter facilities in the isoventilation zones was determined for use in this equipment optimization study. As can be noted in Figure 5, less than 3 percent of the facilities are

TABLE I

SUMMARY OF NFSS SHELTERS

FACILITY	OCCUPANCY LEVEL	NUMBER OF:			
		Facilities	Shelter-Parts	Existing Spaces	Added Vent. Spaces
Above-Ground	50 People and Greater	77,303	388,973	105,637,872	---
Above-Ground	Less than 50 People	6,867	7,631	172,226	---
Below-Ground	50 People and Greater	138,459	230,092	44,967,089	34,994,730
Below-Ground	Less than 50 People	76,362	80,505	1,771,776	5,712,143
Special	50 People and Greater	11,019	25,727	12,495,713	---
Special (see Note 3)	Less than 50 People	6,916	9,815	189,620	---
TOTAL		316,926	742,743	165,234,296	40,706,873

NOTES:

1) NFSS data compilation as of 25 October 1967.

2) Summary includes Virgin Islands, Puerto Rico, Canal Zone, American Samoa.

3) Mines, caverns, caves, tunnels, subways, underpasses storage-types, basement extensions, and other underground facilities.

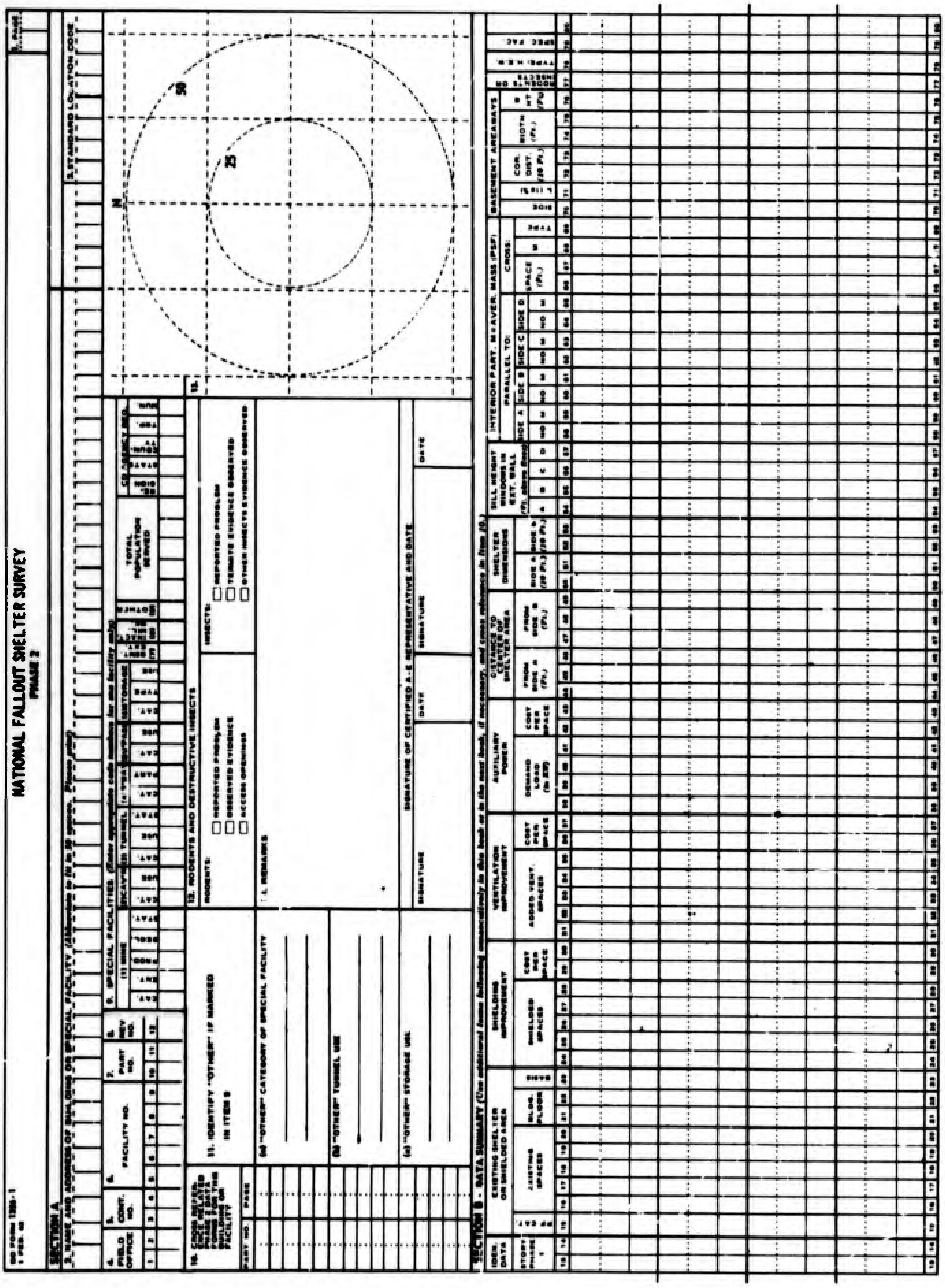
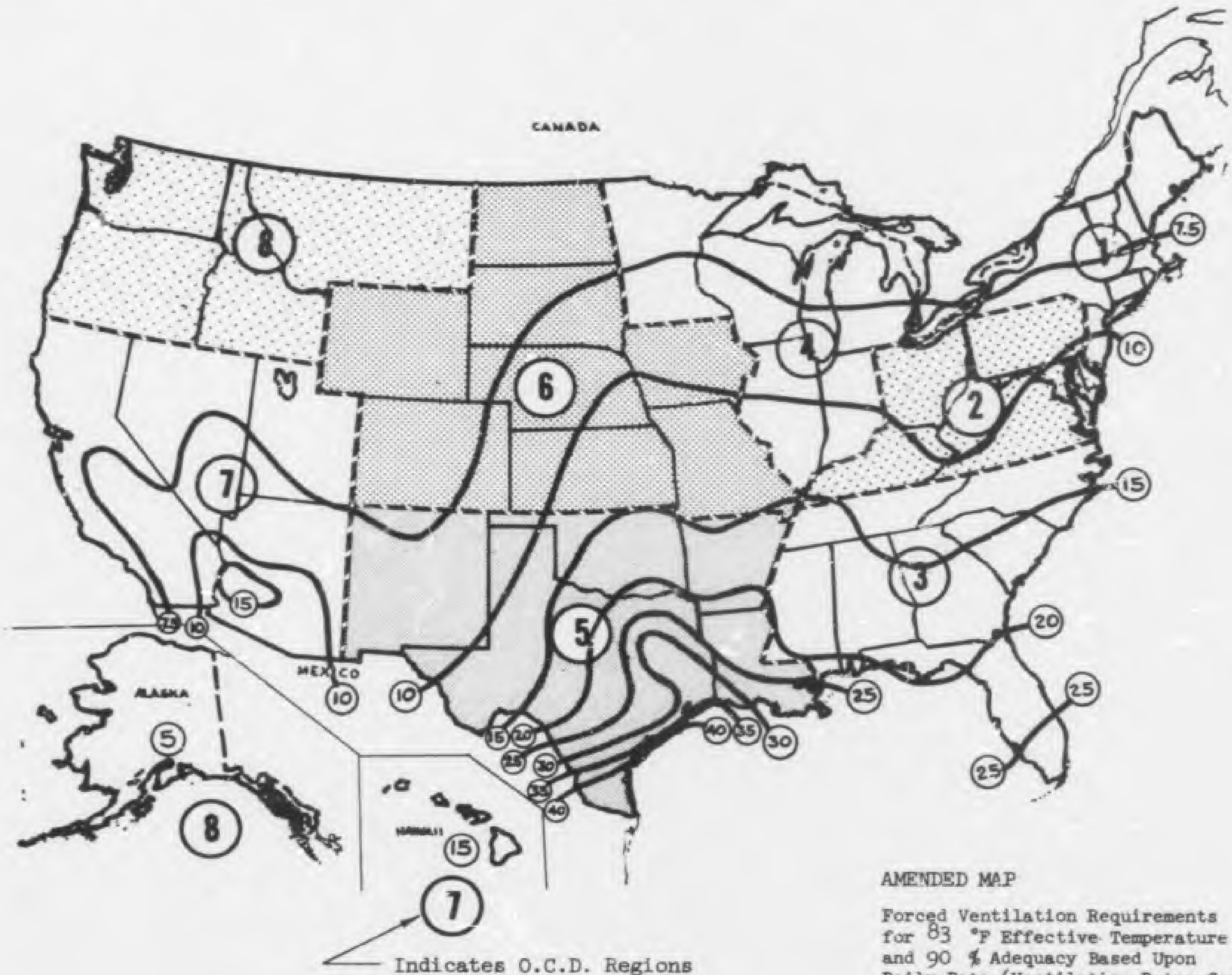

NATIONAL FALLOUT SHELTER SURVEY
PHASE 2

Figure 3 PHASE 2, NATION/ FALLOUT SHELTER SURVEY FORM (FROM REF. 14)



AMENDED MAP

Forced Ventilation Requirements for 83 °F Effective Temperature and 90 % Adequacy Based Upon Daily Data (Ventilation Rates for Standard Air Density = 0.075 lb/ft^3)

Figure 4 FORCED VENTILATION REQUIREMENTS (FROM REF. 15, p. B.13.a)

TABLE II

NFSS (PHASE 2) BASEMENT SHELTERS GROUPED ACCORDING TO VENTILATION AIR COOLING REQUIREMENTS

CODE		TOTALS		7.5 CFM/OCC.		10 CFM/OCC.		15 CFM/OCC.		20 CFM/OCC.		25 CFM/OCC.		30 CFM/OCC.		40 CFM/OCC.		50 CFM/OCC.	
		Facilities	Spaces	Facilities	Spaces	Facilities	Spaces	Facilities	Spaces	Facilities	Spaces	Facilities	Spaces	Facilities	Spaces	Facilities	Spaces	Facilities	Spaces
1000	OCD REGION 1	49,740	26,266,[illegible]	938	459,416	48,802	25,757,185												
1100	CONNECTICUT	2,457	1,231,261			2,457	1,231,261												
1200	MAINE	706	313,608	706	313,608														
1300	MASSACHUSETTS	5,762	3,163,157			5,762	3,163,157												
1400	NEW HAMPSHIRE	460	198,909	23	12,309	437	186,600												
1500	NEW JERSEY	6,755	3,507,389			6,755	3,507,389												
1600	NEW YORK	32,336	17,352,416	169	133,496	32,167	17,218,920												
1700	RHODE ISLAND	984	379,175			984	379,175												
1800	VERMONT	290	101,060			290	101,060												
2000	OCD REGION 2	29,127	15,153,392			19,517	9,963,444	9,610	5,189,[illegible]										
2100	DELAWARE	578	229,629					578	229,629										
2200	DISTRICT OF COLUMBIA	3,365	2,347,590					3,365	2,347,590										
2300	KENTUCKY	1,303	743,948			161	68,428	1,142	674,970										
2400	MARYLAND	1,444	1,214,2[illegible]			295	124,761	[illegible]	1,09[illegible]										
2500	OHIO	6,398	3,530,9[illegible]			6,396	3,530,994												
2600	PENNSYLVANIA	11,466	5,633,277			11,466	5,633,277												
2700	VIRGINIA	2,831	1,101,025			10	2,800	2,821	1,098,225										
2800	WEST VIRGINIA	649	247,364			649	247,364												
3000	OCD REGION 3	6,794	3,916,087					2,4[illegible]	1,442,6[illegible]	3,139	1,822,0[illegible]	477	324,964	232	178,563				
3100	ALABAMA	1,092	583,393					214	124,121	800	410,[illegible]								
3200	FLORIDA	650	642,142							65	47,385	63	46,308						
3300	GEORGIA	1,420	961,486							1,238	940,551	353	263,514	232	178,563				
3400	MISSISSIPPI	356	183,330					130	80,595	295	162,938								
3500	N. CAROLINA	1,600	658,918					1,322	623,[illegible]	79	30,272	61	21,482						
3600	S. CAROLINA	540	295,608					299	164,93[illegible]	241	152,670								
3700	TENNESSEE	1,329	771,200					958	494,035	372	277,165								
4000	OCD REGION 4	21,720	14,617,531	5,385	3,554,9[illegible]	14,445	10,111,152	1,896	951,534										
4100	ILLINOIS	7,316	4,455,1[illegible]			5,963	3,530,655	1,353	924,534										
4200	INDIANA	2,584	1,854,053			2,041	1,527,053	543	327,000										
4300	MICHIGAN	4,425	3,391,810	834	649,145	3,591	2,[illegible],665												
4400	MINNESOTA	3,482	2,368,870	1,637	1,042,720	1,845	1,336,150												
4500	WISCONSIN	3,919	2,537,[illegible]	2,914	2,005,[illegible]	1,005	531,629												
5000	OCD REGION 5	6,429	4,421,747	234	128,744	576	366,778	405	[illegible]	1,[illegible]	1,[illegible]	1,2[illegible]	[illegible]	1,2[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5100	ARKANSAS	5[illegible]4	281,396					44	14,667	519	2[illegible],33[illegible]	22	7,414						
5200	LOUISIANA	669	299,441							4	240	308	182,480	244	102,579	18	1,122		
5300	NEW MEXICO	384	204,670	234	128,744	165	75,871												
5400	OKLAHOMA	1,337	702,058			23	7,777	923	331,231	656	351,188	35	11,162						
5500	TEXAS	[illegible]	[illegible]			[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	541,135	1,218	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6000	OCD REGION 6	13,511	7,304,047	3,626	1,803,[illegible]	3,30[illegible]	1,5[illegible]	6,5[illegible]	1,6[illegible]										
6100	COLORADO	1,659	1,058,014	1,599	1,039,930	60	18,084												
6200	IOWA	2,084	1,073,977			1,947	1,[illegible],815	137	53,162										
6300	KANSAS	2,656	1,215,342			263	60,786	2,393	1,154,5[illegible]										
6400	MISSOURI	3,505	2,168,409					3,505	2,168,409										
6500	NEBRASKA	1,546	737,758	80	26,516	920	378,534	546	302,708										
6600	NORTH DAKOTA	560	326,087	560	326,087														
6700	SOUTH DAKOTA	780	288,143	644	237,834	136	50,309												
6800	WYOMING	441	173,319	441	173,319														
7000	OCD REGION 7	7,233	6,547,[illegible]	3,519	2,649,627	2,795	3,2[illegible]	572	344,715	247	231,325								
7100	ARIZONA	448	343,432			22	12,485	174	[illegible],662	247	231,325								
7200	CALIFORNIA	5,519	5,500,251	2,546	2,118,304	2,764	3,252,144	208	129,803										
7300	HAWAII	185	120,470					185	120,470										
7400	NEVADA	162	95,507	157	93,885	5	1,622												
7500	UTAH	620	488,173	616	487,438	4	735												
8000	OCD REGION 8	3,[illegible]	2,014,227	3,951	2,013,227														
8100	ALASKA	177	[illegible],651	177	[illegible],651														
8200	IDAHO	382	162,756	382	162,756														
8300	MONTANA	632	209,265	632	209,265														
8400	OREGON	988	616,947	988	616,947														
8500	WASHINGTON	1,772	927,608	1,772	927,6[illegible]														
9000	U. S. TOTALS	138,[illegible]	79,885,[illegible]	17,631	10,659,[illegible]	29,43[illegible]	31,000,913	22,[illegible]	12,158,475	4,7[illegible]	3,553,527	1,6[illegible]	1,567,035	1,518	573,4[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

NOTES:
(1) U. S. totals exclude the Virgin Islands (0 Facilities - 0 Spaces), Puerto Rico (168 Facilities - 119,520 Spaces), Canal Zone (17 Facilities - 8,184 Spaces), American Samoa (0 Facilities - 0 Spaces), and Guam (13 Facilities - 7,325 Spaces). Totals in these areas: 198 Facilities - 135,334 Spaces.
(2) Facilities identified for an occupancy of 50 people and greater.
(3) Facilities identified with a protection factor 40 and greater.
(4) Number of spaces shown above are the arithmetic sum of "existing spaces" and "added vent. spaces".
(5) Ventilation requirements are based on 82°F effective temperature and 90% adequacy factor (see Ref. 17).
(6) Special and Above-Ground Facilities (see Table I, page 4) have been excluded from this tabulation.

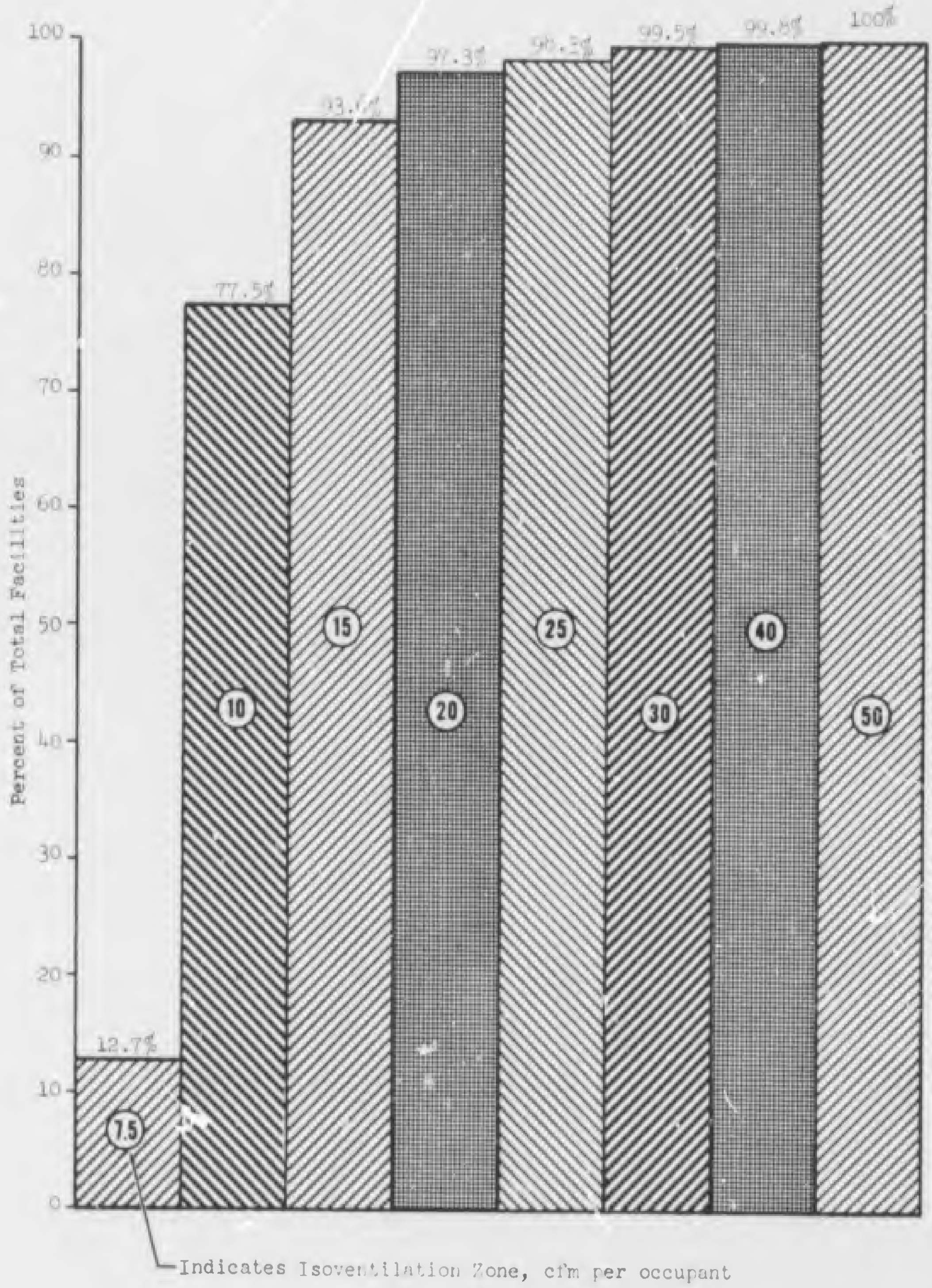


Figure 5 GEOGRAPHICAL DISTRIBUTION OF NFSS BASEMENT SHELTERS

in the zones 25 cfm per occupant or greater, and that 78 percent of the facilities require 10 cfm per occupant or less.

The tabulation shown in Table II is limited to below-grade shelters greater than 500 square feet (50 people at 10 square feet per person). Subways, tunnels, caves and mines were excluded. The number of spaces shown is the sum of the "existing spaces" and the "added vent. spaces" (see Figure 3, colums 16-20 and 31-35). Because of the lack of data for the ventilation requirements of the Virgin Islands, Puerto Rico, Canal Zone, American Samoa and Guam, the 198 facilities identified in these possessions were excluded from the tabulation.

2.3 Random Sample of Shelters

Although a great deal of data pertaining to the ventilation problem was generated in the NFSS (see Figure 3), not all of the data necessary to determine the ventilation equipment requirements were obtained. Such critical data as how the shelters are partitioned, room size, location and physical area of apertures in the exterior walls of the shelter, and the location of interior stairwells and elevator shafts (which could be used as the air supply or exhaust) were not provided. All of these data are required to define the shelter descriptors for use in the optimization study.

To limit the number of shelters analyzed, a statistical random sample of 160 facilities was taken to represent the NFSS shelters. The statistical sample of facilities, designed and surveyed by the Research Triangle Institute (Ref. 17), was drawn from a universe consisting of all facilities surveyed in Phase 2 of the NFSS in the 216 Standard Metropolitan Statistical Areas (SMSA*) of the United States. The master sample consisted of four SMSA's in each of the OCD Regions plus the New York City, Philadelphia, Chicago, and Los Angeles areas

*An SMSA is generally an urban county or group of counties, combined by the Bureau of Census for statistical purposes.

(see Table III). For the sub-sample to be surveyed by RTI, eight facilities were selected in each of two SMSA's for each OCD region and the four cities. The floor plans prepared for these facilities are presented in Appendix B. Since entry was denied in two facilities in Seattle (no substitute facilities were available in the master sample), and since one San Francisco building (Facility No. 103) was determined to have no usable fallout shelter space, the sub-sample finally consisted of 157 facilities. These 157 facilities consisted of 175 parts; hence, the ratio of shelter-parts to facilities is 1.115. The significant characteristics of the random sample facilities are presented in Figures 6 through 8. For example, 50 percent of the shelter-parts have a floor area less than 4,000 square feet, and 13 percent have an area greater than 15,000 square feet (see Figure 6). Approximately 70 percent of the shelter-parts have less than 9 rooms,and less than 9 percent have more than 20 rooms (see Figure 7). Roughly, 67 percent of the rooms have an area less than 500 square feet, and only 4 percent of the rooms are larger than 4,000 square feet (see Figure 8). The aperture location and sizes are shown on the floor plans (see Appendix B).

The sampling procedure insured the selection of buildings from all geographic areas of the United States. Moreover, the selection of facilities from different areas within the sample SMSA's was guaranteed. Results of this sample are adequate for making estimates on the National level: however, RTI points out that due to the small number of buildings in each OCD region and the resulting relative error, Regional estimates should not be made. GARD agrees that the sample when broken down by facilities in each region or isoventilation zone (see Figure 4, page 11) is too small for accurate shelter sampling; however, since larger samples in each region are not

Table III

Master Sample of SMSA's and Sample of SMSA's Surveyed by RTI
(from Ref. 17, p. B-1)

OCD Region	SMSA	Surveyed by RTI
1	Rochester, New York	
	Boston, Massachusetts	x
	Providence, Rhode Island	
	Newark, New Jersey	x
2	Lexington, Kentucky	x
	Washington, D C.	
	Pittsburgh, Pennsylvania	x
	Cleveland, Ohio	
3	Nashville, Tennessee	
	Augusta, Georgia	x
	Birmingham, Alabama	
	Tampa, Florida	x
4	Minneapolis, Minnesota	x
	St. Louis, Missouri	
	Detroit, Michigan	x
	Jackson, Michigan	
5	El Paso, Texas	x
	San Antonio, Texas	
	Dallas, Texas	x
	Houston, Texas	
6	Fargo, North Dakota	x
	Kansas City, Missouri-Kansas	
	Springfield, Missouri	x
	Des Moines, Iowa	
7	Reno, Nevada	x
	Bakersfield, California	
	San Francisco, California	x
	Las Vegas, Nevada	
8	Seattle, Washington	x
	Tacoma, Washington	
	Portland, Oregon	
	Spokane, Washington	x
Four Largest SMSA's		
1	New York City, New York	x
2	Philadelphia, Pennsylvania	x
4	Chicago, Illinois	x
7	Los Angeles, California	x

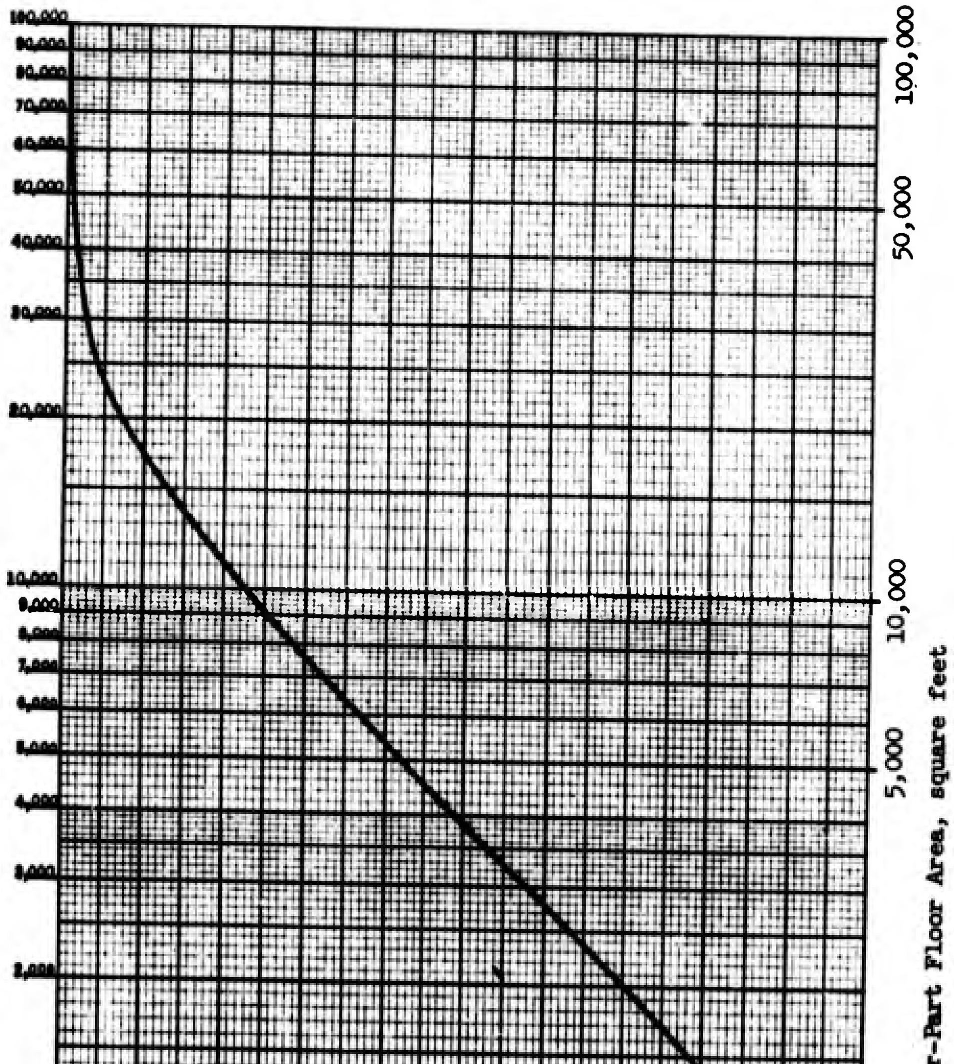


Figure 6 DISTRIBUTION OF THE SHELTER-PART FLOOR AREAS FOR THE RTI RANDOM SAMPLE OF SHELTERS

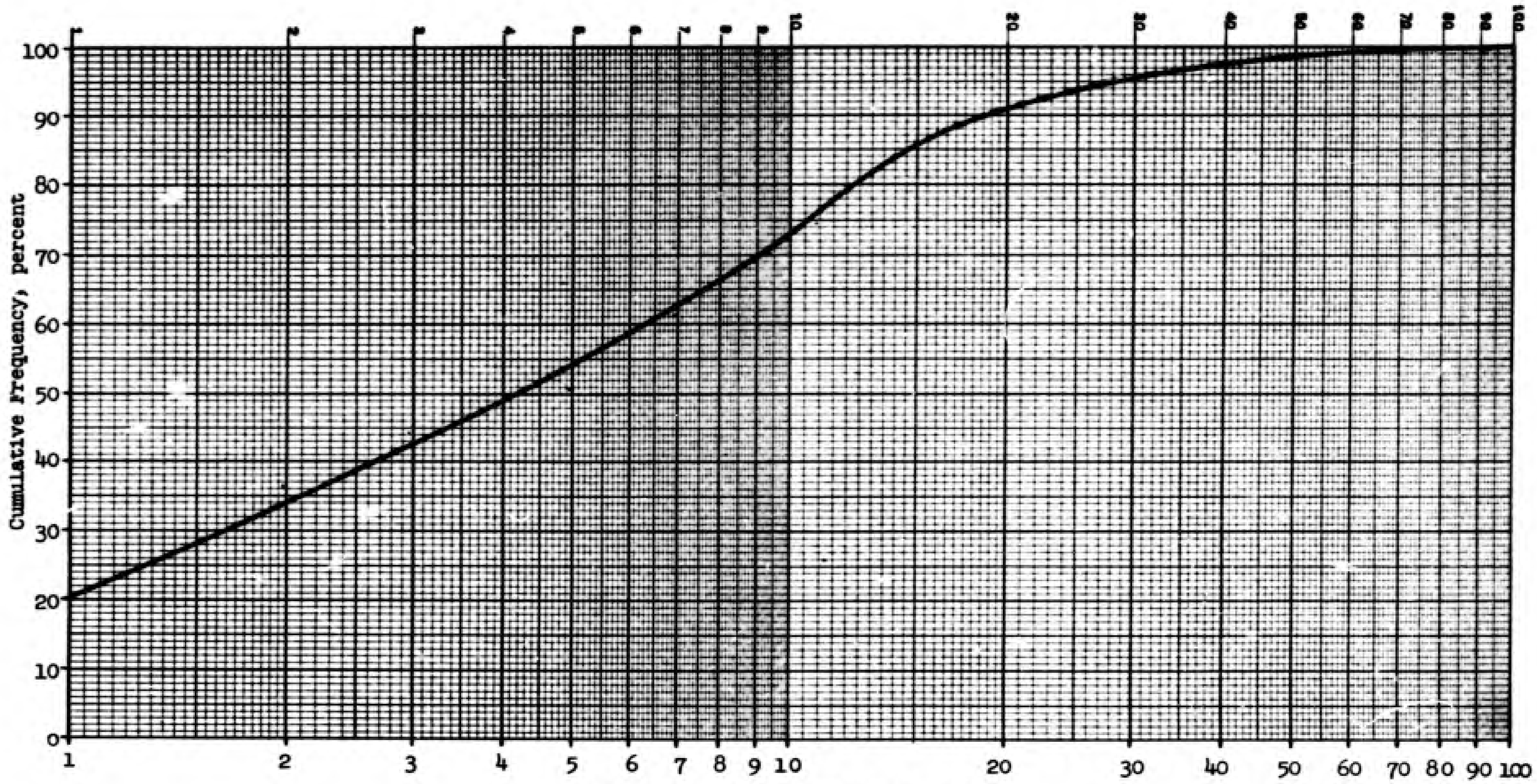


Figure 7 DISTRIBUTION OF THE NUMBER OF ROOMS PER SHELTER-PART FOR THE RTI RANDOM SAMPLE OF SHELTERS

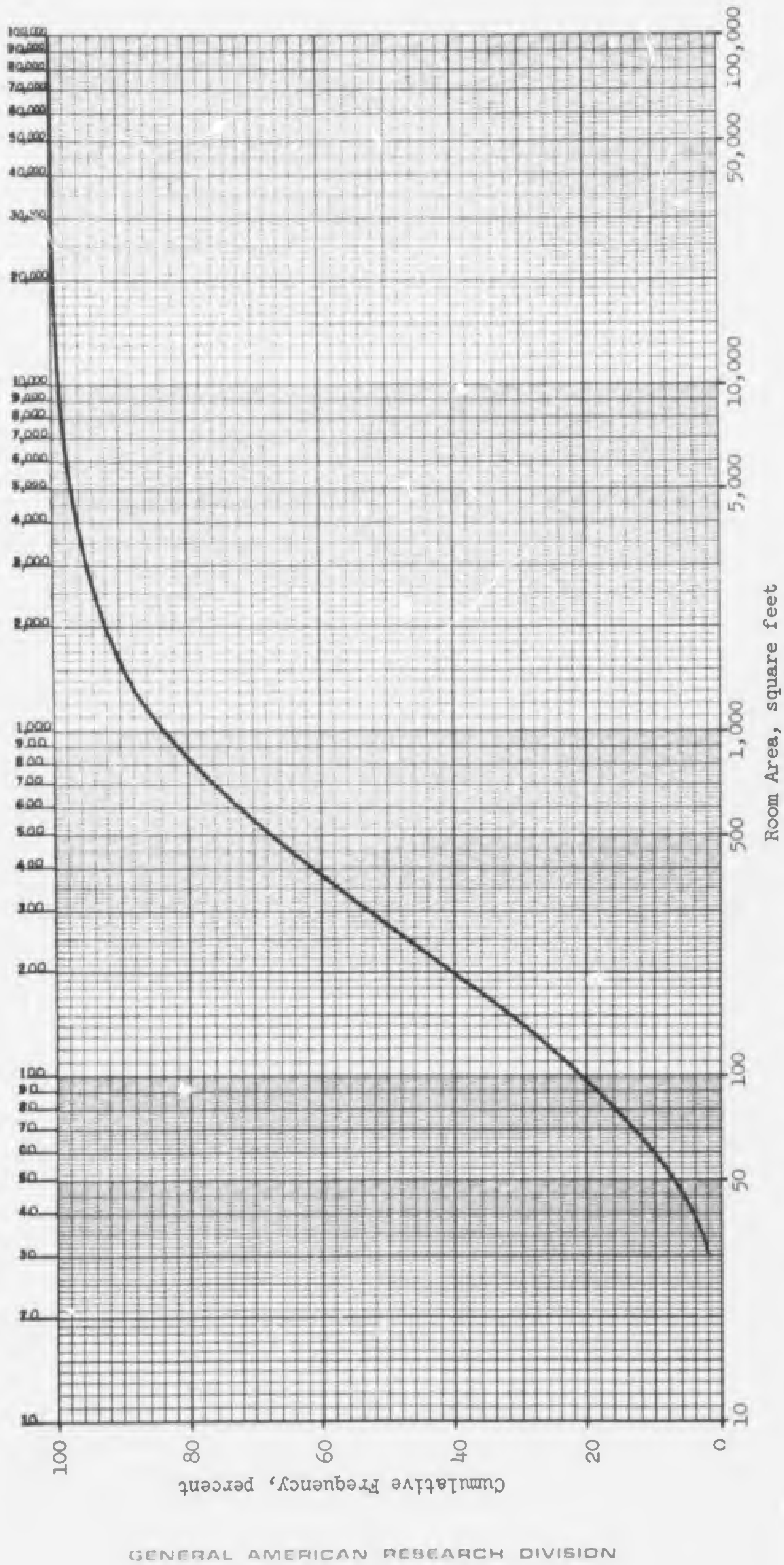


Figure 8 DISTRIBUTION OF THE ROOM FLOOR AREAS FOR THE RTI RANDOM SAMPLE OF SHELTERS

available, the entire RTI sample was applied to each isoventilation zone. It is therefore implied that the type of construction of shelters is similar throughout the United States, and the sample is representative of the type of basement shelters that exist in each isoventilation zone. These assumptions were necessary to provide a basis for defining the shelter descriptors to optimize the number and capacity of ventilation kits, and to estimate the total cost for the optimum ventilation kits.

2.4 Shelter Descriptors

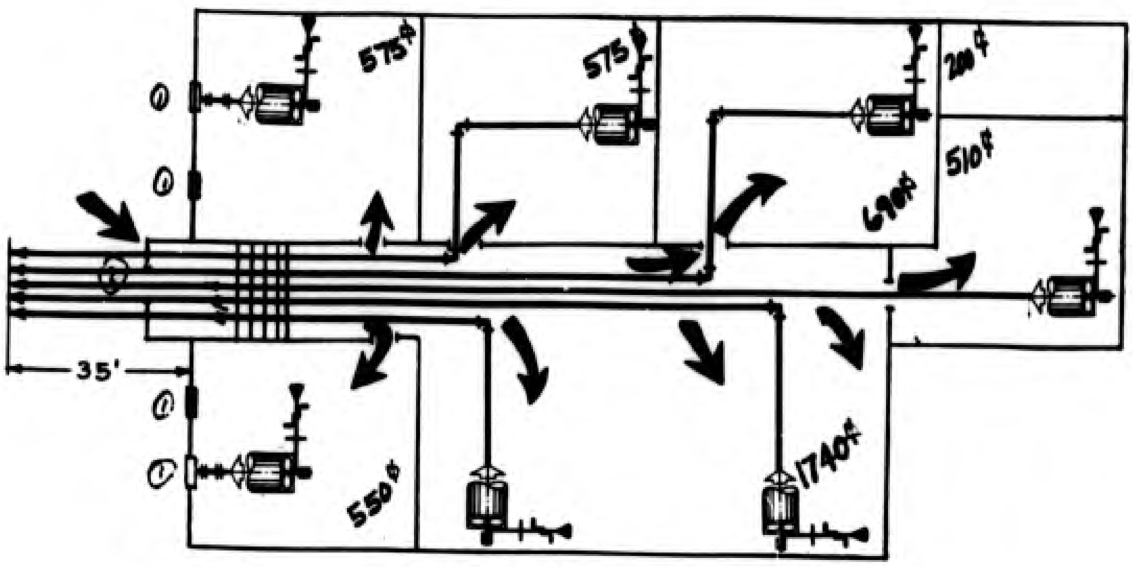
Five methods of deploying ventilators were analyzed in detail using the 157 sample floor plans presented in Appendix B. Initially, we were attempting to locate at least one ventilator in each room with a floor area greater than 500 square feet (as illustrated in Figure 9); however, it was soon determined that insufficient openings existed in the basement shelters to get the ducts out from the shelter. Assuming the entire sample of shelters to be in each of the 10, 20, 30, and 50 cfm per occupant isoventilation zones, it can be shown that 24, 44, 52, and 68 percent, respectively, of the sample shelters cannot be ventilated with one or more MIL-V-40645, 20-inch impeller diameter ventilators in each room with an area greater than 500 square feet. The percentage which can be ventilated could have been increased with a series of variable capacity units, such that the number of units in each room would have been limited to one (except in those large rooms which exceed the capacity of the largest ventilator). However, in our analysis, this approach would not significantly increase the number of shelters which could be ventilated.

The deployment approach which yielded the best coverage considered the shelter to be one open-area, although the partitions and arrangement of the rooms did define the duct system required with each ventilator. The apertures

RTI Facility No. 24 (from Appendix B)

Central Bible Institute
Administration Building
N. E. Grant and Norton Street
Springfield, Missouri

SL 6441-0001
FN 02002



OPENINGS

① WINDOW 48" x 24" x 42" sill
② DOOR 48" x 78"

SCALE 1" = 20'-0

Figure 9 ILLUSTRATION OF A KIT DEPLOYMENT METHOD WHICH REQUIRES ONE OR MORE VENTILATORS IN EACH LARGE ROOM and their sizes were considered in the optimization program, since in the process of defining and analyzing ventilation systems, it was found that their shortage limited the number of ventilators which could be used in a shelter. This lack of openings resulted in designing and analyzing (performance and cost) larger capacity ventilators, such as the 4-, 6-, and 8-man pedal-driven units, and the motor-driven ventilators. The basic descriptors deduced from the sample shelters by this deployment approach are itemized below, and the physical shelter descriptors for all the RTI sample shelters are presented in Appendix A.

1. Shelter Floor Area of each shelter-part.

   NOTE: These shelter-parts are the same building story numbers as used during Phase 1, and also are the entries in Columns 13-14, Section B, of the phase 2 Data Collection Form (DD Form 1356-1, see Figure 3).

2. Total Aperture Area available to the outside air, including windows, stairwells, and elevator shafts.

3. Maximum Number of openings to be used for routing ducts to non-shelter areas within the building or the outside environment.

4. Remaining Aperture Area available for the air inlet.

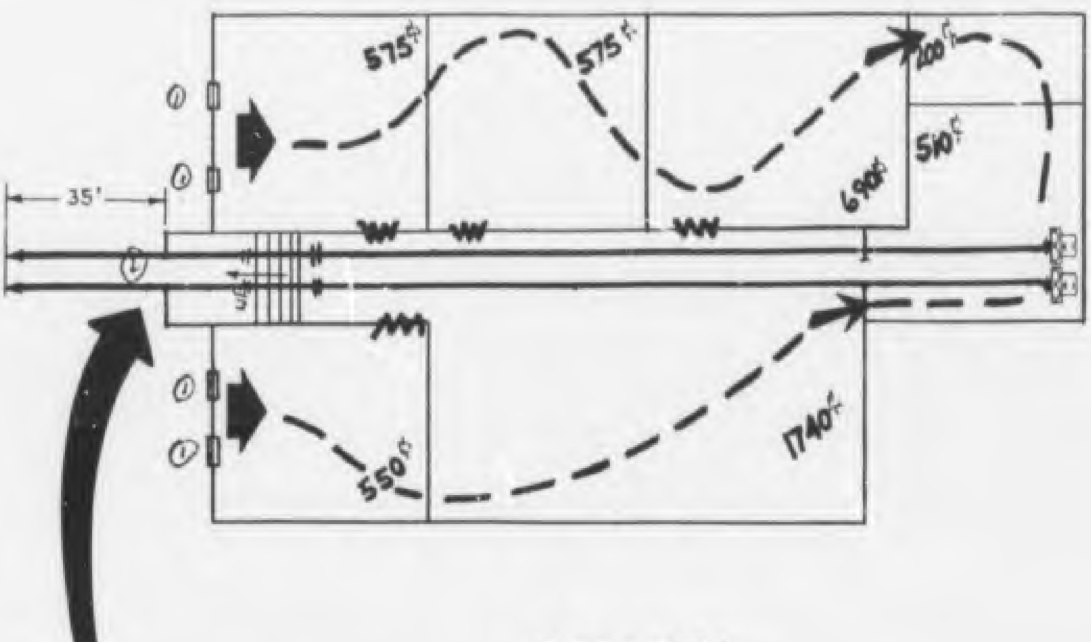
5. Average Equivalent Duct Length (EDL) for each ventilator (excluding the pseudo-EDL resulting from an additional pressure-drop caused by a high air flow rate through the apertures allocated for the inlet air (see Section 3.2 and Equation 16).

Shelter Floor Area -- Using the total floor area for each shelter-part results generally in a significant reduction in the total number of ventilation kits required. For example, Facility No. 24, using the open-area concept, results in two units (see Figure 10), as compared to a minimum of six ventilators for

RTI Facility No. 24 (from Appendix B)

Central Bible Institute
Administration Building
N. E. Grant and Norton Street
Springfield, Missouri

SL 6441-0001
FN 02002



OPENINGS

① WINDOW 48" x 24" x 42" sill
② DOOR 48" x 78"

SCALE 1" = 20'-0

Figure 10 KIT DEPLOYMENT METHOD BASED ON THE OPEN-AREA APPROACH

the initial method. (Note: The selection of the two ventilation kits for this shelter is a result of the optimization study when the air requirement is 10 cfm per occupant.) Using the open-area method allocates more aperture area for getting the air into the shelter. If the aperture area is insufficient, larger capacity ventilators would be selected to reduce the number of units required and consequently increase the aperture area available for the inlet air.

Apertures -- The apertures to non-shelter areas of the facility and to the outside environment are a most significant parameter, since their location, availability and size generally will control the selection of equipment. In most cases, stairwells and elevator shafts offer the best access to ventilation air and a means of exhausting the air. Stairwells and elevator shaft doors were assumed in all cases to have an area of 20 square feet. An escalator was always considered for use as an air source (see Facility No. 16, Appendix B), unless it was the only aperture to the shelter area. In the case of escalators, the cross-sectional area as measured was used in the data take-off from the floor plans. The aperture areas of garage doors (see Facility No. 11, Appendix B), double doors, ramps, windows, and others were as scheduled on the floor plans. Since the smallest doors in the outside walls of educational, government and public service, commercial, and industrial buildings are 3'-0" by 6'-8", it was assumed that the largest duct which can pass through or be attached is 36 inches in diameter.

Maximum Number of Ventilators -- As the first approximation in the optimization program, it was assumed that at least one-half of the total aperture area is used for getting the air into the shelter, unless this geometrically is not feasible, and the remaining area is available for the exhaust ducts of the ventilation equipment. After selecting which openings should be used for the ventilation equipment (actual floor plan layout required), the following guidelines were used to determine the maximum number of units which may be placed in the shelter.

1. Two units per door, stairwell, or elevator shaft (see Figure 11).
2. One unit per window or opening if the minimum size is 36 inches by 36 inches (see Figure 12) and the horizontal dimension is less than 72 inches.
3. For garage doors, ramps, and other large openings, one unit high only and spaced on 3-foot centers.

When a facility has shelter space on more than one story, it is important that the same stairwells and elevator shaft be used for either supply air or exhaust air. As illustrated by Figure 13, which is Facility No. 89 of Appendix B, this can present a serious problem in getting this idea across in the shelteree instruction manual.

If the capacity of each ventilator is to be determined considering the pressure drop of the inlet air, it would be necessary to assign a certain portion of this loss to each ventilator. To attempt to allocate this pressure loss amongst the ventilators would necessitate arbitrarily defining areas about each ventilator which would receive air only from certain openings. This would imply that there is no mixing of the air supplied to the ventilator from different openings in the shelter. However, since for ventilation purposes, a shelter has been defined as one room or a contiguous group of rooms, it is obvious that mixing of inlet air does occur. Therefore the overall pressure loss due to lack of openings in the exterior walls is assumed to be the same for each ventilator in the shelter. It is also

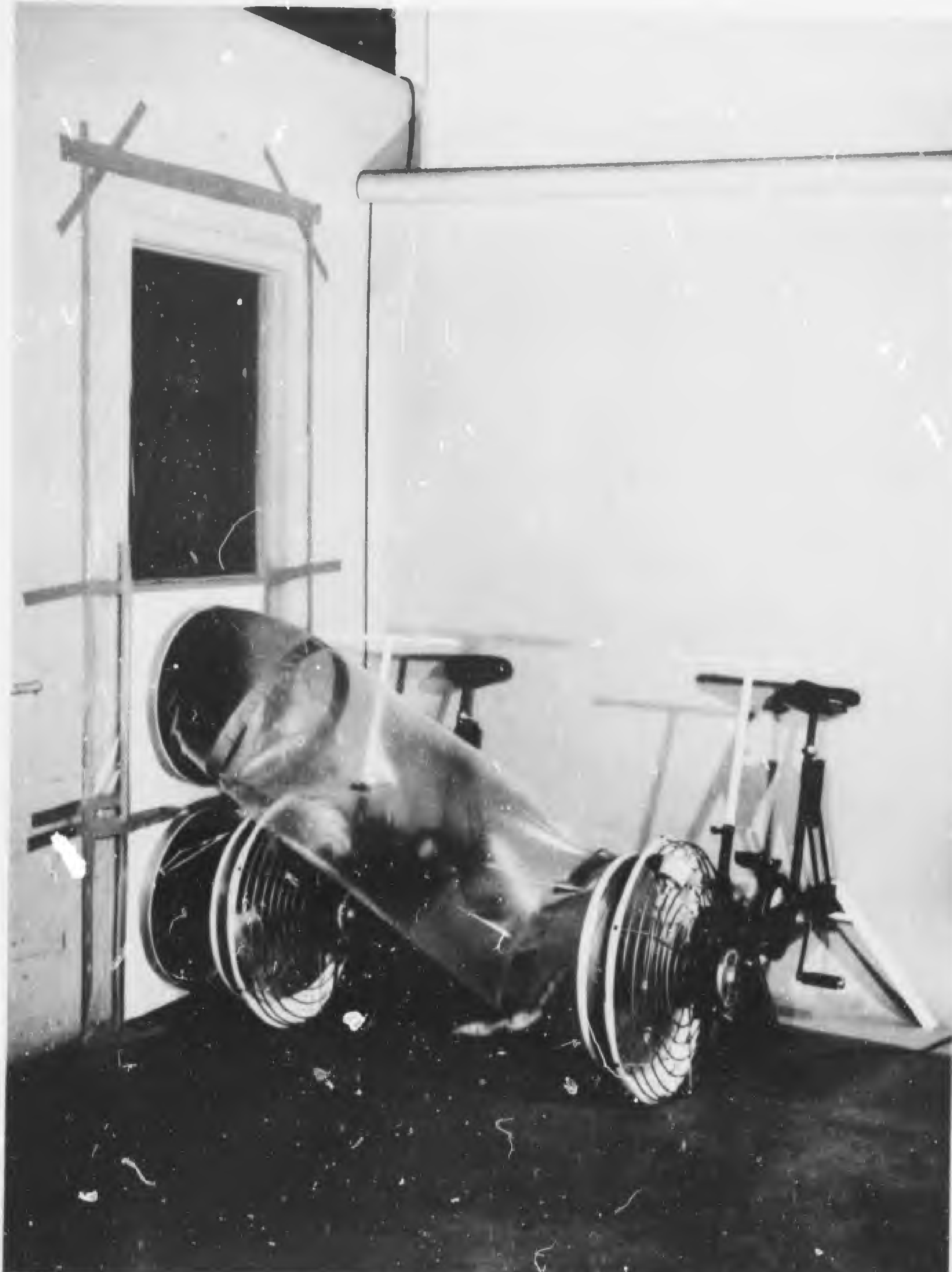


Figure 11 ILLUSTRATION OF ATTACHING TWO VENTILATORS TO A DOOR

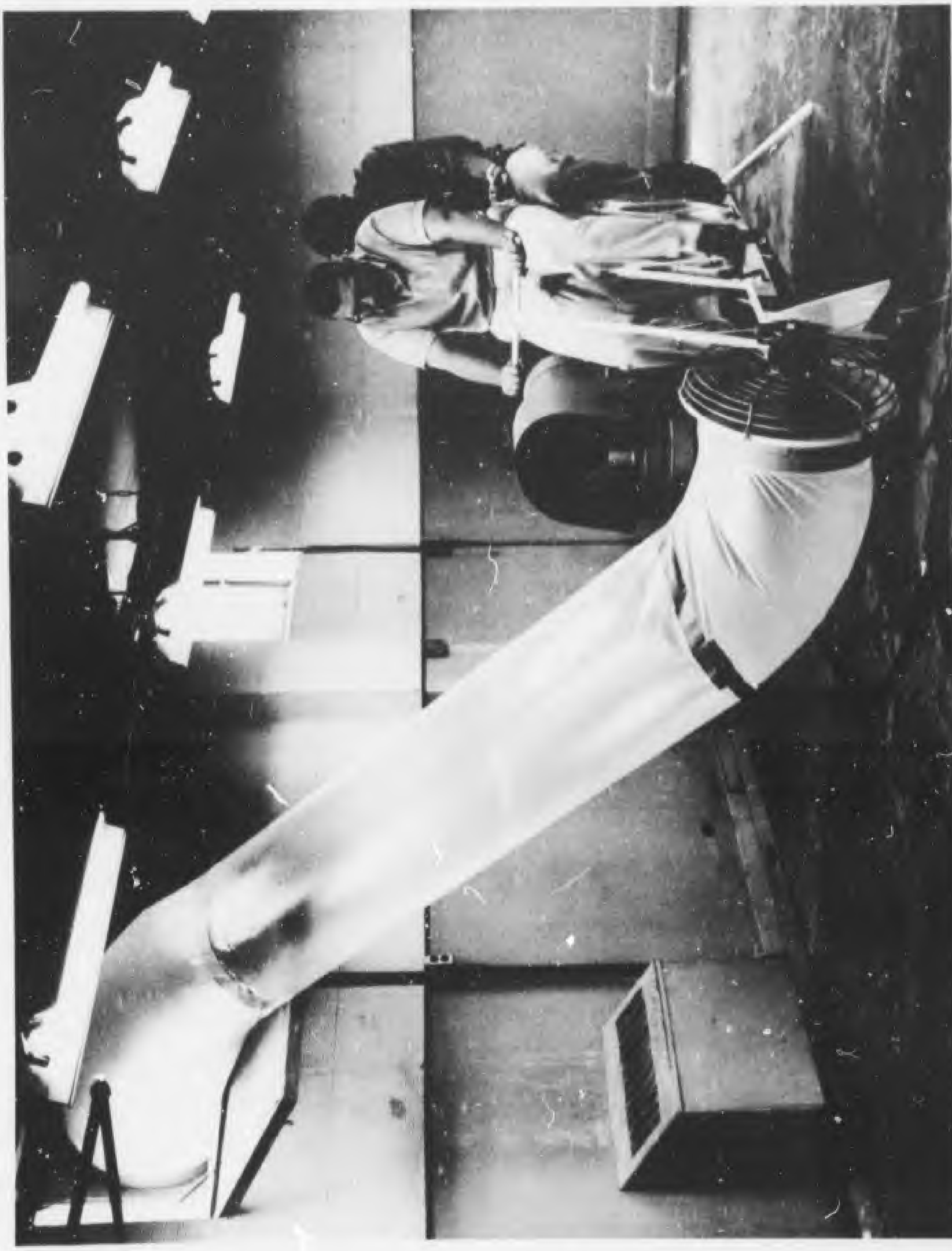
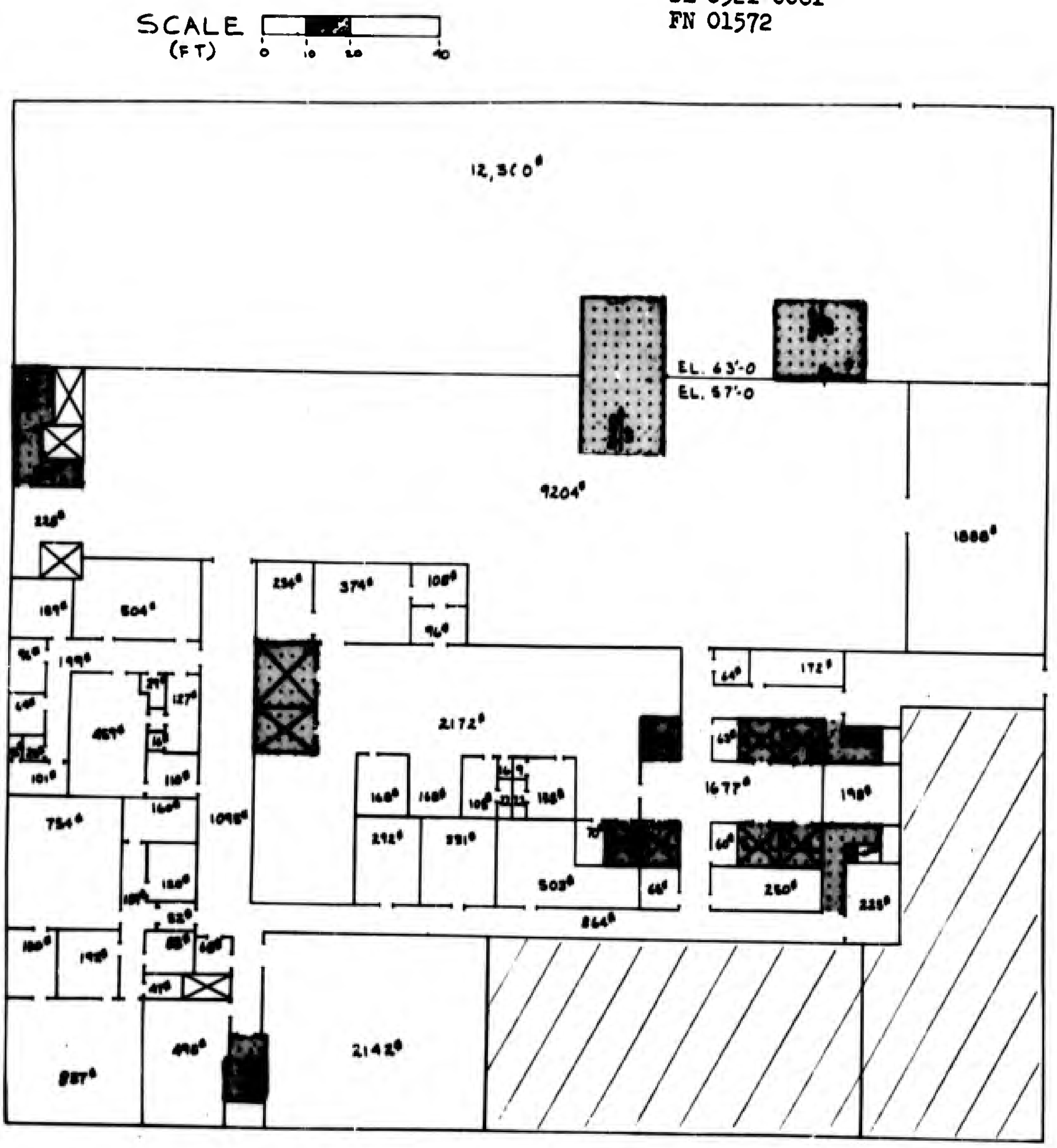


Figure 12 APPLICATION OF A VENTILATOR WHEN USED WITH A WINDOW

RTI Facility No. 89-2

Public Safety Building (5 Parts)
610-22 3rd Avenue
Seattle, Washington

SL 8521-0061
FN 01572



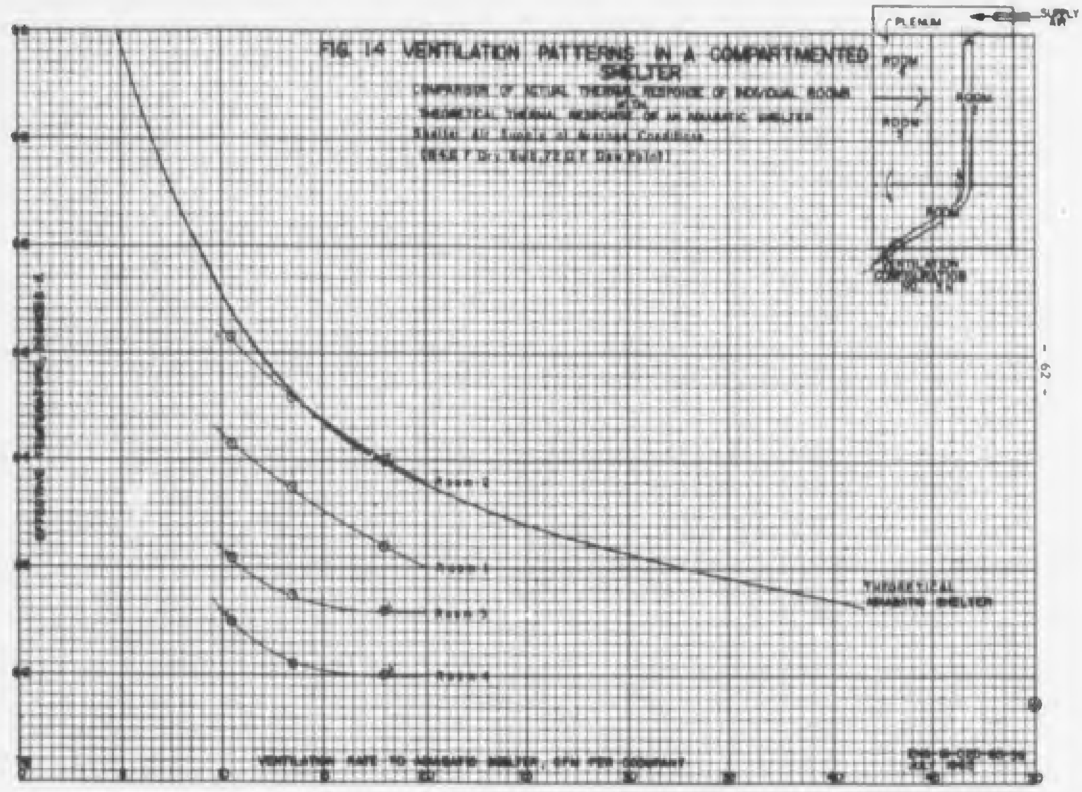
NOTE: This is the second sub-basement of a facility which has 16 stories. The four stairwells, nine elevator shafts, and two ramps which can be used for either the supply or exhaust of the ventilation air are shown shaded.

Figure 13 FACILITY NO. 89 -- ILLUSTRATION OF THE COMPLEXITY WHEN USING ELEVATOR SHAFTS OR STAIRWELLS AT EACH STORY LEVEL FOR EITHER THE SUPPLY OR EXHAUST AIR assumed that no pressure losses result when the air flows through the shelter. Intentional holes in the interior partitions would, in addition to giving good air distribution, minimize any internal system pressure losses.

If placing holes in partitions is not feasible, the units should be located in the larger rooms of the shelter; however, this approach in the majority of cases will result in a very ineffective air distribution system and a decrease in ventilation air because of the increased pressure drop due to the restricted flow throughout the shelter. A study (Ref. 18) showed that the minimum spread of effective temperature will result if the rooms are in series, as compared to a random orientation of the rooms (see Figure 14). Analysis of the interior partition data in the sample survey showed them to be of light construction. Consequently, holes could easily be made with a 3-pound hammer.

When optimizing the equipment (see Section 4), the number of ventilators was decreased by one from the maximum allowable to one. The solution was chosen from equipment ranging from 11 inches to 36 inches diameter, which resulted in the minimum cost ventilation system. Since most system layouts in the sample shelters use doors, stairwells, and elevator shafts (see Appendix B), the aperture area associated with the inlet air was increased by 20 square feet every time the number of ventilators in the optimization program was reduced by two ventilators.

Duct Systems -- The location of ventilator units within each shelter is important from the standpoint of air distribution and ventilator performance. The location of units in the sample shelters was chosen such that the best air distribution could be obtained using the shortest duct system.



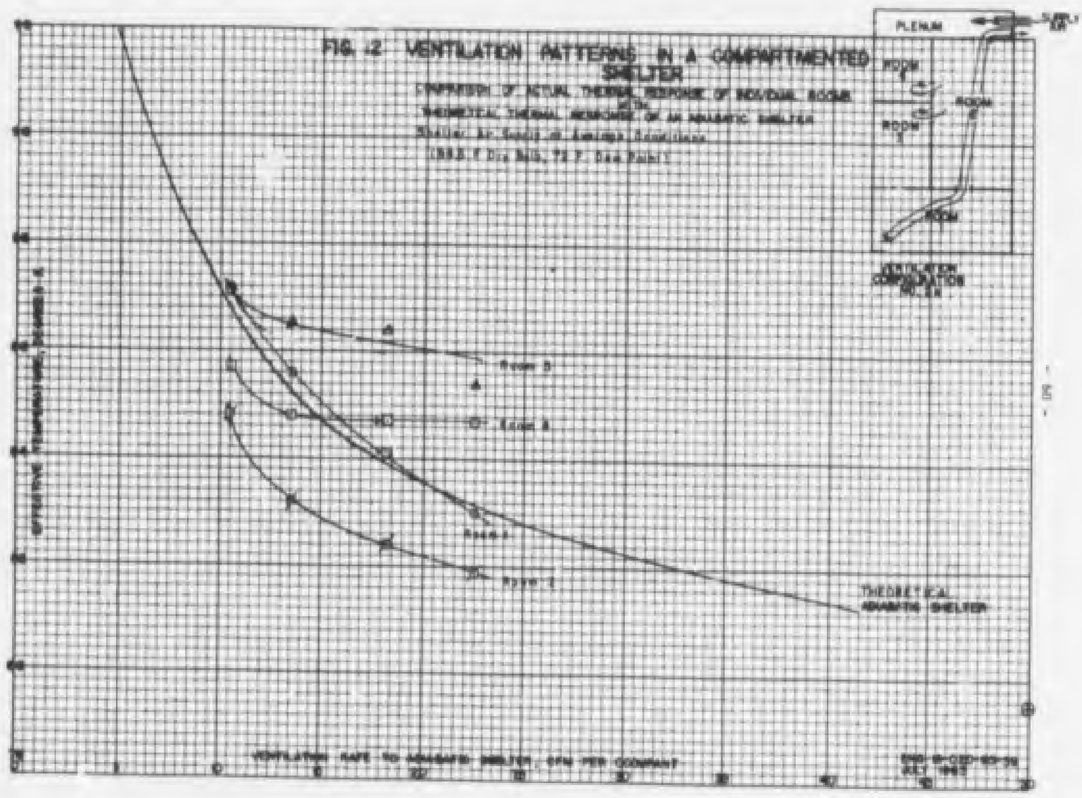


Figure 14 VENTILATION PATTERNS IN COMPARTMENTED SHELTERS
(Figures as noted from Ref. 18)

This was done because long duct systems are difficult to implement and the pressure drop associated with the duct friction could increase the number of units necessary to ventilate the shelter. Whenever possible, the ventilators were located so that they would exhaust directly through an opening in the exterior wall (see Figures 1, 11 and 12). Existing openings and/or intentionally placed holes in the partitions were used to distribute the air. Where possible, elevator shafts and windows were used for the exhaust ducts from the ventilators, rather than relying on the doors and stairwells.

The equivalent duct length (EDL) for each ventilator is the straight length of duct plus the equivalent length of any elbows used (see Section 3.2). Ducts which go directly from a ventilator are considered to have an EDL of two feet (see Figure 1, page 3). Ducts which go directly from a ventilator to an elevated opening (such as windows) require 20 feet of straight duct and two 45° elbows (see Figure 12, page 27). Ducts which go from one floor to another have 20 feet of straight duct and either a 45° or 90° elbow at each end (see Figure 15). Ducts which go through openings which are large enough to be used both as an air source and exhaust must be extended at least 35 feet from the openings to prevent recirculation of the exhaust air (see Figure 10, page 23).

After deploying the maximum number of ventilators (see Shelter Descriptor Data, Appendix A) on the sample floor plans and laying out the duct systems, it was found that in 83 percent of the shelters the difference between the largest and shortest EDL was 50 feet or less. Of the remaining 17 percent, none have minimum-to-maximum difference greater than 300 feet. The average minimum-maximum difference in these remaining shelters is less than 150 feet. This large difference generally occurs because one or two ducts are much longer or shorter than the rest. In fact, if the two ducts which deviate most from the average in each of these remaining shelters are deleted, only 2 percent of the shelters have a min-max EDL difference greater than 50 feet and none exceed 150 feet. Because the EDL's of the individual ventilators in each shelter vary only a small amount from their average, it is convenient to use this average equivalent duct length as the system characteristic for each ventilator from the maximum number of ventilators considered to the minimum possible of one. This feature was used in our equipment selection program, and can be effectively used in an equipment selection computer data processing system, since the effort required to obtain each ventilator duct system is minimized.

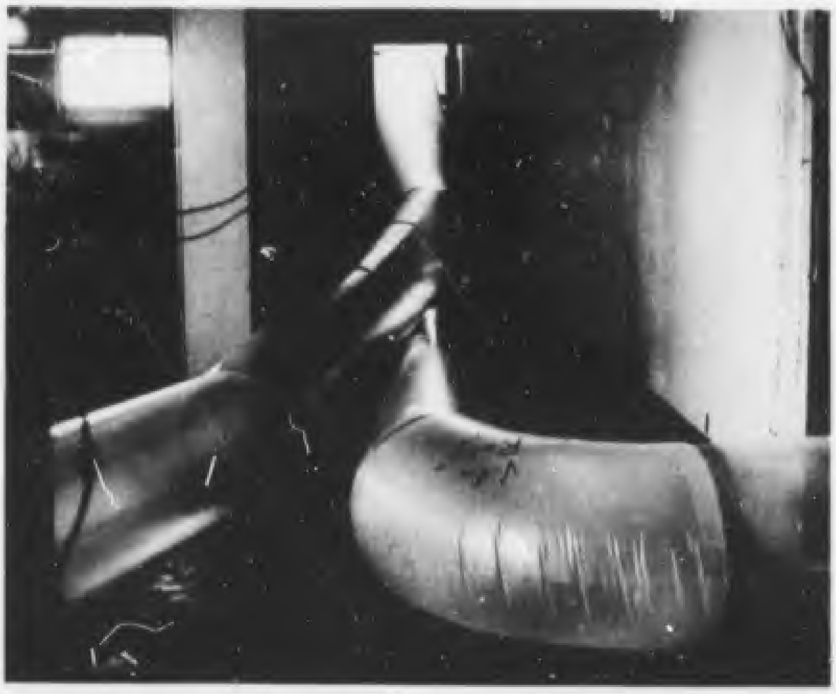


Figure 15 ILLUSTRATION OF TWO 20-INCH DIAMETER DUCTS ROUTED THROUGH A STAIRWELL

SECTION 3

EQUIPMENT PERFORMANCE

In Section 2 the random sample of shelters was analyzed to define the necessary parameters or descriptors that define their ventilation system characteristics, and these characteristics were assumed to be representative of the NFSS basement shelters. This section presents the ventilator designs considered, the cost analysis for each design, and the performance characteristics of each impeller. The initial reduction or screening, based on high kit cost and low or marginal impeller performance, from the 636 ventilators considered to the best 28 units is also presented in this section. Section 4 presents an analysis of the remaining high performing and economical units, and predictions on the National level for the best seven kits are presented.

3.1 Impellers

Impellers are cataloged by constant speed curves for static pressure and brake horsepower as a function of flow rate. Since manually-driven fans have a limited capability to move air, as compared to a motor-driven unit, it is economically necessary to operate the shelter ventilator units at a variable speed such that the maximum air flow for a fixed system can be attained. This maximum air flow occurs at the maximum sustained power output capability of the operators. Based on previous human factors studies (Ref. 4), this maximum capability is 0.10 horsepower at the fan shaft for a mechanical system with an efficiency greater than 90 percent.

For our systems analysis, it was necessary to reduce the empirical catalog data into analytical expressions which are readily adaptable to digital computer manipulations. This was accomplished by using the following fan law (Ref. 19: Fixed Fan Size, Constant System, Constant Air Density) relationships to obtain the desired constant horsepower operating points,

$$\frac{N_1}{N_2} = \left(\frac{H_1}{H_2}\right)^{\frac{1}{3}} \qquad (1)$$

$$\frac{Q_1}{Q_2} = \left(\frac{H_1}{H_2}\right)^{\frac{1}{3}} \qquad (2)$$

$$\frac{P_1}{P_2} = \left(\frac{H_1}{H_2}\right)^{\frac{2}{3}} \qquad (3)$$

where:

Q = air flow, CFM

P = static pressure, inches W.G.

H = horsepower

N = impeller speed, rpm

and by fitting the data to the following polynomial expressions by applying the least squares curve fitting technique. The "i"'s indicate the impeller being analyzed, and the "A"'s and "B"'s are the fitted coefficients for the polynomial expressions.

$$P_i = A_{1i} + A_{2i}Q_i + A_{3i}Q_i^2 \qquad (4)$$

$$N_i = B_{1i} + B_{2i}Q_i + B_{3i}Q_i^2 \qquad (5)$$

For our designs, as discussed in Section 3.3, we considered using both "Modular" and "Unitary" equipment. The modular equipment was designed with a two-step chain and sprocket transmission for operation at 0.1, 0.2, 0.4, 0.6 and 0.8 brake horsepower or 1 through 8 operators. For the 189 impellers analyzed, this resulted in 589 candidate designs. To these 589 two-step designs were added 34 single-step units ranging in diameter from 26 inches through 36 inches (see Figure 17, page 43). Based on earlier transmission tests on the 20-inch diameter MIL-V-40645 unit, it was assumed for all designs that the transmission efficiencies would exceed 90 percent (Ref. 3, page 63). Also, to establish a designs' cost (see Section 3.3), it was assumed in the case of the two-step modular units and the single-step unitary units that the sprocket ratio was 20 to 1 and 5 to 1, respectively. For the final ventilator designs, the sprocket ratio of each unit must be such that the pedal speed range is from 45 to 63 rpm throughout the air flow-static pressure operating range of the unit. Slight variations to the 20/1 and 5/1 sprocket ratios are tolerable as long as the costs used in this optimization study are not significantly upset.

In an attempt to reduce the costs for ventilating the smaller shelters requiring less than 1800 cfm, six hand-cranked blowers (see Figure 22, page 54) were added for consideration to the family of pedal-driven units. If the frequency of utilization of these units in the NFSS shelters is high, the cost of the total ventilating system would be reduced significantly. Comparing the present MIL-V-40645 20-inch diameter unit to a blower unit results in reducing the per-capita cost of a 50 space shelter from $3.10 to less than $0.50. The physiological criteria for people to develop power with their arm(s) are not as well established as for cycling, therefore it was assumed that 0.08 brake horsepower is available at the fan shaft. After performing a literature search, it appears that this value is high. According to Krendel (Ref. 20), 0.03 horsepower can be expected from a hand-crank device for periods longer than 10 minutes, and for 30 seconds, less than 0.07 horsepower can be developed (see Figure 16). As will be shown in Section 4.4, the hand-cranked blower did not survive, not even at this high capacity rating. Therefore, for this study we did not downgrade its performance to a rating which the operators were more likely to maintain.

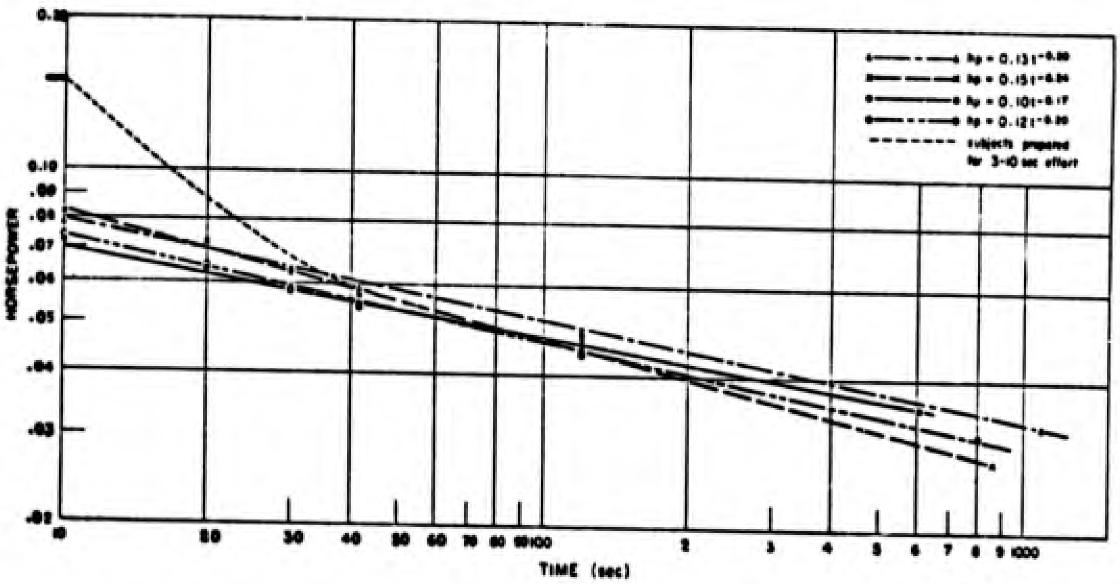


Figure 16 POWER GENERATED IN HAND-CRANKING AS INFLUENCED BY SUBJECT'S EXPECTATION OF TASK LENGTH (Source: Ref. 20)

As the performance characteristics of the manually-driven units were matched to the system characteristics of the sample shelters, the requirement for large capacity units became evident. Therefore, in addition to the manually-driven ventilators, motor-driven ventilators were considered (see Figure 24, page 59). Available commercial data for fan-motor ventilators were studied and seven fan-motor sets were chosen having impeller sizes from 18 inches through 36 inches in diameter, and free air capacities up to 24,000 cfm at a nominal motor rating of 5 horsepower.

Although this study was entirely computerized, the fitted coefficients for the constant horsepower performance curves, Equation 4, are on-file in Appendix C for the 623 pedal-driven units and the 6 hand-cranked blowers.

Also presented are the coefficients for the seven motor-driven impellers. These performance curves are for a nominal 1750 rpm motor. The actual impeller speed varies slightly and depends on the specific motor design (slip), and the load on the motor. The propeller and blower performance data were obtained from The Torrington Manufacturing Company, and the motor-driven ventilator data was furnished by the Aerovent Fan Company. If a manufacturer (such as the Brookside Corporation, Revcor, Incorporated, and the Meier Division of the Lau Blower Company) has an impeller which meets the minimum performance requirements for the same physical size specified (based on the optimization study), the Quality Assurance Provisions of the Specifications would allow substitution based on a qualification test of the impeller.

3.2 Plastic Ducting

The ventilator exhausts air through flexible plastic ducting deployed throughout the shelter and out appropriate apertures. Friction losses are manifested as pressure loss experienced by the air as it flows through the length of plastic ducting, and power is expended in moving air through the ducting against friction. Elbows as well as straight lengths of duct contribute to pressure loss in the ducting system. However, the pressure loss through an elbow may be expressed in terms of the pressure loss through an equivalent length of straight duct. Therefore, duct performance is expressed in terms of a static pressure loss that is a function of air flow rate and equivalent duct length (EDL).

Tests were conducted by GARD (Ref. 21) to determine the pressure drop characteristics of 20-inch diameter, 4-mil thick, polyethylene tubing and both factory- and shelter-fabricated 90° elbows. Fully inflated 20-inch diameter plastic duct was found to have about three-quarters of the pressure drop of sheet metal duct. However, the last 50 feet of a plastic duct system which is not completely inflated has 1-1/2 to 3 times the pressure drop per foot of fully inflated plastic tubing. Test data for straight duct for lengths from 50 to 450 feet were analyzed and correlated by the expression:

$$\Delta P_{20} = 1.915 \times 10^{-6} \left[Q^{1.349} + 0.01096 \left(\frac{L}{50} - 1 \right) Q^{1.833} \right] \quad (6)$$

where:

ΔP_{20} = static pressure drop in 20" diameter ducting, inches W.G.

Q = air flow, SCFM

L = duct length (for 50 feet or longer), feet

The equivalent duct length of any plastic tubing system can be determined by adding the total length of straight tubing plus the number of elbows multiplied by their respective equivalent duct length. It was determined that the factory-fabricated 90° elbow was equivalent to 50 feet of straight duct and the shelter-fabricated 90° elbow was equivalent to 90 feet of duct. Therefore, the equivalent duct length in a system becomes:

$$EDL = L + 50\, N_f + 90\, N_s \quad (7)$$

where:

EDL = equivalent duct length of the system, feet

L = length of straight duct in the system, feet

N_f = number of factory-fabricated elbows in the system

N_s = number of shelter-fabricated elbows in the system

Applying the equivalent duct concept to the duct friction equation yields the pressure drop in the system as:

$$\Delta P_{20} = 1.915 \times 10^{-6} \left[Q^{1.349} + 0.01096 \left(\frac{EDL}{50} - 1 \right) Q^{1.833} \right] \quad (8)$$

In developing the analysis, it was necessary to extend the considerations to all size fans ranging from 16-inch to 36-inch diameter. Since the detailed friction loss has only been measured for the 20-inch diameter duct, these results were scaled to estimate the pressure drop for other diameters. In turbulent flow, the pressure drop in a duct varies as (Ref. 22):

$$\Delta P \sim \frac{L\, V^{2-n}}{D^{1.4-n}} \tag{9}$$

where:

ΔP = pressure drop, inches W.G.

L = length of duct, feet

V = velocity, fpm

D = diameter, inches

n = roughness coefficient

For a constant cross-sectional area, the air flow rate, Q, is proportional to the velocity, V, so that is is assumed:

$$\Delta P \sim \frac{L\, Q^{2-n}}{D^{1.4-n}} \tag{10}$$

Thus, by equating the exponent (2-n) from equation (10) to the exponent 1.833 of equation (8), the roughness coefficient, n, may be computed as:

$$[2-n] = 1.833 \qquad \text{or} \qquad n = 0.167$$

It may be noted that computing the roughness factor in this manner ignores the effect of the last 50 feet of ducting as far as its effect upon the roughness factor. Furthermore, since equation (8) is an experimental correlation for 20-inch diameter duct, the static pressure is approximated for other duct diameters by scaling as:

$$\frac{\Delta P_{20}}{\Delta P_T} = \left(\frac{D_T}{20}\right)^{1.4-0.167} = \left(\frac{D_T}{20}\right)^{1.233} \tag{11}$$

Thus, the static pressure of any diameter ducting may be approximated by:

$$\Delta P = \frac{\Delta P_{20}}{(D/20)^{1.233}} = \frac{1.915 \times 10^{-6}}{(D/20)^{1.233}} \left[Q^{1.349} + 0.01096 \left(\frac{EDL}{50} - 1\right) Q^{1.833} \right] \quad (12)$$

This relationship is being verified by tests under another program by GARD (Ref. 23).

The overall pressure loss due to intake openings remains to be attributed to the performance of the ventilator. Thus far, the pressure effects due to straight ducts and elbows have been treated using the concept of equivalent duct length (EDL). The ventilator must overcome the pressure losses due to the air intake, as well as that caused by the duct system. An intake aperture in a shelter acts as a restriction to atmospheric air much like an orifice. Experimental investigations of pressure changes and of pressure losses at the abrupt change in area of the aperture indicate that the excess pressure loss over the normal friction loss is a dynamic one, due to a faster stream expanding into a slower stream as determined by the areas occupied by the flow. No perceptible dynamic loss is due to the converging of the air stream itself where the flow is contracted, but the air stream continues to converge beyond the edge of the aperture and reaches a minimum at the vena contracta. At the aperture, therefore, the dynamic loss is caused by expansion from the vena contracta to the full area following the contraction. The loss at the aperture can be expressed as:

$$\Delta P_{\alpha} = C \left[\frac{V_a}{4005}\right]^2 \quad (13)$$

where:

ΔP_{α} = dynamic pressure loss due to the aperture, inches W.G.

V_a = velocity of the air through the aperture, fpm

C = loss coefficient

For small cross-section apertures relative to the shelter cross-section, the aperture entrances have been considered as a square orifice, thus leading to a loss coefficient of 2.5 (Ref. 24). Therefore, the aperture dynamic pressure loss is computed as follows;

$$\Delta P_\alpha = 2.5 \left[\frac{V_a}{4005}\right]^2 \qquad (14)$$

and the velocity of air through the aperture can be computed by the following relationship:

$$V_a = \frac{Q_T}{A} \qquad (15)$$

where:

Q_T = total air flow rate for the entire shelter-part, CFM

A = cross-sectional area of the air source apertures, square feet

Thus, the pressure drop attributed to each ventilator is the sum of the friction and dynamic pressure, i.e.,

$$\Delta P_T = \Delta P_\tau + \Delta P_\alpha \qquad (16)$$

or

$$\Delta P_T = \frac{1.915 \times 10^{-6}}{(D/20)^{1.233}} \left[Q^{1.349} + 0.01096 \left(\frac{EDL}{50} - 1\right) Q^{1.833}\right] + 2.5 \left[\frac{V_a}{4005}\right]^2 \qquad (17)$$

3.3 Ventilator Designs and Cost Analysis

This section presents the designs for use with the impellers considered feasible in Section 3.1. As indicated earlier, the hand-cranked centrifugal blowers were introduced to determine in the elimination process if this type of equipment is feasible. Also, the power units were added to determine if these units would significantly increase the number of shelters which can be adequately ventilated. These designs were cost analyzed and in the elimination or screening process, Section 4, the least cost ventilating systems were chosen.

3.3.1 Pedal-Driven Ventilators

Propeller fans from 16 to 36 inches in diameter were considered for pedal-driven ventilator designs, driven by one, two, four, six and eight people. Two designs of one-man units evolved from the optimization analysis. One design has a single speed step-up sprocket-and-chain transmission, and the other one-man unit design has a two-step sprocket-and-chain transmission. The two, four, six, and eight man designs have a two-step sprocket-and-chain transmission, and the drive-modules are in tandem with respect to the fan assembly.

The single-step transmission one-man design, called herein the "Unitary Ventilator", is applicable for fan diameters 30 inches and greater (see Figure 17) and is packaged within one carton. With the use of the Unitary Ventilator, the only assembly required within the shelter is that of assembling the duct system. The two-step speed increase transmission one-man design, known as the "Non-Modular Ventilator", is applicable for fan diameters up to and including 28 inches (see Figure 18). The design is based on the 20-inch diameter Package Ventilation Kit as described by Specification MIL-V-40645 (Ref. 3). In order to minimize costs, design simplifications were implemented based on GARD's previous experience with this unit. In addition to deleting the motor, the drive-assembly frame has been redesigned to consist of two drawn steel stampings which are resistance-welded together. Also, the crank assembly includes one sprocket, rather than the riveted assembly of two sprockets which is required for the modular designs. Since the unit is non-modular, the components are packaged in one container; thus the packaging costs are significantly decreased. The unit was designed as two assemblies so that the

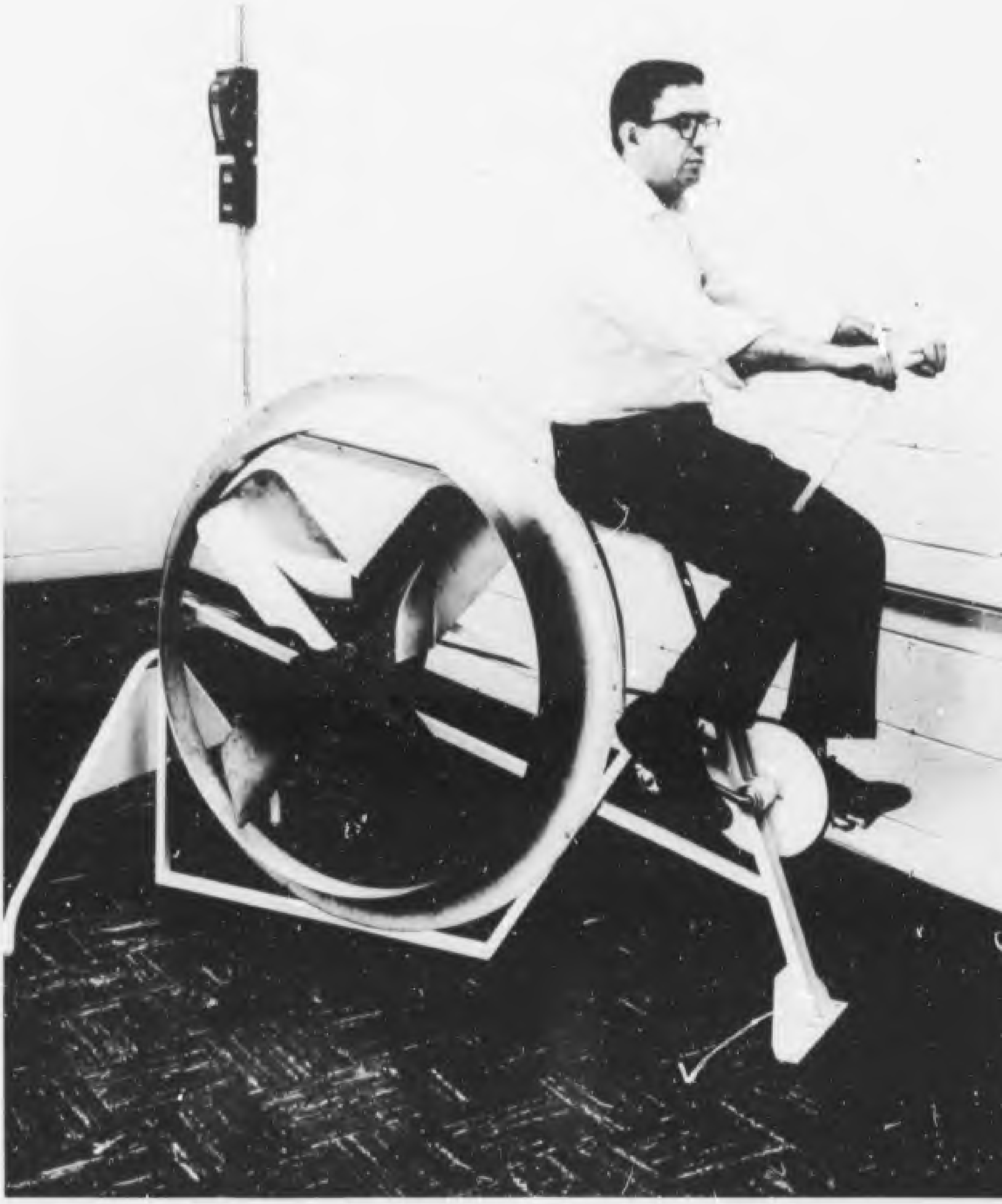


Figure 17 UNITARY VENTILATION CONCEPT

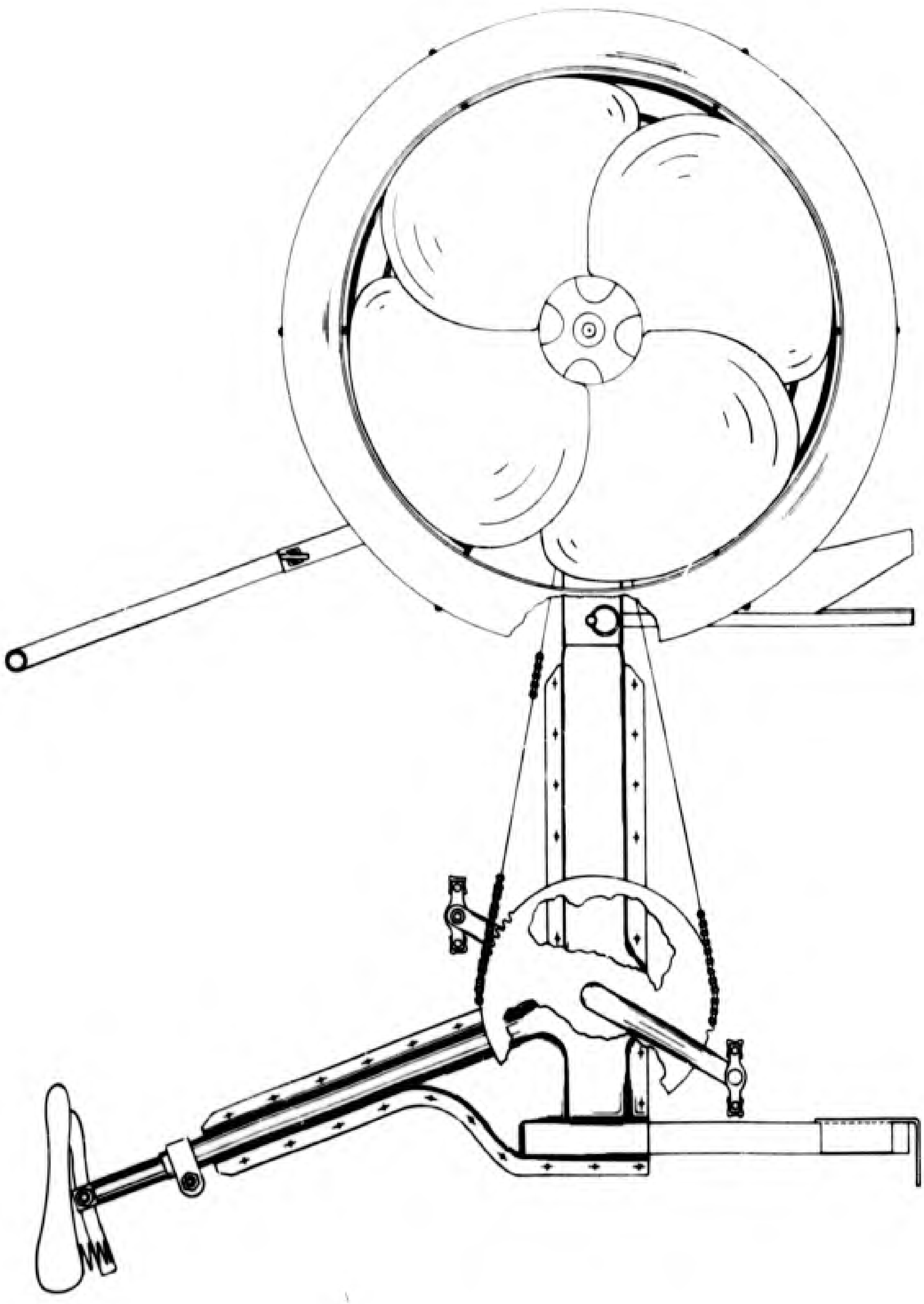


Figure 18 NON-MODULAR VENTILATOR CONCEPT

storage volume of the kit would be minimized. One-half inch pitch "bicycle chain" is suitable for use in the non-modular design, and was selected because of the lower cost advantage it offers over the 3/8-inch pitch, ASA No. 35 chain used in the MIL-V-40645 PVK.

The "Modular" designs are basically the same as the MIL-V-40645 PVK. The unit has been redesigned so that cost economies could be realized wherever possible. The drive modules are intended to be added tandemly, and intermediate supports are to be added wherever required for the four, six, and eight-man units. A substantial cost reduction was realized by deleting the electric motor and power cord, and by using a narrower tubular spine to permit simplification of the pedal and sprocket assembly. As mentioned earlier, using 1/2-inch pitch chain, rather than 3/8-inch pitch ASA No. 35 chain, will afford another cost reduction. By replacing the molded polystyrene foam inserts with fiberboard spacers and an interior single-wall fiberboard container, the packaging costs would be reduced. All design changes have been reflected in the cost analysis.

The costs of a 20-inch and 30-inch diameter fan assembly for use with 2, 4, 6, and 8 drive-modules were determined in detail as shown in Table IV, and the cost of the other diameter fan assemblies was determined by linearly interpolating, and the results are summarized in Table V. The fan assembly

TABLE V

FAN ASSEMBLY COSTS FOR THE MODULAR UNITS

Fan Diameter, inches								
16	18	20	22	24	26	28	30	36
$29	$33	$37*	$41	$45	$48	$52	$56*	$68

*Cost based on detailed analysis in Table IV.

TABLE IV

COST ANALYSIS OF THE FAN ASSEMBLY FOR THE MODULAR VENTILATORS

Fan Diameter	20-Inch		30-Inch	
Purchased Parts & Materials:		$ 15.16		$ 22.17
Fan	3.28		5.82	
Shroud, Aluminum	2.20		4.95	
Guard	1.14		2.56	
Chains	1.56		1.48	
	1.56		0.92	
Sprockets	1.58		1.40	
	0.42		0.42	
Bearings	0.60		0.60	
Fasteners	0.18		0.22	
Locating Pin	0.22		0.22	
Stand	0.50		0.65	
Material & Tooling	1.92		2.93	
Finishing:		1.50		2.20
Frame & Sprocket	1.20		1.70	
Stand	0.30		0.50	
Accessories:		6.75		8.61
Elbow	1.28		2.88	
Duct, 10 ft.	0.28		0.42	
Duct Adaptor	0.79		0.91	
Tape, 36 yds.	1.20		1.20	
Scissors	0.17		0.17	
Lubricant	0.03		0.03	
Hammer, 3 lb. Blacksmith	2.00		2.00	
Wrench, 9/16"	1.00		1.00	
Packaging:		5.52		12.20
Inner Box	2.09		4.04	
Vapor Barrier Bag	1.75		5.44	
Exterior Carton	0.87		1.80	
Duct Boxes & Dunnage	0.81		0.92	
Labor:		2.65		2.65
Arc Welding	1.23		1.23	
Machining	0.09		0.09	
Forming	0.25		0.25	
Spot & Projection Wldg.	0.37		0.37	
Assembly	0.42		0.42	
Rear Stand	0.29		0.29	
Labor Overhead (50%):		1.33		1.33
Sub-Total		$ 32.91		$ 49.16
General & Administrative Services (8%)		2.63		3.93
Sub-Total		$ 35.54		$ 53.09
Profit:		1.46		2.91
Total		$ 37.00		$ 56.00

package includes the accessories as noted and the variable height rear support stand. The drive-module for use with these fan assemblies is estimated to cost $27.00 (see Table VI). To determine the cost of a 2-, 4-, 6-, and 8-man unit, the fixed module cost was added to the variable fan assembly costs. The costs of the Modular Units are summarized in Table XI, page 62. During the design of the 4-man, 36-inch diameter unit, the kit essentially consisted of (1) the fan assembly, and (2) the drive assembly as shown in Figure 19. It is assumed the cost for the fan assembly package would not exceed $68, and the drive assembly package would cost approximately $108. The cost for this kit, as well as all other kits, must be roughly the same as estimated in our analysis for the results of the optimization study to be legitimate.

Table VII presents the detailed cost analysis of a 20-inch diameter two-piece, one-man unit (Non-Modular Design) and a 30-inch diameter integral Unitary unit. The costs for intermediate sizes were determined by linear interpolation for a rate of cost variation equivalent to the modular units. These costs are summarized in Table XI, page 62.

3.3.2 Hand-Crank Blowers

To decrease the cost of ventilation for the smaller shelters, a series of blowers equipped with a commercially manufactured gear transmission was roughly cost analyzed, and the schedule in Table VIII, page 52 was used in the first and second screening of the ventilator designs as described in Section 3.4. During the preliminary screening of ventilators, this transmission, which consisted of a spur gear and pinion enclosed in a cast iron housing (see Figure 20), was evaluated and it was found that the mechanical efficiency of the transmission was low. The low efficiency was due to interference in the mating of the gears stemming from poor machining, and to the lack of good bearings. In

TABLE VI

COST ANALYSIS OF THE DRIVE-MODULE FOR THE MODULAR VENTILATORS

Purchased Parts & Materials:		$ 11.57
Chain	2.30	
Sprockets	0.96	
	0.92	
Bearings	0.63	
Fasteners	0.05	
Saddle & Hardware	1.02	
Pedals	0.46	
Crank	1.40	
Locating Pin	0.22	
Material & Tooling	3.61	
Finishing:		3.13
Handle-bar	0.35	
Seat Post	0.15	
Sprocket	0.70	
Pin	0.03	
Frame	1.90	
Packaging:		3.98
Inner Box	1.24	
Vapor Barrier Bag	1.42	
Outer Container	0.47	
Duct Boxes & Dunnage	0.85	
Labor:		3.55
Arc Welding	2.50	
Machining	0.33	
Forming	0.26	
Spot & Projection Welding	0.02	
Assembly	0.44	
Labor Overhead (50%):		1.77
Sub-Total		$ 24.00
General & Administrative Services (8%):		1.92
Sub-Total		$ 25.92
Profit:		1.08
Total		$ 27.00

Figure 19 FOUR-MAN MODULAR VENTILATOR CONCEPT

TABLE VII

COST ANALYSIS OF THE NON-MODULAR AND UNITARY VENTILATORS

Ventilator Design	Non-Modular		Unitary	
Fan Diameter	20-Inch		30-Inch	
Purchased Parts & Materials:		$ 21.69		$ 31.78
Fan	3.28		5.82	
Shroud, Aluminum	2.20		4.95	
Guard	1.14		1.71	
Chains	1.51		3.82	
	1.49		---	
Sprockets	1.49		0.42	
	0.42		2.56	
	0.90		---	
Bearings	0.60		0.60	
	0.63		0.63	
Fasteners	0.18		0.47	
Saddle & Hardware	1.02		1.02	
Pedals	0.46		0.46	
Crank	1.40		1.40	
Locating Pin	0.22		---	
Material & Tooling	4.75		7.92	
Finishing:		4.20		2.70
Frame & Sprocket	3.40		2.25	
Handle-bar	0.35		---	
Seat Post	0.15		0.15	
Stand	0.30		0.30	
Accessories:		6.75		9.48
Elbow	1.28		2.88	
Duct, 10 ft.	0.28		0.42	
Duct Adaptor	0.79		1.78	
Tape, 36 yds.	1.20		1.20	
Scissors	0.17		0.17	
Lubricant	0.03		0.03	
Hammer, 3 lb. blacksmith	2.00		2.00	
Wrench, 9/16"	1.00		1.00	
Packaging:		5.52		7.83
Inner Box	2.09		3.91	
Vapor Barrier Bag	1.75		1.71	
Outer Container	0.87		1.56	
Duct Boxes & Dunnage	0.81		0.65	
Labor:		3.82		5.73
Arc Welding	1.23		4.00	
Machining	0.24		0.20	
Forming	0.60		0.28	
Spot & Projection Welding	0.72		---	
Assembly	1.03		1.25	
Labor Overhead (50%):		1.91		2.87
Sub-Total		$ 43.89		$ 60.39
General & Administrative Services (8%):		3.51		4.83
Sub-Total		$ 47.40		$ 65.22
Profit:		1.60		1.78
Total		$ 49.00		$ 67.00

Figure 20 HAND-CRANK GEAR TRANSMISSION

this design, the shafts bear directly on the cast iron of the housing. Since power losses were excessive for this transmission, it was eliminated from further consideration. Other production gear-drive transmissions were evaluated and were eliminated either due to excessive size, cost or an inappropriate

TABLE VIII

PRELIMINARY COST ANALYSIS OF BLOWERS

Blower Size: Wheel Diameter, inches Wheel Width, inches	9 7	9 9	10 8	10 10	12 9	12 12
Outlet Size: Height, inches Width, inches	10.25 9.19	10.25 11.81	11.38 10.50	11.38 13.12	13.44 12.25	13.44 15.62
Duct Diameter, inches	11	13	13	14	15	16
Cost of the Kit, dollars (see note)	22.59	22.96	23.69	24.33	29.36	29.88

NOTE: Includes blower, commercially manufactured gear transmission, protective finish, labor, accessories (one elbow, tape, scissors), packaging, overhead, and profit.

gear ratio. Also considered for this application were a pulley and timing belt system, and a chain and sprocket transmission. The timing belt transmission is especially well suited for an open, hand-crank drive. However, because of the lower price of the chain-drive components, the latter type of transmission was favored. A two-step speed increase chain transmission having an overall ratio of 8.0/1 was therefore designed (see Figure 21), and built for a 12-inch diameter blower as illustrated in Figure 22. In order to minimize power losses in the transmission, ground needle bearings were used in the sprocket hubs and the crank handle. The blower has a double inlet air intake and requires a 16-inch diameter duct system.

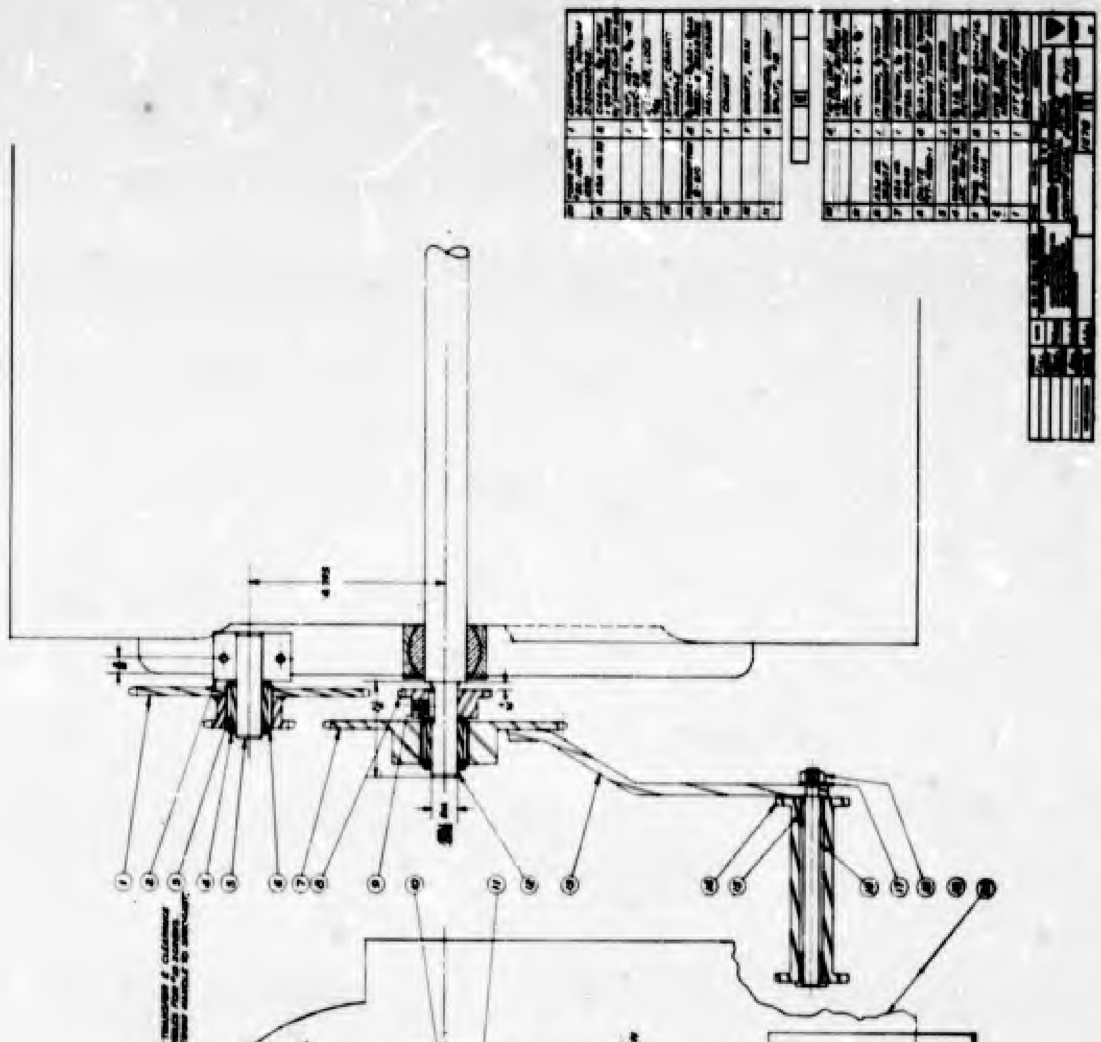


Figure 21 ASSEMBLY DRAWING -- HAND-CRANK BLOWER

Figure 22 HAND-CRANK BLOWER

After the first screening of the ventilators, in which these blower performance characteristics were evaluated, all units were eliminated except the blower with the 12-inch by 12-inch wheel (see Section 3.4). Therefore, the cost of this unit was analyzed in detail (see Table IX), primarily to reflect the increased cost of the transmission, and this cost was used in the optimization program described in Section 4. The estimated cost of the 12-inch diameter blower kit is $41.00.

3.3.3 Power-Driven Ventilators

Propeller-type impeller ventilators driven directly by 220 volt, 3-phase, 60-cycle motors, in nominal sizes of 1/3, 1/2, 1, 1-1/2, 2, 3, and 5 horsepower (see Figure 23) have been included in the optimization study, and the costs as scheduled in Table X were used. To insure the functioning of the ventilators, an engine-generator set is included in the ventilation system as illustrated in Figure 24. The generator is located outside the shelter so that no ventilation air would be used for combustion, toxic exhaust gases would be external to the shelter, and the noise in the shelter due to the engine would be attenuated. It is assumed that 200 feet of electrical cable would be required for each engine-generator set.

According to a recent study (Ref. 25), "the standard engine-generator set with a heavy-duty, four-stroke-cycle, internal combustion engine and a wound-rotor, rotating-armature, air-cooled generator is satisfactory for many shelter applications (10-year storage followed by operation)". According to the same report, the proper method of "storage" consists of weekly operation for one-half hour at part-load. Possible fuels for reciprocating spark-ignition engines are natural gas, gasoline, and LP gas. The cost analysis does not include the piping system for the use of natural gas, or the container

TABLE IX

COST ANALYSIS OF THE HAND-CRANK BLOWER

BLOWER SIZE:		
Wheel Diameter, inches	12	
Wheel Width, inches	12	
Duct Diameter, inch	16	
Purchased Parts & Material:		$ 22.85
Fan	12.70	
Fasteners	0.15	
Transmission	10.00	
Finishing:		2.00
Accessories:		4.96
Elbow	0.82	
Duct, 10 ft.	0.23	
Duct Adaptor	0.51	
Tape	1.20	
Scissors	0.17	
Lubricant	0.03	
Hammer, 3 lb. blacksmith	2.00	
Packaging (Method IA-14 Per MIL-P-116):		4.77
Inner Container	2.00	
Vapor Barrier Bag	2.06	
Exterior Box	0.71	
Labor (0.5 hrs @ $2.50/hr):		1.25
Labor Overhead (50%):		0.63
Sub-Total		36.46
General & Administrative Services (8%):		2.92
Sub-Total		39.38
Profit:		1.62
Total		$ 41.00

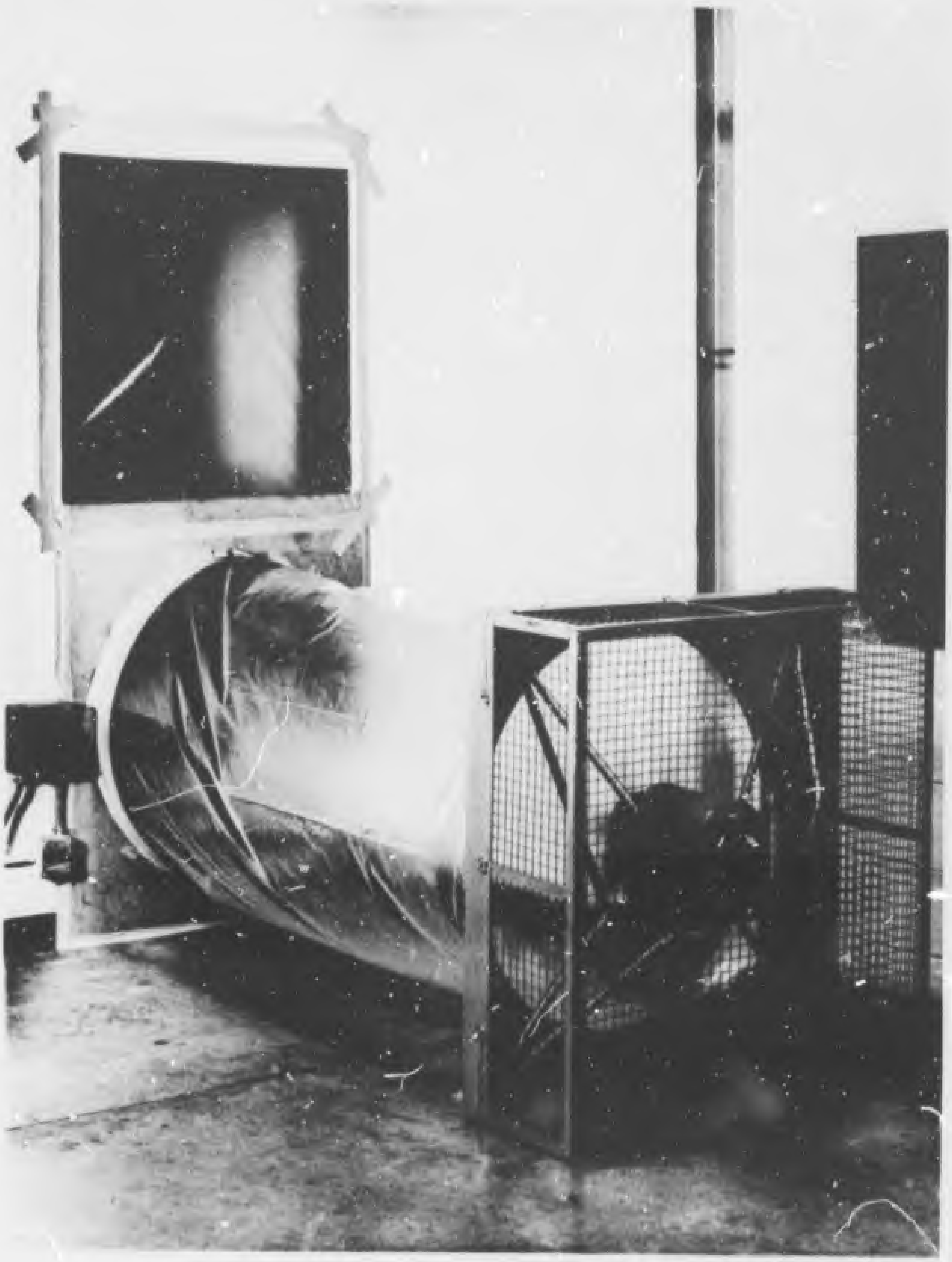


Figure 23 5-HP, 36-INCH DIAMETER, POWER VENTILATOR CONCEPT

TABLE X

COST ANALYSIS OF POWER-DRIVEN VENTILATORS

Fan Diameter, inches	18	24	27	27	32	36	36
Fan Horsepower (Nominal, see Note 1)	1/3	1/2	1	1-1/2	2	3	5
Ventilator Power Input, watts, (see Note 2)	244	514	700	1[illegible]30	1770	2340	3560
Motor Starting KVA	2.9	3.8	8.8	11.7	17.2	19.1	30.5
Engine-Generator Rating, watts	1500	1500	3000	4000	4000	5000	7500
VENTILATOR							
Purchased Parts & Materials:	89.80	108.80	124.60	153.80	177.60	206.40	226.80
Ventilator Assembly, including Finishing	89.80	108.80	124.60	153.80	177.60	206.40	226.80
Accessories:	5.30	6.69	7.52	7.52	9.12	10.57	10.57
Duct, 10 feet	0.25	0.34	0.38	0.38	0.45	0.51	0.51
Duct Adaptor	0.64	1.14	1.44	1.44	2.02	2.54	2.54
Duct Tape, 36 yds.	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Elbow	1.04	1.84	2.33	2.33	3.28	4.15	4.15
Scissors	0.17	0.17	0.17	0.17	0.17	0.17	0.17
Hammer, 3 lb. Blacksmith	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Packaging Cost: (15% Ventilator Assembly)	13.50	16.30	18.70	23.10	26.60	31.00	34.00
Sub-Total	108.60	131.79	150.82	184.42	213.32	247.97	271.37
General & Administrative Services: (8%)	8.69	10.54	12.07	14.75	17.07	19.84	21.71
Sub-Total	117.29	142.33	162.89	199.17	230.39	267.81	293.08
Profit:	5.71	7.67	7.11	8.83	9.61	11.19	13.92
Ventilator Total	$123.	$150.	$170.	$208.	$240.	$279.	$307.
ENGINE-GENERATOR SET							
Purchased Parts & Materials:	286.00	286.00	388.00	456.00	456.00	522.00	690.00
Engine-Generator Set Basic Cost, Including Finishing	286.00	286.00	388.00	456.00	456.00	522.00	690.00
Accessories:	8.65	8.65	11.45	18.55	18.55	19.15	27.35
Engine Oil, 4 changes	2.10	2.10	1.50	3.60	3.60	4.20	4.20
Wrench, 6 inch Adjustable	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Electrical Wire, 200 feet	5.60	5.60	9.00	14.00	14.00	14.00	22.20
Packaging Cost: (15% Basic Cost)	42.90	42.90	58.20	68.40	68.40	78.30	103.50
Sub-Total	337.55	337.55	457.65	542.95	542.95	619.45	820.85
General & Administrative Services: (8%)	27.00	27.00	36.61	43.44	43.44	49.55	65.67
Sub-Total	364.55	364.55	494.26	586.39	586.39	669.01	886.52
Profit:	15.45	15.45	19.74	23.61	23.61	26.99	35.48
Engine-Generator Total	380.00	380.00	514.00	610.00	610.00	696.00	922.00
Engine-Generator Total Attributable to Ventilation (see Note 3)	$ 62.	$130.	$120.	$172.	$270.	$326.	$438.
TOTAL	$18[illegible].	$280.	$290.	$380.	$510.	$605.	$745.

NOTES: (1) Motor characteristics: 220 volt, 3-phase, 60 cps.

(2) Based on a motor efficiency of 80 percent, and a ventilator without external resistance.

(3) (Engine-Generator Total Cost, $) X $\left[\frac{\text{(Ventilator Input, Watts)}}{\text{(Engine-Generator Capacity, Watts)}}\right]$

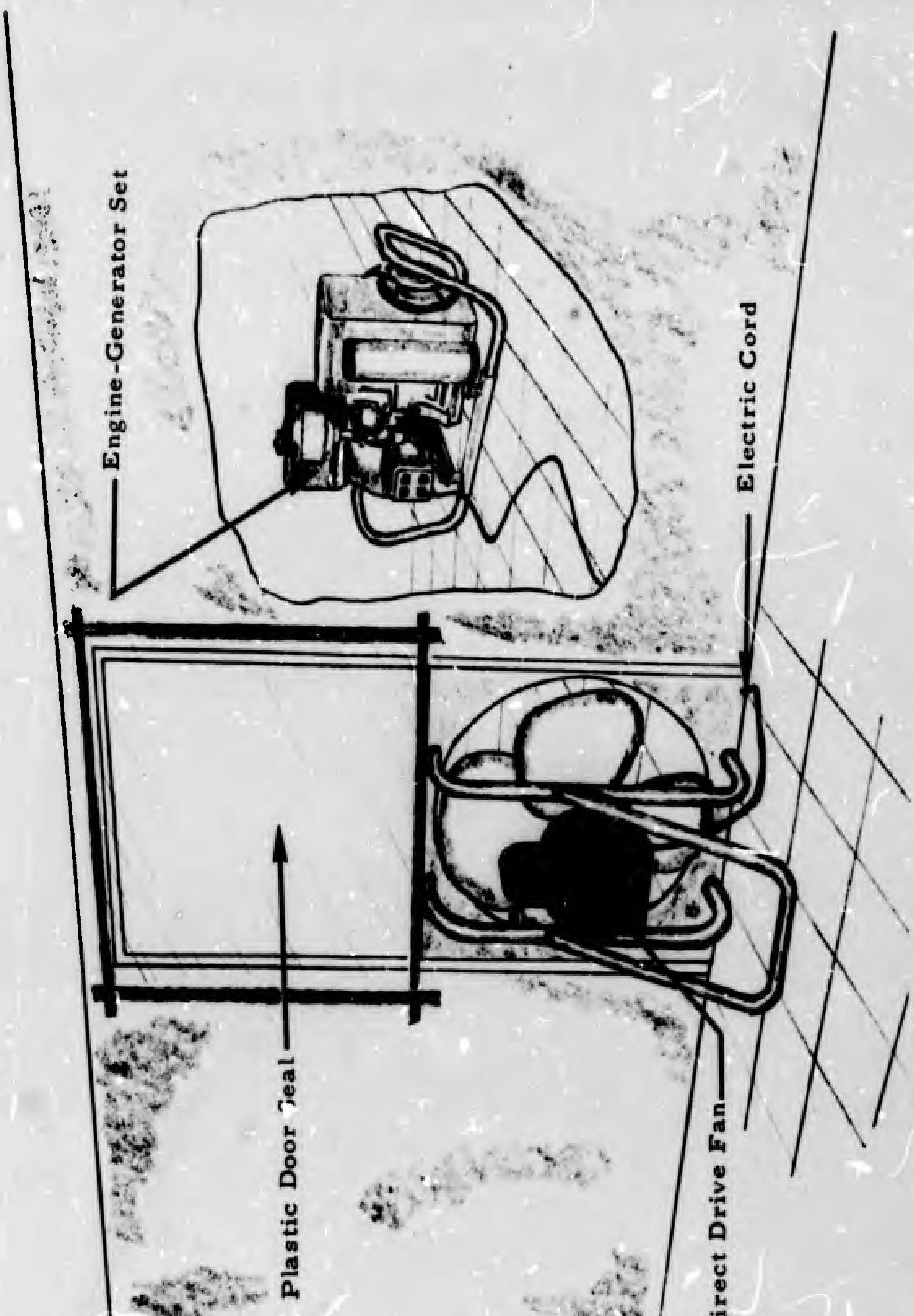


Figure 24 POWER VENTILATOR SYSTEM CONCEPT

and fuel for the storage of gasoline or LP gas. We feel gasoline can be obtained by siphoning from automobiles and the storage tanks at the local gas stations. Protective measures should be taken when leaving the shelter for any task as outlined in the "Handbook For Radiological Monitors" (Ref. 26). Further research is required to determine the minimum requirements for stowing engine-generator sets, and how often the units should be exercised.

The selection of the engine-generators in Table X was made from production units of three manufacturers of industrial units. The gasoline engines in the engine-generator sets are four-cycle, air-cooled, and have cast iron cylinder blocks with either one or two cylinders. These engines are on the Qualified Products List and are described by Specification MIL-E-11275 D, "Engines, Gasolines, Industrial Type". The engines have a minimum life of 500 hours operating continuously at rated load, and were matched to the locked rotor (LR) or starting current of the ventilator motors. As noted, the kilowatt capacity of the generators selected greatly exceed the operating power requirements of the ventilators. For example, the 27-inch diameter ventilator equipped with a 1-horsepower motor requires 23 amperes (LR) or 8.8 kilovolt-amperes to start the ventilator. While only 700 watts are required to operate the ventilator without any duct system, a 3000 watt generator driven by a 7-horsepower engine is required to start the ventilator.

In estimating the cost of each power-driven ventilator, the cost of the engine-generator set is pro-rated according to the operating power requirements of the ventilator motor. The excess power capability of the generator set can be consumed by the shelter lighting system and other accessories, such as a radio for communications, a battery charger for the radiological equipment, or heating.

3.3.4 Summary of Costs

A summary of the design costs used in the optimization analysis, as discussed in Section 4, is presented in Table XI. In the optimization analysis, the length of straight plastic duct was considered a parameter, since the length of duct required depends upon the shelter characteristics (see Section 2.4). Elbows, ten feet of duct (which is intended for sealing the apertures), duct tape, a duct adapter, and a blacksmith's hammer are assumed to be a fixed cost for each ventilator kit. The cost schedule for the plastic duct used in the optimization analysis is shown in Table XII.

3.4 Impeller Screening

For our optimization study or any operational system, it is necessary to match the shelter characteristics to the performance characteristics of the impellers. This is accomplished by equating Equations (4) and (17) as shown below and solving for the operating point of the system (see Figure 25).

$$A_{1i} + A_{2i}Q + A_{3i}Q^2 = \frac{1.915 \times 10^{-6}}{(D/20)^{1.233}} \left[Q^{1.349} + 0.01096 \left(\frac{EDL}{50} - 1 \right) Q^{1.833} \right] + 2.5 \left[\frac{V_a}{4005} \right]^2 \quad (18)$$

Multiple impellers are possible; however, our entire analysis is based on least cost solutions. The initial screening of impellers which follows was performed in order to eliminate the bulk of the low performing and expensive kits.

3.4.1 First Screening of Impellers

When inspecting Equation (18), it is evident that to solve for the capacity would result in a non-linear equation yielding multiple roots, involving such shelter parameters as the equivalent duct length (EDL) and the velocity of inlet air through the air source apertures (V_a). To avoid introducing shelter parameters at this point in our systems analysis, the

TABLE XI SUMMARY OF VENTILATOR COSTS*

Type of Ventilator	Blower Diameter, inches	Fan Diameter, inches										
	12	16	18	20	22	24	26	27	28	30	32	36
Pedal-Driven Fan, Single Man:												
Non-Modular		42	46	49	53	57	61	--	65	--	--	--
Unitary		--	--	--	--	--	--	--	--	67	--	73
Pedal-Driven Fan, Modular:												
2-Man		83	87	91	95	99	102	--	106	110	--	122
4-Man		137	141	145	149	153	156	--	160	164	--	176
6-Man		191	195	199	203	207	210	--	214	218	--	230
8-Man		245	249	253	257	261	264	--	268	272	--	284
Hand-Cranked Blower:	41											
Power-Driven Fan:												
1/3 (horsepower)			185									
1/2						280						
1								299				
1-1/2								380				
2											510	
3												605
5												745

*All costs are in dollars.

TABLE XII COST SCHEDULE FOR PLASTIC DUCT

Duct Diameter, inches	16	18	20	22	24	26	27	28	30	32	36
Duct Cost, $ per 100 feet	2.25	2.53	2.81	3.09	3.37	3.66	3.80	3.94	4.22	4.50	5.06

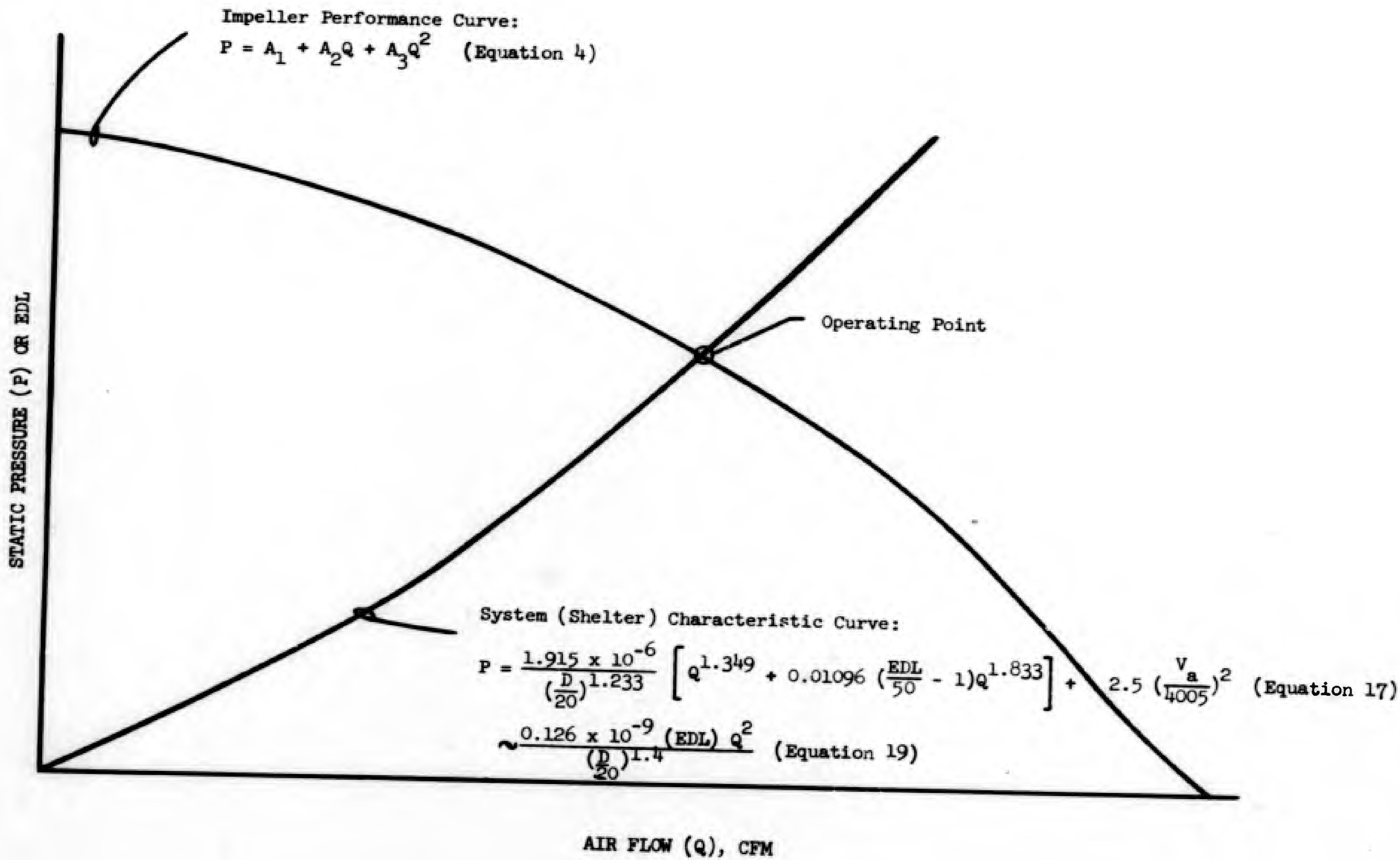


Figure 25 AN EXAMPLE OF MATCHING SHELTER AND IMPELLER CHARACTERISTICS

dynamic pressure term was ignored, and the exact duct friction equation was approximated by the following expression. The value of K,

$$\Delta P = \frac{K\,(EDL)\,Q^2}{(D/20)^{1.4}} \qquad (19)$$

0.126×10^{-9}, was obtained by fitting this expression by the least squares technique to the plastic duct friction data (Ref. 21). With these simplifications, the following quadratic equation results:

$$EDL = \frac{(D/20)^{1.4}}{0.126 \times 10^{-9}} \left[\frac{A_{1i}}{Q^2} + \frac{A_{2i}}{Q} + A_{3i} \right] \qquad (20)$$

Using this quadratic equation, three fixed EDL's, and the cost scheduled in Table XIII, the low performance, high cost units were eliminated. The results showed that all but 48 pedal-driven ventilators and 5 hand-crank blowers were eliminated strictly on the basis of cost and performance (see Table XIV). Of these 53 screened units, it was possible to choose 1 hand-crank blower and 17 pedal-driven ventilation units which cover narrow performance ranges, thus eliminating unnecessary close performing units with similar costs. The cost schedule used was prepared prior to the detailed analysis presented in Section 3.3. Since the cost differences were small, the results of the initial screening would not have changed.

3.4.2 Second Screening of Impellers

For the second screening process, the 6- and 8-module pedal-driven ventilators were eliminated from further consideration and the power-driven units as well as the 36-inch diameter 1-, 2-, and 4-man ventilators were added for further screening. At this point in the study, the detailed cost schedules summarized in Table XI for the ventilators were applied. Since the number of candidate designs had diminished to reasonable proportions, the exact duct

TABLE XIII

COST SCHEDULE USED FOR THE FIRST SCREENING OF VENTILATORS

MODULAR VENTILATORS

Fan Diameter (inches)	Fan Assembly Cost (Dollars/Fan Assembly)	Module Cost (Dollars/Module)
16	29.40	29.32
18	31.90	29.32
20	34.30	29.32
22	36.80	29.32
24	39.30	29.32
26	41.75	29.32
28	44.30	29.32
30	46.80	29.32

NOTE: Fan assembly costs include packaging and all accessories except the polyethylene duct. Duct cost used is as scheduled in Table XII.

ONE-MAN UNITS

Fan Diameter (inches)	Unitary Design Cost (dollars)	Simplified Design Cost	
		Fan Assembly Cost (dollars)	Drive Assembly Cost (dollars)
16	-	27.95	15.03
18	-	30.30	15.03
20	-	32.69	15.03
22	-	35.10	15.03
24	-	37.40	15.03
26	52.75	39.80	15.03
28	52.75	42.20	15.03
30	52.75	44.60	15.03

NOTE: Duct costs not included. Units packaged in one carton.

TABLE XIV

RESULTS OF THE FIRST AND SECOND IMPELLER SCREENINGS

HORSE-POWER	IMPELLER NOMENCLATURE	FIRST SCREENING PROCESS						NOTES	SECOND SCREENING PROCESS						MASTER LIST OF IMPELLERS
		EDL = 50 FT.		EDL = 300 FT.		EDL = 700 FT.			EDL = 50 FT.		EDL = 300 FT.		EDL = 700 FT.		
		CFM	COST,$	CFM	COST,$	CFM	COST,$		CFM	COST,$	CFM	COST,$	CFM	COST,$	
0.08	HC 916 704	1005	23.36	944	27.24	876	33.44								
0.08	BC 916 916	1180	23.87	1101	28.45	1007	35.77								
0.08	BC 1020 1020	1366	23.51	1244	30.24	1109	38.12								
0.08	BC 1220 916	1451	30.41	1298	35.69	1155	44.13								
0.08	BC 1220 1220	1650	31.00	1420	36.63	1239	45.[illegible]	*	1559	42.12	1370	47.75	120[illegible]	56.75	1
0.1	E-1616-4					1461	58.73								
0.1	E-1624-4	2109	44.10	1703	49.73			*	1988	43.12	1643	48.75	1352	57.75	2
0.1	A-1839-5	2421	46.59												
0.1	P-1816-4			1814	52.92	1516	63.04	*	2063	47.26	1765	53.59	1486	63.7[illegible]	3
0.1	E-2024-4			1926	56.15			*	2513	50.40	1836	57.43			4
0.1	N-2040-4	2833	49.12												
0.1	N-2224-4			2001	59.40	1562	71.76	*			1921	62.27	1502	74.63	7
0.1	E-2416-4					1682	76.02								
0.1	E-2424-4	3106	54.11	2137	62.54			*	2846	58.68	2037	67.11	1552	80.59	10
0.1	N-2624-4			2169	65.81			*	2951	62.83	2059	71.98			13
0.1	N-2632-4	3355	56.66												
0.1	A-2833-5	3486	59.20												
0.1	R-3020-4			2305	71.79			*	3140	69.15	2185	7[illegible].70	1647	96.58	16
0.1	R-3027-4	3738	60.54												
0.1	R-3627-4							**	3808	75.53	2270	88.18			19
0.2	E-1624-4					1754	103.79								
0.2	P-1816-4					1910	108.25								
0.2	E-2024-4			2427	101.37			*			2367	99.43	1837	110.67	5
0.2	N-2224-4			2521	104.71	1968	117.07	*			2471	104.27	1927	116.63	8
0.2	E-2416-4					2120	121.53								
0.2	E-2424-4	3914	99.62	2692	108.05			*			2550	109.11	1965	122.59	11
0.2	N-2624-4			2733	111.37			*	3831	103.83	2653	112.98	1986	127.62	14
0.2	N-2632-4	4226	102.22												
0.2	A-2833-5	4392	104.91												
0.2	R-3020-4			2904	118.10	2138	134.98	*	4086	112.11	2824	122.66	2128	139.54	17
0.2	R-3027-4	4709	107.55												
0.2	R-3627-4							**	5040	124.53	2945	137.18			20
0.4	E-2024-4			3058	160.[illegible]	2352	171.25	*			3068	153.43	2372	164.67	6
0.4	N-2224-4			3176	163.[illegible]5	2479	175.71	*			3166	158.27	2499	170.63	9
0.4	E-2416-4					2671	180.17								
0.4	E-2424-4	4931	158.26	3392	166.[illegible]9			*			3402	163.11	2584	176.59	12
0.4	N-2624-4			3443	170.01			*			3433	166.98			15
0.4	N-2632-4	5325	160.86												
0.4	A-2833-5	5534	163.55												
0.4	R-3020-4			3659	176.74	2757	193.62	*	5304	16[illegible].11	3627	176.66	2736	193.54	18
0.4	R-3027-4	5934	166.19												
0.4	R-3627-4							**	6651	178.53	3823	191.18			21
0.6	N-2224-4					2838	234.35	***							
0.6	E-2416-4					3058	238.81	***							
0.6	E-2424-4			3883	225.33			***							
0.6	N-2624-4			3942	228.65			***							
0.6	N-2632-4	6095	219.50					***							
0.6	A-2833-5	6335	222.19					***							
0.6	R-3020-4			4188	235.38	3156	252.26	***							
0.6	R-3027-4	6793	224.83					***							
0.6	R-3627-4							***							
0.8	E-2416-4							***							
0.8	E-2424-4			4274	2[illegible]3.97	3365	297.45	***							
0.8	N-2624-4			4339	287.29			***							
0.8	A-2833-5	6973	280.83					***							
0.8	R-3020-4			4610	294.02	3474	310.90	***							
0.8	R-3027-4	7476	283.47					***							
0.8	R-3627-4							***							
0.33	183-18-1/3							**							22
0.5	247-24-1/2							**							23
1.0	280-27-1							**	7872	291.90	5288	301.40	3828	316.60	24
1.5	281-27-1-1/2							**	9104	381.90	5764	391.40	4077	406.60	25
2.0	329-32-2							**	12867	512.25	7307	523.50	48[illegible]8	541.50	26
3.0	368-36-3							**	17032	607.53	9170	620.18	6201	640.42	27
5.0	375-35-5							**	20128	747.53	10589	760.18	6877	780.42	28

NOTES: * Chosen for second screening.

** Added to second screening.

*** Eliminated from further consideration.

Impeller Nomenclature:

Hand-Crank Blower

BC 1200 1200
- 1200 (second) — Width, inches & 32nds
- 1200 (first) — Diameter, inches & 32nds
- BC — Type of Blower

Pedal-Driven Impeller

4 R - 3627 - 4
- 4 (last) — Number of Blades
- 27 — Pitch, degrees
- 36 — Diameter, inches
- R — Shape of Propeller Blade
- 4 (first) — Number of Operators

Power-Driven Ventilator

375 - 36 - 5
- 5 — Motor Rating Horsepower
- 36 — Diameter, inches
- 375 — Series Designation Number

friction relation was used to compute the kits required as a function of EDL. The dynamic pressure term was, however, still neglected. The results of the screening process showed that all but one of the 36-inch diameter impellers (R-3627-4) were eliminated, all the manual-drive ventilators survived, and five of the power-driven units were chosen. Again, the basis for selection was cost and performance. Therefore, on the basis of the two screening processes, a master list of 28 candidate ventilators was selected for use in the final equipment optimization program presented in Section 4. The performance curves for this master list of units are presented in Figures 26 through 29, and the individual impeller performance curves including the air flow-speed performance curves for these 28 ventilators are presented in Appendix D.

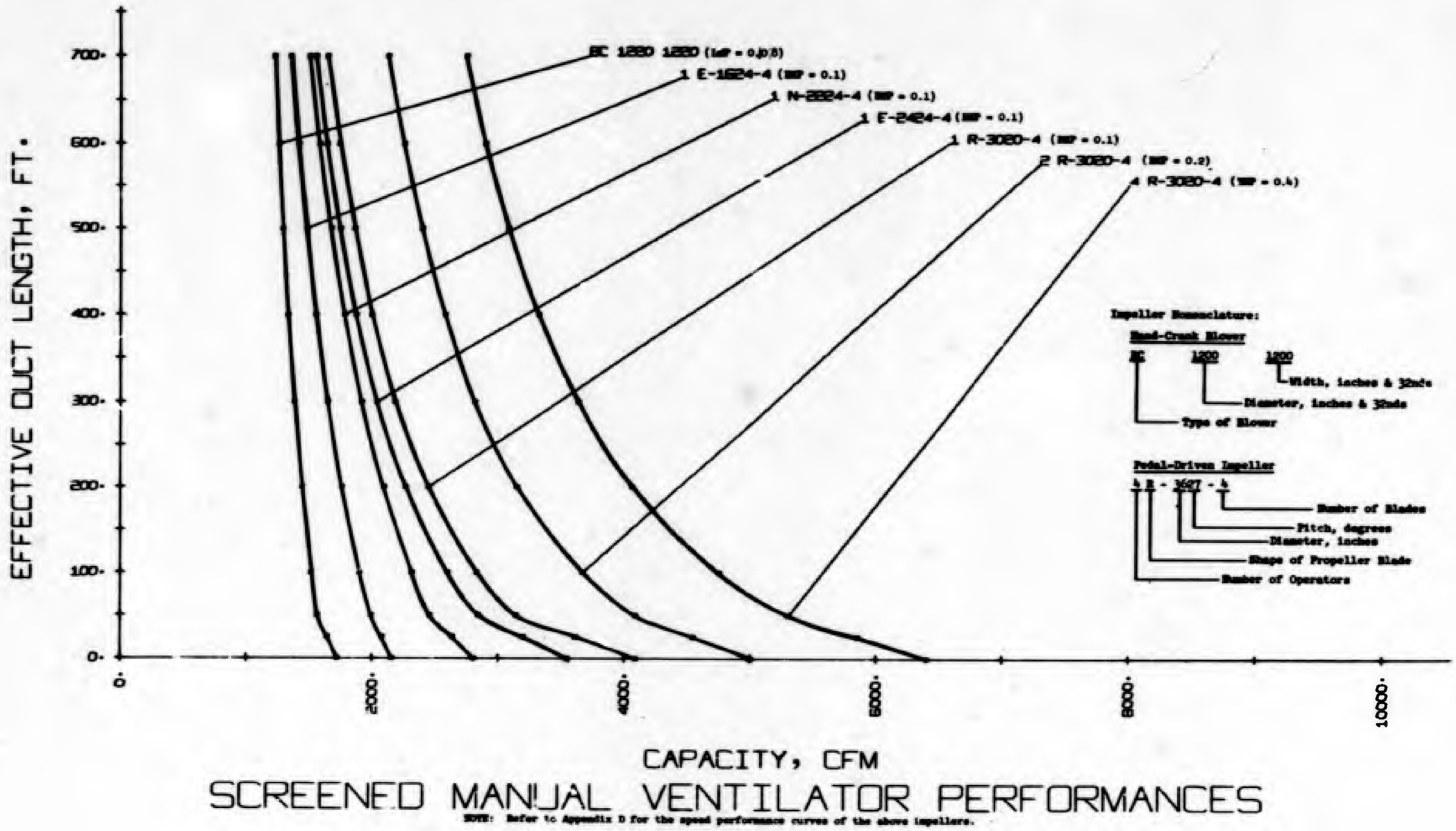
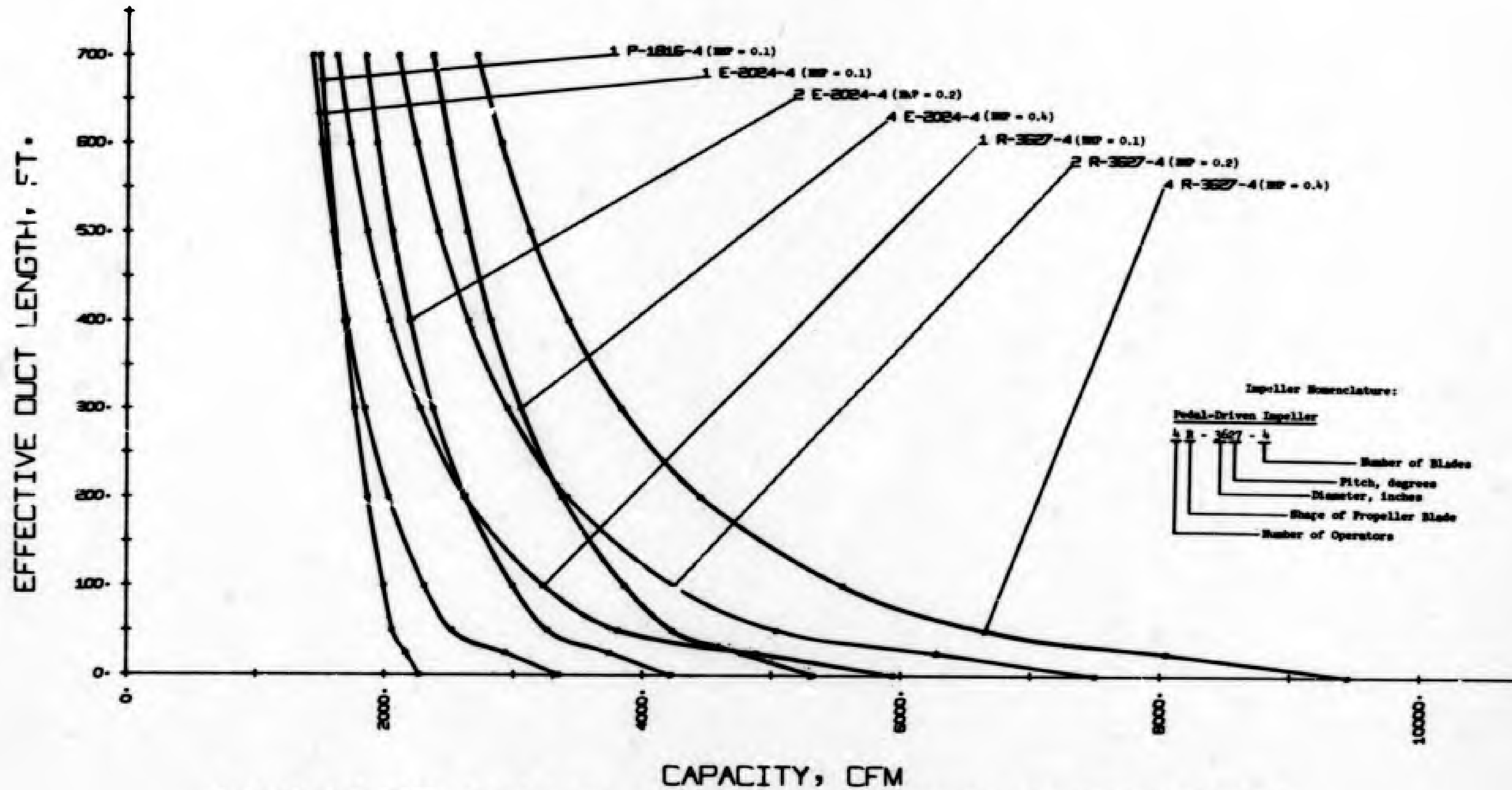


Figure 26 PERFORMANCE CURVES FOR THE MASTER LIST OF VENTILATORS (SHEET 1 OF 4)



SCREENED MANUAL VENTILATOR PERFORMANCES

NOTE: Refer to Appendix D for the speed performance curves of the above impellers.

Figure 27 PERFORMANCE CURVES FOR THE MASTER LIST OF VENTILATORS (SHEET 2 OF 4)

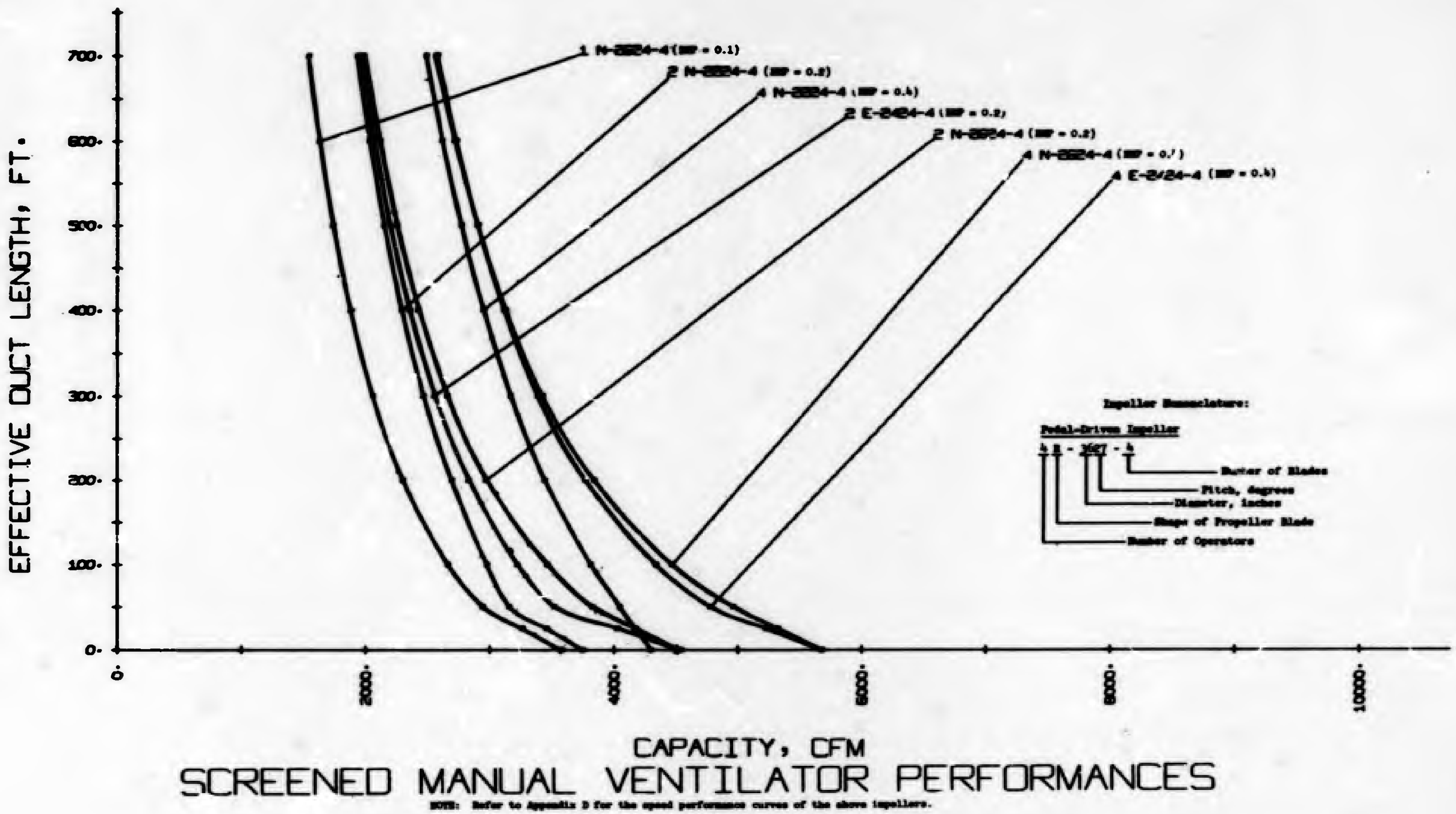
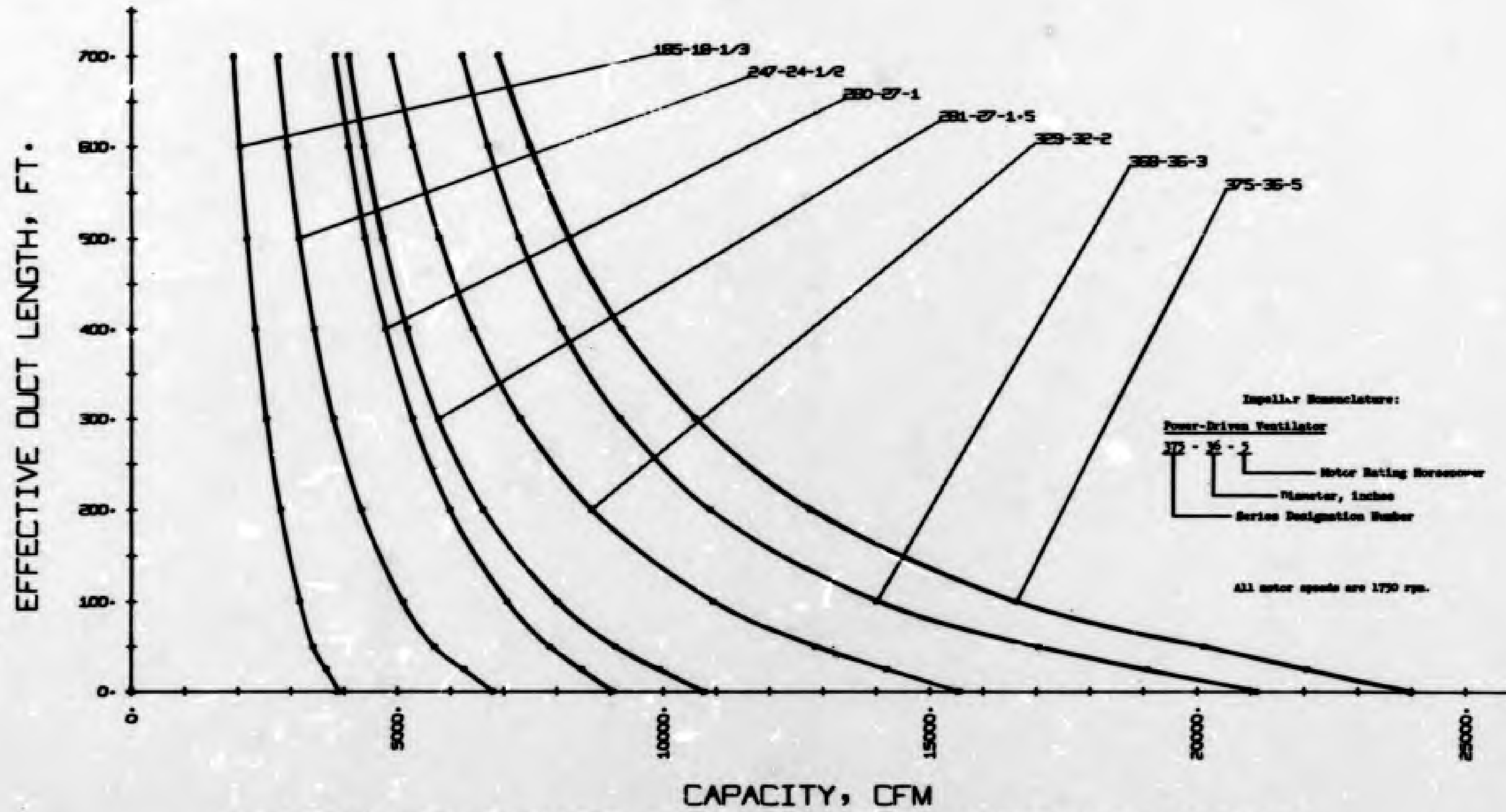


Figure 28 PERFORMANCE CURVES FOR THE MASTER LIST OF VENTILATORS (SHEET 3 OF 4)



SCREENED POWER VENTILATOR PERFORMANCES

Figure 29 PERFORMANCE CURVES FOR THE MASTER LIST OF VENTILATORS (SHEET 4 OF 4)

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SECTION 4

OPTIMIZATION OF VENTILATION KITS

As discussed in Section 3.4, the ventilation equipment was screened on the basis of cost and performance and all but the best 28 ventilators were eliminated. These surviving units ranged in capacity from a small hand-crank blower to a large 5 horsepower ventilator. In this section the methods used to match the shelter characteristics to the performance characteristics of the master list of 28 ventilators are discussed and the best seven ventilation kits selected. For these seven kits, predictions were made as to the NFSS basement shelter-parts ventilated and the total cost for the ventilator kits. The final selection from these seven units must be based on factors other than engineering; primarily the necessary instructional aids to reasonably assure a reliable ventilating system.

4.1 Surveyor Program

The basis for matching and selecting the least-cost equipment is a file of the shelter characteristics for any combination of equipment size and any number of installed units (number of openings) from the maximum possible to a minimum of one. This summary of data is called the "surveyor file" and was generated by use of a computer program using as input the shelter descriptors developed according to the approach discussed in Section 2 and summarized in Appendix A. The output format of the computer program, as illustrated on the next page, gives for each shelter-part of the RTI survey the pseudo-equivalent duct length as a function of (1) the possible duct diameters, and (2) the number of ventilators from the maximum possible to one unit.

		NO. OF OPENINGS			PSEUDO-EQUIVALENT DUCT LENGTH FOR THE FOLLOWING IMPELLER DIAMETERS									
					16" D	18" D	20" D	22" D	24" D	26" D	27" D	30" D	32" D	36" D
		N_{max}												
		N_{max-1}												
		.												
		.												
		.												
		1												

The pseudo-equivalent duct length of a system is defined as the straight length of a duct for a given ventilator and duct diameter which will produce the total pressure drop of the shelter ventilating system (see Equation 16, page 41). These data are used repetitively through the optimization program for choosing the most effective ventilator designs to cover the sample shelters. If our systems approach is adopted, these data would also be necessary to select the equipment; however, it would only be done for the equipment or duct diameters used in the operational system.

To illustrate the surveyor program, Facility No. 148 of the sample survey (see Appendix B) was selected and the results are presented in Table XV. As determined previously and summarized in Appendix A, the descriptors for this shelter are as follows:

Total Area	=	19,344 square feet
Avg. Equivalent Duct Length	=	85 feet
Total Aperture Area	=	140 square feet
Maximum Number of Ventilators	=	6
Aperture Area for Inlet Air	=	40 square feet.

TABLE XV SURVEYOR FILE FOR RTI FACILITY NO. 148

VENTILATION RATE	TOTAL CFM REQ'D	AVG. DUCT LENGTH (ft)	NO. OF OPENINGS	VELOCITY (fpm)	CFM/UNIT	PSEUDO-EQUIVALENT DUCT LENGTH FOR THE FOLLOWING IMPELLER DIAMETERS									
						16" D	18" D	20" D	22" D	24" D	26" D	27" D	30" D	32" D	36" D
50 CFM/OCC	96,700	85	6	2410	16,100	116	121	127	132	137	143	145	154	160	171
			5	2410	19,300	107	111	115	118	122	126	128	134	138	147
			4	1610	24,100	91	92	93	95	96	97	97	99	100	103
			3	1610	32,200	88	89	90	90	91	92	92	93	94	95
			2	1200	48,300	86	86	86	86	86	86	87	87	87	87
			1	1200	96,700	85	85	85	85	85	85	85	85	85	85
40 CFM/OCC	77,300	85	6	1930	12,800	115	120	125	130	135	141	143	151	157	168
			5	1930	15,400	109	110	114	117	121	125	127	132	136	144
			4	1280	19,300	91	92	93	94	95	96	97	99	100	102
			3	1280	25,700	88	89	90	90	91	91	92	93	94	95
			2	967	38,600	86	86	86	86	86	86	86	87	87	87
			1	967	77,300	85	85	85	85	85	85	85	85	85	85
30 CFM/OCC	58,000	85	6	1450	9,670	114	118	123	128	133	138	140	148	154	164
			5	1450	11,600	106	109	112	116	119	123	125	130	134	142
			4	967	14,500	91	92	93	94	95	96	96	98	99	101
			3	967	19,300	88	89	89	90	91	91	91	92	93	94
			2	725	29,000	85	86	86	86	86	86	86	87	87	87
			1	725	58,000	85	85	85	85	85	85	85	85	85	85
25 CFM/OCC	48,300	85	6	1200	8,060	113	117	122	127	131	136	139	146	151	162
			5	1200	9,670	105	108	111	115	118	122	123	129	132	140
			4	806	12,000	91	91	92	93	94	95	96	98	99	101
			3	806	16,100	88	89	89	90	90	91	91	92	93	94
			2	604	24,100	85	86	86	86	86	86	86	87	87	87
			1	604	48,300	85	85	85	85	85	85	85	85	85	85
20 CFM/OCC	38,600	85	6	967	6,440	112	116	121	125	130	134	137	144	149	159
			5	967	7,730	104	107	110	114	117	120	122	127	131	138
			4	644	9,670	90	91	92	93	94	95	96	97	98	100
			3	644	12,800	88	88	89	90	90	91	91	92	93	94
			2	483	19,300	85	86	86	86	86	86	86	86	87	87
			1	483	38,600	85	85	85	85	85	85	85	85	85	85
15 CFM/OCC	29,000	85	6	725	4,830	111	115	119	123	128	132	134	141	146	156
			5	725	5,800	103	106	109	112	115	119	120	125	129	135
			4	483	7,250	90	91	92	93	94	95	95	97	97	100
			3	483	9,670	88	88	89	89	90	90	91	92	92	93
			2	362	14,500	85	86	86	86	86	86	86	86	87	87
			1	362	29,000	85	85	85	85	85	85	85	85	85	85
10 CFM/OCC	19,300	85	6	483	3,220	109	113	117	121	125	129	131	138	142	151
			5	483	3,860	102	105	108	110	113	116	118	122	126	132
			4	322	4,830	90	90	91	92	93	94	94	96	97	99
			3	322	6,440	88	88	89	89	90	90	90	91	92	93
			2	241	9,670	85	85	86	86	86	86	86	86	86	87
			1	241	19,300	85	85	85	85	85	85	85	85	85	85
7.5 CFM/OCC	14,500	85	6	362	2,410	108	111	115	119	123	127	129	135	139	148
			5	362	2,900	101	104	106	109	112	115	116	121	124	130
			4	241	3,620	89	90	91	92	93	93	94	95	96	98
			3	241	4,830	87	88	88	89	89	90	90	91	91	92
			2	181	7,250	85	85	86	86	86	86	86	86	86	87
			1	181	14,500	85	85	85	85	85	85	85	85	85	85

As can be seen from Figure 30, the total aperture area available to this shelter is 140 square feet. This aperture area is obtained as follows:

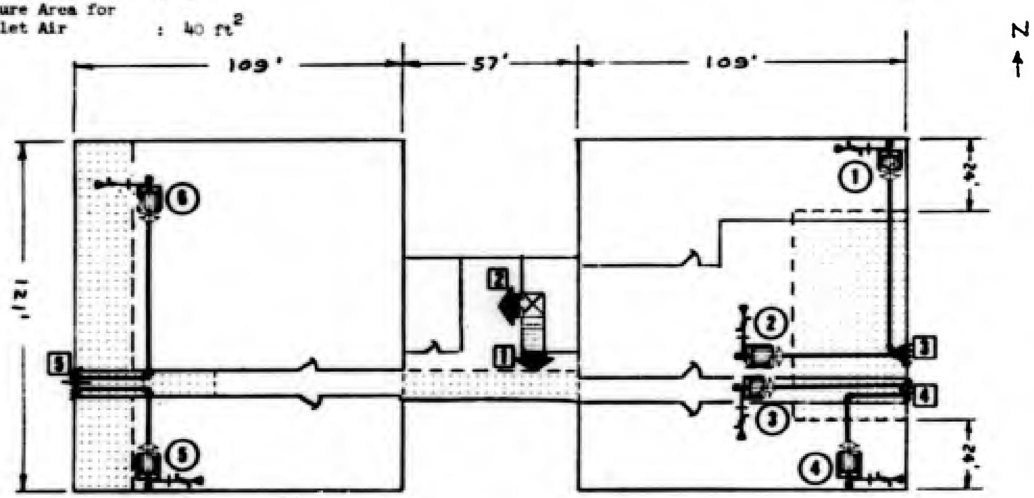
Stairwell Door No. 1		20 sq. ft.
Elevator Door No. 2		20 sq. ft.
Door No. 3		20 sq. ft.
Double Doors No. 4		40 sq. ft.
Double Doors No. 5		40 sq. ft.
Total Aperture Area	=	140 sq. ft.

Double doors Nos. 4 and 5 are considered as large apertures and therefore the aperture areas are as measured from the floor plan (see Section 2.4, Apertures, page 24).

By inspecting the floor plan, the shelter lends itself geometrically to using the centrally located stairwell and elevator shaft for the air source; therefore, the minimum aperture area for getting the air to the shelter is 40 square feet, i.e., 20 square feet each for stairwell No. 1 and elevator door No. 2. The remainder of the apertures can be used for determining the maximum number of ventilators which may be deployed. In this case, two units are attached vertically to door No. 3; and two each can be located horizontally on both double doors Nos. 4 and 5; thus resulting in a maximum of 6 units. As shown in Figure 30, the average equivalent duct length for the 6 units is 85 feet.

In determining the pseudo-equivalent duct lengths, the total air flow (CFM) required was calculated for each of the isoventilation zones based on an occupancy density of 10 square feet per shelteree (see Table XV). The air flow per ventilator was determined simply by dividing the total ventilation requirement by the number of units from the maximum to one, or in this case,

Total Area : 19,344 ft^2
Avg. EDL : 85'
Total Aperture Area : 140 ft^2
Max. No. of Vents : 6
Aperture Area for Inlet Air : 40 ft^2



Equivalent Duct Length of the Systems :

System No.	$L + 50 N_F + 90 N_S$	=	EDL
1	70 + (50)(1) + 0	=	120'
2	40 + 0 + 0	=	40'
3	45 + 0 + 0	=	45'
4	25 + (50)(1) + 0	=	75'
5	50 + (50)(1) + 0	=	100'
6	80 + (50)(1) + 0	=	130'
	Average EDL	=	85'

Inlet Air Aperture Area:
[1] Stairwell Door = 20 sq. ft.
[2] Elevator Door = 20 sq. ft.
Total = 40 sq. ft.

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FN 00260

[ ] Non-Shelter Area

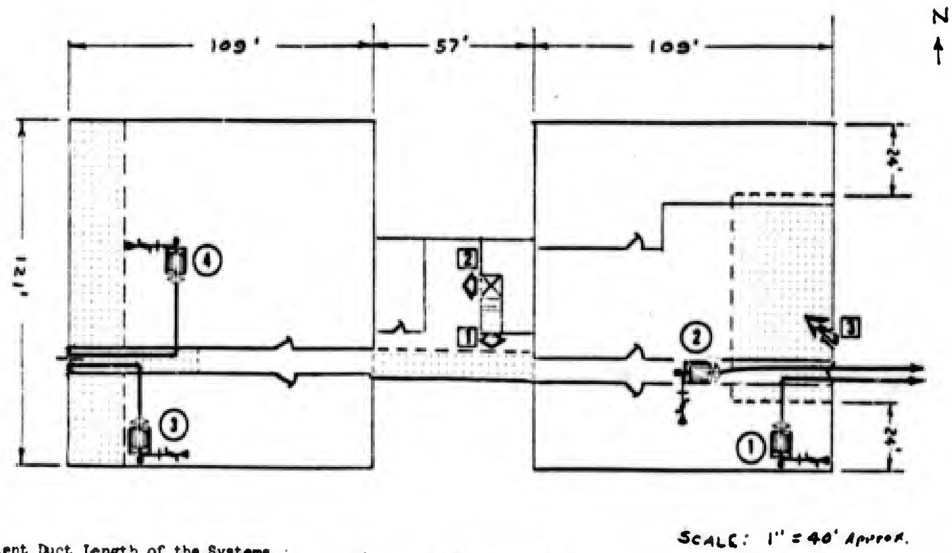
Figure 30 VENTILATION SYSTEM LAYOUTS (FACILITY NO. 148) WHEN THE MAXIMUM NUMBER OF VENTILATORS ARE DEPLOYED

6, 5, 4, 3, 2, and 1. As the number of ventilators is decreased by two in the computer program, the inlet aperture area is increased by 20 square feet, since it is assumed that as two units are removed, an additional 20 square feet of aperture area is available for the inlet air (see Section 2.4, Maximum Number of Ventilators, page 24). As the inlet area increased, the aperture face velocity decreases, therefore resulting in reduced pressure losses (see Equation 14, page 41). Thus, for 4 and 3 units, the ventilation system would be as shown in Figure 31, and 60 square feet of aperture area is used for the air inlet source. The duct layouts for two units might be as shown in Figure 32, although other doors may have been utilized. In this case, 80 square feet of aperture area is available for the air source.

As a result of the optimization program in Section 4, the solution for Facility No. 148, if it were located in the 10 CFM isoventilation zone, is four one-man units with an impeller diameter of 36 inches. This solution is discussed in detail in Section 4.5. From the "surveyor file" of this shelter (see Table XV), it can be seen that the pseudo-equivalent duct length is 99 feet, and since the average equivalent duct length is 85 feet, the dynamic losses are 14 feet of 36 inch diameter duct. The air flow per unit is 4,830 CFM/unit and the aperture (60 sq. ft.) face velocity is 322 feet per minute.

4.2 Ventilation Kit Selections

The "surveyor file" established the pseudo-equivalent duct length for all the diameters in the master list of 28 ventilator designs. For each shelter-part, it is evident that based on performance only, several of the



Equivalent Duct Length of the Systems :

System No.	L + 50 N_F + 90 N_S = EDL
1	50 + (50)(1) + 0 = 100'
2	75 + 0 + 0 = 75'
3	40 + (50)(1) + 0 = 90'
4	30 + (50)(1) + 0 = 80'
	Average EDL = 89'

Inlet Air Aperture Area:

[1]	Stairwell Door	= 20 sq. ft.
[2]	Elevator Door	= 20 sq. ft.
[3]	Door	= 20 sq. ft.
	Total	= 60 sq. ft.

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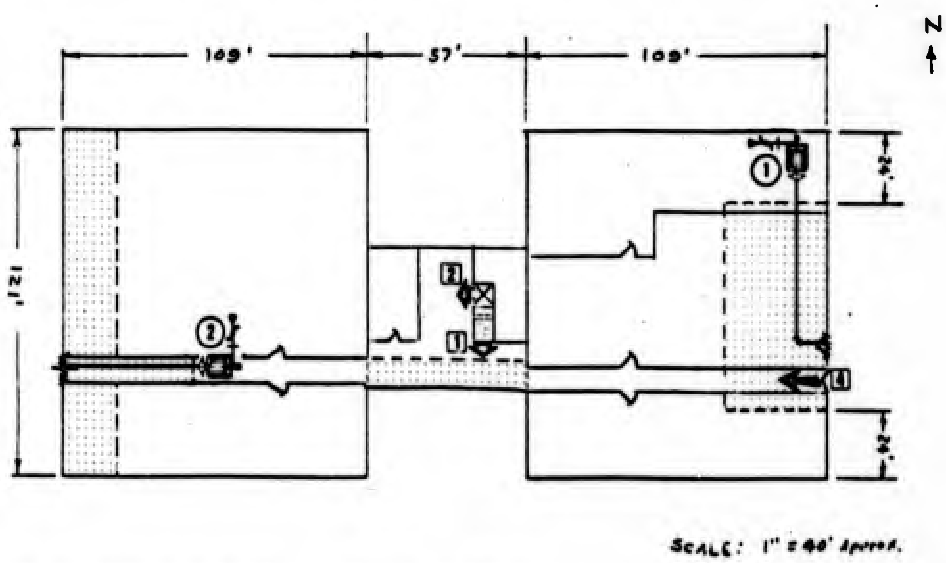
[ ] Non-Shelter Area

Figure 31 FACILITY NO. 148 WITH FOUR VENTILATORS DEPLOYED



Equivalent Duct Length of the Systems :

System No.	L + 50 N_F + 90 N_S = EDL
1	100 + (50)(1) + 0 = 150'
2	50 + 0 + 0 = 50'
	Average EDL = 100'

Inlet Air Aperture Area:

[1]	Stairwell Door	= 20 sq. ft.
[2]	Elevator Door	= 20 sq. ft.
[4]	Double Door	= 40 sq. ft.
	Total	= 80 sq. ft.

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[ ] Non-Shelter Area

Figure 32 FACILITY NO. 148 WITH TWO VENTILATORS DEPLOYED ventilators in the master list would meet the ventilation requirements; however, since cost is a factor it is possible to select the equipment for every shelter that meets or exceeds the ventilation requirements at the lowest cost. On this basis, a computer program was developed for which the input is the shelter characteristics "surveyor file" and the output is the type of equipment and the number of kits required to ventilate the shelter at minimum cost. In storage of the computer is the performance characteristics of each ventilator, the cost of each ventilator kit, and the unit length cost of the duct system. As indicated, the least-cost criterion is used effectively in selecting the best ventilator for each shelter-part, but the minimum total cost varies with each changing group of ventilators considered. Starting with the master list of 28 fans, the equipment computer program produced solutions for each isoventilation zone as if the 175 RTI sample shelter-parts were located therein. The frequency of occurrence of the 28 units was summarized and the results were tabulated in Table XVI. Based on the frequency of occurrence, all but the 10 most called-out ventilators were eliminated. Those retained from the master list of 28 had a frequency of occurrence greater than 100. By repeating the process for the 10 remaining ventilators, the distribution of chosen ventilator designs is as given in Table XVI.

For the 10 remaining ventilators, it was decided to eliminate arbitrarily one ventilator in each of the low, moderate, and high capacity ranges. Therefore, the three eliminated ventilators were the 1E-1624-4, the 2R-3627-4, and the 368-36-3. The performance curves for the remaining seven ventilators

TABLE XVI SCREENED VENTILATOR DESIGNS FOR THE RTI SAMPLE SHELTERS

Master List of Impellers	Nomenclature	Selected from List of 28 Fans: 7.5 CFM/OCC	10 CFM/OCC	15 CFM/OCC	20 CFM/OCC	25 CFM/OCC	30 CFM/OCC	40 CFM/OCC	50 CFM/OCC	TOTAL SELECTED	Selected from List of 10 Fans: 7.5 CFM/OCC	10 CFM/OCC	15 CFM/OCC	20 CFM/OCC	25 CFM/OCC	30 CFM/OCC	40 CFM/OCC	50 CFM/OCC	TOTAL SELECTED
1	BC 1220 1220	60	39	25	13	5	7	0	0	149	60	39	25	13	5	7	0	0	149
2	1B-1624-4	61	32	26	15	15	7	7	0	163	61	32	25	16	15	7	7	0	163
3	1P-1816-4	9	7	3	8	2	3	5	0	37									
4	1B-2024-4	58	91	58	52	20	13	8	7	307	67	93	63	58	22	16	13	7	339
5	2B-2024-4	0	0	0	0	0	0	0	0	0									
6	4B-2024-4	0	0	0	0	0	0	0	0	0									
7	1B-2224-4	7	1	0	1	1	0	1	0	11									
8	2B-2224-4	1	1	7	2	1	6	2	0	20									
9	4B-2224-4	0	1	0	3	2	1	5	0	12									
10	1B-2424-4	18	30	23	15	9	11	4	5	115	24	41	34	18	11	13	5	5	151
11	2B-2424-4	9	0	2	0	1	2	0	0	14									
12	4B-2424-4	0	9	3	5	1	0	0	6	24									
13	1B-2624-4	6	16	10	7	9	5	2	0	55									
14	2B-2624-4	4	8	10	12	2	6	8	1	51									
15	4B-2624-4	0	0	4	8	0	3	4	1	20									
16	1B-3020-4	11	12	14	19	10	6	3	8	83									
17	2B-3020-4	10	4	21	3	0	8	8	4	58									
18	4B-3020-4	0	8	9	17	14	6	8	4	66									
19	1B-3627-4	71	88	208	132	110	84	42	23	658	88	112	123	157	129	95	46	33	783
20	2B-3627-4	12	17	52	47	100	54	52	34	368	34	30	88	61	104	77	67	39	500
21	4B-3627-4	0	20	19	26	34	87	73	72	331	2	38	36	62	50	94	93	87	462
22	185-18-1/3	0	0	0	0	0	0	0	0	0									
23	247-24-1/2	0	0	0	0	0	0	0	2	2									
24	280-27-1	2	0	[illegible]	33	46	62	50	20	256	2	0	29	41	54	64	50	30	270
25	281-27-1-1/2	0	2	0	4	11	2	4	6	29									
26	329-38-2	0	0	2	9	14	16	35	19	95									
27	368-36-3	2	1	5	33	38	32	69	126	306	2	3	14	42	51	48	99	141	400
28	375-36-5	0	1	1	5	27	64	51	54	203	0	1	1	5	27	64	57	58	213

Note: See Table XIV for impeller nomenclature.

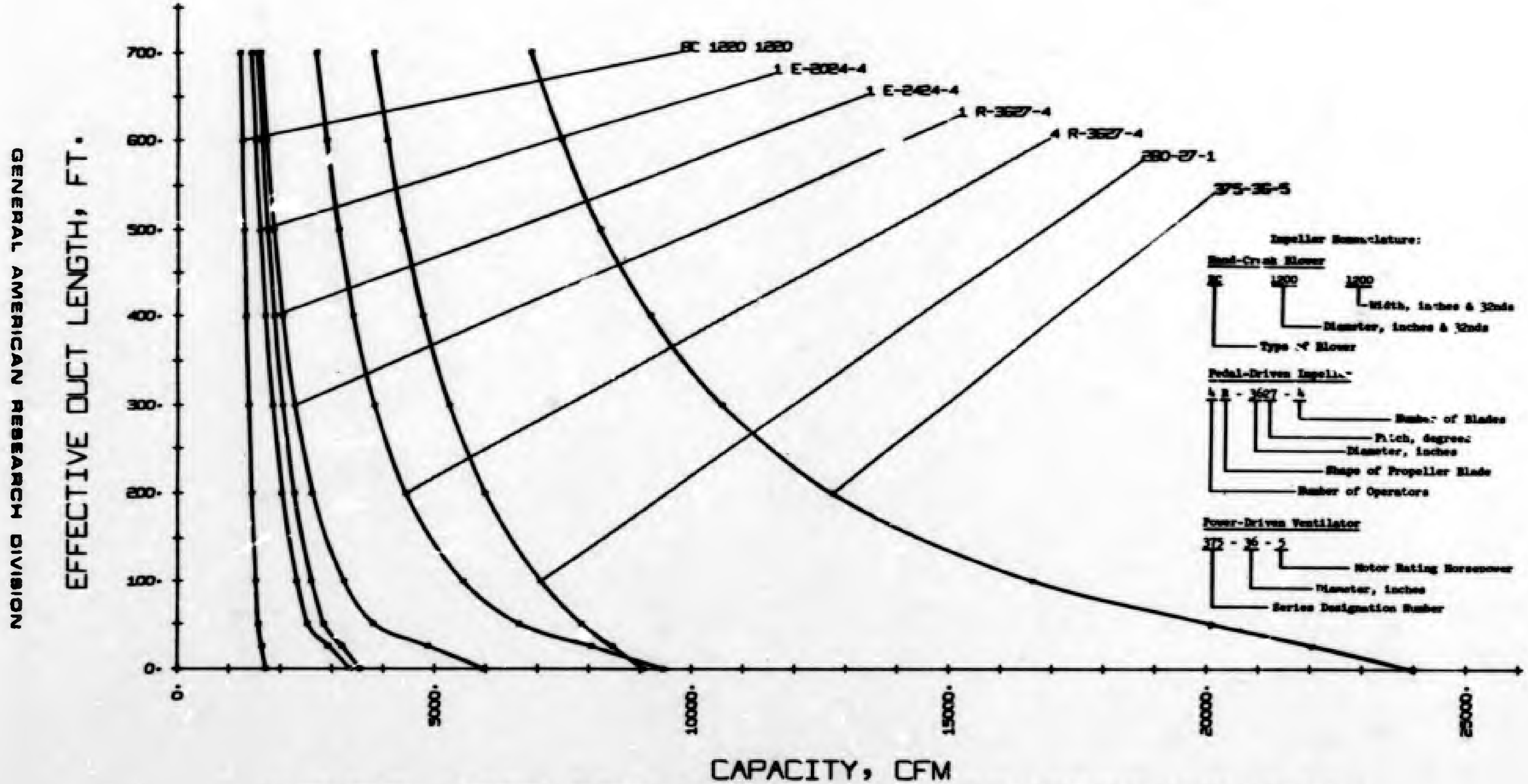
are given in Figure 33, and these ventilators were used in selecting the optimum number of shelter ventilation kits for the NFSS basement shelters without any human factors considerations.

In this study, ventilator designs were not mixed for each shelter-part. By varying kits within a shelter-part it is possible to reduce the cost for the ventilation equipment further; however, it is felt that the deployment instructions required with many types of kits for each shelter-part would be unnecessarily complicated. However, this study allowed mixing of ventilator designs from story to story, and for shelter-parts of a story level. The human factors studies (Ref. 6) should include these possibilities in determining the minimum shelteree instructions required.

4.3 National Predictions

Thus far, the selection of ventilators was made by applying the RTI surveyed shelters to the performance of impellers and selecting the ventilator designs by cost for each RTI sample shelter. Using the count of facilities classified into ventilation zones (see Section 2.2), and the ratio of 1.115 shelter-parts per facility in the survey (see Section 2.3), predictions using the RTI survey to provide the statistics can be made as to the shelter-parts ventilated and the total cost of the ventilators necessary to stock the NFSS facilities.

Table XVII shows the predictions for the identified 138,261 basement shelters when considering stocking 28, 10, and 7 ventilation kits. As an example, consider the 20 CFM/occupant listings in Table XVII. Provided the motor-driven ventilators are available, it is possible to ventilate 169 of



VENTILATOR PERFORMANCES FOR OPTIMIZATION

NOTE: Refer to Appendix D for the speed performance curves of the above impellers.

Figure 33 PERFORMANCE CURVES FOR THE SEVEN VENTILATORS USED IN THE OPTIMIZATION PROGRAM

TABLE XVII COST AND VENTILATION COOLING COVERAGE ESTIMATES FOR THE NFSS SHELTERS

RTI SHELTER SAMPLES							NFSS PHASE 2 BELOW-GRADE SHELTERS					28 VENTILATOR KITS			10 VENTILATOR KITS			7 VENTILATOR KITS		
												RTI SAMPLE SHELTER			RTI SAMPLE SHELTER			RTI SAMPLE SHELTER		
VENTILATION ZONE (CFM/OCC)	TOTAL SHELTER-PARTS	SHELTER-PARTS VENTILATED	% SHELTER-PARTS VENTILATED	TOTAL PEOPLE	PEOPLE VENTILATED	% PEOPLE VENTILATED	TOTAL FACILITIES (SEE SEC. 2.2)	ESTI-MATED TOTAL SHELTER-PARTS	TOTAL PEOPLE	PREDICTED NUMBER OF SHELTER-PARTS VENTILATED	PREDICTED NUMBER OF PEOPLE IN THESE SHELTERS	TOTAL COST, $	$/SHELTER-PART	PREDICTED COST FOR NFSS SHELTERS (MILLIONS $)	TOTAL COST, $	$/SHELTER-PART	PREDICTED COST FOR NFSS SHELTERS (MILLIONS $)	TOTAL COST, $	$/SHELTER-PART	PREDICTED COST FOR NFSS SHELTERS (MILLIONS $)
7.5	175	174	99.4	135,338	124,838	92.2	17,611	19,636	10,659,595	19,518	9,528,147	27,924	132	2.571	23,706	136	2.474	26,101	150	2.928
10	175	173	98.8	135,338	122,638	90.6	89,439	99,724	51,000,513	96,527	46,206,465	30,740	178	17.507	32,174	186	18.324	34,149	197	19.449
15	175	172	98.2	135,338	121,838	90.0	22,520	25,110	12,158,375	24,658	10,942,.38	51,269	298	7.350	52,516	305	7.529	58,983	343	8.456
20	175	169	96.5	135,338	118,623	87.6	4,760	5,307	3,553,507	5,121	3,112,890	74,145	439	2.247	77,376	459	2.351	84,155	498	2.790
25	175	169	96.5	135,338	118,623	87.6	1,602	1,786	1,067,035	1,723	934,723	102,929	609	1.049	103,584	613	1.056	113,443	671	1.157
30	175	166	94.8	135,338	109,326	80.7	1 .19	1,694	573,902	1,606	463,439	128,091	772	1.239	130,460	786	1.262	130,983	788	1.286
40	175	155	88.5	135,338	89,231	65.9	619	690	544,049	611	424,428	141,150	911	0.556	145,164	937	0.572	156,452	1,009	0.617
50	175	148	84.5	135,338	82,339	60.9	191	213	168,480	180	109,610	164,172	1,096	0.197	165,645	1,119	0.201	179,177	1,211	0.218
						TOTALS	138,261	154,160	79,895,485	151,944 (98.6%)*	72,014,940 (90.2%)*			32.716			33.954			36.647

NOTE: *Percentages shown above are based on the estimated total number of shelter-parts and the total number of people.

the 175 RTI sample shelter-parts, or 96.5 percent of the total. This coverage corresponds to 87.6 percent (118,623) of the maximum occupancy loading of 135,338 people. From NFSS, Phase 2, it was determined that in the 20 CFM/occupant ventilation zone, 4760 facilities exist, accommodating 3,553,527 people. Applying the 1.115 shelter-parts per facility, it is estimated that 5,307 shelter-parts would result. Since the sample predicts 96.5 percent of the shelter-parts would be ventilatable, 5,121 shelter-parts are predicted as ventilatable in the 20 CFM/occupant zone. Similarly, since 87.6 percent of the people are in the ventilated shelters, it is predicted that 3,112,890 people would be in the ventilated shelters in the 20 CFM/occupant zone.

To ventilate the 175 RTI sample shelter-parts at 20 CFM per person with ventilator choices from the 28 screened master ventilators the cost would be $74,145 or $439 per shelter-part. Since there are 5,121 predicted NFSS shelter-parts ventilatable, the cost of ventilation equipment for the NFSS shelters is 2.247 million dollars. If the ventilator choices were made from the listing of the 10 best fans, the predicted cost of ventilation equipment would be 2.351 million dollars, the difference in cost being the result of eliminating 18 units from the choices of ventilators available, thus resulting in some shelters with a ventilation system that over-ventilates the shelter. If the ventilator choices are further reduced to seven ventilators, the predicted total cost would be 2.550 million dollars.

The predictions are made for all ventilation zones and the totals show that out of 138,261 facilities or 154,160 shelter-parts, 98.6 percent of the shelter-parts are ventilatable. The spaces available in these shelters are

90.2 percent (72,014,940) of the maximum possible (79,824,485). When the selections are made from 28, 10 and 7 ventilators, the total estimated cost for ventilation equipment is 32.7, 33.9 and 36.6 million dollars, respectively. For seven ventilators, the estimated cost is only 3.9 million dollars more than when 28 units are possible; therefore, it is of definite advantage to reduce the number of kits in an operational system to no more than seven, and possibly less.

4.4 Final Ventilator Kit Selections

Two approaches were considered for the final kit selections. One approach assumed a power unit would be feasible, and the other considered the power unit not to be feasible.

4.4.1 Operational Manual and Power Systems

Although our costs include a power generating unit, we have considered utilizing either a 36-inch diameter, 5 horsepower (HP) unit and a 27-inch diameter, 1 HP unit. The significance of the 1 HP unit is that the unit could be operated on a 115 volt, 15 ampere circuit in a building, while the 5 HP unit would require a 240 volt, 3-phase, power source. The smaller unit could therefore be operated in most buildings with commercially available power at some reduced system reliability. With the 5 HP unit, 90.2 percent of the identified spaces could be ventilated, as compared to 83.7 percent if the 1 HP unit is the largest in inventory (see Table XVIII). For further analysis, we have assumed a generator set would be stocked, and therefore the 5 HP unit would be available. Table XVIII summarizes the best six, five, four, three, and two kits. These selections were determined by eliminating

TABLE XVIII OPTIMA VENTILATORS WITH POWER AVAILABLE

MAX. SIZE UNIT	5 HP, 36-INCH DIAMETER						1 HP, 27"DIA.	UNITS TO KEEP WHEN INCLUDING THE MIL-V-40645 IMPELLER
NOMENCLATURE	7 UNITS	6 UNITS	5 UNITS	4 UNITS	3 UNITS	2 UNITS	6 UNITS	
BC 1220 1220	33,739	33,739					33,739	
1E-2024-4 (see Note 1)	52,319	52,319	86,058	93,785			52,319	93,785
1E-2424-4	47,817	47,817	47,817				47,817	
1R-3627-4	123,482	123,482	123,482	160,921	250,745	250,743	123,482	160,921
4R-3627-4	59,019	61,813	61,813	61,813	61,811		59,019	
280-27-1	7,947						7,956	
375-36-5	9,483	13,151	13,151	13,151	13,152	41,679		41,679
TOTAL NUMBER OF VENTILATORS	333,806	332,321	332,321	329,670	325,708	292,422	324,332	296,385
TOTAL COST	$36.664 M	$37.593 M	$37.890 M	$38.326 M	$40.534 M	$50.729 M	$29.528 M	$48.521 M
NUMBER OF SHELTER PARTS	151,944 (98.6%)	151,944 (98.6%)	151,944 (98.6%)	151,944 (98.6%)	151,944 (98.6%)	151,944 (98.6%)	146,987 (95.3%)	151,944 (98.6%)
NUMBER OF PEOPLE	72,014,940 (90.2%)	72,014,940 (90.2%)	72,014,940 (90.2%)	72,014,940 (90.2%)	72,014,940 (90.2%)	72,014,940 (90.2%)	66,825,132 (83.7%)	72,014,940 (90.2%)

NOTES: (1) Impeller selected for the MIL-V-40645 20-Inch Diameter "Package Ventilation Kit".
(2) Percentages are based on the estimated total number of shelter-parts (154,160) and the total number of people (79,825,485).

the unit which would result in the minimum rise of the total system cost. For all combinations of the six power units, the least total cost results when the 1 horsepower unit is eliminated. Further reductions down to five and four units eliminates the hand-crank BC 1220 1220 unit and the 1-man, 24-inch diameter ventilator at a slight increase in total cost. Eliminating the 20-inch diameter kit, as described by Specification MIL-V-40645, increases the total equipment cost from 38.326 to 40.534 million dollars; however, reducing the number of units from three to two results in a significant cost increase as illustrated by Figure 34. Therefore we recommend three kits for deployment throughout the NFSS shelters; however, human factors must also be considered before making the final choice of units.

If the present ventilation kit as described by Specification MIL-V-40645 is retained with the 5 HP unit, the most economical third unit would be the 1R-3627-4 at a total cost of 48.5 million dollars. This approximately 8 million dollar increase over the three units is felt to be sufficient to eliminate the idea of basing the choice of units around the MIL-V-40645 PVK. If it is desirable to retain the MIL-V-40645 PVK, it is recommended that four kits be stocked. Four kits compared to the three kits would result in saving 2.2 million dollars.

4.4.2 Operational Manual Systems

As indicated in Table XIX, the shelter coverage reduces significantly when eliminating the power units from the system. Roughly, 82 percent of the identified spaces would be adequately ventilated; however, the best five kits would cover 93.6 percent of the identified shelter-parts at an estimated cost

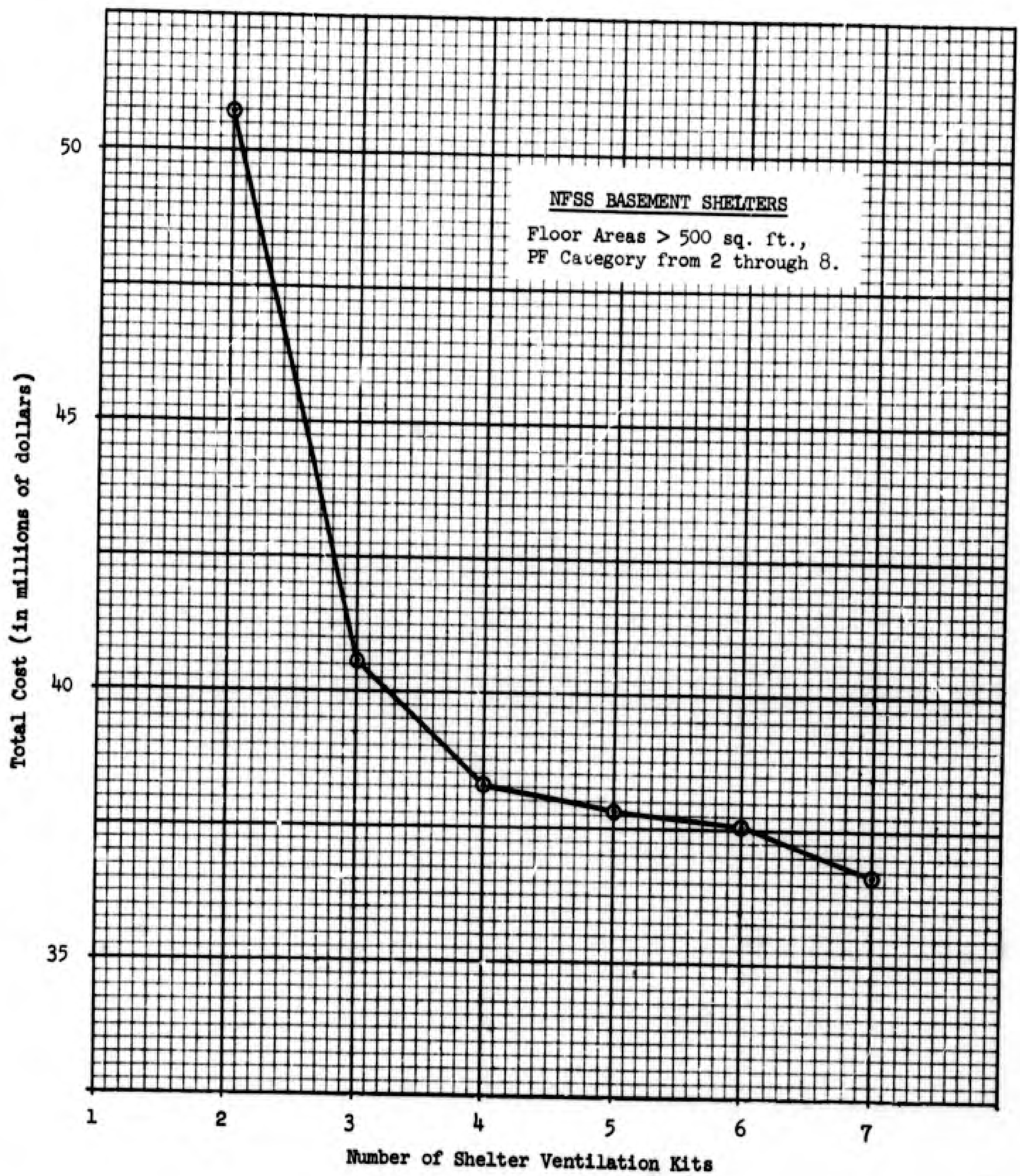


Figure 34 TOTAL COST OF VENTILATION KITS WITH A POWER UNIT AVAILABLE

TABLE XIX OPTIMA VENTILATORS WITHOUT POWER AVAILABLE

NOMENCLATURE	5 UNITS	4 UNITS	3 UNITS	2 UNITS
BC-1220-1220	33,739			
1E-2024-4 (see Note 1)	52,319	86,058	93,785	
1E-2424-4	47,817	47,817		
1R-3627-4	123,482	123,482	160,921	250,743
4R-3627-4	61,813	61,813	61,813	61,813
TOTAL NUMBER OF VENTILATORS	319,170	319,170	316,519	312,556
TOTAL COST	$27.689 M	$27.986 M	$28.422 M	$30.630 M
NUMBER OF SHELTER-PARTS	144,258 (93.5%)	144,258 (93.5%)	144,258 (93.5%)	144,258 (93.5%)
NUMBER OF PEOPLE	65,353,075 (81.9%)	65,353,075 (81.9%)	65,353,075 (81.9%)	65,353,075 (81.9%)

NOTES: (1) Impeller selected for the MIL-V-40645 20-Inch Diameter "Package Ventilation Kit".
(2) Percentages are based on the estimated total number of shelter-parts (154,160) and the total number of people (79,825,485).

of 27.7 million dollars. Reducing the number of kits from five to four and three, increases the cost slightly to 28.0 and 28.4 million dollars, respectively. We recommend stocking the 1R-3627-4 and the 4R-3627-4 kits. These units will provide ventilation for an estimated 65,353,075 people at an estimated cost of 30.6 million dollars. Significantly, the same manual units are optimum for either a manual or power-manual system. In no case will a power unit be used in a shelter if it is possible to ventilate the shelter with the largest capacity manual unit available.

4.5 Sample Problem

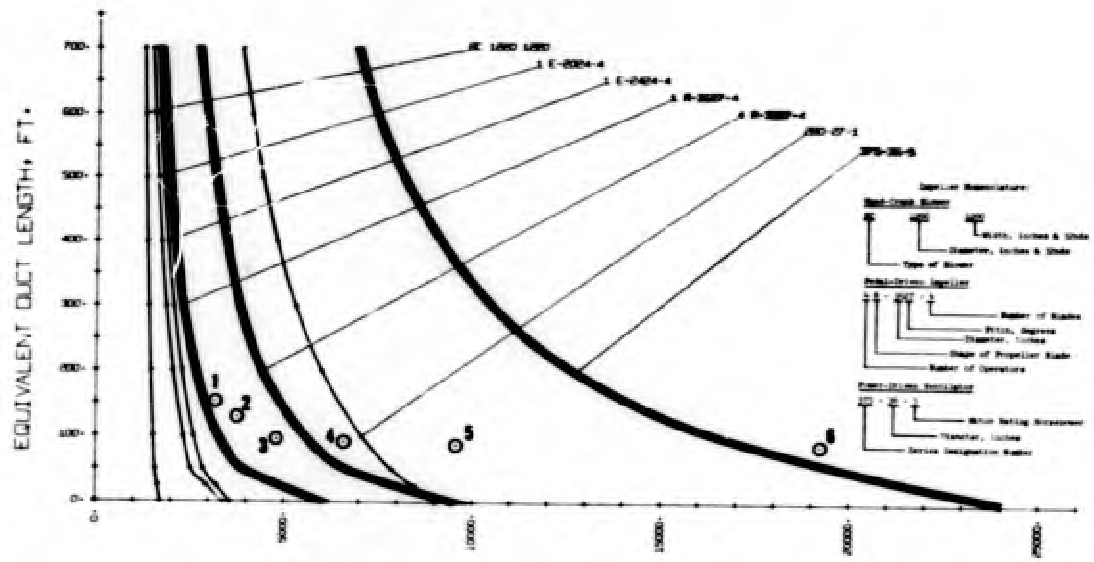
RTI sample Facility No. 148 has been selected to illustrate the selection of at least cost equipment based on (1) the shelter characteristics discussed in detail in Section 4.1, (2) the availability of the suggested 1R-3627-4, 4R-3627-4, and 375-36-5 kits, and (3) a ventilation requirement of 10 cfm per occupant. The solution is summarized in Figure 35, and as shown, the pertinent shelter characteristics have been abstracted from Table XV. Also the performance of the three units has been reproduced from the curves for the best seven units, Figure 33.

Overlaying the shelter characteristics on the performance curves for the units, the proper unit can be selected, and with the unit costs available, each candidate system cost can be calculated and the least cost system identified. For example, if a system in which four ventilators are considered, each unit must move at least 4,830 cfm of air at an external resistance to air flow equivalent to 99 feet of 36-inch diameter polyethylene duct. As shown on the performance curves, the unit which meets this requirement is the 4R-3627-4 kit. Four of these kits with only 85 feet of duct, supplied with each kit, costs $720.26 (kit costs include one elbow). This solution is the least cost system. The next least expensive system requires five 4R-3627-4 kits at an increase in cost of 33 percent. Other solutions, and the cost for the systems, are summarized in the table in Figure 35. As noted, no single unit can meet the shelter system requirements.

SHELTER CHARACTERISTICS

VENTILATION ZONE	TOTAL CFM REQ'D	AVG. DUCT LENGTH (ft)	NUMBER OF OPENINGS	VELOCITY (fpm)	CFM/UNIT	PSEUDO-EQUIVALENT DUCT SYSTEM 36-Inch Diameter System	SYSTEM NO. INDICATED BELOW
10 CFM/OCC	19,300	85	6	483	3,220	151	1
			5	483	3,860	132	2
			4	322	4,830	99	3
			3	322	6,440	93	4
			2	241	9,670	87	5
			1	241	19,300	66	6

EQUIPMENT CHARACTERISTICS



NOTE: The heavy performance curves represent the best three ventilation kits.

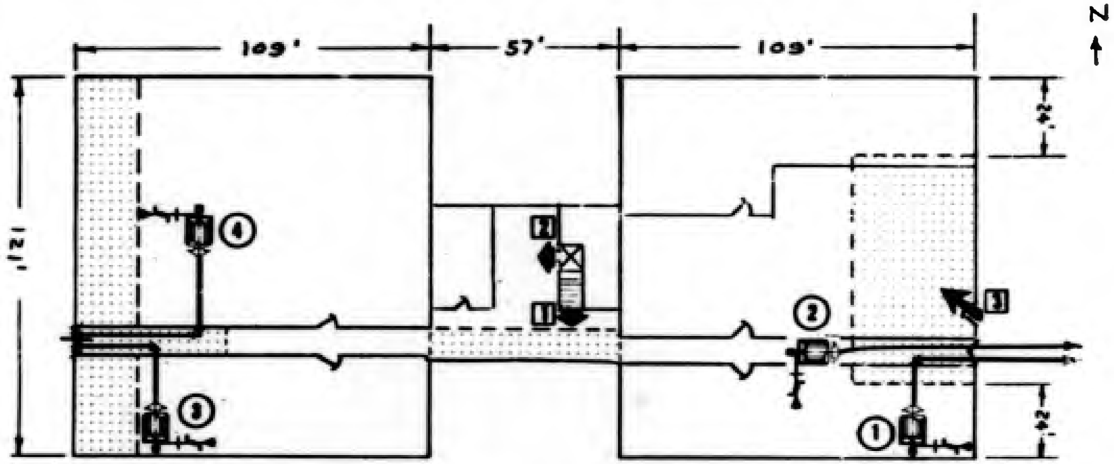
EQUIPMENT ANALYSIS AND SELECTION OF THE LEAST-COST SYSTEM

SYSTEM NO. AND NUMBER OF UNITS	CFM/UNIT	EQUIVALENT DUCT LENGTH	VENTILATOR SELECTION	COST OF SYSTEM*
1	19,300	85	Not Possible	--
2	9,670	87	375-36-5	$ 1,498.13
3	6,440	93	375-36-5	2,247.19
4	4,830	99	4R-3627-4	720.26 ⇐ LEAST COST SYSTEM
5	3,860	132	4R-3627-4	1,000.32
6	3,220	151	4R-3627-4	1,080.38

*For equipment cost, see Table XI, page

1R-3627-4	$73/Kit
4R-3627-4	$176/Kit
375-36-5	$745/Kit
Duct Cost	$5.06/100 feet

EQUIPMENT AND DUCT SYSTEM LAYOUT



SCALE: 1" = 40' Approx.

Equivalent Duct Length of the Systems*:

System No.	$L + 50\,N_F + 90\,N_S = EDL$
1	50 + (50)(1) + 0 = 100'
2	75 + 0 + 0 = 75'
3	40 + (50)(1) + 0 = 90'
4	30 + (50)(1) + 0 = 80'
	Average EDL = 89'

*Equation 7, page 38.

Inlet Air Aperture Area:

1 Stairwell Door = 20 sq. ft.
2 Elevator Door = 20 sq. ft.
3 Door = 20 sq. ft.
Total = 60 sq. ft.

RTI Facility No. 148

College Union Building
University of South Florida
Tampa, Florida

SL 3261-0065
FN 00260

Non-Shelter Area

Figure 35 Sample Problem for Facility No. 148

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SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

The Office of Civil Defense had developed a method of placing the manual 1- and 2-module, 20-inch diameter units (described by Specification MIL-V-40645) in basement shelters. This method (Ref. 27) essentially states that each room shall be stocked with one or more units. The number of ventilators required depends on the size of the room, length of the duct required to exhaust the air from the unit to the outside, and the geographic location of the facility. Using this concept, it was found that insufficient stairwells, elevator shafts, windows, and other exterior apertures were available to supply and exhaust air for the RTI sample shelters. Therefore, using this method would result in stocking shelters with equipment that cannot ventilate the shelters as intended. The original OCD format for data collection is excellent; however, the method should be upgraded to include other capacity ventilators, as well as an entry for apertures available for each facility. To illustrate the need for other size units, the MIL-V-40645 PVK, 1- and 2-module units were applied to the RTI sample shelters according to the techniques described in Section 2. The results showed that 122,669 shelter-parts or 79.6 percent of the total number of shelter-parts can be adequately ventilated (see Table XX). These shelters cover 55.6 percent of the maximum number of shelter spaces available.

The shelter ventilation equipment optimization study presented in this report provides the means for selecting from 28 ventilator designs the best ventilators to ventilate the NFSS below-grade fallout shelters. When power is available from an auxiliary engine-generator set, we suggest the

TABLE XX COMPARISON OF SHELTER COOLING SYSTEMS

VENTILATION ZONE (see Figure 5)	PARAMETER	MIL-V-40645 20-Inch PVK (1-& 2-Module Units)		AIR COOLING SYSTEMS ONLY Without Power Units (see Table XIX)		AIR COOLING SYSTEMS ONLY With Power Units (see Table XVIII)	
7.5 CFM/OCC	Shelter-Parts People	17,869 8,143,931	(91.0%) (76.4%)	19,067 9,508,359	(97.1%) (89.2%)	19,518 9,828,147	(99.4%) (92.2%)
10 CFM/OCC	Shelter-Parts People	84,765 30,855,310	(85.0%) (60.5%)	96,234 44,676,449	(96.5%) (87.6%)	98,527 46,206,465	(98.8%) (90.6%)
15 CFM/OCC	Shelter-Parts People	16,070 4,474,282	(64.0%) (36.8%)	22,097 8,377,120	(88.0%) (68.9%)	24,658 10,942,538	(98.2%) (90.0%)
20 CFM/OCC	Shelter-Parts People	2,654 767,562	(50.0%) (21.6%)	4,246 1,950,886	(80.0%) (54.9%)	5,121 3,112,890	(96.5%) (87.6%)
25 CFM/OCC	Shelter-Parts People	661 128,044	(37.0%) (12.0%)	1,214 470,562	(68.0%) (44.1%)	1,723 934,723	(96.5%) (87.6%)
30 CFM/OCC	Shelter Parts People	491 42,469	(29.0%) (7.4%)	996 218,083	(58.8%) (38.0%)	1,606 463,139	(94.8%) (80.7%)
40 CFM/OCC	Shelter-Parts People	131 21,898	(19.0%) (3.4%)	327 127,522	(47.4%) (19.8%)	611 424,428	(88.5%) (65.9%)
50 CFM/OCC	Shelter-Parts People	28 2,587	(13.0%) (1.5%)	77 24,094	(36.0%) (14.3%)	180 102,610	(84.5%) (60.9%)
TOTAL	Number of Shelter Parts	122,669	(79.6%)	144,258	(93.6%)	151,944	(98.6%)
TOTAL	Number of People	44,436,023	(55.6%)	65,353,075	(81.9%)	72,014,940	(90.2%)

NOTE: Percentages are based on the estimated total number of shelter-parts (154,160) and the total number of people (79,825,485).

1-man, 36-inch diameter Unitary Ventilator; the 4-man, 36-inch diameter Modular Unit; and the 5 horsepower, 36-inch diameter Power Unit. These units are illustrated in Figure 36, and will provide ventilation for an estimated 98.6 percent of the identified basement shelter-parts (see Tables XX and XXI). The shelters will accommodate an estimated 72,014,940 people or 90.2 percent of the maximum number of people which could be sheltered at a floor loading of 10 square feet per person. The cost for the equipment

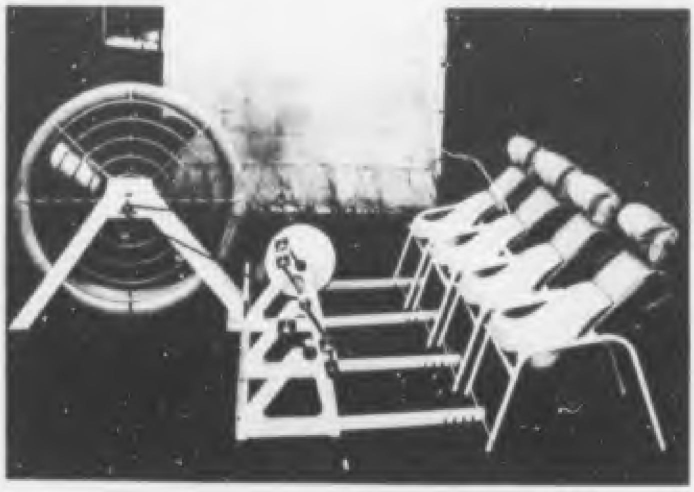
TABLE XXI

SUMMARY OF THE RECOMMENDED VENTILATOR KITS FOR THE NFSS BASEMENT SHELTERS

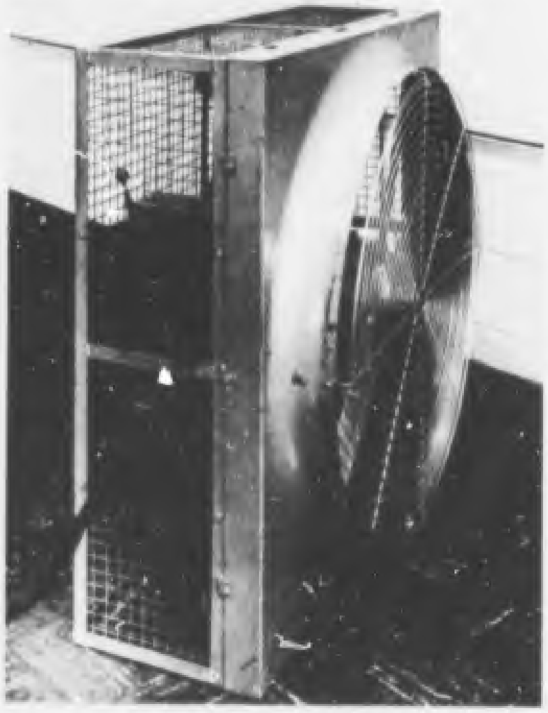
Type of System	Manually-Driven Ventilators	Manually- and Electric Motor-Driven Ventilators
Percentage of Estimated Shelter-Parts which can be ventilated	93.5%	98.6%
Percentage of the Maximum Number of People who can be protected with increased ventilation	81.9%	90.2%
Recommended Number of Kits	2	3
Style of Ventilators with Estimated Number of Kits Required	1R-3627-4: 250,743 4R-3627-4: 61,813	1R-3627-4: 250,745 4R-3627-4: 61,811 375-36-5: 13,152
Estimated Cost for Equipment, (dollars in millions)	$ 30.630	$ 40.534
Per Capita Cost for the Equipment	$0.47	$0.56

*Costs do not include the expense for the survey, selection of equipment, warehousing, instructions, and freight.

UNITARY VENTILATOR
(1R-3627-4)



4-MAN MODULAR UNIT
(4R-3627-4)



POWER UNIT
(375-36-5)

Figure 36 RECOMMENDED VENTILATOR KITS WHEN A POWER UNIT IS USED to ventilate these shelters is estimated at 40.5 million dollars or 56 cents per person. This dollar value does not include the expense of the survey, selection of equipment, instructions, warehousing, and freight.

If manual units only are feasible, the suggested kits are again the 1R-3627-4 Unitary Ventilator, and the 4R-3627-4 four-man Modular Unit. These units will provide ventilation for an estimated 81.9 percent of the maximum number of people which could be sheltered in the 138,261 identified NFSS basement facilities. As indicated in Section 3.3.3, further research* is required to determine the minimum requirement for stowing engine-generator sets, and how often they should be exercised.

During the program it was learned that large capacity units were required in order to get reasonable ventilation coverage when considering all of the NFSS basement shelters. This means that many rooms in these shelters are covered by one ventilator, and therefore the deployment of the ventilators will always significantly affect the distribution of air throughout the shelters. Since the air distribution within the shelters is highly dependent upon the placement of the ventilators, the geometry of the shelter, and the occupancy density throughout the shelter, it may be necessary to selectively seal doors and apertures, and intentionally put holes of various sizes in the interior partitions. Additional studies are necessary to define the minimum shelter air distribution requirements, and to determine if additional distribution devices and instruments (such as the punkah or a baffle kit and dry-bulb thermometers) should be incorporated into the system. Baffles, with the proper instructions, can be used very effectively to control the flow of

*OCD Notice: A Final Report, "Deterioration of Fuels and Fuel-Using Equipment" prepared under SRI Subcontract No. B-70922(4949A-27)-US, OCD Work Unit 1413A, has recently been published by Battelle Memorial Institute.

air throughout a shelter. Dry-bulb temperature is an excellent guide in establishing the air distribution within the shelter for the actual distribution of metabolic and internal heat loads. For example, when the air flow is insufficient to various rooms or corridors in the shelter, the dry-bulb temperature will be one of the maximum recorded, and the effective temperature would exceed 85°F. This condition is represented by Rooms 4 and 5 in Figure 37. If all the rooms had the design quantity of air for an outside design condition as indicated on the psychrometric chart, all rooms for an adiabatic shelter would reach a common dry-bulb temperature on the 85°F effective temperature line. Without controlling the air distribution, we feel a good percentage of the air will in effect by-pass the shelter or in other words, go through and leave at the inlet condition. If this occurs to any extent, the conditions within the shelter cannot be kept within survival limits.

As shown in the program and system operational flow diagram in Figure 2, page 5, the authors have indicated a detailed shelteree instruction format. After the shelter has been surveyed and the equipment selected, the units must be deployed by the shelter analyst on the floor plans which were prepared at the time of the survey. Prior to shipment of the kits from the warehouse to the shelters, the detailed floor plan (deployment instructions), photographs of typical duct system (duct system fabrication instruction), and assembly and operating instruction for the kit must be attached to the packages. This sequence of preparing and handling the instruction material was caused by the difficulty experienced in instructing people to deploy the units with generalized instructions. The procedure outlined above is only intended as a guideline for the human factors studies which are being performed under OCD Work Unit 1522A (Ref. 6). On the floor plans of the RTI sample shelters in

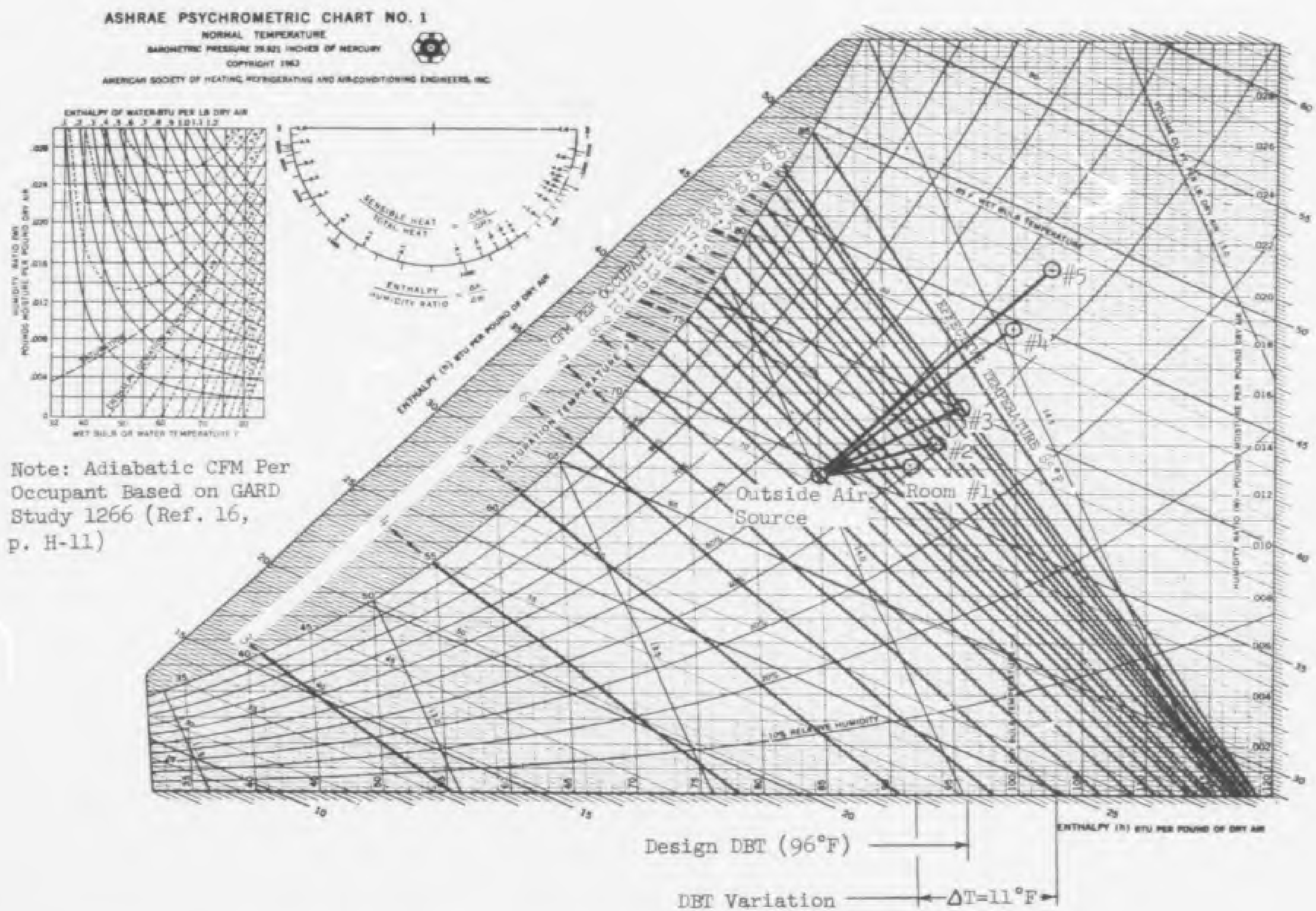


Figure 37 ILLUSTRATION OF TEMPERATURE VARIATION DUE TO POOR AIR DISTRIBUTION

Appendix B, we have shown the least cost operational systems for a ventilation requirement of 10 cfm per occupant. We choose this ventilation requirement since the majority require 7-1/2 and 10 cfm per person. Only 20 percent of the NFSS shelters require an air quantity greater than 10 cfm per person (see Figure 6, page 13). These layouts have been reproduced primarily to visually aid further engineering analysis and human factors research.

If the ventilators can be deployed for the system approach described herein, and if air distribution within a shelter is not a problem, it is recommended that the three optimum shelter ventilation kits presented herein and the approach described be adopted and implemented. A statement-of-work to complete this effort is as follows:

I. Develop Shelter Ventilation Kits

a. Fabricate and mechanically/structurally test the ventilators.

b. Test the impeller-shroud assembly per AMCA Bulletin 210 or NEMA Standards FM 1-7.02 to determine the performance rating for each unit.

c. Prepare production drawings and specifications for each kit.

II. Performance of Plastic Tubing

Determine the resistance to air flow offered by 36-inch diameter plastic tubing.

III. Instructions

a. Prepare the "Ventilation Kit" Data Collection Form and the survey instructions.

b. Prepare the Automatic Data Processing (ADP) computer program for selecting the choice of ventilator and number of kits required for each shelter-part surveyed.

c. Complete shelteree instructions.

For an operational system, which is shown shaded in Figure 2, the question arises as to what steps should be followed to fabricate and eventually stock the shelters with these ventilators. Two basic philosophies of stocking procedure are possible, i.e., fabricating the shelter ventilation kits based on predictions before the shelters are surveyed, or surveying the shelters and then fabricating the actual number of units required. For either method of stocking shelters, a survey of the shelters is required. As noted by the schematic diagram, the survey data may be used to update the estimated total cost for ventilation equipment.

Procurement of ventilation kits before any survey of the shelters is initiated can be accomplished using the estimates presented in this report. As the survey of shelters progresses, the results can be used to improve the estimates of each type of ventilation kit required. Excess and deficit inventory can then be fed back to the Defense Supply Agency, Civil Defense Material Division, so that the number of kits procured can be modified based on the predictions. If the survey of shelters is accomplished before procurement of the kits, Path "B" in Figure 2 would be followed. As the survey is performed, the shelter descriptor data are processed to select the kits for each shelter. When sufficient shelters have been surveyed and analyzed, the required number of each kit can be procured.

If the problems of shelteree instructions and air distribution within a shelter cannot be adequately overcome, refrigeration systems for maintaining survival conditions within the NFSS basement shelters should be investigated. We suspect that each room of reasonable size would require a dehumidifier (see Figure 38), and the energy would be rejected to a heat

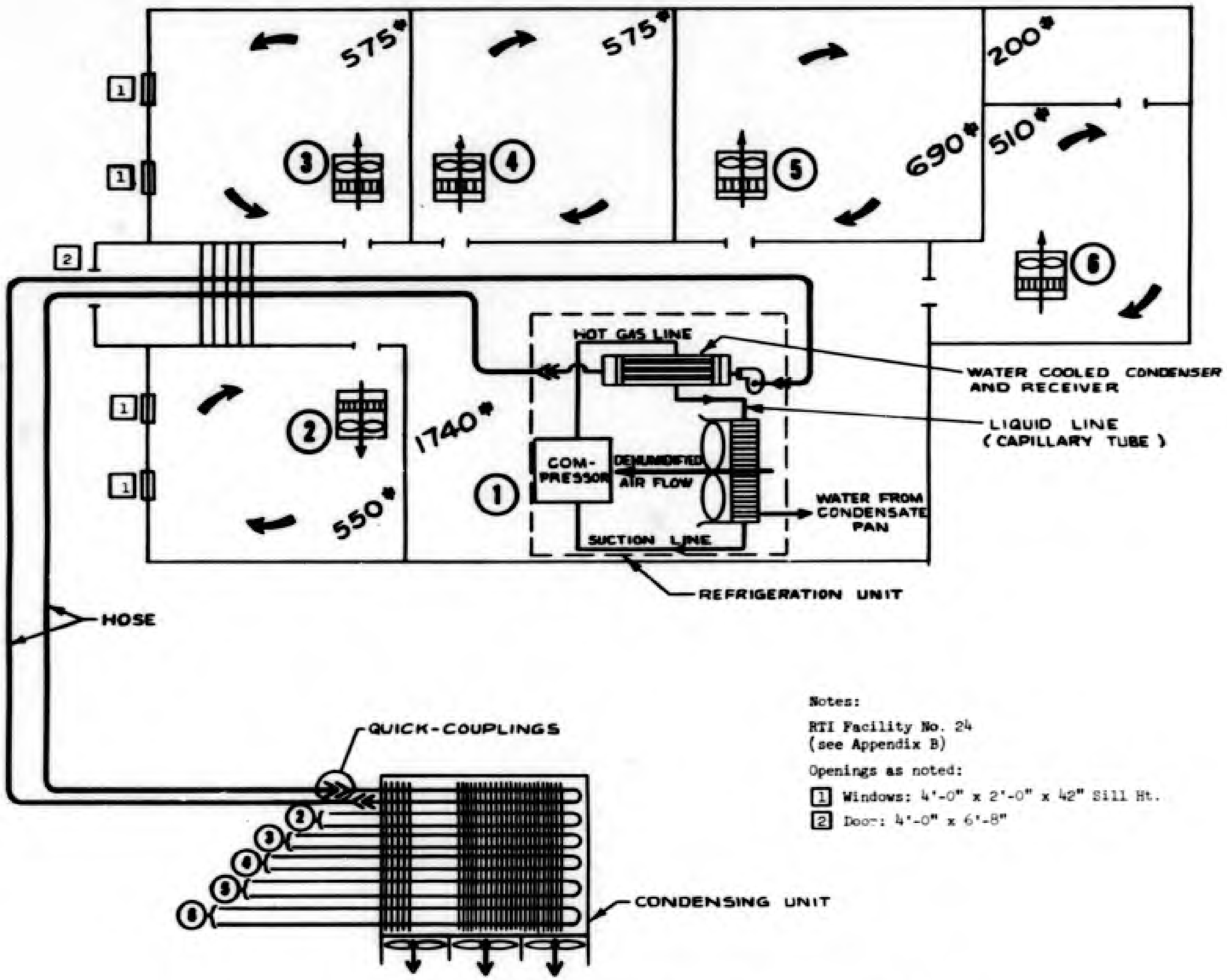


Figure 38 REFRIGERATION SYSTEM CONCEPT

exchanger remote from the shelter. Flexible hoses could be utilized to connect the water-cooled condenser of the refrigeration unit and the cooling tower. The remote heat exchanger, as noted in Figure 38, might accommodate more than one "room unit". This type of equipment, which requires generalized instructions, would be used to minimize temperature gradients throughout the shelter. A refrigeration system would have an air system, sized at 3 cfm per occupant, to control the carbon dioxide concentration in the shelters.

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APPENDIX A

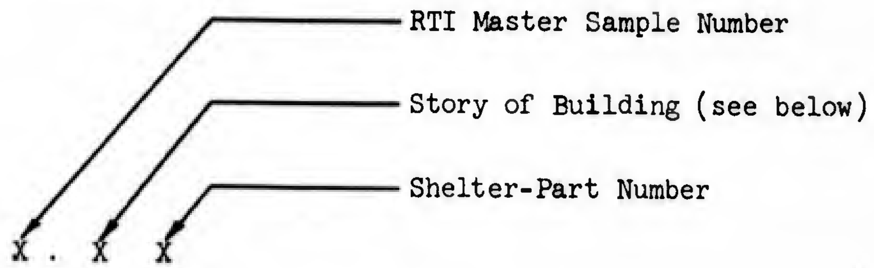
SUMMARY OF SHELTER DESCRIPTORS

FOR THE

RTI SAMPLE SURVEY

FOREWORD TO APPENDIX A

Shelter Identification Code:



Story:

-2	=	2nd Sub-basement
-1	=	1st Sub-basement
0	=	Basement
1	=	1st Floor
2	=	2nd Floor

NOTES:

(1) All shelters are basements unless indicated otherwise, and in all cases for which there is only one shelter-part, the "0" is not indicated.

(2) Floor plans for each RTI sample shelter are presented in Appendix B.

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SHLTR IDENT	TOTAL AREA (FT2)	AVG. DUCT LENGTH (FT)	TOTAL OPNG AREA (FT2)	MAX NMBR OF OPNGS	MIN INLET OPNG AREA (FT2)
1	2344.	2.	139.	2	119.
2	1620.	185.	32.	1	22.
3	1720.	2.	107.	2	87.
4.01	972.	320.	13.	1	3.
4.02	988.	320.	13.	1	3.
5	1540.	70.	40.	2	20.
6	8585.	2.	70.	2	50.
7	8050.	2.	80.	2	60.
8	9308.	2.	120.	2	100.
9	3485.	20.	40.	2	20.
10	3348.	2.	57.	2	37.
11	3400.	2.	84.	2	68.
12	3302.	270.	70.	1	60.
13	4325.	2.	90.	2	52.
14	2442.	70.	215.	2	140.
15	7114.	2.	126.	4	86.
16	19286.	2.	610.	4	570.
17	768.	2.	100.	2	56.
18	67360.	2.	250.	18	70.
19	6110.	250.	60.	2	40.
20	13741.	50.	324.	6	160.
21	7473.	70.	255.	5	175.
22	2865.	435.	108.	2	64.
23	1552.	150.	48.	2	22.
24	4840.	185.	52.	2	32.

SHLTR IDENT	TOTAL AREA (FT2)	AVG. DUCT LENGTH (FT)	TOTAL OPNG AREA (FT2)	MAX NMBR OF OPNGS	MIN INLET OPNG AREA (FT2)
25	1600.	235.	20.	1	10.
26	3175.	2.	40.	2	20.
27	610.	210.	32.	1	16.
28	610.	155.	84.	1	64.
29	436.	25.	60.	2	40.
30	2476.	70.	84.	1	72.
31	1141.	2.	110.	2	70.
32	840.	125.	29.	1	20.
33	870.	2.	72.	2	46.
34	2498.	125.	100.	2	80.
35	3830.	2.	136.	2	85.
36	445.	195.	38.	2	20.
37	17206.	75.	200.	5	100.
38	1790.	295.	30.	1	20.
39	1105.	2.	40.	2	20.
40	7252.	70.	190.	4	110.
41.01	2010.	2.	80.	2	20.
41.02	1600.	2.	76.	2	16.
42	8934.	70.	688.	8	428.
43	2775.	2.	110.	2	55.
44	3600.	2.	130.	2	75.
45.01	3150.	2.	60.	2	40.
45.02	1005.	250.	20.	1	10.
46	9415.	85.	80.	4	40.
47	655.	70.	80.	2	40.

SHLTR IDENT	TOTAL AREA (FT2)	AVG. DUCT LENGTH (FT)	TOTAL OPNG AREA (FT2)	MAX NMBR OF OPNGS	MIN INLET OPNG AREA (FT2)
48	18431.	20.	260.	8	180.
49	11425.	50.	60.	4	20.
50	4813.	60.	195.	2	120.
51	44282.	30.	150.	12	30.
52	7022.	30.	80.	4	40.
53	6543.	140.	44.	2	24.
54	8602.	35.	80.	4	40.
55	4130.	70.	155.	3	120.
56	68506.	60.	235.	14	95.
57	3924.	2.	152.	4	90.
58	728.	70.	18.	1	9.
59	11105.	70.	339.	6	250.
60	4370.	95.	70.	2	50.
61	2360.	70.	46.	2	20.
62	2835.	2.	310.	2	210.
63	3870.	70.	347.	4	140.
64	1344.	2.	140.	2	70.
65	1450.	2.	67.	2	47.
66	3540.	125.	60.	2	20.
67	1575.	115.	40.	2	20.
68	1910.	225.	50.	2	30.
69	16000.	140.	125.	4	65.
69.-1	4738.	125.	40.	2	20.
70	586.	130.	40.	2	20.

SHLTR IDENT	TOTAL AREA (FT2)	AVG. DUCT LENGTH (FT)	TOTAL OPNG AREA (FT2)	MAX NMBR OF OPNGS	MIN INLET OPNG AREA (FT2)
71	1220.	20.	30.	2	18.
72	828.	340.	80.	2	60.
73	3132.	105.	60.	2	40.
74	5974.	2.	200.	4	140.
75	3920.	145.	40.	2	20.
76	14380.	90.	80.	3	50.
77	18000.	70.	80.	6	20.
78	1648.	355.	20.	1	10.
79.01	1525.	330.	20.	1	10.
79.02	1125.	295.	44.	2	24.
80	3194.	365.	20.	1	10.
81	1520.	85.	40.	2	20.
82	3821.	2.	100.	4	60.
83	720.	2.	80.	2	50.
84	1090.	70.	46.	2	20.
85	3157.	300.	22.	1	12.
86	640.	2.	120.	2	60.
87	716.	365.	20.	1	10.
88	13200.	2.	140.	4	100.
89.-1	20000.	80.	250.	16	90.
89.-2	41460.	2.	290.	18	110.
189	15900.	2.	210.	12	90.
90	21289.	200.	320.	5	155.
91	13849.	55.	210.	6	138.
92	11531.	90.	250.	6	135.

SHLTR IDENT	TOTAL AREA (FT2)	AVG. DUCT LENGTH (FT)	TOTAL OPNG AREA (FT2)	MAX NMBR OF OPNGS	MIN INLET OPNG AREA (FT2)
93	4520.	85.	100.	4	60.
940	4800.	2.	60.	2	40.
94.-1	4800.	2.	100.	4	60.
95	14645.	190.	155.	4	115.
96	3000.	70.	50.	1	40.
97	4285.	2.	55.	2	35.
98.-1	6100.	70.	60.	2	40.
99	8000.	450.	20.	1	10.
100	4760.	85.	140.	2	120.
101	7800.	240.	120.	2	100.
102	4590.	400.	120.	3	90.
104	8883.	200.	120.	4	80.
105	4090.	350.	100.	3	70.
106	4664.	2.	208.	2	188.
107.01	5320.	70.	100.	4	60.
107.02	2220.	345.	20.	1	10.
107.03	770.	230.	20.	1	10.
108.01	14560.	2.	320.	6	260.
108.02	14000.	180.	240.	6	180.
109	10074.	60.	160.	4	120.
110.01	13843.	70.	880.	4	600.
110.02	898.	90.	220.	2	120.
111	19475.	70.	210.	8	100.
112	700.	345.	35.	2	20.
113	14302.	30.	170.	6	110.

SHLTR IDENT	TOTAL AREA (FT2)	AVG. DUCT LENGTH (FT)	TOTAL OPNG AREA (FT2)	MAX NMBR OF OPNGS	MIN INLET OPNG AREA (FT2)
114	1000.	2.	38.	2	10.
115	11452.	120.	185.	4	145.
116	1798.	2.	76.	2	52.
117	6047.	90.	80.	2	60.
118	3410.	2.	245.	2	130.
119	2125.	350.	20.	1	10.
120	1706.	75.	40.	2	20.
121	21068.	2.	40.	2	20.
122	15186.	2.	185.	6	125.
123	5565.	280.	20.	1	10.
124	1450.	255.	20.	1	10.
125	2424.	70.	47.	2	23.
126	5978.	175.	80.	2	60.
127	10702.	250.	180.	6	120.
128	1290.	330.	20.	1	10.
129	7636.	2.	60.	2	40.
129.-1	1436.	80.	40.	2	20.
130	22000.	300.	38.	2	18.
131.01	1757.	70.	78.	2	60.
131.02	450.	105.	140.	3	110.
132	4369.	90.	120.	2	80.
133	6548.	50.	250.	4	100.
134.01	3916.	70.	172.	2	100.
134.02	1600.	240.	40.	2	20.
134.03	978.	55.	60.	2	40.

SHLTR IDENT	TOTAL AREA (FT2)	AVG. DUCT LENGTH (FT)	TOTAL OPNG AREA (FT2)	MAX NMBR OF OPNGS	MIN INLET OPNG AREA (FT2)
135	6335.	2.	965.	4	875.
136	9792.	100.	100000.	6	400.
137	1365.	320.	32.	2	12.
138	2766.	70.	255.	3	175.
139	774.	30.	68.	4	28.
140	636.	500.	20.	1	10.
141	5039.	35.	130.	4	70.
142	1500.	250.	40.	1	30.
143	3925.	2.	40.	2	20.
144	880.	250.	40.	2	20.
145.01	5900.	250.	72.	2	45.
145.02	4000.	160.	72.	2	45.
146	5500.	300.	20.	1	10.
147.01	5421.	50.	305.	4	165.
147.02	1029.	235.	20.	1	10.
148	19344.	85.	140.	6	40.
149	6759.	70.	300.	4	170.
150	24122.	70.	1640.	20	800.
151	105000.	800.	480.	10	380.
152	16923.	2.	285.	10	185.
153	14400.	2.	180.	8	100.
154	15534.	185.	140.	8	60.
155	9704.	60.	120.	8	40.
156	10826.	85.	290.	4	100.
157	45712.	2.	840.	16	400.
158	3700.	220.	115.	3	70.

APPENDIX B

RTI SAMPLE FACILITIES

WITH

MANUAL AND POWER EQUIPMENT

AND DUCT SYSTEMS

SHOWN FOR THE

10 CFM PER OCCUPANT VENTILATION ZONE

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FOREWORD TO APPENDIX B

This appendix presents the floor plans for the random sample of 160 below-grade shelters as identified and surveyed by the Research Triangle Institute (Ref. 17). Presented on these floor plans are typical ventilation systems for a cooling requirement of 10 cfm per occupant. The solutions shown are for the shelter descriptors summarized in Appendix A, and assumes that the power unit is available. The ventilator symbols used are indicated on the opposite page. Other codes used on the floor plans are as follows:

STANDARD LOCATION CODE (SL)

Order of Digits
1234 5678

1000 0000 OCD-OEP Region 1

The first digit identifies the OCD and OEP Region by number, 1 through 8.

1600 0000 NEW YORK

The second digit identifies a State, the District of Columbia or a non-state area overseas within an OCD-OEP Region by the numbers, 1 through 9, or the letter A. Numbers are assigned in alphabetical sequence of the States (including D. C.) followed by non-state areas with the letter A being used only for the Virgin Islands.

16L0 0000 **JEFFERSON-LEWIS COUNTY AREA, N. Y.

The third digit, a numeral or a letter, identifies an area within a State. Standard Metropolitan Statistical Areas (SMSAs) are assigned the numbers 1 through 9 plus the letters A through F, except Texas which has SMSAs through L. All SMSAs are identified by a single asterisk (*). Special Groupings of Counties (OEP study areas of one to six counties) are assigned the letters G through Q, except for Texas which are M through U. All Special Groupings of Counties are identified by a double asterisk (**). The counties making up the grouping title are listed alphabetically in the title. Residual Groupings of Counties are assigned the letters R through Z, except Texas which are V through Z. All Residual Groupings of Counties are identified by a triple asterisk (***). These Residual Groupings of Counties are named by their location in the State.

16L2 0000 LEWIS COUNTY, NEW YORK

The fourth digit, a numeral or a letter, identifies the county; a parish in Louisiana; an independent city in Maryland, Virginia and Missouri; a part of a county in New England; or, in the non-state areas, those areas that are equivalent to counties.

16L2 0002 DENMARK TOWN

The fifth through the eighth digits identify the Standard Locations. They represent a Census Tract, a Ward, one or more enumeration districts in a city, one to several minor civil divisions or census county divisions, or a small city or town in rural areas.

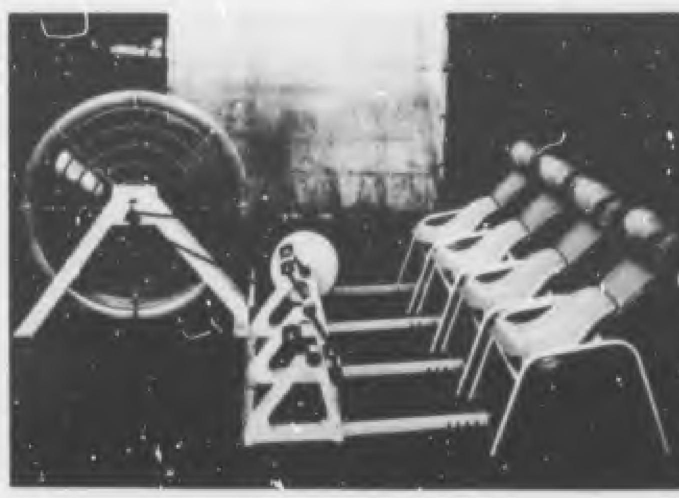
FACILITY NUMBER CODE (FN)

Facility five digit serial number identifying each facility and listed in ascending sequence for each contract. Facility numbers are not duplicated within any contract code number. The left-hand digit (ten thousands space) is marked in accordance with the Facility Number Code.

- 0 - Facilities not coded below
- 1 - U. S. Army - open
- 2 - U. S. Army - sensitive
- 3 - U. S. Navy - open
- 4 - U. S. Navy - sensitive
- 5 - U. S. Air Force - open
- 6 - U. S. Air Force - sensitive
- 7 - AEC, NASA, NSA - open
- 8 - AEC, NASA, NSA - sensitive
- 9 - Other Federal Government - sensitive

UNITARY VENTILATOR
(1R-3627-4)

4-MAN MODULAR UNIT
(4R-3627-4)

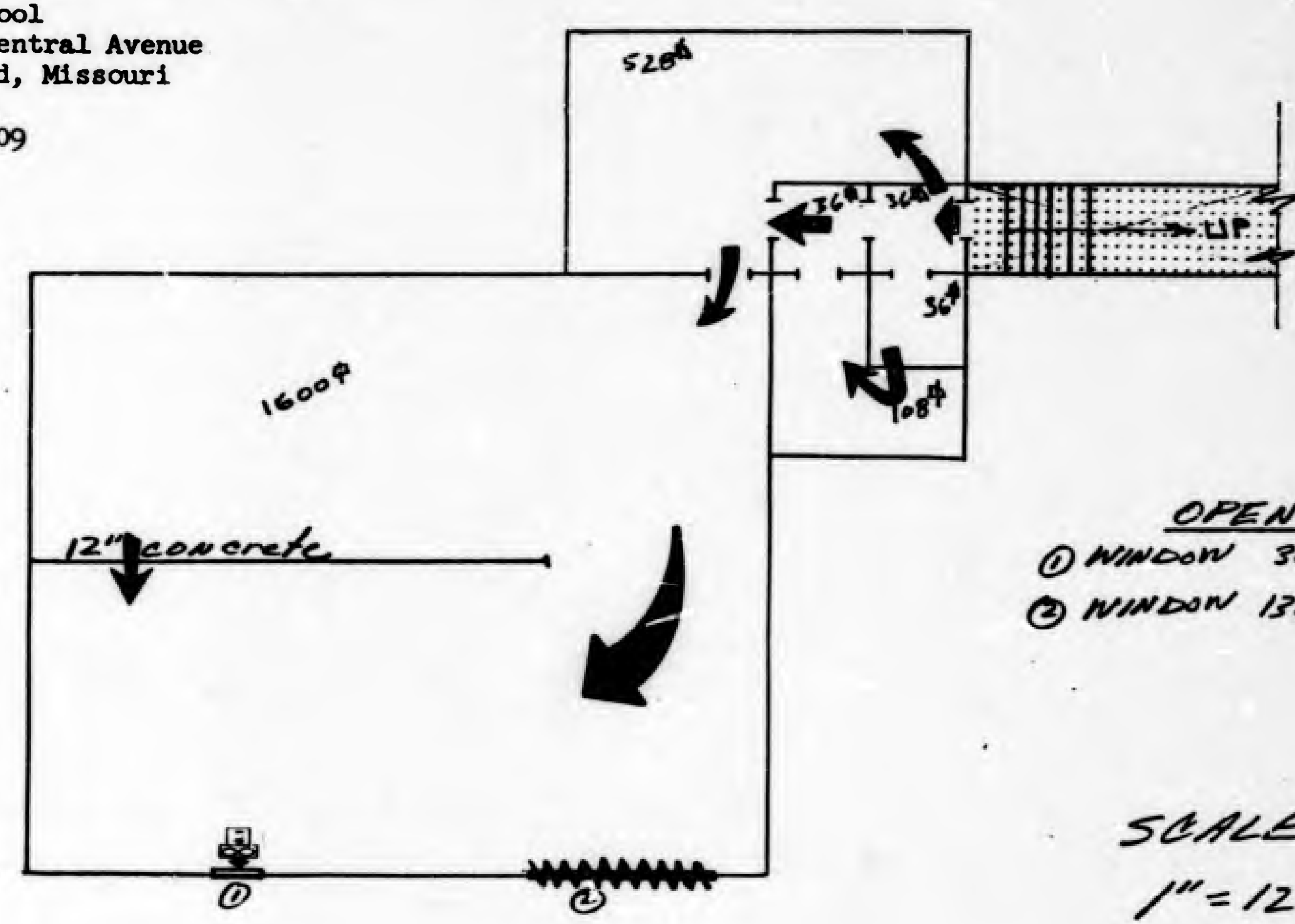


POWER UNIT
(375-36-5)

RTI Facility No. 1

Bailey School
501 West Central Avenue
Springfield, Missouri

SL 6441-0009
FN 02810



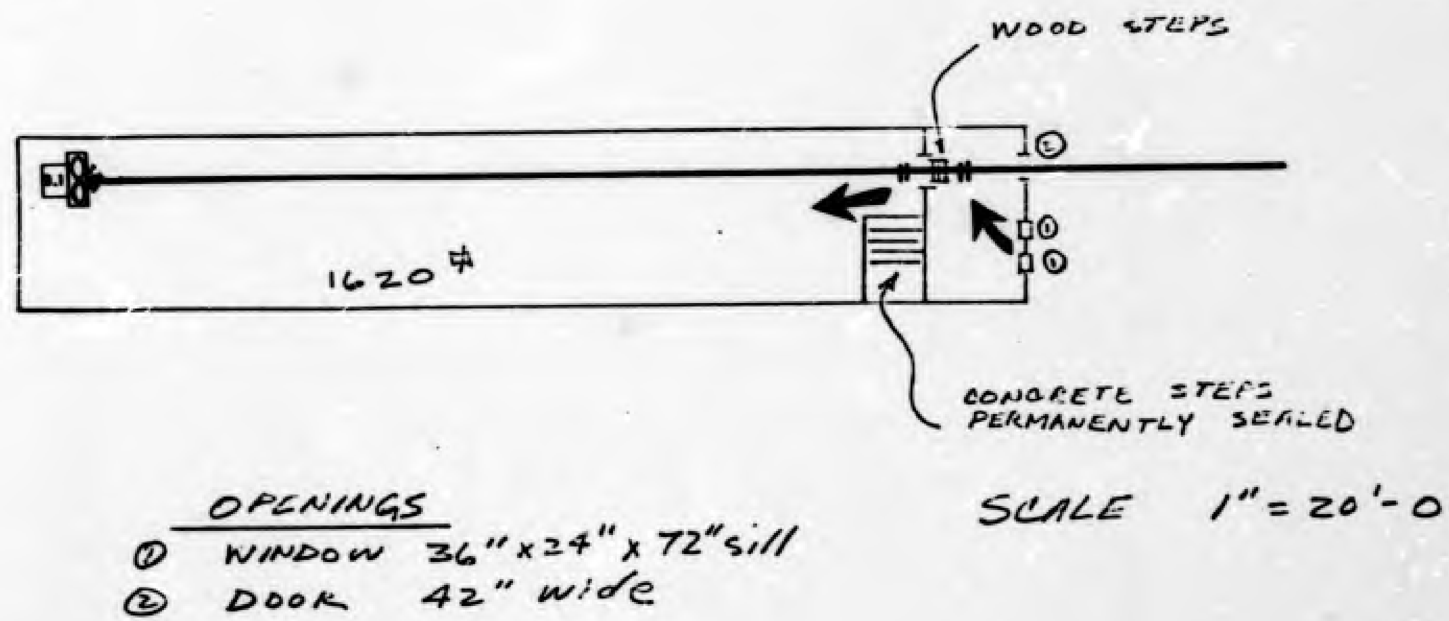
OPENINGS
① WINDOW 36"x36"x120" SILL
② WINDOW 132"x120"x24" SILL

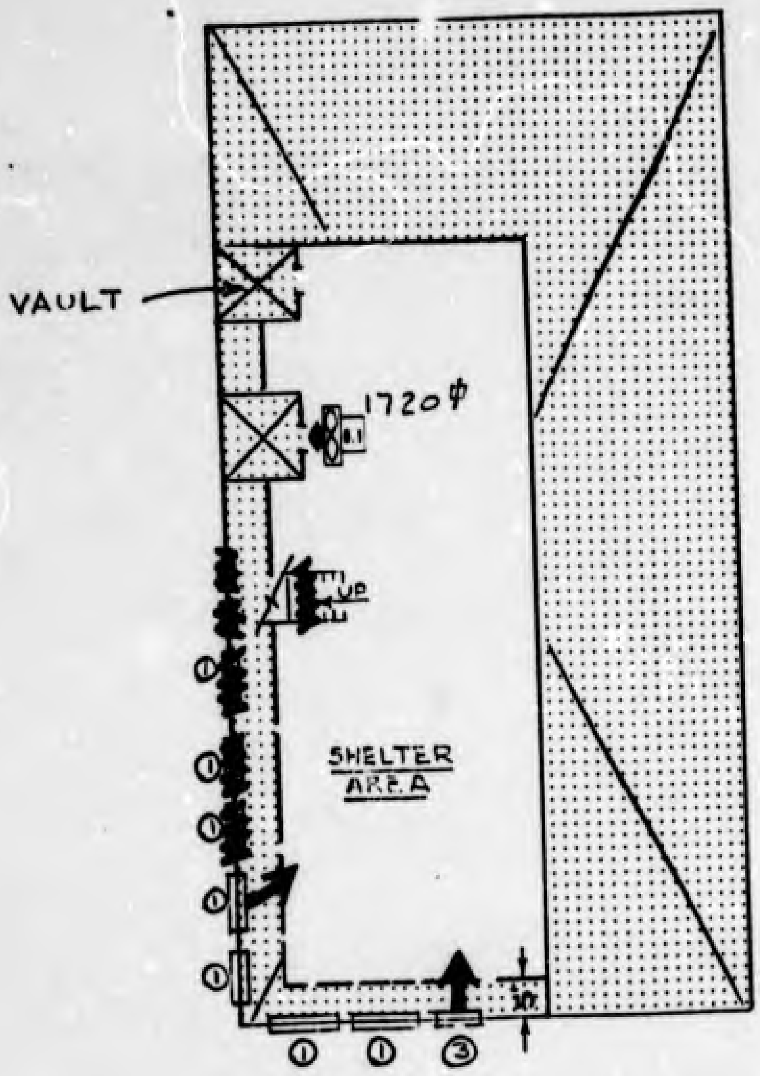
SCALE
1" = 12'-0

RTI Facility No. 2

Cannon Shoe Store
155 Public Square
Springfield, Missouri

SL 6441-0014
FN 03308





OPENING SIZES

① 4'-8" WIDE, 1'-9" HIGH, 5'-7" SILL
② 27" x 24" x 5'-7" SILL
③ 3'-9" x 1'-9" x 5'-7" SILL

SCALE: 1" = 20'

RTI Facility No. 3

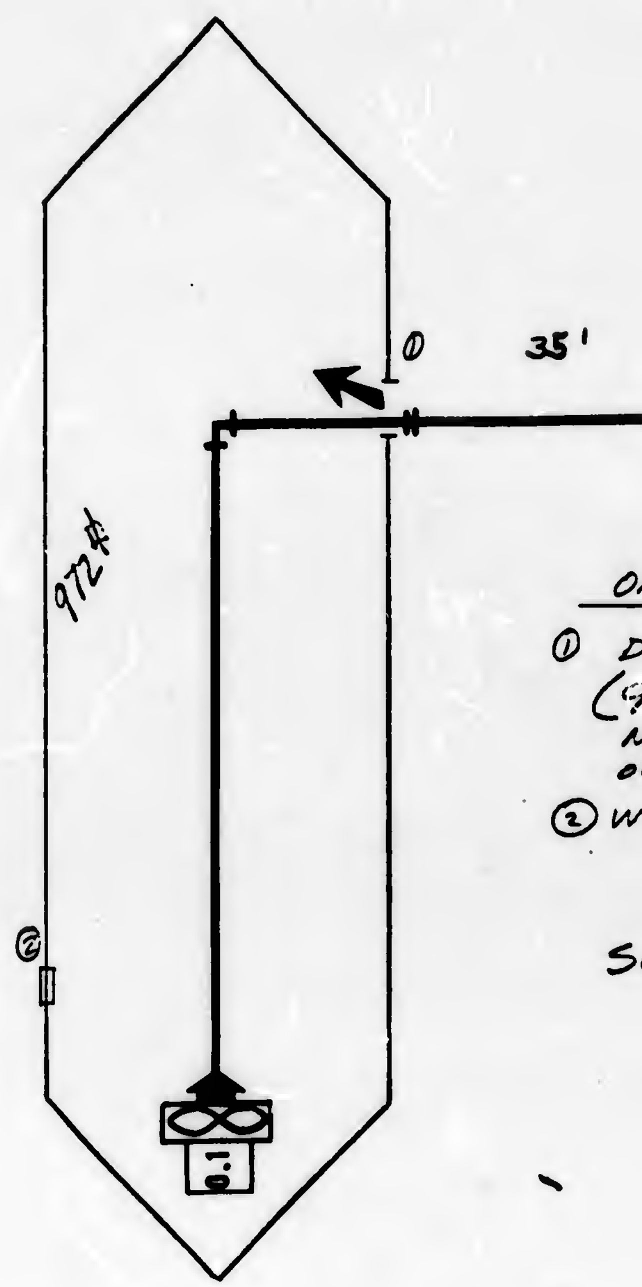
Nask Building
315 Washington Street
Tampa, Florida

SL 3261-0047
FN 94

RTI Facility No. 4.01

City Auditorium (2 Parts)
Crescent Place and North B Street
Tampa, Florida

SL 0046
FN 00203



OPENINGS

① DOOR 36"x48"
(90' AND 2-45° ANGLES TO NEAREST OUTSIDE OPENING)

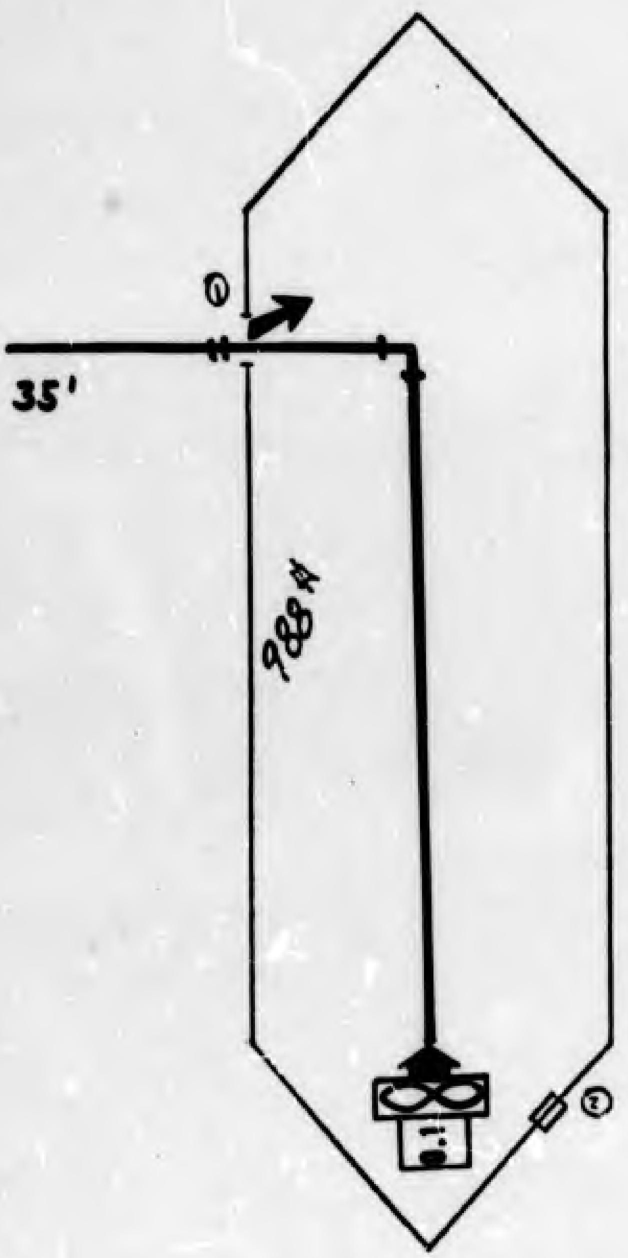
② WINDOW 9"x21"x60" sill

SCALE 1" = 10'-0

RTI Facility No. 4.02

City Auditorium (2 Parts)
Crescent Place and North B Str...
Tampa, Florida

SL 0046
FN 00203



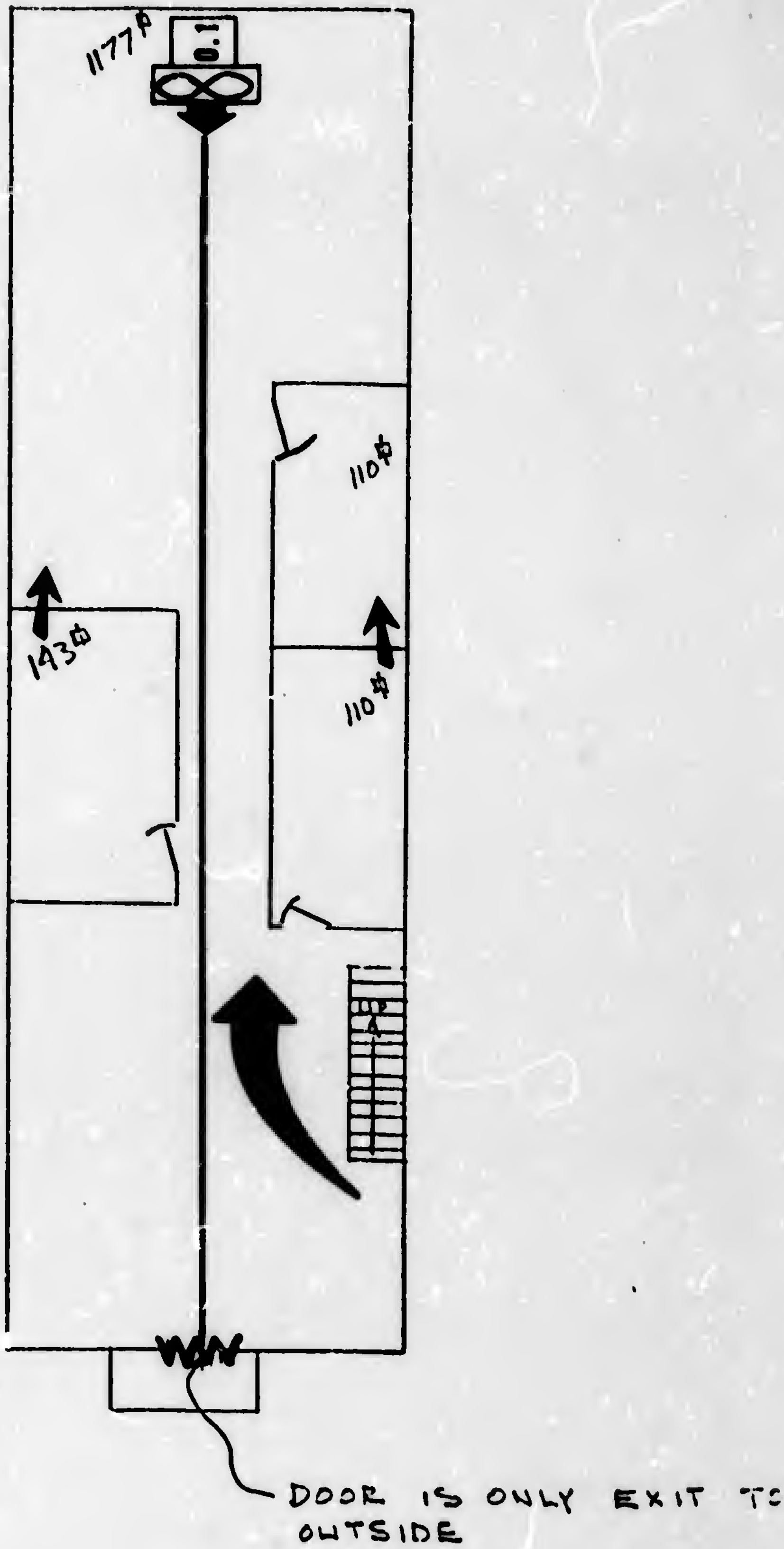
OPENINGS

① DOOR 36" x 48"
(90' AND 2-45° ANGLES TO NEAREST OUTSIDE OPENING)

② WINDOW 9" x 21" x 60" sill

SCALE 1"=10'-0

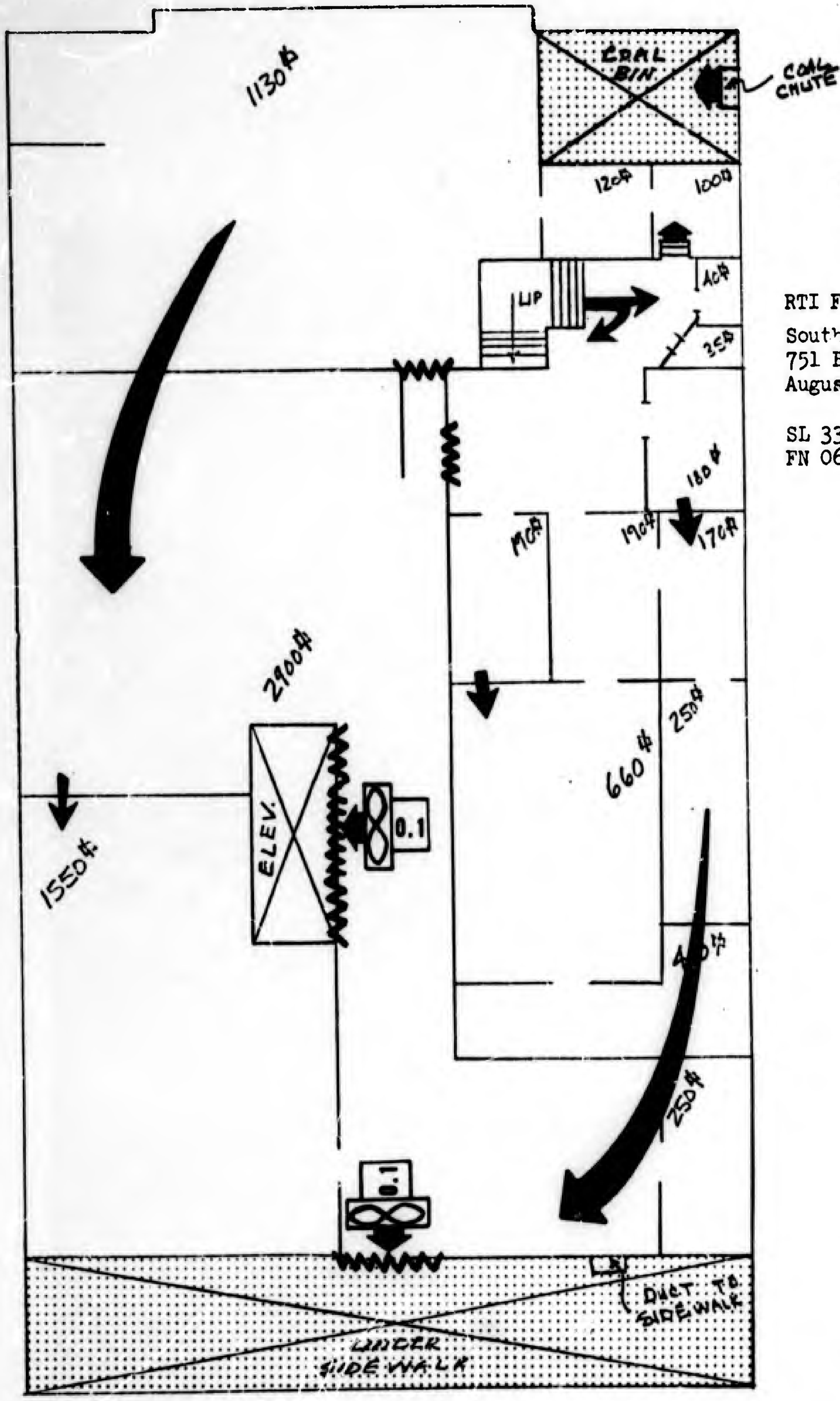
SCALE
1" = 10'-0



RTI Facility No. 5

Cox Bakery
21 S. 8th Street
Fargo, North Dakota

SL 6611-0011
FN 00700

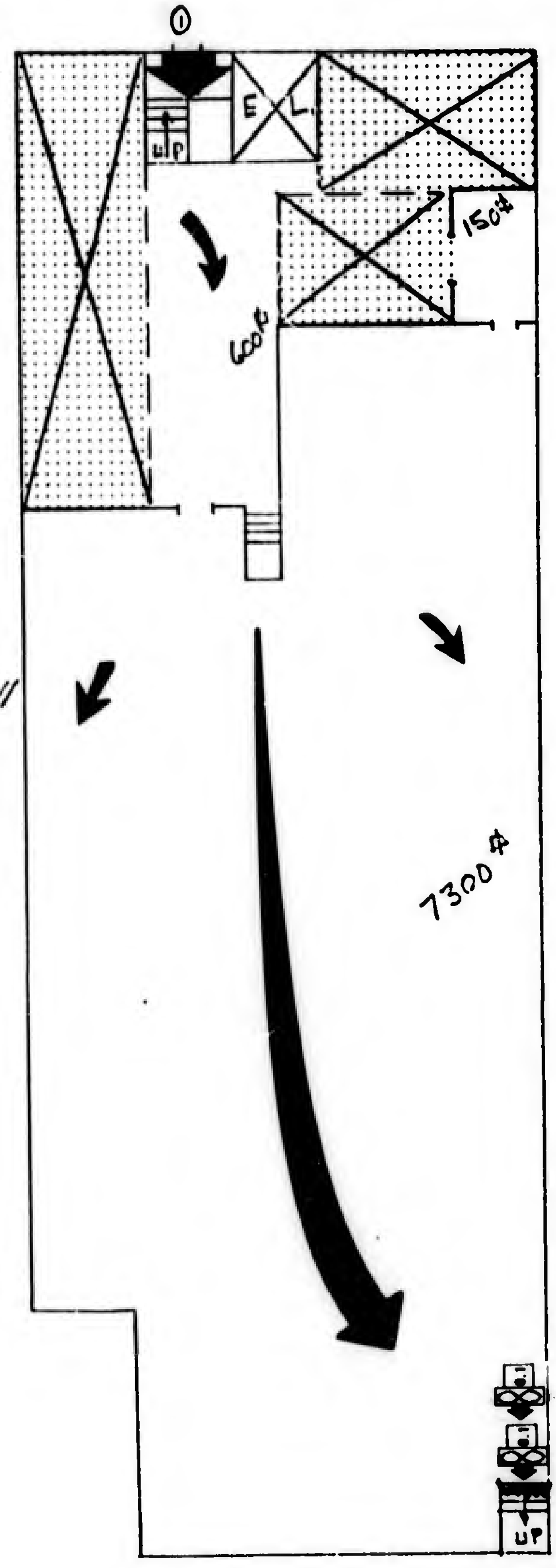


SCALE
1" = 15'-0

RTI Facility No. 6

Southern Finance Building
751 Broad Street
Augusta, Georgia

SL 3331-0005
FN 06456



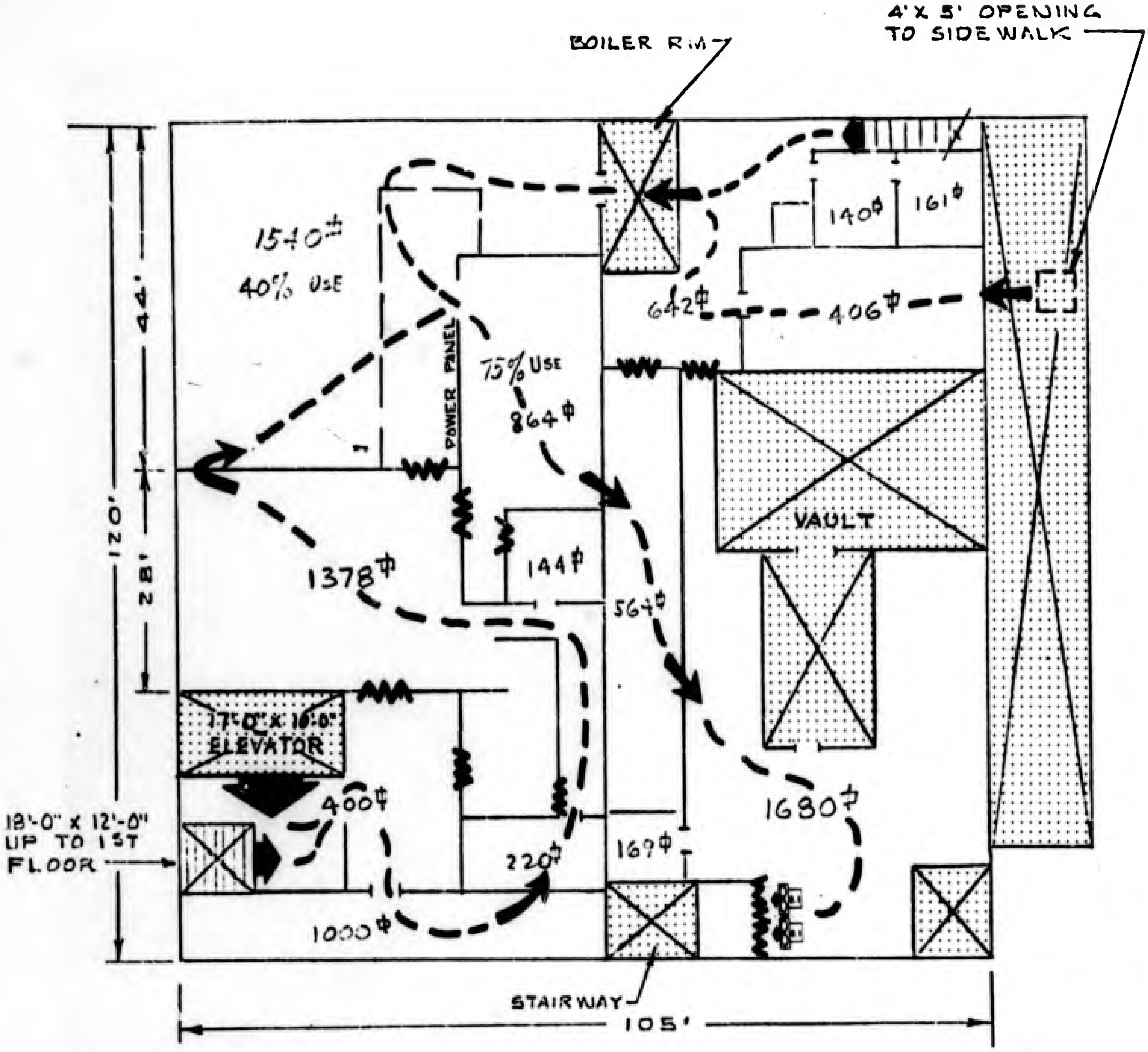
OPENINGS
① WINDOW 36"x48" x 84" sill

SCALE
1" = 20'-0

RTI Facility No. 7

Bowen Bros.
905 Broad Street
Augusta, Georgia

SL 3331-0005
FN 06467

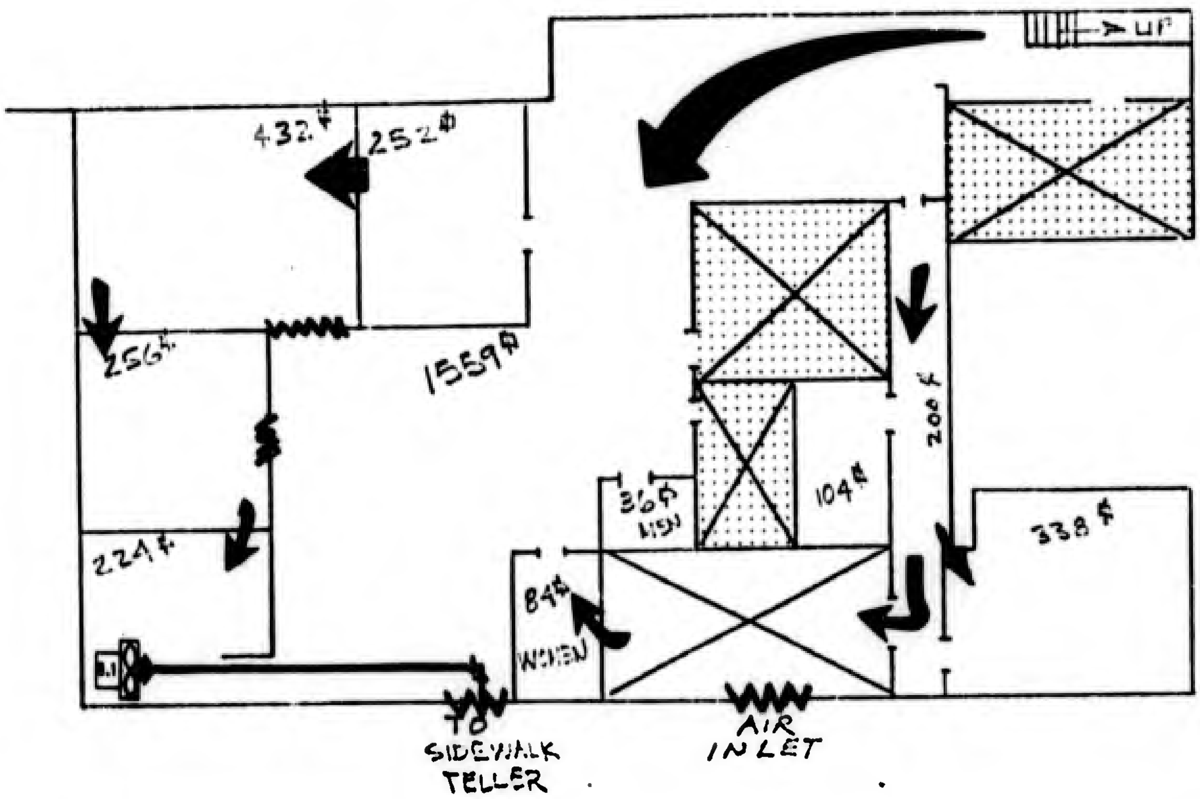


RTI Facility No. 8

NOT TO SCALE

Exchange National Bank (2 Parts.
601 Franklin Street
Tampa, Florida

SL 3261-0047
FN 31



SCALE 1" = 16'-0

RTI Facility No. 9

Ga. R. R. Bank
701 Broad Street
Augusta, Georgia

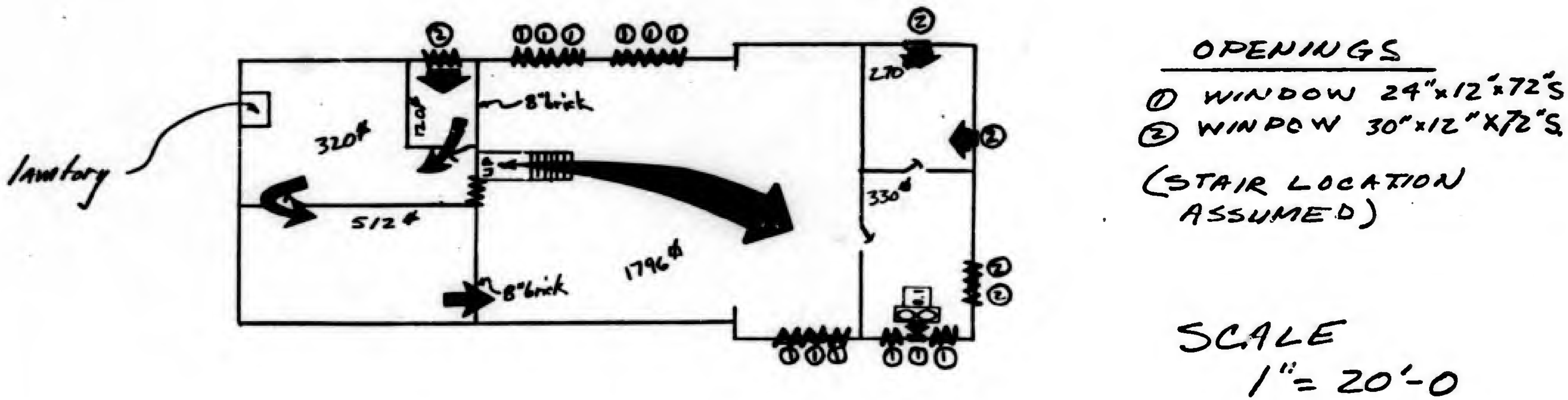
SL 3331-0005
FN 06460-P+01 Basement

RTI Facility No. 10

Wallace Hall: Drury College
930 Benton Street
Springfield, Missouri

SL 6441-0008

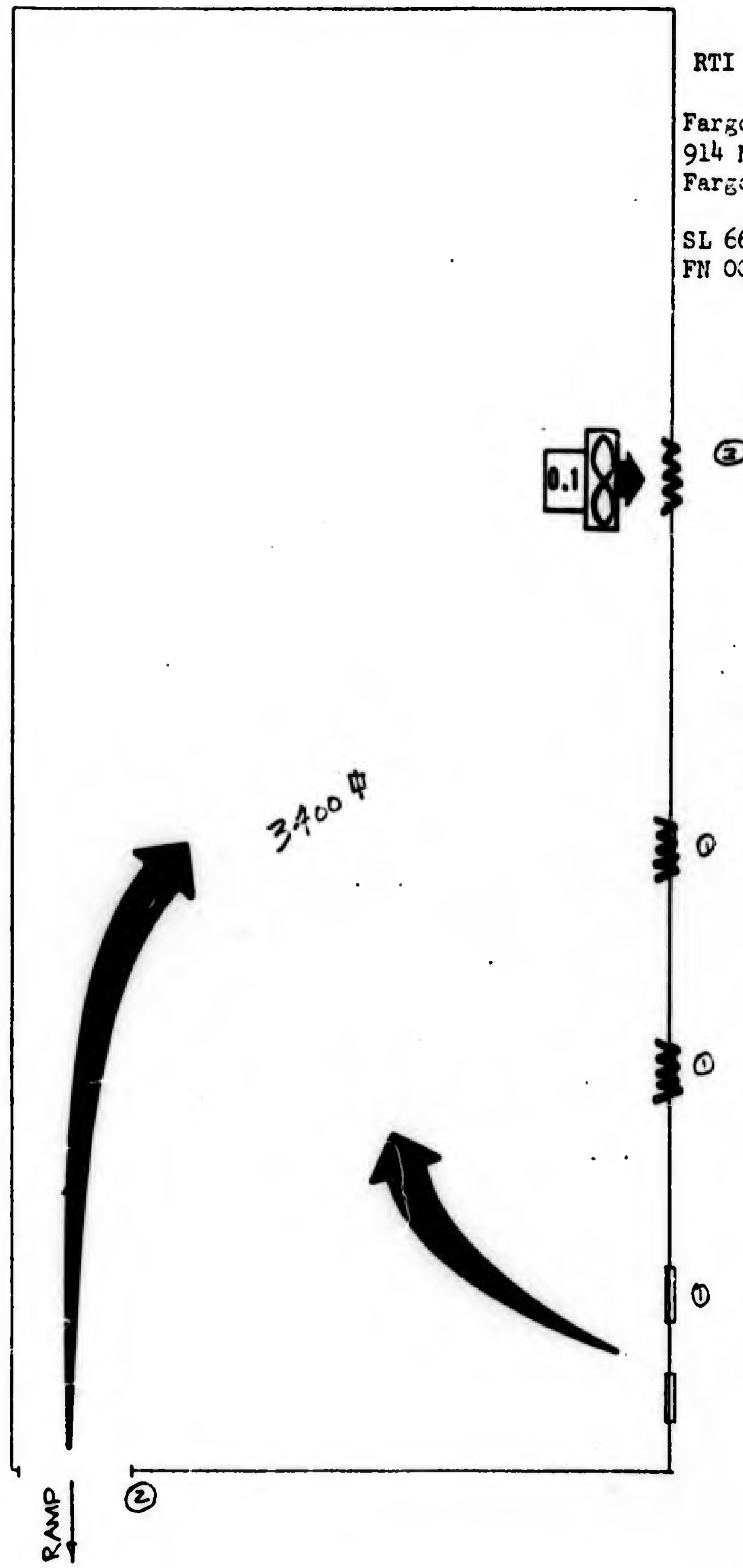
FN 02707



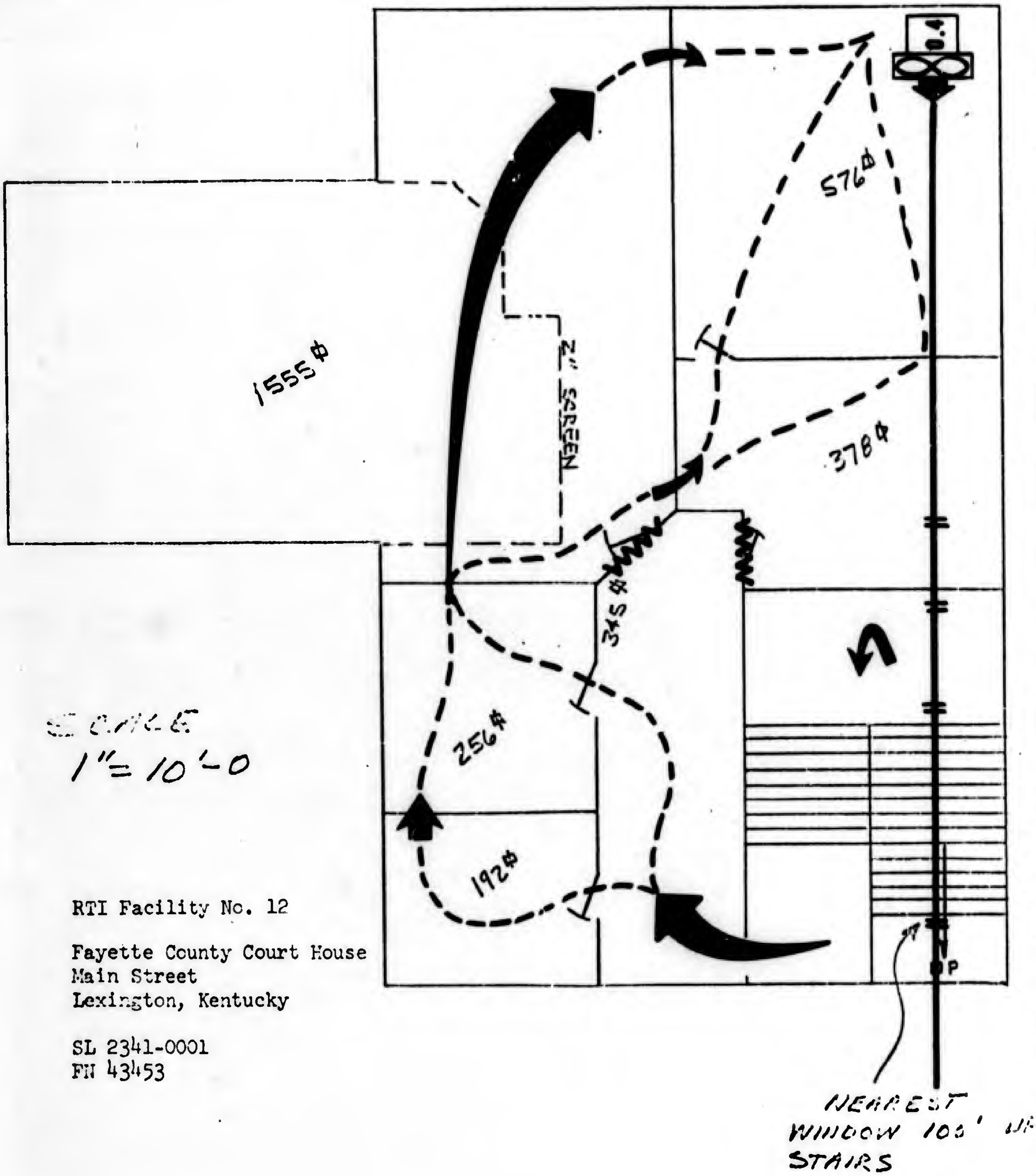
RTI Facility No. 11

Fargo Parks Dept. Office
914 Main Avenue
Fargo, North Dakota

SL 6611-0011
FN 00692



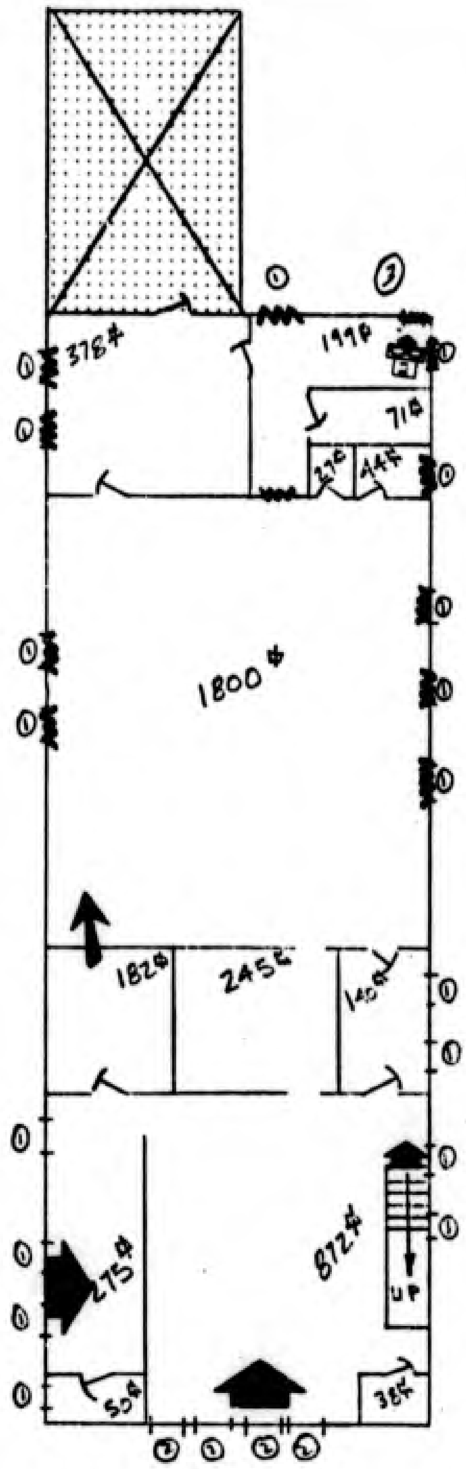
OPENINGS
① WINDOW 36"x36"x5'
② GARAGE DOOR 90"x 94"
③ DOOR
SCALE 1" = 10'-0



RTI Facility No. 12

Fayette County Court House
Main Street
Lexington, Kentucky

SL 2341-0001
FN 43453



RTI Facility No. 13

Y.W.C.A.
155 7th Street
Fargo, North Dakota

SL 6611-0011
FN 00715

OPENINGS

① WINDOW 34" x 24"
x 72" sill

② WINDOW 40" x 60"
x 30" sill

③ DOOR 36" x 54"

SCALE
1" = 20'-0

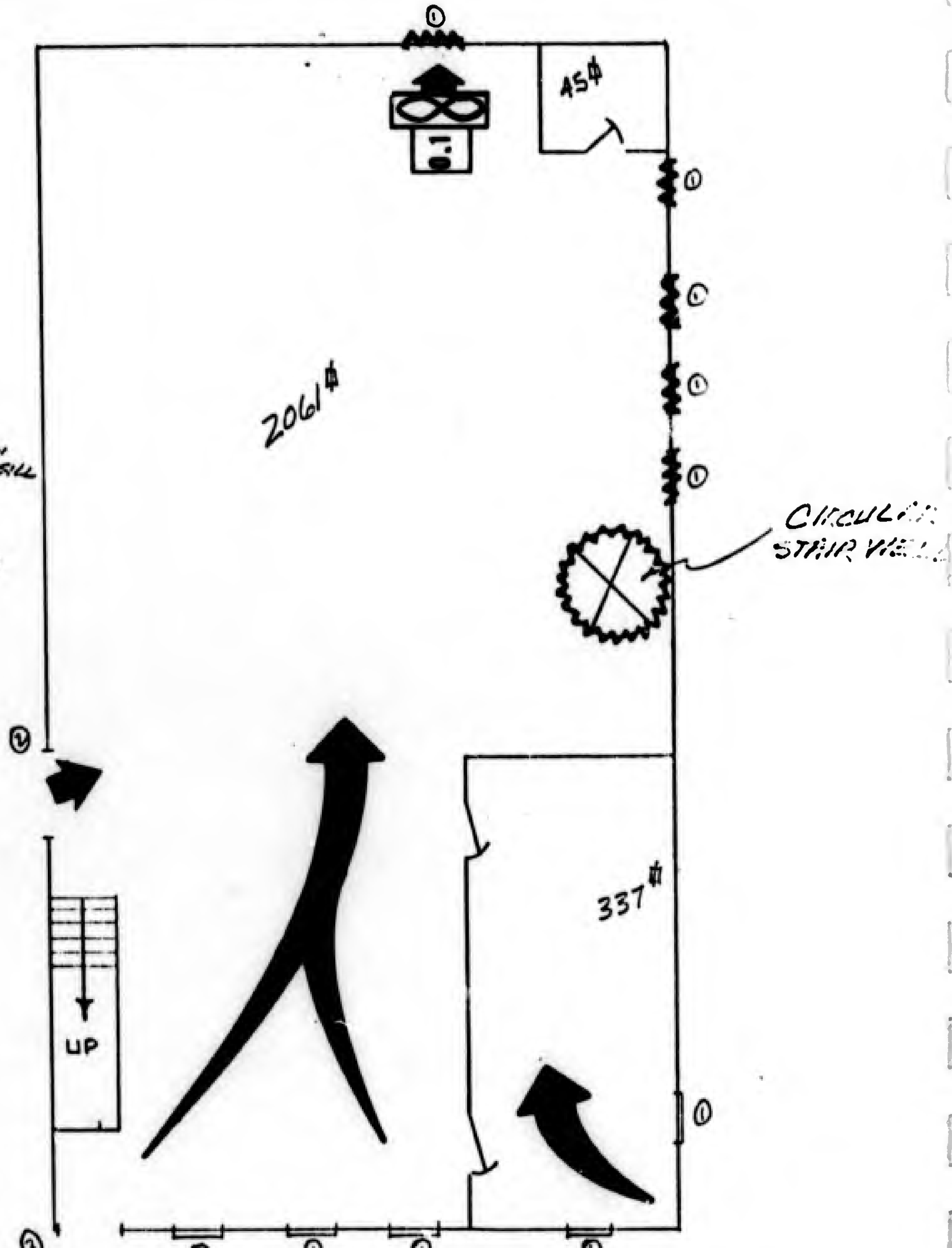
OPENINGS

① WINDOW 40"x54"x66" SILL

② 5' PASSAGEWAY TO OTHER BLDG.

③ 4' PASSAGEWAY TO OTHER BLDG.

SCALE 1"=10'-0



RTI Facility No. 14

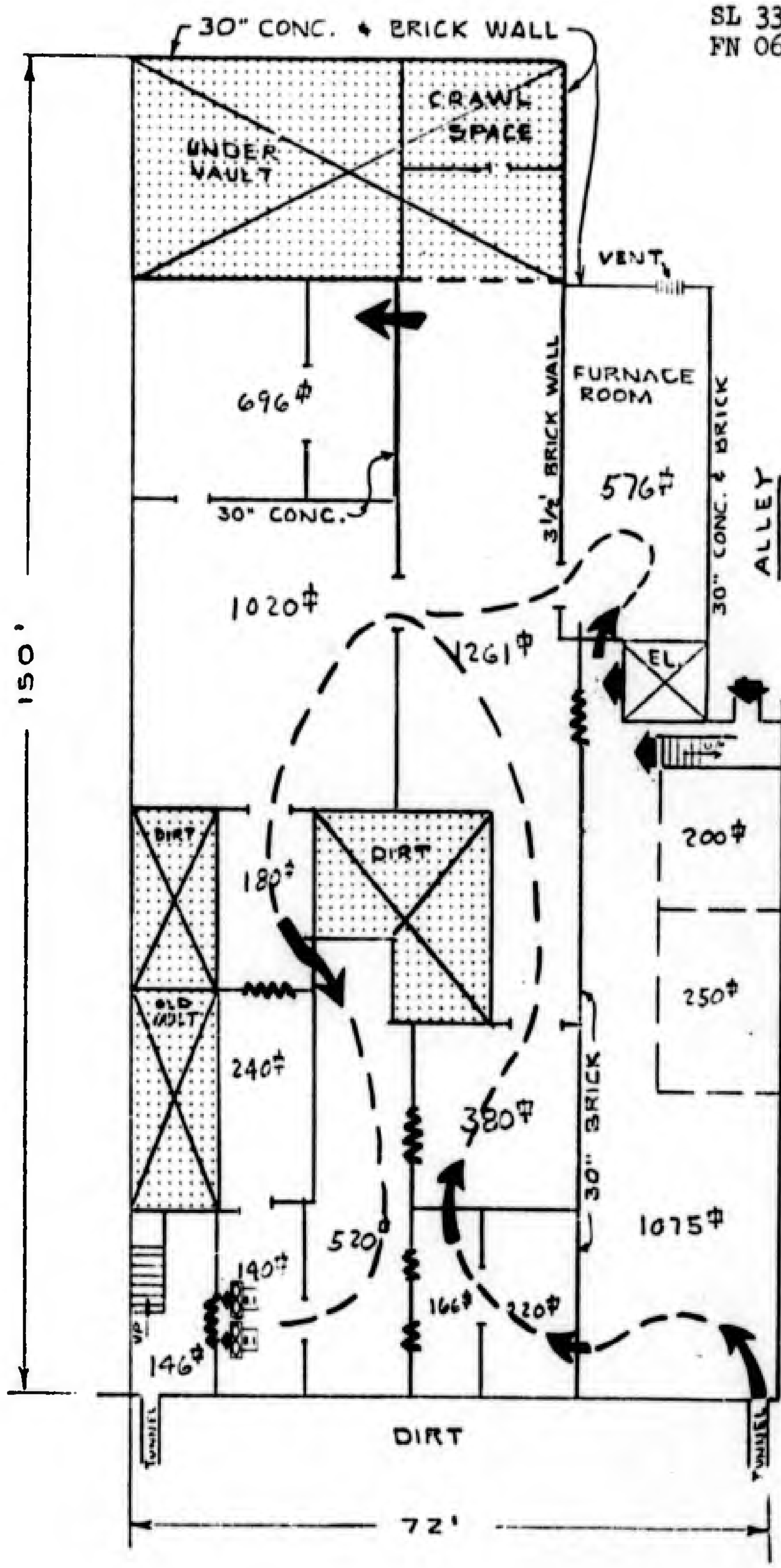
City Water Plant
1308 S. 5th Street
Fargo, North Dakota

SL 6611-0016
FN 00650

RTI Facility No. 15

C & S National Bank
709 Broad Street
Augusta, Georgia

SL 3331-0005
FN 06449



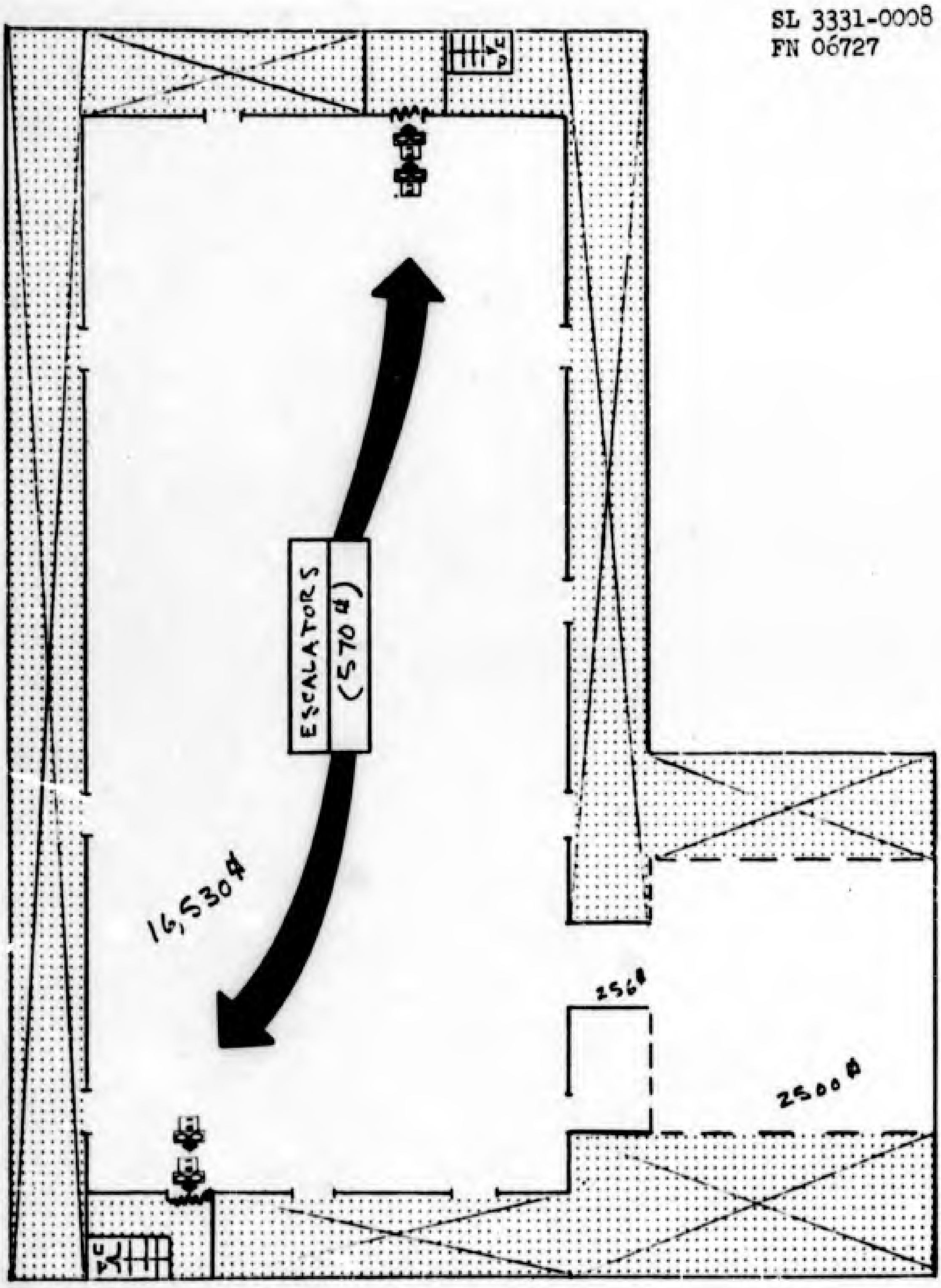
SCALE: 1" = 20'

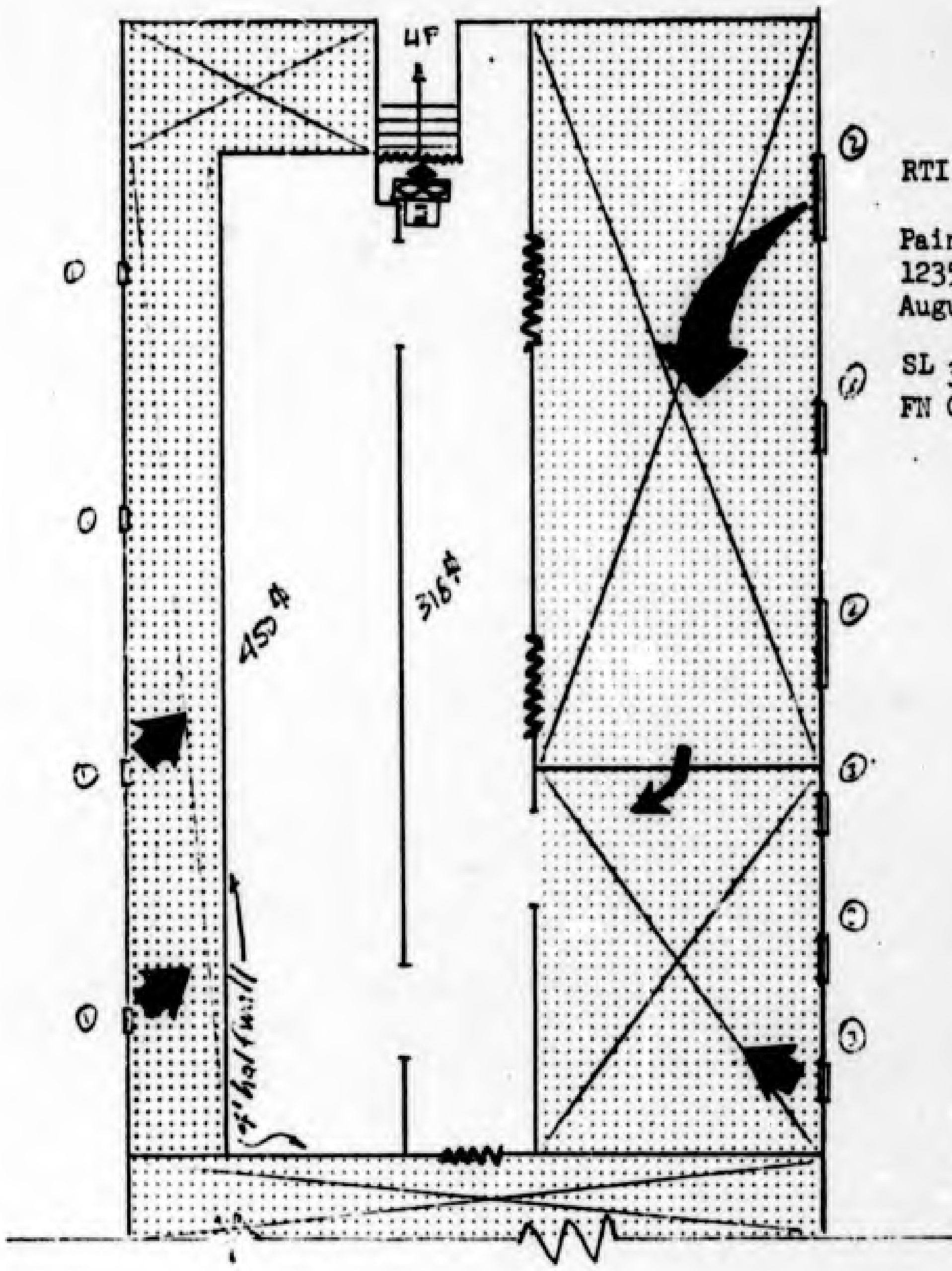
RTI Facility No. 16

Sears Roebuck Dept. Store
1499 Walton Way
Augusta, Georgia

SL 3331-0008
FN 06727

SCALE
1" = 30'-0





RTI Facility No. 17

Paine College - Dorm 2
1235 15th Street
Augusta, Georgia

SL 3331-0010
FN 06903

OPENINGS

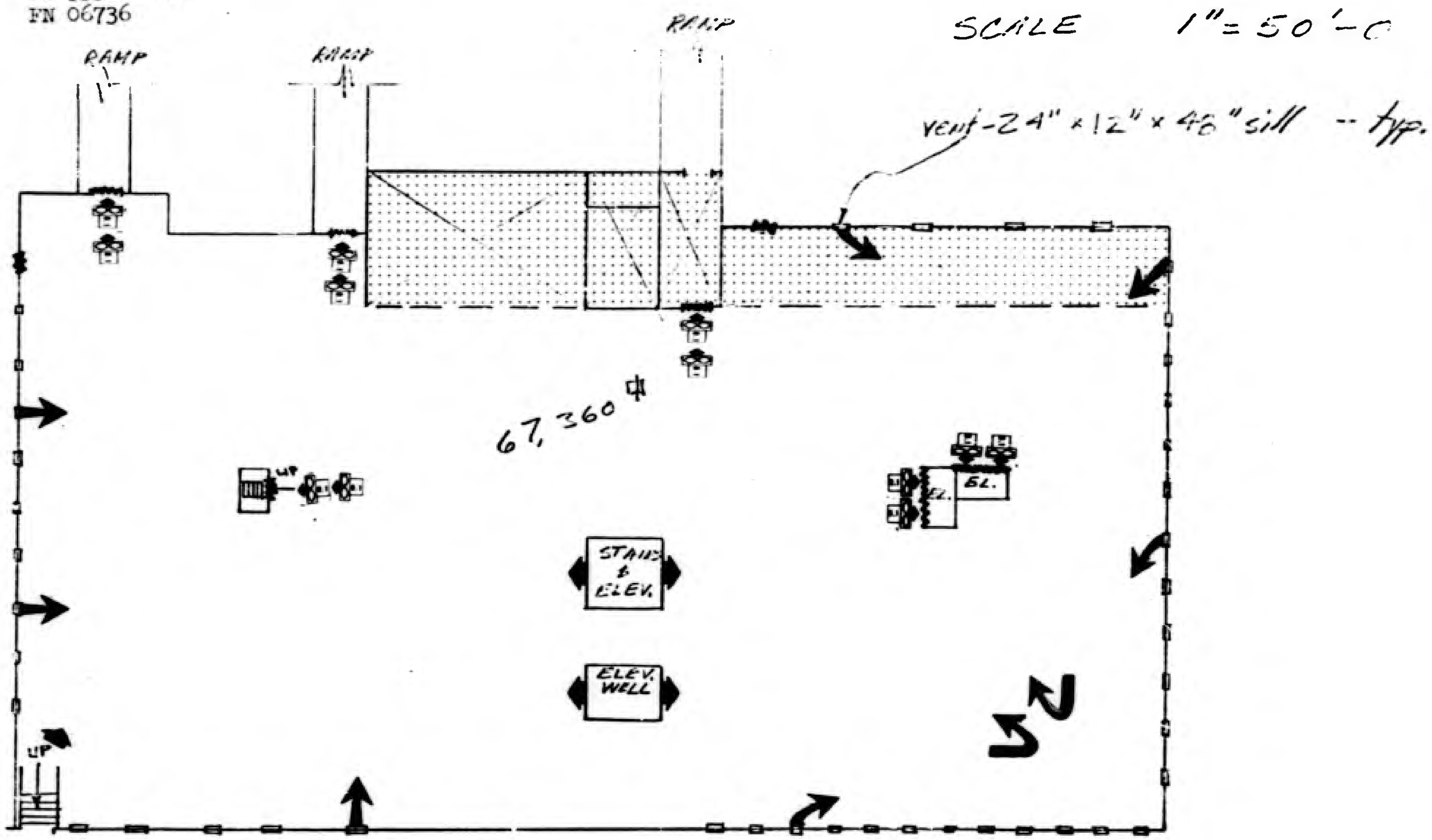
① VENT 24"x6"x 66" SILL
② WINDOW 72"x48" x 42" SILL
③ WINDOW 72"x24"x 42" SILL

SCALE
1" = 10'-0

RTI Facility No. 18

Eugene Talmadge Medical Center
Augusta, Georgia

SL 3331-0008
FN 06736

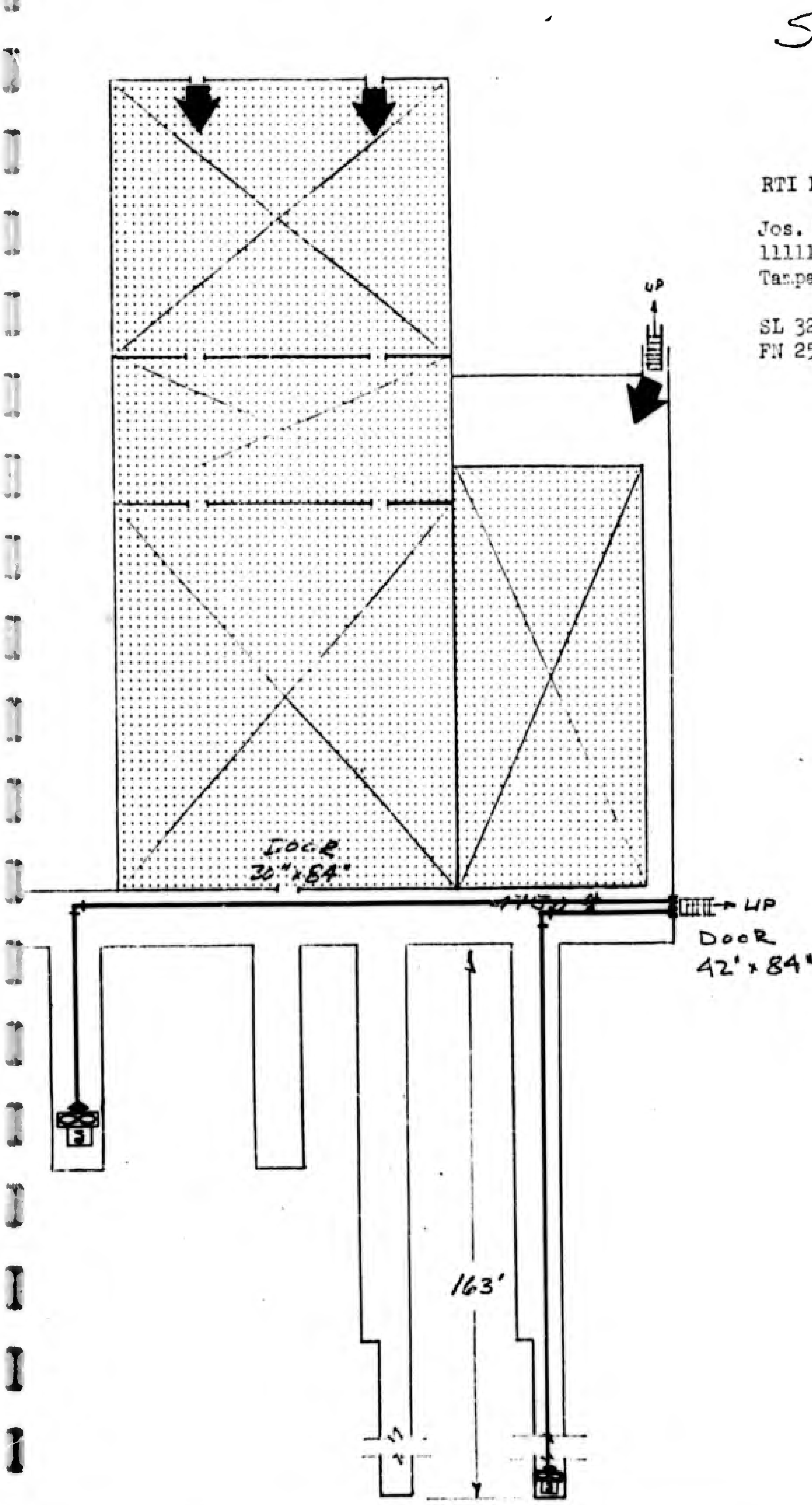


SCALE
1" = 10'-0

RTI Facility No. 19

Jos. Schlitz Brewery
11111 30th Street
Tampa, Florida

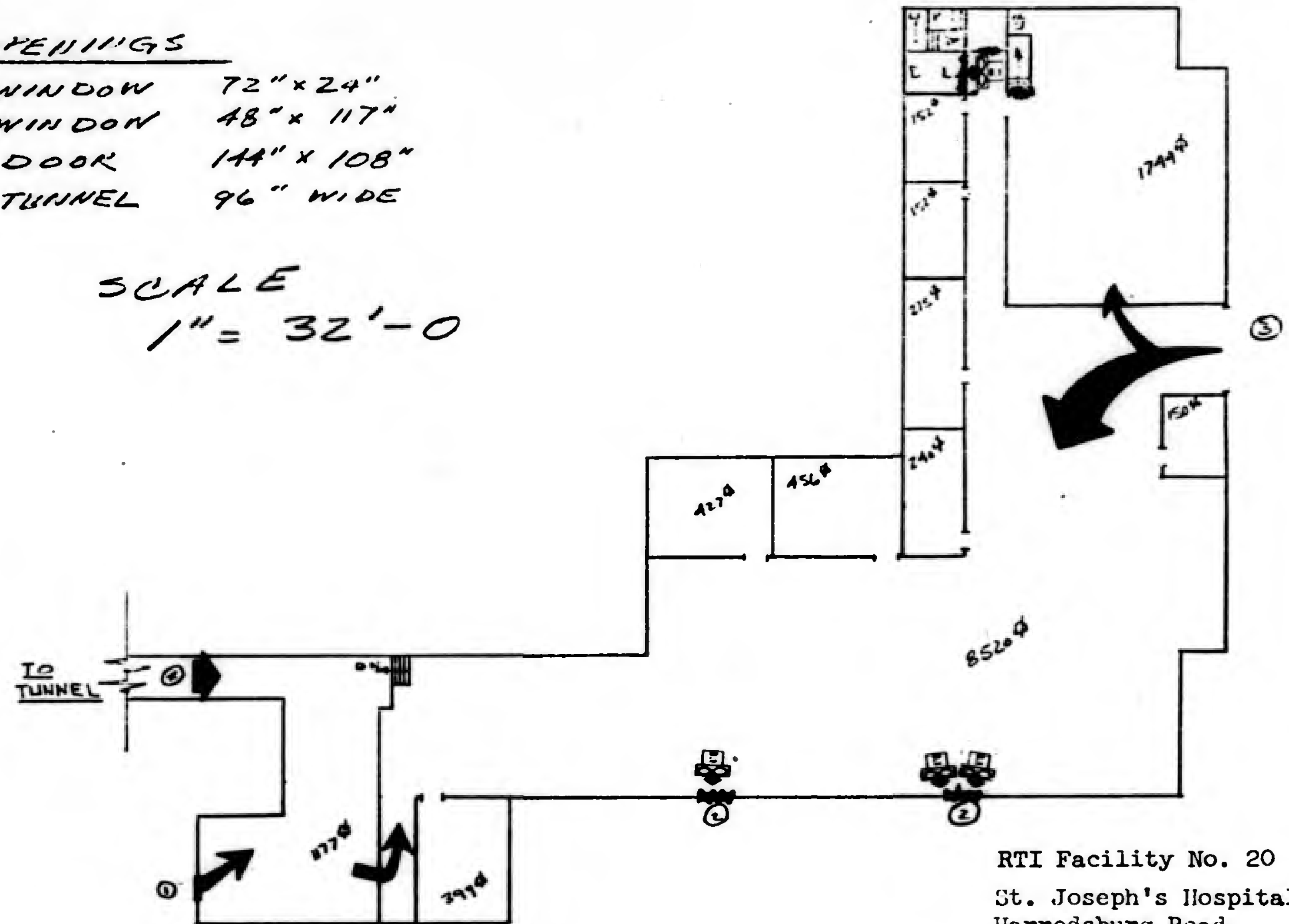
SL 3261-0065
FN 251



OPENINGS

(1)	WINDOW	72" x 24"
(2)	WINDOW	48" x 117"
(3)	DOOR	144" x 108"
(4)	TUNNEL	96" WIDE

SCALE
1" = 32'-0



RTI Facility No. 20
St. Joseph's Hospital
Harrodsburg Road
Lexington, Kentucky

SL 2341-002C
FN 04016

RTI Facility No. 21

Eastern State Hospital
Building 57
W. Fourth Street
Lexington, Kentucky

SL 2341-0011
FN 03005

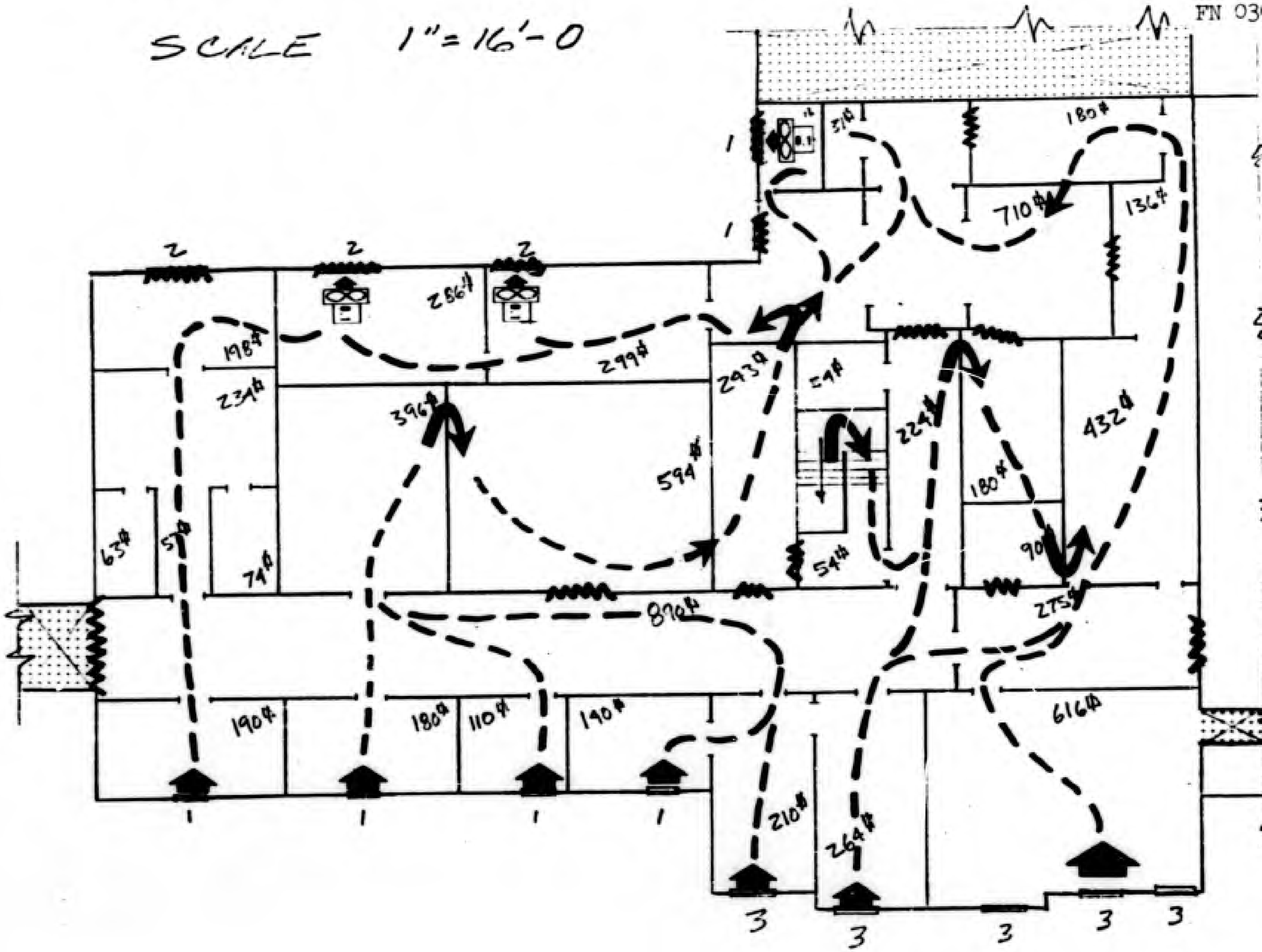
OPENINGS

① WINDOW 37" x 39"

② WINDOW 76" x 39"

③ WINDOW 54" x 39"

SCALE 1" = 16'-0

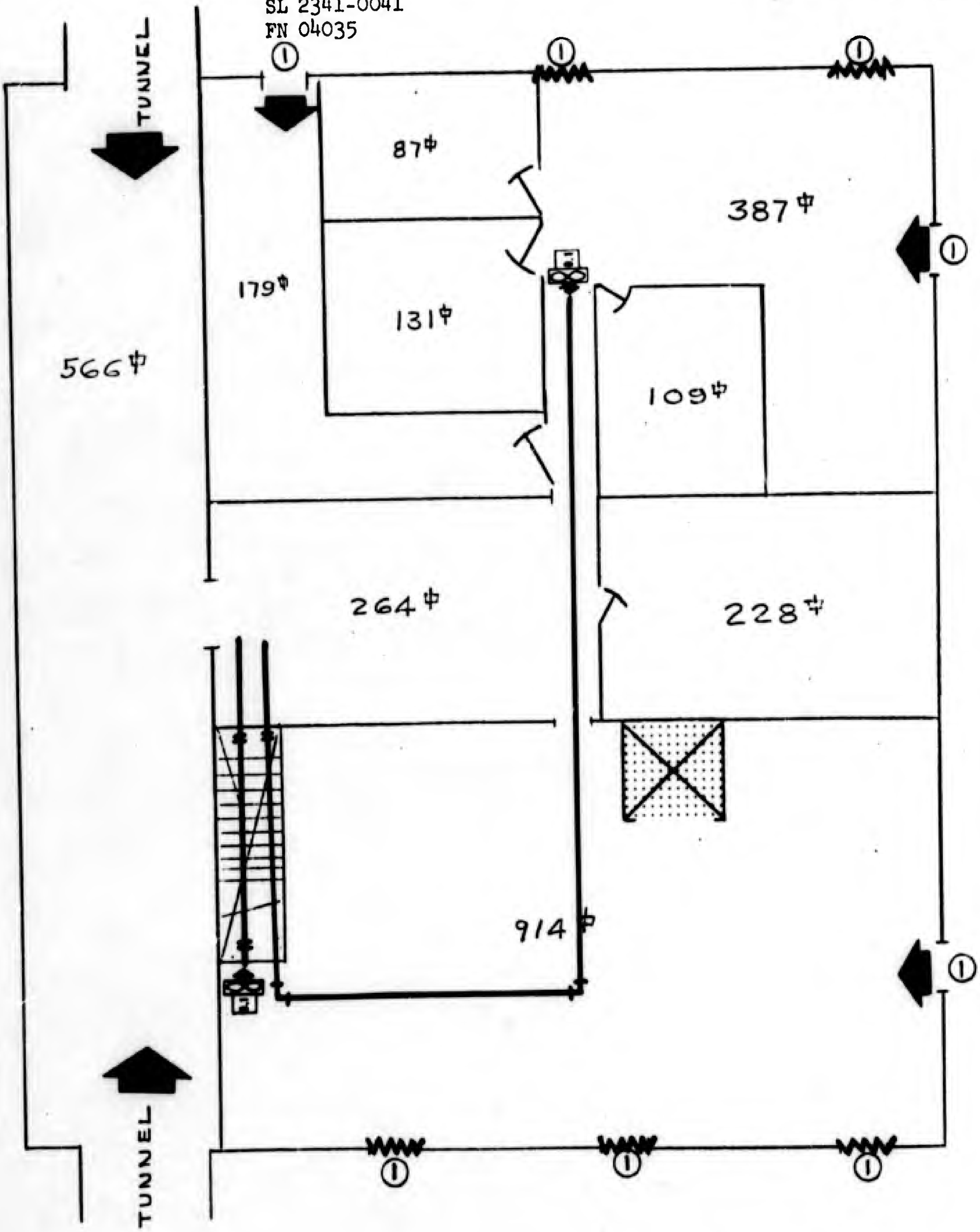


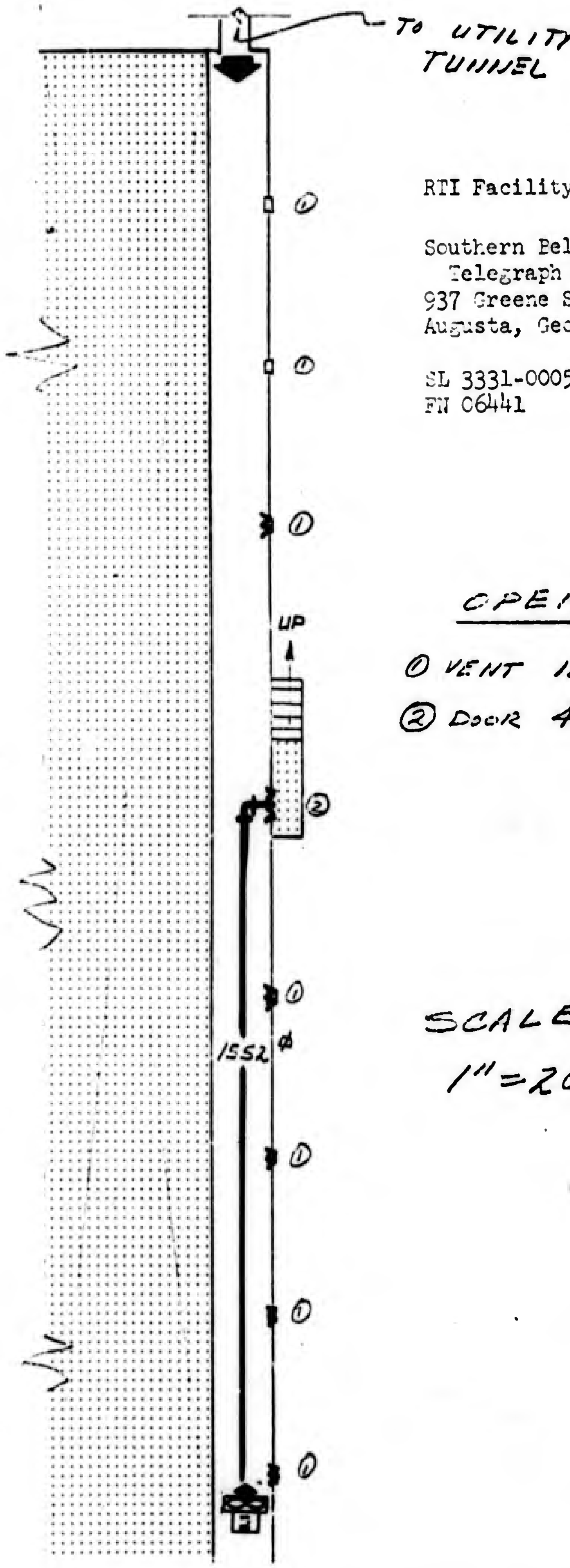
RTI Facility No. 22
Fayette Country Board of
Education
Administration Building
Lexington, Kentucky

SL 2341-0041
FN 04035

SCALE: 1" = 8'

WINDOWS
1. 34" x 24" x 5'-6'S





RTI Facility No. 23

Southern Bell Telephone &
Telegraph Co.
937 Greene Street
Augusta, Georgia

SL 3331-0005
FN 06441

OPENINGS

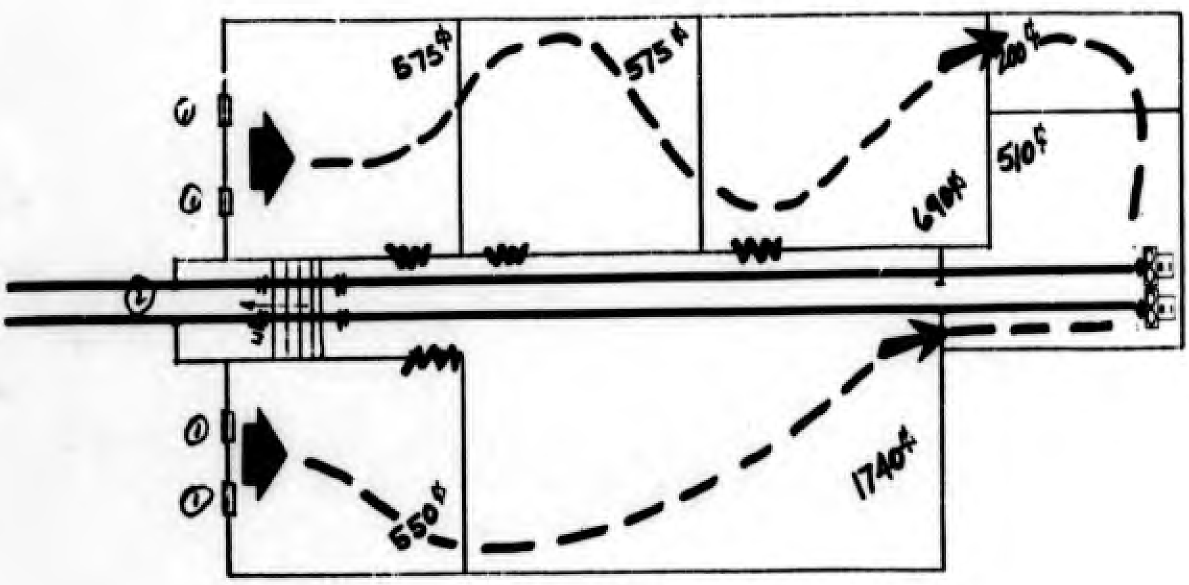
① VENT 18" x 9" x 99" SILL
② DOOR 42" x 78"

SCALE
1" = 20'-0

RTI Facility No. 24

Central Bible Institute
Administration Building
N. E. Grant and Norton Street
Springfield, Missouri

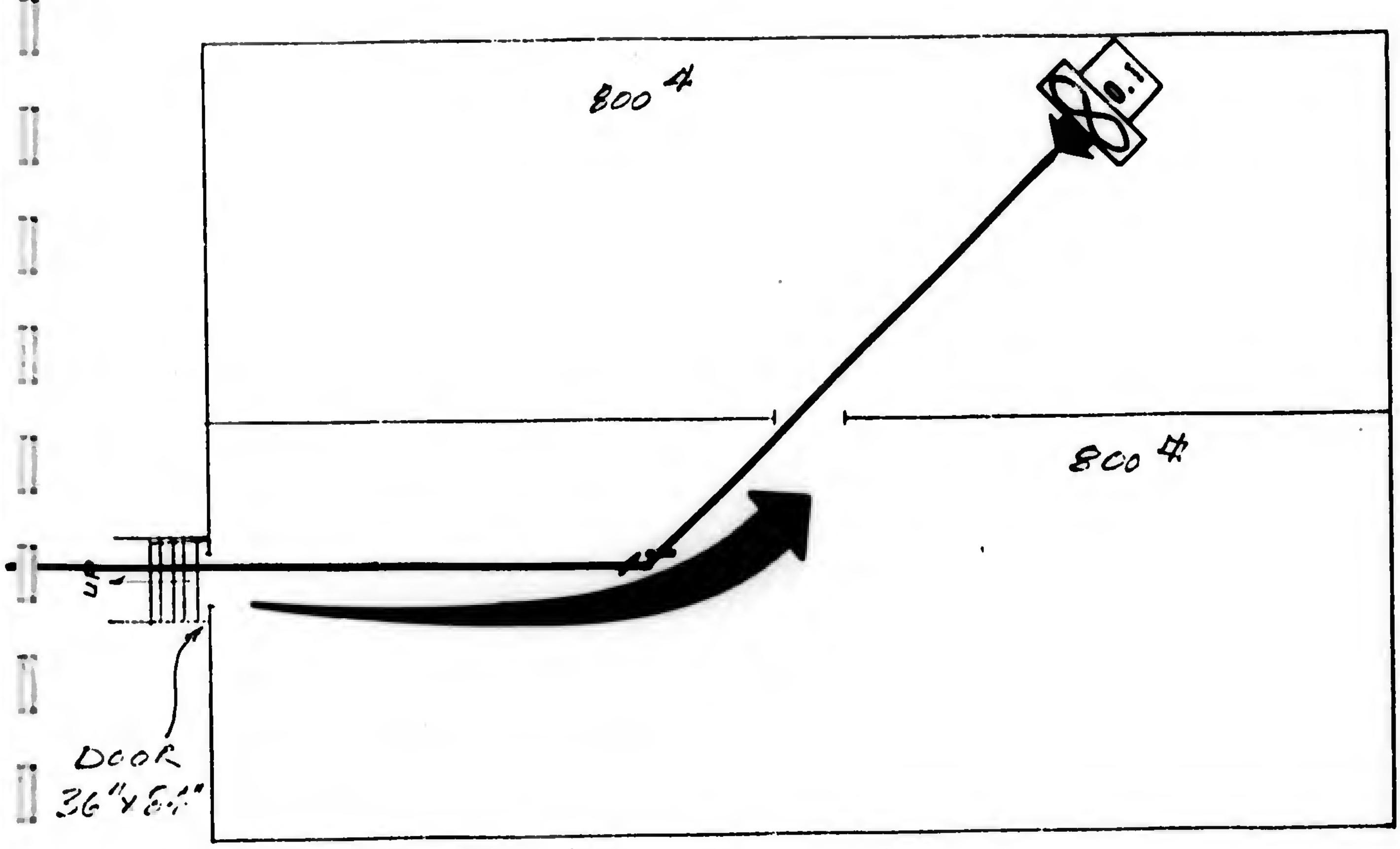
SL 6441-0001
FN 02002



OPENINGS

① WINDOW 48" x 24" x 42" sill
② DOOR 48" x 78"

SCALE 1" = 20'-0

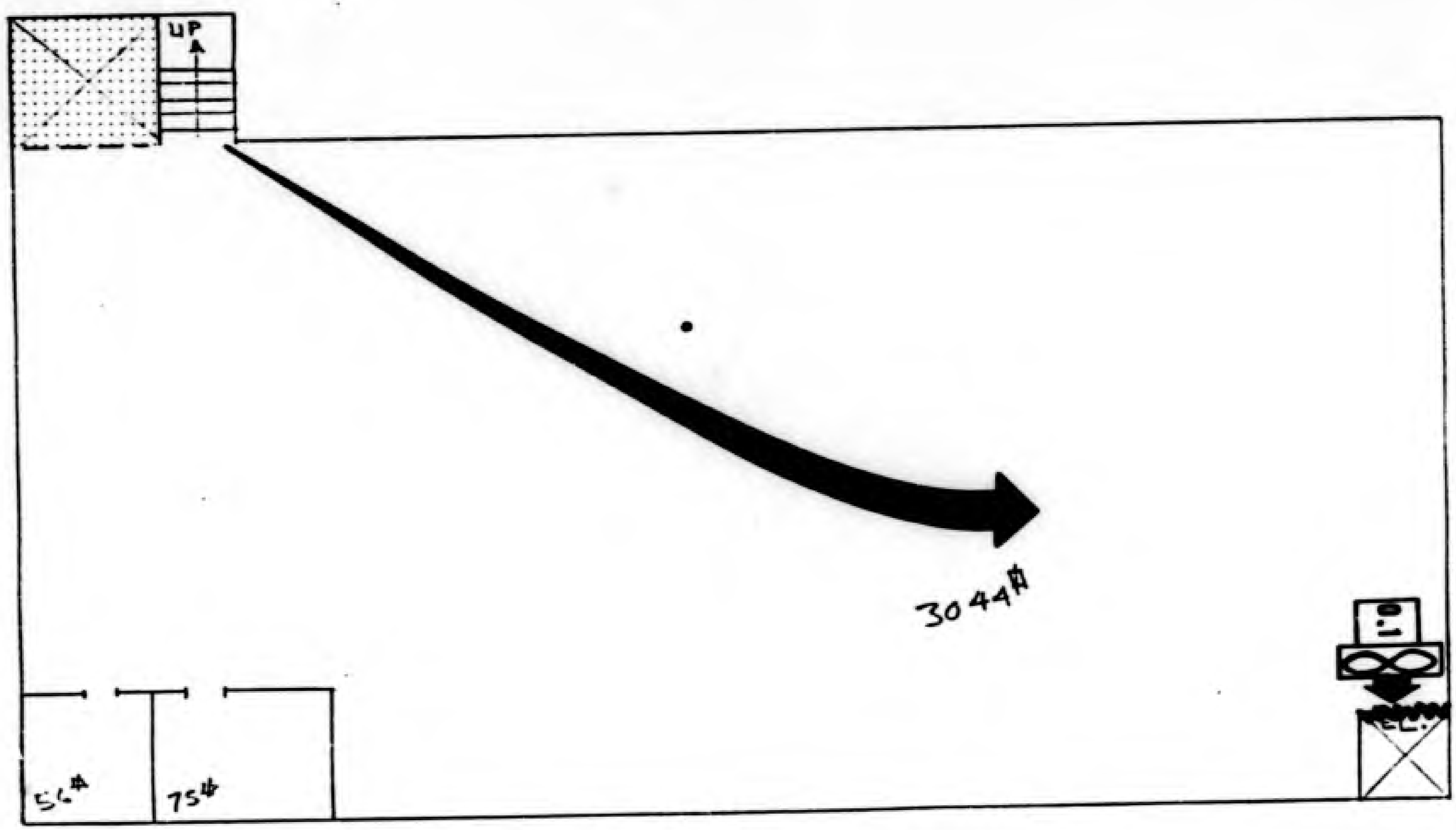


SCALE 1" = 8'-0

RTI Facility No. 25

Rogers and Baldwin (Hardware Whse.)
309 E. Water Street
Springfield, Missouri

SL 6441-0008
FN 02735



RTI Facility No. 26

"Land Bank Building"
Busy Bee Department Store
322 College Street
Springfield, Missouri

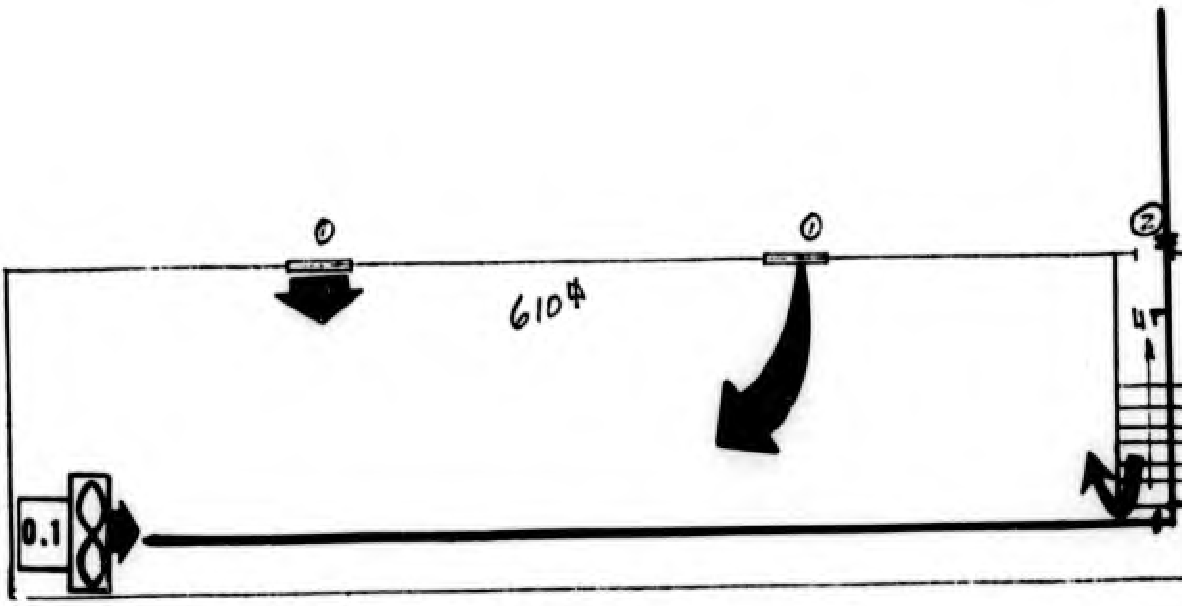
SL 6441-0014
FN 03370

SCALE 1" = 10'-0

RTI Facility No. 27

Wilhoit Building - Cellar 3
320 East Pershing
Springfield, Missouri

SL 6441-0014
FN 03343 CC



OPENINGS

① WINDOW 36" x 24" x 78" sill

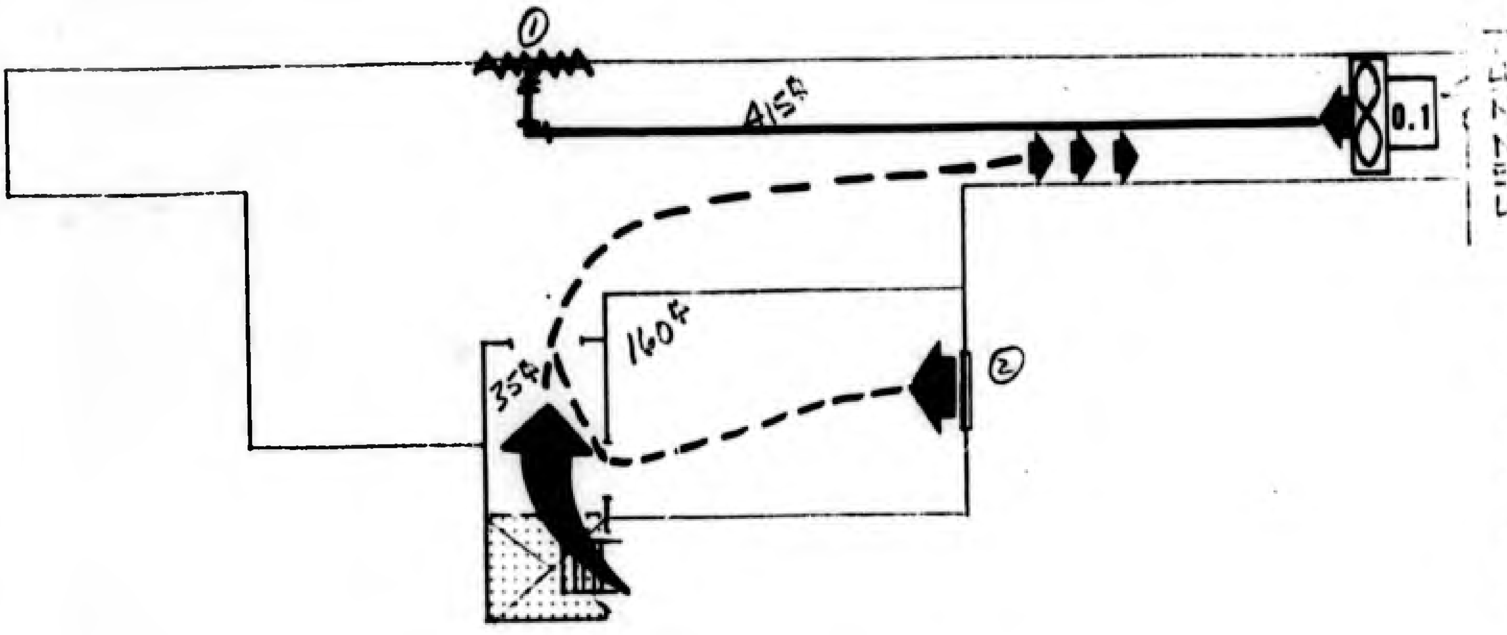
② DOOR 30" x 72"

SCALE 1" = 8'-0

RTI Facility No. 28

Field House, Southwest Missouri
State College
901 South National
Springfield, Missouri

SL 6441-0015
FN 03406



OPENINGS

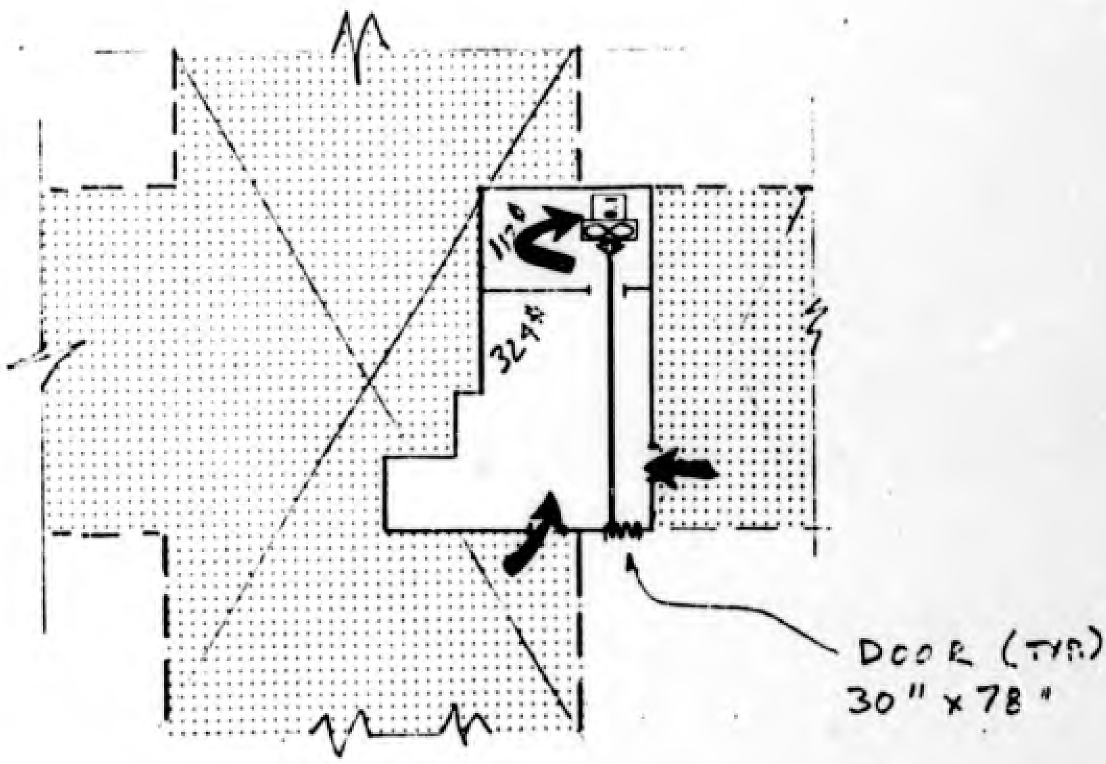
① WINDOW 36" x 18" x 36" SILL
② WINDOW 36" x 48" x 48" SILL

SCALE 1" = 8'-0

RTI Facility No. 29

NYCHA 1055 Rosedale Avenue
Bronx, New York

SL 1641-0034
FN 01300

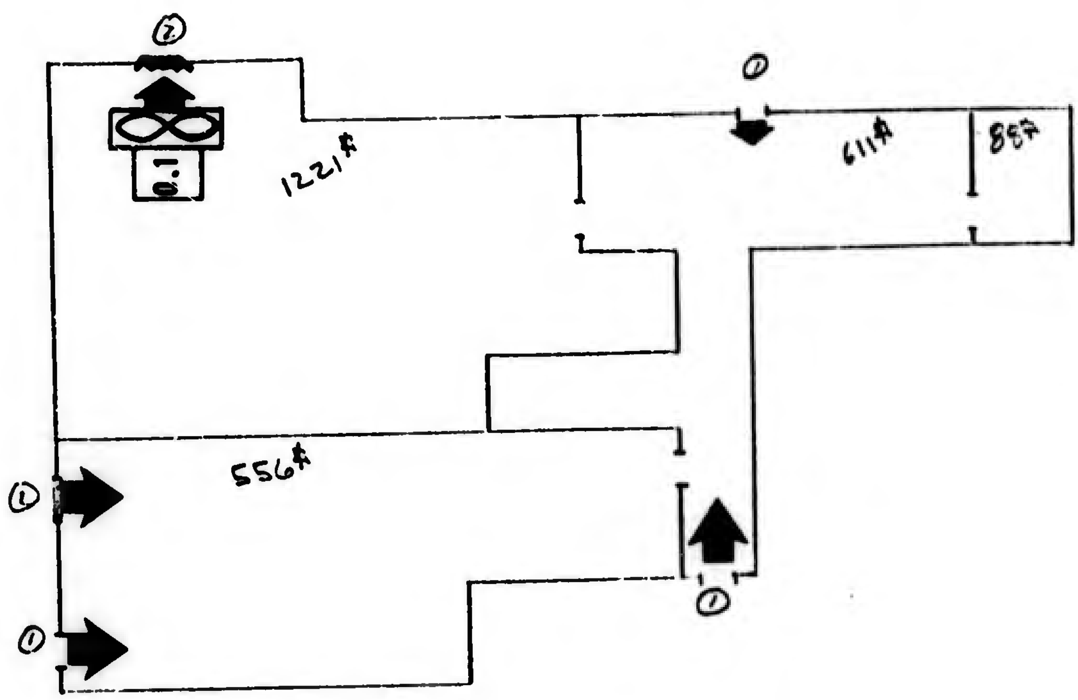


SCALE 1" = 16'-0

RTI Facility No. 30

1824-1826 McGraw Avenue
Bronx, New York City, N. Y.

SL 1641-0056
FN 02061



OPENINGS

① DOOR 30" x 78"

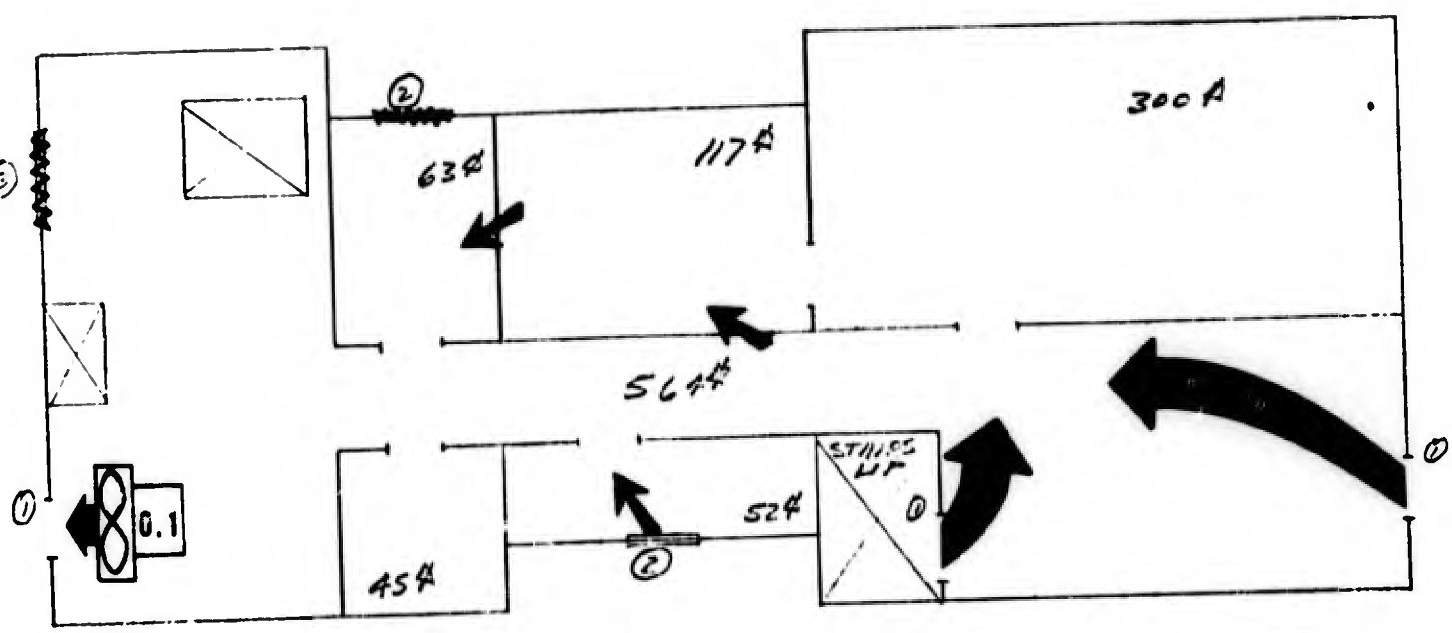
② WINDOW 36" x 18" x 60"

SCALE 1" = 16'-0

RTI Facility No. 31

1165 Washington Avenue
Bronx, New York City, N. Y.

SL 1641-0104
FN 01842 AA



OPENINGS

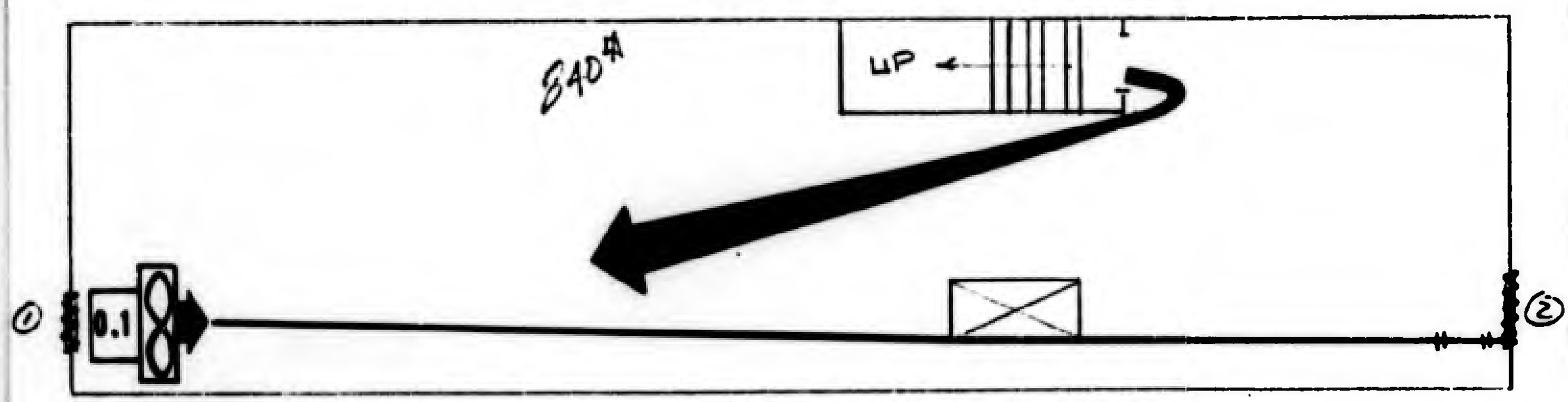
1. DOOR 30" x 75"
2. WINDOW 36" x 60" x 24" sill
3. WINDOW 44" x 60" x 27" sill

SCALE 1" = 8'-0

RTI Facility No. 32

253 Kosciusko Street
Brooklyn, New York City, N.Y.

SL 1642-0233
FN 03483



OPENINGS

① WINDOW 24"x24"x 48"sill

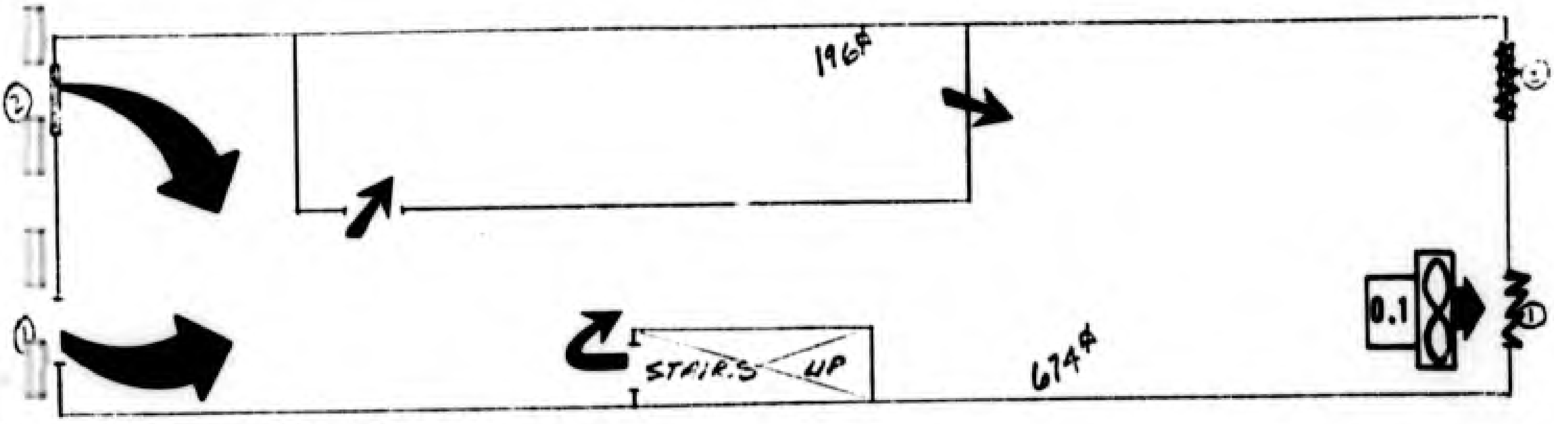
② WINDOW 30"x 30" x 48"sill

SCALE 1"= 8'-0

RTI Facility No. 33

3206 Church Avenue
Brooklyn, New York City, N.Y

SL 1642-0645
FN 00785 AA

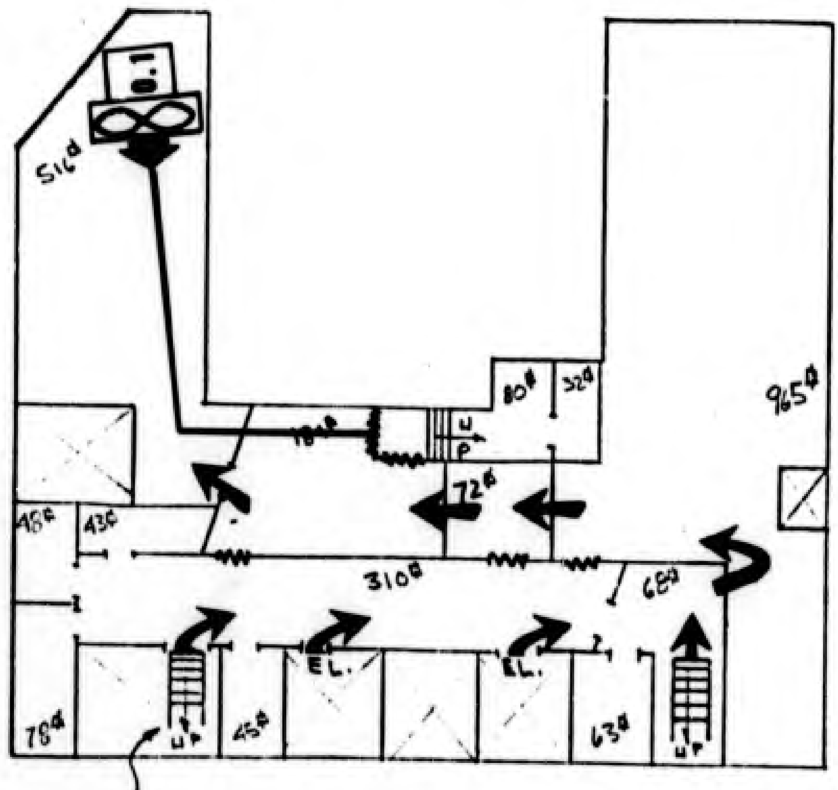


OPENINGS
① DOOR 30" x 78"
② WINDOW 24" x 36" x 48" SILL

RTI Facility No. 34

Times Square Trust Bldg.
149-151 W. 40th Street
Manhattan, New York City

SL 1644-0106
FN 01912



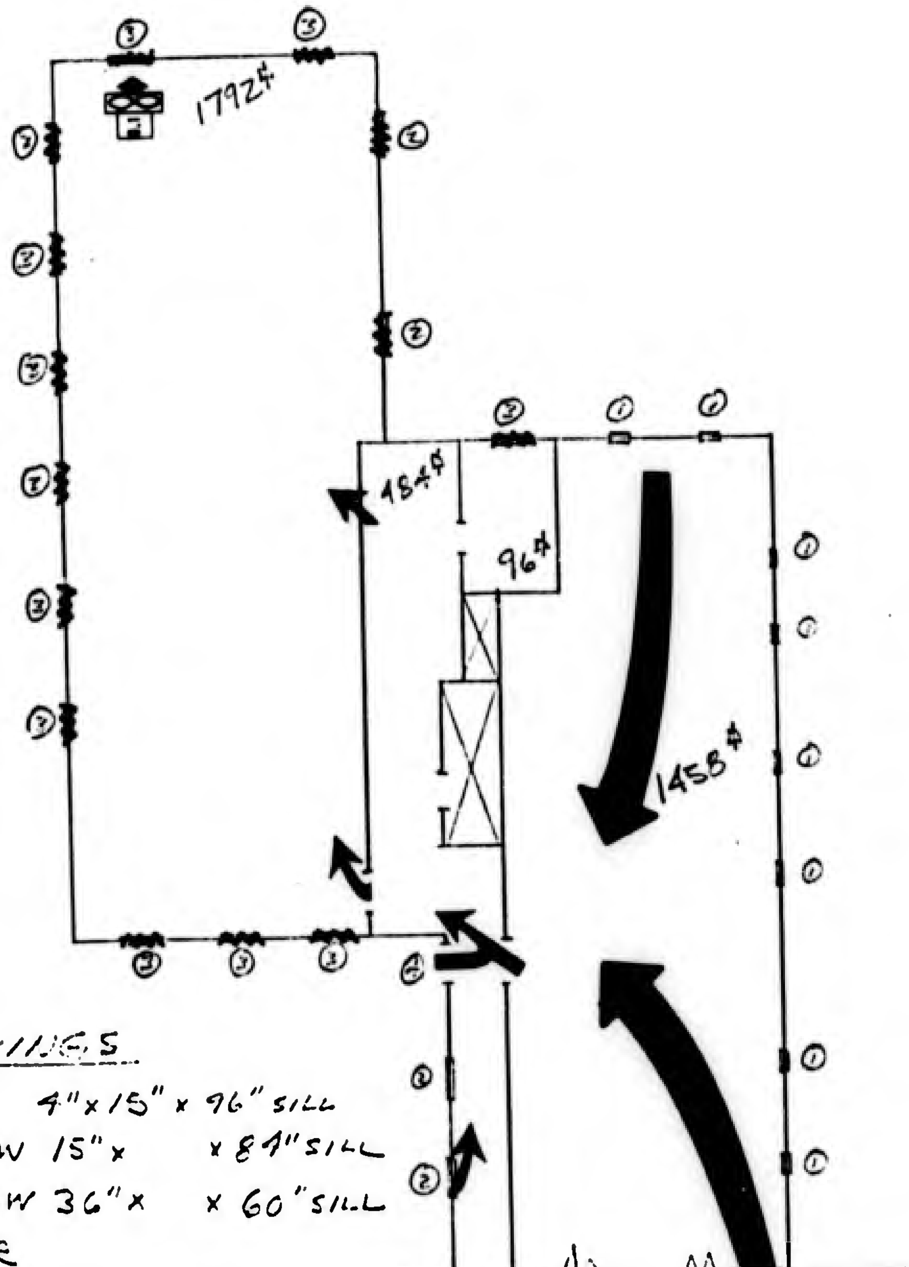
NEAREST OUTSIDE OPENING 25' TO 1ST STORY DOOR

SCALE 1" = 20'-0

RTI Facility No. 35

NYCHA - J. W. Johnson Houses
1565 Park Avenue
New York City, N. Y.

SL 1644-0175
FN 01812



OPENINGS

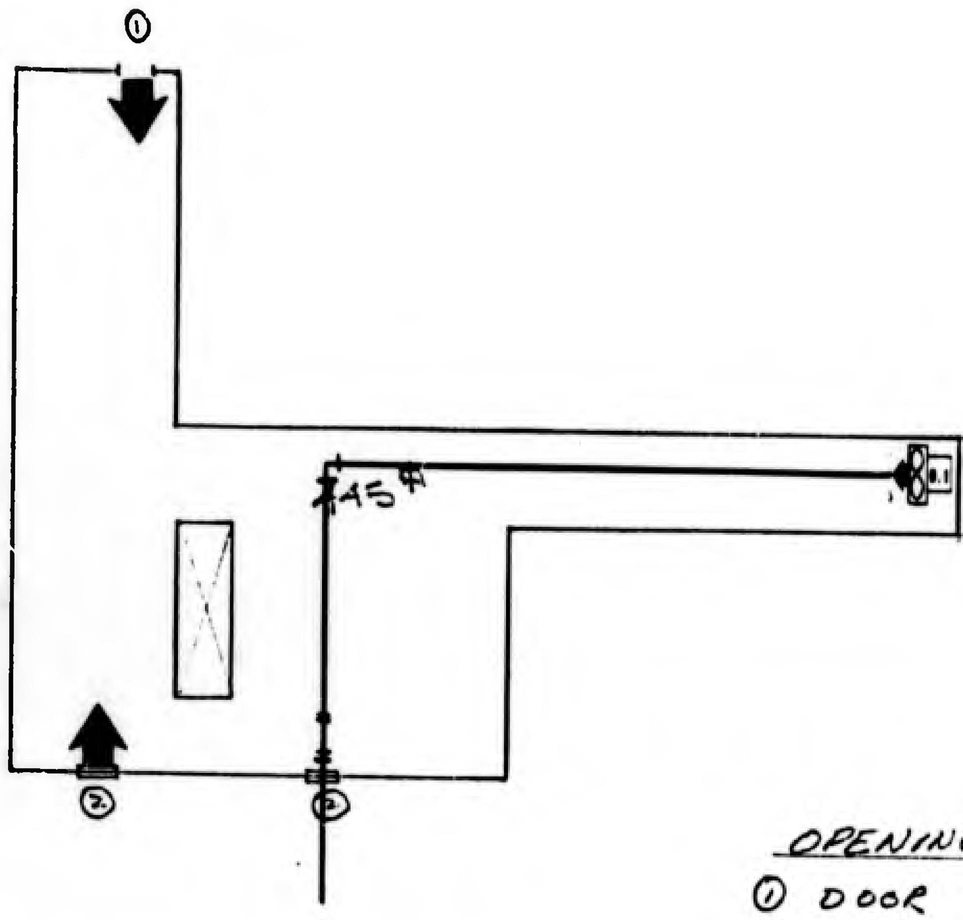
① WINDOW 4" x 15" x 96" SILL
② WINDOW 15" x x 84" SILL
③ WINDOW 36" x x 60" SILL
④ DOOR

SCALE 1" = 16'-0

RTI Facility No. 36

West 207 Street
Manhattan, New York City

SL 1644-0273
FN 02275

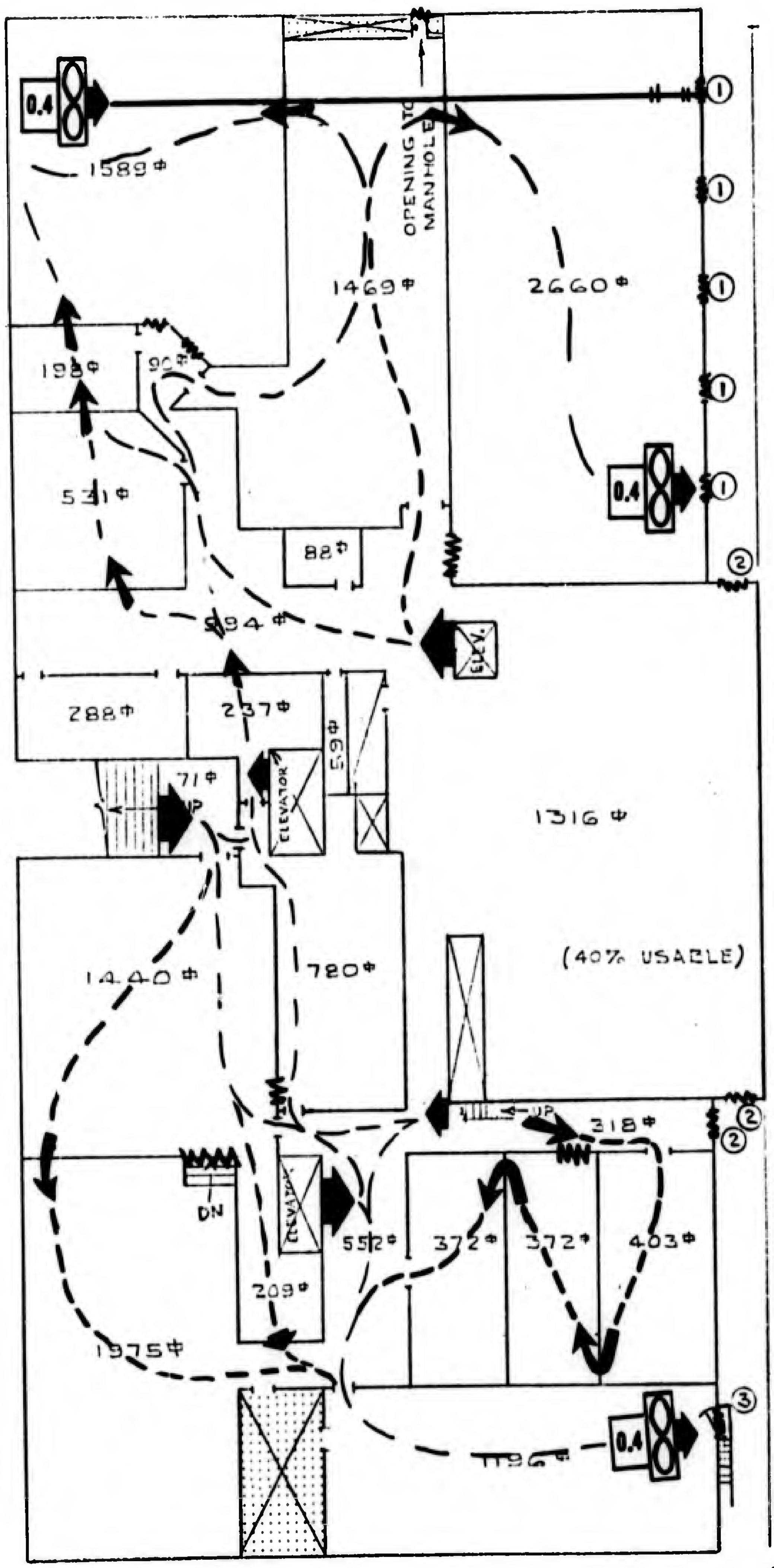


OPENINGS

① DOOR 30"x 78"

② WINDOW 36"x36"x 45"

SCALE 1" = 8'-0"



SCALE: 1" = 20'

OPENINGS
1. 30" DIA. 5'S
2. 3½' x 7' DOOR
3. 3' x 6½' DOOR

RTI Facility No. 37

Hillsboro Hotel (4 Par
Florida Avenue & Twigg
Tampa, Florida

SL 3261-0047
FN 00036

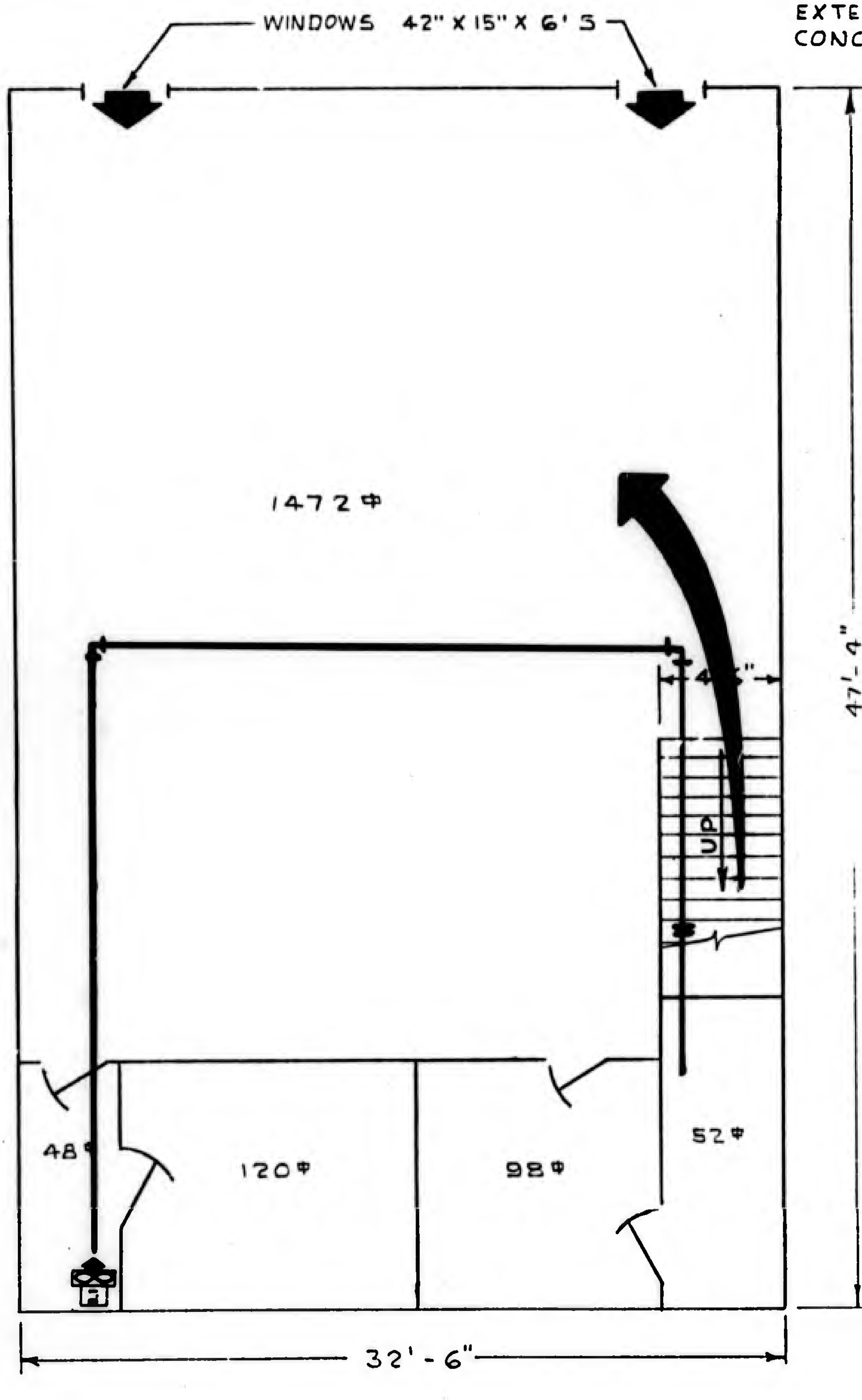
RTI Facility No. 38

Metropolitan Savings & Loan
303 No. 5th Street
Fargo, North Dakota

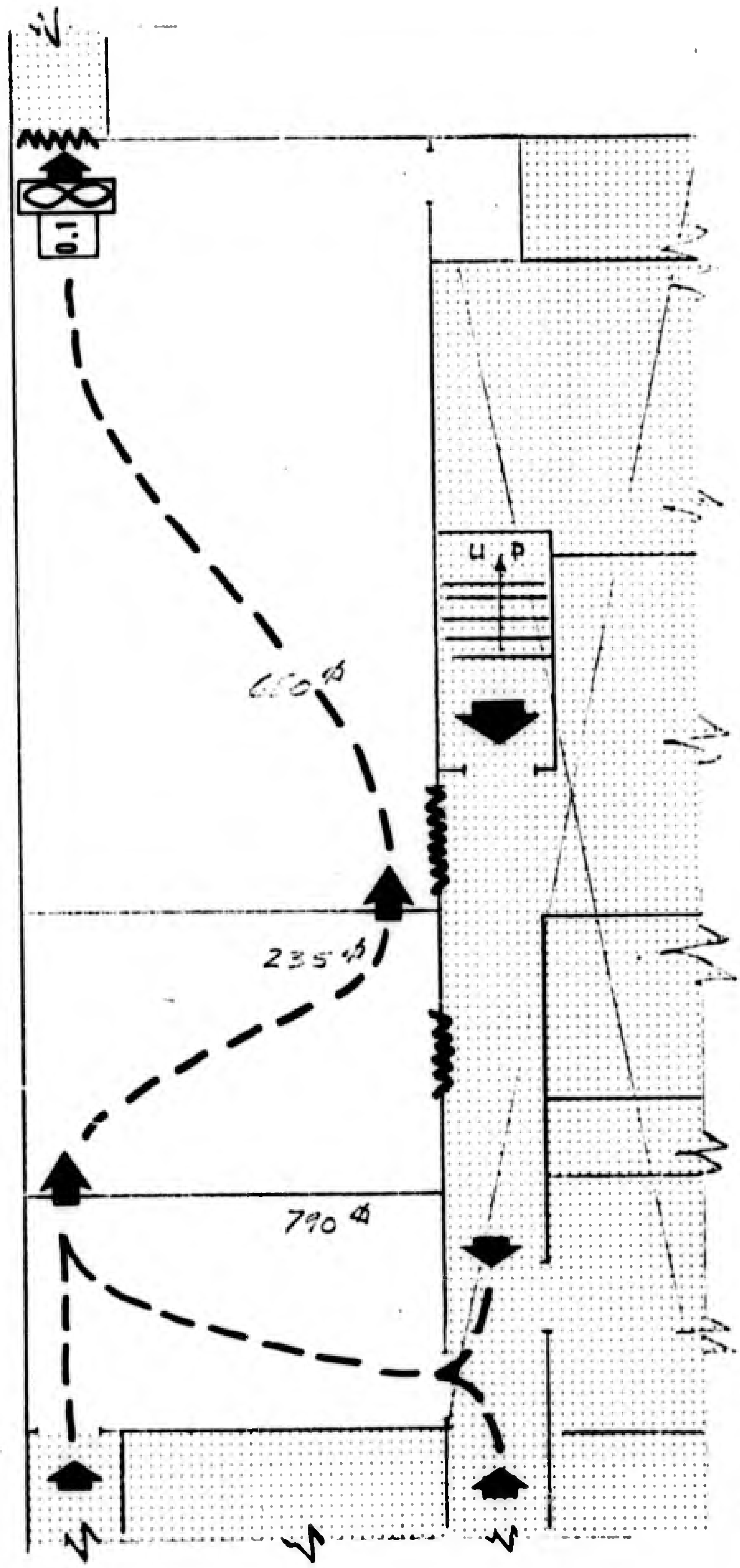
SL 6611-0009
FN 00528

SCALE: 1" = 6'

WALL THICKNESS
EXTERIOR 16"
CONCRETE



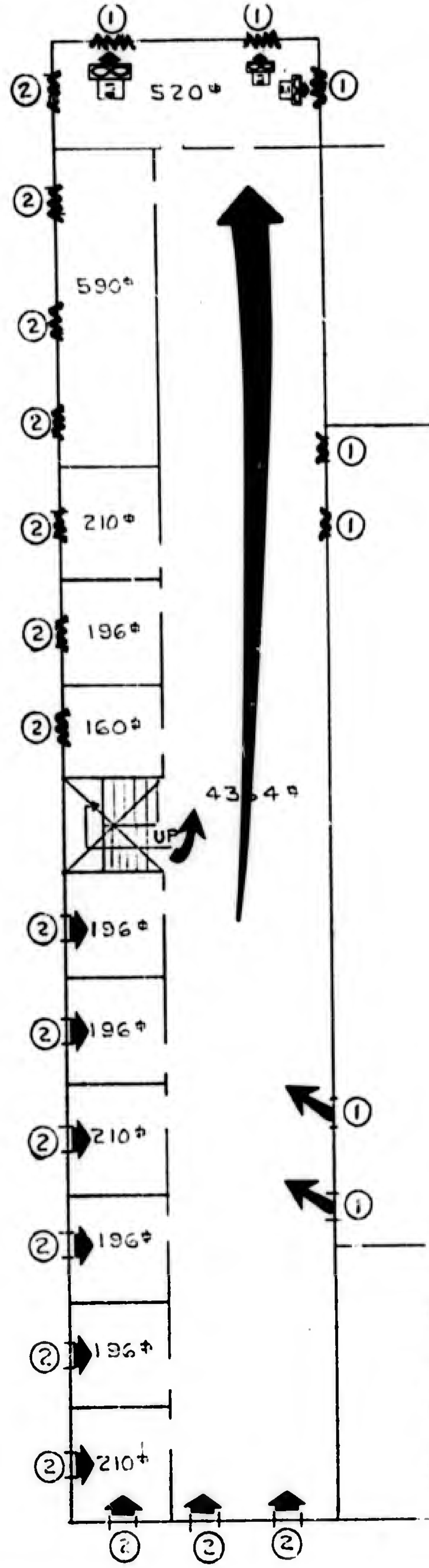
SCALE 1" = 8'-0



RTI Facility No. 39

Reed Hall Dormitory
North Dakota State University
Fargo, North Dakota

SL 6611-0004
FN 00215



WINDOWS
1. 34"W X 42"L X 44"S
2. 40"W X 24"L X 75"S

RTI Facility No. 40

Churchill Hall Boys Dormitory
North Dakota State University
Fargo, North Dakota

SL 6611-0010
FN 00564

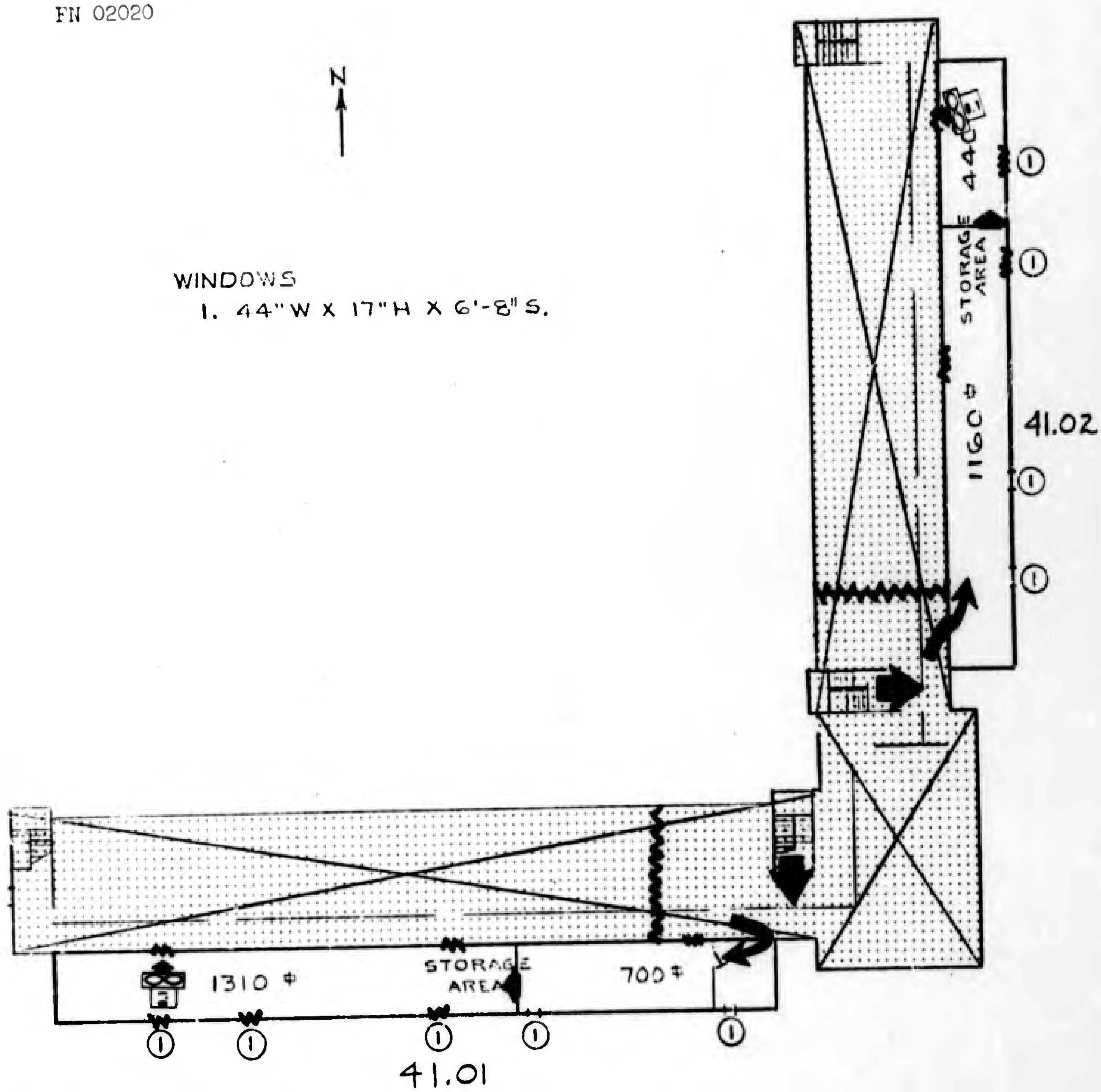
APARTMENT BUILDING D
SCALE: 1" = 30'

RTI Facility No. 41.01 & 41.02

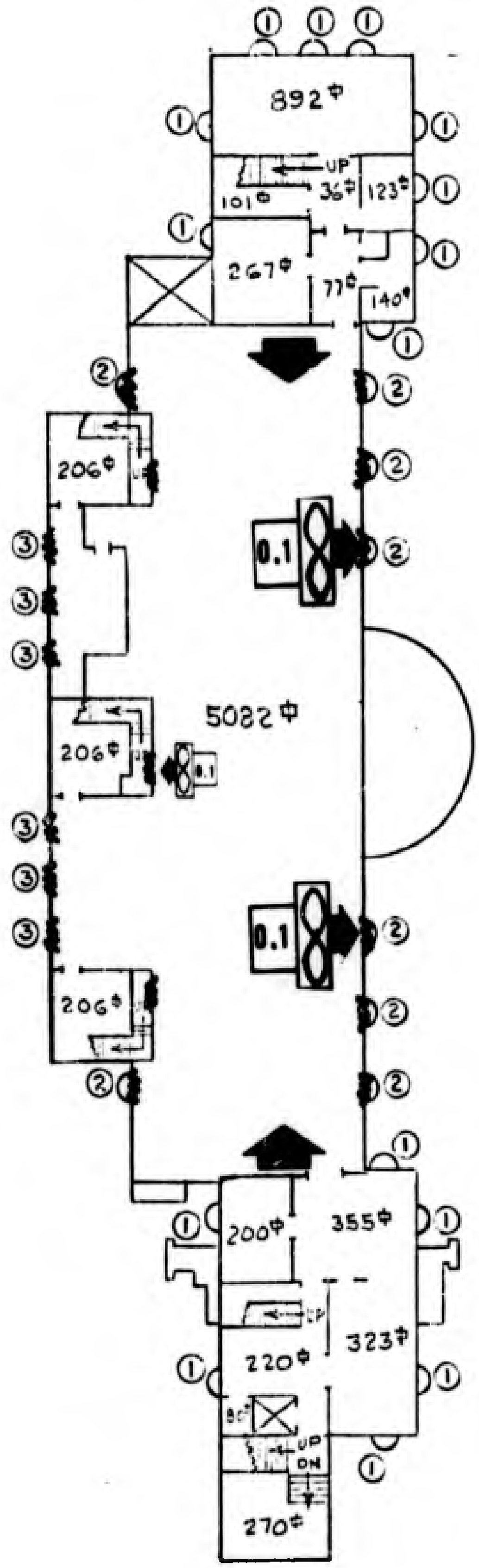
Cooperstown Building
(Married Student Housing)
University of Kentucky
Lexington, Kentucky

SL 2341-0008
FN 02020

WINDOWS
1. 44"W X 17"H X 6'-8"S.



SCALE: 1" = 30'



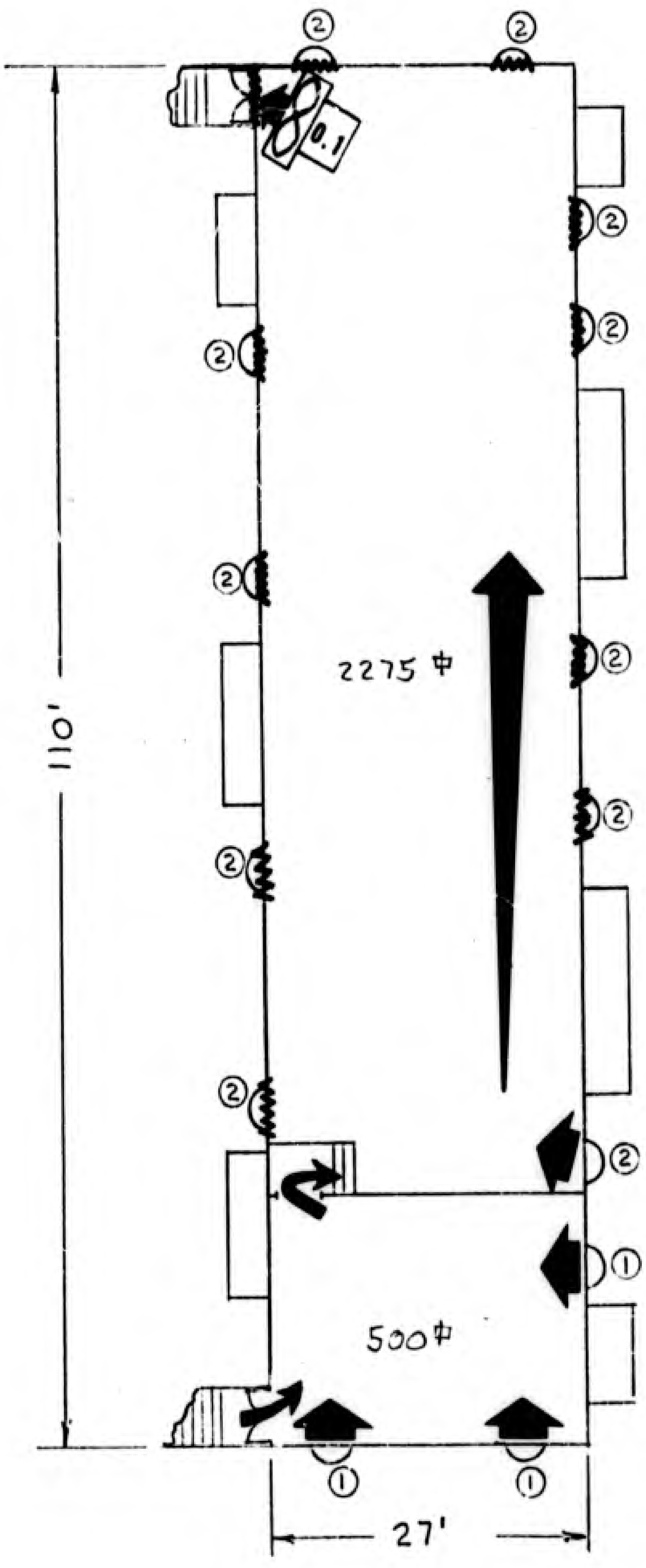
WINDOWS:
1. 4' X 5'-3"
2. 5' X 5'-3"
3. 3'-8" X 1'-10"

RTI Facility No. 42

Bowman Hall,
University of Kentucky
Lexington, Kentucky

SL 2341-0008
FN 01171

SCALE: 3/4" = 10'

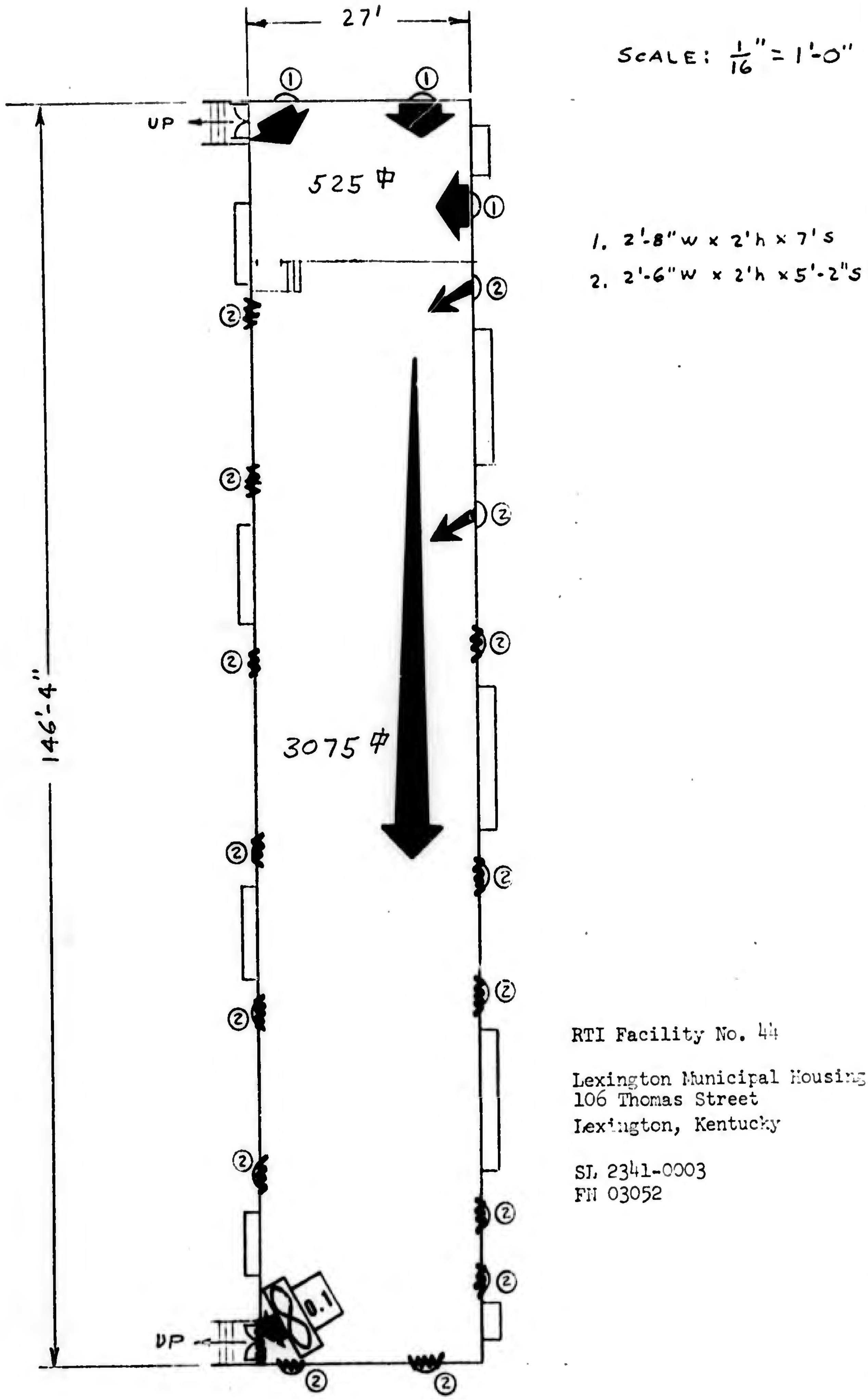


1. 2'-8" X 2'h X 7' S
2. 2'-6" X 2'h X 5'-2' S

RTI Facility No. 43

Lexington Municipal Housing
302 Yellman Drive
Lexington, Kentucky

SL 2341-0004
FN 03039



RTI Facility No. 44

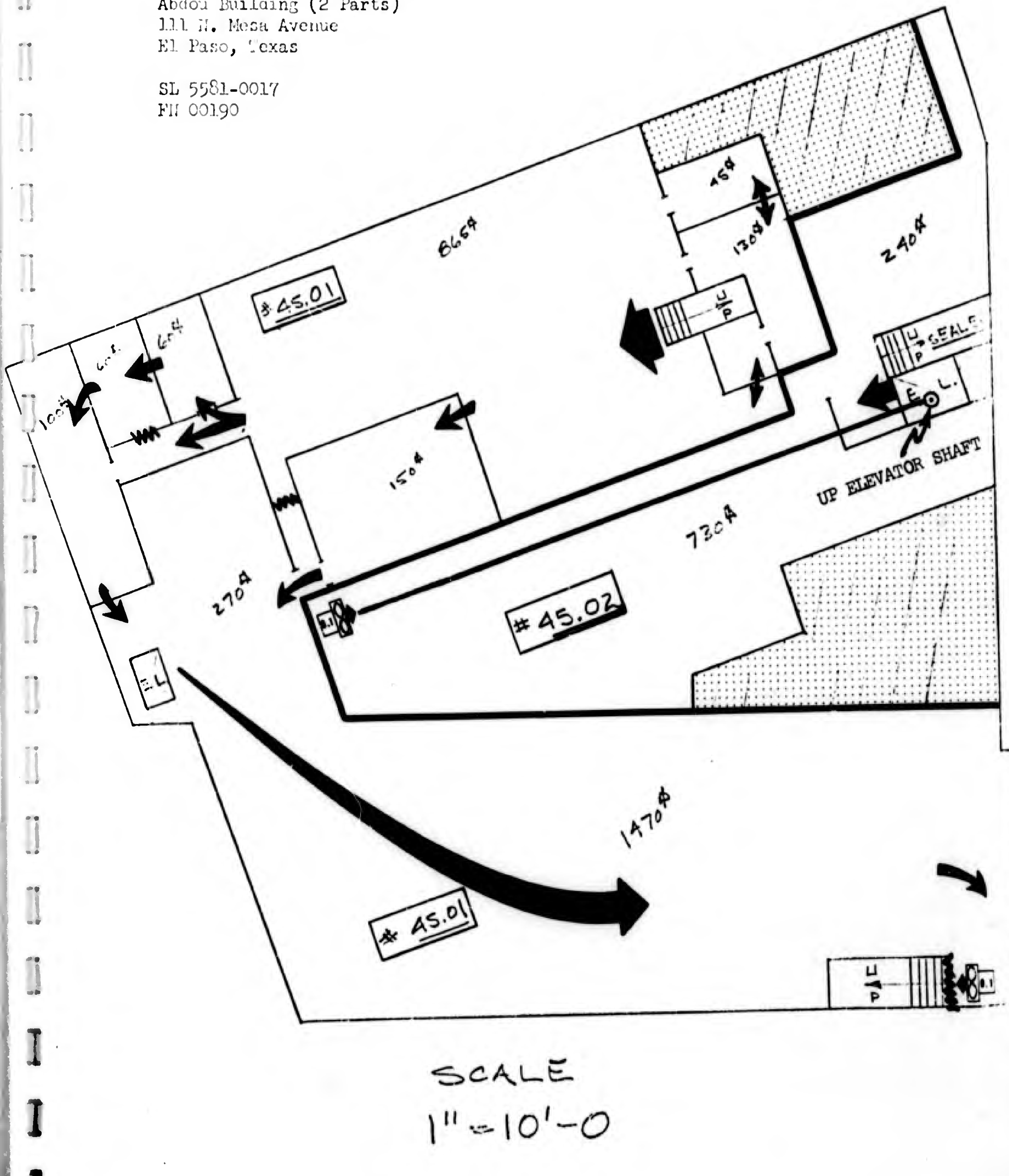
Lexington Municipal Housing
106 Thomas Street
Lexington, Kentucky

SL 2341-0003
FN 03052

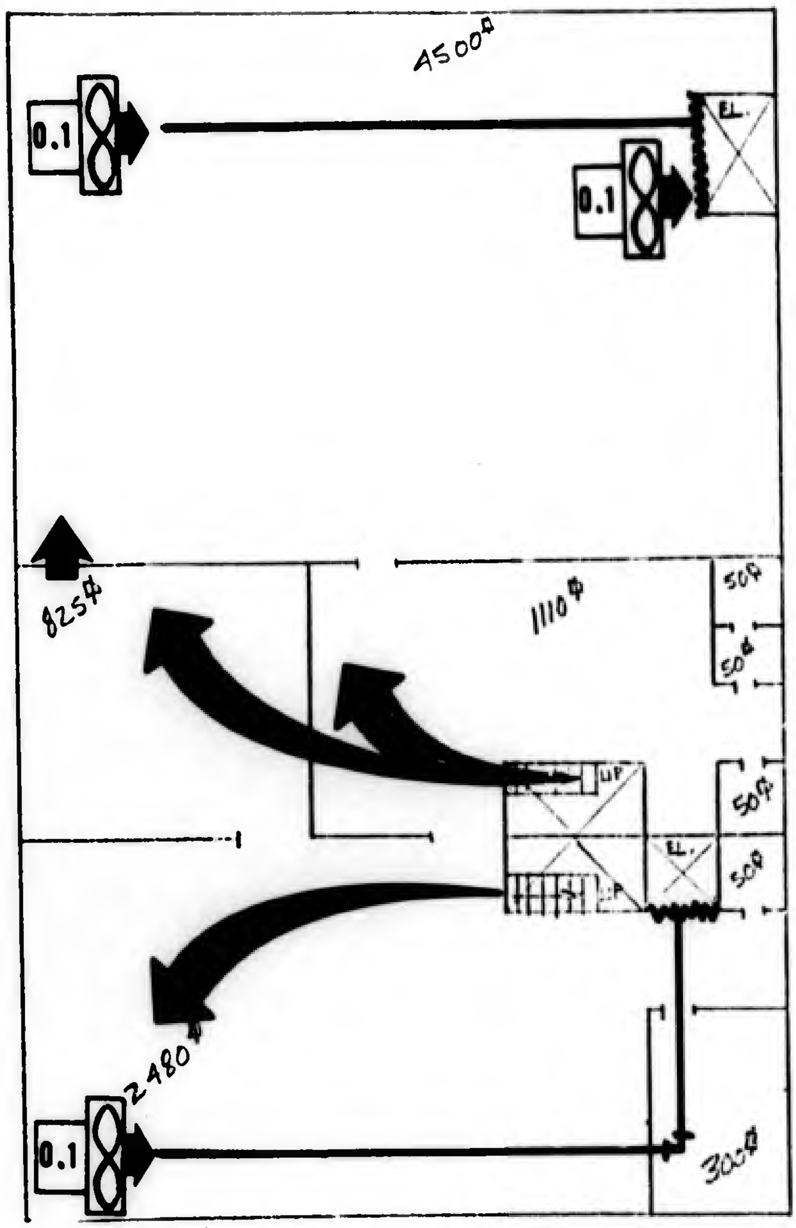
RTI Facility No. 45.01 & 45.02

Abdou Building (2 Parts)
111 N. Mesa Avenue
El Paso, Texas

SL 5581-0017
FN 00190



SCALE
1"=20'-0



RTI Facility No. 46

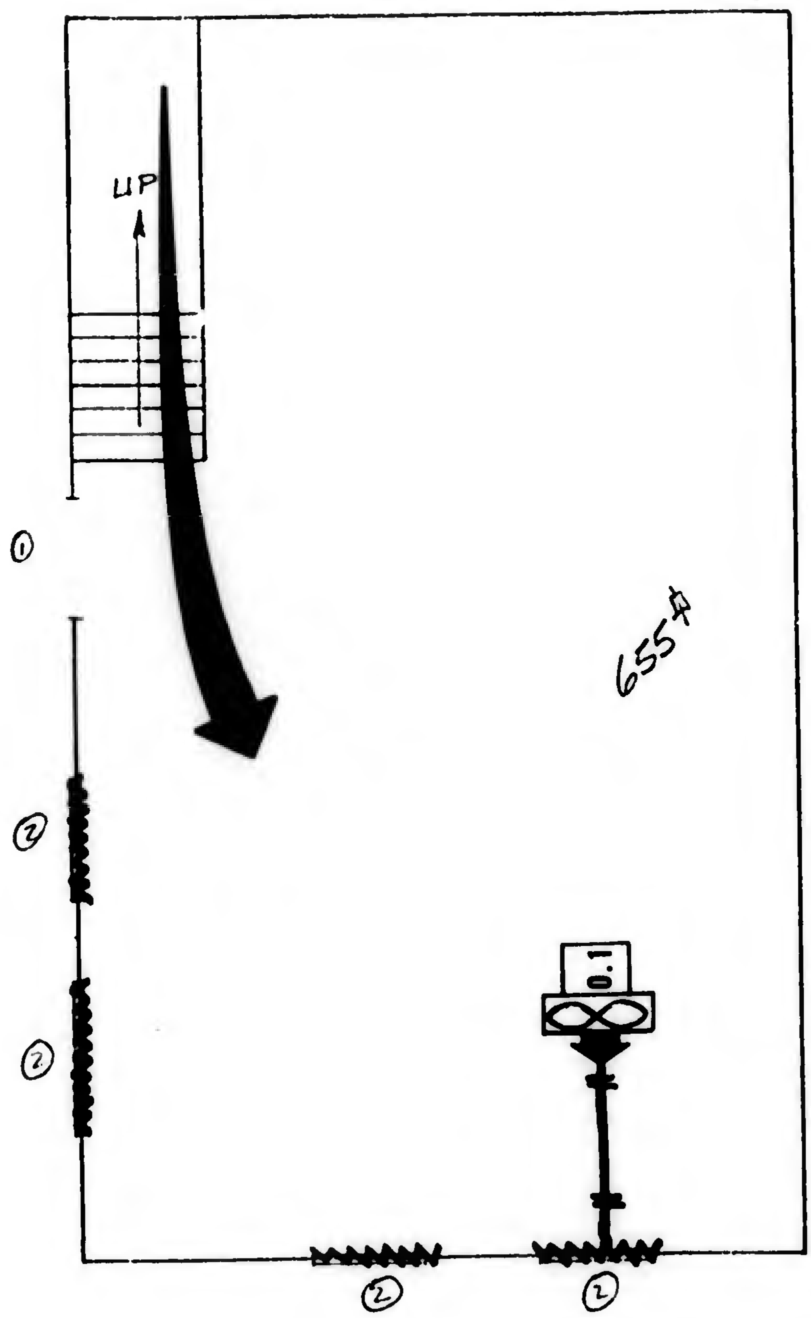
Aaronson Brothers
526 E. Overland Street
El Paso, Texas

SL 5581-0017
FN 00240

RTI Facility No. 47

Southern Pacific Lines
300 N. Campbell Street
El Paso, Texas

SL 5581-0017
FN 00283



OPENINGS

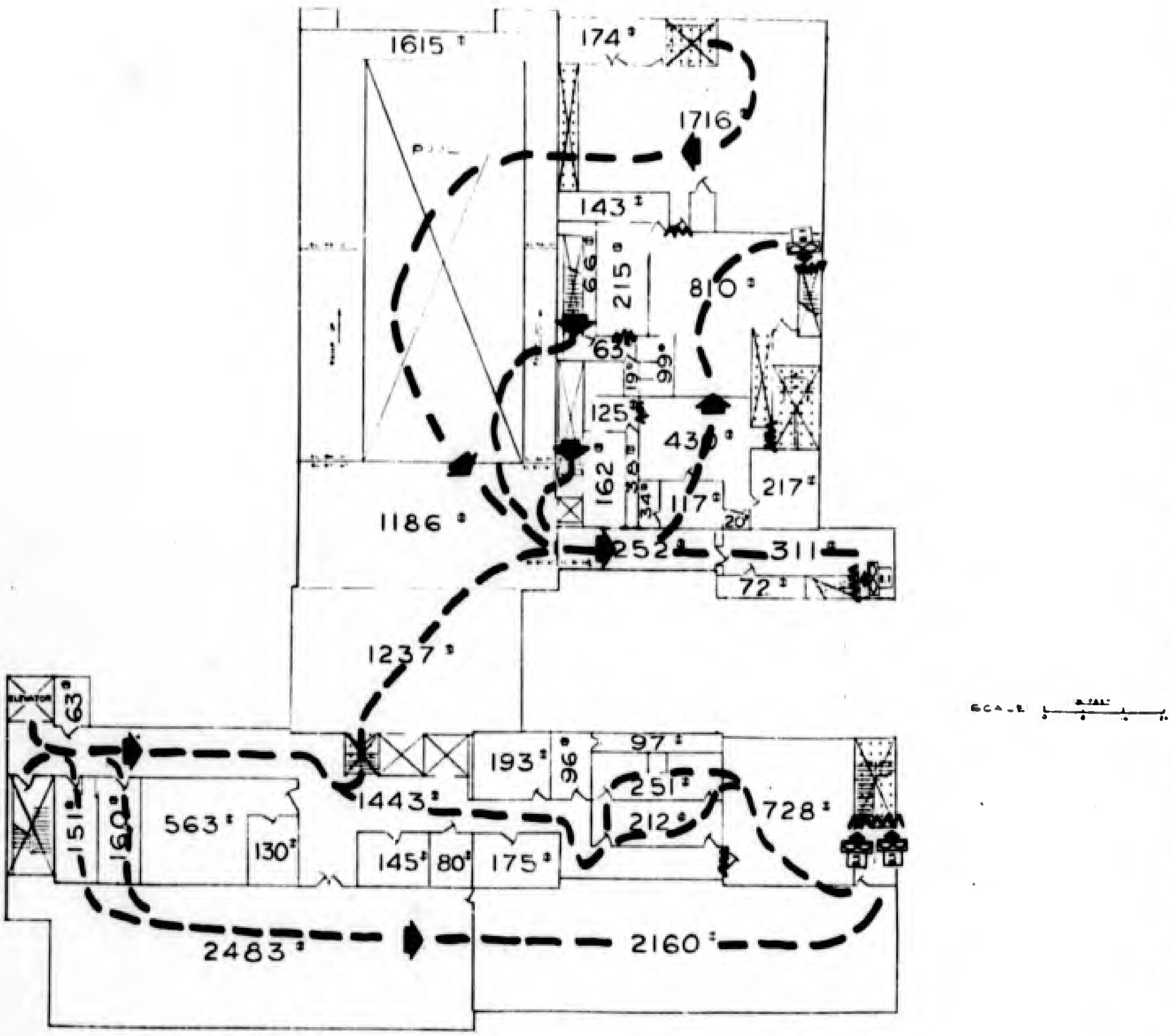
① DOOR
② WINDOW 48"x30"
x 72" SILL

SCALE
1"= 5'-0

RTI Facility No. 48

Y.M.C.A. (5 Parts)
701 Montana Avenue
El Paso, Texas

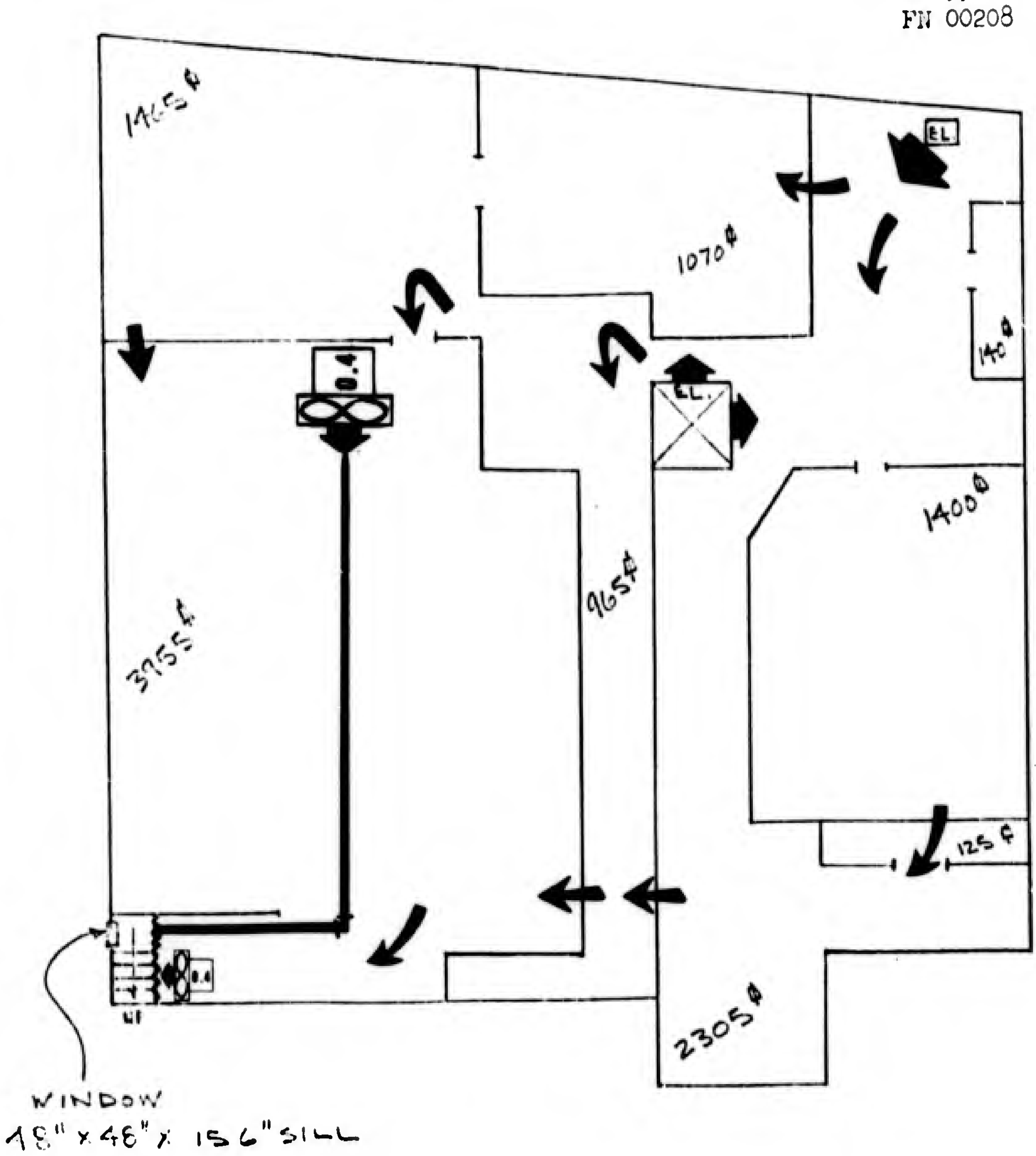
SL 5581-0022
FN 00147



RTI Facility No. 49

Knox Hotel
216 San Francisco Street
El Paso, Texas

SL 5581-0017
FN 00208

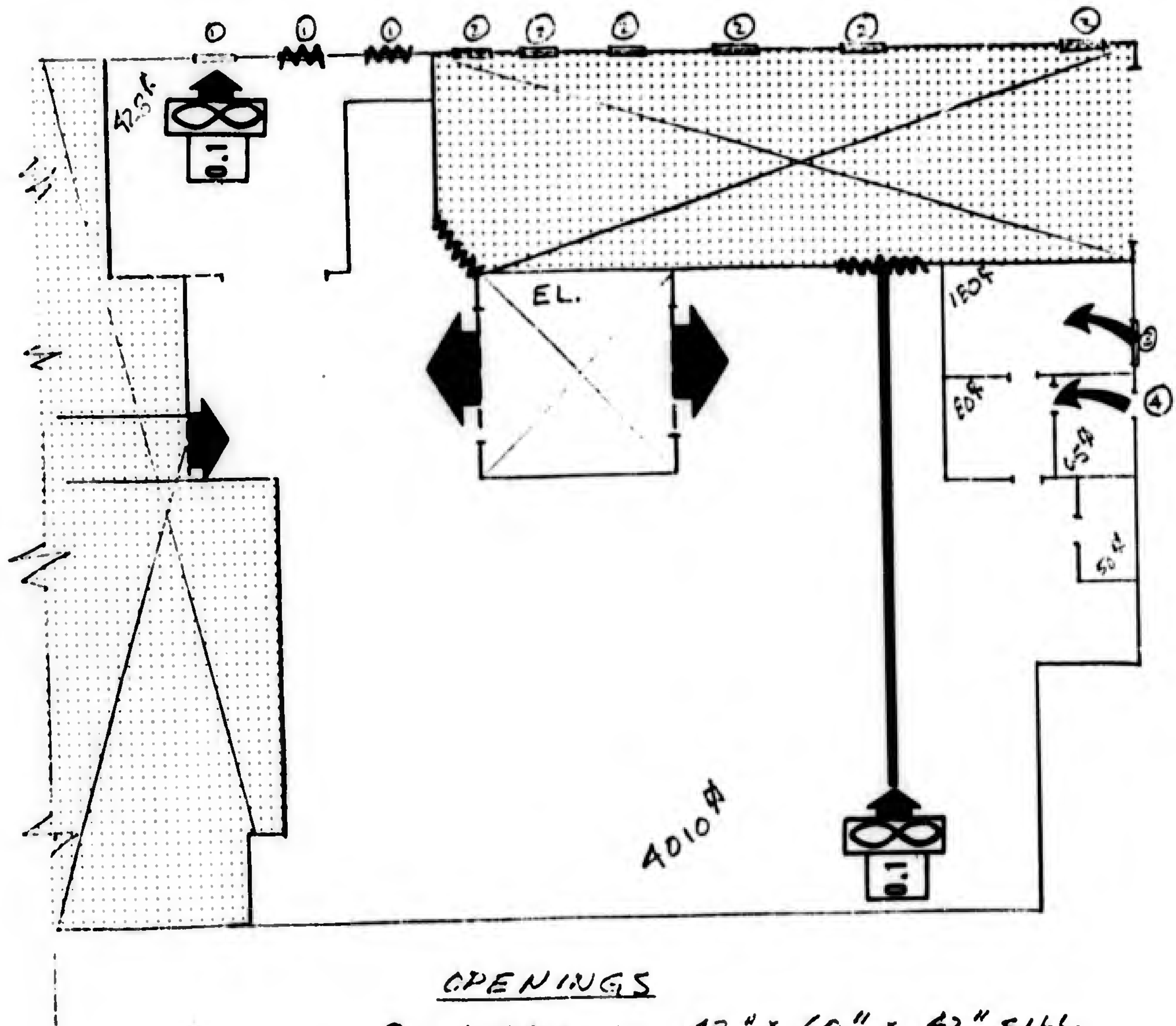


SCALE
1" = 20'-0

RTI Facility No. 50

Security Warehouse Company (Pt. 1)
311 5th Avenue, North
Minneapolis, Minnesota

SL 4433-0037
FN 00664



OPENINGS

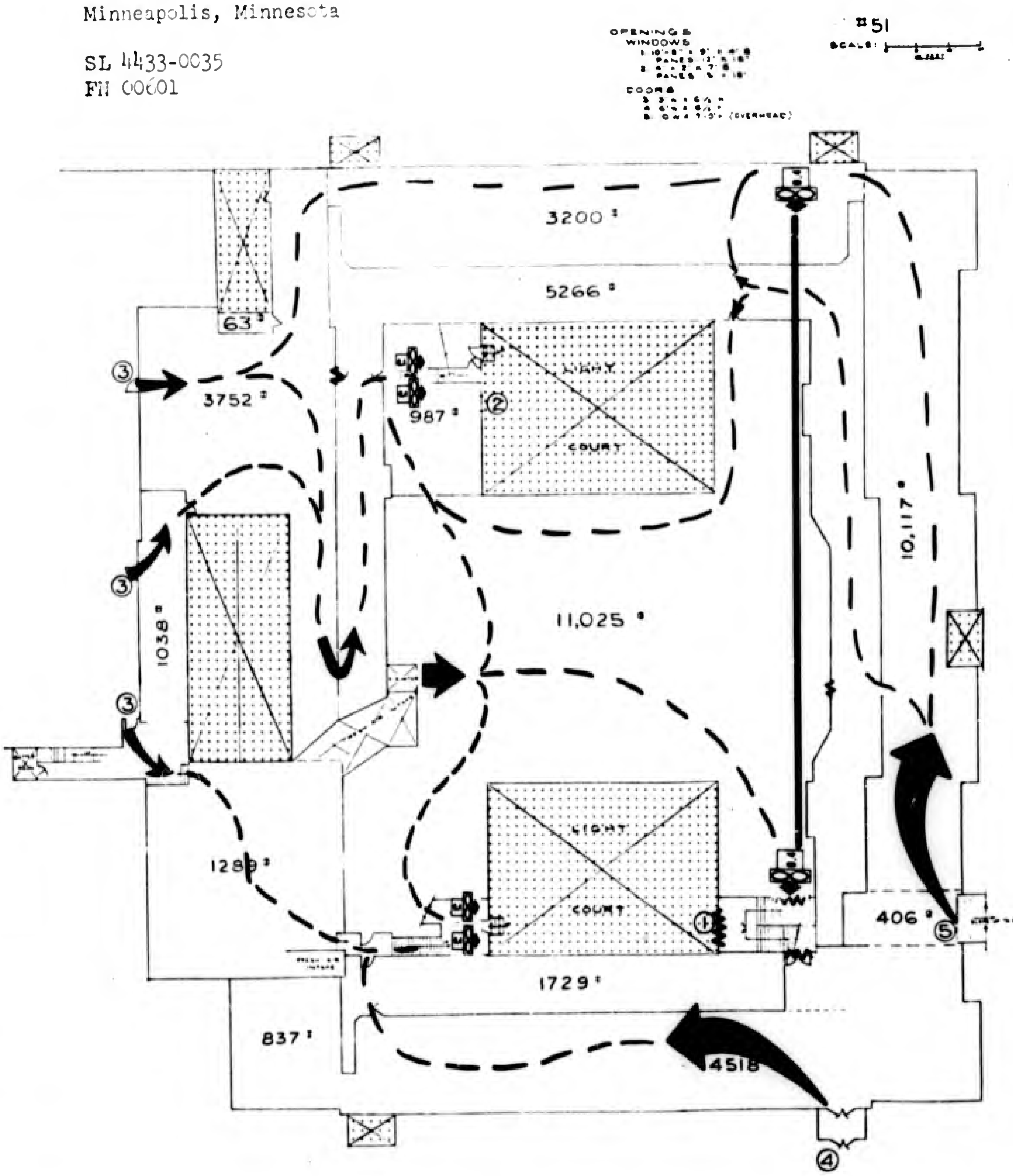
①	WINDOW	43" x 60" x 42" SILL
②	WINDOW	48" x 60" x 84" SILL
③	WINDOW	48" x 60" x 12" SILL
④	DOOR	30" x 78"

SCALE 1" = 16'-0

RTI Facility No. 51

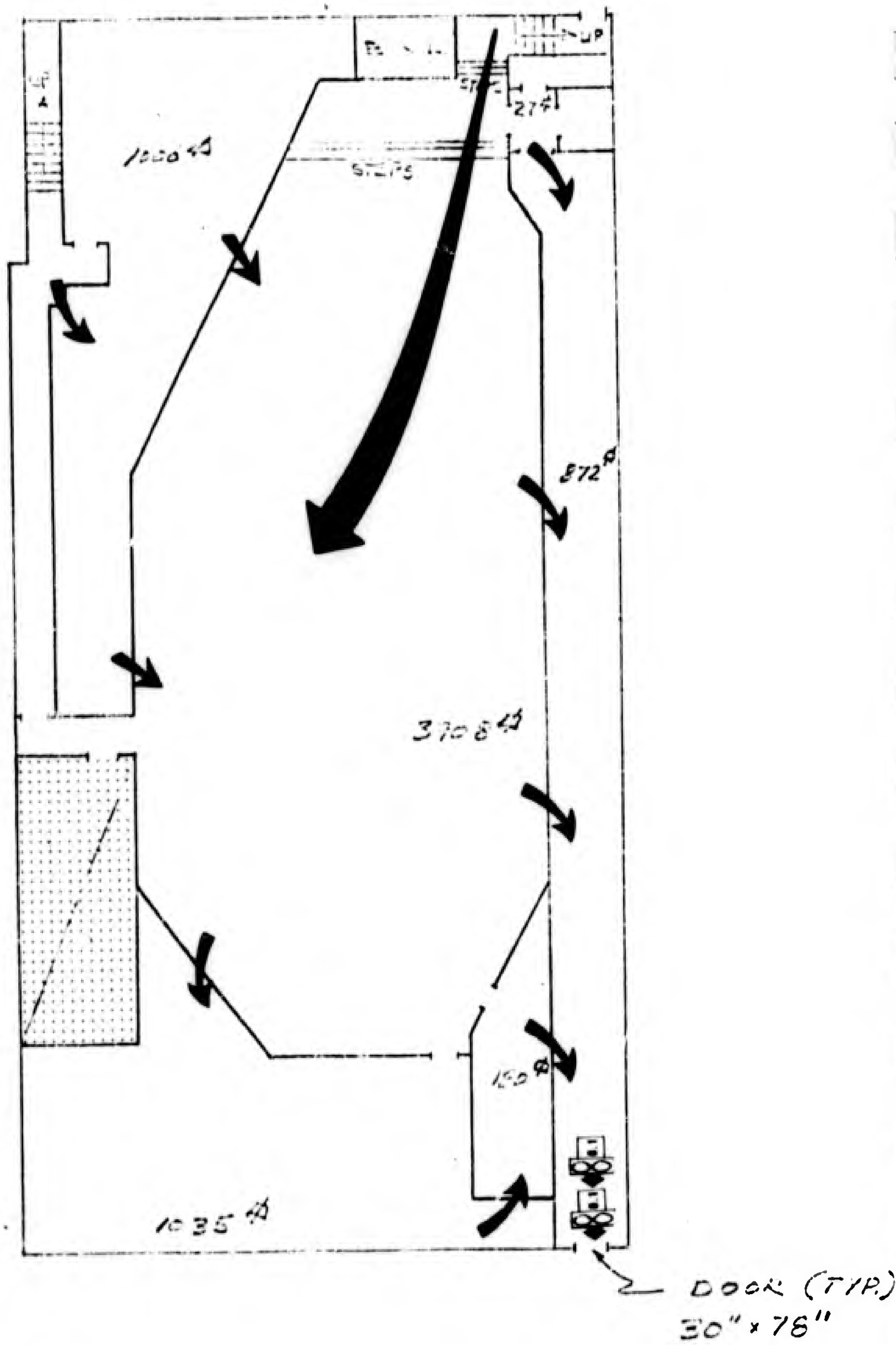
Lincoln Junior High School
2101 12th Avenue, N.
Minneapolis, Minnesota

SL 4433-0035
FN 00601



Facility No. 12
Dupree's Clothing
711 Nicollet Avenue, S.
Minneapolis, Minnesota

SL 4433-0046
IN 01731

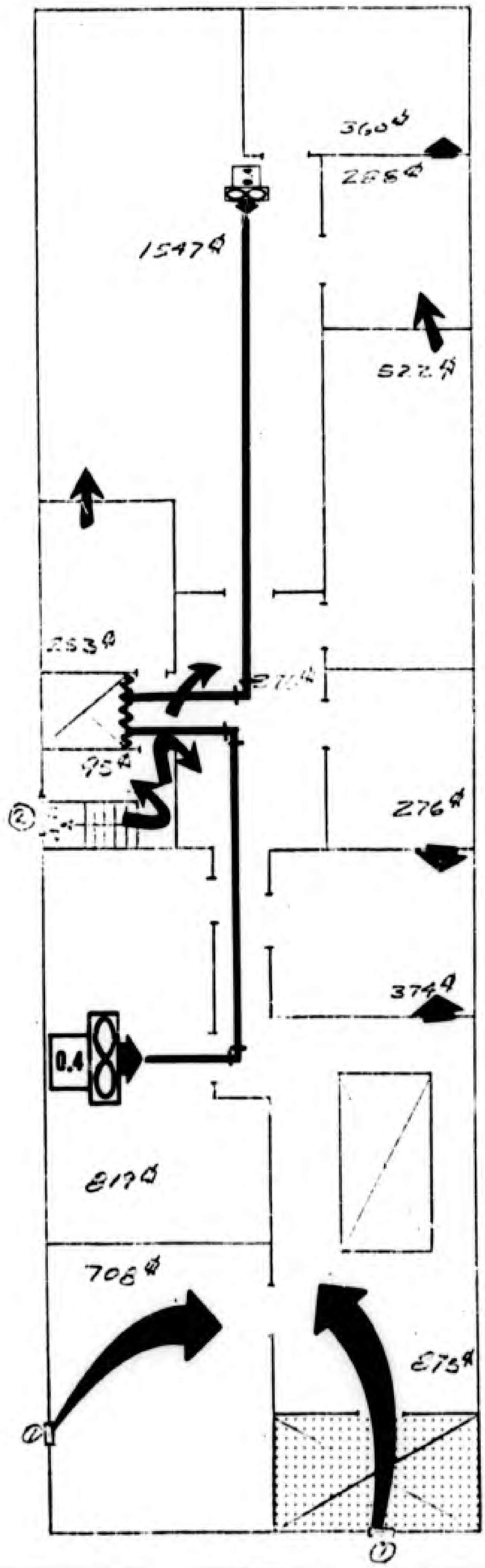


SCALE
1" = 20'-0

RTI Facility No. 53

Andrews Exchange Building
320-322 South 4th Street
Minneapolis, Minnesota

SL 4433-0048
FN 00842



OPENINGS

① WINDOW 18"x6"x108" SILL

② WINDOW (IN STAIRWELL) 48"x 48"

SCALE

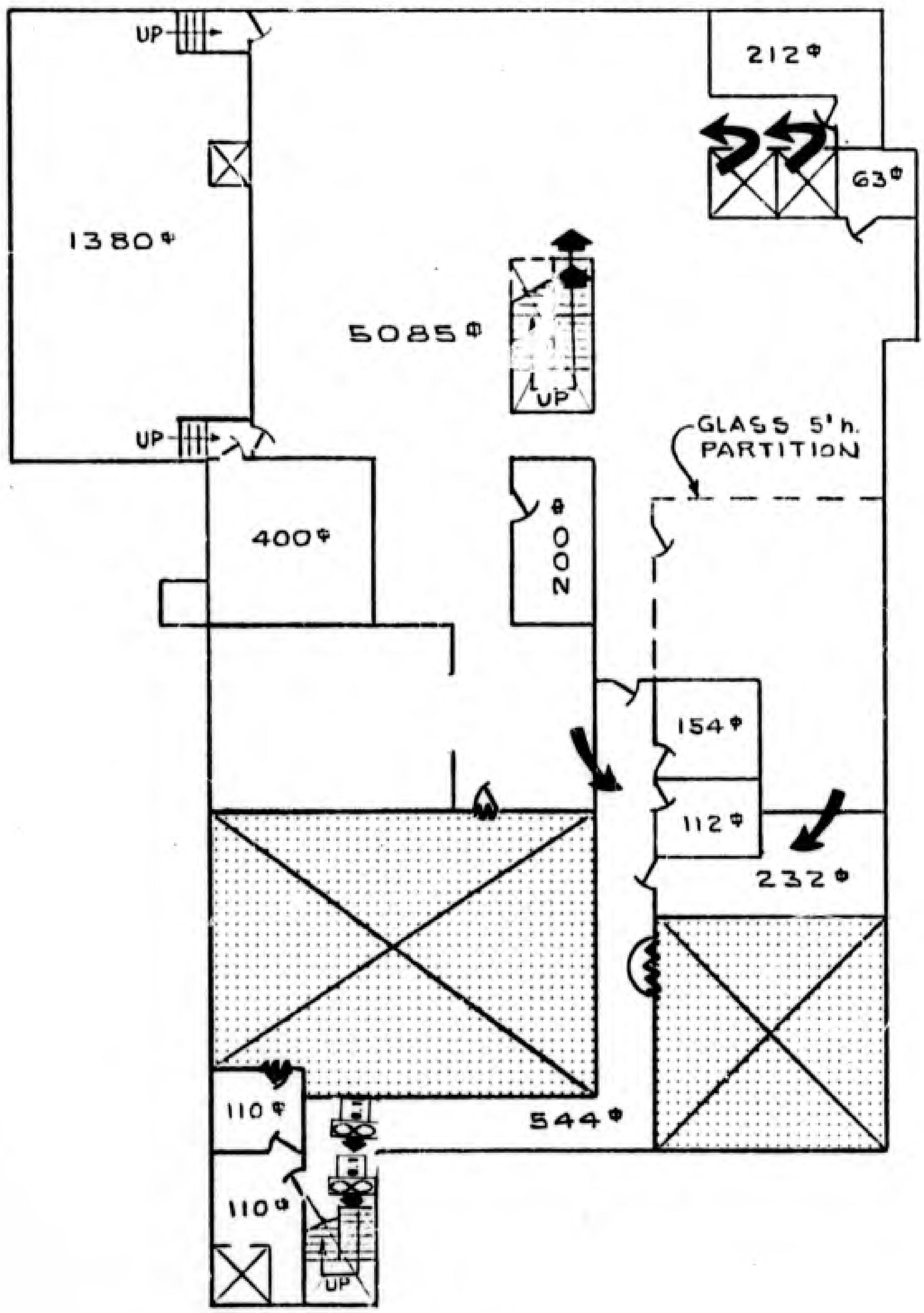
1" = 16'-0

SCALE: 1" = 20'

RTI Facility No. 54

Northwestern National Bank
3030 Nicollet Avenue
Minneapolis, Minnesota

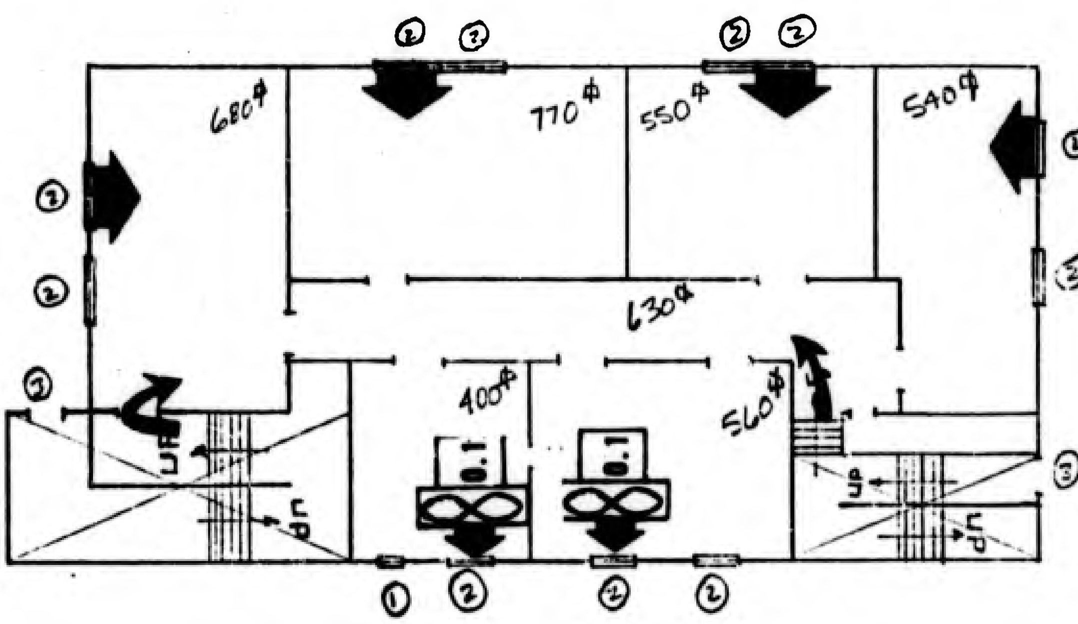
SL 4433-0085
FN 00148



RTI Facility No. 55

St. Charles Parochial School
2017 Montrose Street
Philadelphia, Penn.

SL 2675-0126
FN 02783



OPENINGS

① WINDOW 18" x 36" x 88" SILL
② WINDOW 42" x 36" x 88" SILL
③ DOOR

SCALE 1" = 20'-0

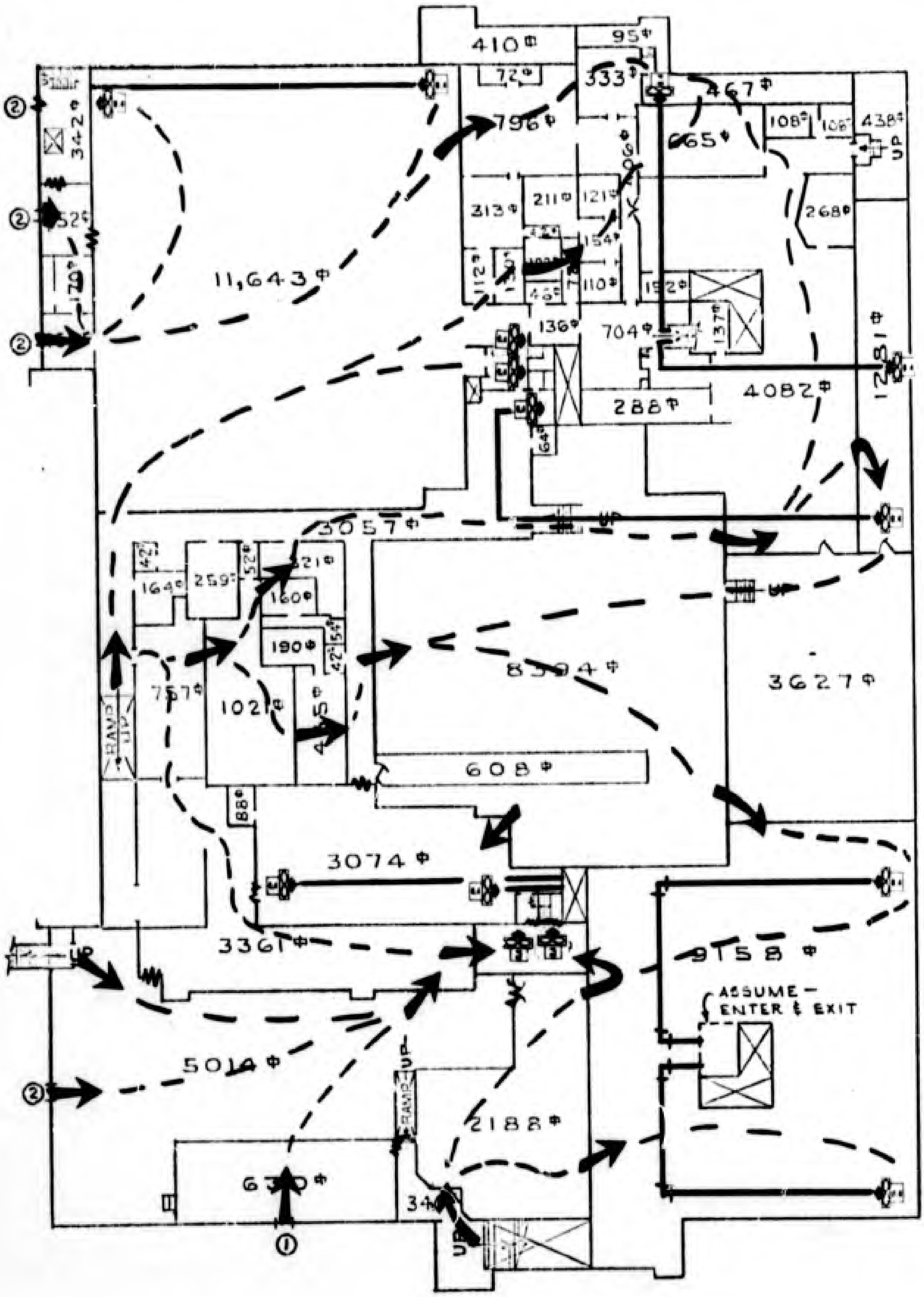
RTI Facility No. 56

Coffman Memorial Union
University of Minnesota
Minneapolis, Minnesota

SL 4433-0052
FN 01239

SCALE: 1" = 40'

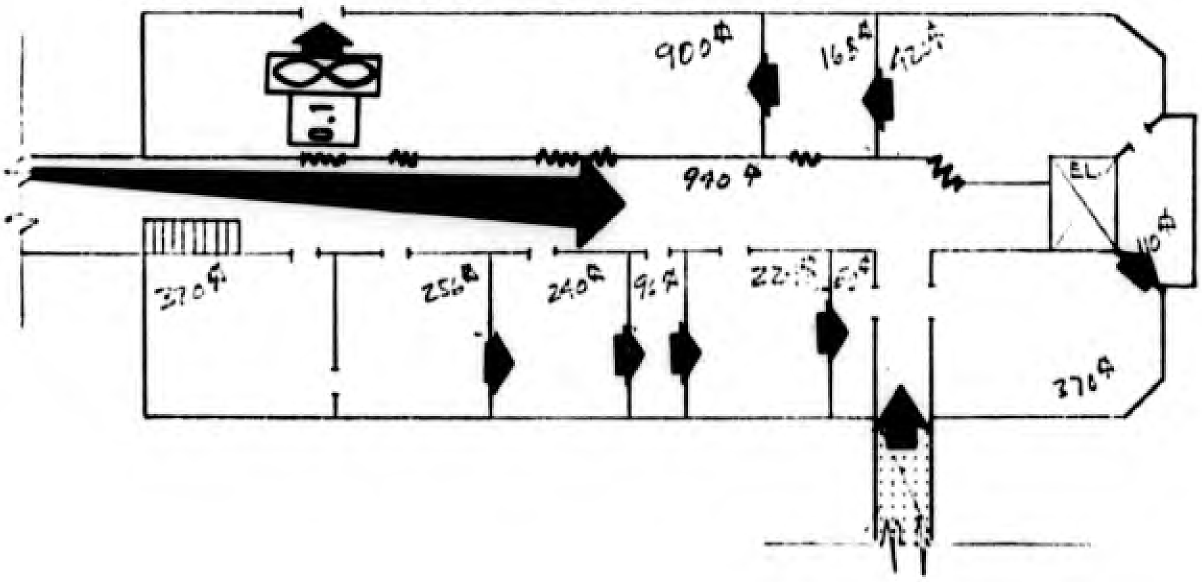
WINDOWS:
1. 36" X 18" X 8' S
2. 36" X 18" X 9' S



RTI Facility No. 57

Curtis Court Apts. (Part 1)
317 South 10th Street
Minneapolis, Minnesota

SL 4433-0056
FN 00994



SCALE 1" = 20'-0

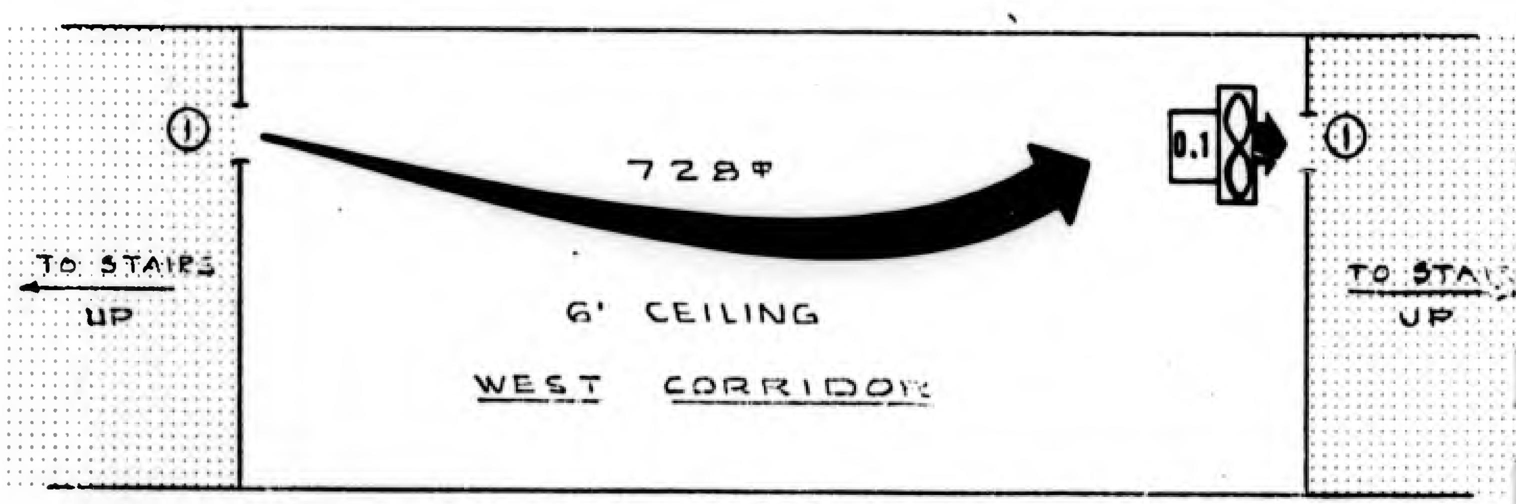
RTI Facility No. 58

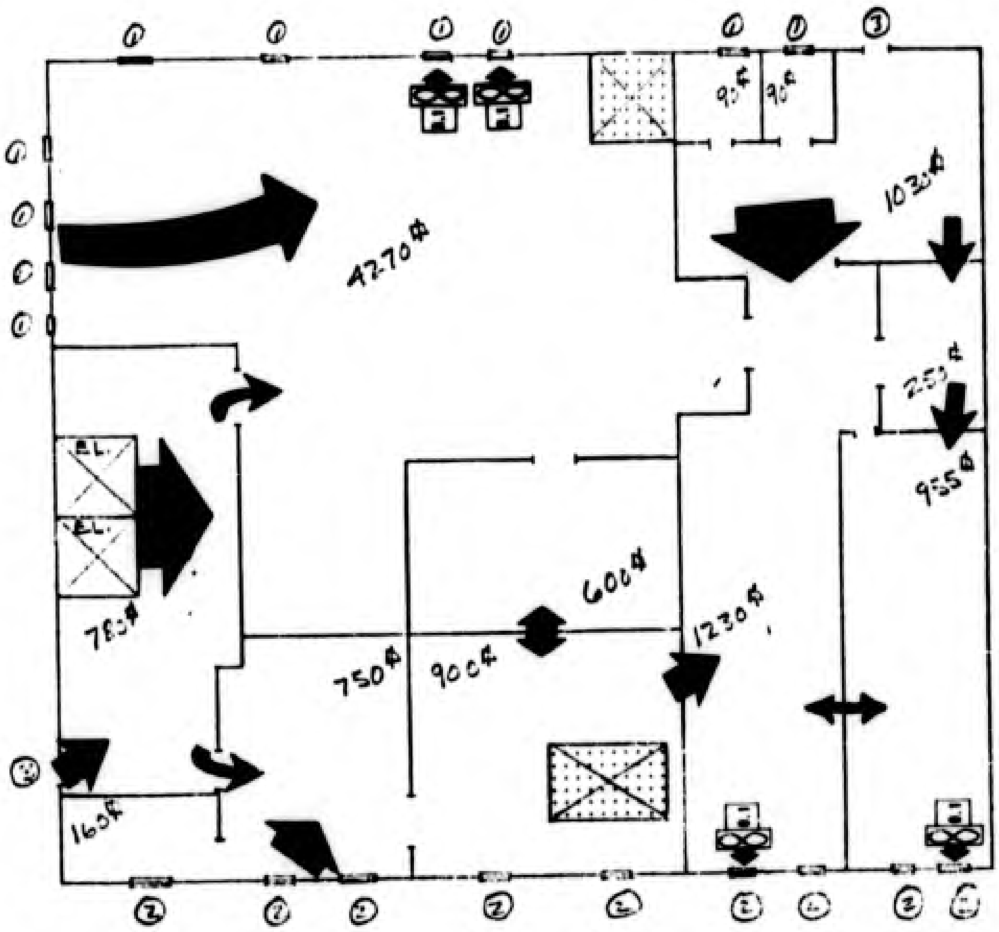
Ramsey Junior High School
4920 Nicollet Avenue South
Minneapolis, Minnesota

SL 4433-0118
FN 00226

SCALE: 1" = 10'

OPENINGS: (DOORS)
1. 30" X 42" X 2'S





OPENINGS
① WINDOW 66" x 42" x 88" SILL
② WINDOW 42" x 30" x 108" SILL
③ DOOR

SCALE 1" = 25'-0

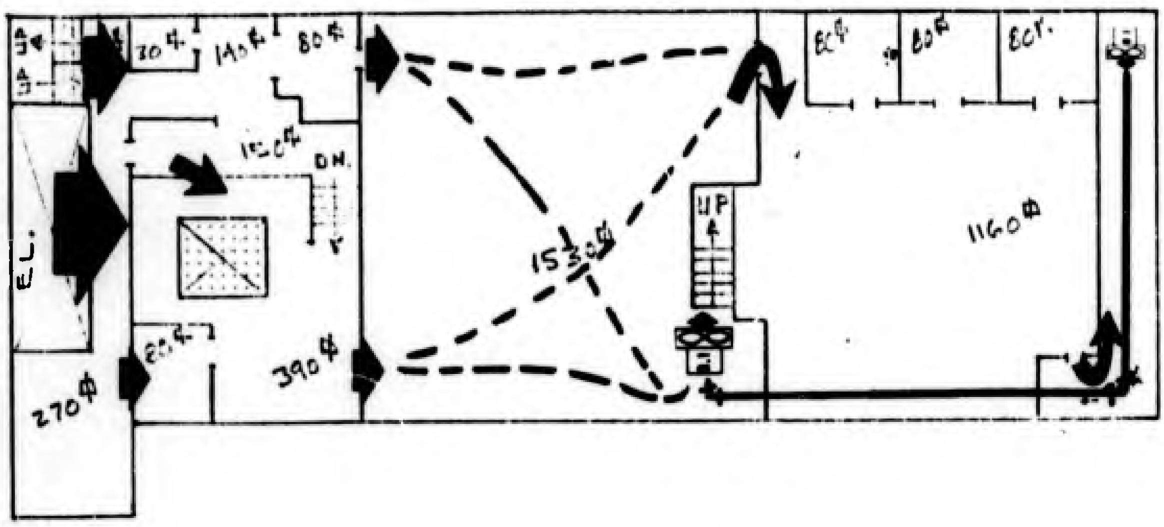
RTI Facility No. 59

Seeds Building
1210 Race Street
Philadelphia, Pennsylvania

SL 2675-0020
FN 01871

RTI Facility No. 60
Broadway Stevens Building
300 Broadway
Camden, New Jersey (Phil SMSA)

SL 1562-0007
FN 00116

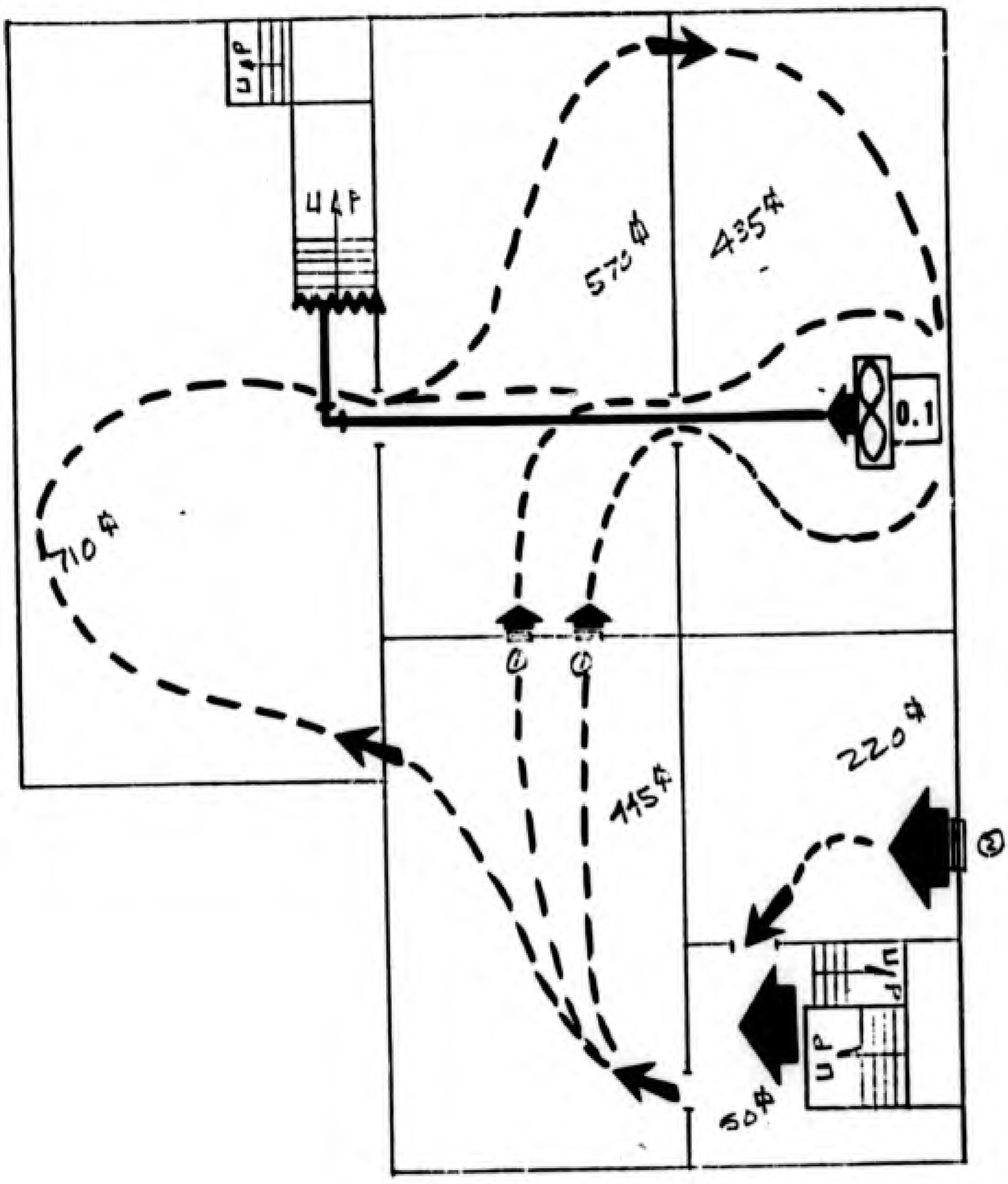


SCALE
1" = 20'-0

RTI Facility No. 61

114 Ellis Street
Haddonfield, New Jersey
(Phil SMSA)

SL 1562-0066
FN 02218



OPENINGS

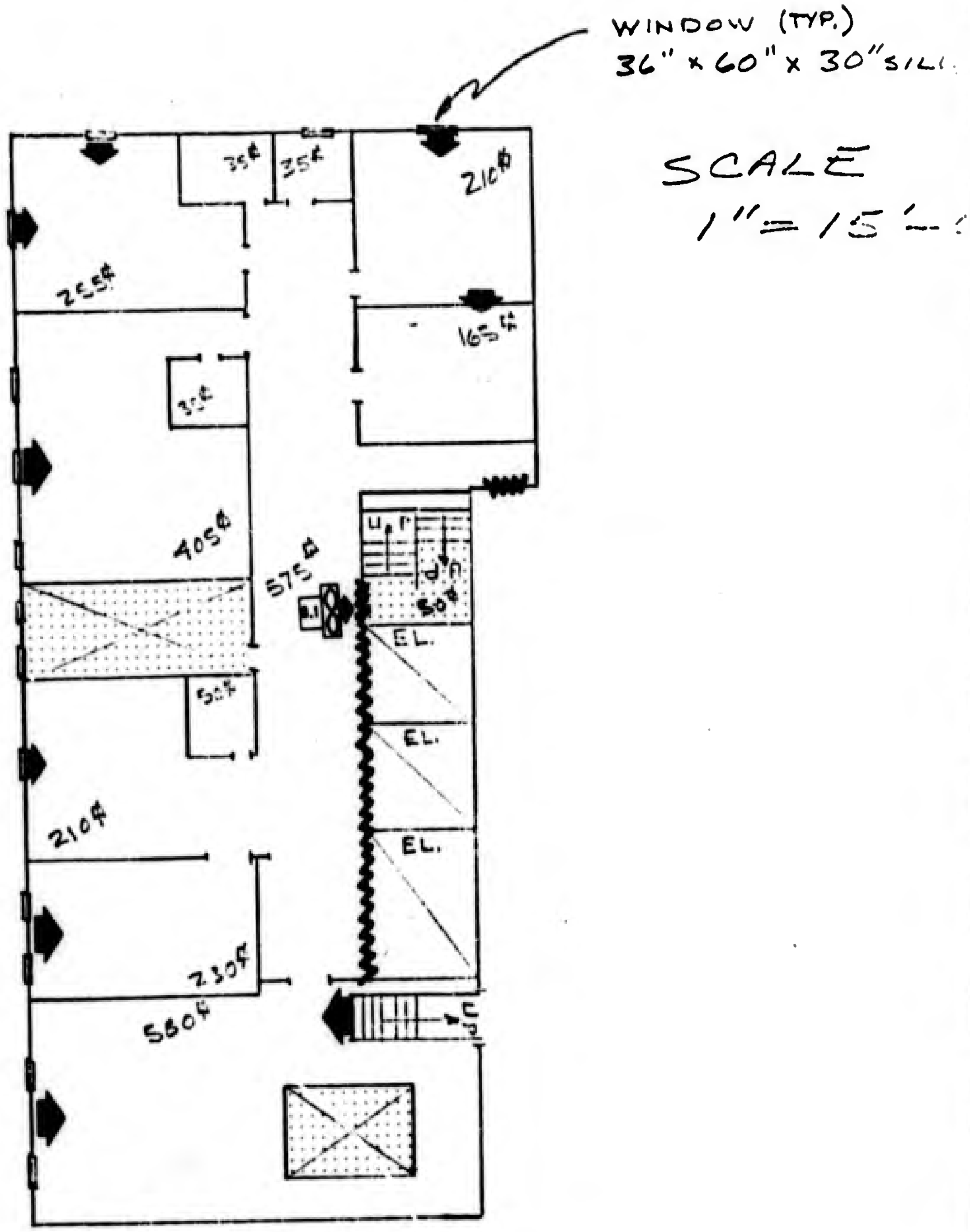
① OPENING 12" diameter x 96" sill
② WINDOW 24" x 36" x 117" sill

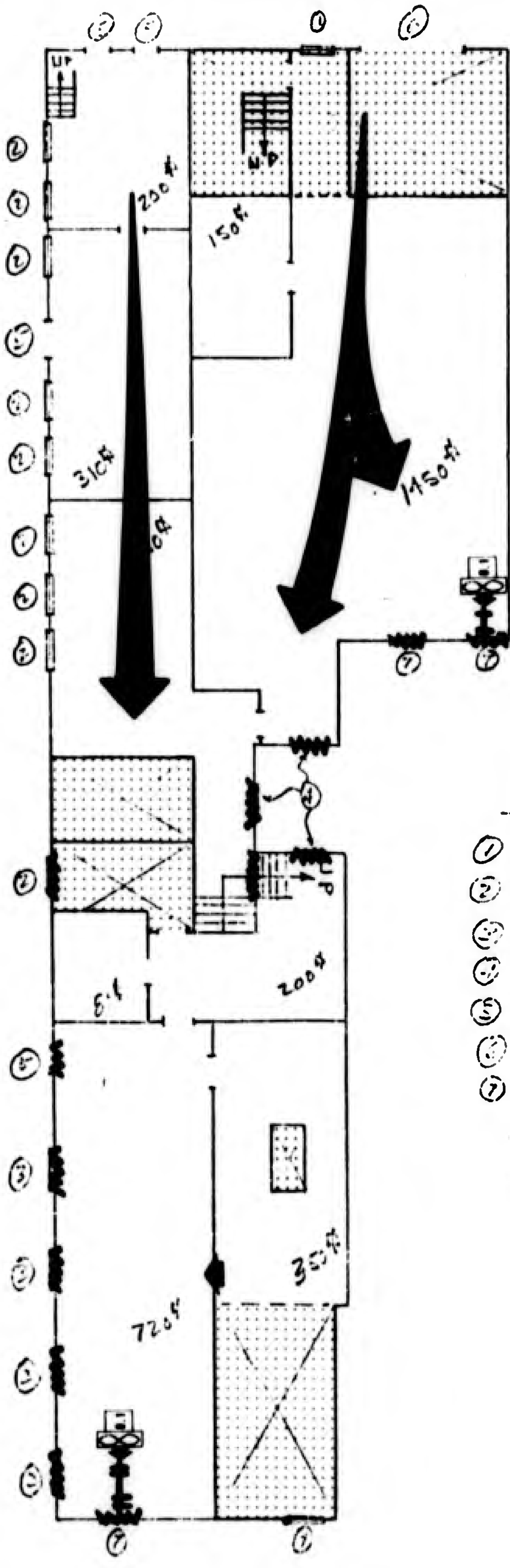
SCALE 1" = 10'-0

RTI Facility No. 62

Town House Apartment
1832-34 Spruce Street
Philadelphia, Penn.

SL 2675-0013
FN 01258





RTI Facility No. 63
Galilee Mission Chapel
823 Vine Street
Philadelphia, Penn.

SL 2675-0026
FN 02275

OPENINGS

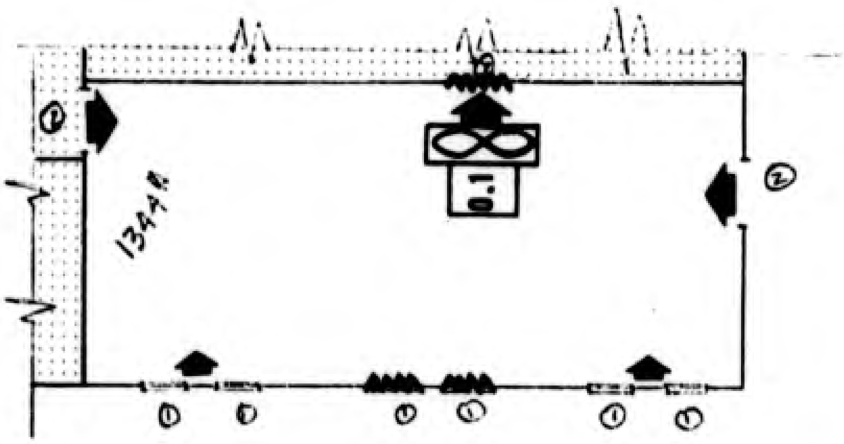
① WINDOW 25" x 26" x 69" SILL
② WINDOW 35" x 44" x 62" SIL
③ WINDOW 56" x 56" x 42" SIL
④ WINDOW 41" x 60" x 30" SIL
⑤ DOOR
⑥ GARAGE DOOR
⑦ WINDOW

SCALE
1" = 16'-0

RTI Facility No. 64

Sacred Heart Manor
6445 Germantown Avenue
Philadelphia, Penn.

SL 2675-0075
FN 01553



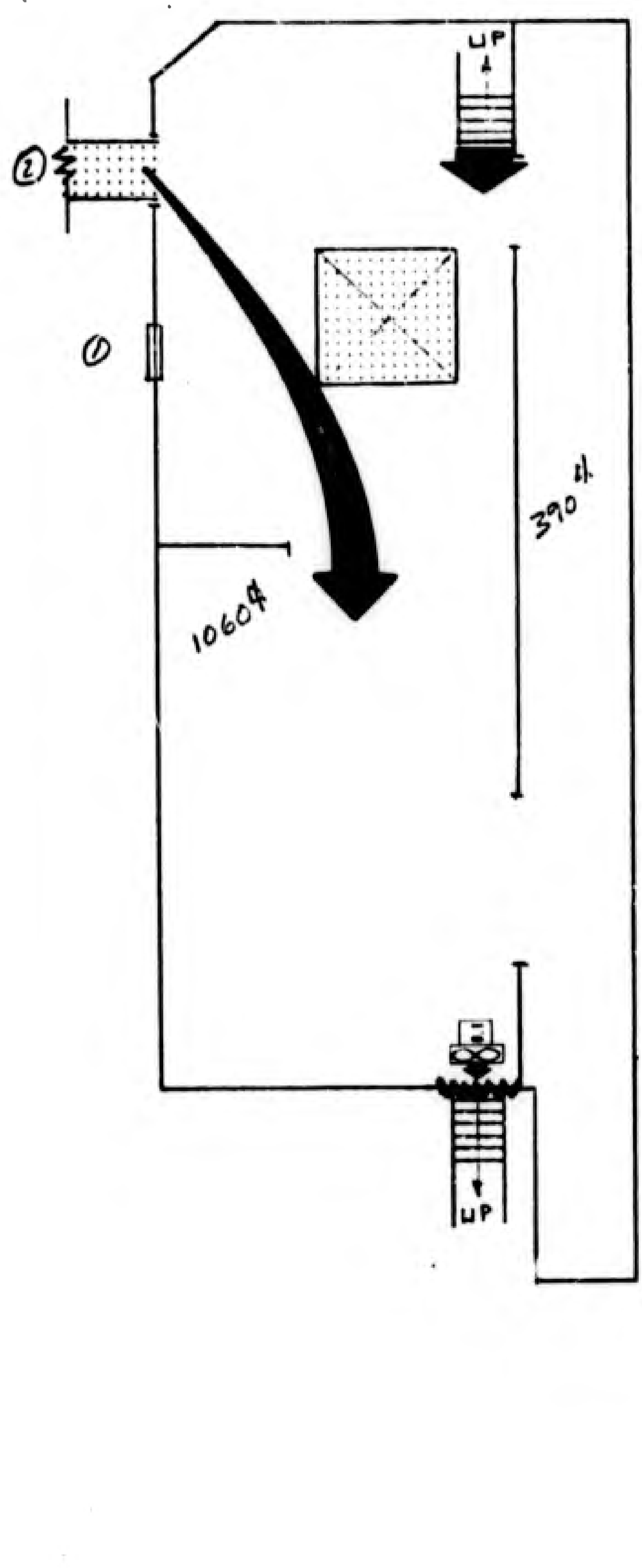
OPENINGS
① WINDOW
② DOUBLE DOOR
③ DOOR

SCALE
1" = 16'-0

RTI Facility No. 65

Dougherty's Bar
5301 Woodland Avenue
Philadelphia, Penn.

SL 2675-0296
FN 06207



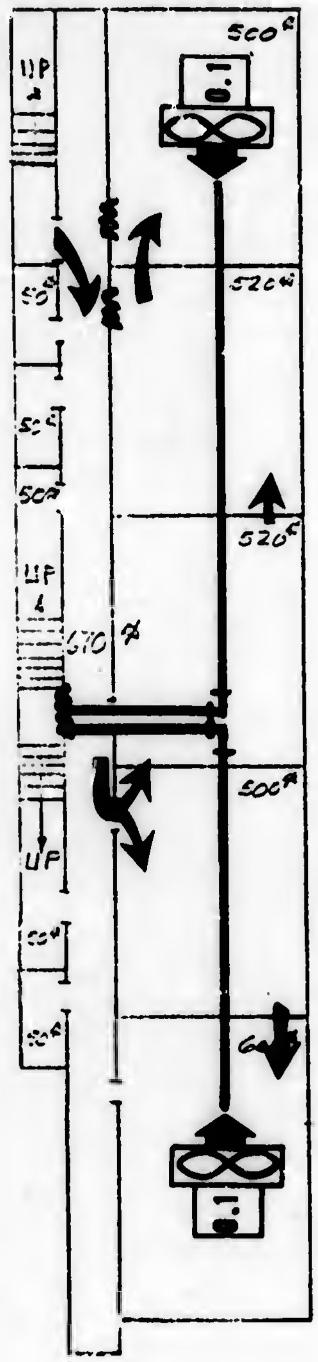
OPENINGS

① WINDOW
30" x 36" x 36" SILL
② RAMP TO STREET

SCALE
1" = 10'-0

RTI Facility No. 66
Northtown Shopping Center
Unit A
Spokane, Washington

SL 8531-0003
FN 00563

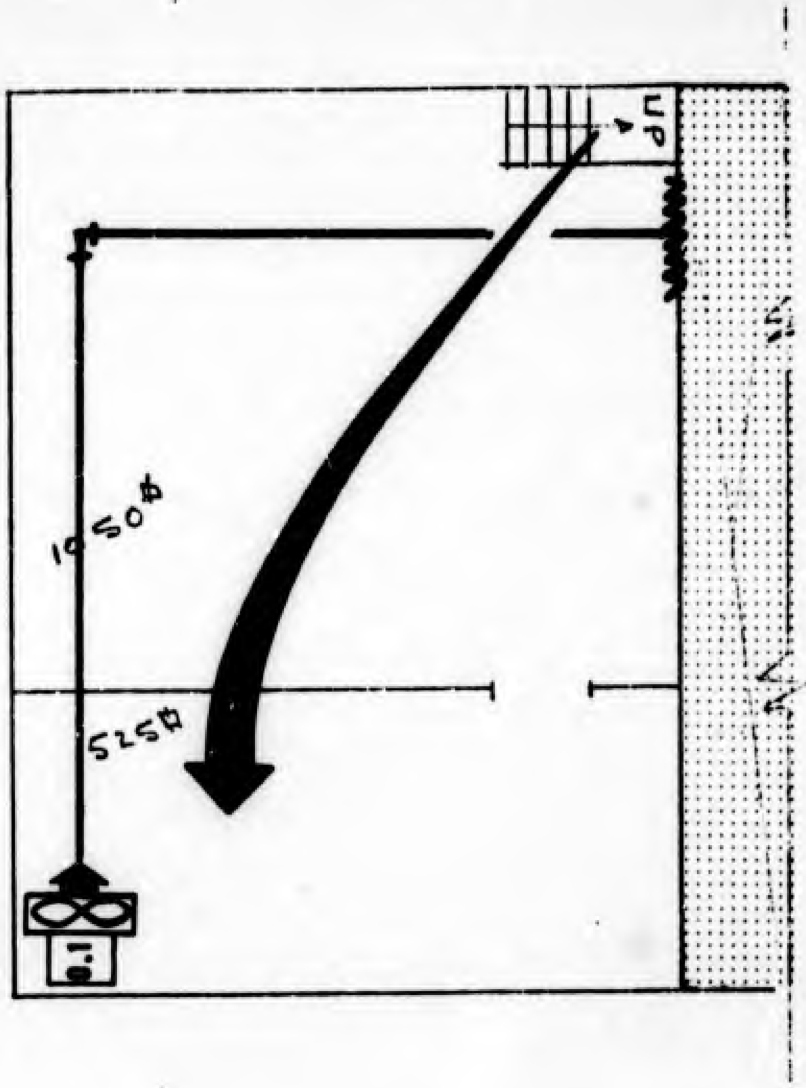


SCALE
1" = 20'-0

RTI Facility No. 67

Salvation Army - East Part
W 235 Main Avenue
Spokane, Washington

SL 8531-0025
FN 00836



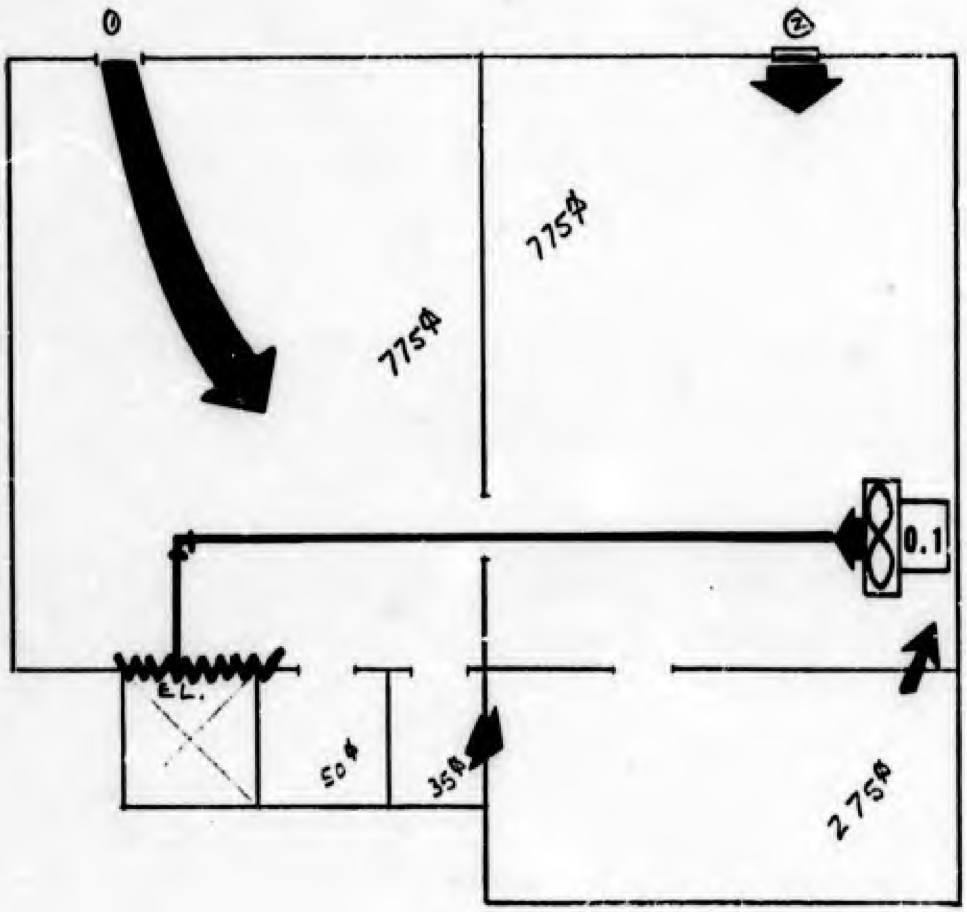
SCALE
1" = 10' - 0

OPENINGS

① DOOR TO ST. EL. 48" × 60"

② WINDOW TO ST. 60" × 24" × 126" SILL

SCALE 1" = 10'-0



RTI Facility No. 68

Carmel Hotel
201 Broadway
Santa Monica, Calif.

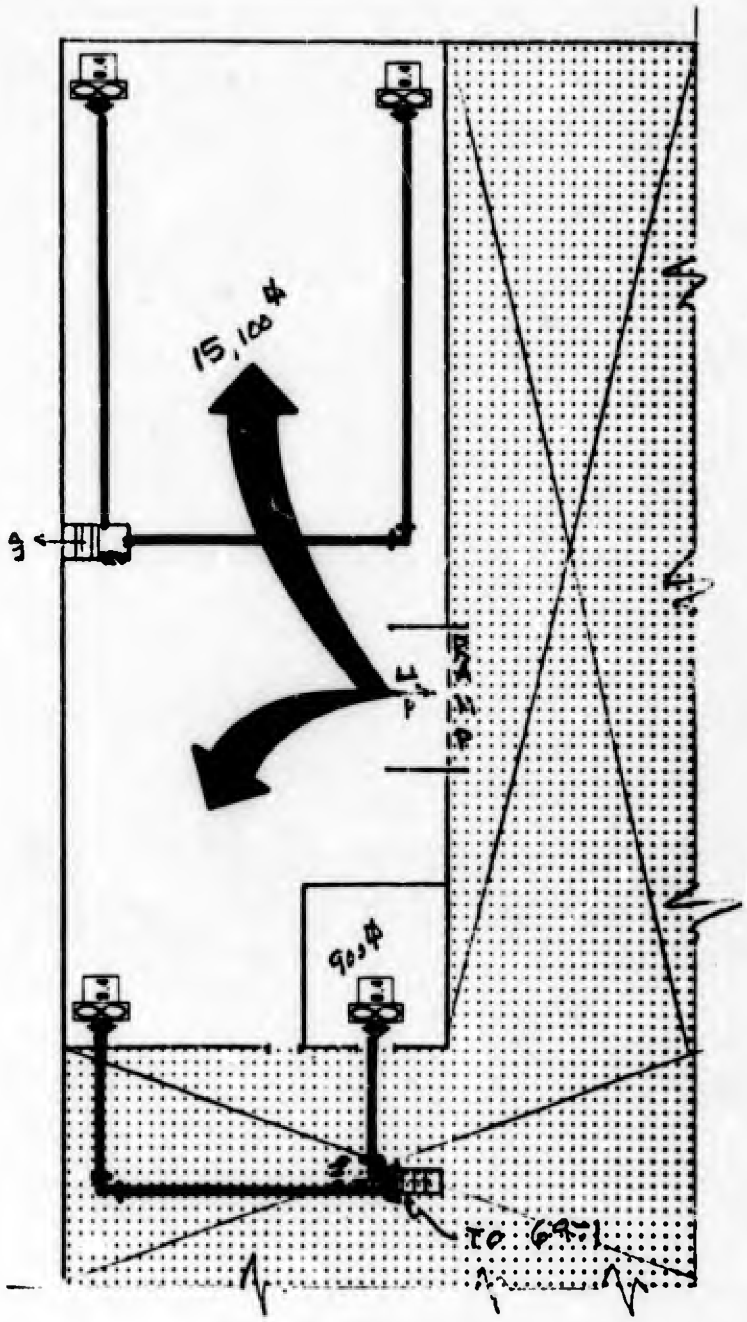
SL 7231-0827
FN 05306

RTI Facility No. 69

California Federal Saving Bldg.
4705 Sunset Blvd.
Los Angeles, Calif.

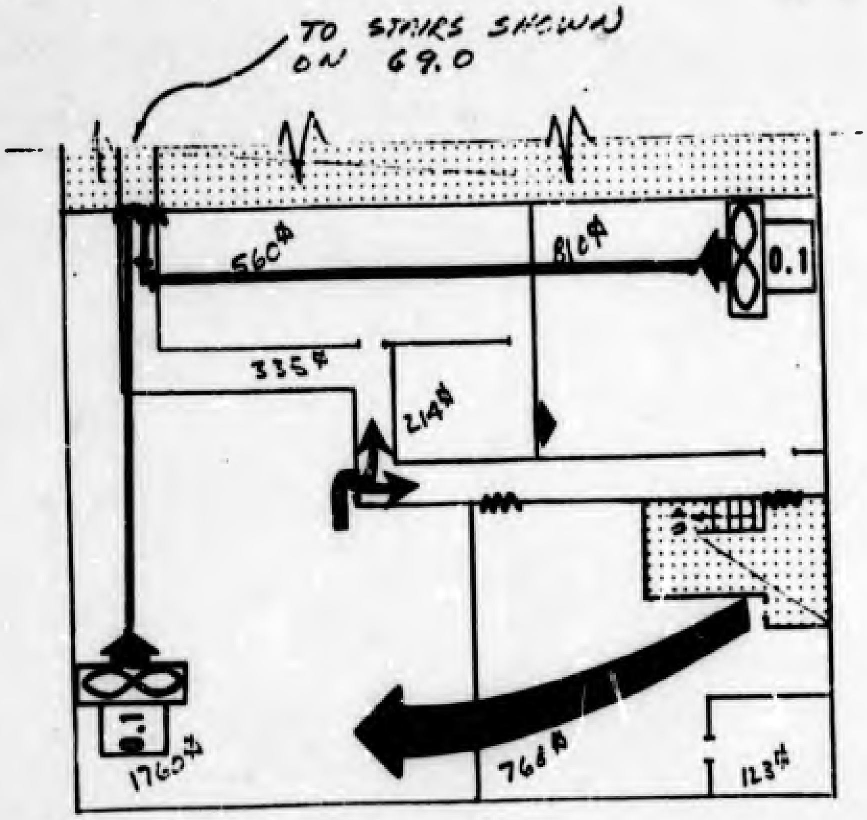
SL 7231-0371
FN 00708

SCALE 1" = 20'-0



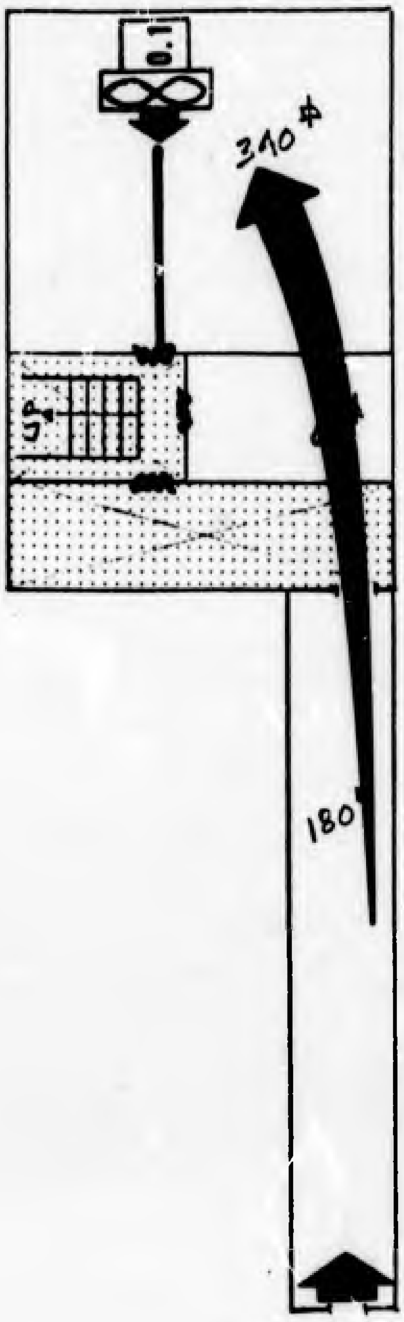
RTI Facility No. 69.-1
California Federal Saving Bldg.
4705 Sunset Blvd.
Los Angeles, Calif.

SL 7231-0371
FN 00708



SCALE
1" = 20'-0

SCALE
1" = 10'-0



RTI Facility No. 70

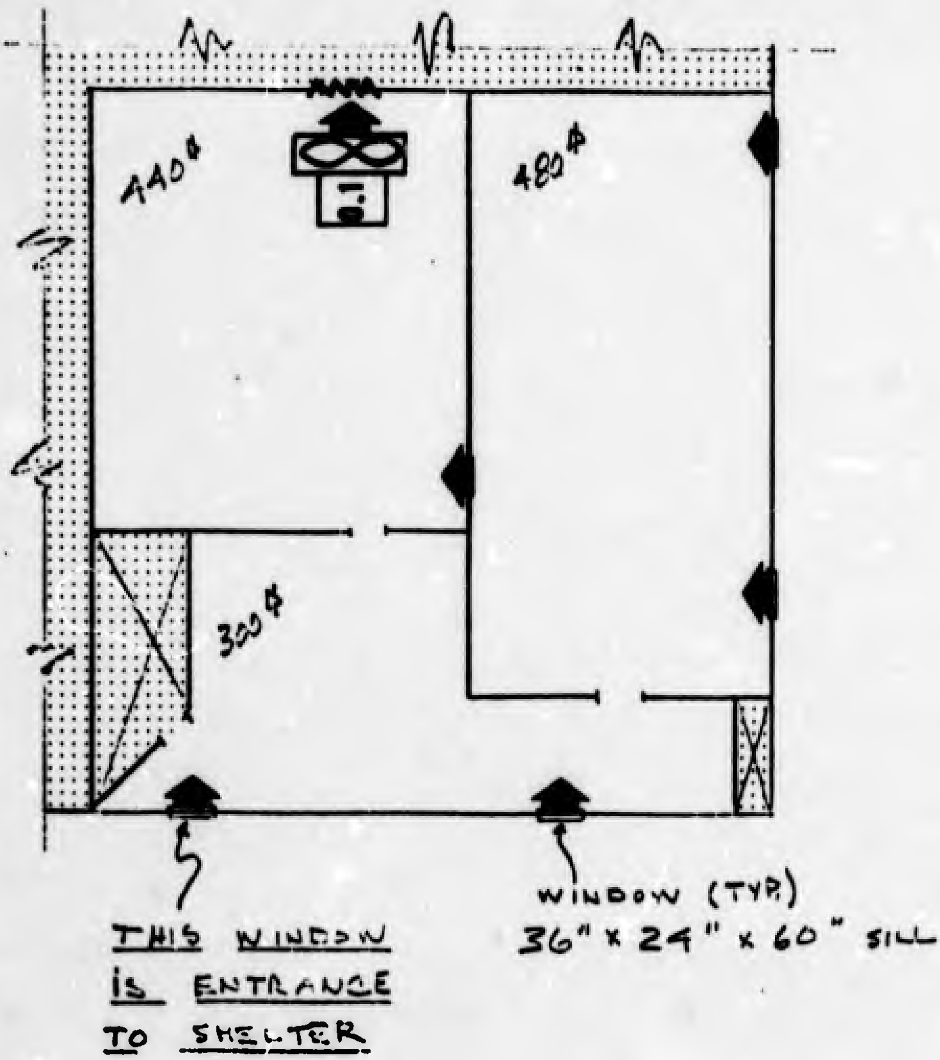
Soul Clinic Hotel
625 E. 5th Street
Los Angeles, Calif.

SL 7231-0443
FN 01564

RTI Facility No. 71

Ancakia School (Hilltop House)
701 West Foothill
Arcadia, Calif.

SL 7231-0946
FN 00119

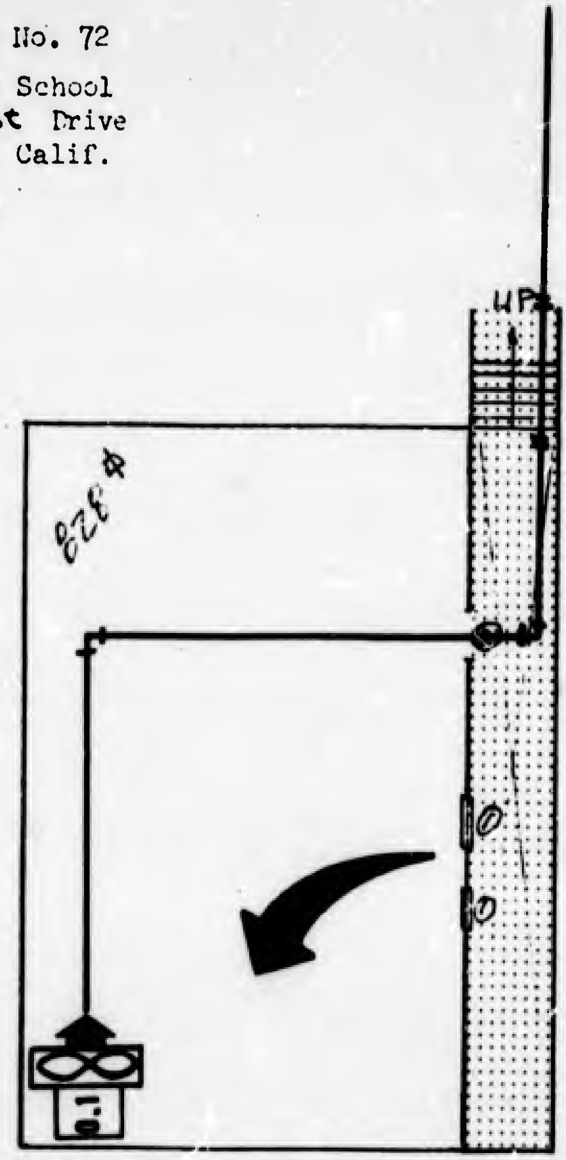


SCALE
1" = 10'-0

RTI Facility No. 72

Menlo Avenue School
850 West 41st Drive
Los Angeles, Calif.

SL 7231-0587
FN 00067



OPENINGS

① WINDOW 36" x 120", 8" SILL

② DOOR

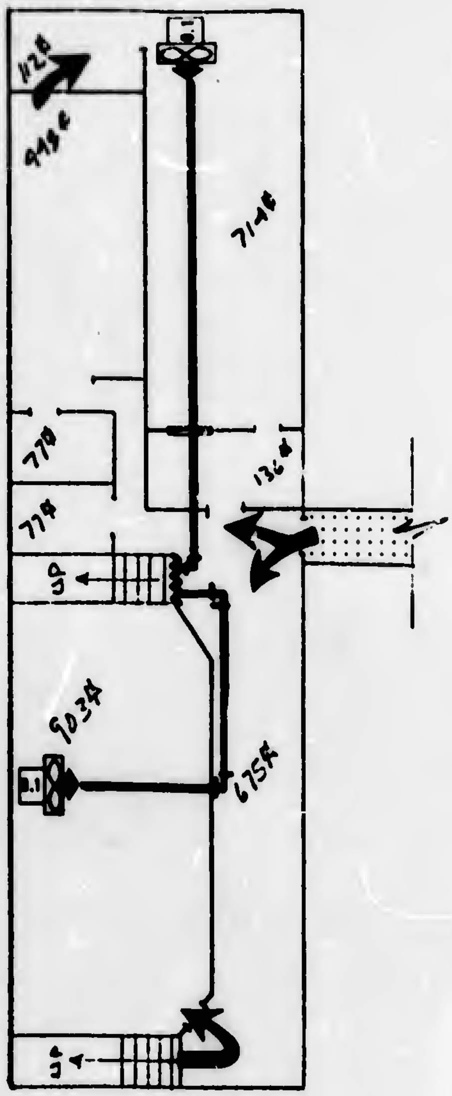
SCALE

1" = 10'-0

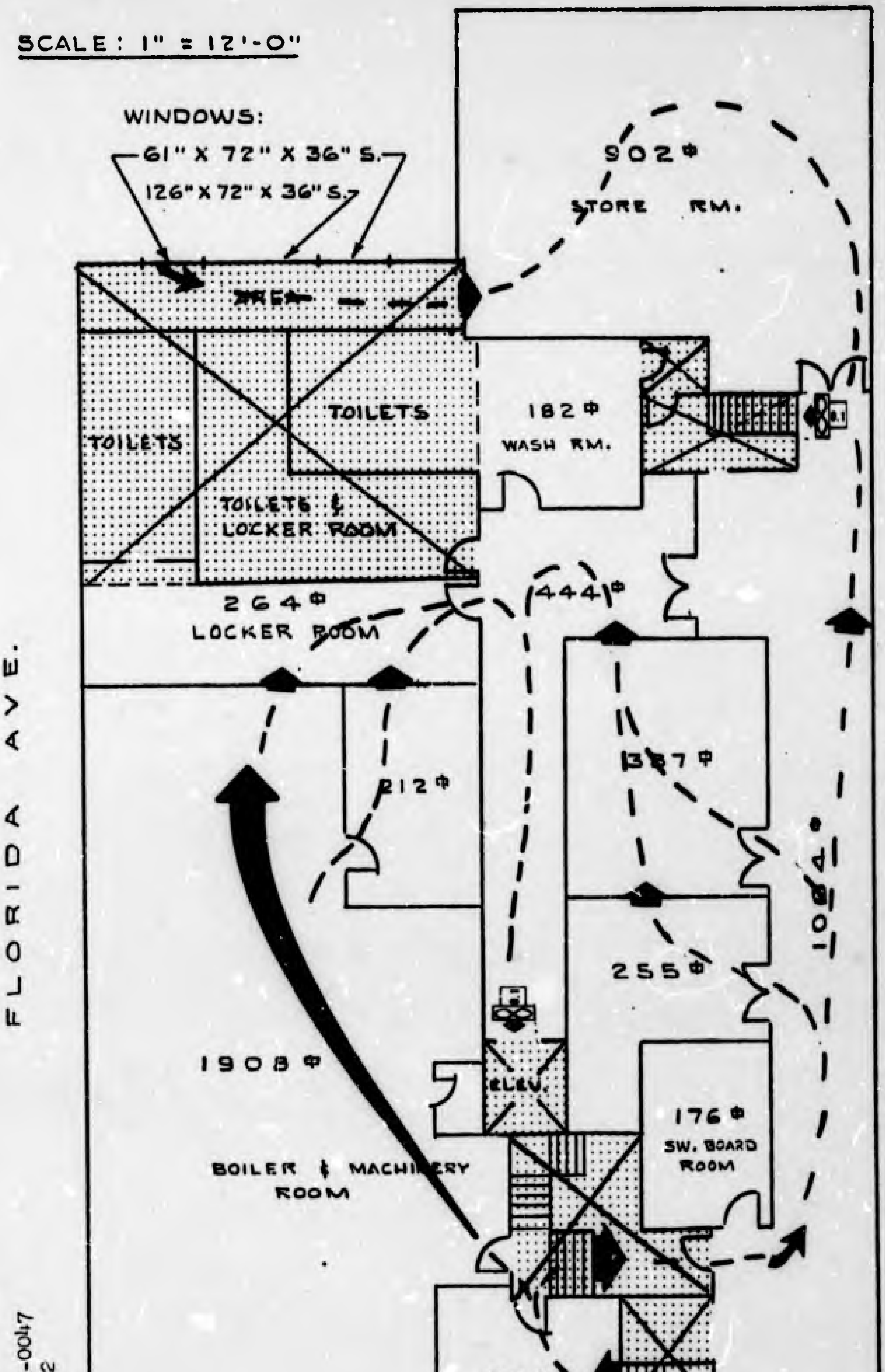
RTI Facility No. 73

Cathedral High School
1309 N. Stanton Street
El Paso, Texas

SL 5581-0016
FN 00169



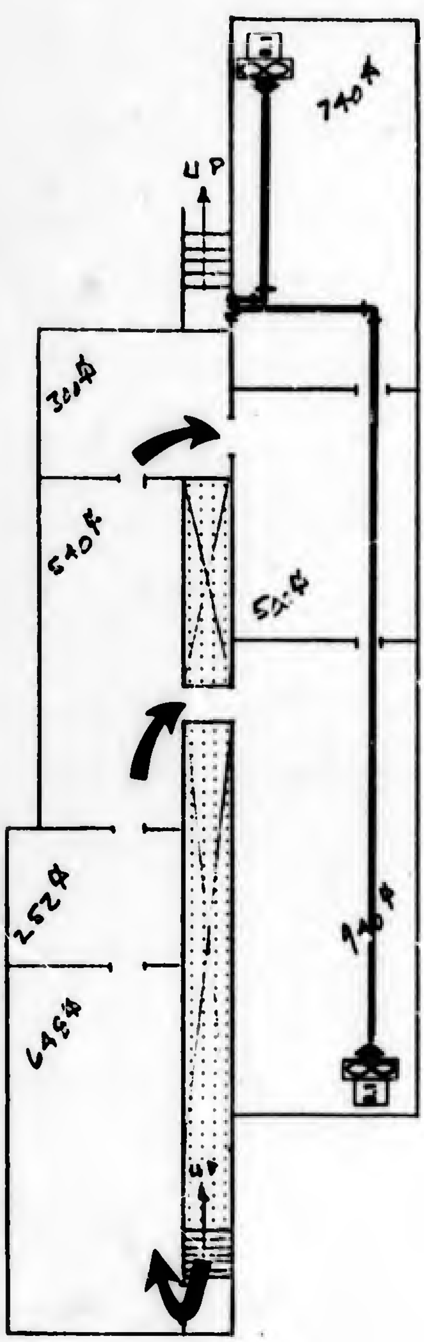
SCALE
1" = 20'-0



RTI Facility No. 74 (Pt. 1)
Tampa Terrace Hotel
411 Florida Venue
Tampa, Florida

SL 3261-0047
FN 00082

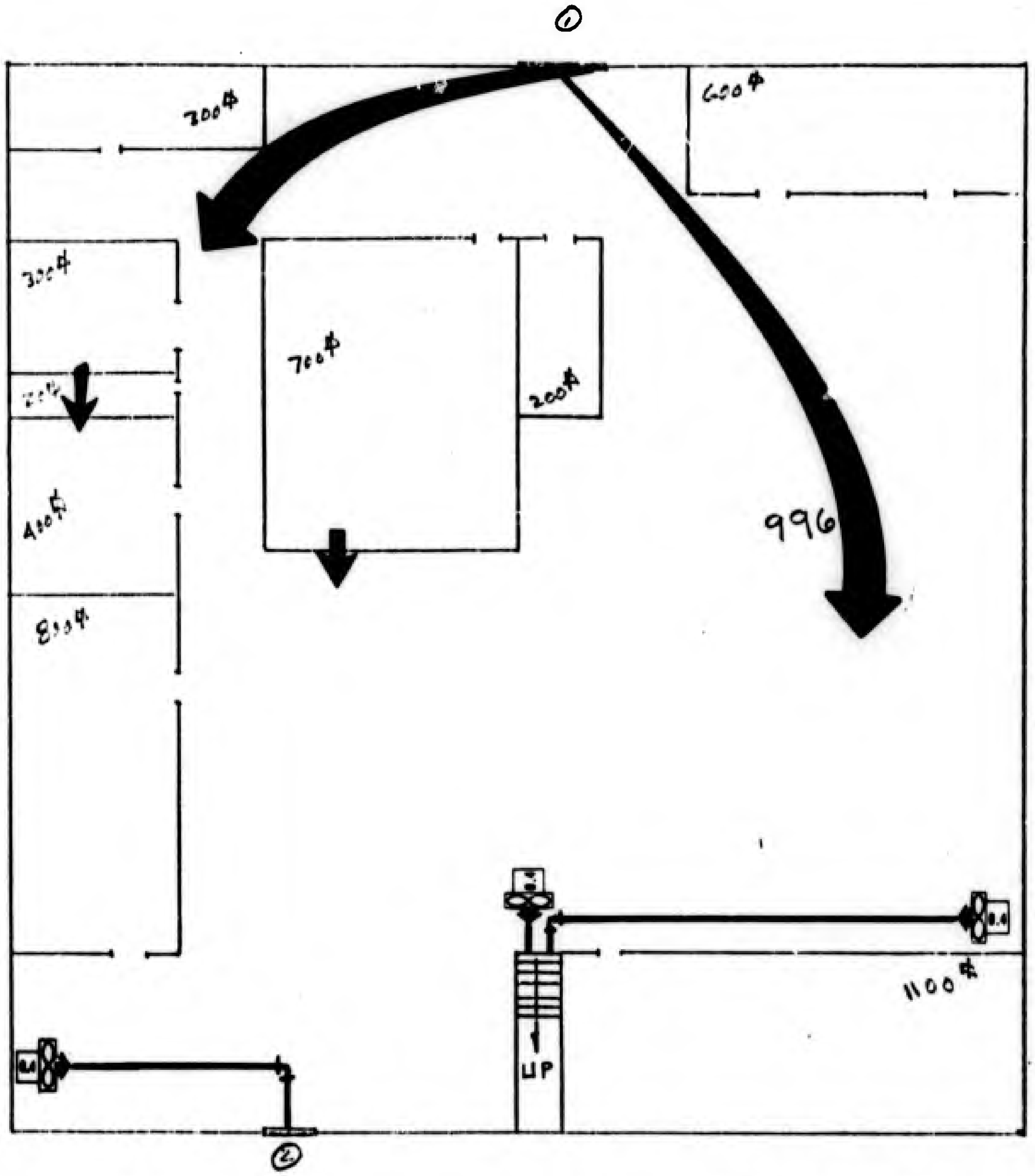
SCALE
1" = 20'-0



RTI Facility No. 75

Robert E. McKee Building
1918 Texas Street
El Paso, Texas

SL 5581-0021
FN 00157



SCALE
1" = 20'-0

OPENINGS
① VENT 36" x 120"
② WINDOW 36" x 54" x 48" SILL

RTI Facility No. 76

Reno Newspapers Building
401 West 2nd Street
Reno, Nevada

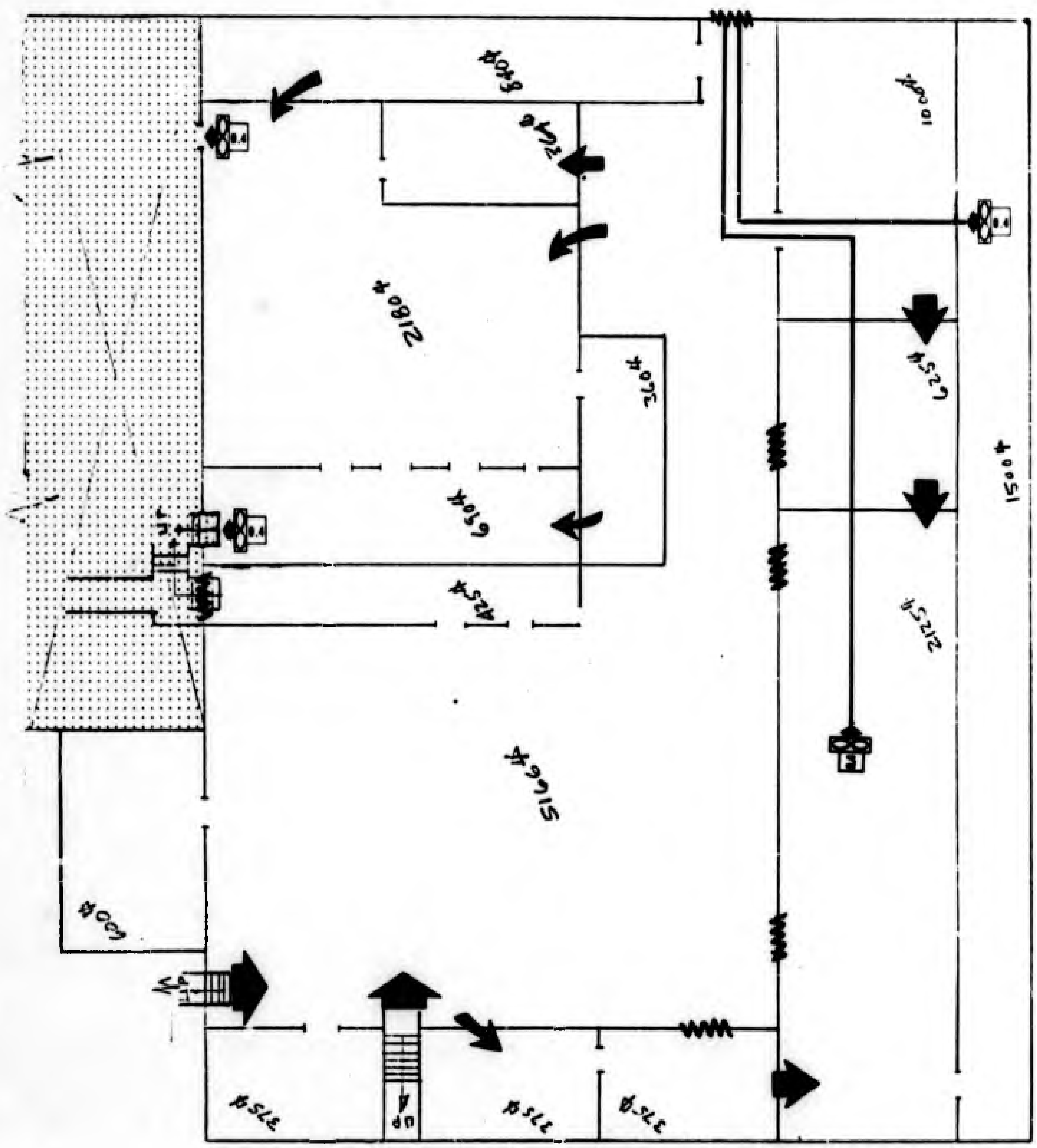
SL 7421-0004
FN 01748

RTI Facility No. 77

Shadle Park High School
4327 N. Ash Street
Spokane, Washington

SI. 5531-0008
FN 00611

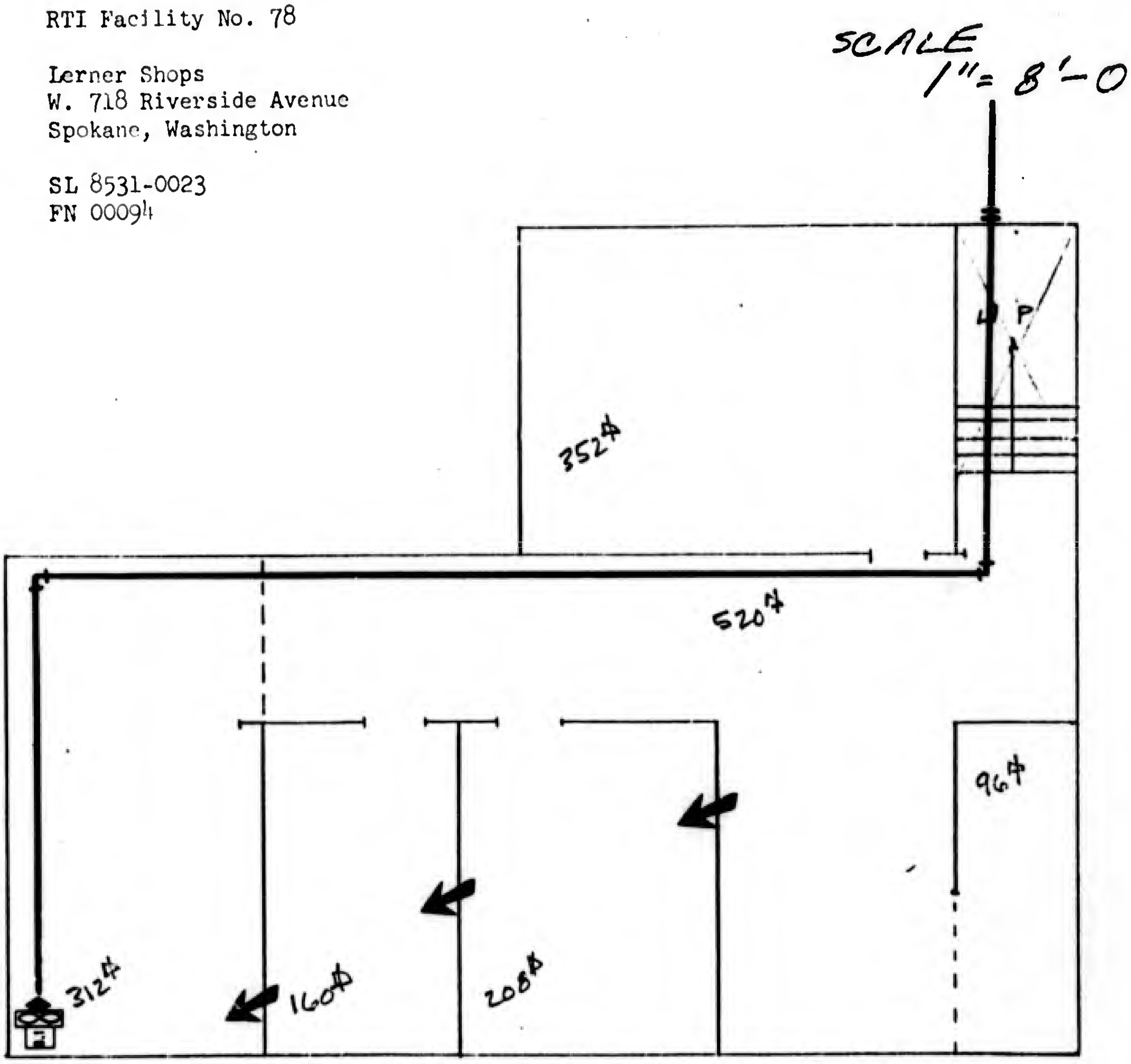
SCALE
1" = 20'-0



RTI Facility No. 78

Lerner Shops
W. 718 Riverside Avenue
Spokane, Washington

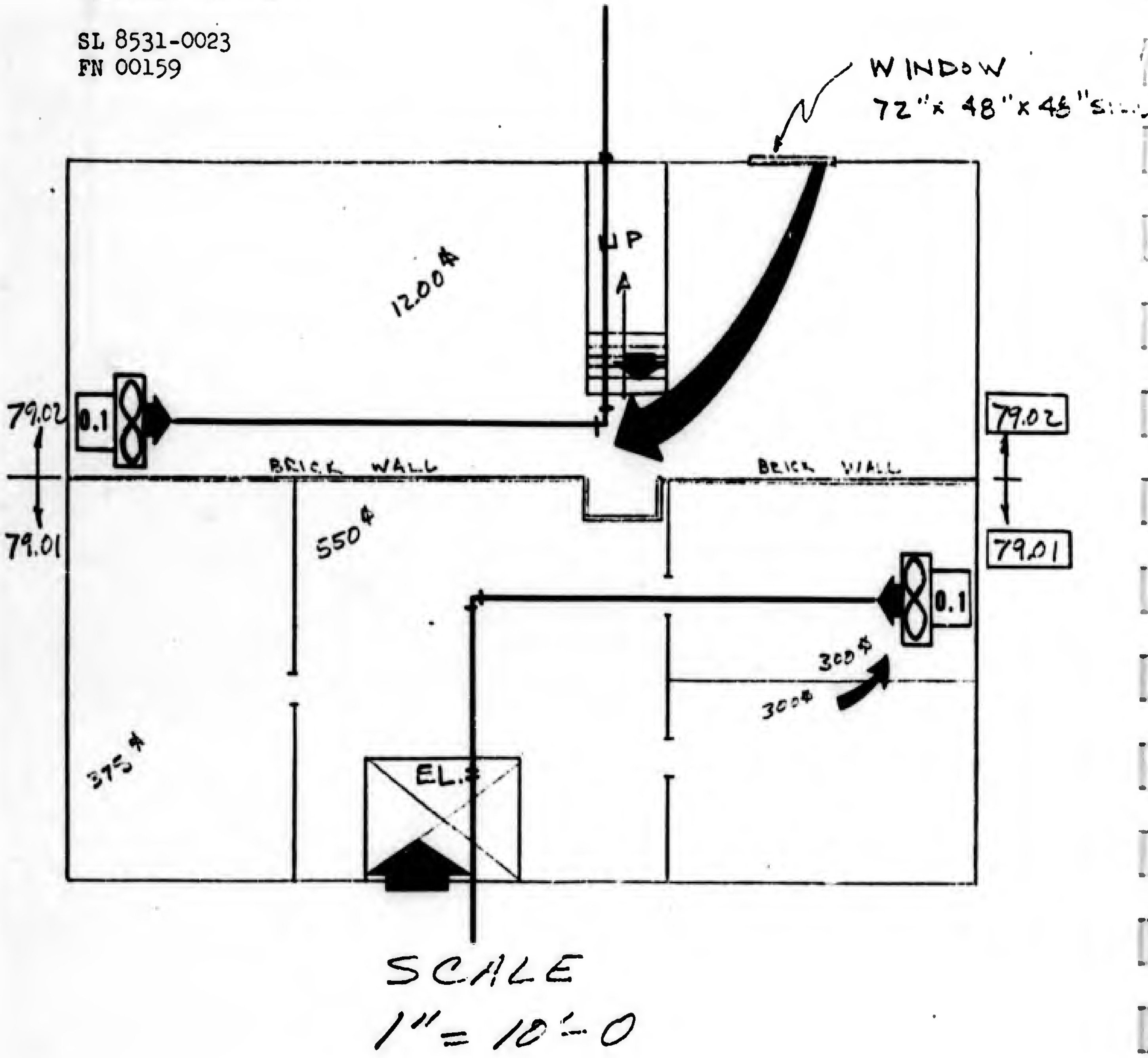
SL 8531-0023
FN 00094

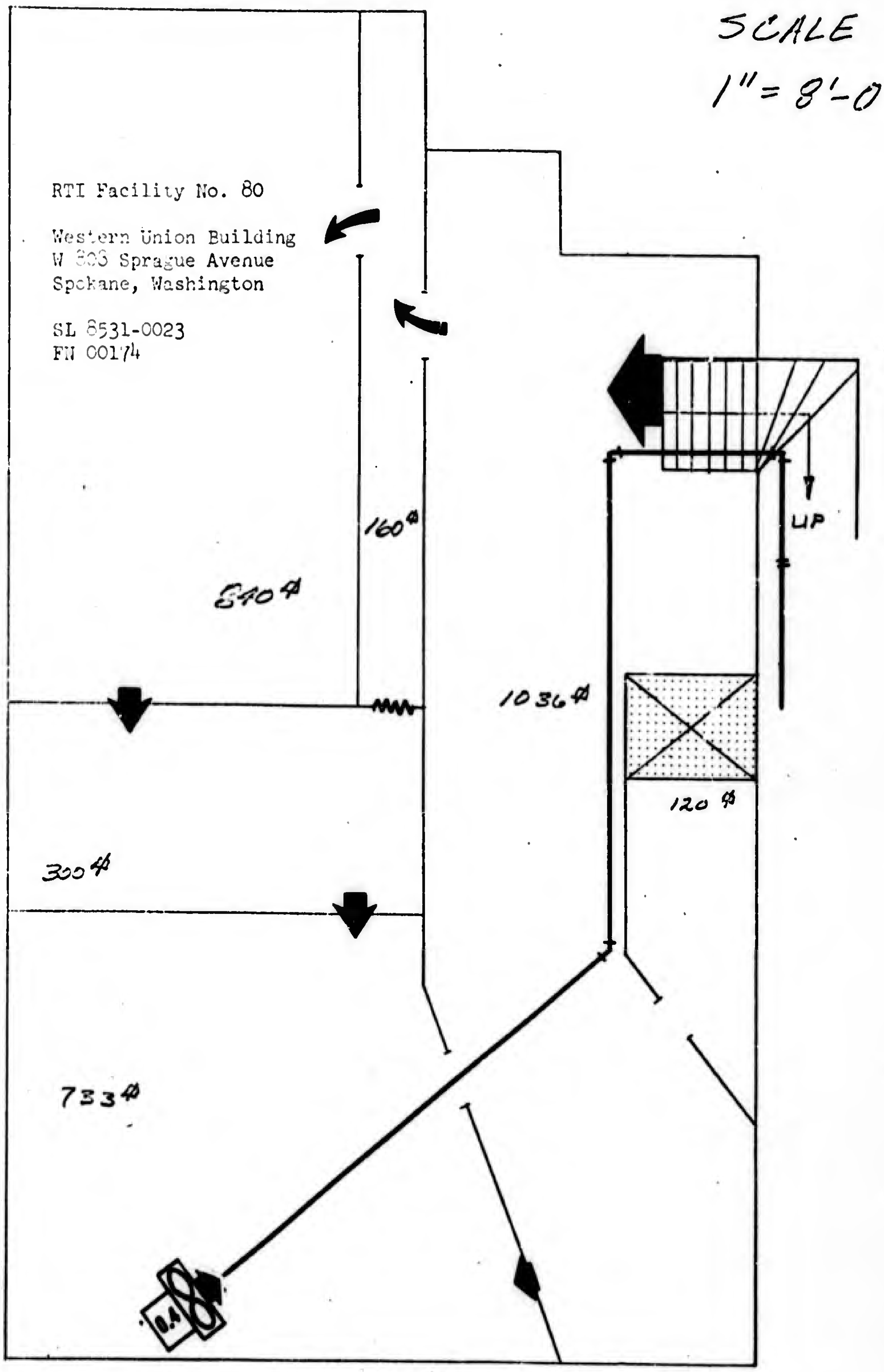


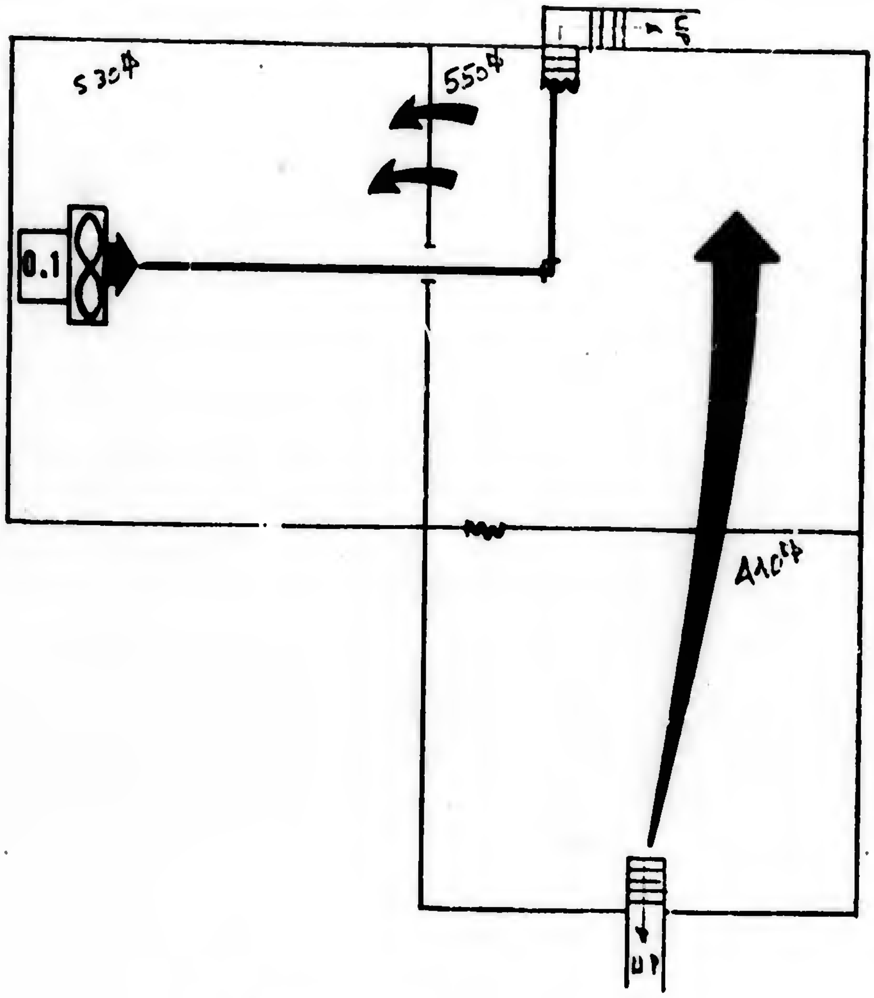
RTI Facility No. 79.01 & 79.02

Victoria Hotel
W. 618 1st Avenue
Spokane, Washington

SL 8531-0023
FN 00159




RTI Facility No. 80
Western Union Building
W 606 Sprague Avenue
Spokane, Washington
SL 8531-0023
FN 00174
SCALE
1" = 8'-0
160 ⌀
840 ⌀
1036 ⌀
120 ⌀
300 ⌀
733 ⌀
UP
0.4



SCALE
1" = 10'-0

RTI Facility No. 81

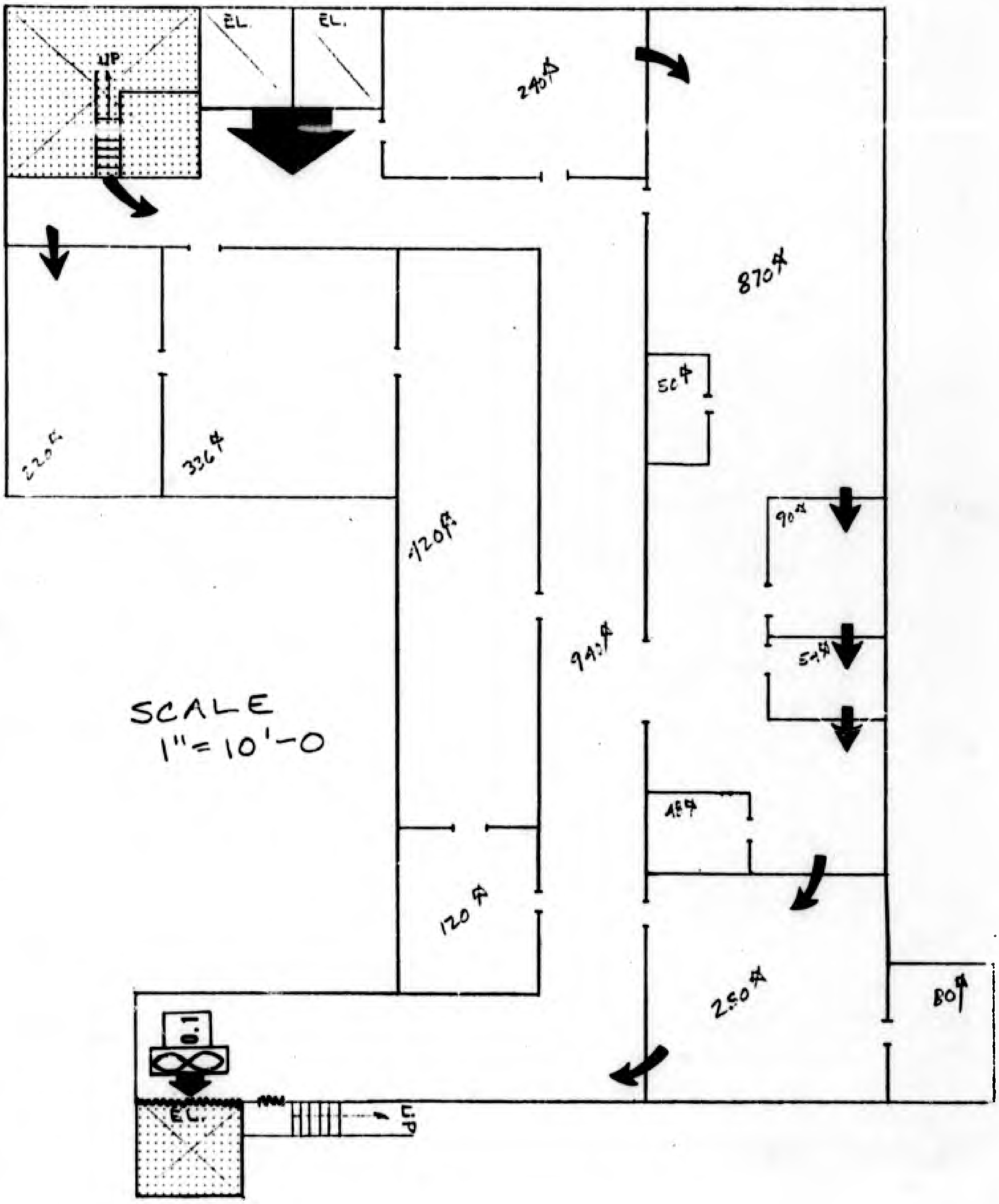
James B. Angell School
3849 Beverly
Berkley, Michigan

SL 4332-0034
FN 00725

RTI Facility No. 82

Pontiac Osteopathic Hospital
46-54 N. Perry
Pontiac, Michigan

SL 4332-0010
FN 01303

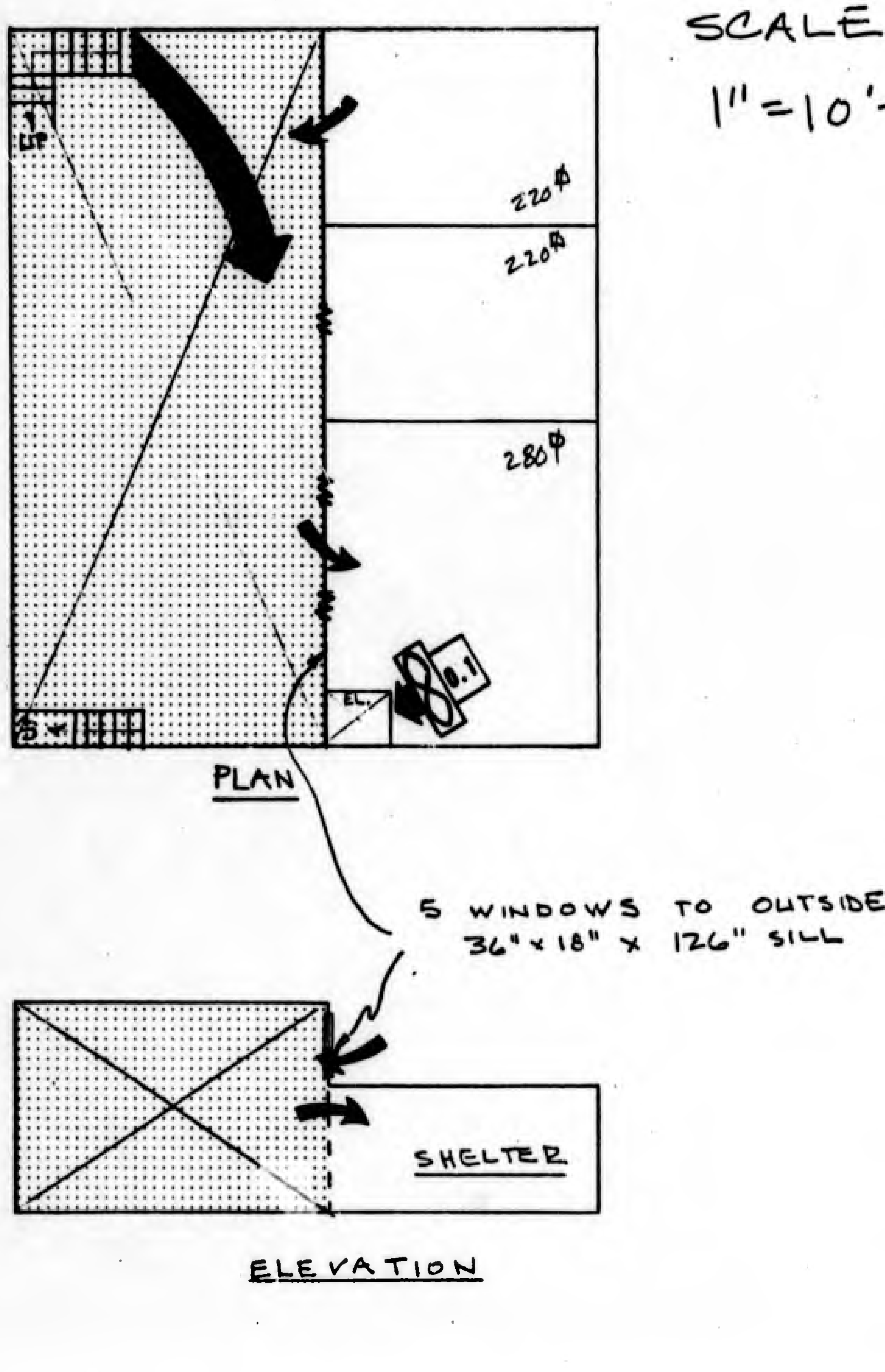


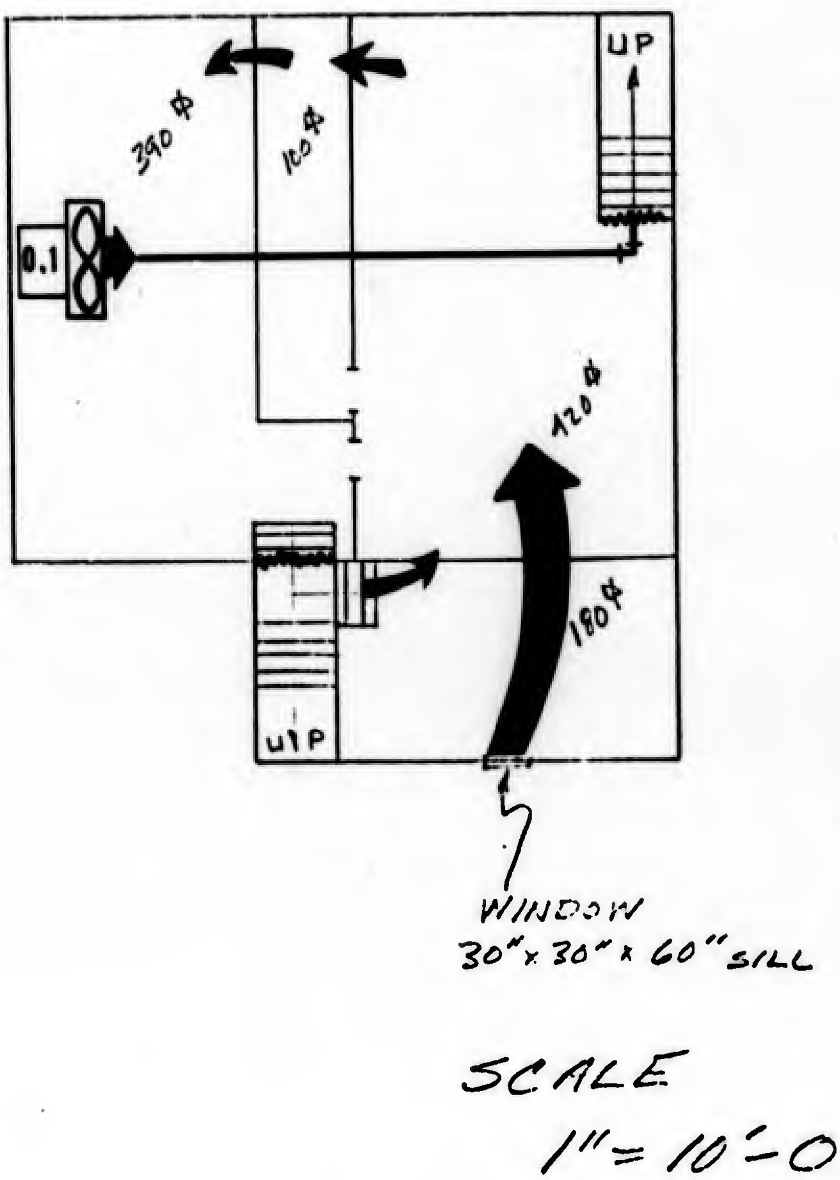
RTI Facility No. 83

Washington School
1201 Livernois
Ferndale, Michigan

SL 4332-0026
FN 01161

SCALE
1" = 10'-0



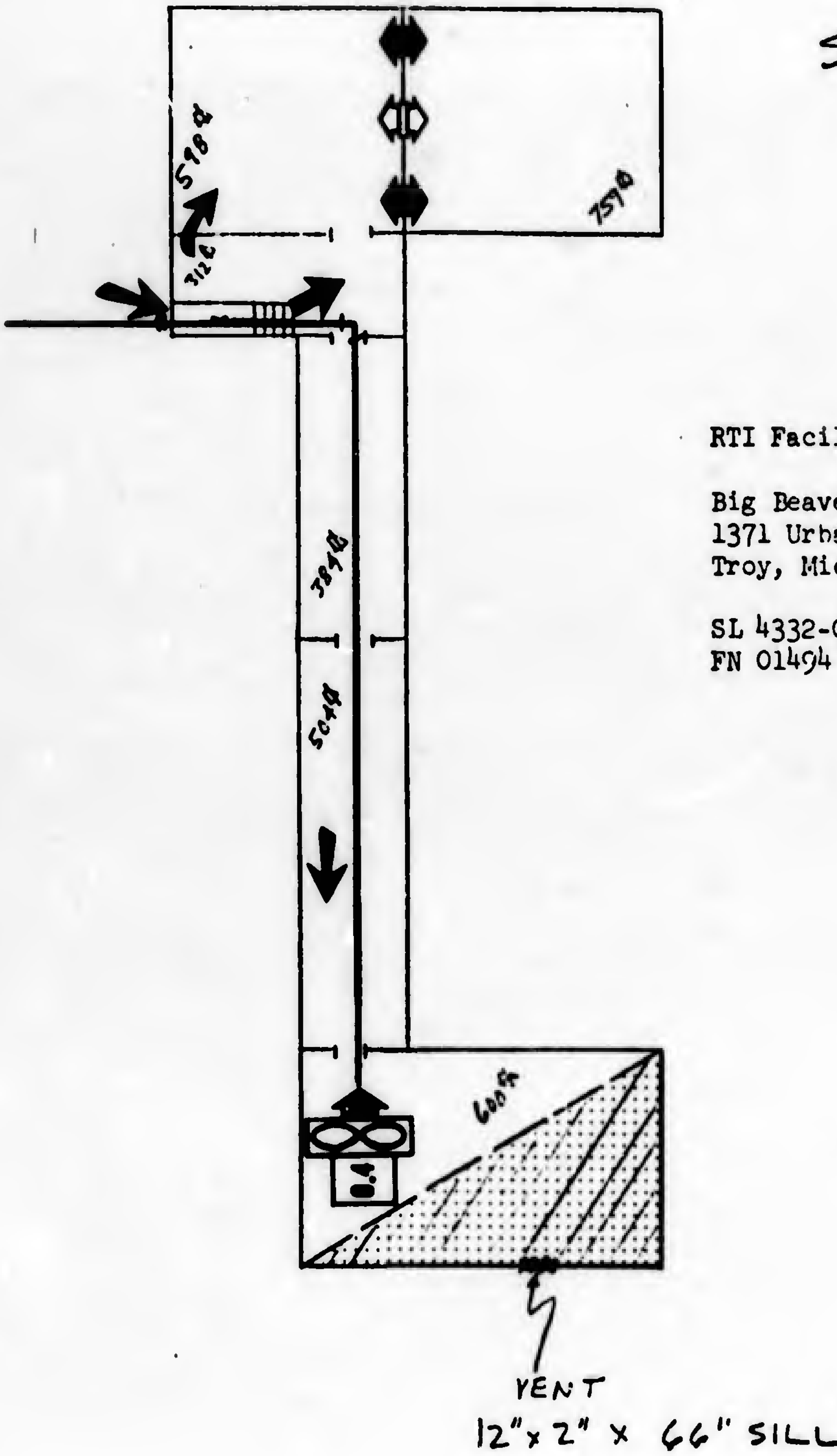


RTI Facility No. 84

Auto Supply Store
418-420 S. Main Street
Royal Oak, Michigan

SL 4332-0035
FN 01649

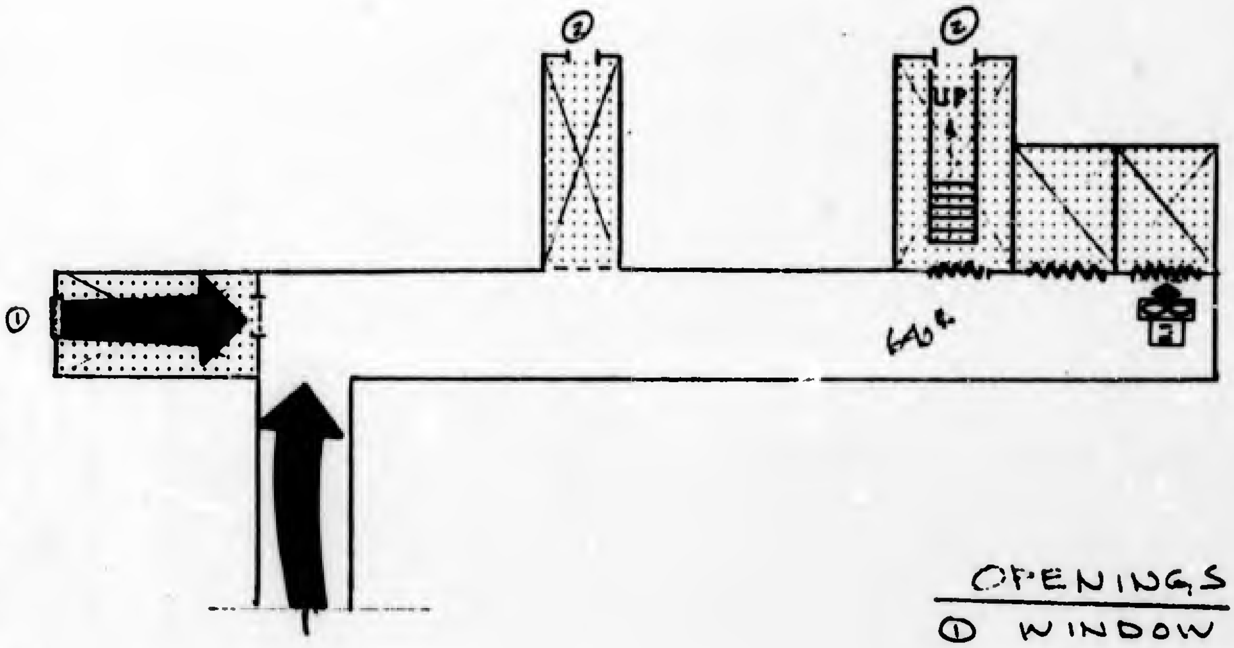
SCALE
1" = 20'-0



RTI Facility No. 85

Big Beaver Elementary School
1371 Urbancrest Road
Troy, Michigan

SL 4332-0091
FN 01494



OPENINGS
① WINDOW
② DOOR

SCALE
1" = 16'-0

RTI Facility No. 86

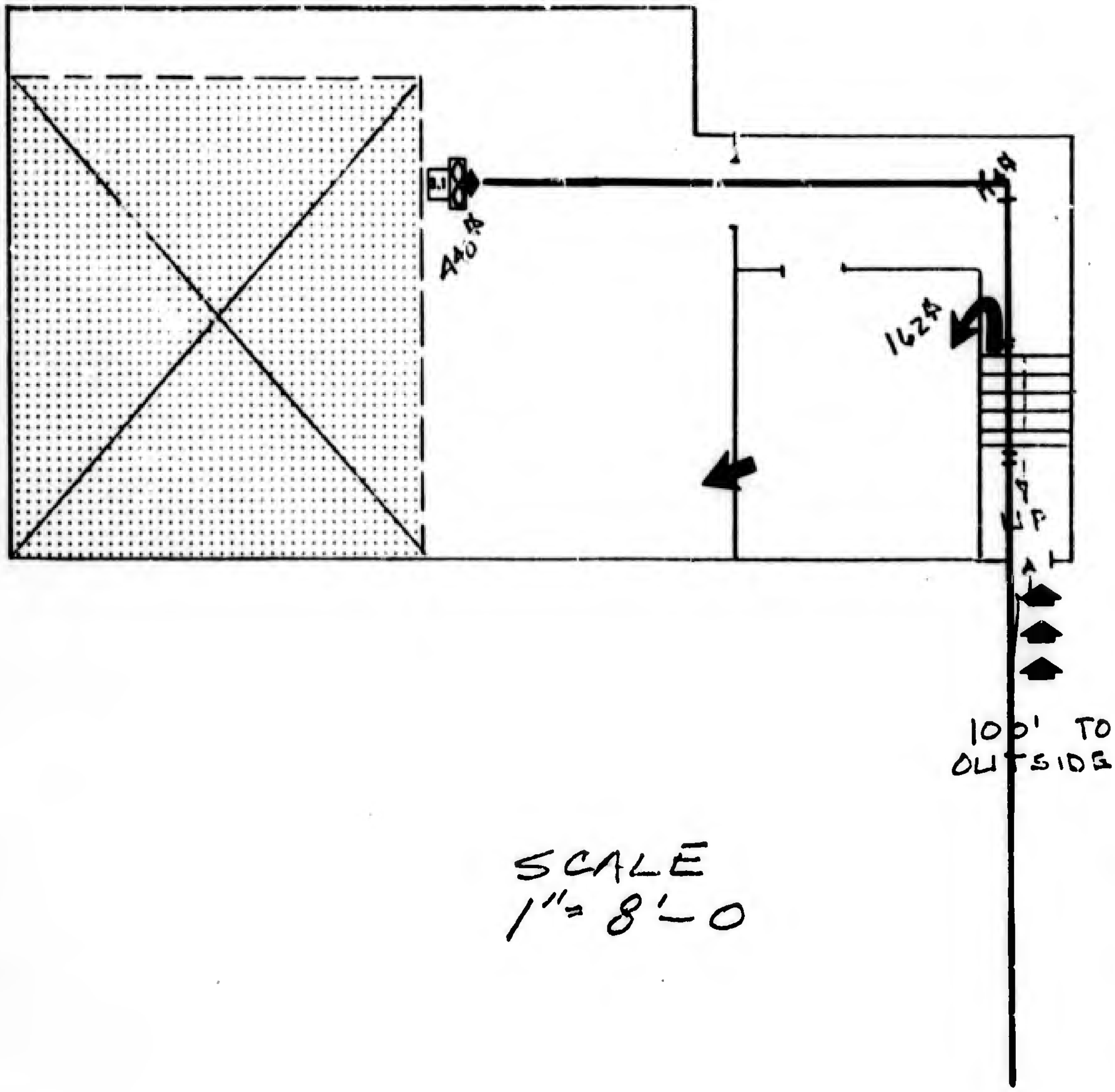
Maynard Hospital
1309 Summit
Seattle, Washington

SL 8521-0064
FN 01899

RTI Facility No. 87

Bank of California
815 Second Avenue
Seattle, Washington

SL 8521-0061
FN 01539

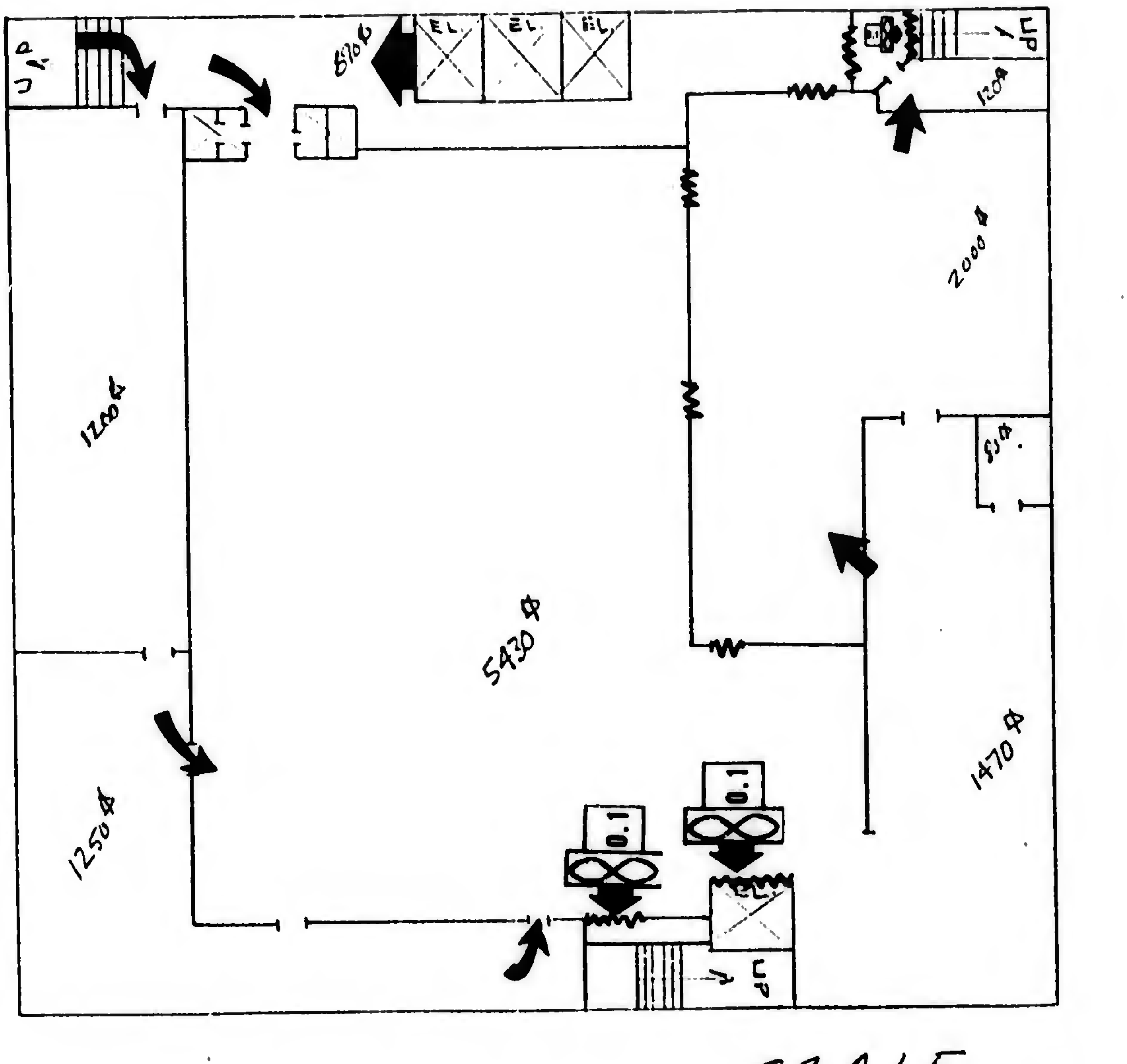


SCALE
1" = 8'-0

RTI Facility No. 88

Ranke Building
1511 5th Avenue
Seattle, Washington

SL 8521-0061
FN 01457

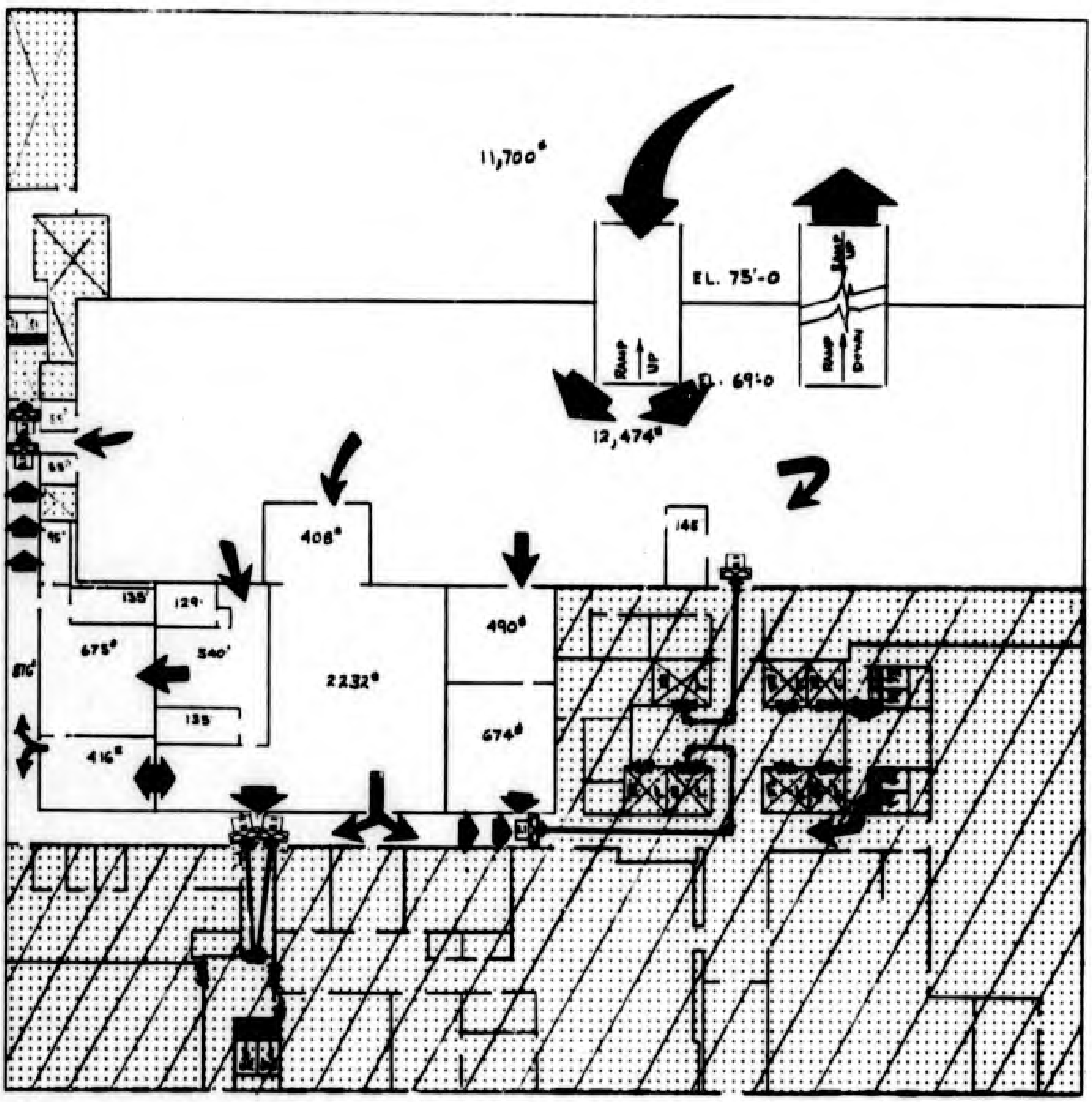


RTI Facility No. 89-1

Public Safety Building (5 Parts)
610-22 3rd Avenue
Seattle, Washington

SL 8521-C061
FN 01572

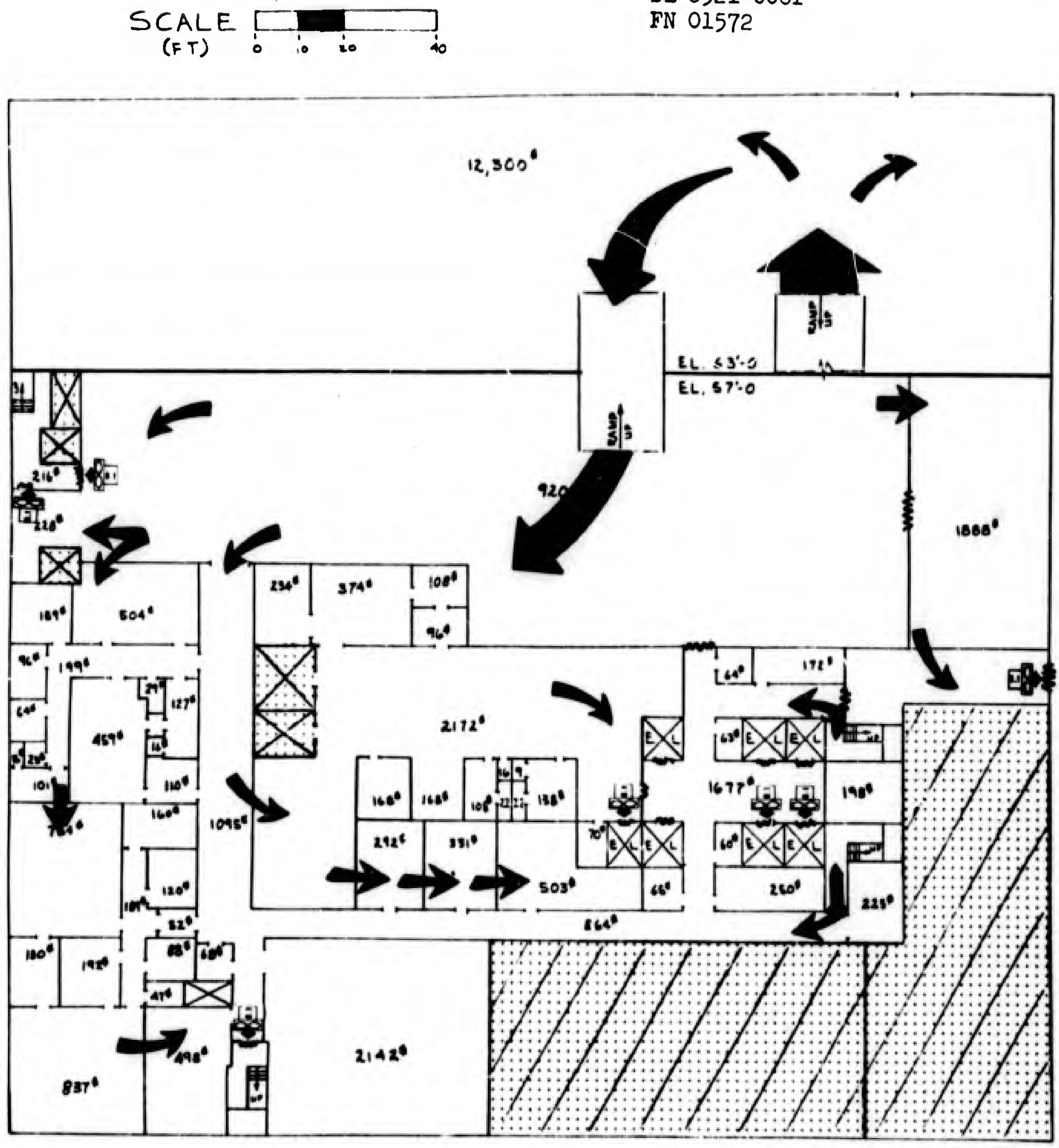
SCALE
(FT)



RTI Facility No. 89-2

Public Safety Building (5 Parts)
610-22 3rd Avenue
Seattle, Washington

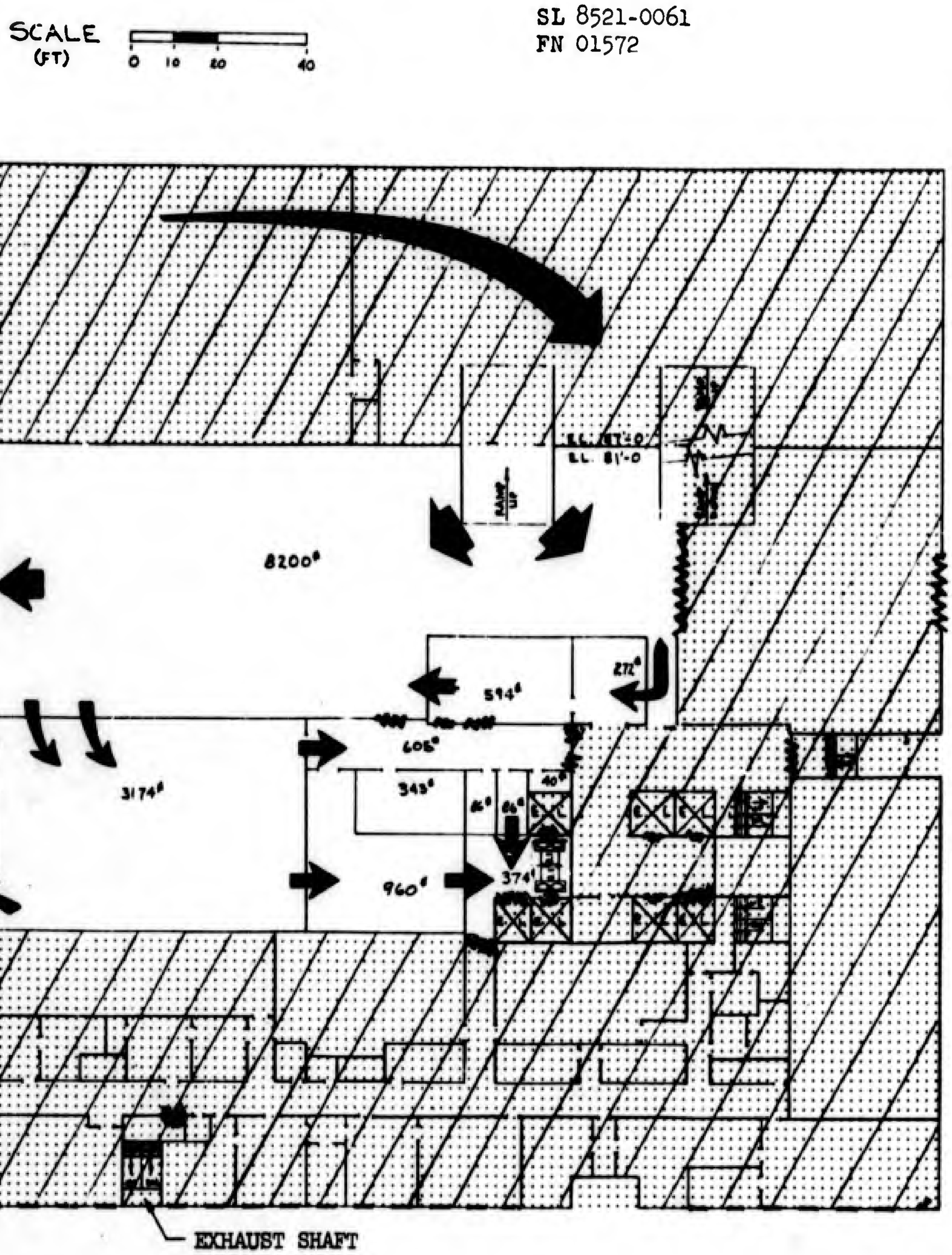
SL 8521-0061
FN 01572



RTI Facility No. 89

Public Safety Building (5 Parts)
610-22 3rd Avenue
Seattle, Washington

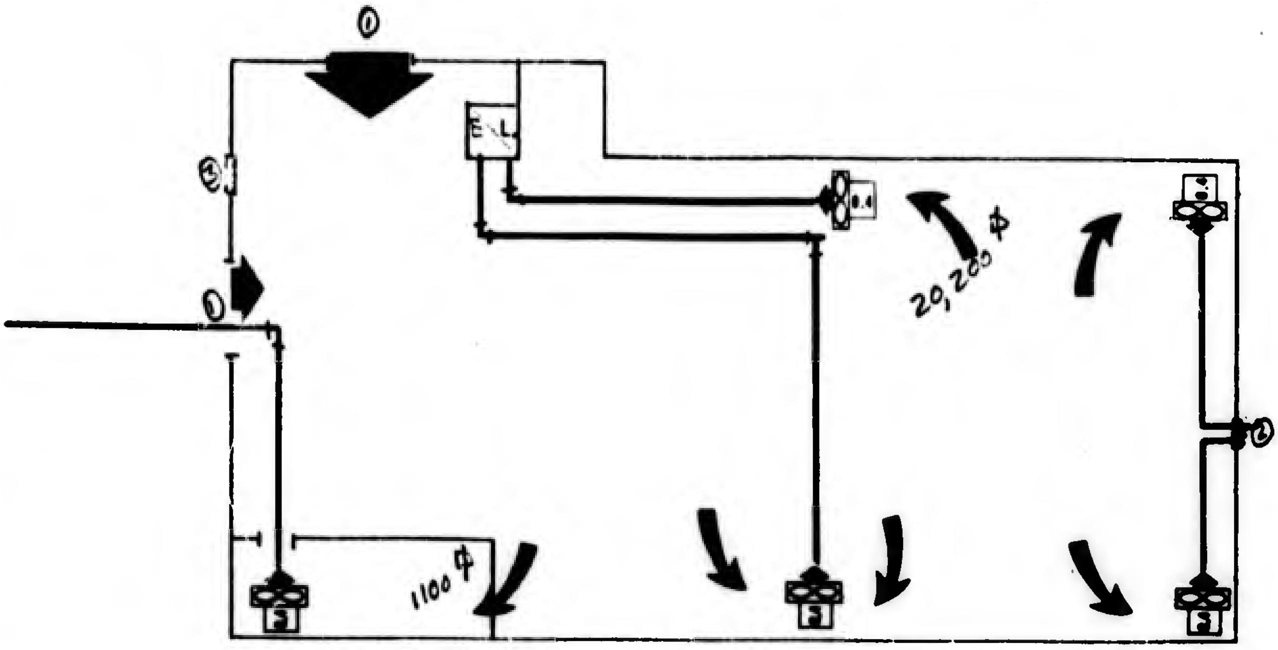
SL 8521-0061
FN 01572



RTI Facility No. 90

Dining Hall Men's Residence
University of Washington
Seattle, Washington

SL 8521-0021
FN 02037



OPENINGS

① Sliding Door 204" x 90"
② Door 36" x 78"
③ 2 openings 24" x 48"

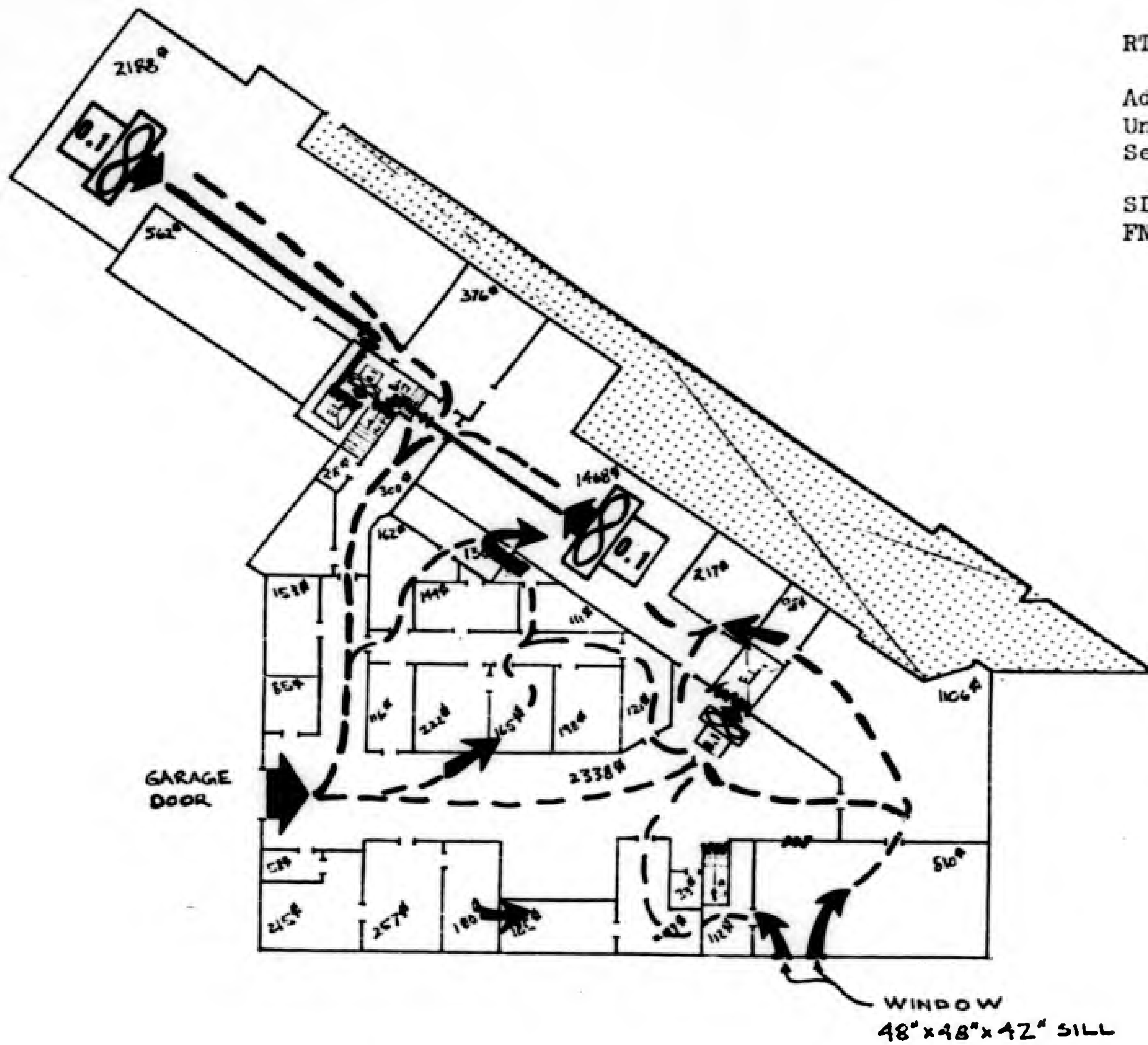
SCALE 1" = 40'-0

SCALE
1" = 30'-0

RTI Facility No. 91

Administration Building
University of Washington
Seattle, Washington

SL 8521-0021
FN 02063



SCALE: 1" = 20'

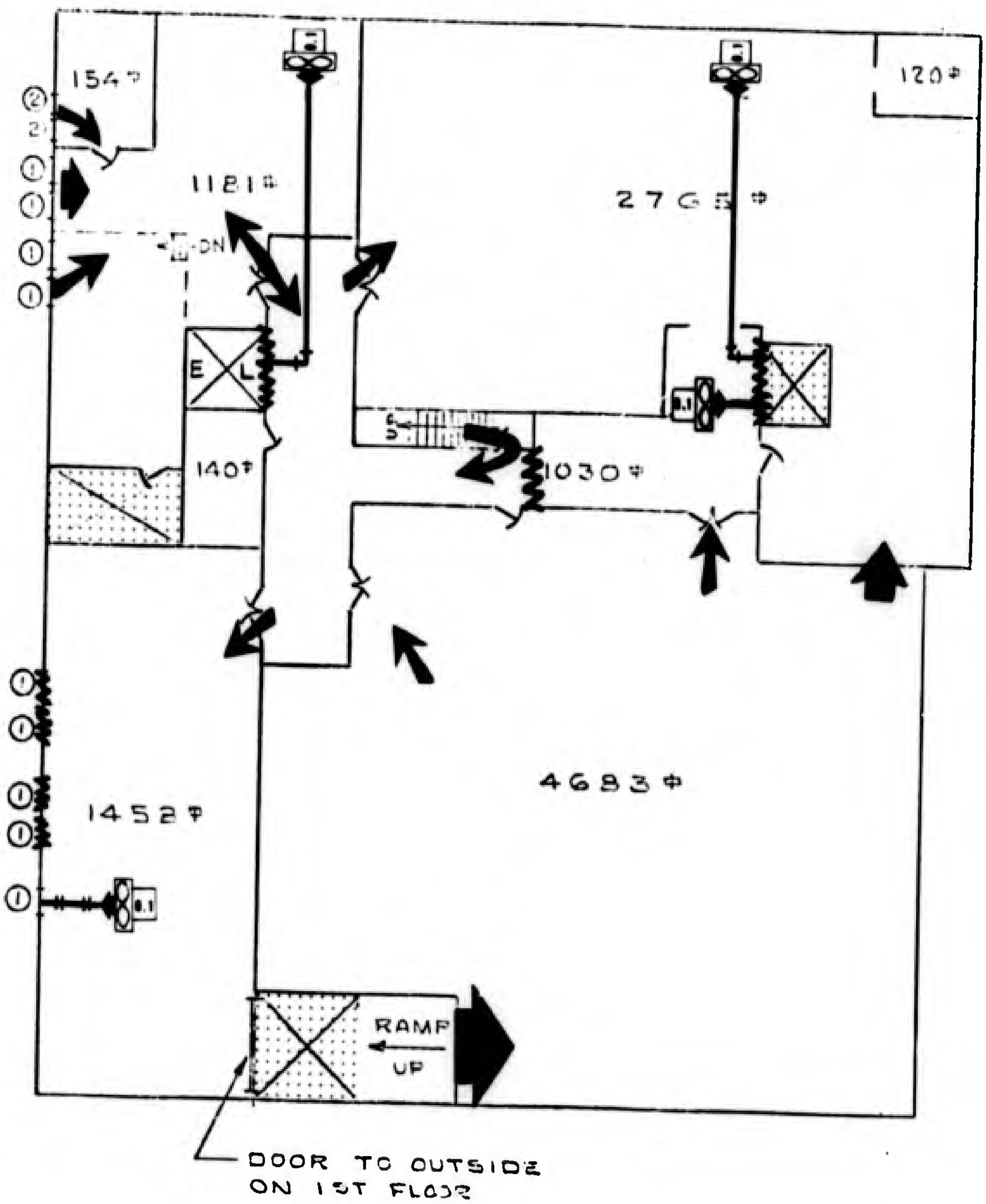
RTI Facility No. 92

Headquarters Building
Seattle Fire Department
2nd St. & E. Main St.
Seattle, Washington

SL 0521-0070
FN 021-1

WINDOWS:

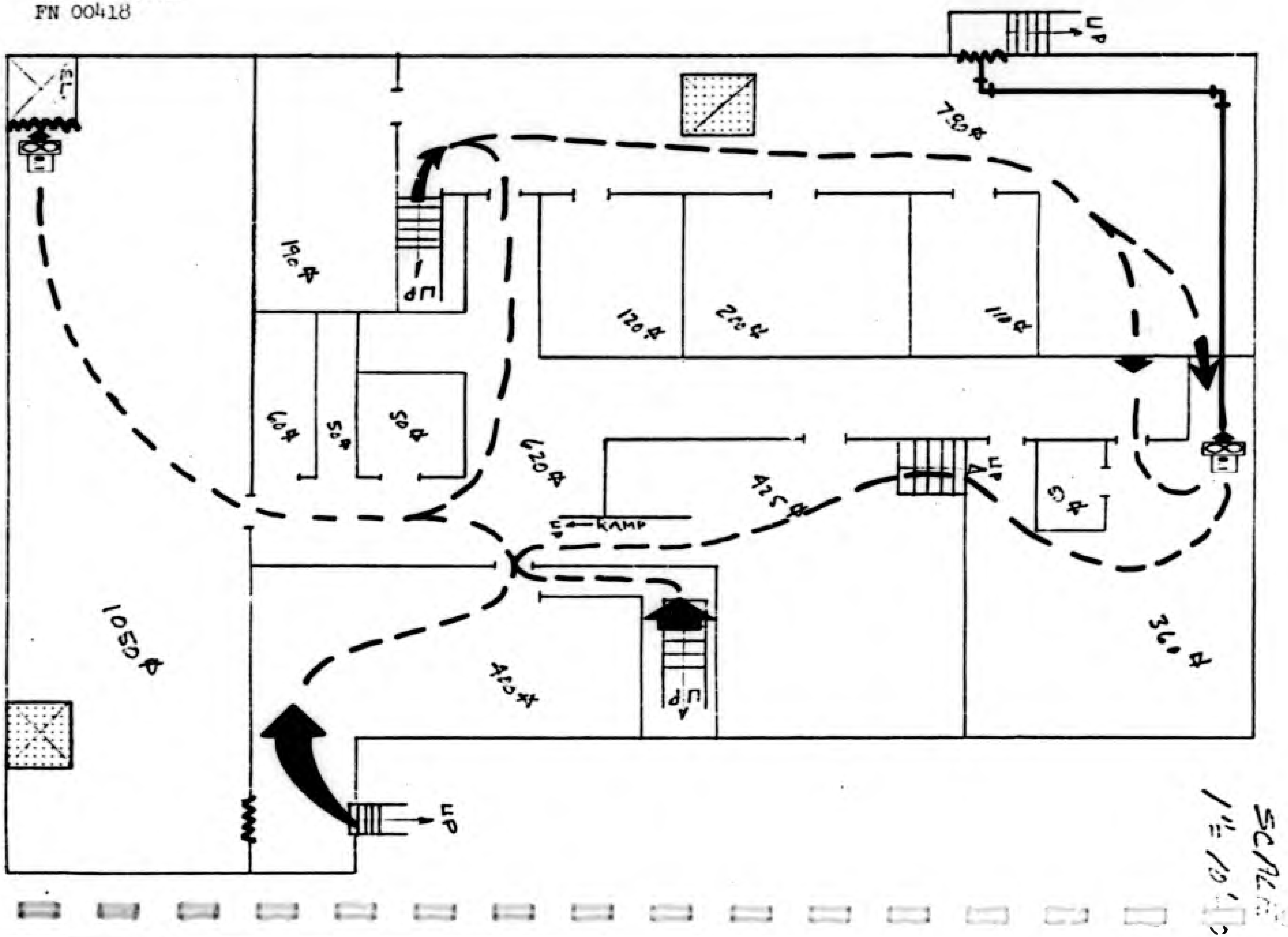
1. 36" X 36" X 8' S
2. 30" X 36 X 8' S



RTI Facility No. 93

National Bank of McKeesport
500 5th Avenue
McKeesport, Penn.

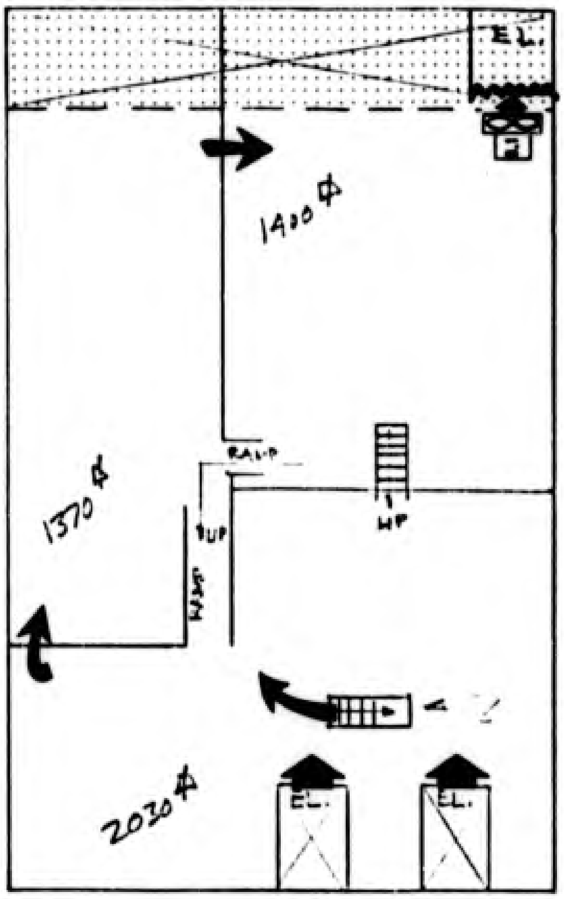
SL 2681-0001
FN 00418



RTI Facility No. 94

Benedum Trees Building
221-225 Fourth Avenue
Pittsburgh, Penn.

SL 2681-0017
FN 00195



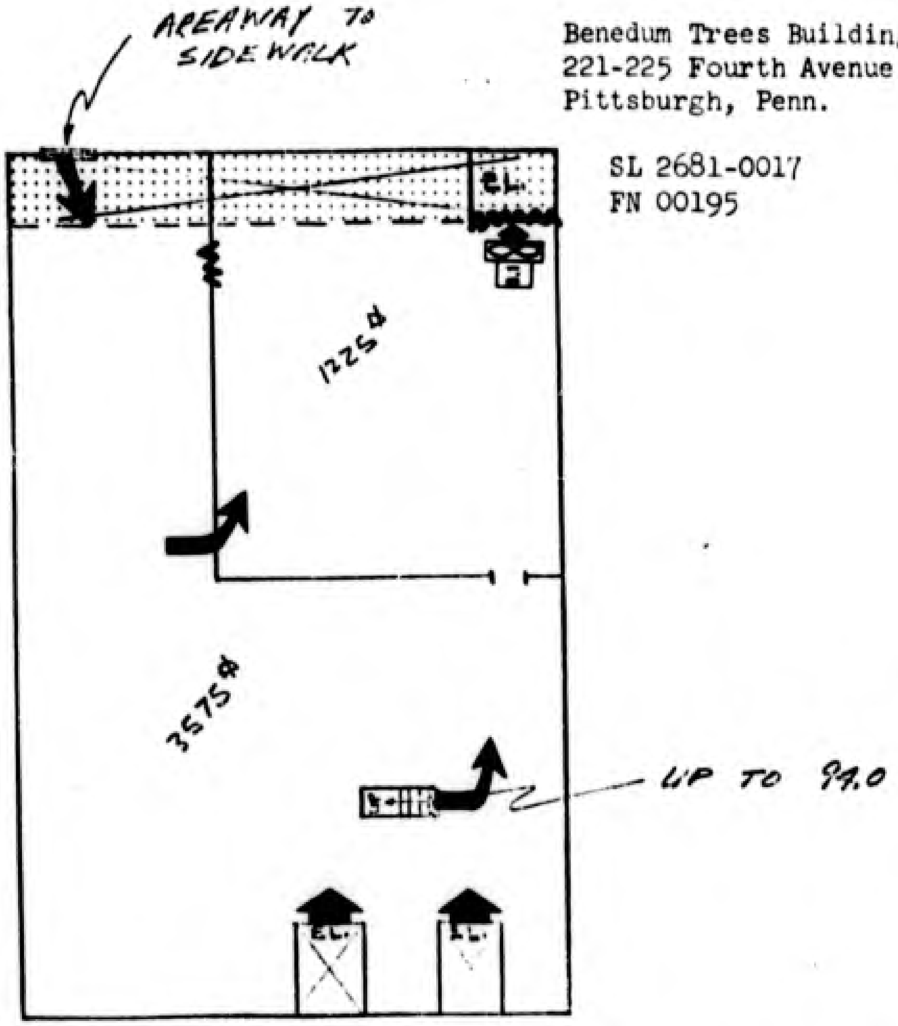
DOWN TO 94-1

SCALE
1" = 20'-0

RTI Facility No. 94-1

Benedum Trees Building
221-225 Fourth Avenue
Pittsburgh, Penn.

SL 2681-0017
FN 00195

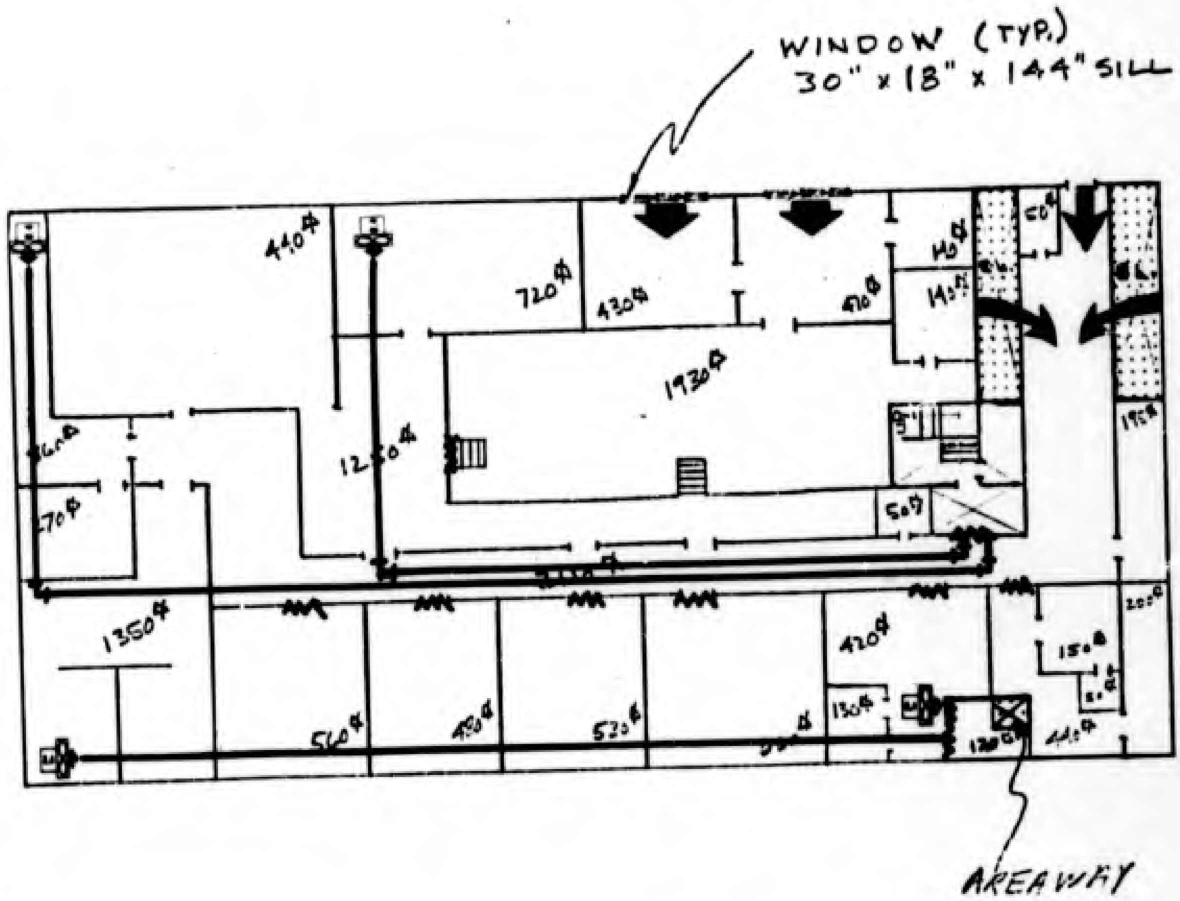


SCALE
1" = 20'-0

RTI Facility No. 95

Clark Building
701-717 Liberty Avenue
Pittsburgh, Penn.

SL 2681-0019
FN 00396

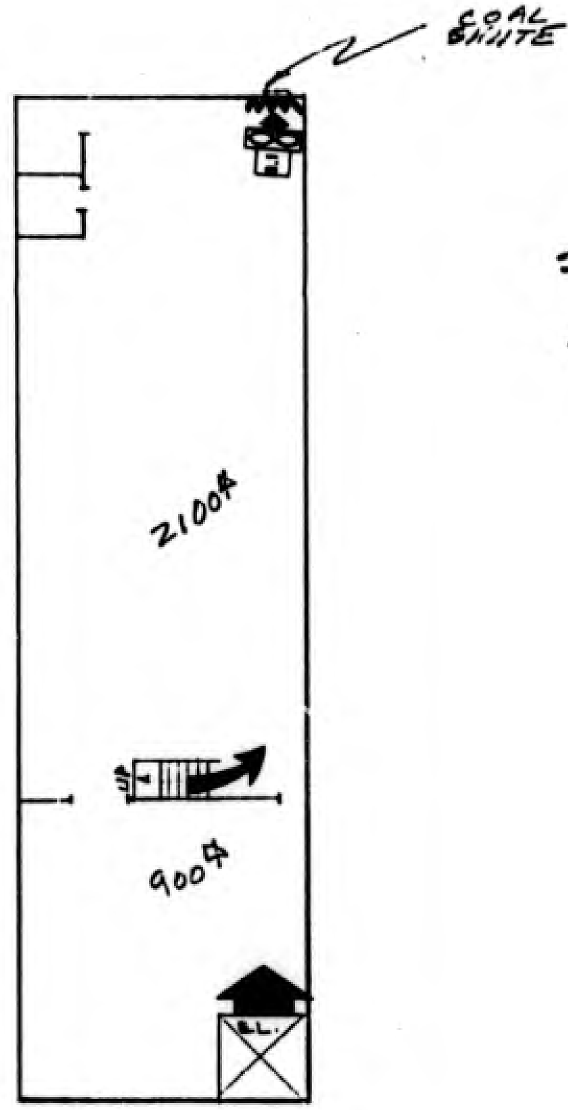


SCALE
1" = 30'-0

RTI Facility No. 96

Pitt Chemical and Sanitary Supply
1315-1319 Penn Avenue
Pittsburgh, Penn.

SL 2681-0021
FN 00645

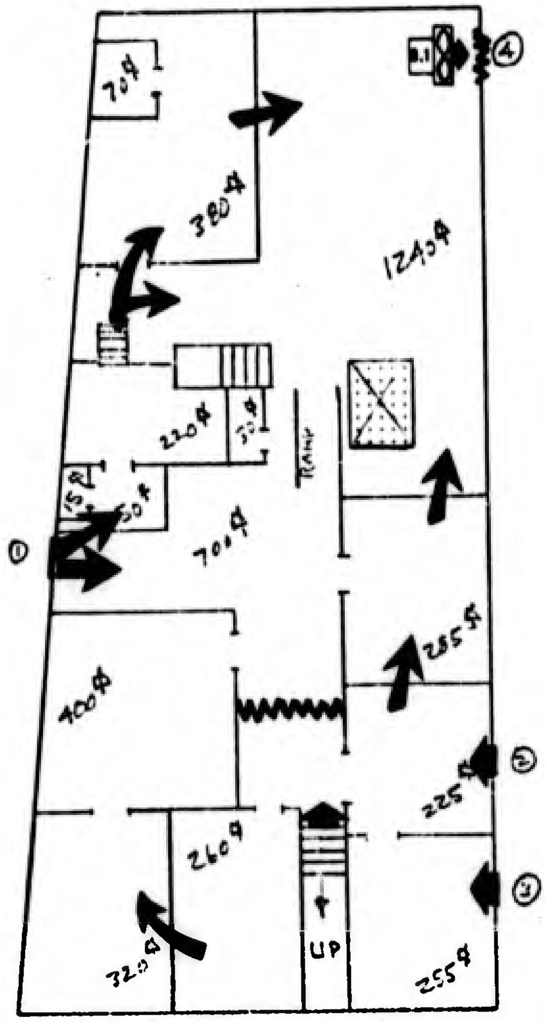


SCALE
1" = 20'-0

RTI Facility No. 97

Stores and Wilmar Apartments
4524-26 Forbes Avenue
Pittsburgh, Penn.

SL 2631-0029
FN 00720



OPENINGS

① WINDOW 36"x 30" x 48" SILL

② WINDOW 36"x 30" x 60" SILL

③ WINDOW 18"x 24" x 60" SILL

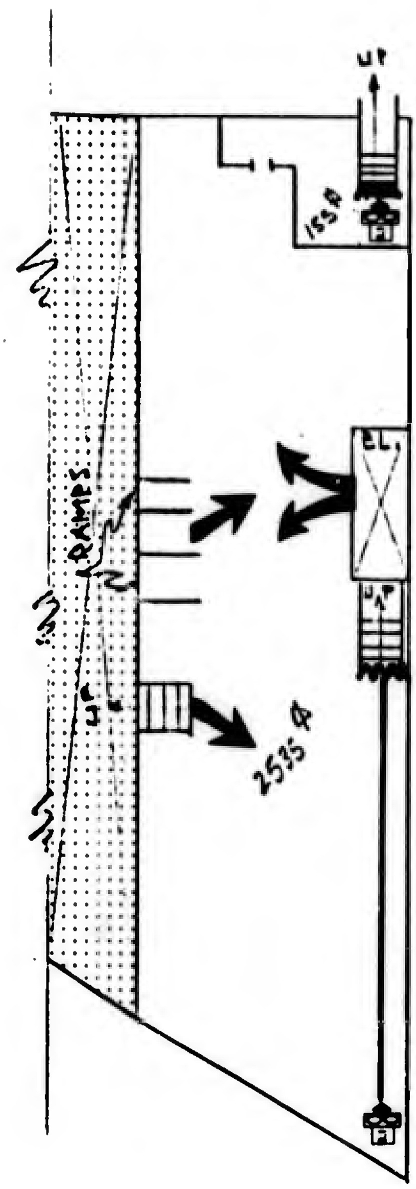
④ DOOR

SCALE
1" = 20'-0

RTI Facility No. 98-1

Tire Service (now Plaza Rubber Corp.) Part 2
4615-27 Baum Blvd.
Pittsburgh, Penn.

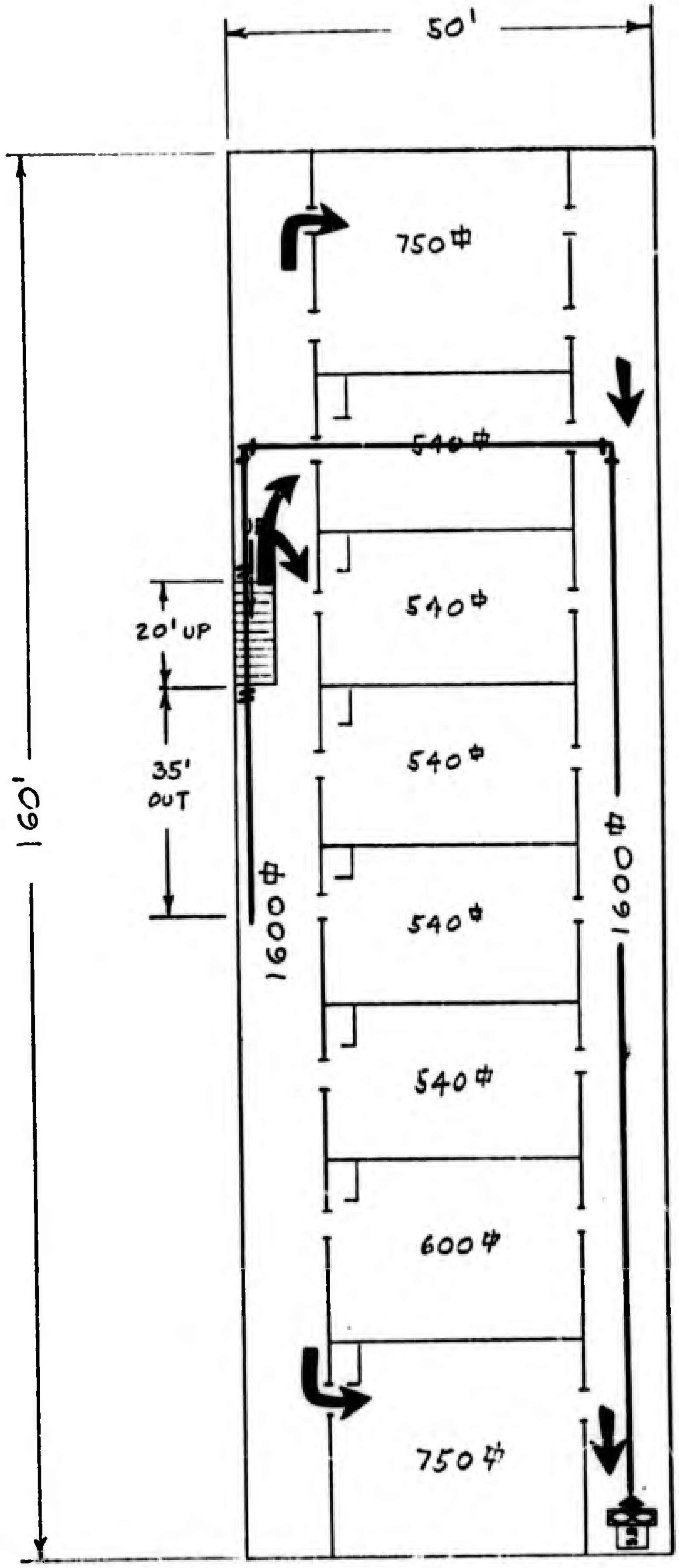
SL 2631-0040
FN 00788



SCALE
1" = 30'-0

SUB-BASEMENT

SCALE: 1" = 20'



RTI Facility No. 99

Brilliant Pumping Station
Allegheny River Blvd.
Pittsburgh, Penn.

SL 2681-0082
FN 01470

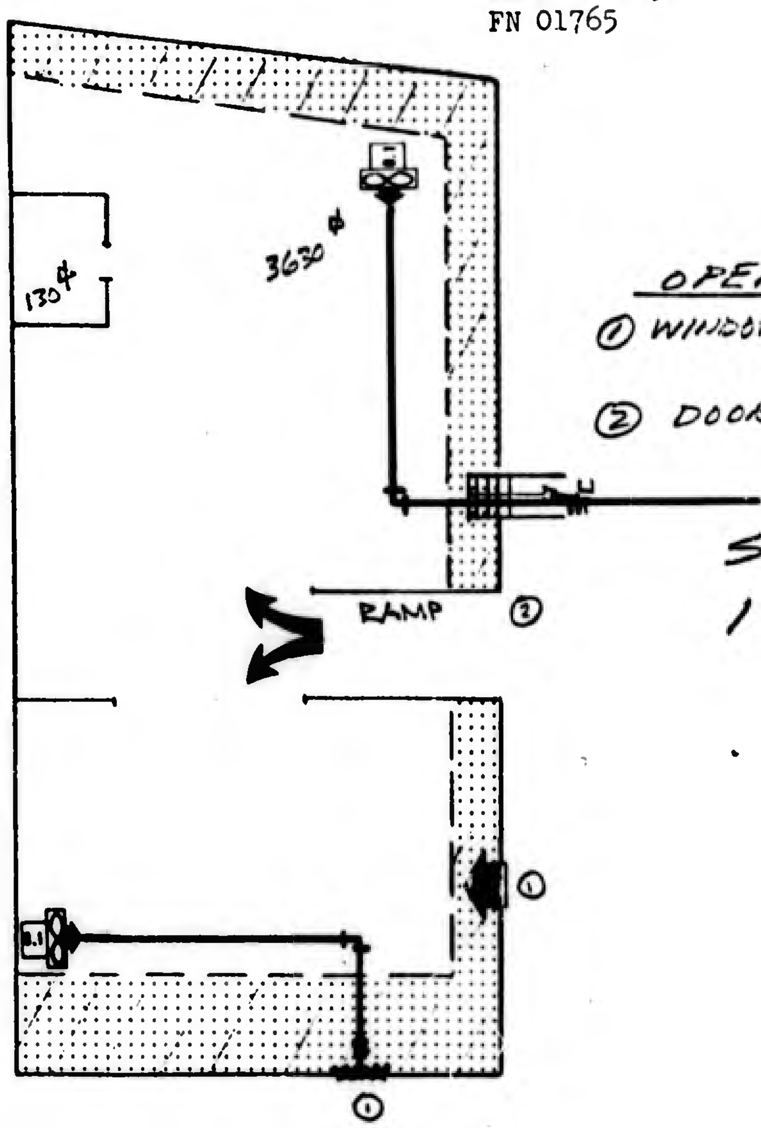
NO WINDOWS

EXTERIOR WALLS 2' THK.

RTI Facility No. 100

Merge Motors Garage
5600 Wilkins Avenue
Pittsburgh, Penn.

SL 2681-0098
FN 01765



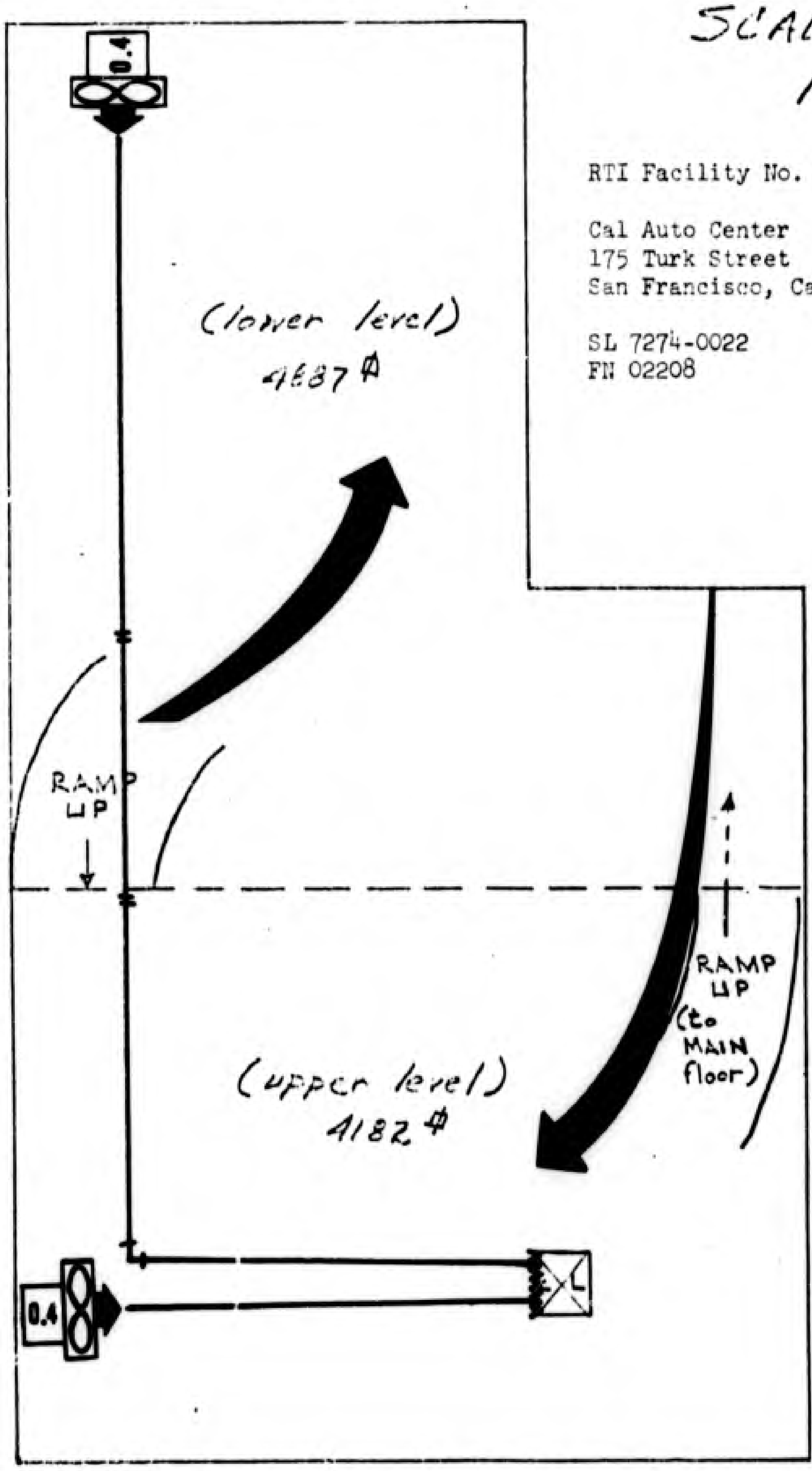
OPENINGS

① WINDOW 162" x 54"
x 48" SILL

② DOOR 132" WI

SCALE
1" = 20'-0"

SCALE
1" = 16'-0



RTI Facility No. 101

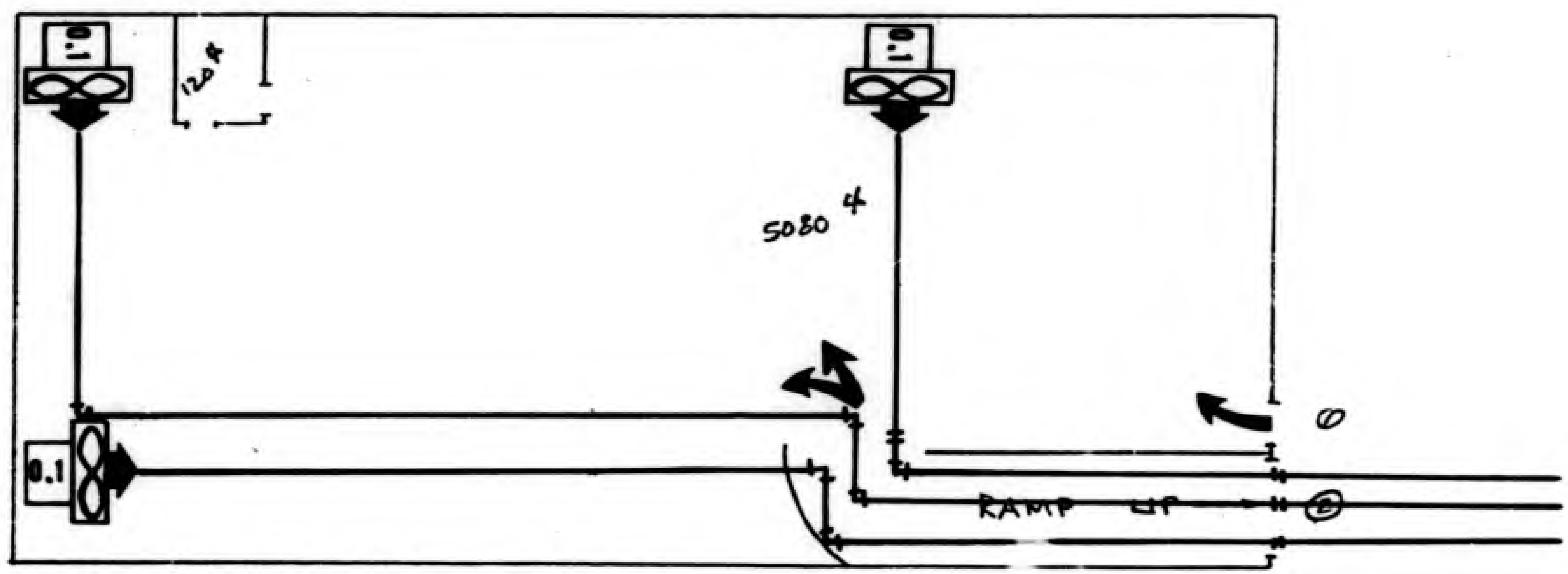
Cal Auto Center
175 Turk Street
San Francisco, Calif.

SL 7274-0022
FN 02208

RTI Facility No. 102

Munroe Motors
2035 Divisadero Street
San Francisco, Calif.

SL 7274-0032
FN 03265



OPENINGS

① WINDOW 48" x 18" x 96" SILL
② DOOR 108" x 120"

SCALE
1" = 20'-0

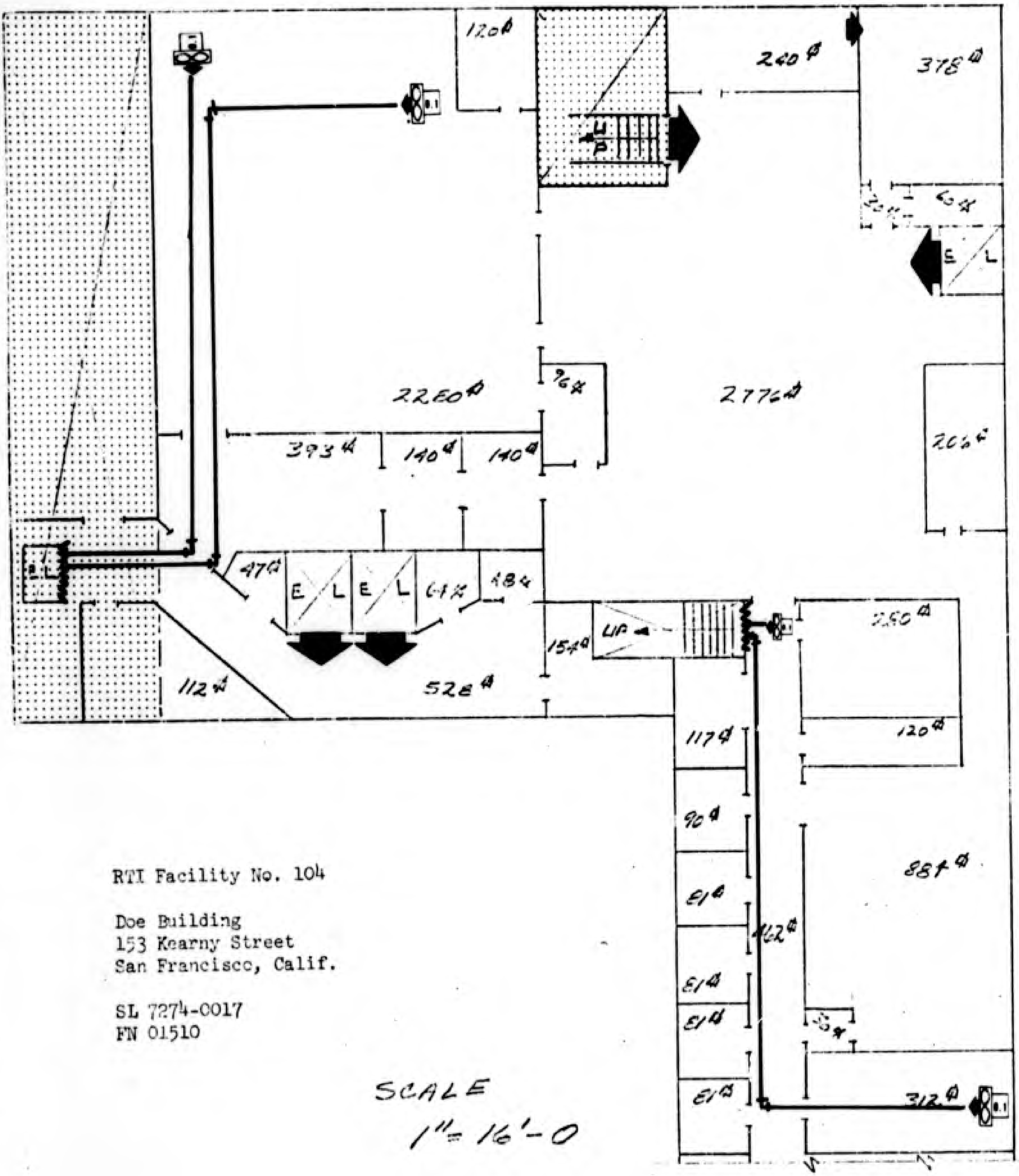
RTI Facility No. 103

Patrero Terrace Housing Unit
G-10 995 Connecticut Avenue
San Francisco, California

SL 7274-0075
FN 03911

This facility has no usable fallout shelter space on the first floor. The space identified by the Phase 2 sketch is an unlighted, inaccessible, uneven floored, crawl space. Investigation of another building in the same area of the housing unit revealed an area very much like the one on the Phase 2 sketch.

No form was prepared on this facility.

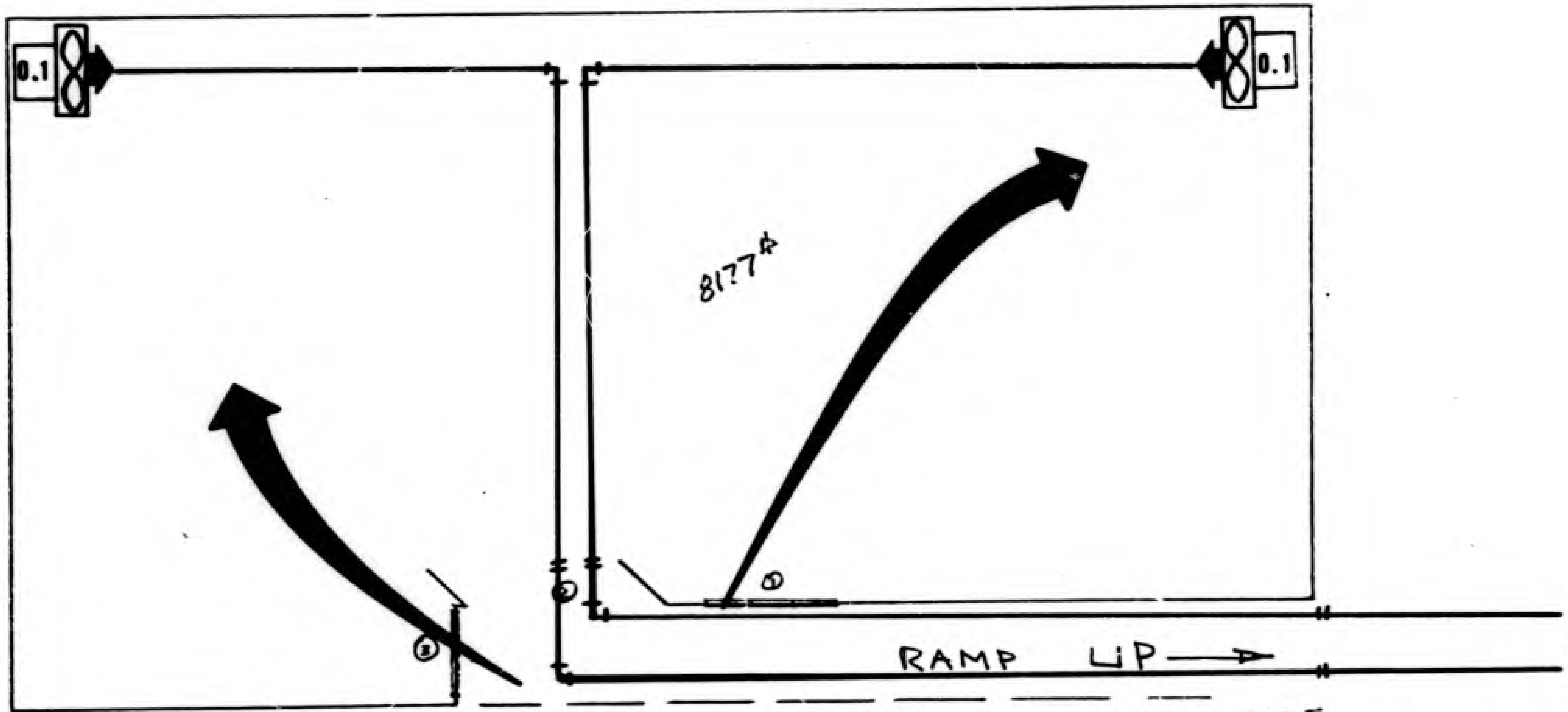


RTI Facility No. 104

Doe Building
153 Kearny Street
San Francisco, Calif.

SL 7274-0017
FN 01510

SCALE
1" = 16'-0



RTI Facility No. 105

Garage (Honour Garage)
1725 Sacramento Street
San Francisco, Calif.

SL 7274-0010
FN 01792

SCALE
1" = 16'-0

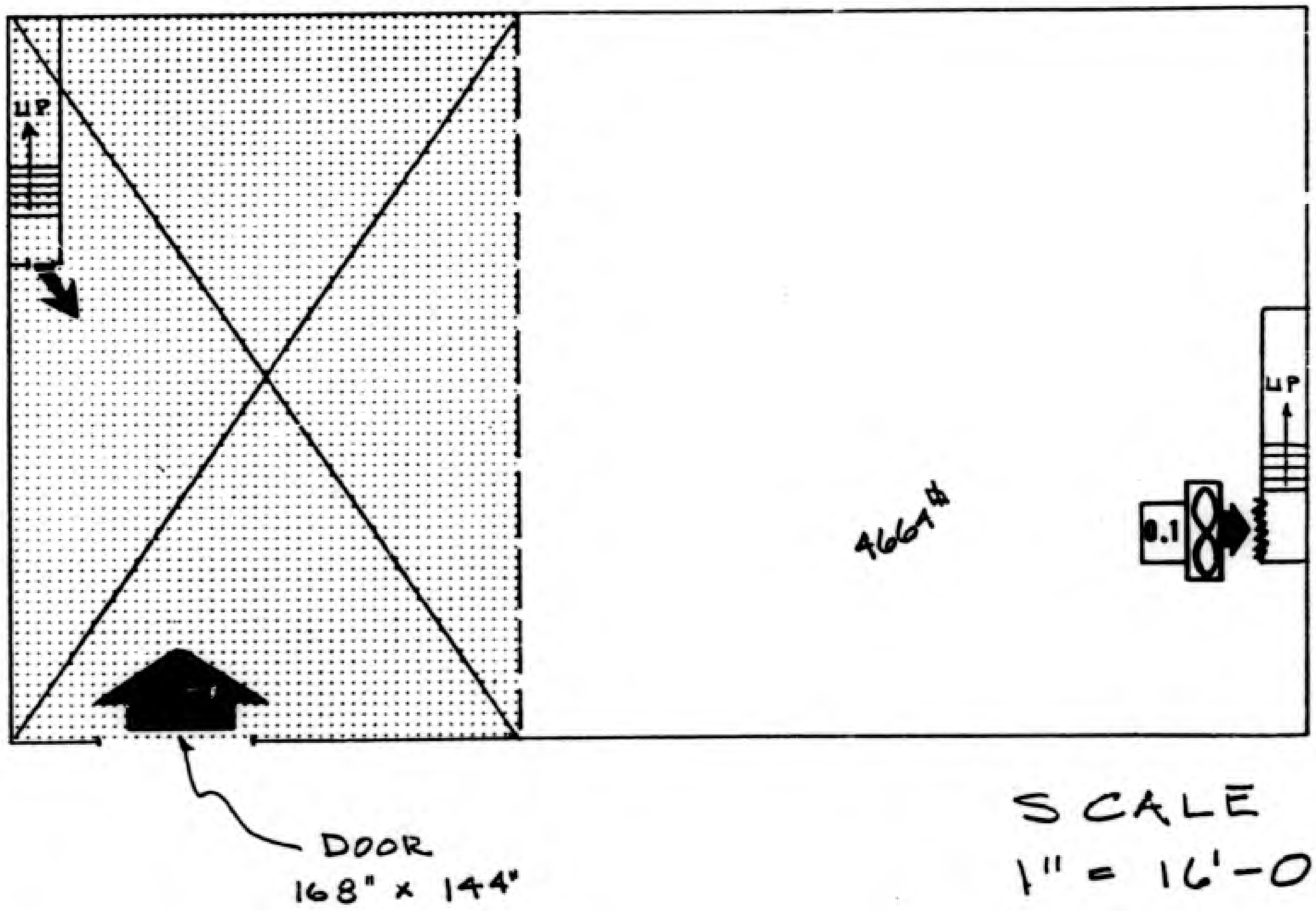
OPENINGS

1. 3-WINDOWS 56" x 40" x 72" SILL
2. DOOR 240" WIDE
3. OPENING 96" x 96" x 36" SILL

RTI Facility No. 106

Garage (Union Oil Company)
401 Harrison
San Francisco, Calif.

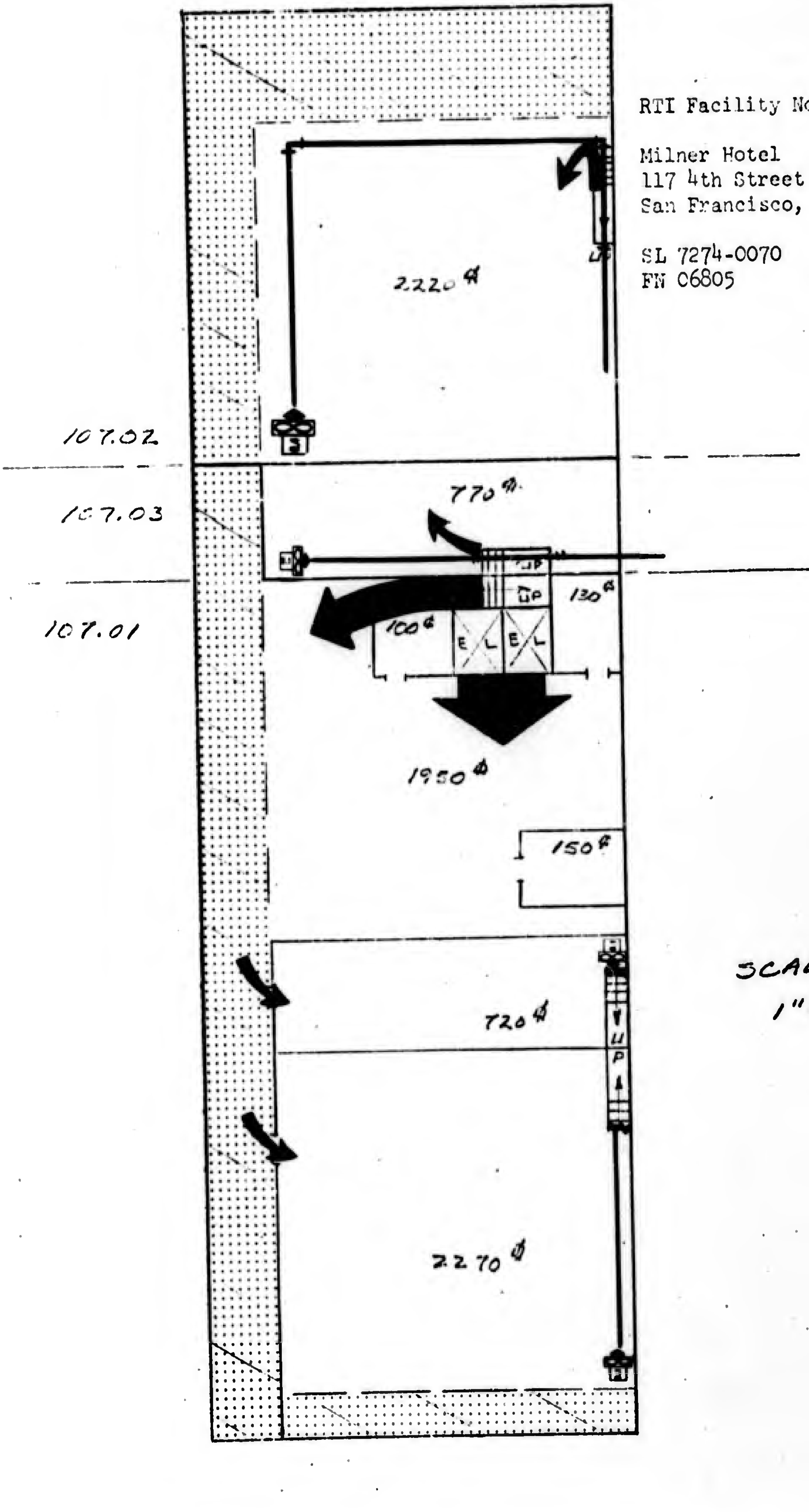
SL 7274-0069
FN 05509



RTI Facility No. 107.01, 107.02 & 107.03

Milner Hotel
117 4th Street
San Francisco, Calif.

SL 7274-0070
FN 06805

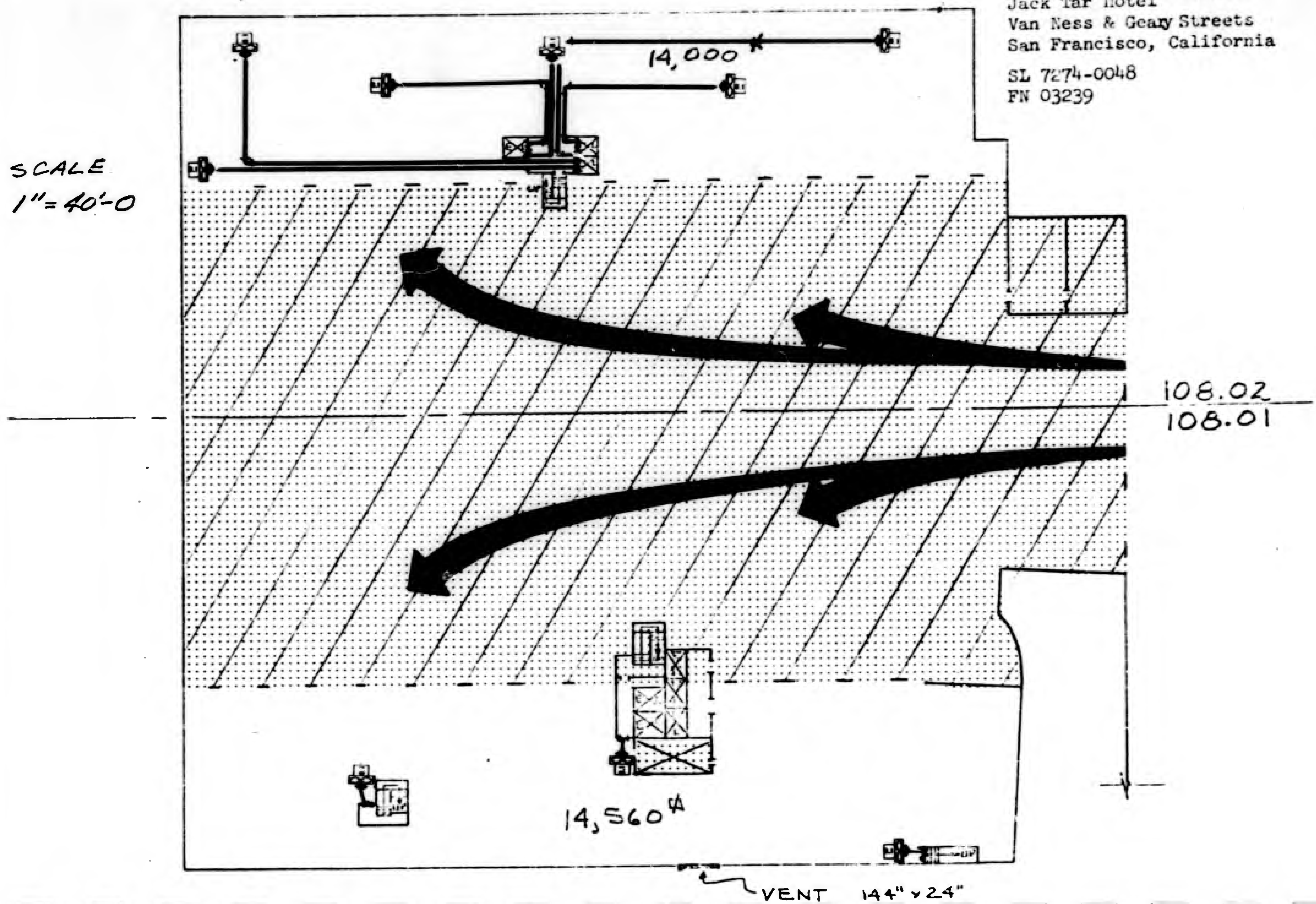


SCALE
1" = 20'-0

RTI Facility No. 108.01 &
108.02

Jack Tar Hotel
Van Ness & Geary Streets
San Francisco, California

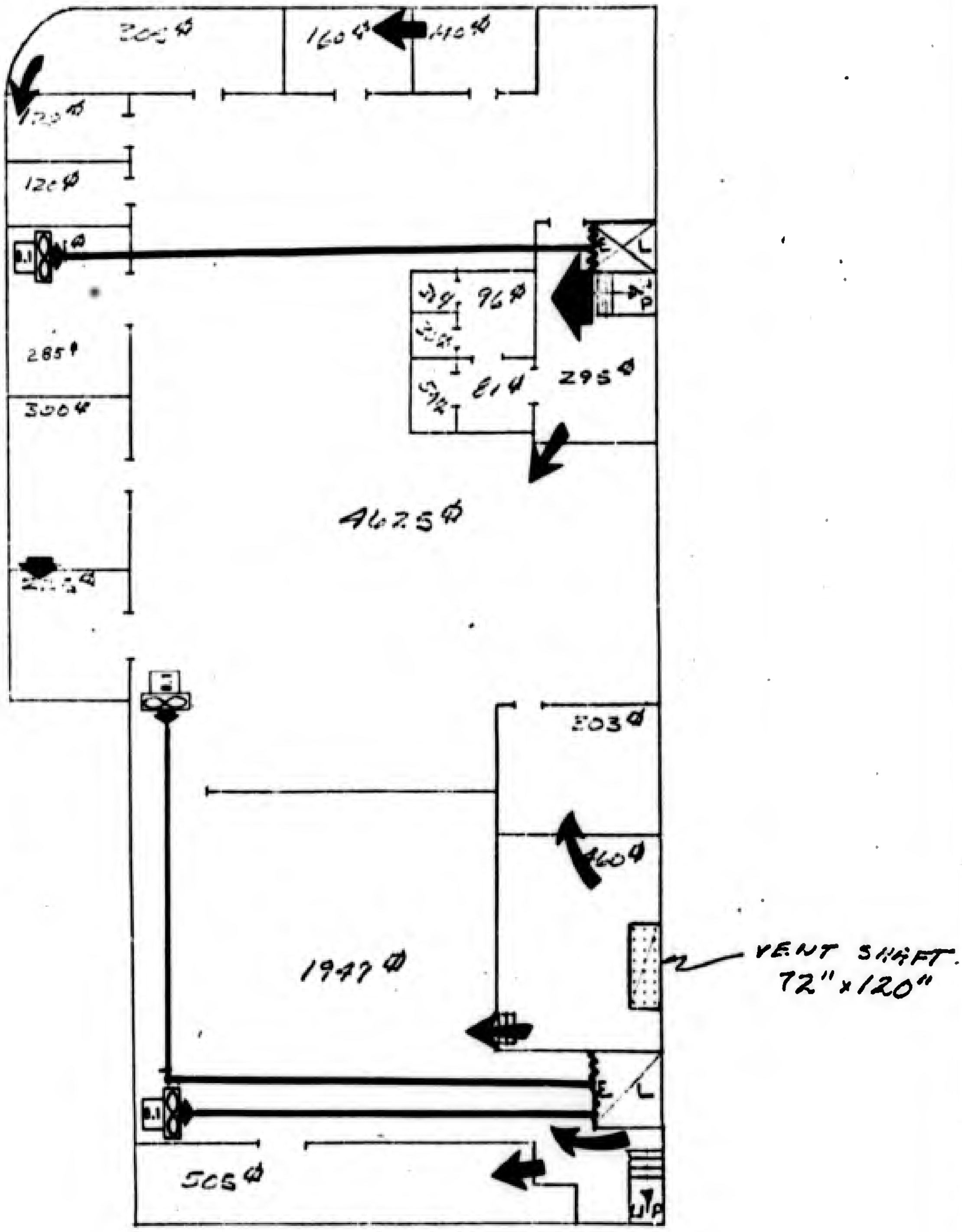
SL 7274-0048
FN 03239



RTI Facility No. 109

First National Bank
206 North Virginia
Reno, Nevada

SL 74-21-0005
FN 01736



SCALE
1"=20'-0

RTI Facility No. 110.01 &
110.02

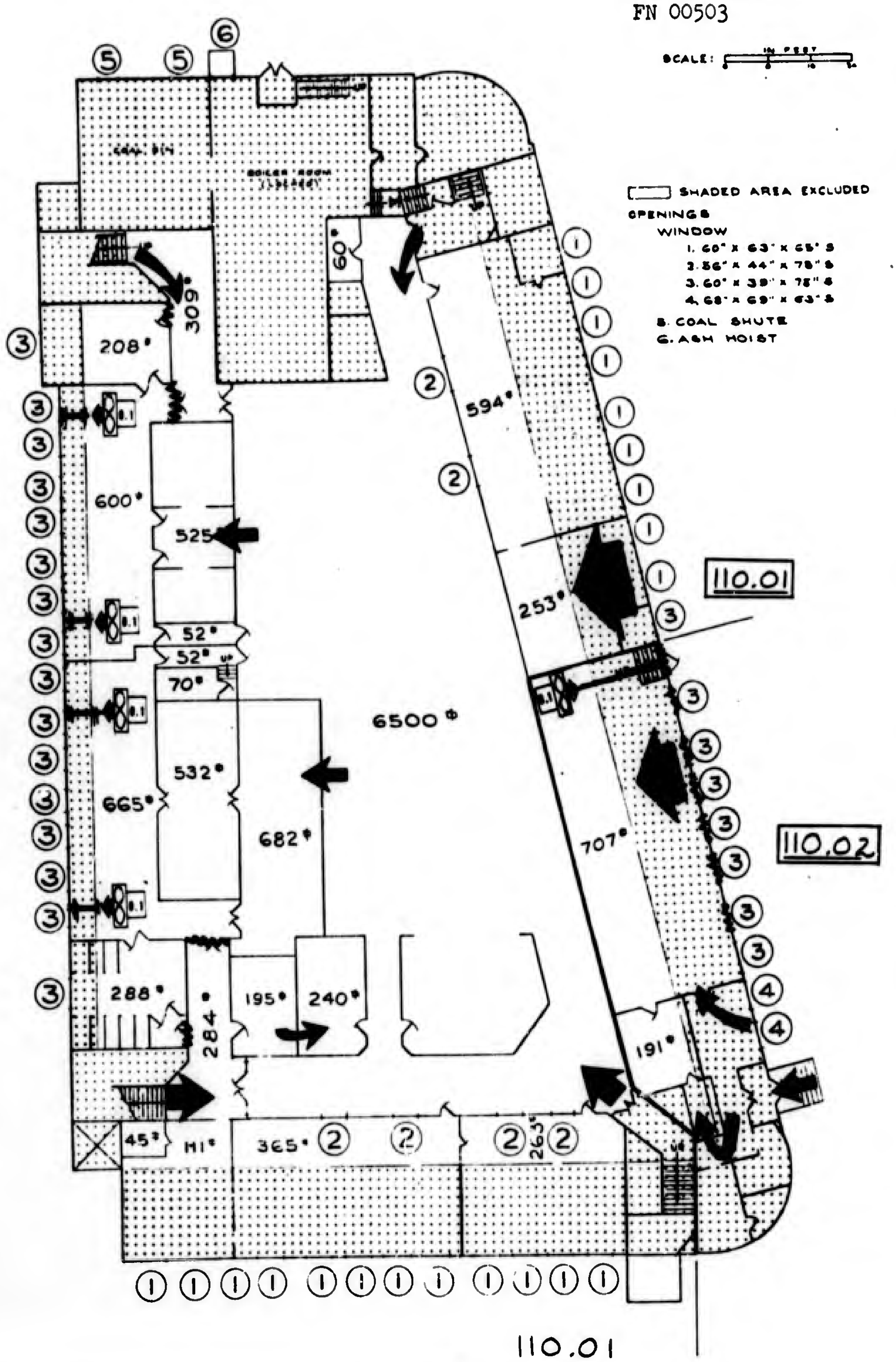
Roberts School
225 Windsor Street
Cambridge, Mass.

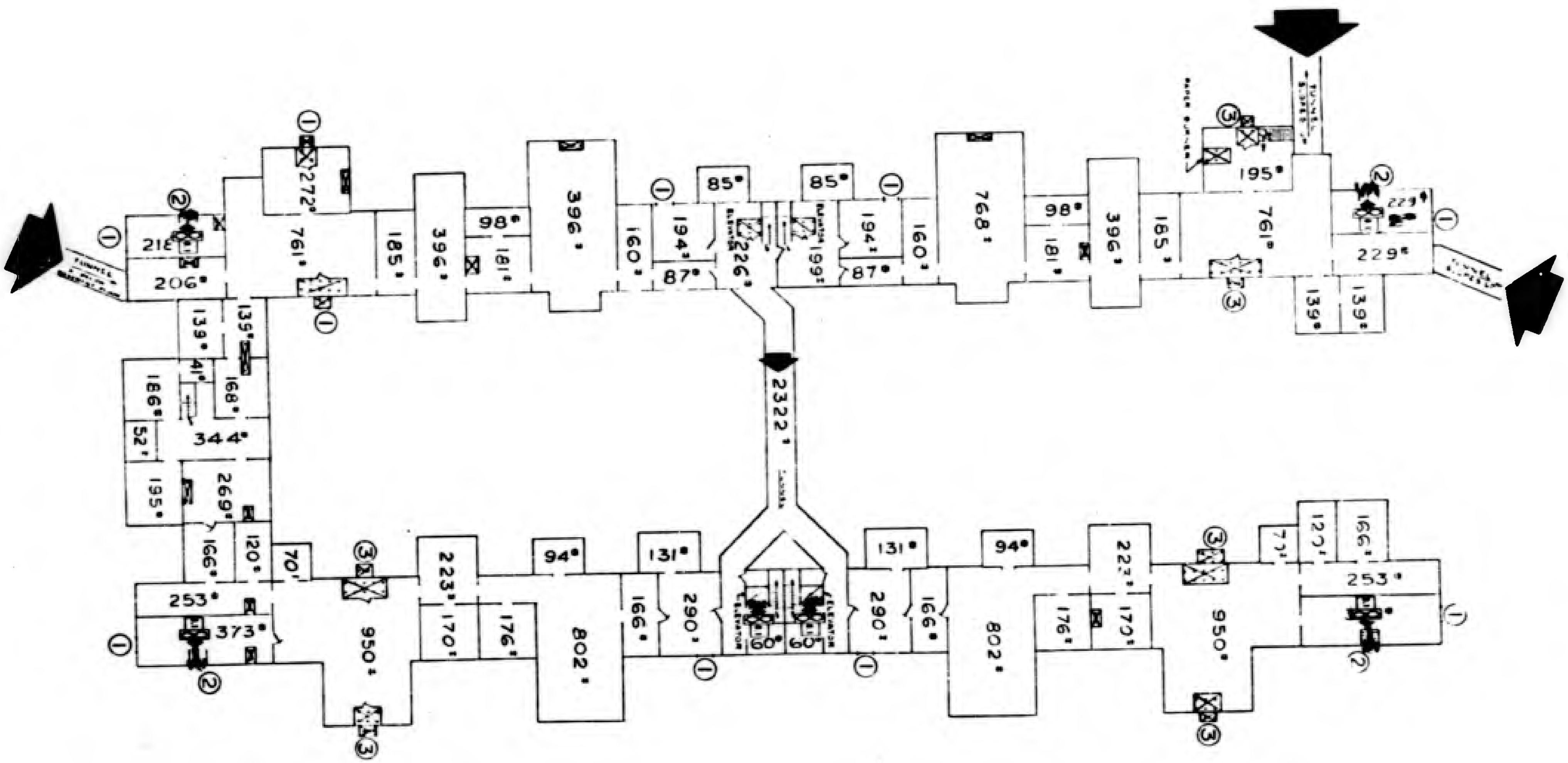
SL 1312-0005
FN 00503

SCALE: IN FEET

SHADED AREA EXCLUDED

OPENINGS
WINDOW
1. 60" x 63" x 65" S
2. 36" x 44" x 78" S
3. 60" x 39" x 78" S
4. 68" x 69" x 63" S
5. COAL SHUTE
6. ASH HOIST





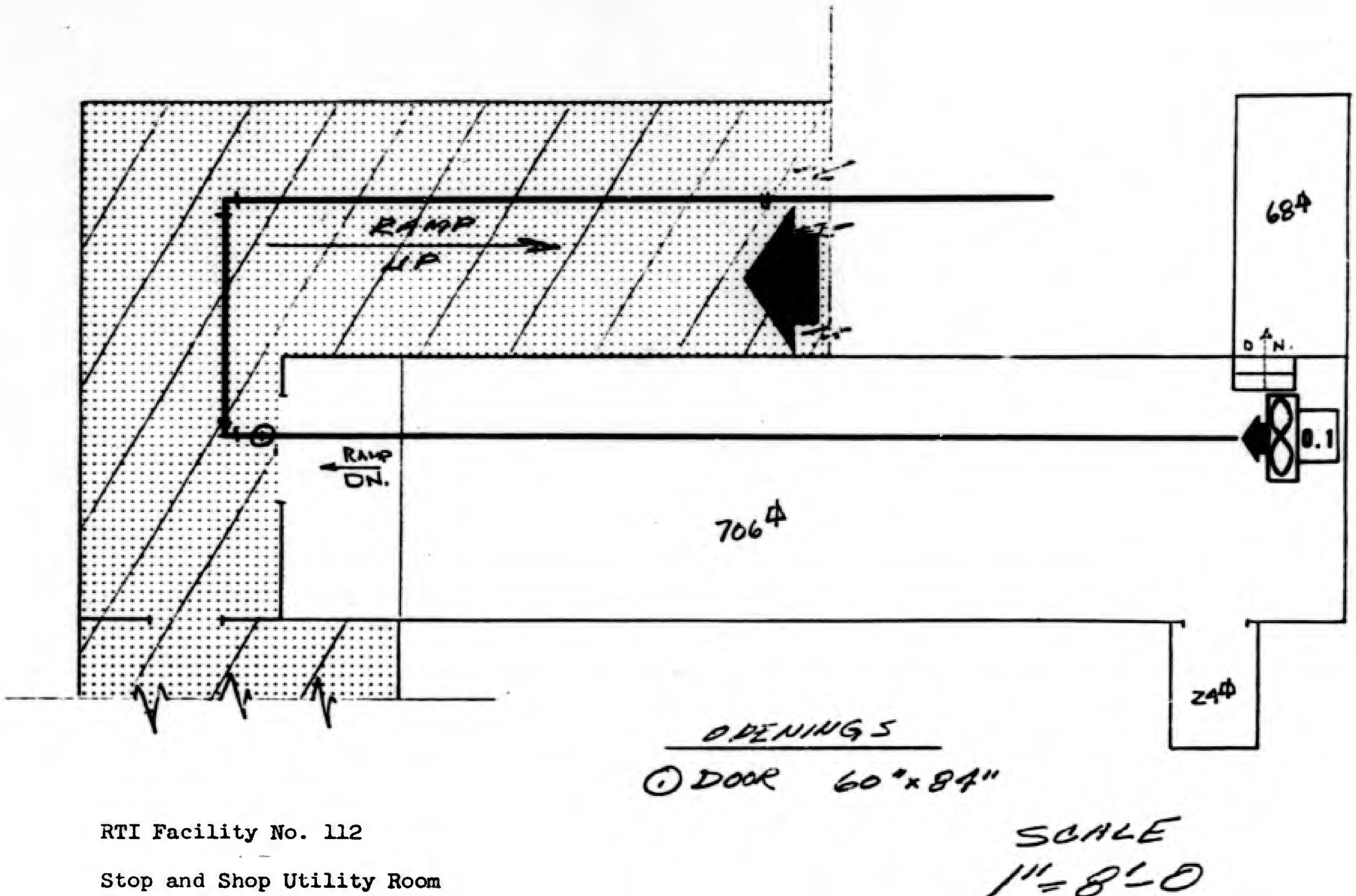
OPENINGS
1. WINDOW
2. DOOR-OUTSIDE
3. AIR CHAMBER TO OUTSIDE

#111

RTI Facility No. 111

Girls Close Perkins Institution
175 N. Beacon Street
Watertown, Mass.

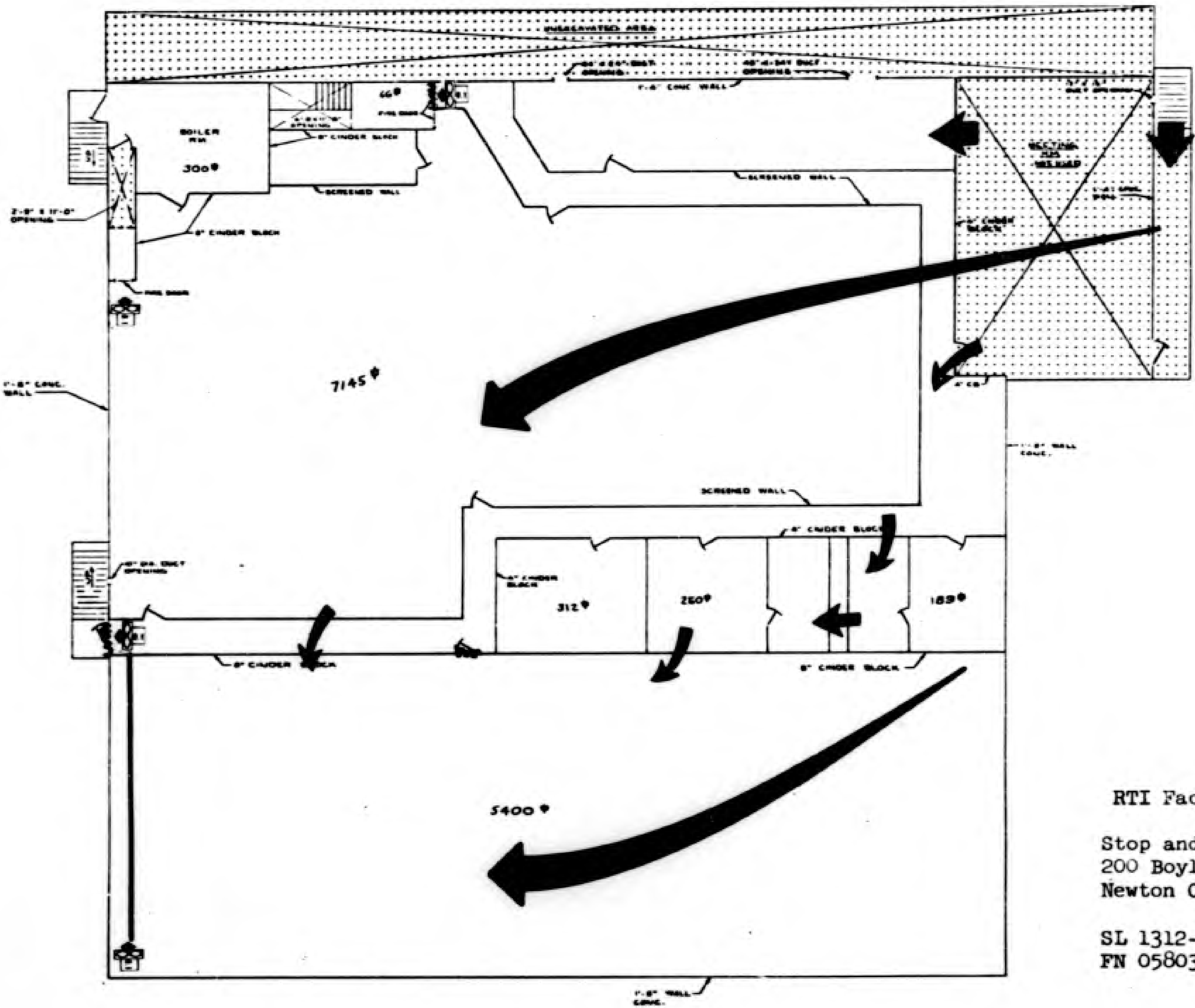
SL 1312-0117
FN 03907



RTI Facility No. 112

Stop and Shop Utility Room
Shoppers World
Framington, Mass.

SL 1312-0140
FN 04022



RTI Facility No. 113

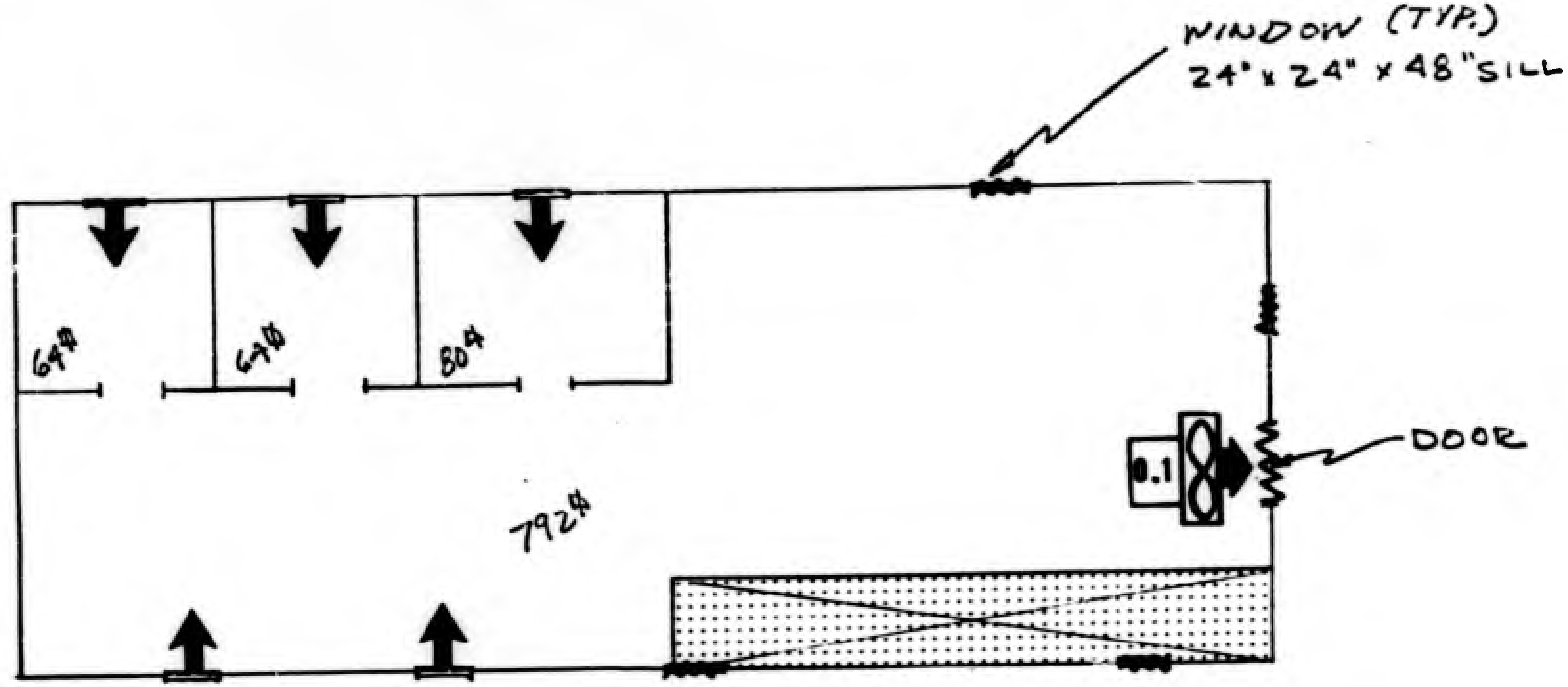
Stop and Shop
200 Boylston Street
Newton Center, Mass.

SL 1312-0058
FN 05803

RTI Facility No. 114

Apartment
4725 N. Beacon
Chicago, Illinois

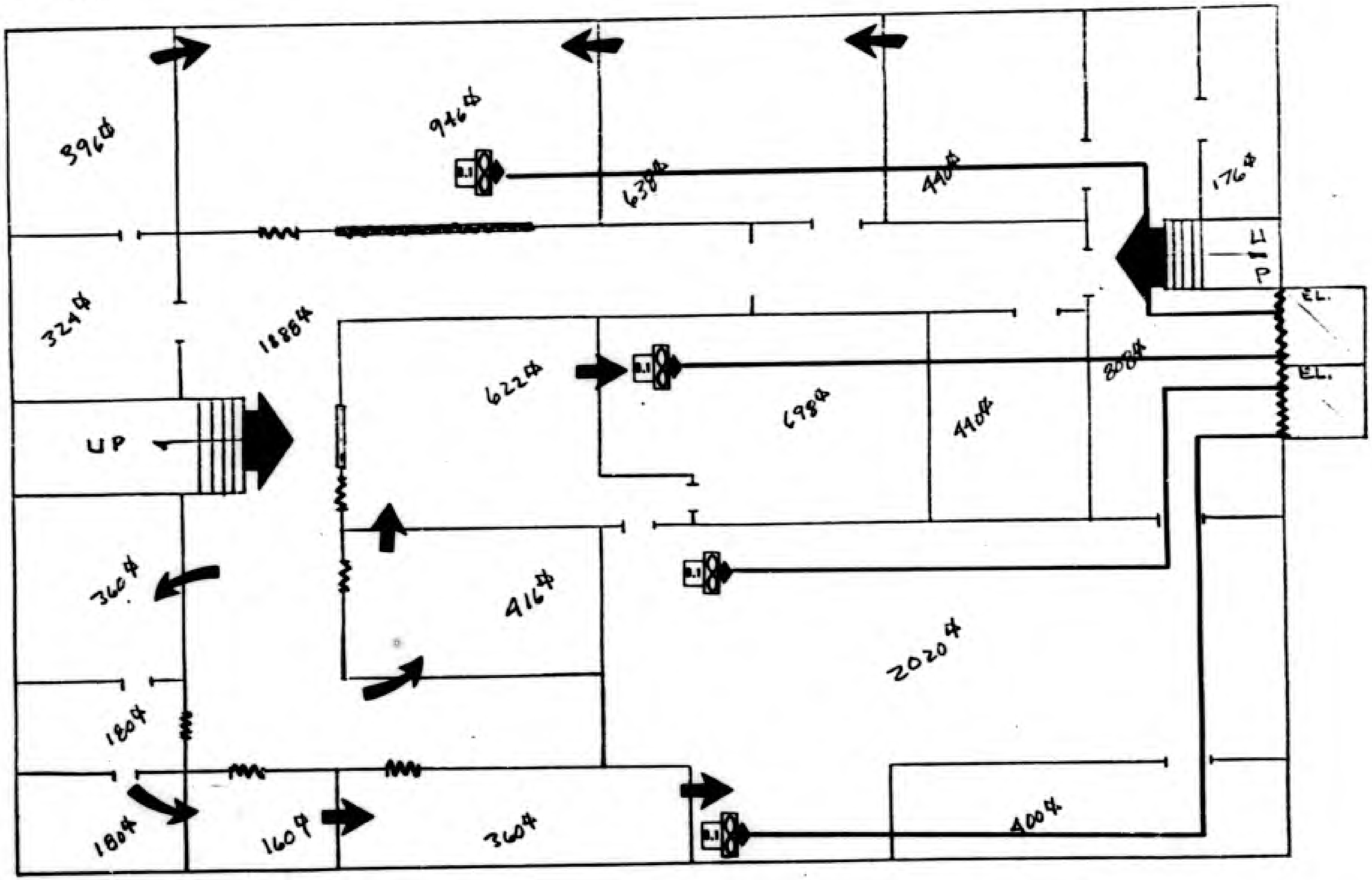
SL 4121-0033
FN 05085



SCALE
1" = 8'-0

Peoples Saving and Loan Company
168 Ottawa Street
Joliet, Illinois

SL 4126-0010
FN 04237

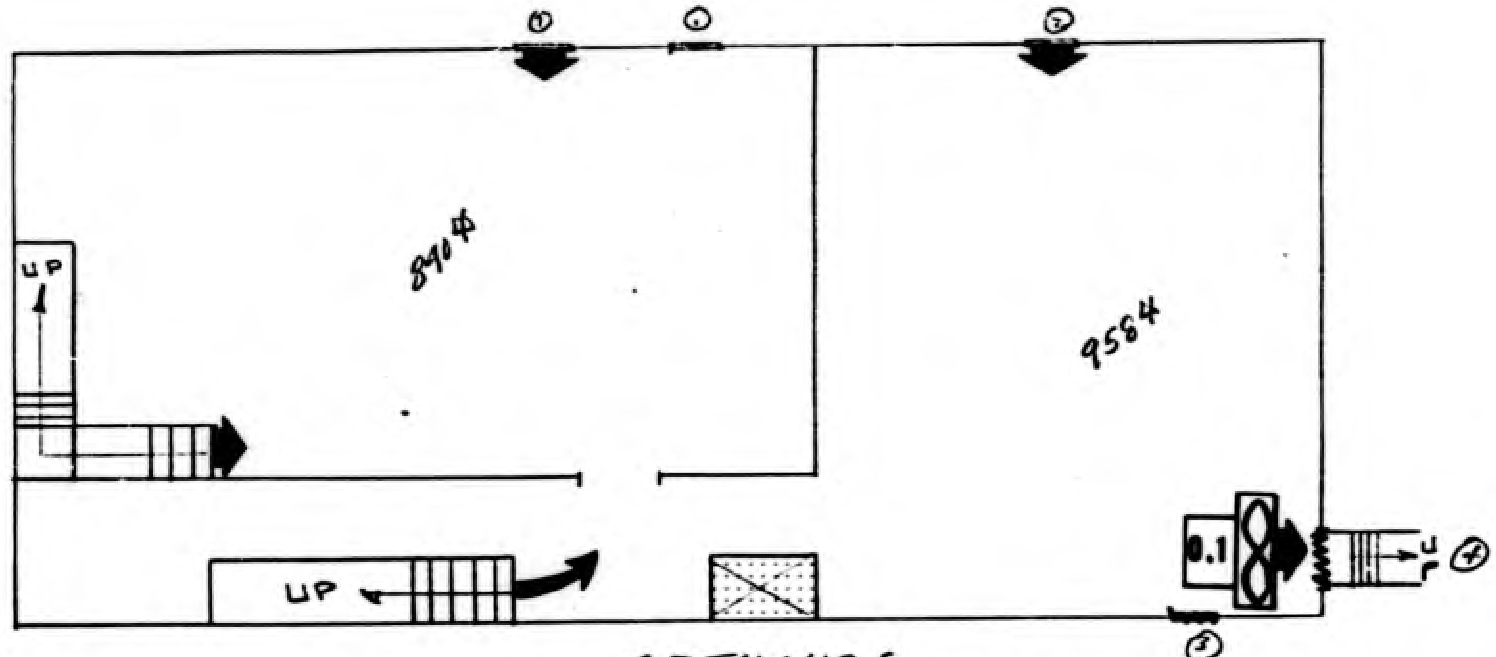


SCALE
1" = 16'-0

RTI Facility No. 116

Store and Apartments
625 W. Willow Street
Chicago, Illinois

SL 4121-0125
FN 08094



OPENINGS

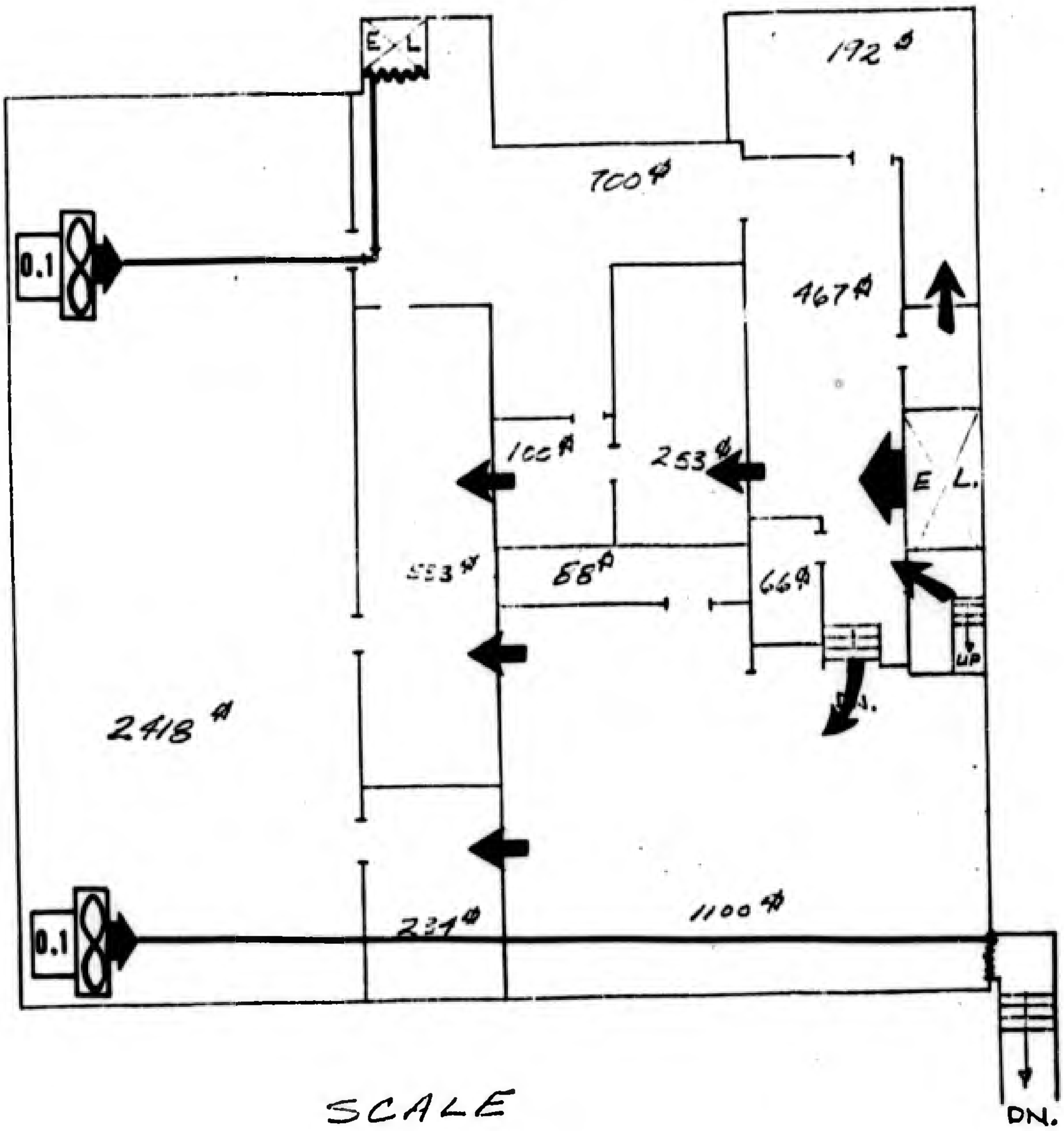
① WINDOW 30" x 42" x 60" SILL
② WINDOW 24" x 24" x 36" SILL
③ WINDOW 12" x 24" x 60" SILL
④ DOOR

SCALE
1" = 10'-0"

RTI Facility No. 117

Lone Star Gas Company Building
313 S. Harwood Street
Dallas, Texas

SL 5572-0041
FN 06047

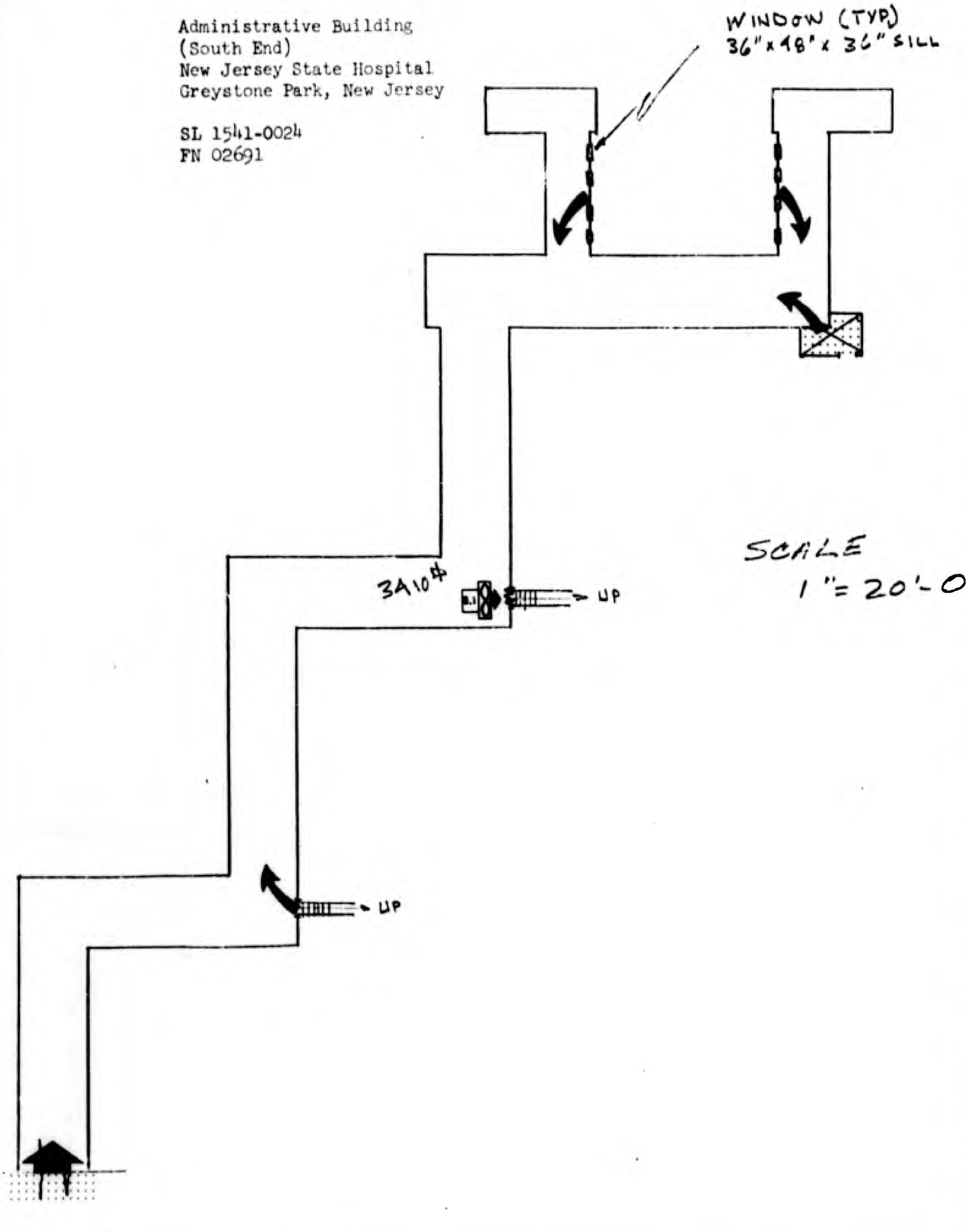


SCALE
1" = 16'-0

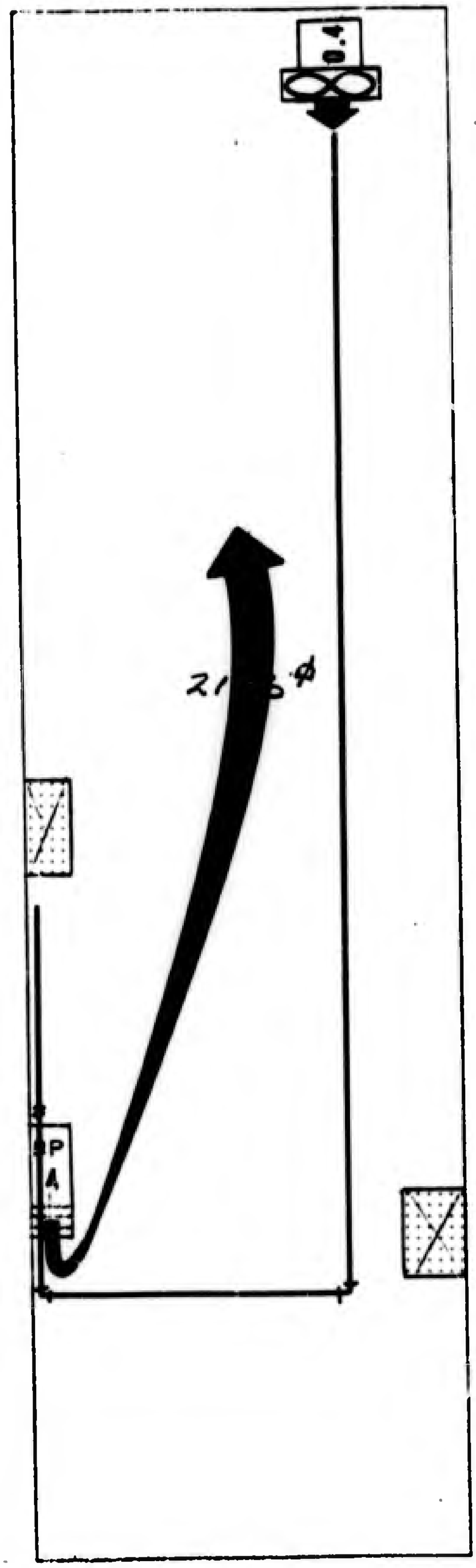
RTI Facility No. 118

Administrative Building
(South End)
New Jersey State Hospital
Greystone Park, New Jersey

SL 1541-0024
FN 02691



SCALE
1" = 10'-0



RTI Facility No. 119

Borinquen Express Co.
766 Milwaukee Avenue
Chicago, Illinois

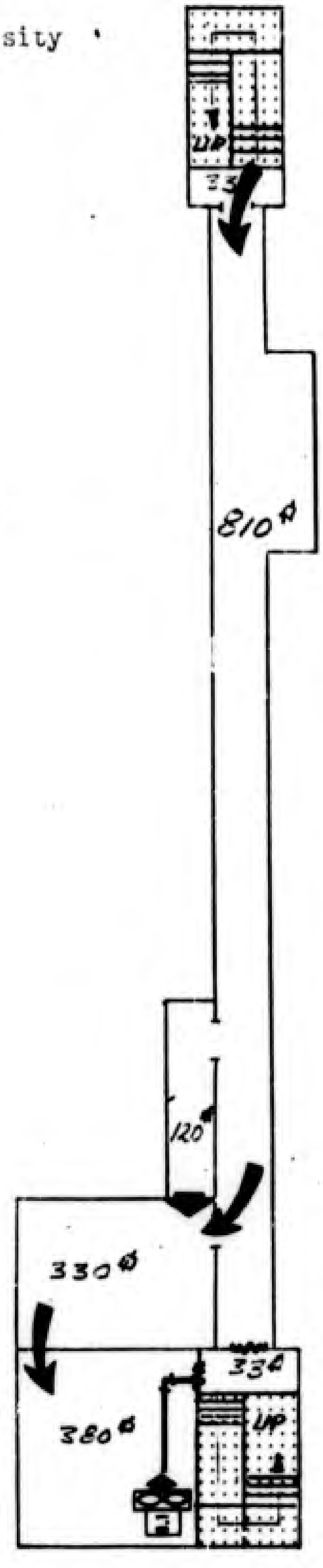
SL 4121-0327
FN 04501

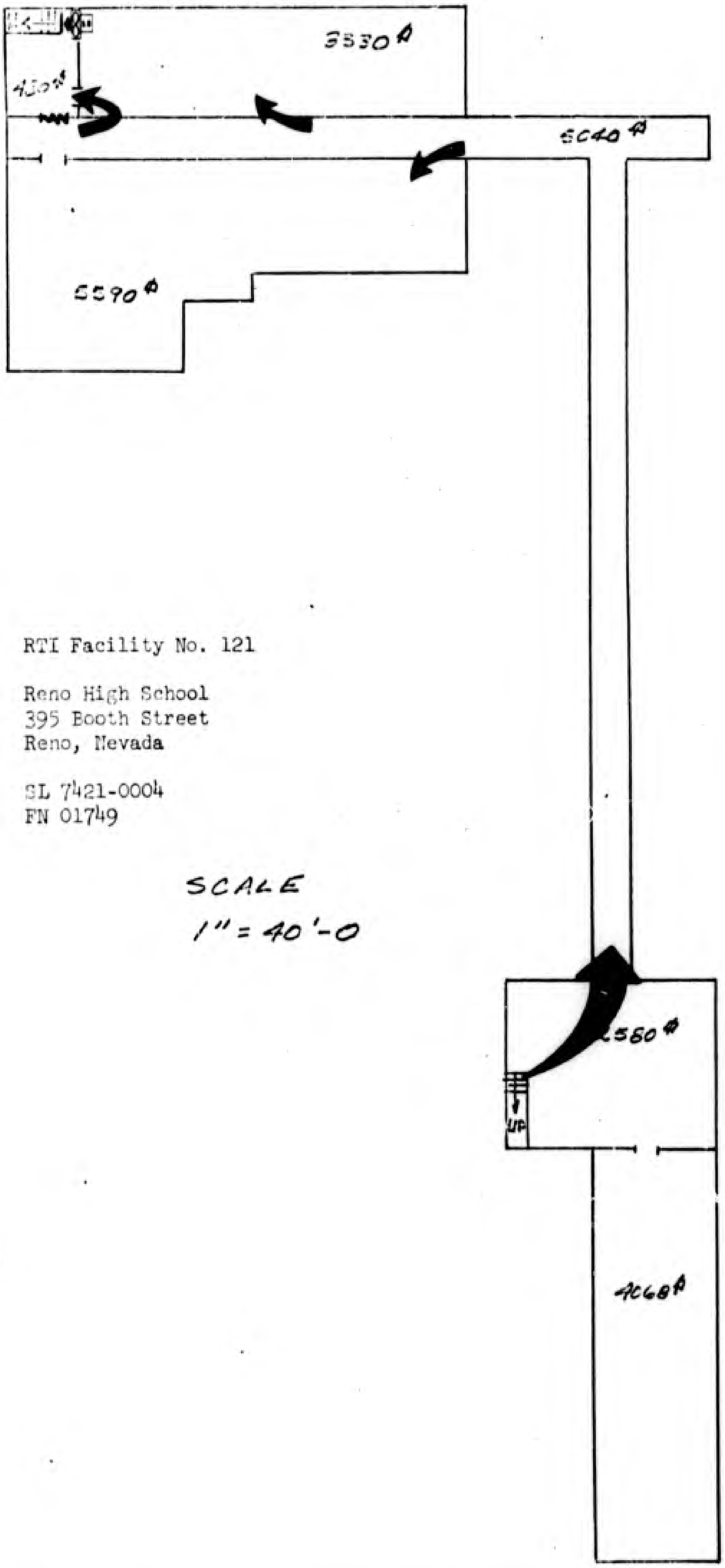
RTI Facility No. 120

Martin Dormitory
Southern Methodist University
5402 Hillcrest Avenue
Dallas, Texas

SL 5572-0235
FN 00005

SCALE
1" = 20'-0





RTI Facility No. 121

Reno High School
395 Booth Street
Reno, Nevada

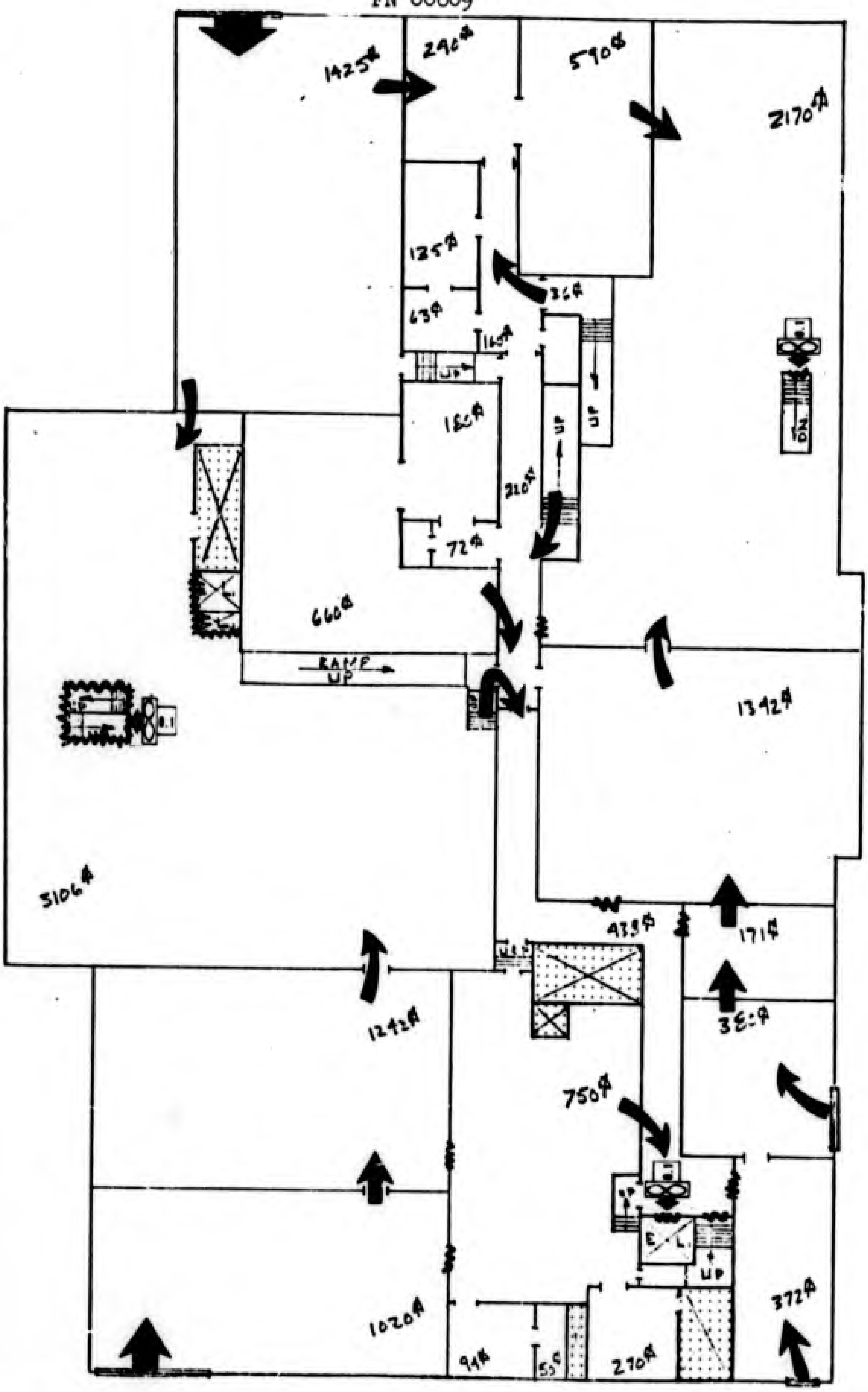
SL 7421-0004
FN 01749

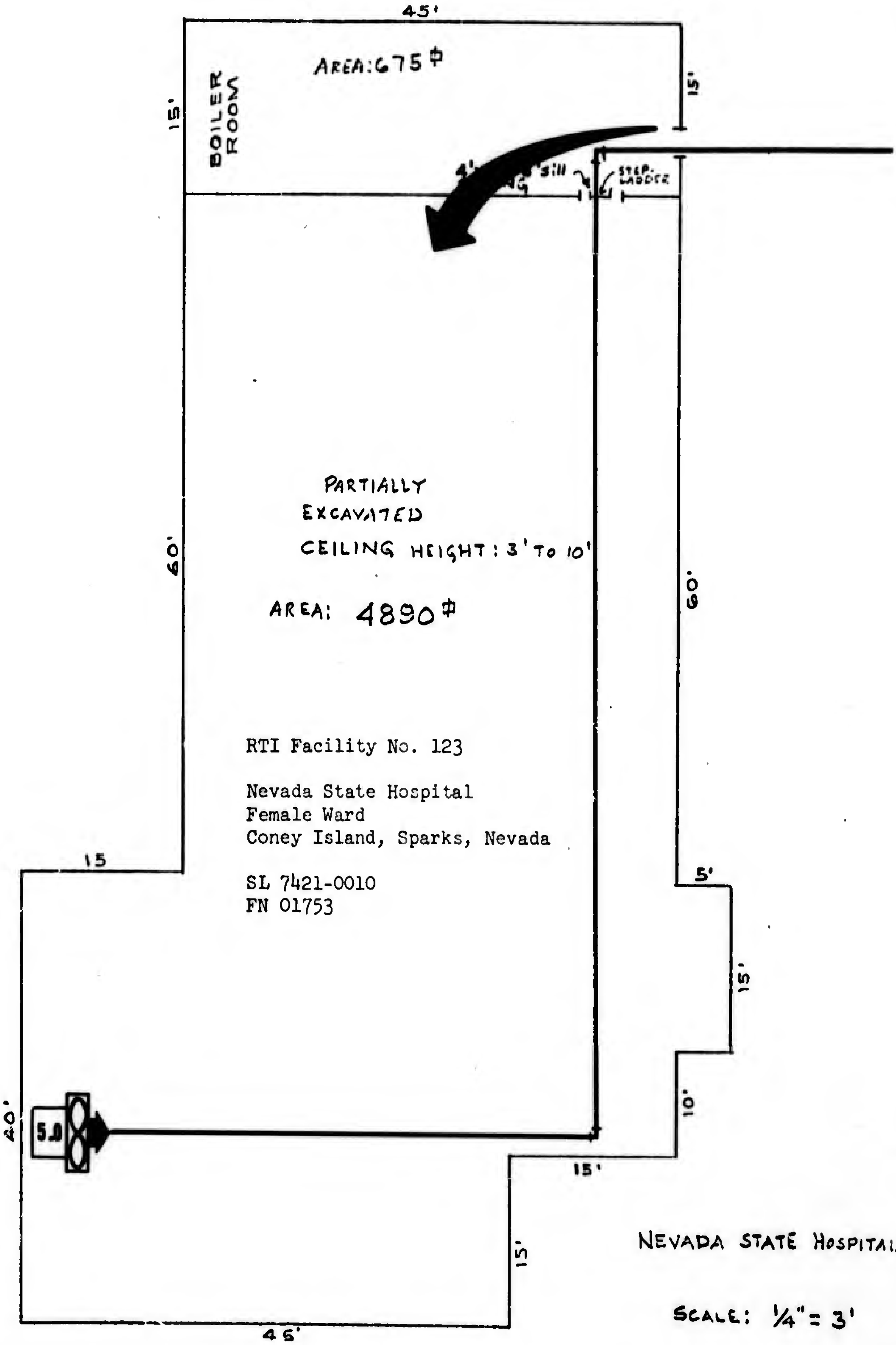
RTI Facility No. 122

Doheny Library
U. S. C. Campus
3554 University Avenue
Los Angeles, Calif.

SL 7231-0053
FN 00609

SCALE
1" = 20'-0





RTI Facility No. 123

Nevada State Hospital
Female Ward
Coney Island, Sparks, Nevada

SL 7421-0010
FN 01753

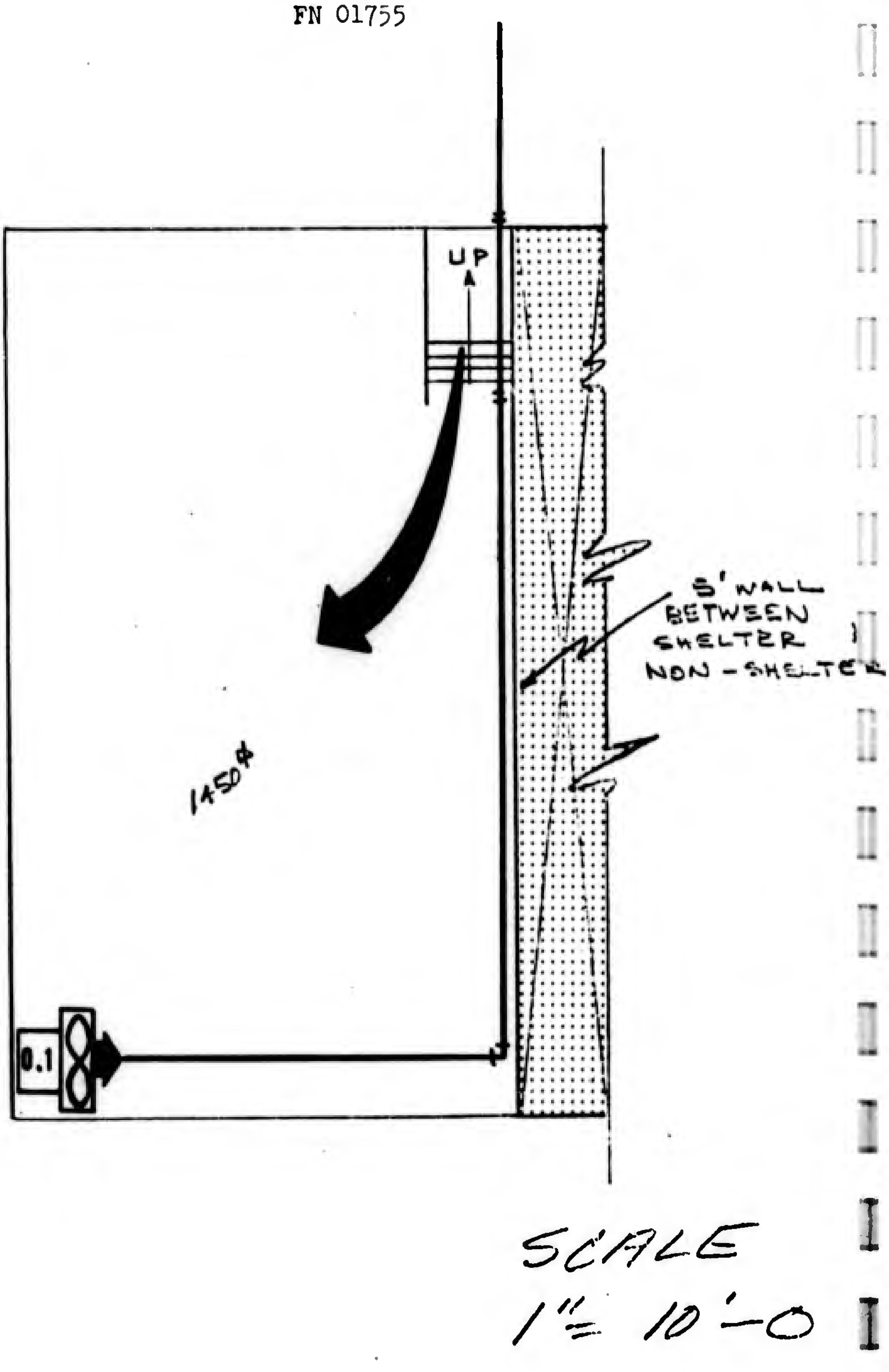
NEVADA STATE HOSPITAL

SCALE: 1/4" = 3'

RTI Facility No. 124

Nevada State Hospital
Male Ward
Coney Island, Sparks, Nevada

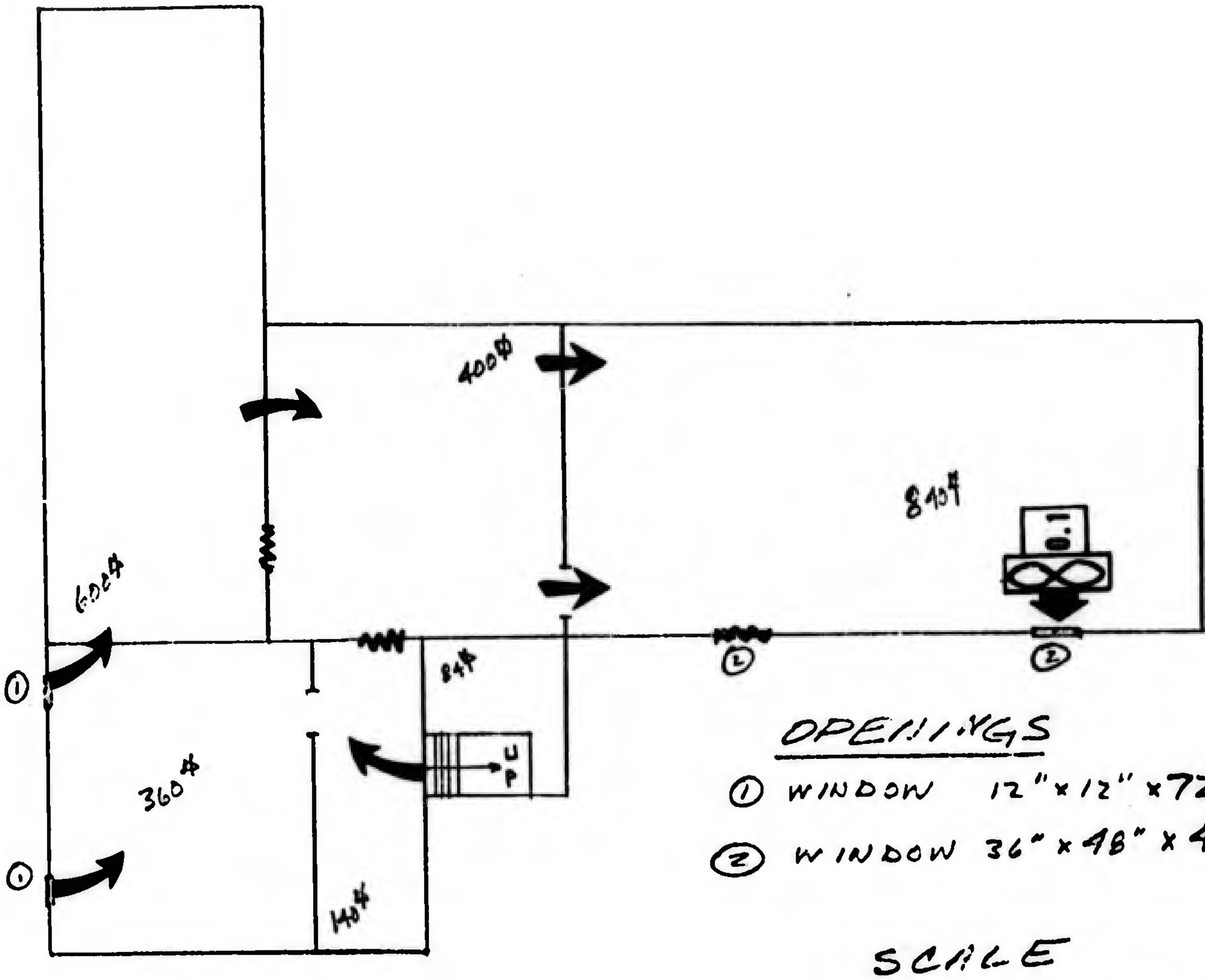
SL 7421-0010
FN 01755



RTI Facility No. 125

Manzanita Hall
University of Nevada
Reno, Nevada

SL 7421-0006
FN 01760



OPENINGS

① WINDOW 12" x 12" x 72" SILL

② WINDOW 36" x 48" x 42" SILL

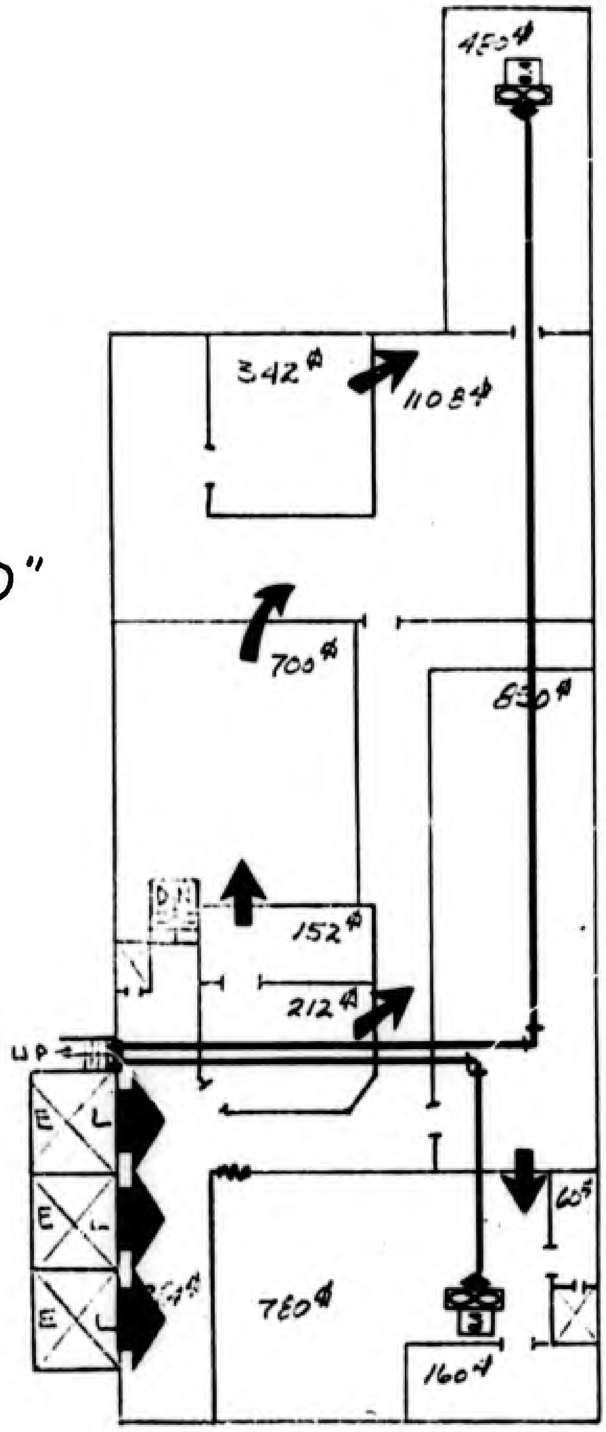
SCALE
1" = 12'-0

RTI Facility No. 126

Fidelity Building
1000 Main Street
Dallas, Texas

SL 5572-0041
FN 01009

SCALE:
1"=20'-0"

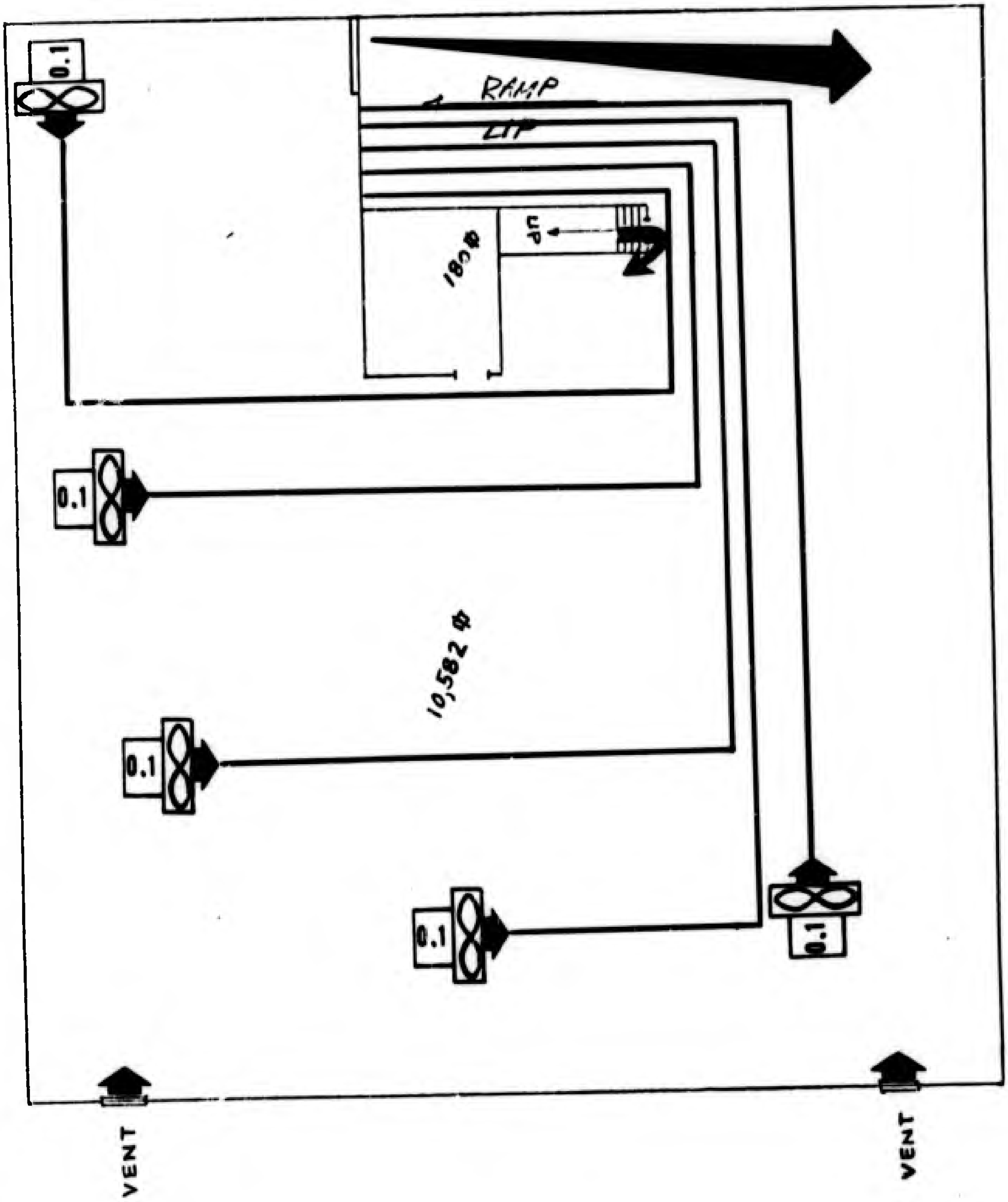


RTI Facility No. 127

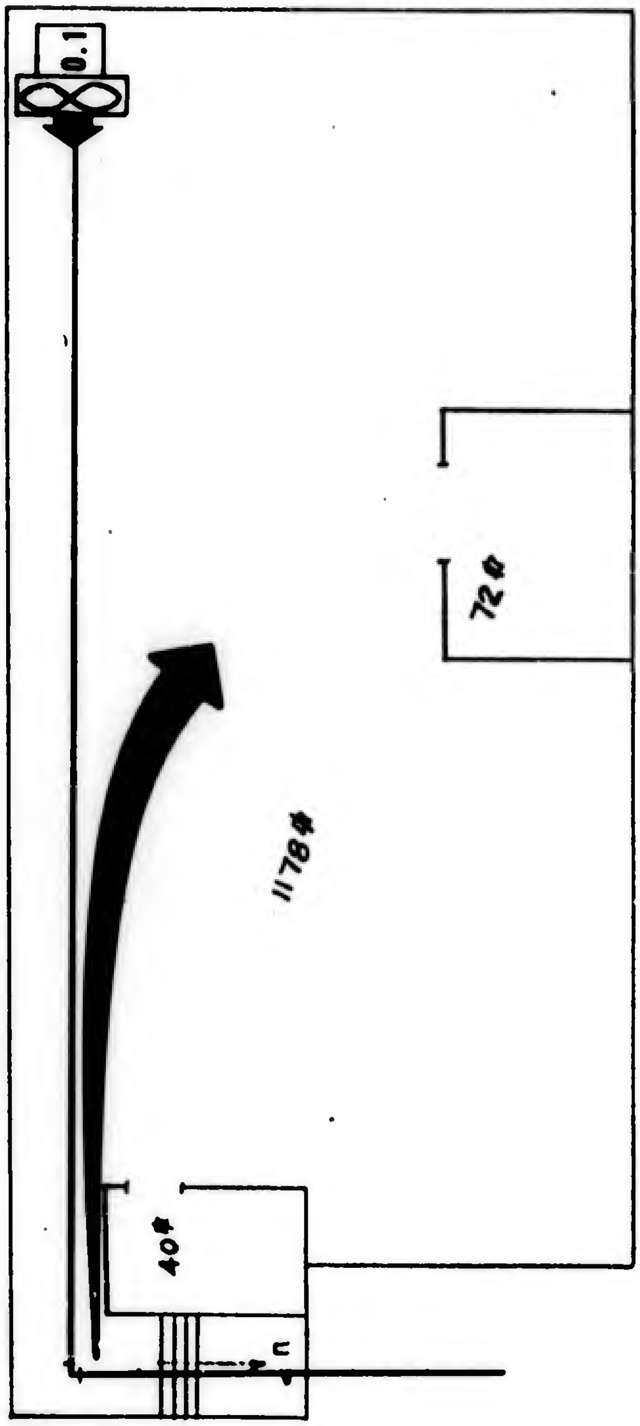
Wells Plaza Parking Station
425 S.Wells Street
Chicago, Illinois

SL 4121-0490
FN 05680

SCALE
1" = 16'-0



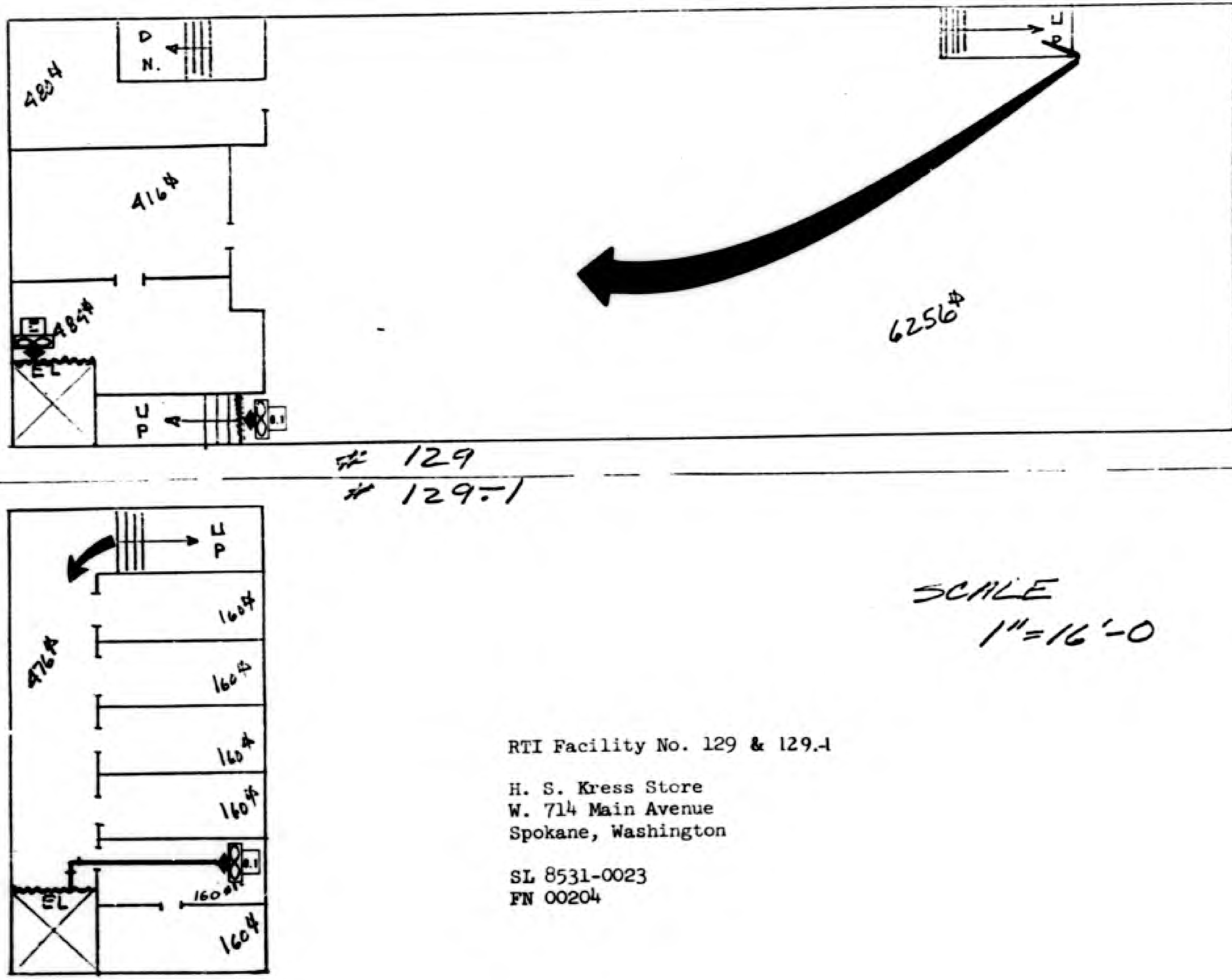
SCALE
1" = 8'-0



RTI Facility No. 128

St. Christina Parish House
11005 S. Homan
Chicago, Illinois

SL 4121-0562
FN 05803



SCALE
1"=16'-0

RTI Facility No. 129 & 129.1

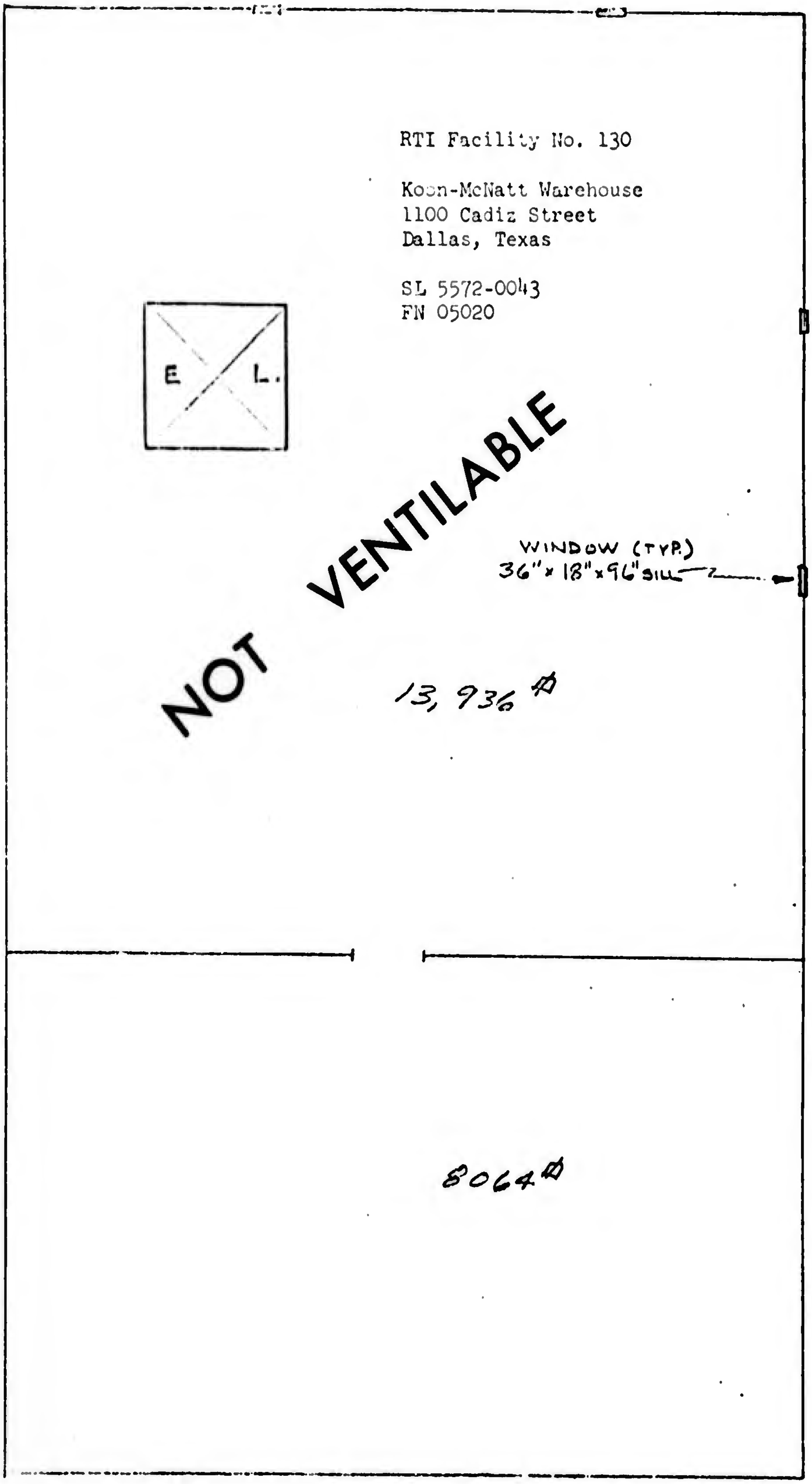
H. S. Kress Store
W. 714 Main Avenue
Spokane, Washington

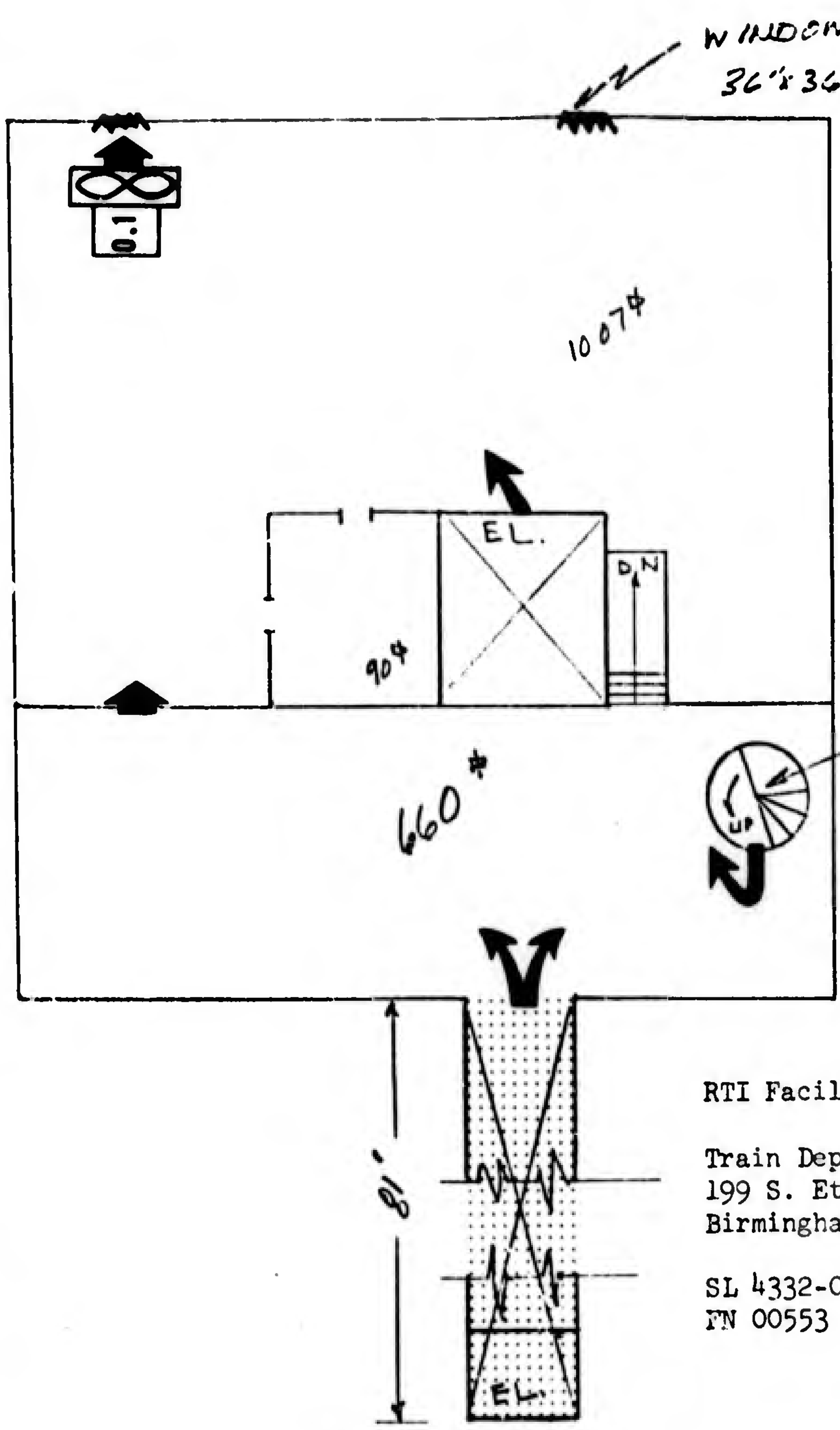
SL 8531-0023
FN 00204

RTI Facility No. 130

Koon-McNatt Warehouse
1100 Cadiz Street
Dallas, Texas

SL 5572-0043
FN 05020





RTI Facility No. 131.01 & 131.02

Train Depot
199 S. Eton
Birmingham, Michigan

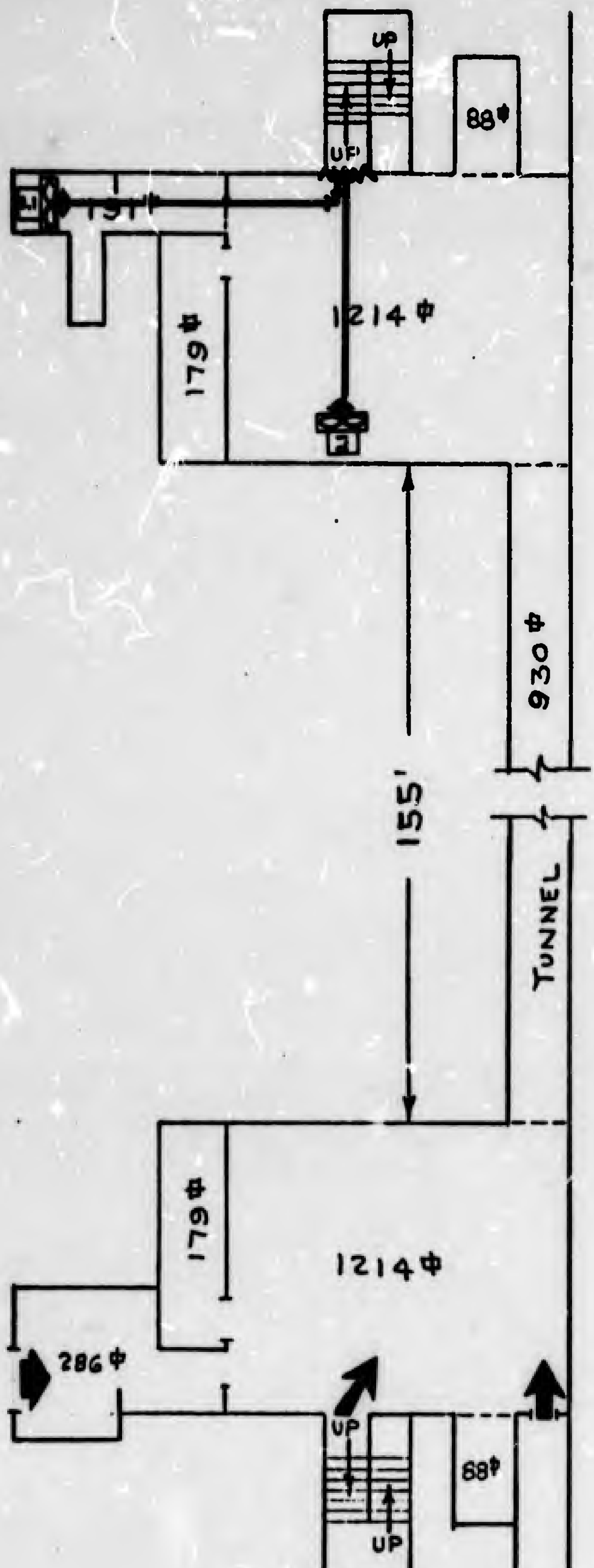
SL 4332-0044
FN 00553

SCALE
1" = 10'-0

#131.01

#131.02

SCALE: 1" = 20'



RTI Facility No. 132

Continuous Treatment Ward (F)
Metropolitan State Hospital
11400 S. Norwalk,
Norwalk, Calif.

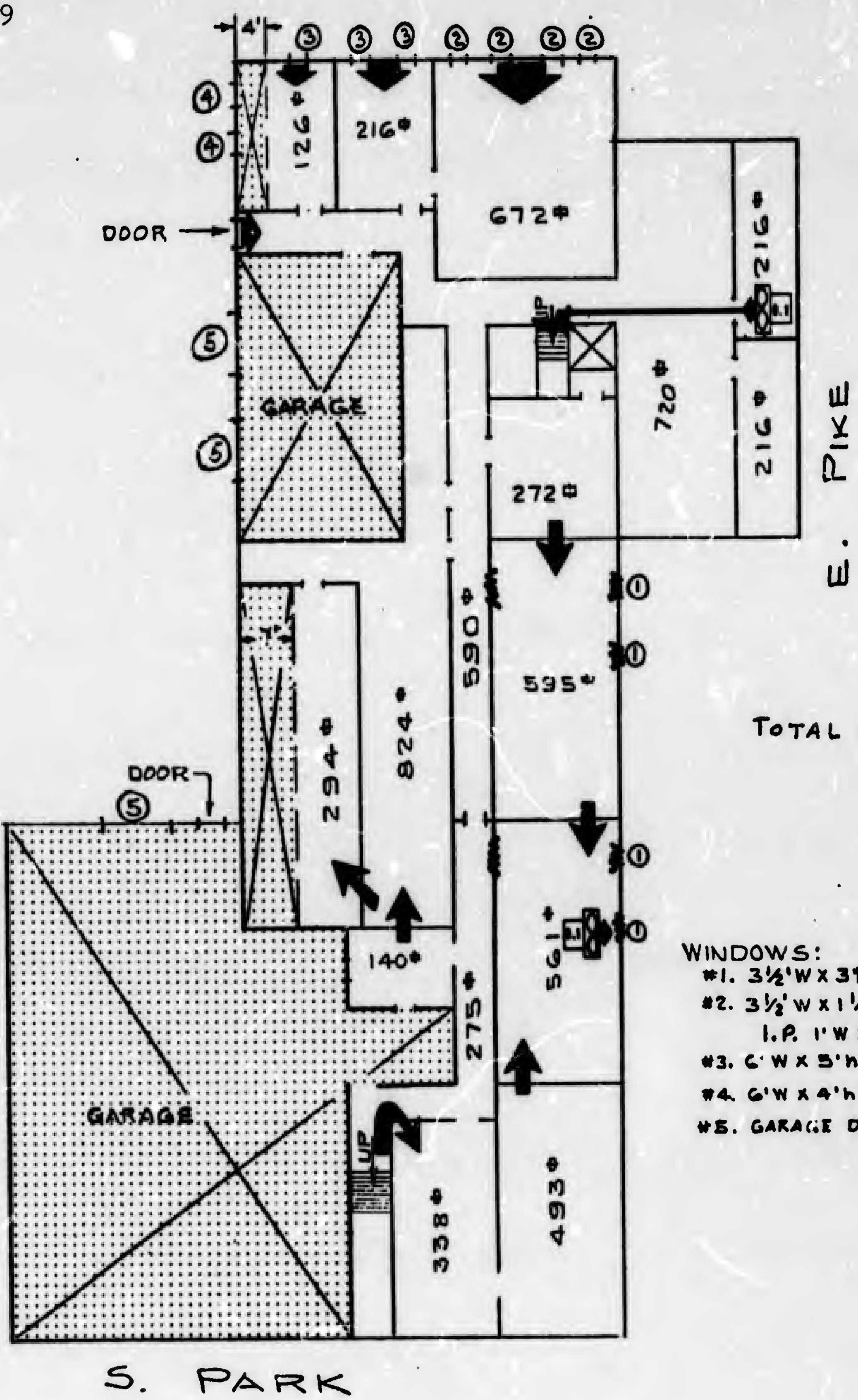
SL 7231-1148
FN 00029

RTI Facility No. 133

Municipal Court, N. Wing
110 & 112 E. Pike,
Pontiac, Michigan

SL 4332-0011
FN 00389

SCALE: 1" = 20'



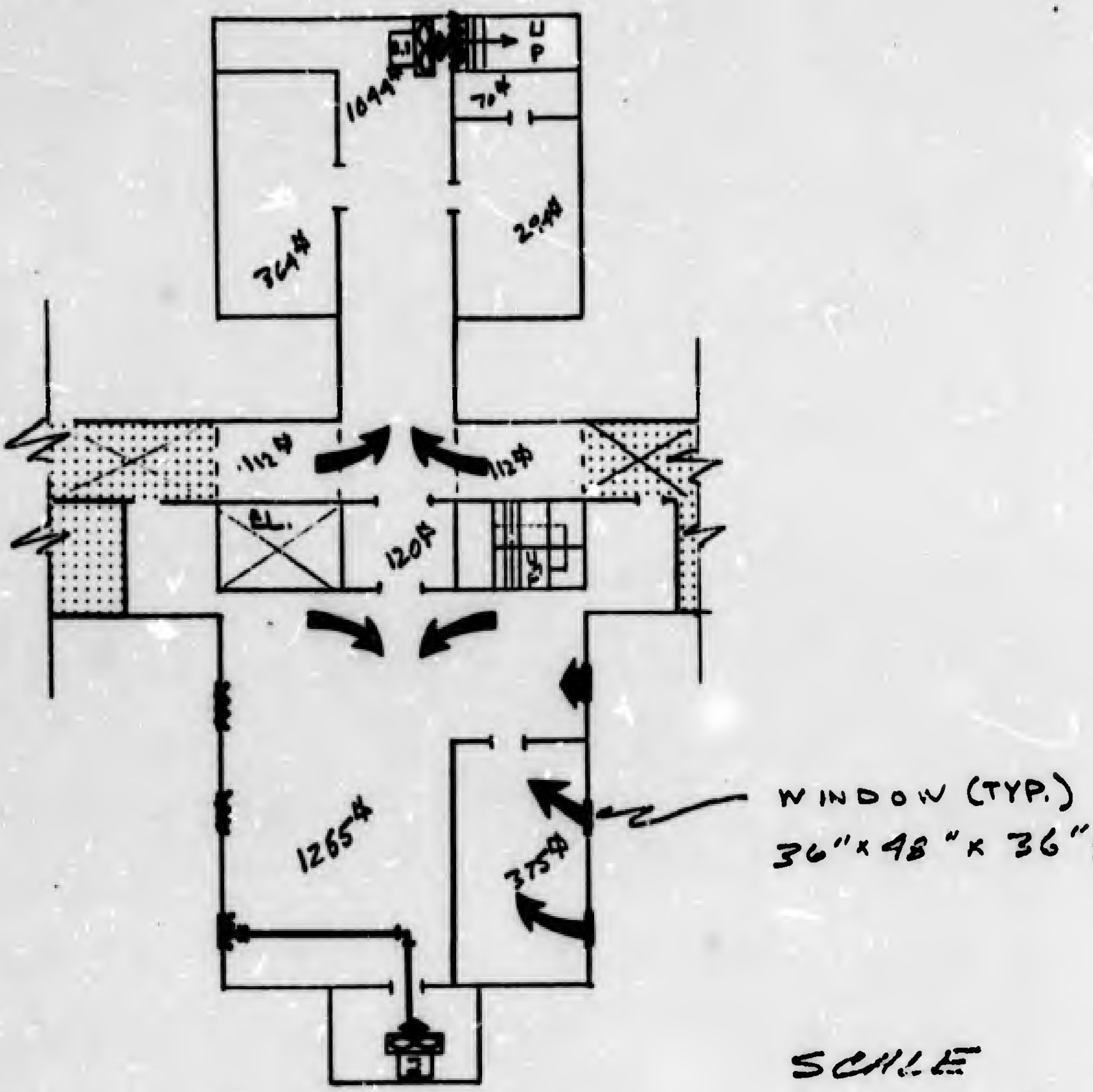
TOTAL AREA: 6548#

WINDOWS:
#1. 3½'W x 3½ x 3'S, l.P. 3'W x 1½'h p.g.
#2. 3½'W x 1½'h x 5'S,
l.P. 1'W x 1½'h p.g.
#3. 6'W x 5'h x 3'S, l.P. 1½' x 2h p.g.
#4. 6'W x 4'h x 3'S, l.P. 1½' x 2½'h p.g.
#5. GARAGE DOORS, l.P. 8"W x 12"h

RTI Facility No. 134.01

Pontiac State Hospital
Buildings 1 and 2
Pontiac, Michigan

SL 4332-0007
FN 00478

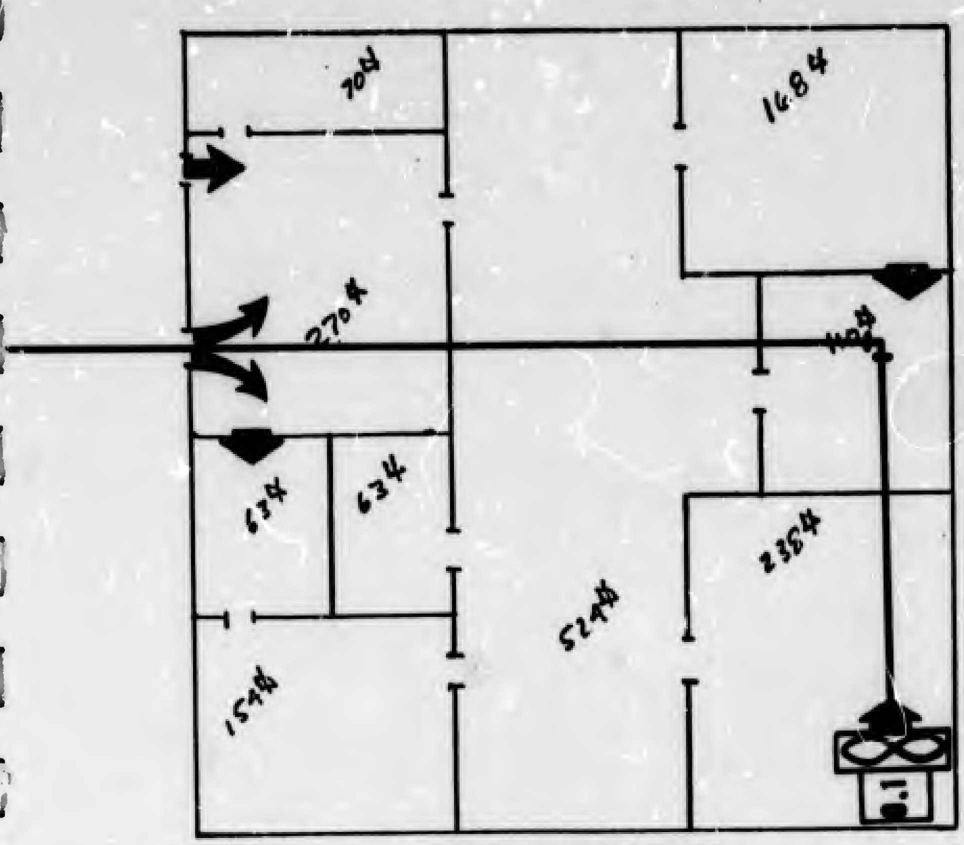


#134.01

SCALE
1" = 20'-0

RTI Facility No. 134.02 &
134.03
Pontiac State Hospital
Buildings 1 and 2
Pontiac, Michigan

SL 4332-0007
FN 00478



134.02

SCALE
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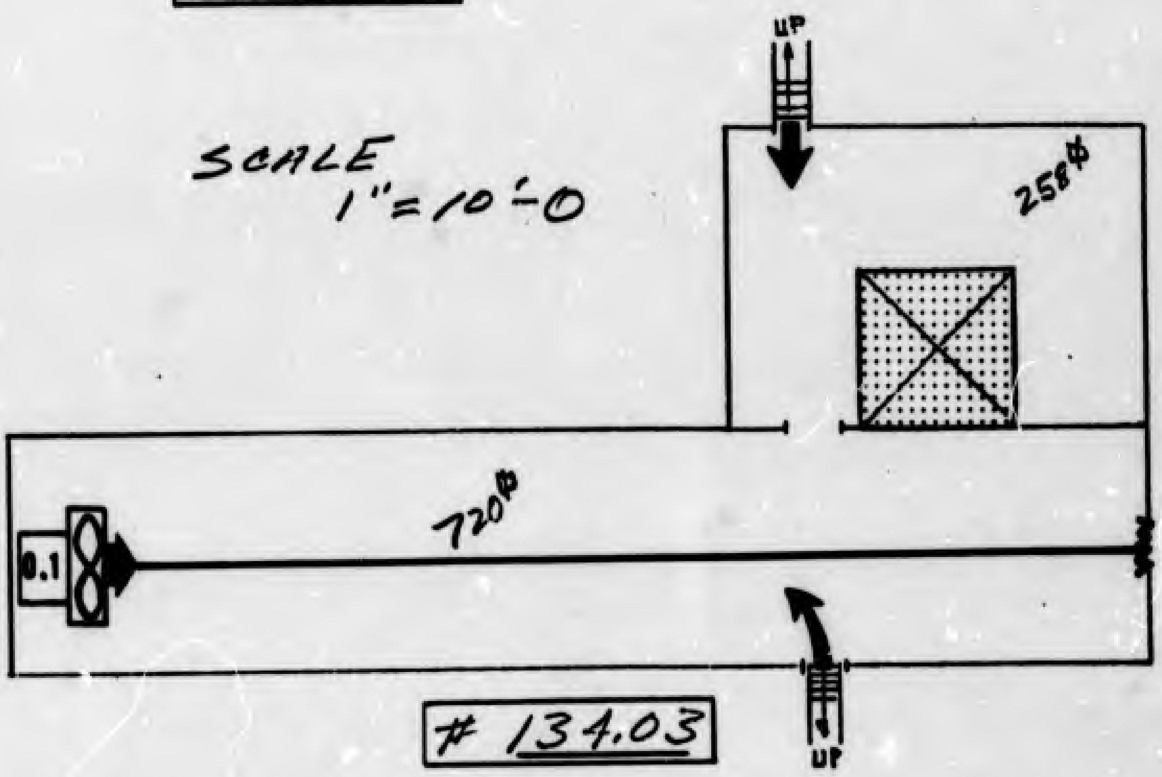
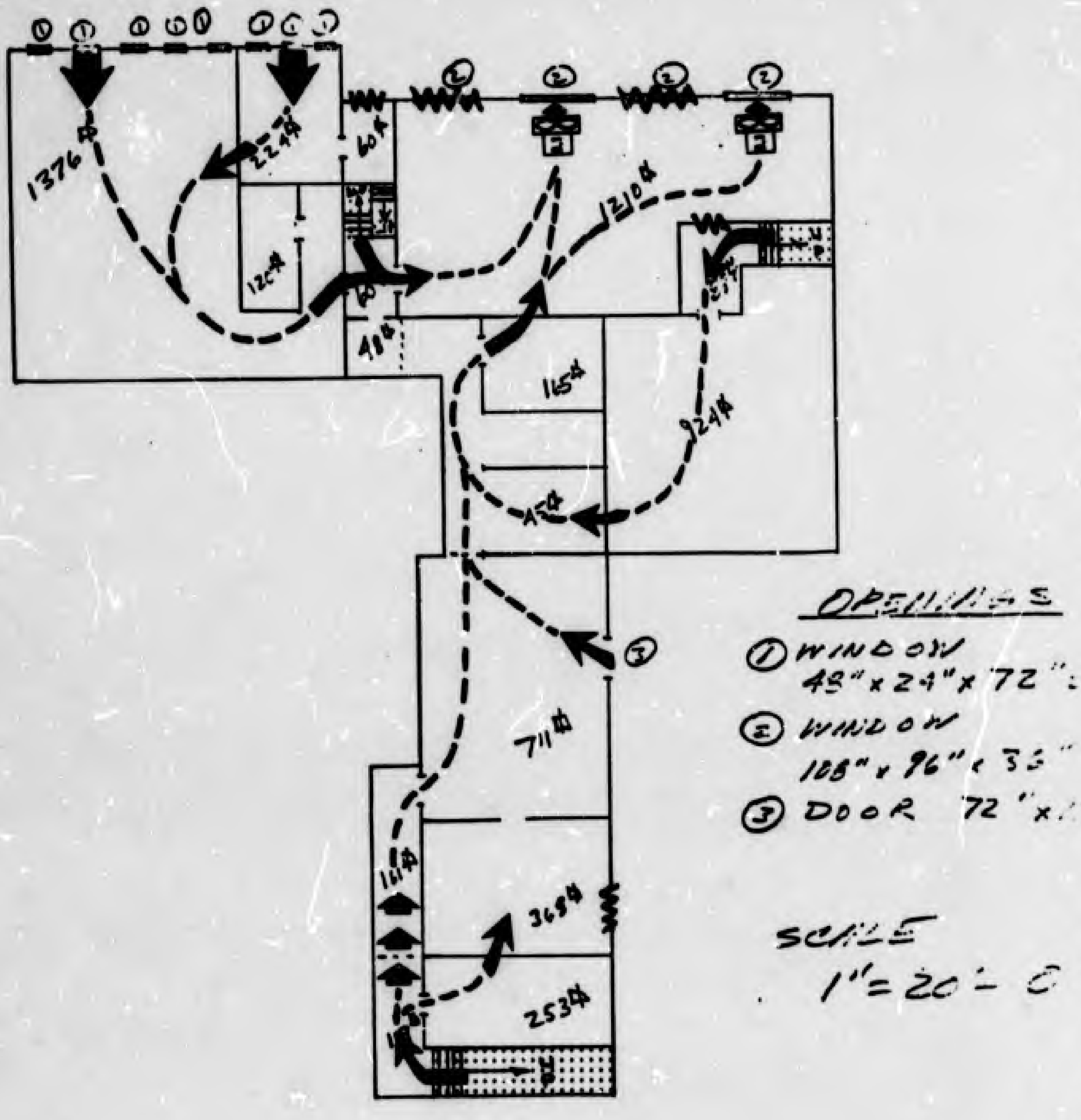


134.03

RTI Facility No. 135

Junior High School
52 Fairmont
Chatham, New Jersey

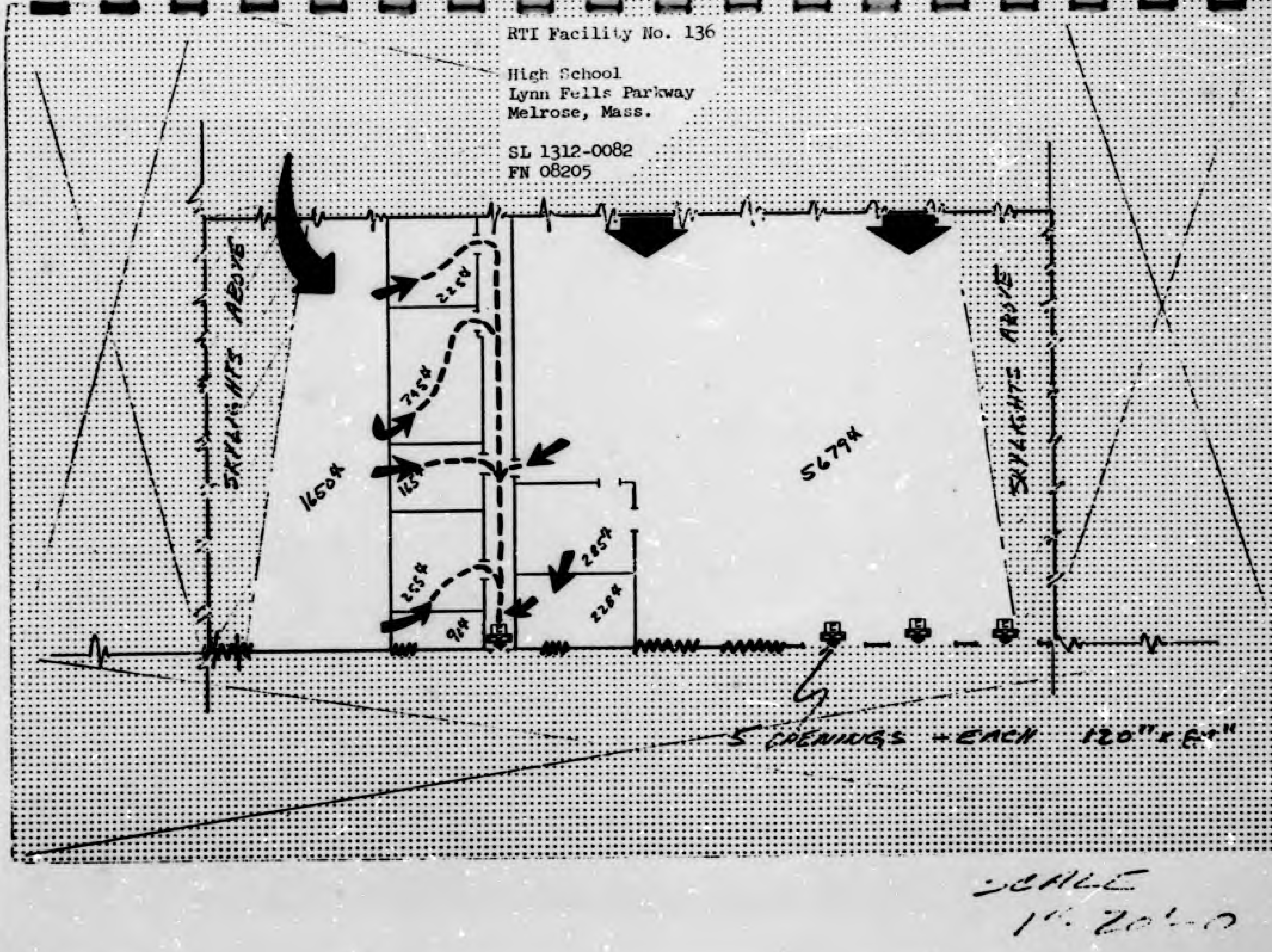
SL 1541-0028
FN 04281

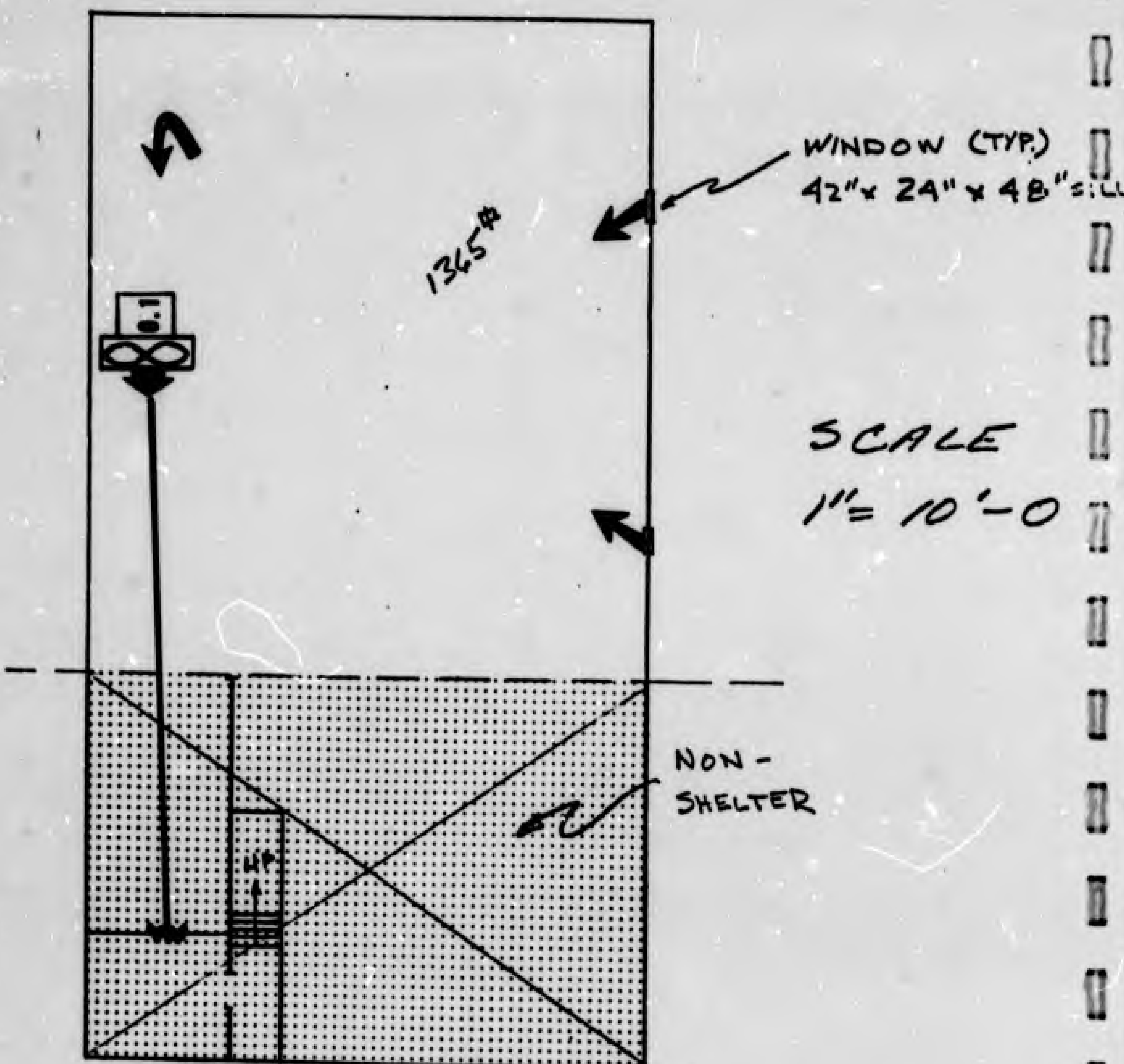


RTI Facility No. 136

High School
Lynn Fells Parkway
Melrose, Mass.

SL 1312-0082
FN 08205





RTI Facility No. 137

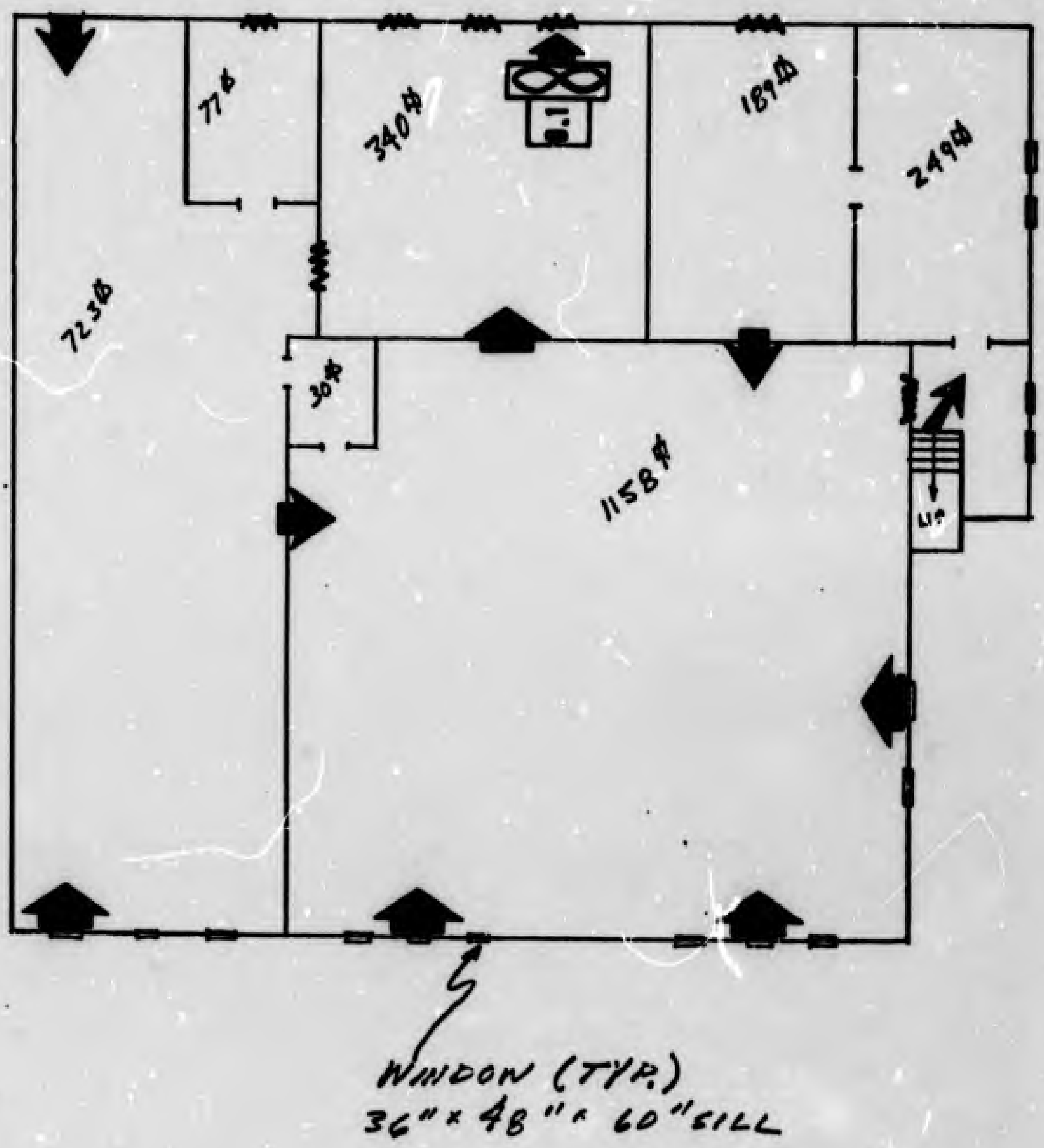
Madison Trust Company
20-22 Waverly Place
Madison, New Jersey

SL 1541-0030
FN 04295

RTI Facility No. 138

Building No. 455 Picatinny Arsenal
Rockaway Township
New Jersey

SL 1541-0044
FN 10004

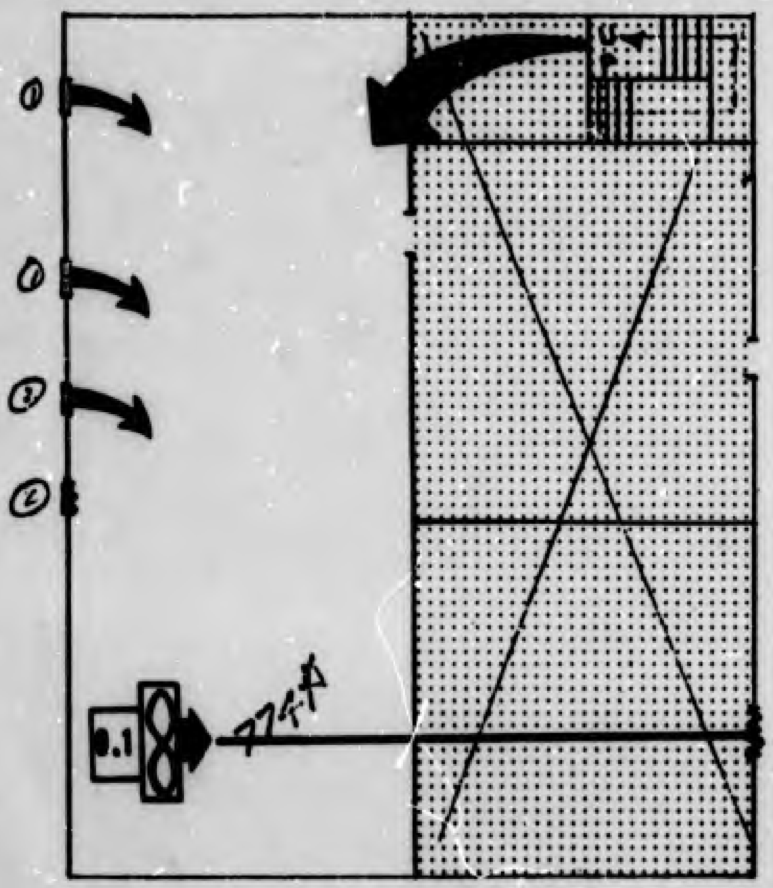


SCALE
1" = 10'-0

RTI Facility No. 139

E-1 Control Room, Thiokol Rocket Co.
Morris Avenue
Denville, New Jersey

SL 1541-0013
FN 05091



OPENINGS
① WINDOW 24" x 12" x 48" SILL
② WINDOW 24" x 12" x 36" SILL

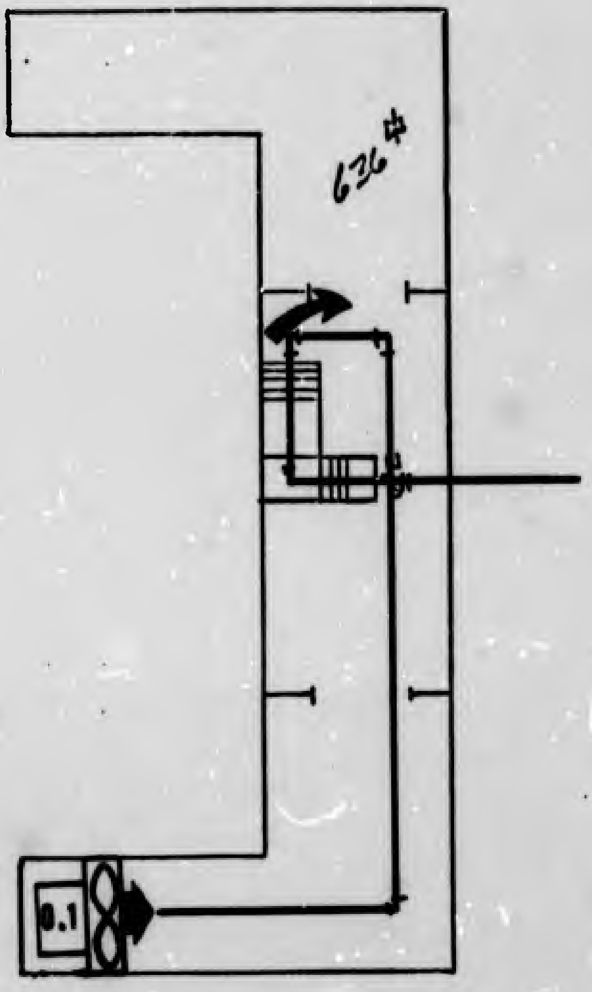
SCALE

1" = 10'-0

RTI Facility No. 140

Dr. Jurkens Residence
N. J. State Hospital
Greystone Park, New Jersey

SL 1541-0024
FN 02733



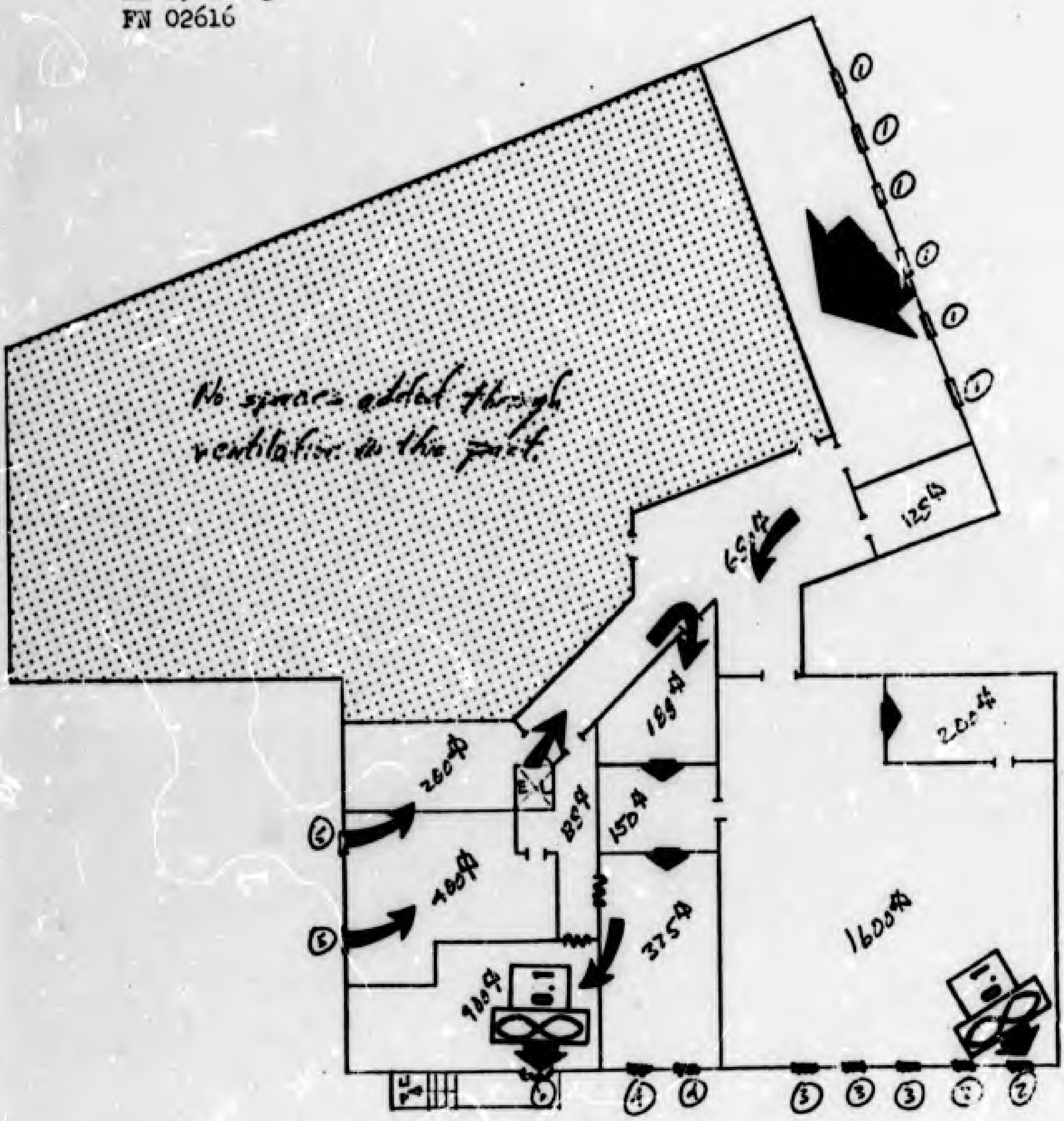
SCALE

1" = 10'-0

RTI Facility No. 141

Y. M.C.A. Building
60 Washington Street
Morristown, New Jersey

SL 1541-0038
FN 02616



SCALE
1" = 20'-0

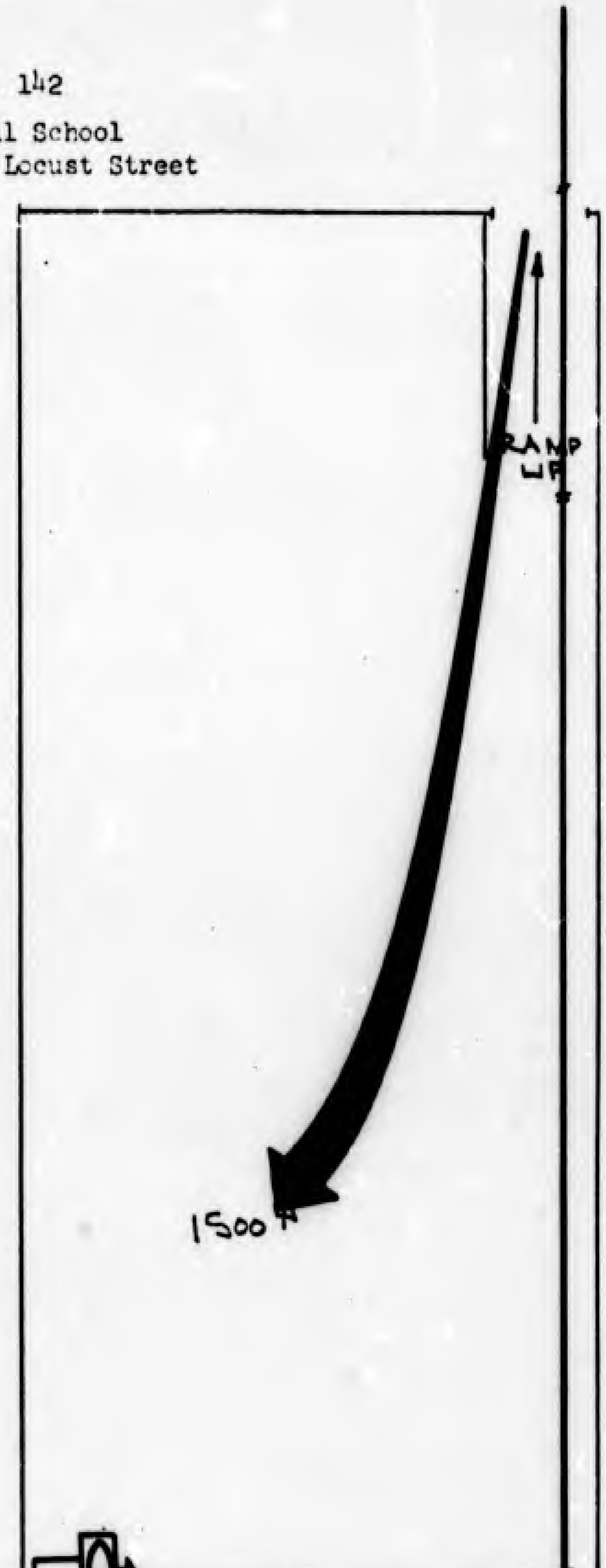
OPENINGS

1. TWO WINDOWS - EACH 12" x 36" x 36" SILL
2. WINDOW 48" x 60" x 48" SILL
3. WINDOW 36" x 36" x 72" SILL
4. WINDOW 36" x 24" x 72" SILL
5. WINDOW 24" x 24" x 168" SILL
6. DOOR

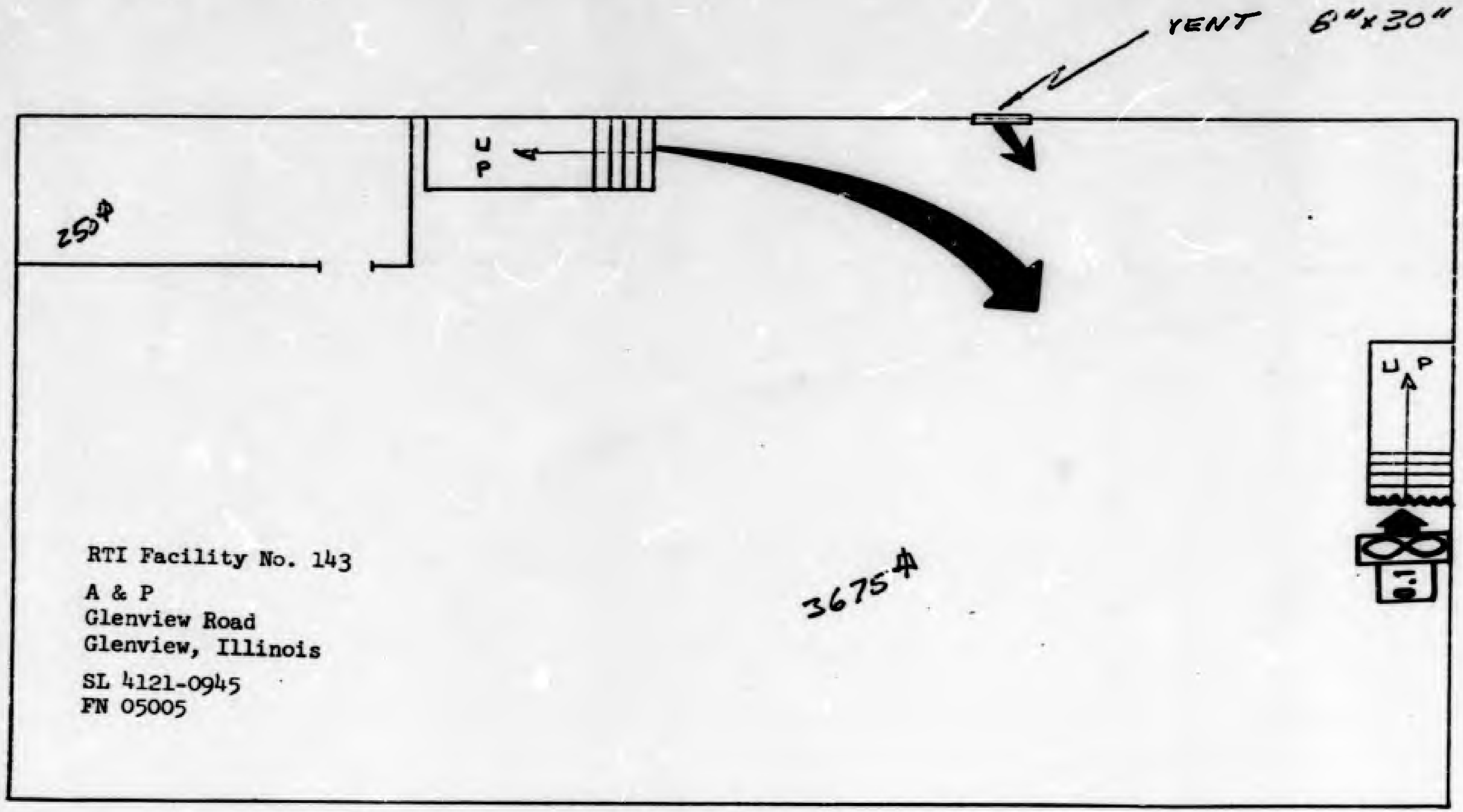
RTI Facility No. 142

Veterans Memorial School
Vasear Street & Locust Street
Reno, Nevada

SL 7421-0008
FN 01751



SCALE
1" = 8'-0

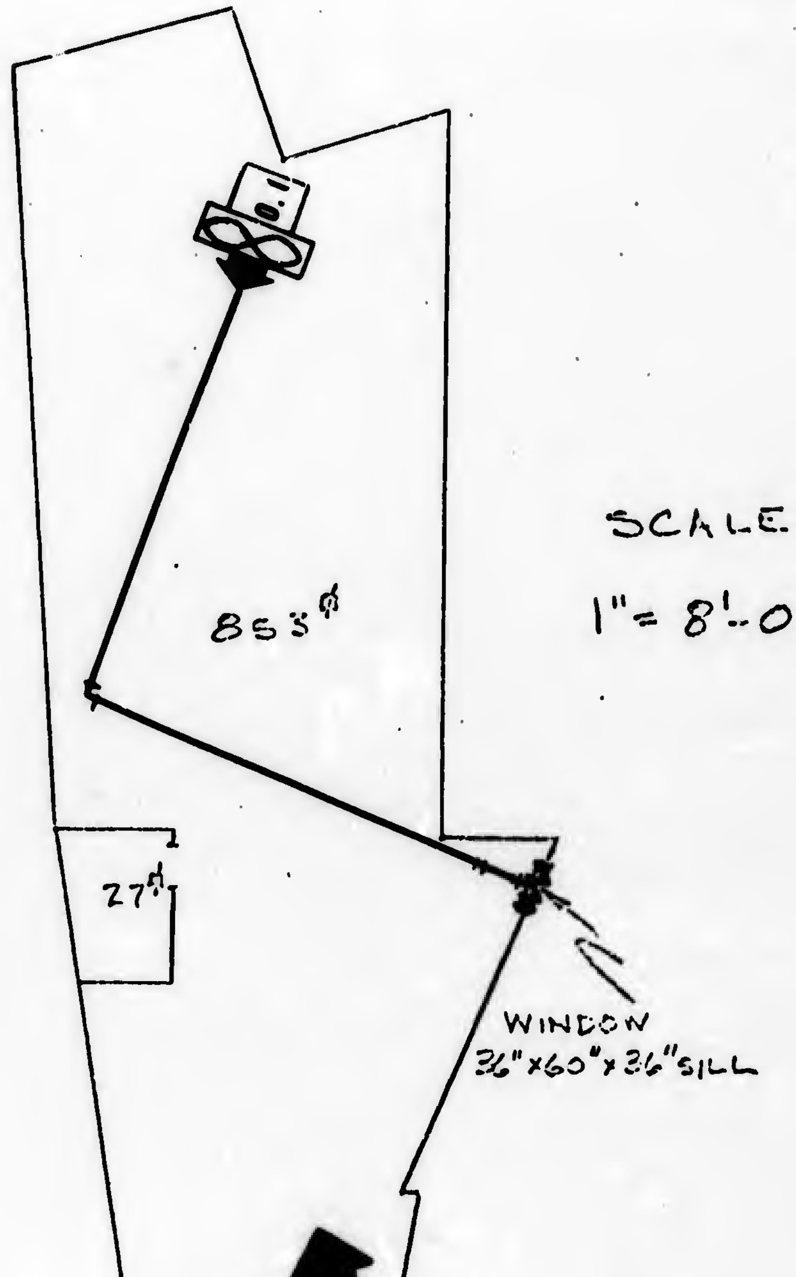

YENT 8"x30"
UP
250 Φ
UP
RTI Facility No. 143
A & P
Glenview Road
Glenview, Illinois
SL 4121-0945
FN 05005
3675 Φ

SCALE
1" = 10'-0

RTI Facility No. 144

Stores
3 Pleasant Street
Malden, Mass.

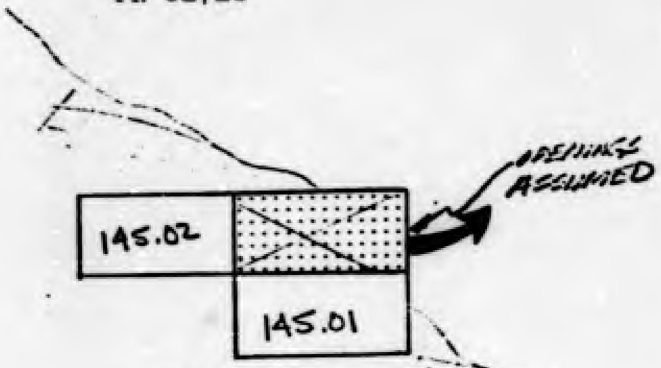
SL 1312-0037
FN 03748



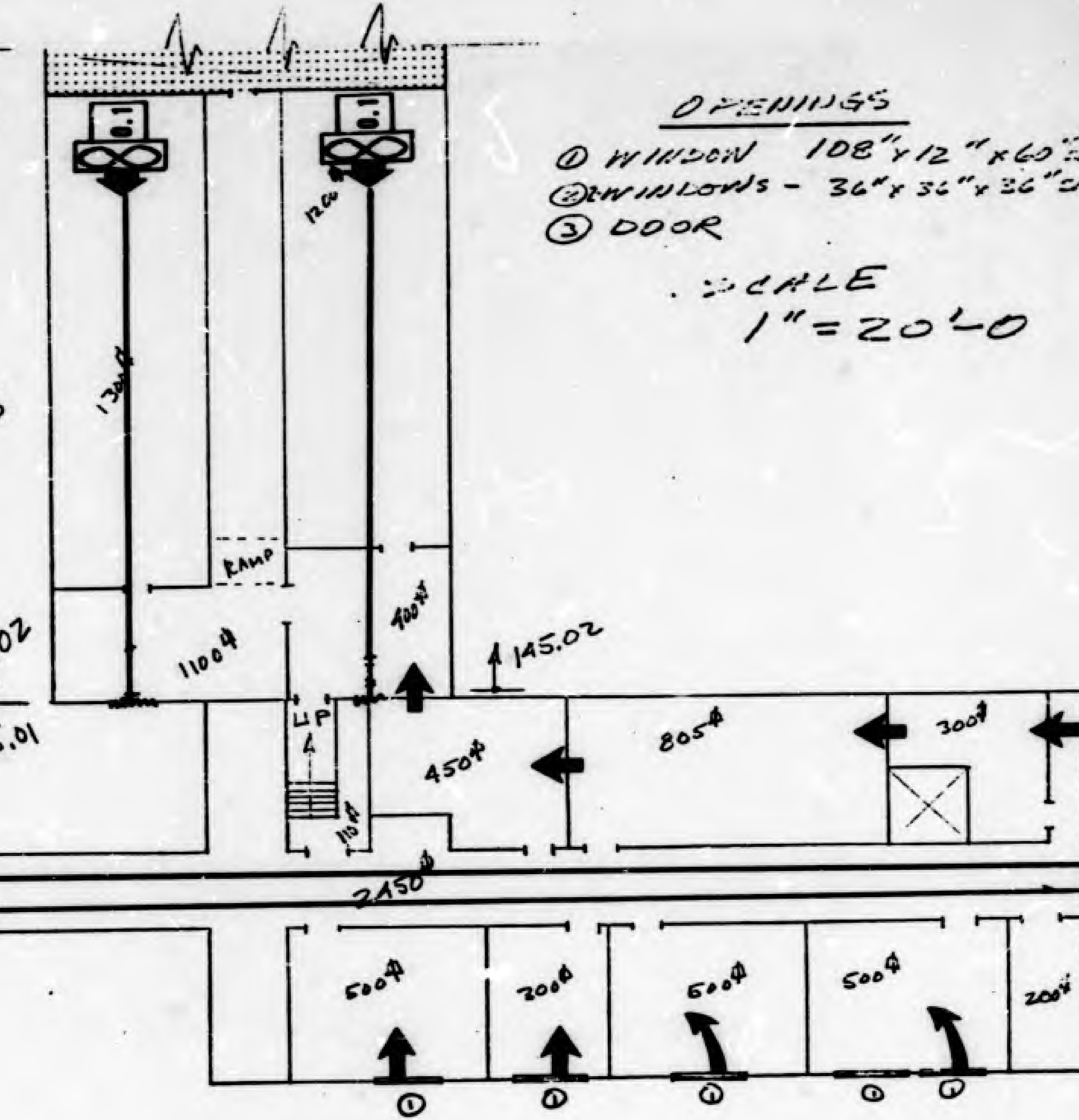
RTI Facility No. 145.01 & 145.02

U. S. Bureau of Mines
1605 Evans Street
Reno, Nevada

SL 7421-0006
FN 01716



ELEVATION SKETCH



OPENINGS

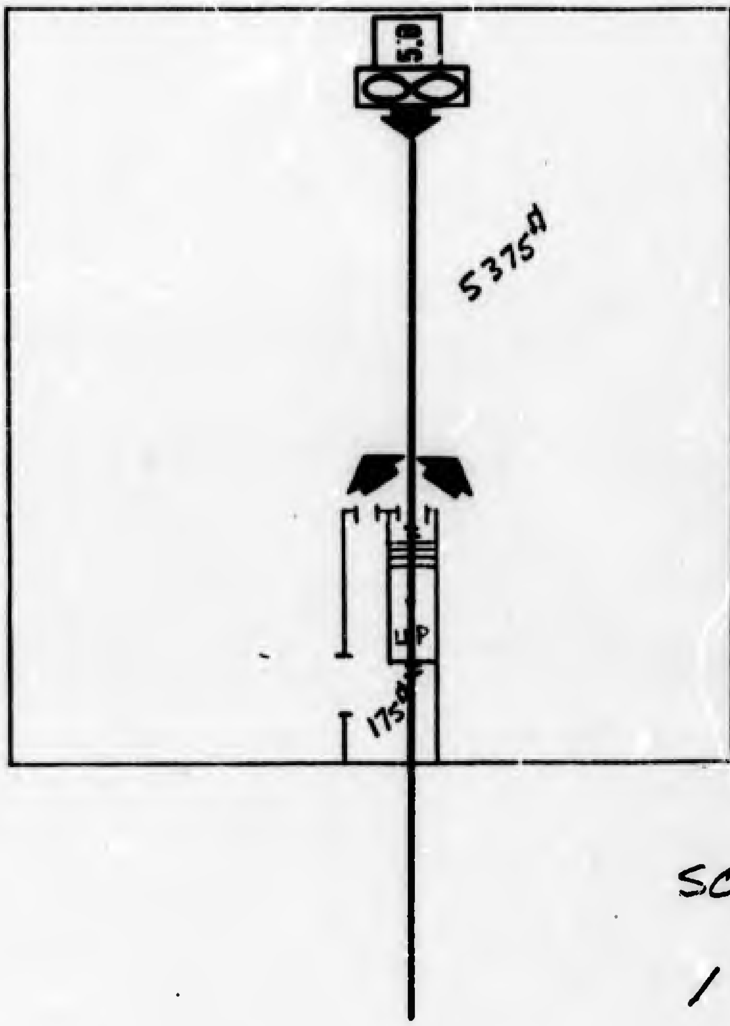
① WINDOW 108" x 12" x 60"
② WINDOWS - 36" x 36" x 36"
③ DOOR

SCALE
1" = 20'-0

RTI Facility No. 146

Fondren Science Building
Southern Methodist University
3115 Daniels Avenue
Dallas, Texas

SL 5572-0235
FN 00024



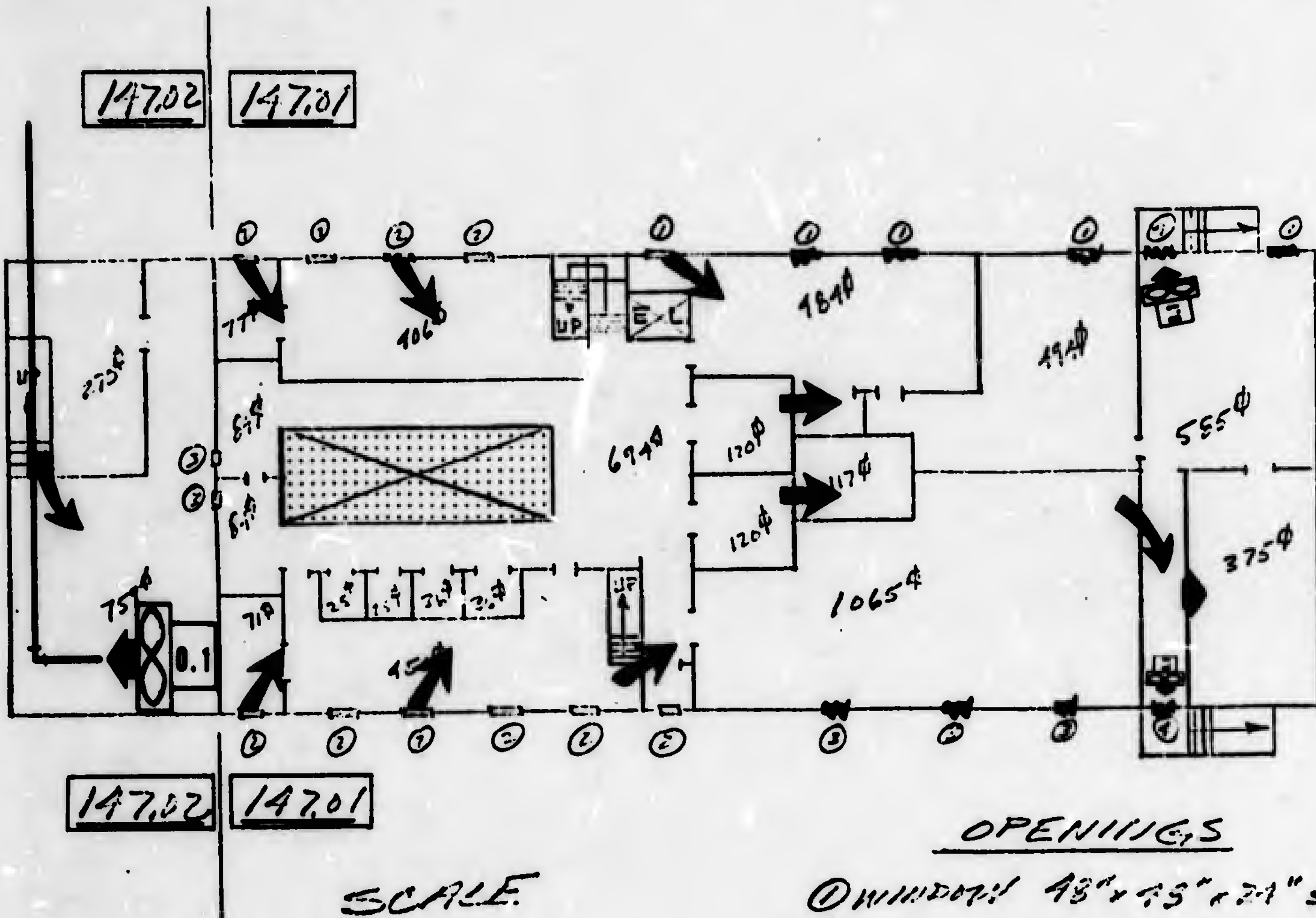
SCALE

1" = 20'-0

RTI Facility No. 147.01 & 147.02

First National Iron Bank
24-26 South Street
Morristown, New Jersey

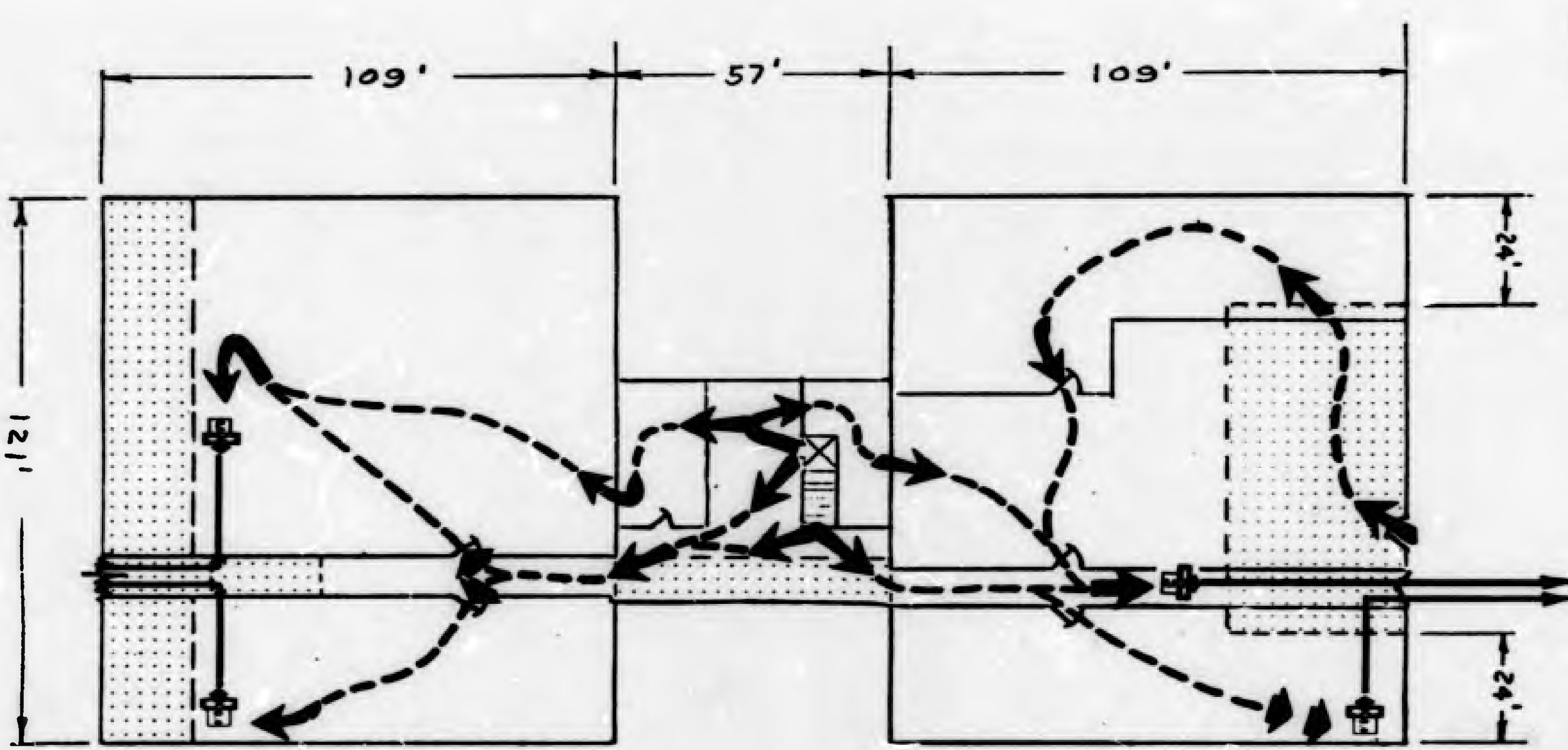
SL 1541-0036
FN 02534



SCALE
1" = 20'-0

OPENINGS

1 WINDOW 48" x 45" x 24" SI
2 WINDOW 36" x 48" x 36"
3 WINDOW 6" x 36" x 60"
4 DOOR 48" WIDE



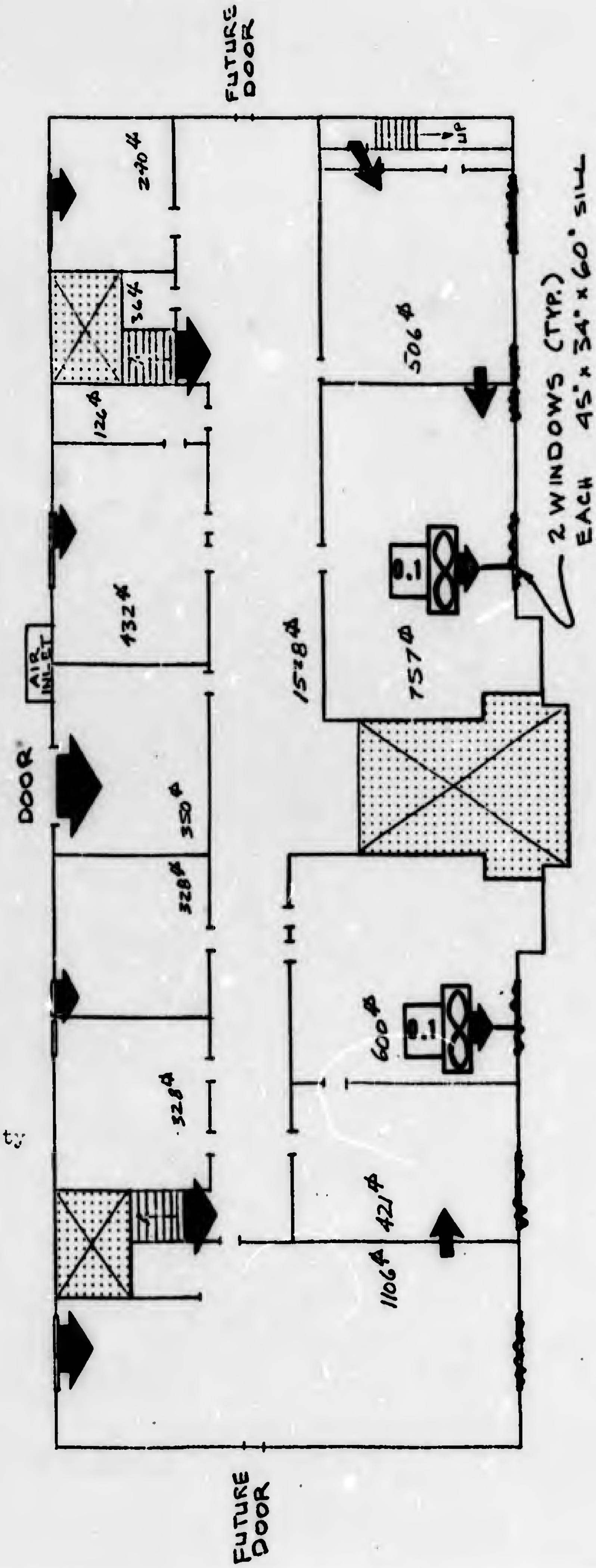
SCALE: 1" = 40' Approx.

RTI Facility No. 148

College Union Building
University of South Florida
Tampa, Florida

SL 3261-0065
FN 00260

[ ] Non-Shelter Area



SCALE
1" = 16'-0

RTI Facility No. 149

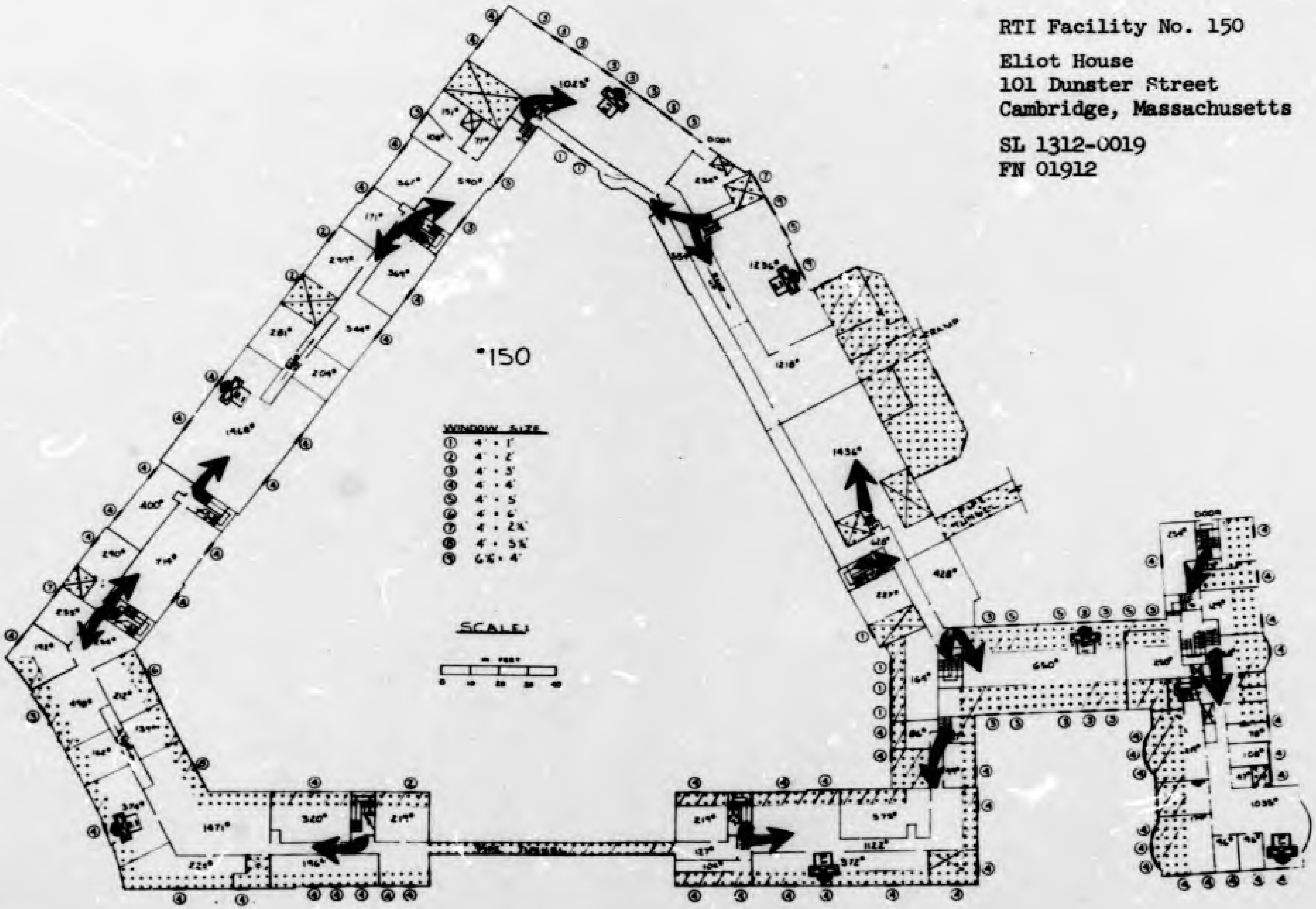
Morrill Hall
North Dakota State University
Fargo, North Dakota

SL 6611-0010
FN 00571

RTI Facility No. 150

Eliot House
101 Dunster Street
Cambridge, Massachusetts

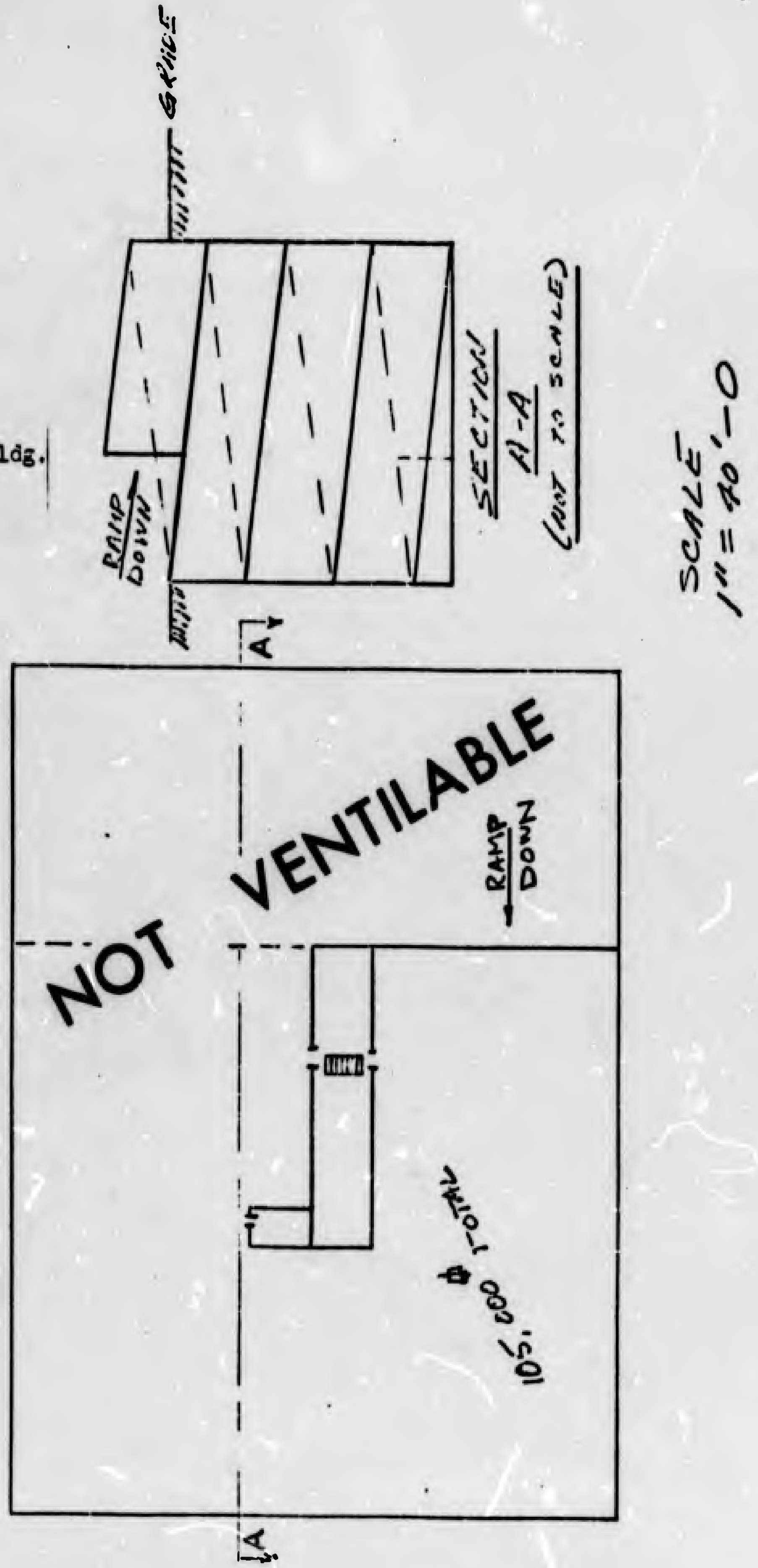
SL 1312-0019
FN 01912



RTI Facility No. 151

Mercantile Continental Bldg.
1810 Commerce STreet
Dallas, Texas

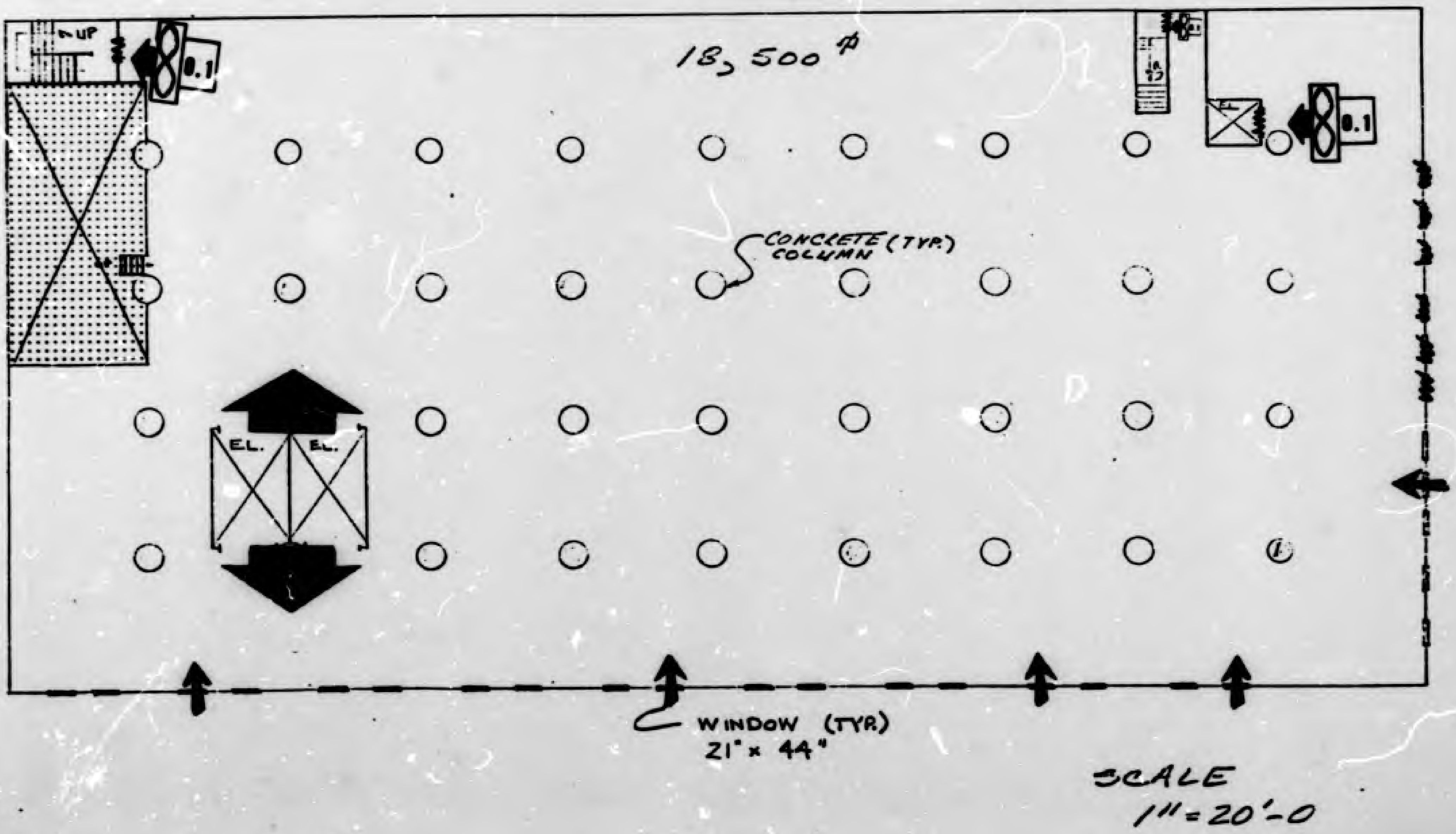
SL 5572-0041
FH 01034

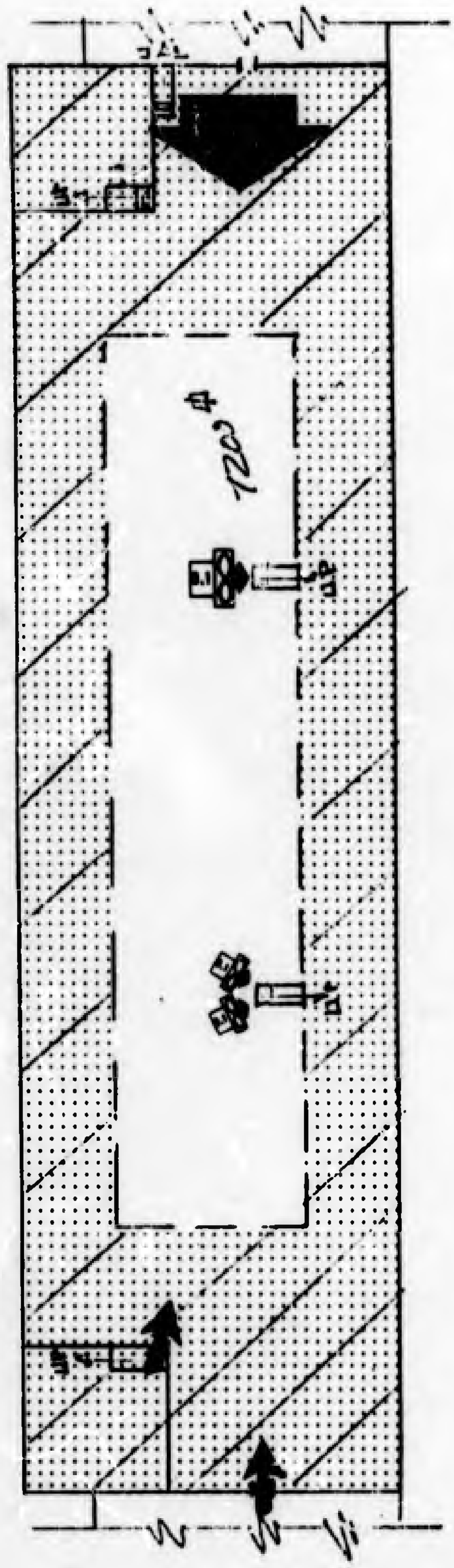


RTI Facility No. 152

M-K-T Warehouse
301 Market Street
Dallas, Texas

SL 5572-0029
FN 05029





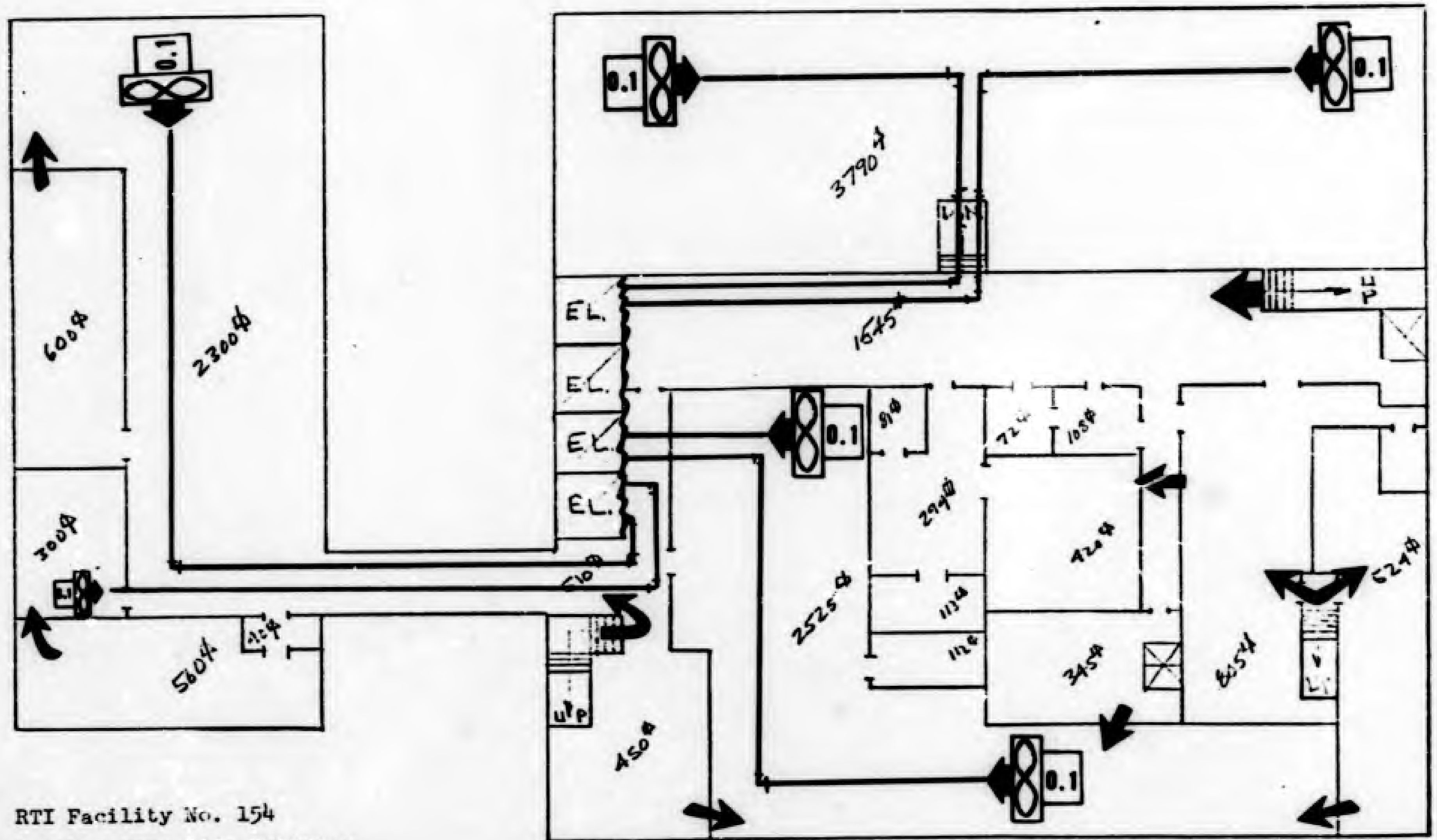
NOTE: SHELTER HAS TWO IDENTICAL BELOW GRADE LEVELS CONNECTED BY SPACES AROUND BOOKSTACKS THROUGH BOTH LEVELS.

SCALE 1" = 20'-0

RTI Facility No. 153

William-Rainey Harper Library
University of Chicago
Chicago, Illinois

SL 4121-0573
FN 08607



RTI Facility No. 154

Southwestern Life Building
1506 Main Street
Dallas, Texas

SL 5572-0041
FN 05049

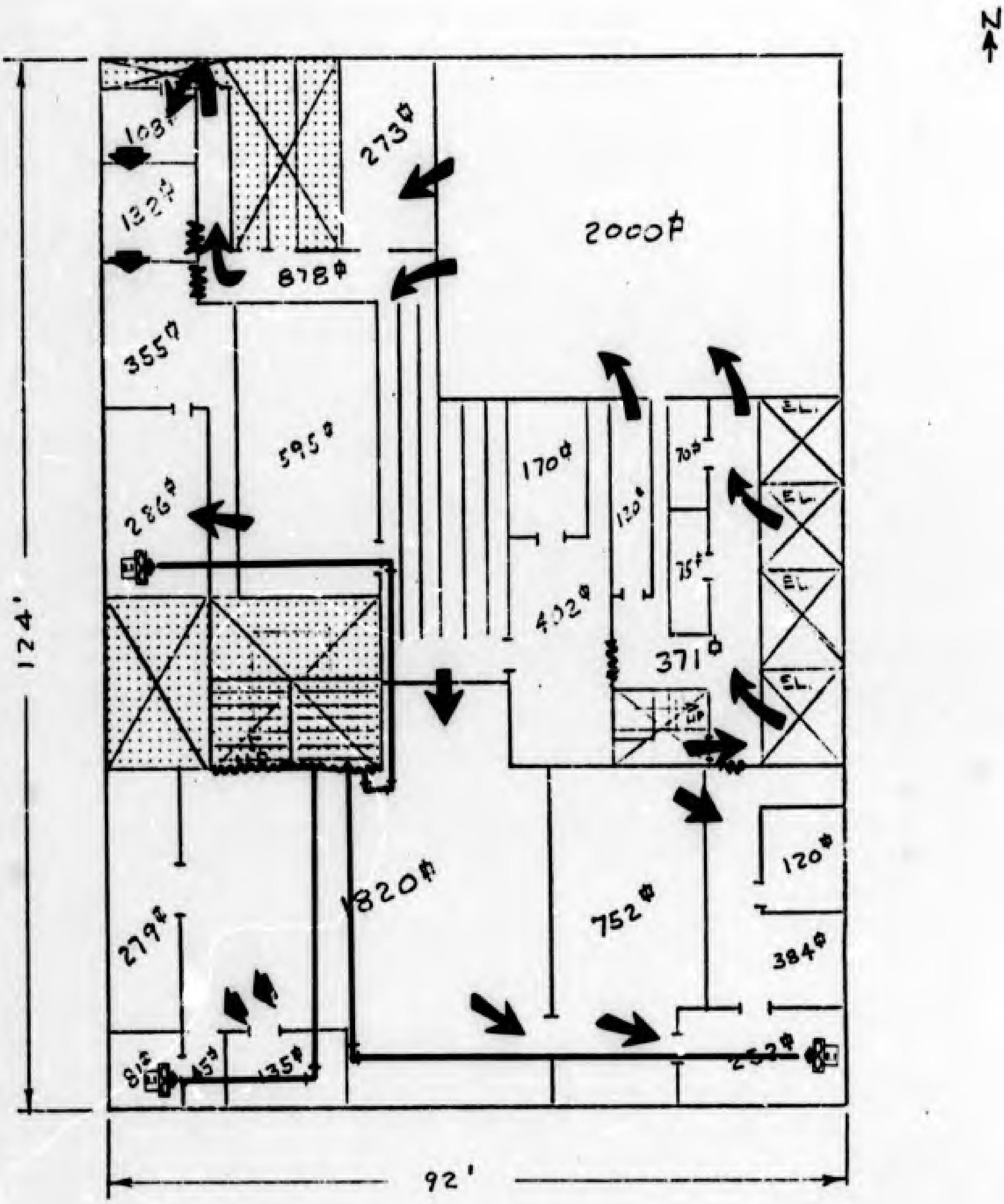
SCALE
1" = 20'-0

· RTI Facility No. 155

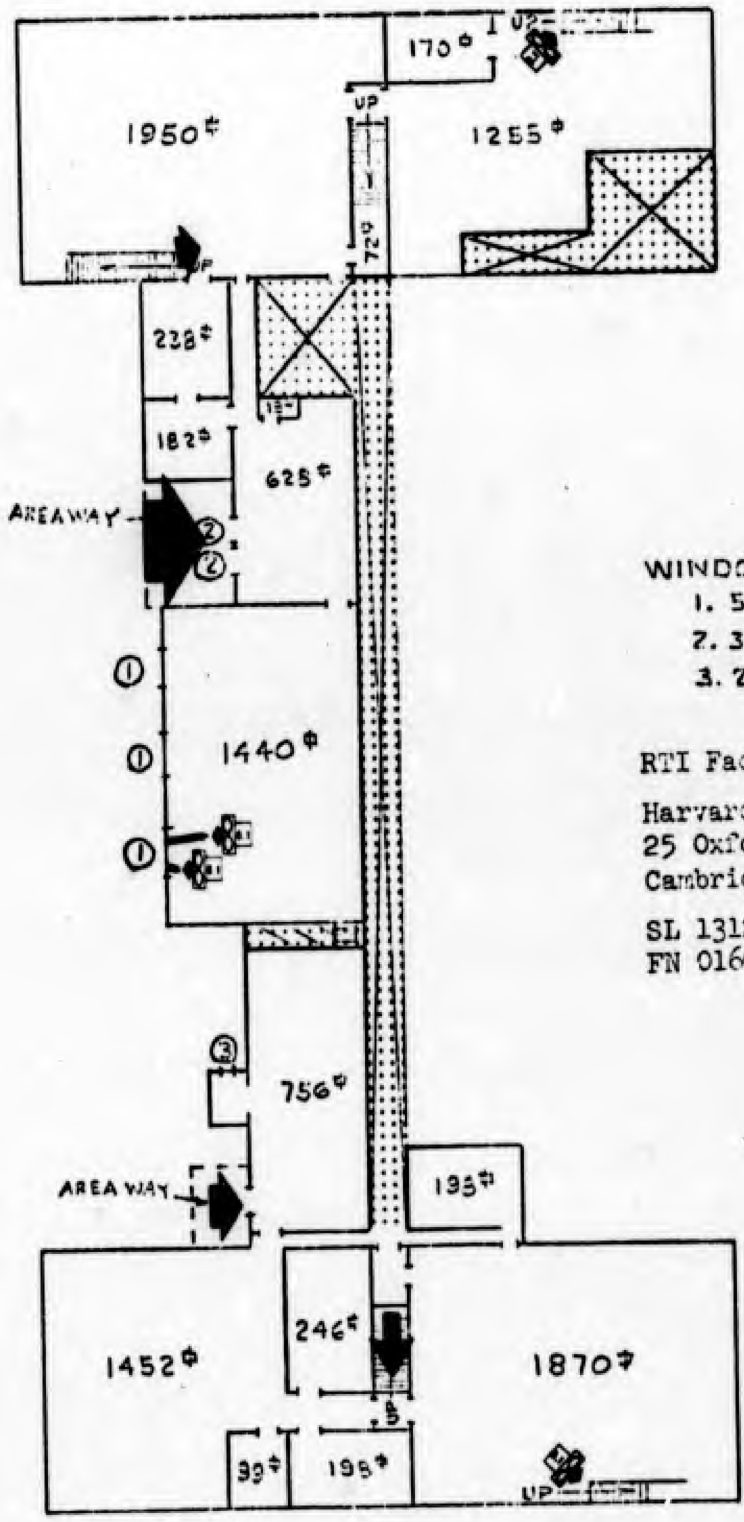
Old National Bank
West 422 Riverside Avenue
Spokane, Washington

SL 8531-0025
FN 00859

SCALE: 1" = 20'



SCALE: 1" = 30'



WINDOWS:
1. 5'W x 10'H x 7' SILL
2. 3'W x 6'H x 5' SILL
3. 2'W x 2'H x 5' SILL

RTI Facility No. 156

Harvard University- Pierce Hall
25 Oxford Street
Cambridge, Mass.

SL 1312-0016
FN 01609

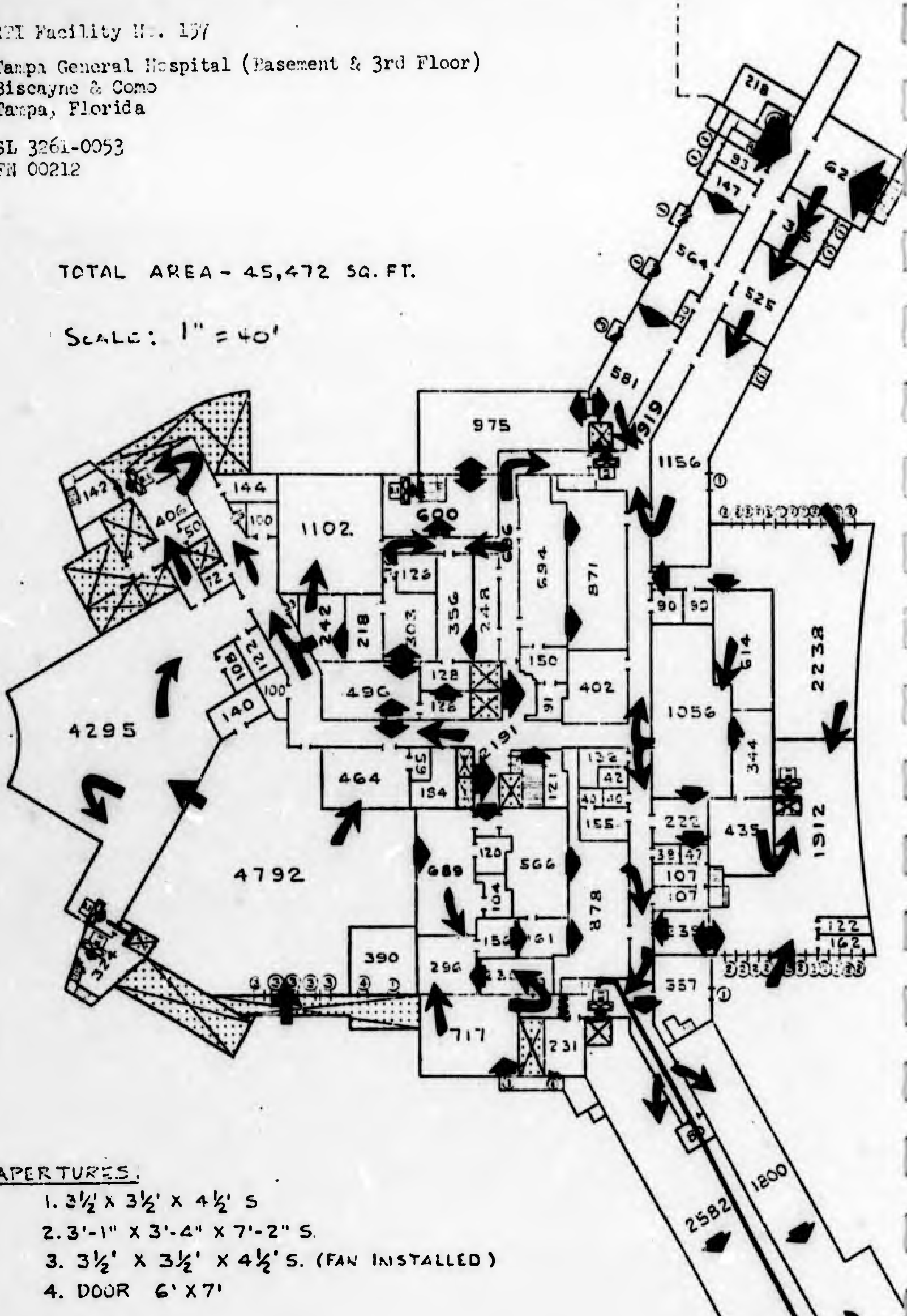
RFI Facility No. 157

Tampa General Hospital (Basement & 3rd Floor)
Biscayne & Como
Tampa, Florida

SL 3261-0053
FN 00212

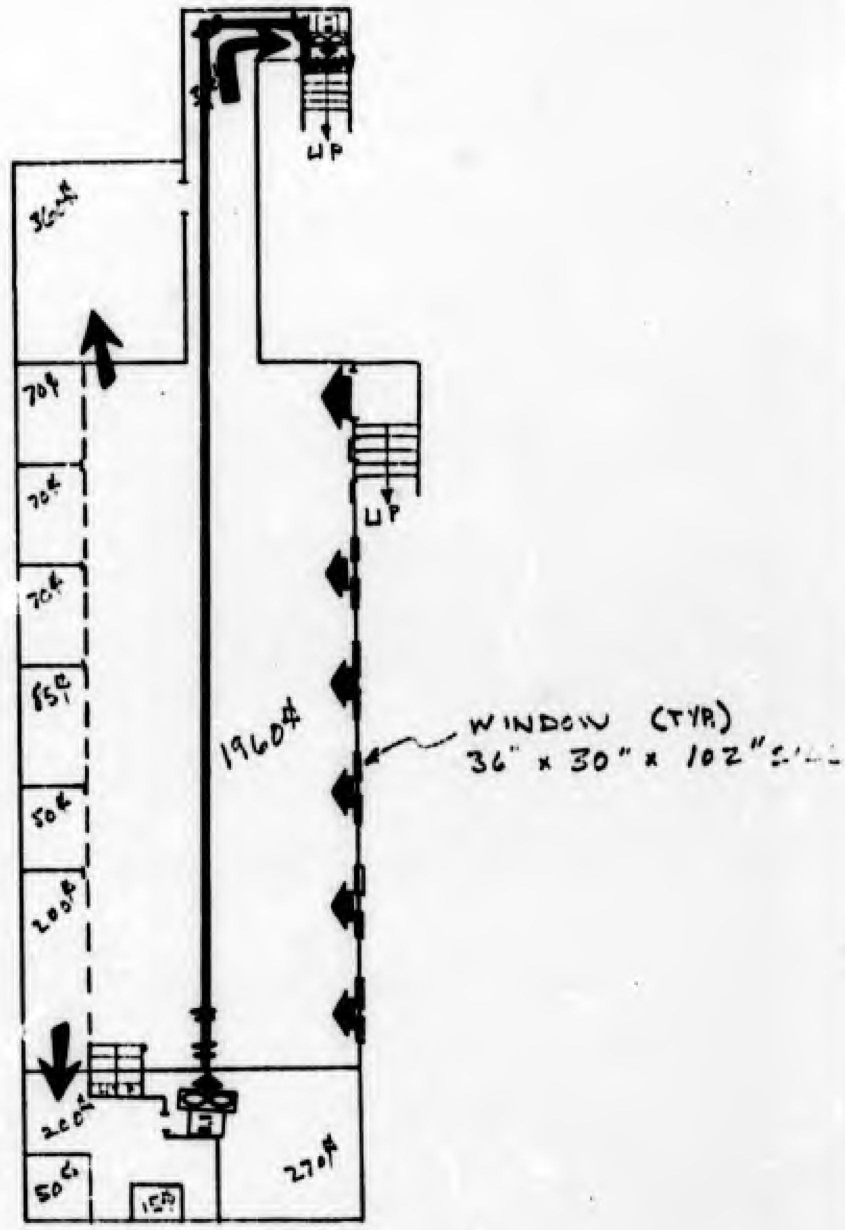
TOTAL AREA - 45,472 SQ. FT.

SCALE: 1" = 40'



APERTURES.

1. 3½' X 3½' X 4½' S
2. 3'-1" X 3'-4" X 7'-2" S.
3. 3½' X 3½' X 4½' S. (FAN INSTALLED)
4. DOOR 6' X 7'



SCALE
1" = 20'-0

RTI Facility No. 158

St. James Episcopal Church
1205 Fremont Avenue
South Pasadena, Calif.

SL 7231-1001
FN 04203

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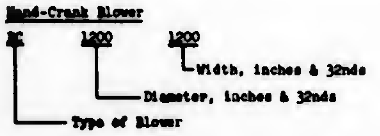
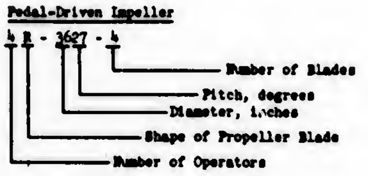
APPENDIX C

ANALYTICAL EXPRESSIONS FOR THE PERFORMANCE OF THE IMPELLERS USED IN THE STUDY

FOREWORD TO APPENDIX C

Impeller Nomenclature:





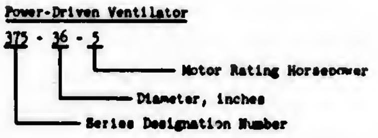
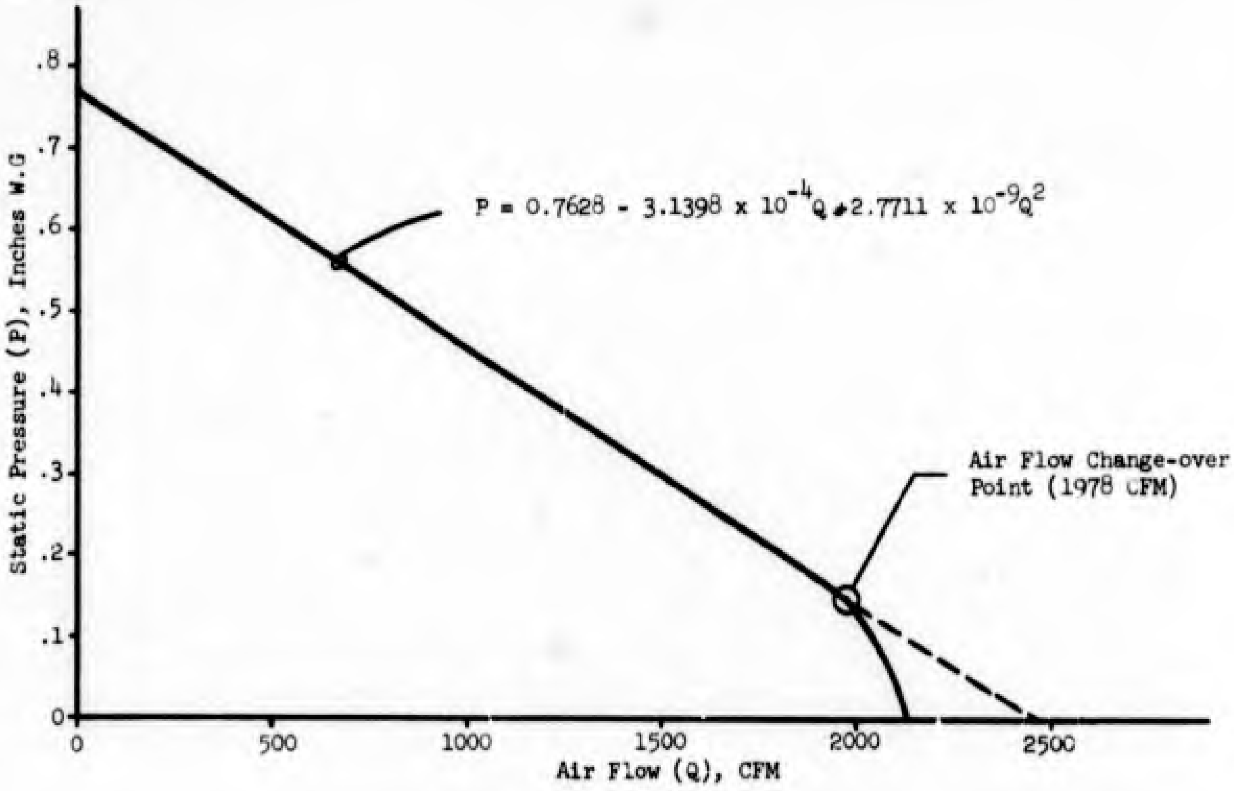


Illustration of the Air Flow Change-over Point for the 2A-1625-5 Impeller:



Impeller Nomenclature	Impeller Brake Horsepower	Air Flow (CFM) Change-over Point @ 62 RPM*	Polynomial Coefficients: $P = A_1 + A_2Q + A_3Q^2$		
			A_1	A_2	A_3
A-1625-5	0.1		0.4805	-2.4921×10^{-4}	2.7714×10^{-9}
	0.2	1978	0.7628	-3.1398×10^{-4}	2.7711×10^{-9}
A-1629-5	0.1		0.4347	-2.0668×10^{-4}	1.7218×10^{-9}
	0.2		0.6900	-2.6040×10^{-4}	1.7217×10^{-9}
	0.4	479	1.0953	-3.2808×10^{-4}	1.7220×10^{-9}
A-1633-5	0.1		0.3951	-1.6851×10^{-4}	-7.0981×10^{-9}
	0.2		0.6272	-2.1231×10^{-4}	-7.0988×10^{-9}
	0.4	1258	0.9956	-2.6749×10^{-4}	-7.0981×10^{-9}
A-1639-5	0.1		0.3603	-1.6477×10^{-4}	1.5948×10^{-9}
	0.2		0.5719	-2.0760×10^{-4}	1.5949×10^{-9}
	0.4		0.9079	-2.6156×10^{-4}	1.5948×10^{-9}
	0.6	202	1.1897	-2.9941×10^{-4}	1.5946×10^{-9}
E-1616-4	0.1	334	0.2078	1.0211×10^{-3}	-6.7530×10^{-7}
E-1624-4	0.1		0.5883	-2.4227×10^{-4}	-8.7890×10^{-9}
	0.2	502	0.9338	-3.0524×10^{-4}	-8.7891×10^{-9}
E-1632-4	0.1		0.4470	-1.2366×10^{-4}	-3.5386×10^{-8}
	0.2		0.7096	-1.5580×10^{-4}	-3.5386×10^{-8}
	0.4	225	1.1265	-1.9629×10^{-4}	-3.5386×10^{-8}
E-1640-4	0.1		0.3719	-9.5539×10^{-5}	-3.4829×10^{-8}
	0.2		0.5903	-1.2037×10^{-4}	-3.4829×10^{-8}
	0.4	1324	0.9370	-1.5166×10^{-4}	-3.4829×10^{-8}

*See the illustration at the front of this Appendix for an explanation of the change-over point.

Impeller Nomenclature	Impeller Brake Horsepower	Air Flow (CFM) Change-over Point @ 62 RPM*	Polynomial Coefficients: $P = A_1 + A_2Q + A_3Q^2$		
			A_1	A_2	A_3
N-1616-3	0.1	359	0.6606	-2.3436×10^{-4}	-9.6147×10^{-8}
N-1624-3	0.1		0.5127	-2.0510×10^{-4}	-2.4701×10^{-8}
	0.2	408	0.8138	-2.5840×10^{-4}	-2.4702×10^{-8}
N-1632-3	0.1		0.4307	-1.5944×10^{-4}	-2.3610×10^{-8}
	0.2		0.6837	-2.0088×10^{-4}	-2.3610×10^{-8}
	0.4		1.0853	-2.5309×10^{-4}	-2.3610×10^{-8}
N-1640-3	0.1		0.3657	-1.3297×10^{-4}	-2.2746×10^{-8}
	0.2		0.5805	-1.6754×10^{-4}	-2.2746×10^{-8}
	0.4	1043	0.9215	-2.1108×10^{-4}	-2.2746×10^{-8}
N-1616-4	0.1	804	0.6580	-2.2508×10^{-4}	-1.1825×10^{-7}
N-1624-4	0.1		0.5363	-2.3579×10^{-4}	-8.8863×10^{-9}
	0.2	1024	0.8513	-2.9708×10^{-4}	-8.8859×10^{-9}
N-1632-4	0.1		0.4290	-1.4346×10^{-4}	-3.0415×10^{-8}
	0.2		0.6810	-1.8074×10^{-4}	-3.0416×10^{-8}
	0.4	275	0.1081	-2.2772×10^{-4}	-3.0415×10^{-8}
N-1640-4	0.1		0.3628	-1.5514×10^{-4}	-6.7111×10^{-9}
	0.2		0.5759	-1.9547×10^{-4}	-6.7114×10^{-9}
	0.4	1864	0.9142	-2.4627×10^{-4}	-6.7113×10^{-9}
P-1616-4	0.1	598	0.7228	-3.4052×10^{-4}	-1.2743×10^{-7}
P-1624-4	0.1		0.5083	-9.3278×10^{-5}	-8.9774×10^{-8}
	0.2	615	0.8069	-1.1752×10^{-4}	-8.9774×10^{-8}
P-1632-4	0.1		0.4127	-9.8414×10^{-5}	-4.9011×10^{-8}

*See the illustration at the front of this Appendix for an explanation of the change-over point.

Impeller Nomenclature	Impeller Brake Horsepower	Air Flow (CFM) Change-over Point @ 62 RPM*	Polynomial Coefficients: $P = A_1 + A_2Q + A_3Q^2$		
			A_1	A_2	A_3
P-1632-4	0.2		0.6551	-1.2399×10^{-4}	-4.9011×10^{-8}
	0.4	163	1.0398	-1.5622×10^{-4}	-4.9010×10^{-8}
P-1640-4	0.1		0.3443	-7.7973×10^{-5}	-3.9617×10^{-8}
	0.2		0.5466	-9.8239×10^{-5}	-3.9617×10^{-8}
	0.4	1445	0.8679	-1.2377×10^{-4}	-3.9617×10^{-8}
S-1616-3	0.1		0.6755	-2.6272×10^{-4}	-1.1698×10^{-7}
S-1624-3	0.1		0.3961	1.5368×10^{-3}	-1.7812×10^{-6}
	0.2	48	0.6287	1.9362×10^{-3}	-1.7812×10^{-6}
S-1632-3	0.1		0.4322	-1.1043×10^{-4}	-4.7520×10^{-8}
	0.2	764	0.6861	-1.3913×10^{-4}	-4.7520×10^{-8}
S-1640-3	0.1		0.3678	-1.0101×10^{-4}	-3.8370×10^{-8}
	0.2		0.5839	-1.2727×10^{-4}	-3.8370×10^{-8}
	0.4	504	0.9268	-1.6035×10^{-4}	-3.8370×10^{-8}
S-1616-4	0.1	57	0.7044	-2.4048×10^{-4}	-1.6483×10^{-7}
S-1624-4	0.1		0.5720	-2.3459×10^{-4}	-3.8448×10^{-8}
	0.2	131	0.9080	-2.9557×10^{-4}	-3.8448×10^{-8}
S-1632-4	0.1		0.4485	-1.3052×10^{-4}	-4.9497×10^{-8}
	0.2	1127	0.7120	-1.6444×10^{-4}	-4.9497×10^{-8}
S-1640-4	0.1		0.3671	-9.2734×10^{-5}	-4.1824×10^{-8}
	0.2		0.5827	-1.1684×10^{-4}	-4.1824×10^{-8}
	0.4	851	0.9249	-1.4721×10^{-4}	-4.1825×10^{-8}

*See the illustration at the front of this Appendix for an explanation of the change-over point.

Impeller Nomenclature	Impeller Brake Horsepower	Air Flow (CFM) Change-over Point @ 62 RPM*	Polynomial Coefficients: $P = A_1 + A_2Q + A_3Q^2$		
			A_1	A_2	A_3
A-1825-5	0.1		0.4441	-1.9638×10^{-4}	-5.2106×10^{-9}
	0.2		0.7049	-2.4743×10^{-4}	-5.2107×10^{-9}
	0.4		1.1190	-3.1174×10^{-4}	-5.2104×10^{-9}
	0.6	348	1.4663	-3.5685×10^{-4}	-5.2103×10^{-9}
A-1829-5	0.1		0.4011	-1.6540×10^{-4}	1.8839×10^{-10}
	0.2		0.6367	-2.0839×10^{-4}	1.8859×10^{-10}
	0.4		1.0108	-2.6255×10^{-4}	1.8864×10^{-10}
	0.6	1330	1.3245	-3.0055×10^{-4}	1.8846×10^{-10}
A-1833-5	0.1		0.3783	-1.6868×10^{-4}	9.6152×10^{-9}
	0.2		0.6006	-2.1253×10^{-4}	9.6148×10^{-9}
	0.4		0.9534	-2.6777×10^{-4}	9.6148×10^{-9}
	0.6	2189	1.2493	-3.0652×10^{-4}	9.6148×10^{-9}
A-1839-5	0.1		0.3302	-1.3733×10^{-4}	7.6724×10^{-9}
	0.2		0.5242	-1.7303×10^{-4}	7.6725×10^{-9}
	0.4		0.8322	-2.1800×10^{-4}	7.6725×10^{-9}
	0.6	9985	1.0904	-2.4955×10^{-4}	7.6724×10^{-9}
E-1816-4	0.1		0.6021	-2.2252×10^{-4}	-6.9594×10^{-8}
	0.2	656	0.9558	-2.8036×10^{-4}	-6.9593×10^{-8}
E-1824-4	0.1		0.4610	-1.8452×10^{-4}	1.2553×10^{-9}
	0.2		0.7318	-2.3249×10^{-4}	1.2553×10^{-9}
	0.4	844	1.1617	-2.9291×10^{-4}	1.2555×10^{-9}

*See the illustration at the front of this Appendix for an explanation of the change-over point.

Impeller Nomenclature	Impeller Brake Horsepower	Air Flow (CFM) Change-over Point @ 62 RPM*	Polynomial Coefficients: $P = A_1 + A_2Q + A_3Q^2$		
			A_1	A_2	A_3
E-1832-4	0.1		0.3605	-9.3382×10^{-5}	-2.1459×10^{-8}
	0.2		0.5722	-1.1765×10^{-4}	-2.1459×10^{-8}
	0.4		0.9083	-1.4823×10^{-4}	-2.1459×10^{-8}
	0.6	1218	1.1902	-1.6969×10^{-4}	-2.1459×10^{-8}
E-1840-4	0.1		0.3100	-8.9521×10^{-5}	-1.5021×10^{-8}
	0.2		0.4921	-1.1279×10^{-4}	-1.5021×10^{-8}
	0.4		0.7811	-1.4210×10^{-4}	-1.5021×10^{-8}
	0.6	2864	1.0234	-1.6267×10^{-4}	-1.5021×10^{-8}
N-1816-3	0.1		0.5654	-2.3496×10^{-4}	-1.7240×10^{-8}
	0.2	270	0.8953	-2.9604×10^{-4}	-1.7240×10^{-8}
N-1824-3	0.1		0.4376	-1.7584×10^{-4}	-4.7393×10^{-11}
	0.2		0.6947	-2.2154×10^{-4}	-4.7426×10^{-11}
	0.4	229	1.1027	-2.7913×10^{-4}	-4.7245×10^{-11}
N-1832-3	0.1		0.3578	-9.6541×10^{-5}	-1.8790×10^{-8}
	0.2		0.5680	-1.2163×10^{-4}	-1.8790×10^{-8}
	0.4	1750	0.9016	-1.5325×10^{-4}	-1.8790×10^{-8}
N-1840-3	0.1		0.3062	-8.8952×10^{-5}	-1.4321×10^{-8}
	0.2		0.4860	-1.1207×10^{-4}	-1.4322×10^{-8}
	0.4	3403	0.7715	-1.4120×10^{-4}	-1.4321×10^{-8}
N-1816-4	0.1		0.5936	-1.9714×10^{-4}	-5.2595×10^{-8}
	0.2	882	0.9423	-2.4838×10^{-4}	-5.2594×10^{-8}

***See the illustration at the front of this Appendix for an explanation of the** change-over point.

Impeller Nomenclature	Impeller Brake Horsepower	Air Flow (CFM) Change-over Point @ 62 RPM*	Polynomial Coefficients: $F = A_1 + A_2Q + A_3Q^2$		
			A_1	A_2	A_3
N-1824-4	0.1		0.4599	-1.1209×10^{-4}	-3.4591×10^{-8}
	0.2		0.7300	-1.4123×10^{-4}	-3.4591×10^{-8}
	0.4	788	1.1588	-1.7794×10^{-4}	-3.4591×10^{-8}
N-1832-3	0.1		0.3524	-6.9619×10^{-5}	-2.9323×10^{-8}
	0.2		0.5595	-8.7715×10^{-5}	-2.9322×10^{-8}
	0.4		0.8881	-1.1051×10^{-4}	-2.9322×10^{-8}
	0.6	1368	1.1637	-1.2651×10^{-4}	-2.9323×10^{-8}
N-1840-4	0.1		0.3743	-1.2738×10^{-4}	-1.5846×10^{-8}
	0.2		0.5941	-1.6049×10^{-4}	-1.5846×10^{-8}
	0.4		0.9431	-2.0220×10^{-4}	-1.5846×10^{-8}
	0.6	2791	1.2358	-2.3146×10^{-4}	-1.5846×10^{-8}
P-1816-4	0.1		0.6450	-2.4177×10^{-4}	-1.8793×10^{-8}
	0.2	412	1.0239	-3.0461×10^{-4}	-1.8793×10^{-8}
P-1824-4	0.1		0.4681	-1.4484×10^{-4}	-1.9183×10^{-8}
	0.2		0.7431	-1.8249×10^{-4}	-1.9183×10^{-8}
	0.4	564	1.1796	-2.2992×10^{-4}	-1.9183×10^{-8}
P-1832-4	0.1		0.3679	-1.0507×10^{-4}	-1.7946×10^{-8}
	0.2		0.5841	-1.3238×10^{-4}	-1.7946×10^{-8}
	0.4		0.9271	-1.6679×10^{-4}	-1.7946×10^{-8}
	0.6	873	1.2149	-1.9093×10^{-4}	-1.7946×10^{-8}
P-1840-4	0.1		0.3150	-1.0777×10^{-4}	-4.7872×10^{-9}
	0.2		0.5001	-1.3578×10^{-4}	-4.7871×10^{-9}

*See the illustration at the front of this Appendix for an explanation of the change-over point.

Impeller Nomenclature	Impeller Brake Horsepower	Air Flow (CFM) Change-over Point @ 62 RPM*	Polynomial Coefficients: $P = A_1 + A_2Q + A_3Q^2$		
			A_1	A_2	A_3
P-1840-4	0.4		0.7938	-1.7107×10^{-4}	-4.7872×10^{-9}
	0.6	2261	1.0402	-1.9583×10^{-4}	-4.7871×10^{-9}
S-1816-3	0.1	457	0.6588	-3.2565×10^{-4}	-3.0748×10^{-8}
S-1824-3	0.1		0.4688	-1.4112×10^{-4}	-2.9579×10^{-8}
	0.2	819	0.7441	-1.7780×10^{-4}	-2.9579×10^{-8}
S-1823-3	0.1		0.3855	-1.1394×10^{-4}	-1.9357×10^{-8}
	0.2		0.6120	-1.4356×10^{-4}	-1.9357×10^{-8}
	0.4	750	0.9715	-1.8088×10^{-4}	-1.9357×10^{-8}
S-1840-3	0.1		0.3339	-1.0057×10^{-4}	-1.4516×10^{-8}
	0.2		0.5300	-1.2671×10^{-4}	-1.4516×10^{-8}
	0.4		0.8413	-1.5964×10^{-4}	-1.4516×10^{-8}
	0.6	1074	1.1024	-1.8275×10^{-4}	-1.4516×10^{-8}
S-1816-4	0.1	650	0.6405	-1.3885×10^{-4}	-1.7479×10^{-7}
S-1824-4	0.1		0.4993	-1.2482×10^{-4}	-4.9225×10^{-8}
	0.2		0.7926	-1.5726×10^{-4}	-4.9225×10^{-8}
	0.4		1.2582	-1.9814×10^{-4}	-4.9225×10^{-8}
S-1832-4	0.1		0.4073	-1.3151×10^{-4}	-1.7104×10^{-8}
	0.2		0.6465	-1.6569×10^{-4}	-1.7104×10^{-8}
	0.4		1.0263	-2.0876×10^{-4}	-1.7104×10^{-8}
	0.6		1.3448	-2.3897×10^{-4}	-1.7104×10^{-8}
S-1840-4	0.1		0.3368	-9.2869×10^{-4}	-2.0545×10^{-8}
	0.2		0.5346	-1.1701×10^{-4}	-2.054×10^{-8}

*See the illustration at the front of this Appendix for an explanation of the change-over point.

Impeller Nomenclature	Impeller Brake Horsepower	Air Flow (CFM) Change-over Point @ 62 RPM*	Polynomial Coefficients: $P = A_1 + A_2Q + A_3Q^2$		
			A_1	A_2	A_3
S-1840-4	0.4		0.8487	-1.4742×10^{-4}	-2.0545×10^{-8}
	0.6	1465	1.1121	-1.6875×10^{-4}	-2.0545×10^{-8}
A-2025-5	0.1		0.3584	-1.1571×10^{-4}	-6.9432×10^{-9}
	0.2		0.5689	-1.4578×10^{-4}	-6.9438×10^{-9}
	0.4		0.9030	-1.8368×10^{-4}	-6.9438×10^{-9}
	0.6		1.1833	-2.1026×10^{-4}	-6.9437×10^{-9}
	0.8	1550	1.4334	-2.3142×10^{-4}	-6.9437×10^{-9}
A-2029-5	0.1		0.3155	-8.7287×10^{-4}	-1.0306×10^{-8}
	0.2		0.5008	-1.0997×10^{-4}	-1.0306×10^{-8}
	0.4		0.7950	-1.3856×10^{-4}	-1.0306×10^{-8}
	0.6		1.0417	-1.5861×10^{-4}	-1.0306×10^{-8}
	0.8	2913	1.2620	-1.7458×10^{-4}	-1.0306×10^{-8}
A-2033-5	0.1		0.2946	-8.3600×10^{-5}	-6.8273×10^{-9}
	0.2		0.4676	-1.0533×10^{-4}	-6.8274×10^{-9}
	0.4		0.7422	-1.3271×10^{-4}	-6.8273×10^{-9}
	0.6		0.9726	-1.5191×10^{-4}	-6.8273×10^{-9}
	0.8	4462	1.1782	-1.6720×10^{-4}	-6.8273×10^{-9}
A-2039-5	0.1		0.2700	-7.5817×10^{-5}	-5.4239×10^{-9}
	0.2		0.4286	-9.5524×10^{-5}	-5.4239×10^{-9}
	0.4		0.6804	-1.2035×10^{-4}	-5.4240×10^{-9}
	0.6		0.8916	-1.3777×10^{-4}	-5.4240×10^{-9}
	0.8	5707	1.0801	-1.5164×10^{-4}	-5.4239×10^{-9}

*See the illustration at the front of this Appendix for an explanation of the change-over point.

Impeller Nomenclature	Impeller Brake Horsepower	Air Flow (CFM) Change-over Point @ 62 RPM*	Polynomial Coefficients: $P = A_1 + A_2Q + A_3Q^2$		
			A_1	A_2	A_3
E-2016-4	0.1		0.4984	-2.7143×10^{-4}	3.0333×10^{-8}
	0.2		0.7911	-3.4197×10^{-4}	3.0333×10^{-8}
	0.4	744	1.2558	-4.3086×10^{-4}	3.0333×10^{-8}
E-2024-4	0.1		0.3976	-1.5081×10^{-4}	8.9761×10^{-9}
	0.2		0.6312	-1.9000×10^{-4}	8.9761×10^{-9}
	0.4		1.0019	-2.3939×10^{-4}	8.9760×10^{-9}
	0.6		1.3129	-2.7403×10^{-4}	8.9760×10^{-9}
	0.8	559	1.5905	-3.0161×10^{-4}	8.9760×10^{-9}
E-2032-4	0.1		0.3181	-8.7952×10^{-5}	-8.5201×10^{-9}
	0.2		0.5049	-1.1081×10^{-4}	-8.5201×10^{-9}
	0.4		0.8015	-1.3962×10^{-4}	-8.5201×10^{-9}
	0.6		1.0503	-1.5982×10^{-4}	-8.5201×10^{-9}
	0.8	2674	1.2724	-1.7590×10^{-4}	-8.5200×10^{-9}
E-2040-4	0.1		0.2674	-6.9202×10^{-5}	-9.9414×10^{-9}
	0.2		0.4244	-8.7189×10^{-5}	-9.9412×10^{-9}
	0.4		0.6738	-1.0985×10^{-4}	-9.9414×10^{-9}
	0.6		0.8829	-1.2575×10^{-4}	-9.9413×10^{-9}
	0.8	4824	1.0695	-1.3840×10^{-4}	-9.9412×10^{-9}
F-2015-3	0.1		0.4044	-1.2754×10^{-4}	-1.2025×10^{-8}
	0.2	434	0.6419	-1.6069×10^{-4}	-1.2025×10^{-8}
F-2019-3	0.1		0.3580	-9.1323×10^{-4}	-1.3680×10^{-8}
	0.2	1277	0.5683	-1.1506×10^{-4}	-1.3680×10^{-8}

*See the illustration at the front of this Appendix for an explanation of the change-over point.

Impeller Nomenclature	Impeller Brake Horsepower	Air Flow (CFM) Change-over Point @ 62 RPM*	Polynomial Coefficients: $P = A_1 + A_2Q + A_3Q^2$		
			A_1	A_2	A_3
F-2023-3	0.1		0.3299	-8.2812×10^{-5}	-1.2417×10^{-8}
	0.2		0.5237	-1.0434×10^{-4}	-1.2417×10^{-8}
	0.4	370	0.8314	-1.3146×10^{-4}	-1.2417×10^{-8}
N-2016-3	0.1		0.4771	-1.8270×10^{-4}	-3.9379×10^{-9}
	0.2		0.7573	-2.3019×10^{-4}	-3.9378×10^{-9}
	0.4	119	1.2022	-2.9002×10^{-4}	-3.9377×10^{-9}
N-2024-3	0.1		0.3539	-1.2144×10^{-4}	-6.8311×10^{-10}
	0.2		0.5619	-1.5300×10^{-4}	-6.8322×10^{-10}
	0.4		0.8919	-1.9277×10^{-4}	-6.8328×10^{-10}
	0.6	1135	1.1687	-2.2067×10^{-4}	-6.8325×10^{-10}
N-2032-3	0.1		0.3048	-1.0127×10^{-4}	-1.8443×10^{-9}
	0.2		0.4839	-1.2759×10^{-4}	-1.8442×10^{-9}
	0.4		0.7681	-1.6076×10^{-4}	-1.8443×10^{-9}
	0.6		1.0065	-1.8402×10^{-4}	-1.8443×10^{-9}
	0.8	1805	1.2193	-2.0254×10^{-4}	-1.8442×10^{-9}
N-2040-3	0.1		0.2747	-7.6916×10^{-5}	-7.7079×10^{-9}
	0.2		0.4361	-9.6908×10^{-5}	-7.7079×10^{-9}
	0.4		0.6923	-1.2210×10^{-4}	-7.7079×10^{-9}
	0.6		0.9072	-1.3977×10^{-4}	-7.7079×10^{-9}
	0.8	3768	1.1000	-1.5383×10^{-4}	-7.7080×10^{-9}
N-2016-4	0.1		0.4519	-1.7847×10^{-4}	-1.0360×10^{-8}
	0.2		0.7174	-2.2486×10^{-4}	-1.0360×10^{-8}

*See the illustration at the front of this Appendix for an explanation of the change-over point.

Impeller Nomenclature	Impeller Brake Horsepower	Air Flow (CFM) Change-over Point @ 62 RPM*	Polynomial Coefficients: $P = A_1 + A_2Q + A_3Q^2$		
			A_1	A_2	A_3
N-2016-4	0.4	926	1.1388	-2.8330×10^{-4}	-1.0360×10^{-8}
N-2024-4	0.1		0.3803	-1.3165×10^{-4}	-3.5596×10^{-9}
	0.2		0.6036	-1.6587×10^{-4}	-3.5594×10^{-9}
	0.4		0.9582	-2.0900×10^{-4}	-3.5595×10^{-9}
	0.6		1.2556	-2.3923×10^{-4}	-3.5595×10^{-9}
	0.8	933	1.5210	-2.6331×10^{-4}	-3.5594×10^{-9}
N-2032-4	0.1		0.3326	-8.8129×10^{-5}	-7.0539×10^{-9}
	0.2		0.5279	-1.1104×10^{-4}	-7.0539×10^{-9}
	0.4		0.8380	-1.3990×10^{-4}	-7.0538×10^{-9}
	0.6		1.0982	-1.6014×10^{-4}	-7.0538×10^{-9}
	0.8	2830	1.3303	-1.7626×10^{-4}	-7.0539×10^{-9}
N-2040-4	0.1		0.3037	-7.5257×10^{-5}	-4.9627×10^{-9}
	0.2		0.4821	-9.4818×10^{-5}	-4.9626×10^{-9}
	0.4		0.7653	-1.1946×10^{-4}	-4.9628×10^{-9}
	0.6		1.0028	-1.3675×10^{-4}	-4.9628×10^{-9}
	0.8	4624	1.2148	-1.5051×10^{-4}	-4.9628×10^{-9}
S-2016-4	0.1		0.5142	-1.8190×10^{-4}	-5.2528×10^{-8}
	0.2	537	0.8162	-2.2922×10^{-4}	-5.2528×10^{-8}
S-2024-4	0.1		0.3942	-1.0466×10^{-4}	-1.9035×10^{-8}
	0.2		0.6257	-1.3186×10^{-4}	-1.9036×10^{-8}
	0.4		0.9932	-1.6613×10^{-4}	-1.9036×10^{-8}
	0.6	203	1.3015	-1.9018×10^{-4}	-1.9036×10^{-8}

*See the illustration at the front of this Appendix for an explanation of the change-over point.

Impeller Nomenclature	Impeller Brake Horsepower	Air Flow (CFM) Change-over Point @ 62 RPM*	Polynomial Coefficients: $P = A_1 + A_2Q + A_3Q^2$		
			A_1	A_2	A_3
S-2032-4	0.1		0.3344	-1.0178×10^{-4}	-6.0630×10^{-9}
	0.2		0.5308	-1.2823×10^{-4}	-6.0628×10^{-9}
	0.4		0.8426	-1.6156×10^{-4}	-6.0629×10^{-9}
	0.6		1.1041	-1.8494×10^{-4}	-6.0630×10^{-9}
	0.8	964	1.3376	-2.0356×10^{-4}	-6.0629×10^{-9}
S-2040-4	0.1		0.2841	-7.2863×10^{-5}	-1.2001×10^{-8}
	0.2		0.4510	-9.1801×10^{-5}	-1.2001×10^{-8}
	0.4		0.7159	-1.1566×10^{-4}	-1.2001×10^{-8}
	0.6		0.9381	-1.3240×10^{-4}	-1.2001×10^{-8}
	0.8	2674	1.1364	-1.4572×10^{-4}	-1.2001×10^{-8}
S-2016-3	0.1		0.4892	-2.0078×10^{-4}	-2.5150×10^{-8}
	0.2	94	0.7766	-2.5296×10^{-4}	-2.5150×10^{-8}
S-2024-3	0.1		0.3874	-1.0601×10^{-4}	-1.7662×10^{-8}
	0.2		0.6149	-1.3363×10^{-4}	-1.7662×10^{-8}
	0.4	610	0.9761	-1.6836×10^{-4}	-1.7662×10^{-8}
S-2032-3	0.1		0.3211	-8.8980×10^{-5}	-6.7382×10^{-9}
	0.2		0.5096	-1.1211×10^{-4}	-6.7384×10^{-9}
	0.4		0.8090	-1.4125×10^{-4}	-6.7384×10^{-9}
	0.6		1.0601	-1.6169×10^{-4}	-6.7384×10^{-9}
	0.8	486	1.2842	-1.7796×10^{-4}	-6.7383×10^{-9}
S-2040-3	0.1		0.2753	-7.3108×10^{-5}	-1.0272×10^{-8}
	0.2		0.4370	-9.2110×10^{-5}	-1.0272×10^{-8}

*See the illustration at the front of this Appendix for an explanation of the change-over point.

Impeller Nomenclature	Impeller Brake Horsepower	Air Flow (CFM) Change-over Point @ 62 RPM*	Polynomial Coefficients: $P = A_1 + A_2Q + A_3Q^2$		
			A_1	A_2	A_3
S-2040-3	0.4		0.6938	-1.1605×10^{-4}	-1.0272×10^{-8}
	0.6		0.9091	-1.3285×10^{-4}	-1.0272×10^{-8}
	0.8	2040	1.1013	-1.4622×10^{-4}	-1.0272×10^{-8}
A-2229-5	0.1		0.2875	-6.4672×10^{-5}	-1.1490×10^{-8}
	0.2		0.4564	-8.1481×10^{-5}	-1.1490×10^{-8}
	0.4		0.7245	-1.0266×10^{-4}	-1.1490×10^{-8}
	0.6		0.9494	-1.1752×10^{-4}	-1.1490×10^{-8}
	0.8		1.1501	-1.2934×10^{-4}	-1.1490×10^{-8}
A-2233-5	0.1		0.2642	-4.5075×10^{-5}	-1.4118×10^{-8}
	0.2		0.4194	-5.6790×10^{-5}	-1.4118×10^{-8}
	0.4		0.6658	-7.1551×10^{-5}	-1.4118×10^{-8}
	0.6		0.8724	-8.1905×10^{-5}	-1.4118×10^{-8}
	0.8		1.0569	-9.0150×10^{-5}	-1.4118×10^{-8}
A-2239-5	0.1		0.2401	-5.8092×10^{-5}	-5.8603×10^{-9}
	0.2		0.3812	-7.3191×10^{-5}	-5.8603×10^{-9}
	0.4		0.6050	-9.2215×10^{-5}	-5.8603×10^{-9}
	0.6		0.7928	-1.0556×10^{-4}	-5.8603×10^{-9}
	0.8		0.9605	-1.1618×10^{-4}	-5.8604×10^{-9}
N-2216-4	0.1		0.4035	-1.3748×10^{-4}	-8.4017×10^{-9}
	0.2		0.6405	-1.7322×10^{-4}	-8.4017×10^{-9}
	0.4		1.0168	-2.1824×10^{-4}	-8.4106×10^{-9}
	0.6	1057	1.3324	-2.4982×10^{-4}	-8.4017×10^{-9}

*See the illustration at the front of this Appendix for an explanation of the change-over point.

Impeller Nomenclature	Impeller Brake Horsepower	Air Flow (CFM) Change-over Point @ 62 RPM*	Polynomial Coefficients: $P = A_1 + A_2Q + A_3Q^2$		
			A_1	A_2	A_3
N-2224-4	0.1		0.3126	-4.2199×10^{-5}	-2.3869×10^{-8}
	0.2		0.4962	-5.3167×10^{-5}	-2.3869×10^{-8}
	0.4		0.7876	-6.6987×10^{-5}	-2.3869×10^{-8}
	0.6		1.0321	-7.6682×10^{-5}	-2.3869×10^{-8}
	0.8	2408	1.2503	-8.4399×10^{-5}	-2.3869×10^{-8}
N-2232-4	0.1		0.2683	-5.8255×10^{-5}	-9.8631×10^{-9}
	0.2		0.4260	-7.3397×10^{-5}	-9.8632×10^{-9}
	0.4		0.6762	-9.2474×10^{-5}	-9.8631×10^{-9}
	0.6		0.8860	-1.0586×10^{-4}	-9.8632×10^{-9}
	0.8	5783	1.0724	-1.1651×10^{-4}	-9.8631×10^{-9}
N-2240-4	0.1		0.2181	-3.7380×10^{-5}	-1.0510×10^{-8}
	0.2		0.3462	-4.7095×10^{-5}	-1.0510×10^{-8}
	0.4		0.5495	-5.9336×10^{-5}	-1.0510×10^{-8}
	0.6		0.7201	-6.7923×10^{-5}	-1.0510×10^{-8}
	0.8		0.8724	-7.4759×10^{-5}	-1.0510×10^{-8}
A-2425-5	0.1		0.2787	-7.5461×10^{-5}	-6.1850×10^{-9}
	0.2		0.4424	-9.5075×10^{-5}	-6.1849×10^{-9}
	0.4		0.7022	-1.1979×10^{-4}	-6.1849×10^{-9}
	0.6		0.9201	-1.3712×10^{-4}	-6.1851×10^{-9}
	0.8		1.1147	-1.5092×10^{-4}	-6.1851×10^{-9}
A-2429-5	0.1		0.2653	-5.4885×10^{-5}	-7.7889×10^{-9}
	0.2		0.4212	-6.9151×10^{-5}	-7.7889×10^{-9}

*See the illustration at the front of this Appendix for an explanation of change-over point.

Impeller Nomenclature	Impeller Brake Horsepower	Air Flow (CFM) Change-over Point @ 62 RPM*	Polynomial Coefficients: $P = A_1 + A_2Q + A_3Q^2$		
			A_1	A_2	A_3
A-2429-5	0.4		0.6686	-8.7123×10^{-5}	-7.7891×10^{-9}
	0.6		0.3762	-9.9733×10^{-5}	-7.7887×10^{-9}
	0.8		1.0614	-1.0977×10^{-4}	-7.7889×10^{-9}
A-2433-5	0.1		0.2252	-3.7973×10^{-5}	-7.4648×10^{-9}
	0.2		0.3575	-4.7842×10^{-5}	-7.4649×10^{-9}
	0.4		0.5675	-6.0277×10^{-5}	-7.465[illegible] $\times 10^{-9}$
	0.6		0.7436	-6.9000×10^{-5}	-7.4649×10^{-9}
	0.8		0.9008	-7.5946×10^{-5}	-7.4648×10^{-9}
A-2439-5	0.1		0.2119	-4.4815×10^{-5}	-2.8489×10^{-9}
	0.2		0.3363	-5.6463×10^{-5}	-2.8489×10^{-9}
	0.4		0.5339	-7.1139×10^{-5}	-2.8489×10^{-9}
	0.6		0.6996	-8.1434×10^{-5}	-2.8488×10^{-9}
	0.8		0.8475	-8.9630×10^{-5}	-2.8489×10^{-9}
[illegible]430-5	0.1		0.2741	-6.8771×10^{-5}	-4.8016×10^{-9}
	0.2		0.4351	-8.6646×10^{-5}	-4.8015×10^{-9}
	0.4		0.6907	-1.0917×10^{-4}	-4.8016×10^{-9}
	0.6		0.9051	-1.2497×10^{-4}	-4.8015×10^{-9}
	0.8		1.0964	-1.3754×10^{-4}	-4.8016×10^{-9}
B-2435-5	0.1		0.2370	-5.6349×10^{-5}	-3.8766×10^{-9}
	0.2		0.3762	-7.0996×10^{-5}	-3.8765×10^{-9}
	0.4		0.5971	-8.9449×10^{-5}	-3.8766×10^{-9}
	0.6		0.7825	-1.0239×10^{-4}	-3.8766×10^{-9}

*See the illustration at the front of this Appendix for an explanation of the change-over point.

Impeller Nomenclature	Impeller Brake Horsepower	Air Flow (CFM) Change-over Point @ 62 RPM*	Polynomial Coefficients: $P = A_1 + A_2Q + A_3Q^2$		
			A_1	A_2	A_3
B-2435-5	0.8		0.9479	-1.1270×10^{-4}	-3.8767×10^{-9}
B-2440-5	0.1		0.2143	-5.6428×10^{-5}	-1.7282×10^{-9}
	0.2		0.3401	-7.1095×10^{-5}	-1.7282×10^{-9}
	0.4		0.5400	-8.9575×10^{-5}	-1.7282×10^{-9}
	0.6		0.7075	-1.0254×10^{-4}	-1.7281×10^{-9}
	0.8		0.8571	-1.1286×10^{-4}	-1.7282×10^{-9}
B-2430-4	0.1		0.2614	-7.5311×10^{-5}	2.8336×10^{-10}
	0.2		0.4150	-9.4886×10^{-5}	2.8322×10^{-10}
	0.4		0.6588	-1.1955×10^{-4}	2.8328×10^{-10}
	0.6		0.8632	-1.3685×10^{-4}	2.8330×10^{-10}
	0.8		1.0457	-1.5062×10^{-4}	2.8329×10^{-10}
B-2435-4	0.1		0.2261	-6.8033×10^{-5}	4.3843×10^{-10}
	0.2		0.3589	-8.5716×10^{-5}	4.3843×10^{-10}
	0.4		0.5698	-1.0800×10^{-4}	4.3845×10^{-10}
	0.6		0.7466	-1.2362×10^{-4}	4.3847×10^{-10}
	0.8		0.9045	-1.3607×10^{-4}	4.3852×10^{-10}
B-2440-4	0.1		0.3002	-1.4688×10^{-4}	1.9028×10^{-8}
	0.2		0.4765	-1.8506×10^{-4}	1.9028×10^{-8}
	0.4		0.7563	-2.3316×10^{-4}	1.9028×10^{-8}
	0.6		0.9911	-2.6690×10^{-4}	1.9028×10^{-8}
	0.8		1.2006	-2.9376×10^{-4}	1.9028×10^{-8}

*See the illustration at the front of this Appendix for an explanation of the change-over point.

Impeller Nomenclature	Impeller Brake Horsepower	Air Flow (CFM) Change-over Point @ 62 RPM*	Polynomial Coefficients: $P = A_1 + A_2Q + A_3Q^2$		
			A_1	A_2	A_3
E-2416-4	0.1		0.4107	-1.0301×10^{-4}	-1.5446×10^{-8}
	0.2		0.6520	-1.2979×10^{-4}	-1.5446×10^{-8}
	0.4		1.0350	-1.6352×10^{-4}	-1.5446×10^{-8}
	0.6		1.3562	-1.8719×10^{-4}	-1.5446×10^{-8}
	0.8	1164	1.6430	-2.0603×10^{-4}	-1.5446×10^{-8}
E-2424-4	0.1		0.3242	-8.8839×10^{-5}	-1.1302×10^{-10}
	0.2		0.5147	-1.1193×10^{-4}	-1.1302×10^{-10}
	0.4		0.8170	-1.4102×10^{-4}	-1.1303×10^{-10}
	0.6		1.0706	-1.6143×10^{-4}	-1.1311×10^{-10}
	0.8	4127	1.2969	-1.7768×10^{-4}	-1.1302×10^{-10}
E-2440-4	0.1		0.2171	-4.5303×10^{-5}	-4.0005×10^{-9}
	0.2		0.3446	-5.7078×10^{-5}	-4.0006×10^{-9}
	0.4		0.5470	-7.1914×10^{-5}	-4.0005×10^{-9}
	0.6		0.7169	-8.2321×10^{-5}	-4.0005×10^{-9}
	0.8		0.8684	-9.0606×10^{-5}	-4.0005×10^{-9}
M-2440-4	0.1		0.2122	-4.9727×10^{-5}	-3.5680×10^{-9}
	0.2		0.3368	-6.2652×10^{-5}	-3.5680×10^{-9}
	0.4		0.5347	-7.8936×10^{-5}	-3.5680×10^{-9}
	0.6		0.7007	-9.0360×10^{-5}	-3.5680×10^{-9}
	0.8		0.8488	-9.9454×10^{-5}	-3.5679×10^{-9}
N-2416-4	0.1		0.4105	-1.3853×10^{-4}	-1.7924×10^{-8}
	0.2		0.6517	-1.7454×10^{-4}	-1.7924×10^{-8}

*See the illustration at the front of this Appendix for an explanation of the change-over point.

Impeller Nomenclature	Impeller Brake Horsepower	Air Flow (CFM) Change-over Point @ 62 RPM*	Polynomial Coefficients: $P = A_1 + A_2Q + A_3Q^2$		
			A_1	A_2	A_3
N-2416-4	0.4		1.0345	-2.1990×10^{-4}	-1.7924×10^{-8}
	0.6		1.3555	-2.5173×10^{-4}	-1.7924×10^{-8}
	0.8	1724	1.6421	-2.7706×10^{-4}	-1.7924×10^{-8}
N-2424-4	0.1		0.3003	-6.3269×10^{-5}	-9.6616×10^{-9}
	0.2		0.4768	-7.9714×10^{-5}	-9.6615×10^{-9}
	0.4		0.7568	-1.0043×10^{-4}	-9.6616×10^{-9}
	0.6		0.9917	-1.1450×10^{-4}	-9.6614×10^{-9}
	0.8	5293	1.2014	-1.2654×10^{-4}	-9.6615×10^{-9}
N-2432-4	0.1		0.2378	-5.1359×10^{-5}	-4.6404×10^{-9}
	0.2		0.3775	-6.4708×10^{-5}	-4.6405×10^{-9}
	0.4		0.5993	-8.1527×10^{-5}	-4.6405×10^{-9}
	0.6		0.7853	-9.3324×10^{-5}	-4.6405×10^{-9}
	0.8		0.9513	-1.0272×10^{-4}	-4.6405×10^{-9}
N-2440-4	0.1		0.2084	-5.3250×10^{-5}	-9.8440×10^{-10}
	0.2		0.3308	-6.7091×10^{-5}	-9.8435×10^{-10}
	0.4		0.5252	-8.4528×10^{-5}	-9.8447×10^{-10}
	0.6		0.6882	-9.6761×10^{-5}	-9.8442×10^{-10}
	0.8		0.8337	-1.0650×10^{-4}	-9.8434×10^{-10}
R-2430-4	0.1		0.3597	-1.2205×10^{-4}	1.7866×10^{-9}
	0.2		0.5709	-1.5377×10^{-4}	1.7868×10^{-9}
	0.4		0.9063	-1.9374×10^{-4}	1.7867×10^{-9}
	0.6		1.1876	-2.2177×10^{-4}	1.7865×10^{-9}

*See the illustration at the front of this Appendix for an explanation of the change-over point.

Impeller Nomenclature	Impeller Brake Horsepower	Air Flow (CFM) Change-over Point @ 62 RPM*	Polynomial Coefficients: $P = A_1 + A_2Q + A_3Q^2$		
			A_1	A_2	A_3
R-2420-4	0.8	2109	1.4386	-2.4409×10^{-4}	1.7866×10^{-9}
R-2427-4	0.1		0.2945	-8.3624×10^{-5}	-1.6312×10^{-9}
	0.2		0.4674	-1.0536×10^{-4}	-1.6312×10^{-9}
	0.4		0.7420	-1.3275×10^{-4}	-1.6312×10^{-9}
	0.6		0.9723	-1.5195×10^{-4}	-1.6313×10^{-9}
	0.8		1.1778	-1.6725×10^{-4}	-1.6314×10^{-9}
R-2440-4	0.1		0.2143	-6.2772×10^{-5}	-1.1171×10^{-10}
	0.2		0.3401	-7.9087×10^{-5}	-1.1175×10^{-10}
	0.4		0.5400	-9.9644×10^{-5}	-1.1164×10^{-10}
	0.6		0.7075	-1.1406×10^{-4}	-1.1175×10^{-10}
	0.8		0.8570	-1.2554×10^{-4}	-1.1167×10^{-10}
S-2416-4	0.1		0.3934	-1.0211×10^{-4}	-3.1367×10^{-8}
	0.2		0.6245	-1.2865×10^{-4}	-3.1367×10^{-8}
	0.4		0.9913	-1.6209×10^{-4}	-3.1367×10^{-8}
	0.6	1118	1.3000	-1.8555×10^{-4}	-3.1367×10^{-8}
S-2424-4	0.1		0.4254	-1.4407×10^{-4}	-1.4700×10^{-8}
	0.2		0.6753	-1.8151×10^{-4}	-1.4700×10^{-8}
	0.4	2030	1.0720	-2.2870×10^{-4}	-1.4700×10^{-8}
S-2432-4	0.1		0.2965	-5.8360×10^{-5}	-1.0401×10^{-8}
	0.2		0.4707	-7.3529×10^{-5}	-1.0401×10^{-8}
	0.4		0.7472	-9.2641×10^{-5}	-1.0401×10^{-8}
	0.6		0.9792	-1.0605×10^{-4}	-1.0401×10^{-8}

*See the illustration at the front of this Appendix for an explanation of the change-over point.

Impeller Nomenclature	Impeller Brake Horsepower	Air Flow (CFM) Change-over Point @ 62 RPM*	Polynomial Coefficients: $P = A_1 + A_2Q + A_3Q^2$		
			A_1	A_2	A_3
S-2432-4	0.8	3301	1.1862	-1.1672×10^{-4}	-1.0401×10^{-8}
S-2440-4	0.1		0.2490	-4.1203×10^{-5}	-1.0019×10^{-8}
	0.2		0.3952	-5.1912×10^{-5}	-1.0019×10^{-8}
	0.4		0.6274	-6.5405×10^{-5}	-1.0019×10^{-8}
	0.6		0.8221	-7.4870×10^{-5}	-1.0019×10^{-8}
	0.8	6189	0.9959	-8.2406×10^{-5}	-1.0019×10^{-8}
A-2629-5	0.1		0.2404	-5.9418×10^{-5}	-4.3215×10^{-10}
	0.2		0.3816	-7.4862×10^{-5}	-4.3210×10^{-10}
	0.4		0.6058	-9.4320×10^{-5}	-4.3214×10^{-10}
	0.6		0.7938	-1.0797×10^{-4}	-4.3206×10^{-10}
	0.8		0.9616	-1.1884×10^{-4}	-4.3202×10^{-10}
A-2633-5	0.1		0.2180	-5.1460×10^{-5}	-1.8177×10^{-10}
	0.2		0.3461	-6.4836×10^{-5}	-1.8180×10^{-10}
	0.4		0.5494	-8.1688×10^{-5}	-1.8181×10^{-10}
	0.6		0.7199	-9.3508×10^{-5}	-1.8191×10^{-10}
	0.8		0.8721	-1.0292×10^{-4}	-1.8178×10^{-10}
A-2639-5	0.1		0.2021	-5.3051×10^{-5}	1.3803×10^{-9}
	0.2		0.3207	-6.6840×10^{-5}	1.3803×10^{-9}
	0.4		0.5091	-8.4213×10^{-5}	1.3803×10^{-9}
	0.6		0.6672	-9.6400×10^{-5}	1.3803×10^{-9}
	0.8		0.8082	-1.0610×10^{-4}	1.3803×10^{-9}

*See the illustration at the front of this Appendix for an explanation of the change-over point.

Impeller Nomenclature	Impeller Brake Horsepower	Air Flow (CFM) Change-over Point @ 62 RPM*	Polynomial Coefficients: $P = A_1 + A_2Q + A_3Q^2$		
			A_1	A_2	A_3
N-2616-4	0.1		0.3358	-9.0498×10^{-5}	-7.3036×10^{-9}
	0.2		0.5331	-1.1402×10^{-4}	-7.3038×10^{-9}
	0.4		0.8462	-1.4366×10^{-4}	-7.3036×10^{-9}
	0.6		1.1088	-1.6444×10^{-4}	-7.3038×10^{-9}
	0.8	4749	1.3432	-1.8100×10^{-4}	-7.3036×10^{-9}
N-2624-4	0.1		0.2666	-6.1228×10^{-5}	-2.2169×10^{-9}
	0.2		0.4232	-7.7142×10^{-5}	-2.2169×10^{-9}
	0.4		0.6718	-9.7193×10^{-5}	-2.2169×10^{-9}
	0.6		0.8803	-1.1126×10^{-4}	-2.2170×10^{-9}
	0.8		1.0664	-1.2246×10^{-4}	-2.2170×10^{-9}
N-2632-4	0.1		0.2148	-3.4820×10^{-5}	-4.3417×10^{-9}
	0.2		0.3410	-4.3871×10^{-5}	-4.3417×10^{-9}
	0.4		0.5413	-5.5274×10^{-5}	-4.3417×10^{-9}
	0.6		0.7093	-6.3272×10^{-5}	-4.3418×10^{-9}
	0.8		0.8593	-6.9640×10^{-5}	-4.3417×10^{-9}
N-2640-4	0.1		0.1859	-4.1898×10^{-5}	-1.1843×10^{-9}
	0.2		0.2951	-5.2788×10^{-5}	-1.1844×10^{-9}
	0.4		0.4685	-6.6509×10^{-5}	-1.1844×10^{-9}
	0.6		0.6139	-7.6134×10^{-5}	-1.1844×10^{-9}
	0.8		0.7437	-8.3800×10^{-5}	-1.1844×10^{-9}
A-2829-5	0.1		0.1947	-3.0812×10^{-5}	-3.7176×10^{-9}
	0.2		0.3091	-3.8821×10^{-5}	-3.7175×10^{-9}

*See the illustration at the front of this Appendix for an explanation of the change-over point.

Impeller Nomenclature	Impeller Brake Horsepower	Air Flow (CFM) Change-over Point @ 62 RPM*	Polynomial Coefficients: $P = A_1 + A_2Q + A_3Q^2$		
			A_1	A_2	A_3
A-2829-5	0.4		0.4907	-4.8911×10^{-5}	-3.7175×10^{-9}
	0.6		0.6430	-5.5989×10^{-5}	-3.7176×10^{-9}
	0.8		0.7789	-6.1624×10^{-5}	-3.7176×10^{-9}
A-2833-5	0.1		0.1871	-3.4628×10^{-5}	-1.5216×10^{-9}
	0.2		0.2970	-4.3628×10^{-5}	-1.5216×10^{-9}
	0.4		0.4714	-5.4968×10^{-5}	-1.5216×10^{-9}
	0.6		0.6177	-6.2923×10^{-5}	-1.5216×10^{-9}
	0.8		0.7483	-6.9256×10^{-5}	-1.5215×10^{-9}
A-2839-5	0.1		0.1664	-3.4201×10^{-5}	-6.2235×10^{-10}
	0.2		0.2642	-4.3091×10^{-5}	-6.2236×10^{-10}
	0.4		0.4193	-5.4291×10^{-5}	-6.2234×10^{-10}
	0.6		0.5495	-6.2148×10^{-5}	-6.2232×10^{-10}
	0.8		0.6657	-6.8402×10^{-5}	-6.2232×10^{-10}
A-3025-5	0.1		0.2157	-4.4190×10^{-5}	-2.4887×10^{-9}
	0.2		0.3424	-5.5675×10^{-5}	-2.4887×10^{-9}
	0.4		0.5435	-7.0147×10^{-5}	-2.4887×10^{-9}
	0.6		0.7122	-8.0298×10^{-5}	-2.4888×10^{-9}
	0.8		0.8627	-8.8379×10^{-5}	-2.4887×10^{-9}
A-3029-5	0.1		0.1951	-4.1030×10^{-5}	-5.1789×10^{-10}
	0.2		0.3098	-5.1694×10^{-5}	-5.1788×10^{-10}
	0.4		0.4917	-6.5130×10^{-5}	-5.1791×10^{-10}
	0.6		0.6443	-7.4555×10^{-5}	-5.1749×10^{-10}

*See the illustration at the front of this Appendix for an explanation of the change-over point.

Impeller Nomenclature	Impeller Brake Horsepower	Air Flow (CFM) Change-over Point @ 62 RPM*	Polynomial Coefficients: $P = A_1 + A_2Q + A_3Q^2$		
			A_1	A_2	A_3
A-3029-5	0.8		0.7805	-8.2059×10^{-5}	-5.1794×10^{-10}
A-3033-5	0.1		0.1796	-3.6662×10^{-5}	-1.6977×10^{-10}
	0.2		0.2851	-4.6191×10^{-5}	-1.6979×10^{-10}
	0.4		0.4526	-5.8197×10^{-5}	-1.6976×10^{-10}
	0.6		0.5931	-6.6618×10^{-5}	-1.6983×10^{-10}
	0.8		0.7185	-7.3323×10^{-5}	-1.6978×10^{-10}
A-3039-5	0.1		0.1654	-3.6616×10^{-5}	8.8667×10^{-10}
	0.2		0.2625	-4.6133×10^{-5}	8.8672×10^{-10}
	0.4		0.4167	-5.8124×10^{-5}	8.8667×10^{-10}
	0.6		0.5460	-6.6535×10^{-5}	8.8666×10^{-10}
	0.8		0.6614	-7.3231×10^{-5}	8.8664×10^{-10}
B-3030-5	0.1		0.2115	-4.7426×10^{-5}	-2.3873×10^{-10}
	0.2		0.3357	-5.9753×10^{-5}	-2.3874×10^{-10}
	0.4		0.5329	-7.5284×10^{-5}	-2.3873×10^{-10}
	0.6		0.6983	-8.6179×10^{-5}	-2.3867×10^{-10}
	0.8		0.8460	-9.4852×10^{-5}	-2.3872×10^{-10}
B-3035-5	0.1		0.1860	-4.0506×10^{-5}	-3.4956×10^{-10}
	0.2		0.2953	-5.1034×10^{-5}	-3.4951×10^{-10}
	0.4		0.4688	-6.4299×10^{-5}	-3.4952×10^{-10}
	0.6		0.6143	-7.3604×10^{-5}	-3.4953×10^{-10}
	0.8		0.7442	-8.1011×10^{-5}	-3.4957×10^{-10}

*See the illustration at the front of this Appendix for an explanation of the change-over point.

Impeller Nomenclature	Impeller Brake Horsepower	Air Flow (CFM) Change-over Point @ 62 RPM*	Polynomial Coefficients: $P = A_1 + A_2Q + A_3Q^2$		
			A_1	A_2	A_3
B-3040-5	0.1		0.1724	-3.8410×10^{-5}	9.4351×10^{-11}
	0.2		0.2736	-4.8394×10^{-5}	9.4353×10^{-11}
	0.4		0.4343	-6.0973×10^{-5}	9.4391×10^{-11}
	0.6		0.5691	-6.9796×10^{-5}	9.4369×10^{-11}
	0.8		0.6894	-7.6821×10^{-5}	9.4371×10^{-11}
B-3030-4	0.1		0.1877	-3.0396×10^{-5}	-2.6876×10^{-9}
	0.2		0.2980	-3.8296×10^{-5}	-2.6876×10^{-9}
	0.4		0.4730	-4.8241×10^{-5}	-2.6876×10^{-9}
	0.6		0.6200	-5.5232×10^{-5}	-2.6877×10^{-9}
	0.8		0.7508	-6.0792×10^{-5}	-2.6876×10^{-9}
B-3035-4	0.1		0.1750	-3.6227×10^{-5}	2.3802×10^{-10}
	0.2		0.2778	-4.5643×10^{-5}	2.3802×10^{-10}
	0.4		0.4410	-5.7507×10^{-5}	2.3804×10^{-10}
	0.6		0.5779	-6.5828×10^{-5}	2.3799×10^{-10}
	0.8		0.7001	-7.2454×10^{-5}	2.3801×10^{-10}
B-3040-4	0.1		0.1631	-3.4593×10^{-5}	-1.4857×10^{-10}
	0.2		0.2590	-4.3585×10^{-5}	-1.4852×10^{-10}
	0.4		0.4111	-5.4913×10^{-5}	-1.4856×10^{-10}
	0.6		0.5387	-6.2860×10^{-5}	-1.4857×10^{-10}
	0.8		0.6526	-6.9186×10^{-5}	-1.4856×10^{-10}

*See the illustration at the front of this Appendix for an explanation of the change-over point.

Impeller Nomenclature	Impeller Brake Horsepower	Air Flow (CFM) Change-over Point @ 62 RPM*	Polynomial Coefficients: $P = A_1 + A_2Q + A_3Q^2$		
			A_1	A_2	A_3
M-3040-4	0.1		0.1524	-1.6403×10^{-5}	-2.9724×10^{-9}
	0.2		0.2419	-2.0666×10^{-5}	-2.9724×10^{-9}
	0.4		0.3841	-2.6038×10^{-5}	-2.9724×10^{-9}
	0.6		0.5033	-2.9806×10^{-5}	-2.9724×10^{-9}
	0.8		0.6096	-3.2806×10^{-5}	-2.9724×10^{-9}
R-3020-4	0.1		0.2709	-7.1919×10^{-5}	1.6612×10^{-9}
	0.2		0.4300	-9.0612×10^{-5}	1.6612×10^{-9}
	0.4		0.6826	-1.1416×10^{-4}	1.6612×10^{-9}
	0.6		0.8945	-1.3069×10^{-4}	1.6613×10^{-9}
	0.8		1.0836	-1.4384×10^{-4}	1.6612×10^{-9}
R-3027-4	0.1		0.2342	-6.0540×10^{-5}	3.0079×10^{-9}
	0.2		0.3718	-7.6275×10^{-5}	3.0078×10^{-9}
	0.4		0.5902	-9.6101×10^{-5}	3.0079×10^{-9}
	0.6		0.7734	-1.1001×10^{-4}	3.0079×10^{-9}
	0.8		0.9369	-1.2108×10^{-4}	3.0079×10^{-9}
R-3040-4	0.1		0.1654	-4.0341×10^{-5}	1.1086×10^{-9}
	0.2		0.2625	-5.0827×10^{-5}	1.1086×10^{-9}
	0.4		0.4168	-6.4036×10^{-5}	1.1086×10^{-9}
	0.6		0.5461	-7.3305×10^{-5}	1.1086×10^{-9}
	0.8		0.6616	-8.0683×10^{-5}	1.1086×10^{-9}

***See the illustration at the front of this Appendix for an explanation of the** change-over point.

Impeller Nomenclature	Impeller Brake Horsepower	Air Flow (CFM) Change-over Point @ 62 RPM*	Polynomial Coefficients: $P = A_1 + A_2Q + A_3Q^2$		
			A_1	A_2	A_3
B-3630-4	0.1		0.1541	-2.8736×10^{-5}	6.8244×10^{-10}
	0.2		0.2446	-3.6205×10^{-5}	6.8241×10^{-10}
	0.4		0.3882	-4.5616×10^{-5}	6.8248×10^{-10}
	0.6		0.5087	-5.2216×10^{-5}	6.8241×10^{-10}
	0.8		0.6163	-5.7472×10^{-5}	6.8240×10^{-10}
B-3635-4	0.1		0.1405	-2.9102×10^{-5}	1.1589×10^{-9}
	0.2		0.2230	-3.6666×10^{-5}	1.1589×10^{-9}
	0.4		0.3540	-4.6196×10^{-5}	1.1589×10^{-9}
	0.6		0.4638	-5.2881×10^{-5}	1.1589×10^{-9}
	0.8		0.5619	-5.8203×10^{-5}	1.1589×10^{-9}
B-3640-4	0.1		0.1271	-1.8708×10^{-5}	-3.2961×10^{-10}
	0.2		0.2018	-2.3571×10^{-5}	-3.2961×10^{-10}
	0.4		0.3203	-2.9697×10^{-5}	-3.2961×10^{-10}
	0.6		0.4198	-3.3994×10^{-5}	-3.2963×10^{-10}
	0.8		0.5085	-3.7416×10^{-5}	-3.2960×10^{-10}
B-3630-5	0.1		0.1671	-3.5349×10^{-5}	1.3542×10^{-9}
	0.2		0.2653	-4.4537×10^{-5}	1.3542×10^{-9}
	0.4		0.4212	-5.6113×10^{-5}	1.3542×10^{-9}
	0.6		0.5519	-6.4234×10^{-5}	1.3542×10^{-9}
	0.8		0.6685	-7.0698×10^{-5}	1.3542×10^{-9}

*See the illustration at the front of this Appendix for an explanation of the change-over point.

Impeller Nomenclature	Impeller Brake Horsepower	Air Flow (CFM) Change-over Point @ 62 RPM*	Polynomial Coefficients: $P = A_1 + A_2Q + A_3Q^2$		
			A_1	A_2	A_3
B-3635-5	0.1		0.1405	-2.8776×10^{-5}	1.1546×10^{-9}
	0.2		0.2231	-3.6255×10^{-5}	1.1546×10^{-9}
	0.4		0.3541	-4.5678×10^{-5}	1.1546×10^{-9}
	0.6		0.4640	-5.2288×10^{-5}	1.1546×10^{-9}
	0.8		0.5621	-5.7551×10^{-5}	1.1545×10^{-9}
B-3640-5	0.1		0.1208	-1.7613×10^{-5}	-2.2921×10^{-10}
	0.2		0.1918	-2.2191×10^{-5}	-2.2923×10^{-10}
	0.4		0.3045	-2.7959×10^{-5}	-2.2921×10^{-10}
	0.6		0.3990	-3.2005×10^{-5}	-2.2922×10^{-10}
	0.8		0.4833	-3.5226×10^{-5}	-2.2920×10^{-10}
M-3640-5	0.1		0.1186	-2.2003×10^{-5}	7.1139×10^{-10}
	0.2		0.1882	-2.7722×10^{-5}	7.1139×10^{-10}
	0.4		0.2988	-3.4927×10^{-5}	7.1138×10^{-10}
	0.6		0.3915	-3.9982×10^{-5}	7.1142×10^{-10}
	0.8		0.4743	-4.4006×10^{-5}	7.1140×10^{-10}
R-3620-4	0.1		0.1505	-2.9172×10^{-5}	5.8145×10^{-11}
	0.2		0.2389	-3.6754×10^{-5}	5.8129×10^{-11}
	0.4		0.3793	-4.6308×10^{-5}	5.8220×10^{-11}
	0.6		0.4970	-5.3010×10^{-5}	5.8312×10^{-11}
	0.8		0.6021	-5.8344×10^{-5}	5.8212×10^{-11}

***See the illustration at the front of this Appendix for an explanation of the change-over point.**

Impeller Nomenclature	Impeller Brake Horsepower	Air Flow (CFM) Change-over Point @ 62 RPM*	Polynomial Coefficients: $P = A_1 + A_2Q + A_3Q^2$		
			A_1	A_2	A_3
R-3627-4	0.1		0.1648	-2.7362×10^{-5}	1.6368×10^{-10}
	0.2		0.2615	-3.4473×10^{-5}	1.6367×10^{-10}
	0.4		0.4152	-4.3434×10^{-5}	1.6365×10^{-10}
	0.6		0.5440	-4.9720×10^{-5}	1.6368×10^{-10}
	0.8		0.6590	-5.4723×10^{-5}	1.6368×10^{-10}
R-3640-4	0.1		0.1289	-2.4844×10^{-5}	8.0226×10^{-10}
	0.2		0.2046	-3.1302×10^{-5}	8.0229×10^{-10}
	0.4		0.3248	-3.9438×10^{-5}	8.0227×10^{-10}
	0.6		0.4256	-4.5145×10^{-5}	8.0227×10^{-10}
	0.8		0.5155	-4.9689×10^{-5}	8.0231×10^{-10}
BC 916 704	0.08		2.0585	-3.1163×10^{-3}	1.0781×10^{-6}
BC 916 916	0.08		1.0192	-8.4798×10^{-4}	-1.5113×10^{-9}
BC 1020 800	0.08		1.3871	-1.6117×10^{-3}	3.7949×10^{-7}
BC 1020 1020	0.08		0.7626	-4.4862×10^{-4}	-6.9725×10^{-8}
BC 1220 916	0.08		1.2261	-1.2103×10^{-3}	2.6122×10^{-7}
BC 1220 1220	0.08		1.1548	-1.0739×10^{-3}	2.3524×10^{-7}
185-18-1/3	1/3 nominal		0.5226	-1.9231×10^{-5}	-2.8189×10^{-8}
247-24-1/2	1/2 nominal		0.6489	-2.3770×10^{-5}	-1.0320×10^{-8}
280-27-1	1.0 nominal		0.1027	-2.7759×10^{-5}	-9.2058×10^{-9}
281-27-1 1/2	1 1/2 nominal		1.0744	-1.7461×10^{-5}	-7.5592×10^{-9}
329-32-2	2.0 nominal		0.9492	3.8308×10^{-5}	-6.4552×10^{-9}
368-36-3	3.0 nominal		1.4962	-1.5175×10^{-5}	-2.6365×10^{-9}
375-36-5	5.0 nominal		1.4197	-5.4054×10^{-5}	-4.7291×10^{-9}

*See the illustration at the front of this Appendix for an explanation of the change-over point.

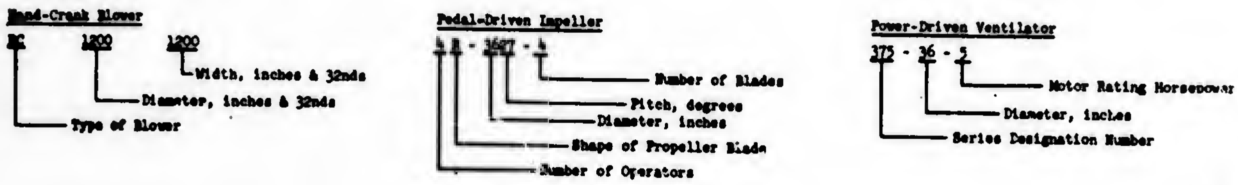
APPENDIX D

IMPELLER PERFORMANCE CURVES

FOR THE 28 SCREENED VENTILATORS

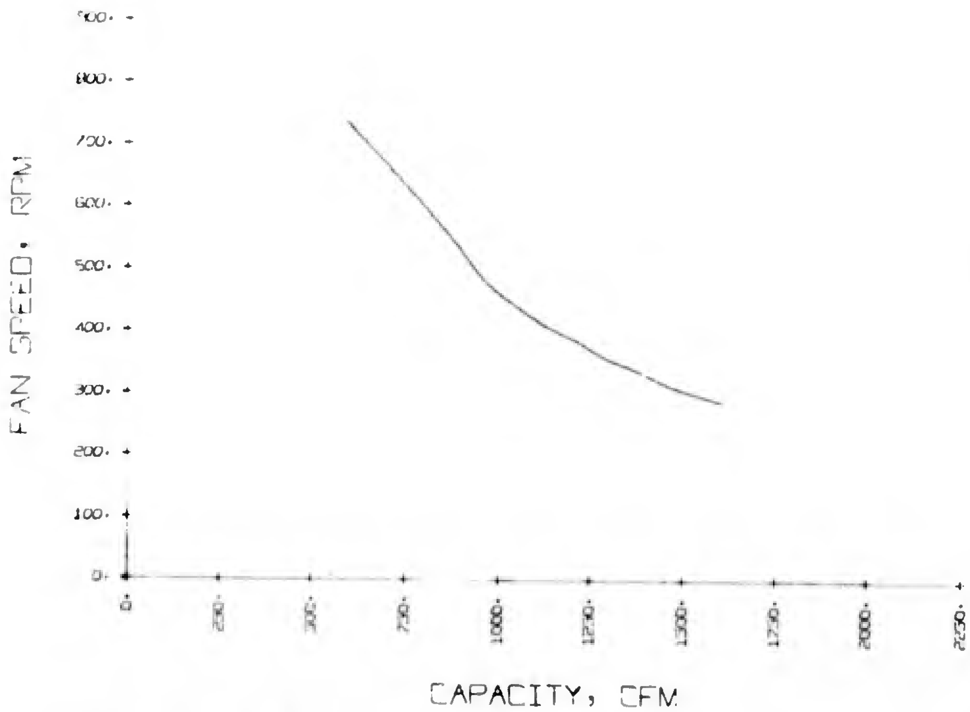
FOREWORD TO APPENDIX D

Impeller Nomenclature:

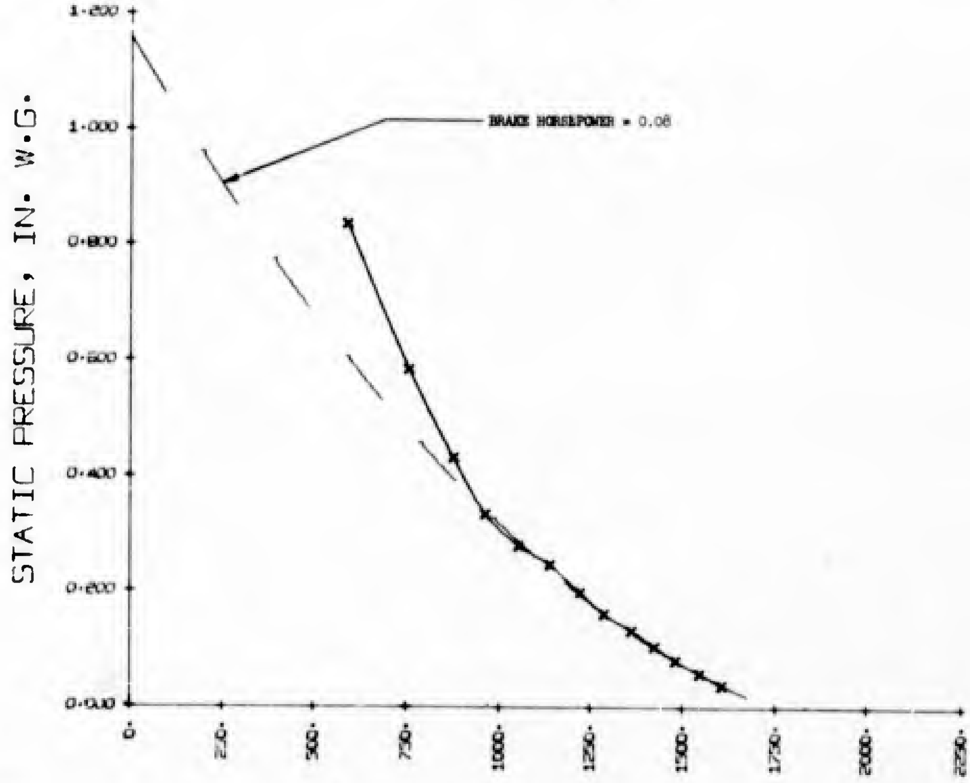


Comments:

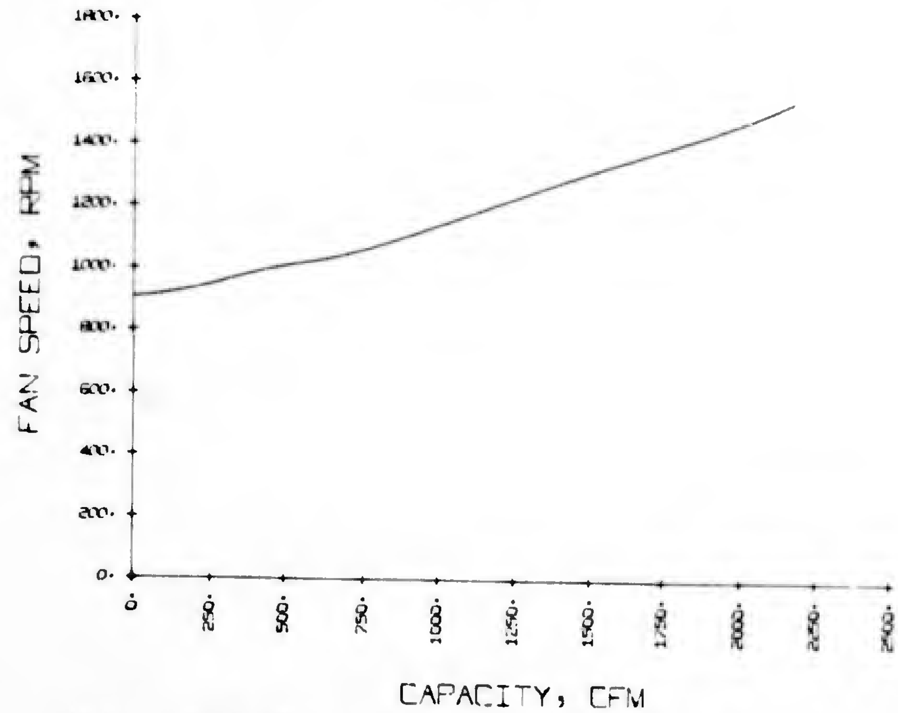
The performance curves for the impellers were developed in the following manner and the results as illustrated in this section were plotted directly by the computer The fan laws were used to convert the manufacturer's constant speed data to the selected constant brake horsepower for an impeller. These calculated constant brake horsepower data points are shown as "X"'s on the following performance curves. Using these data points, and applying the least squares curve fitting technique for a second order polynomial, the air flow-static pressure performance curves were generated. From these curves the variable speed impeller performance curves were calculated and plotted. None of these impellers had a change-over point from the constant horsepower curve to the constant 62 rpm pedal speed curve due to designing the modular units with a sprocket ratio of 20/1, and the unitary units with a ratio of 5/1. Refer to Appendix C for an explanation of the change-over point.



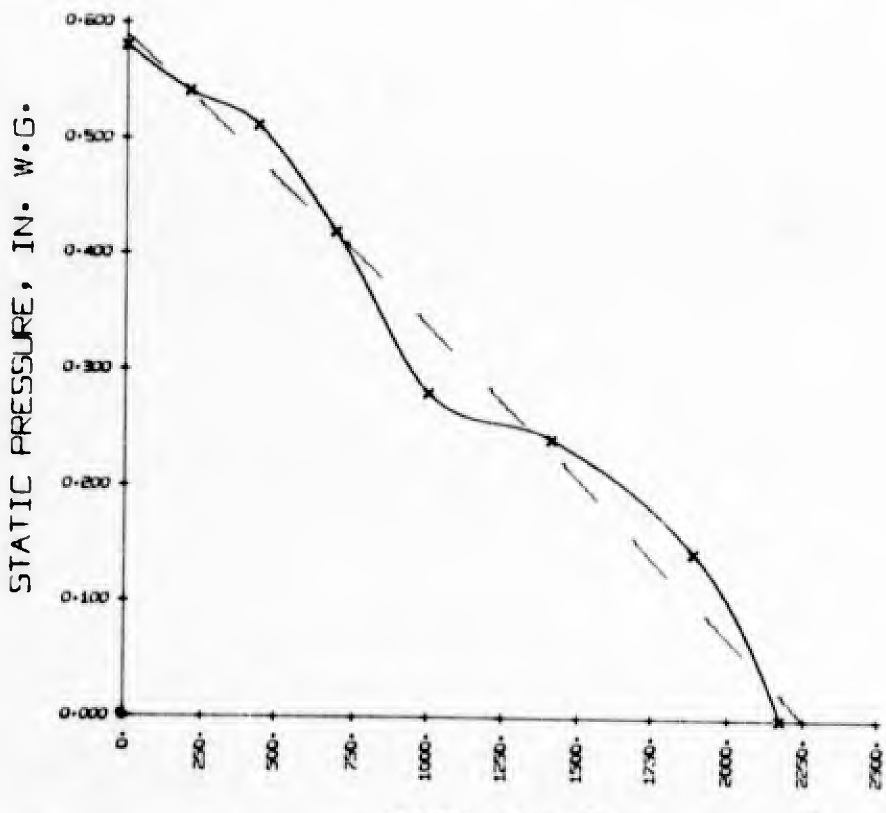
FAN SPEED CURVE FOR BC 1220 1220



FAN PERFORMANCE CURVE FOR BC 1220 1220



FAN SPEED CURVE FOR 1 E-1624-4



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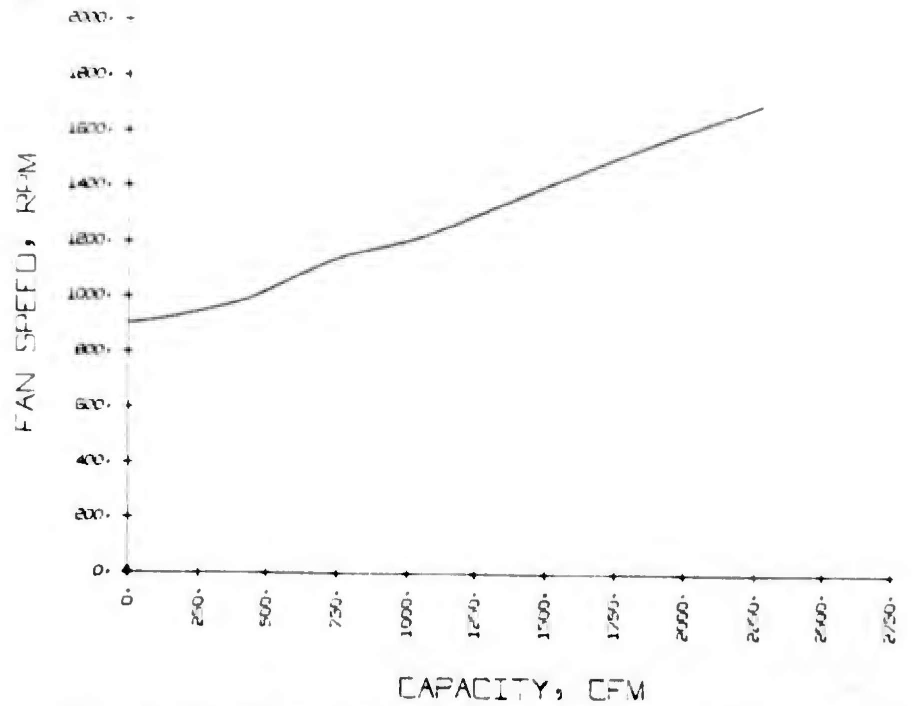
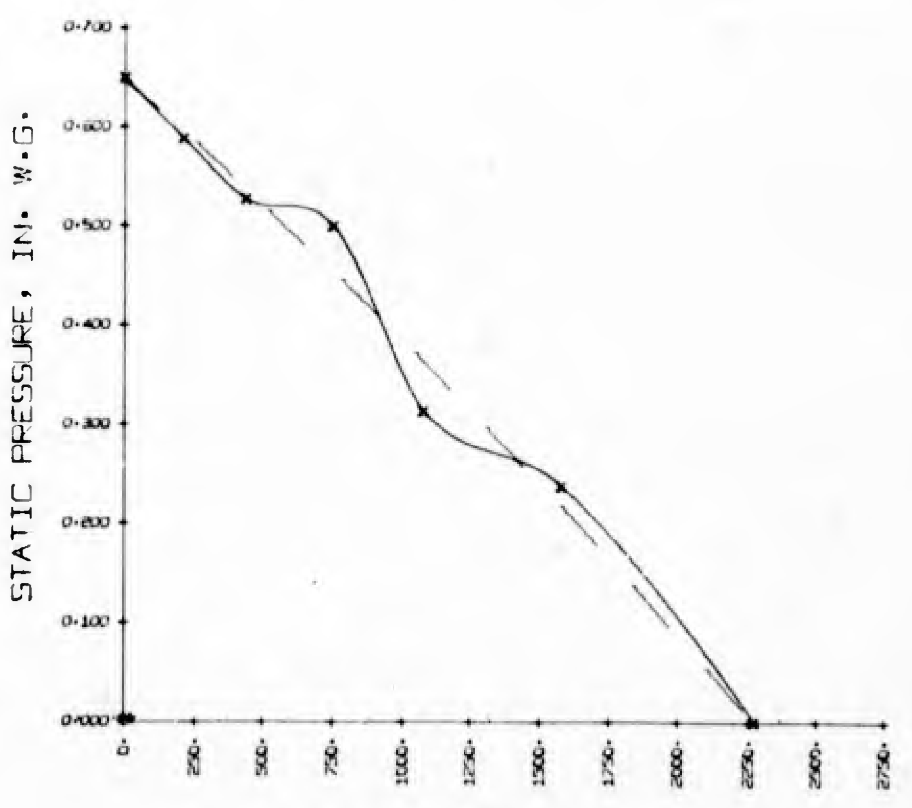
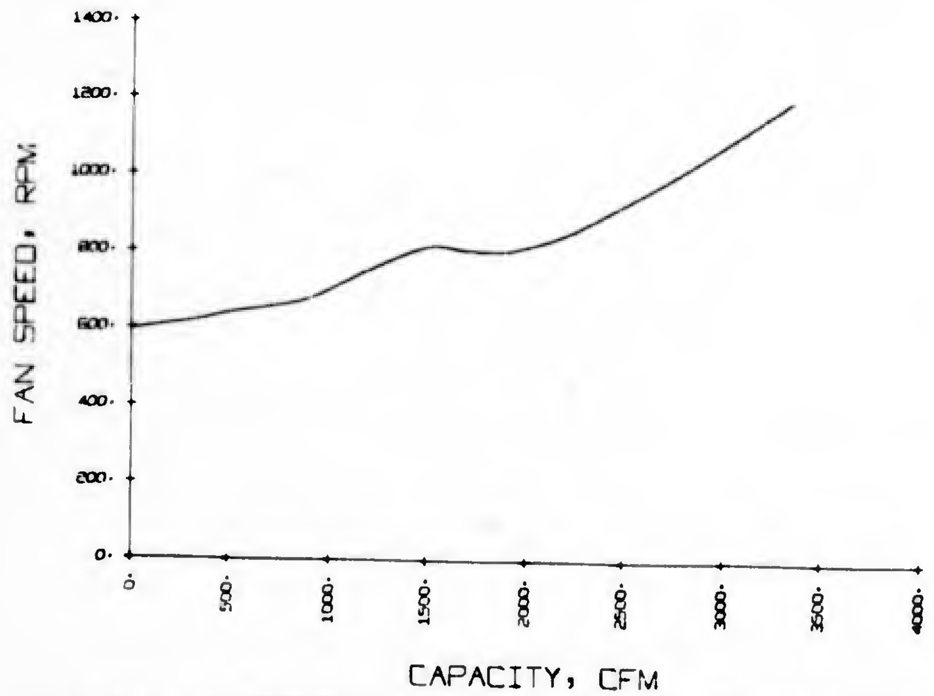


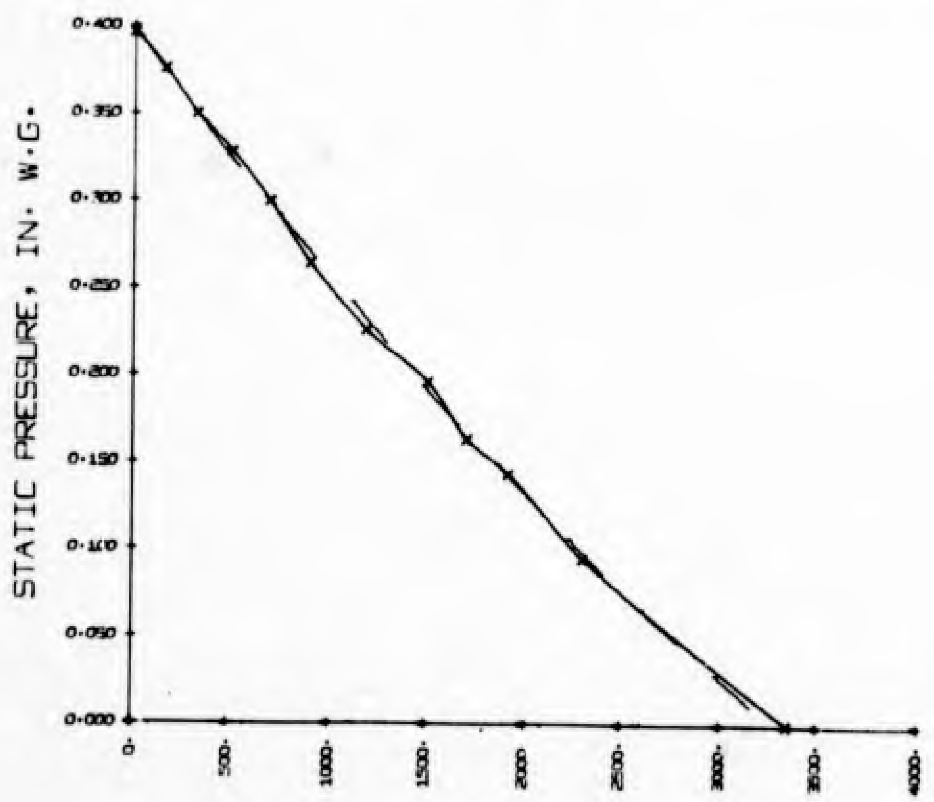
FAN SPEED CURVE FOR 1 P-1816-4



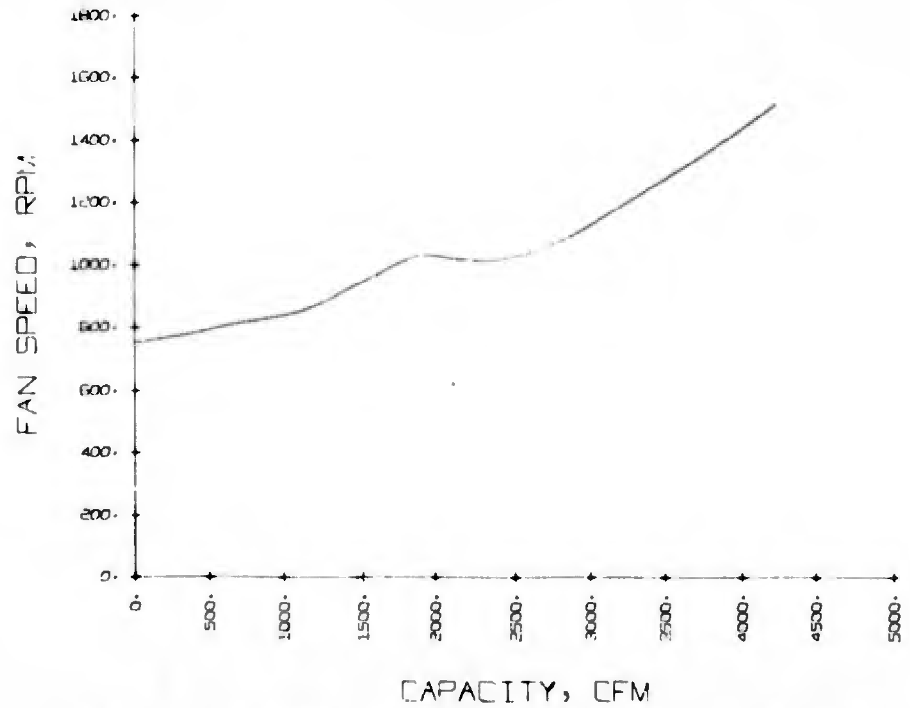
FAN PERFORMANCE CURVE FOR 1 P-1816-4



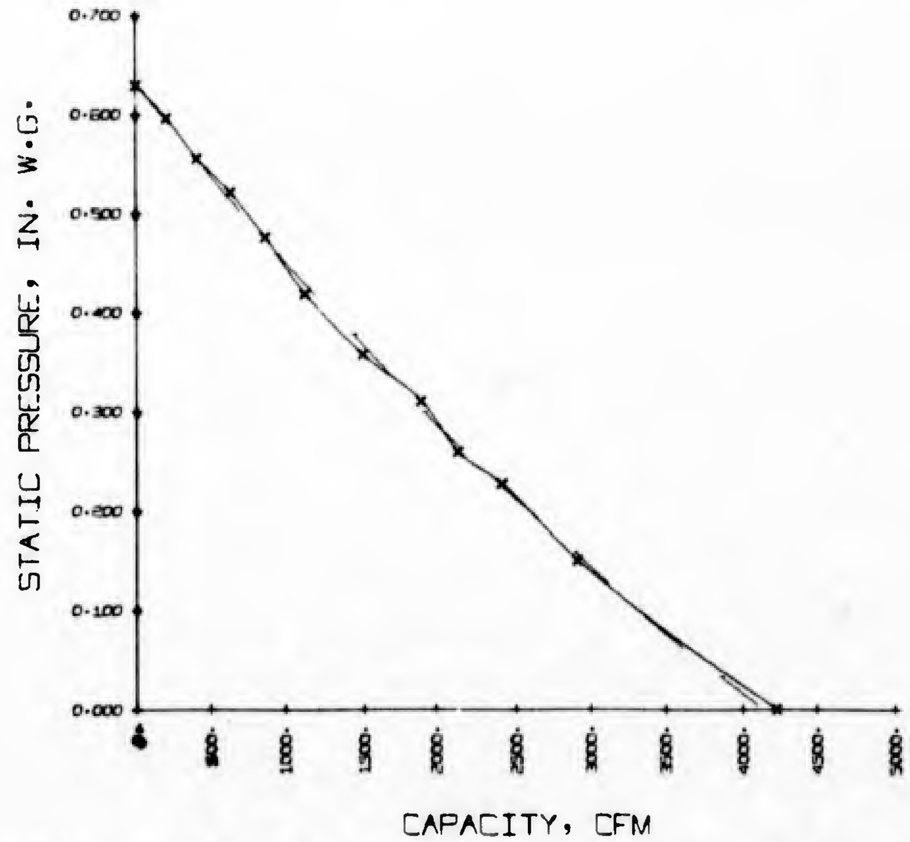
FAN SPEED CURVE FOR 1 E-2024-4



FAN PERFORMANCE CURVE FOR 1 E-2024-4



FAN SPEED CURVE FOR 2 E-2024-4



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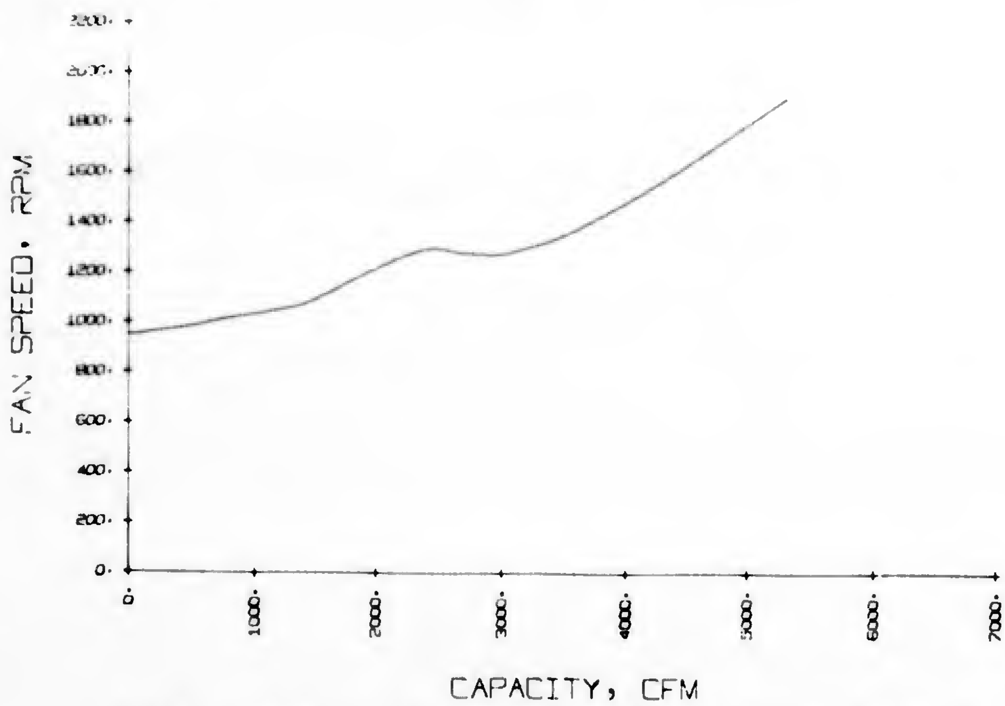
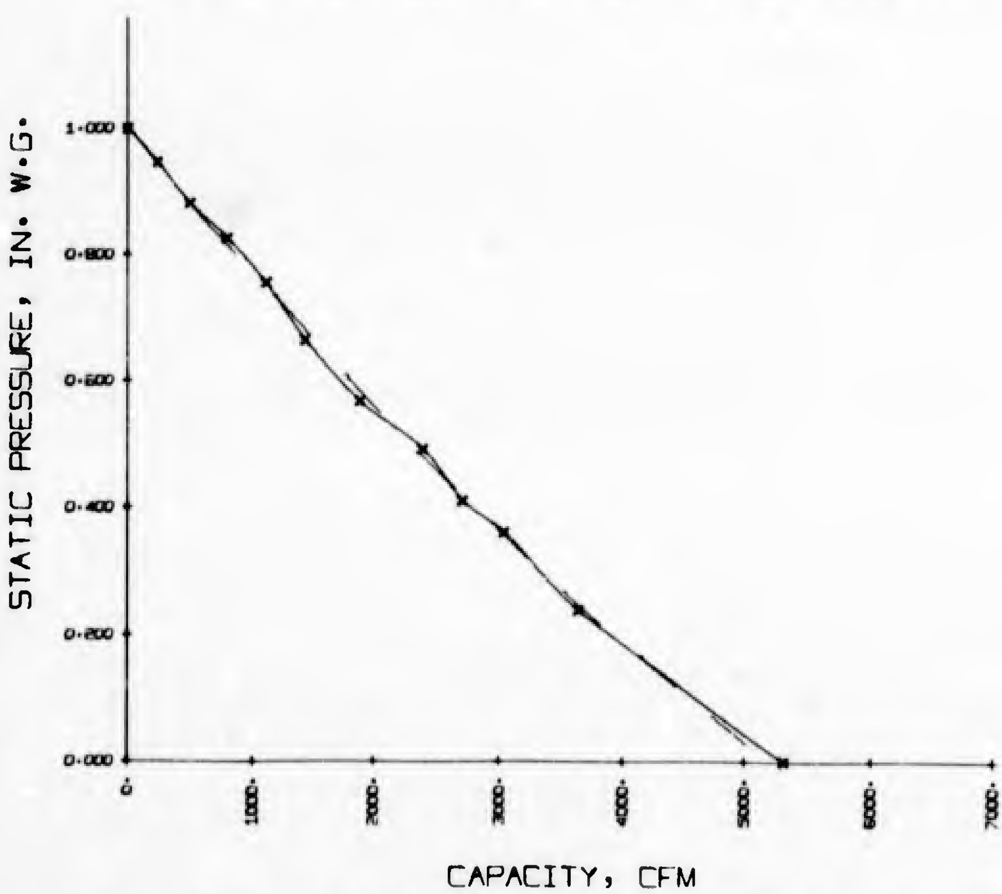
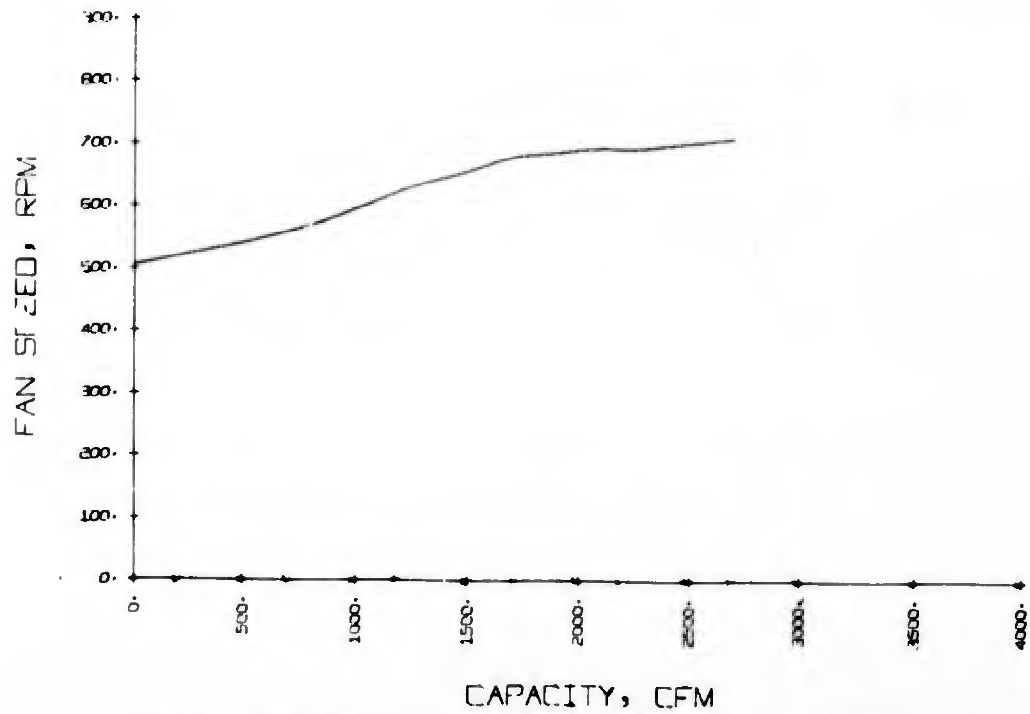


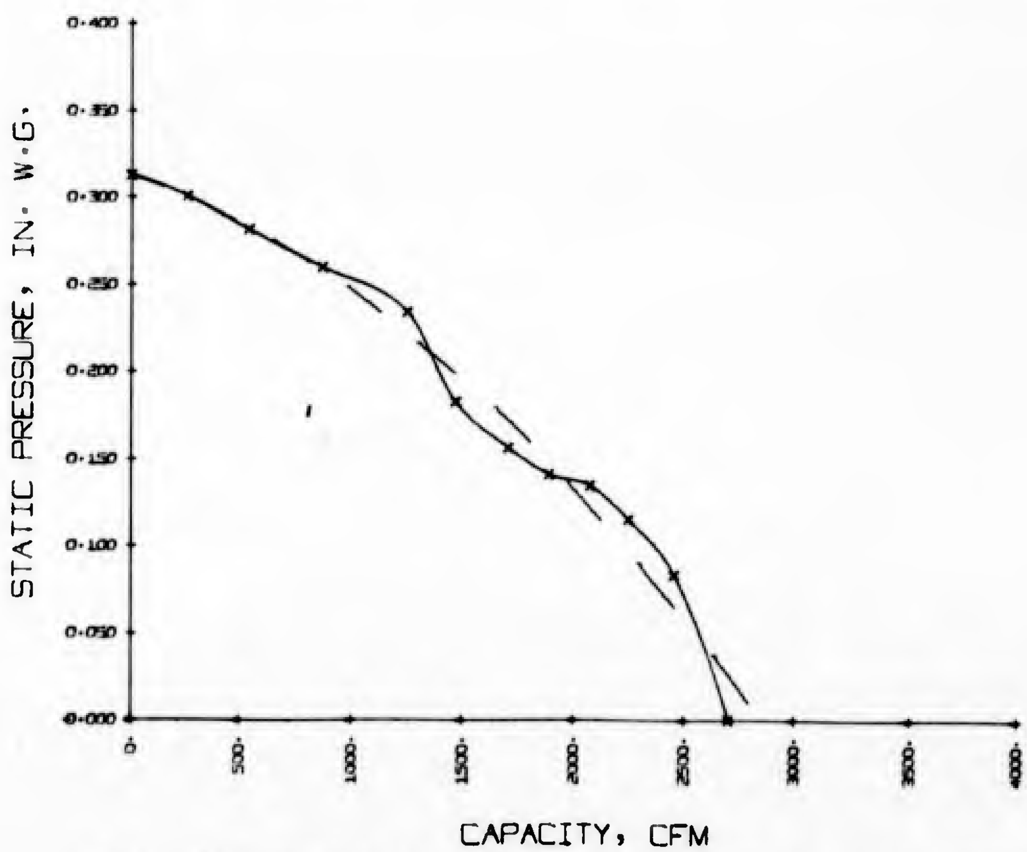
FAN SPEED CURVE FOR 4 E-2024-4



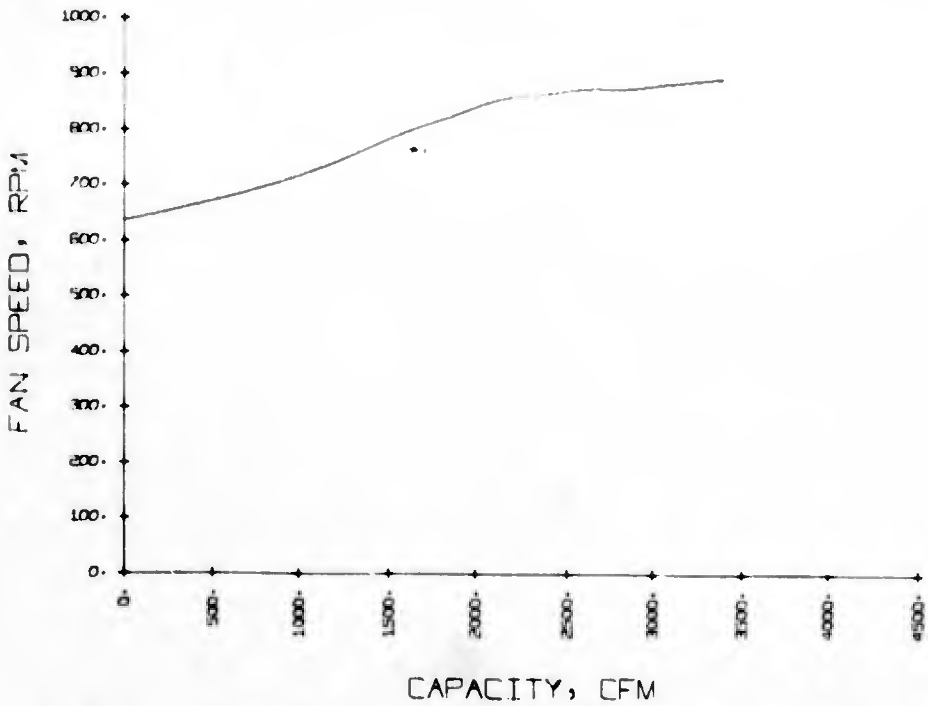
FAN PERFORMANCE CURVE FOR 4 E-2024-4



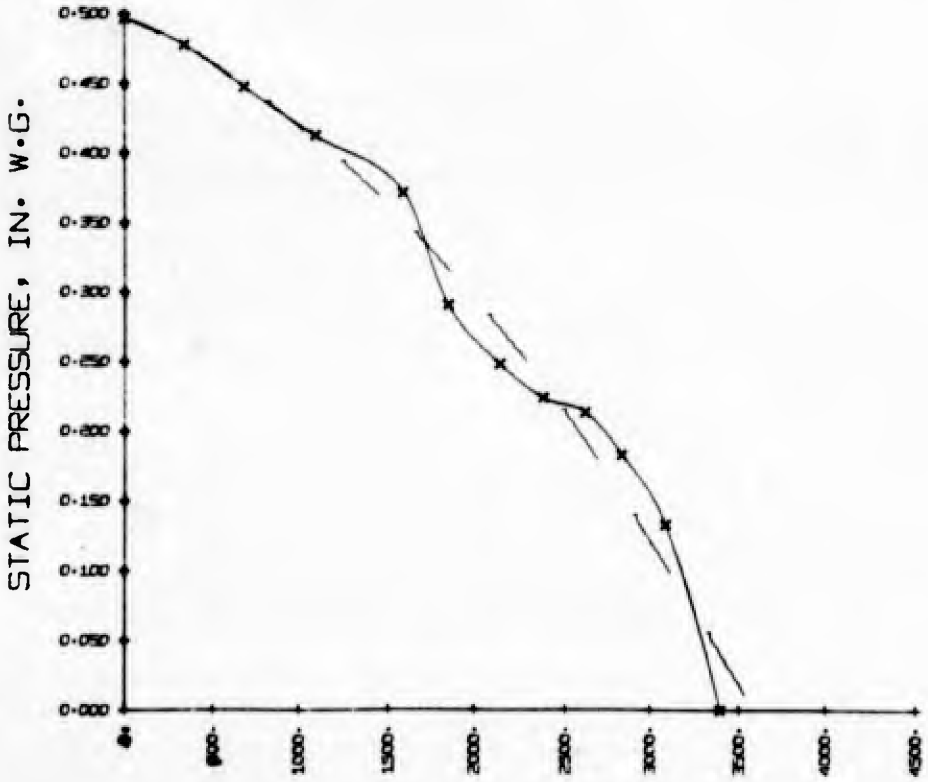
FAN SPEED CURVE FOR 1 N-2224-4



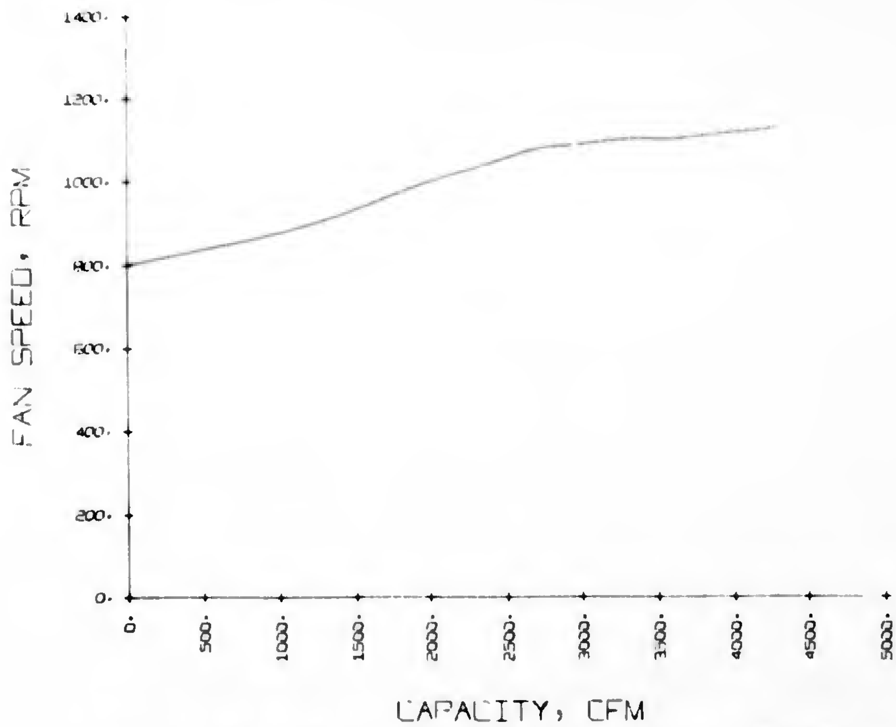
FAN PERFORMANCE CURVE FOR 1 N-2224-4



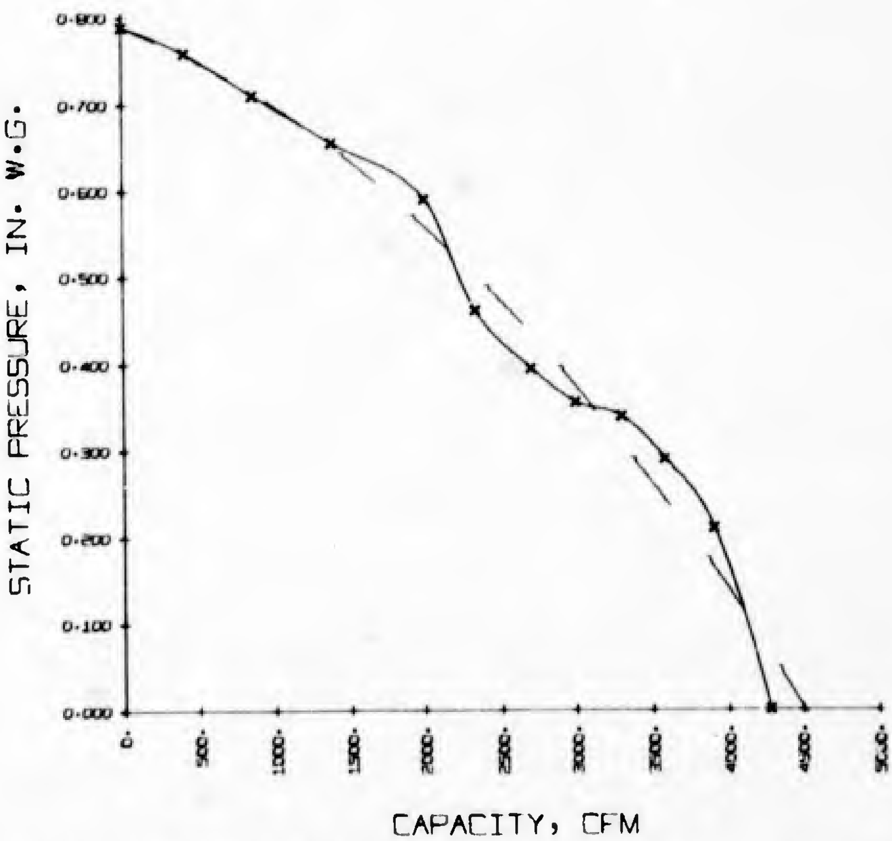
FAN SPEED CURVE FOR 2 N-2224-4



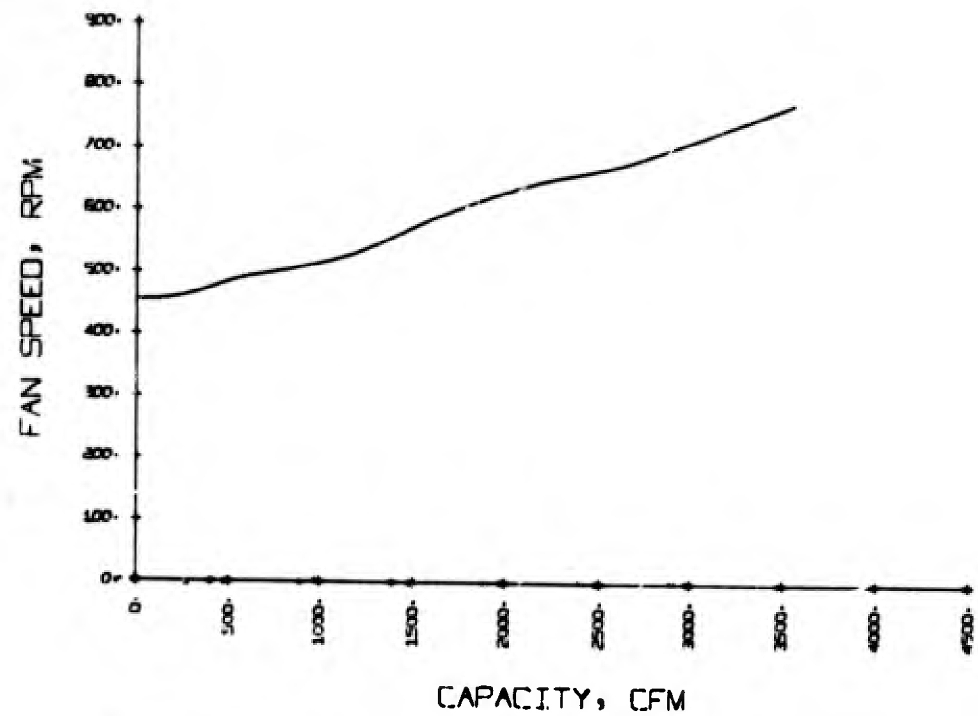
FAN PERFORMANCE CURVE FOR 2 N-2224-4



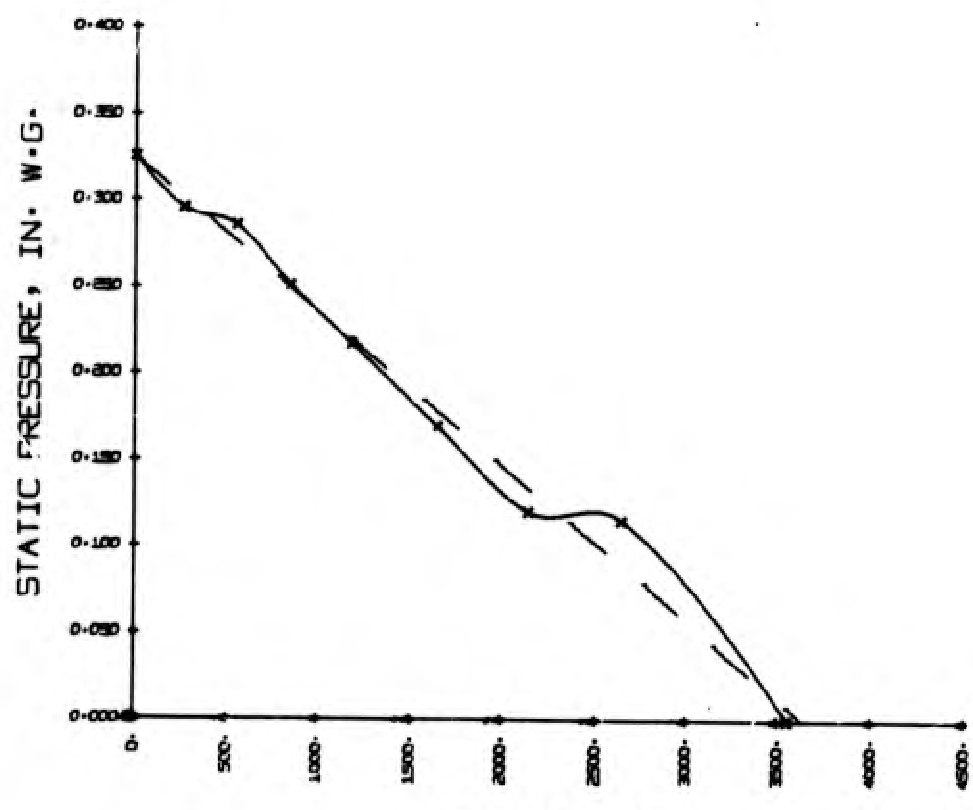
FAN SPEED CURVE FOR 4 N-2224-4



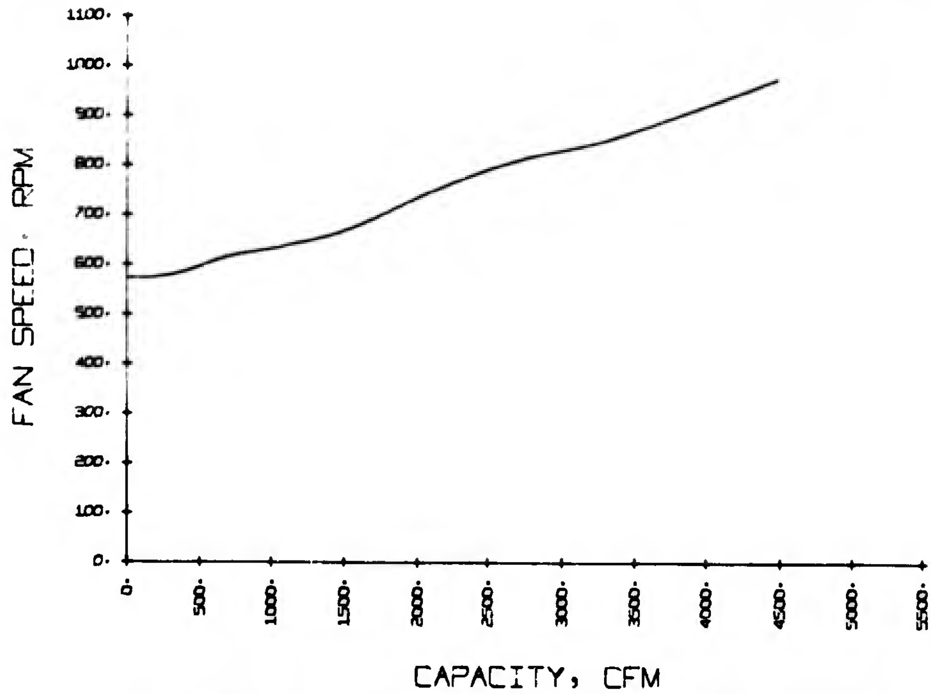
FAN PERFORMANCE CURVE FOR 4 N-2224-4



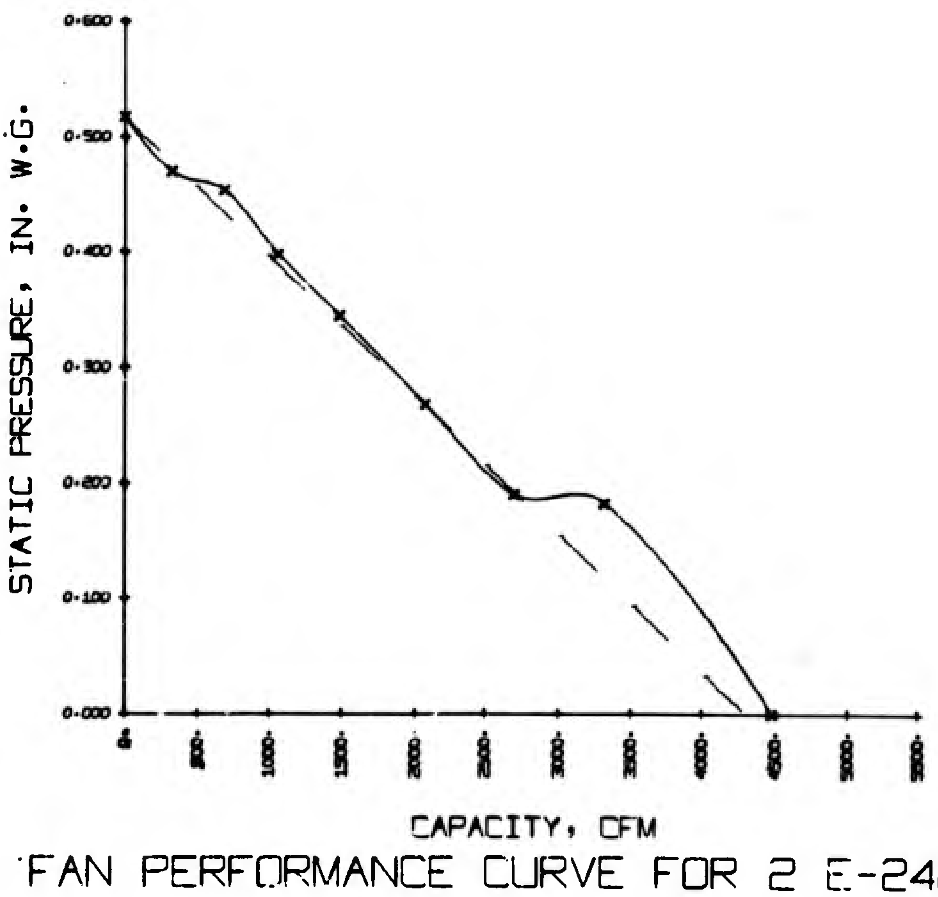
FAN SPEED CURVE FOR 1 E-2424-4



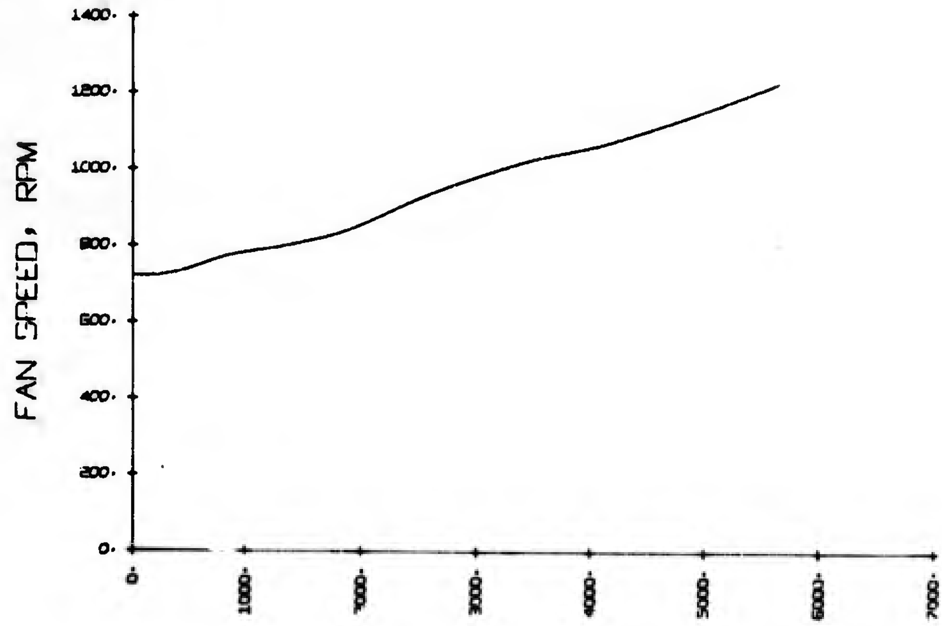
FAN PERFORMANCE CURVE FOR 1 E-2424-4



FAN SPEED CURVE FOR 2 E-2424-4

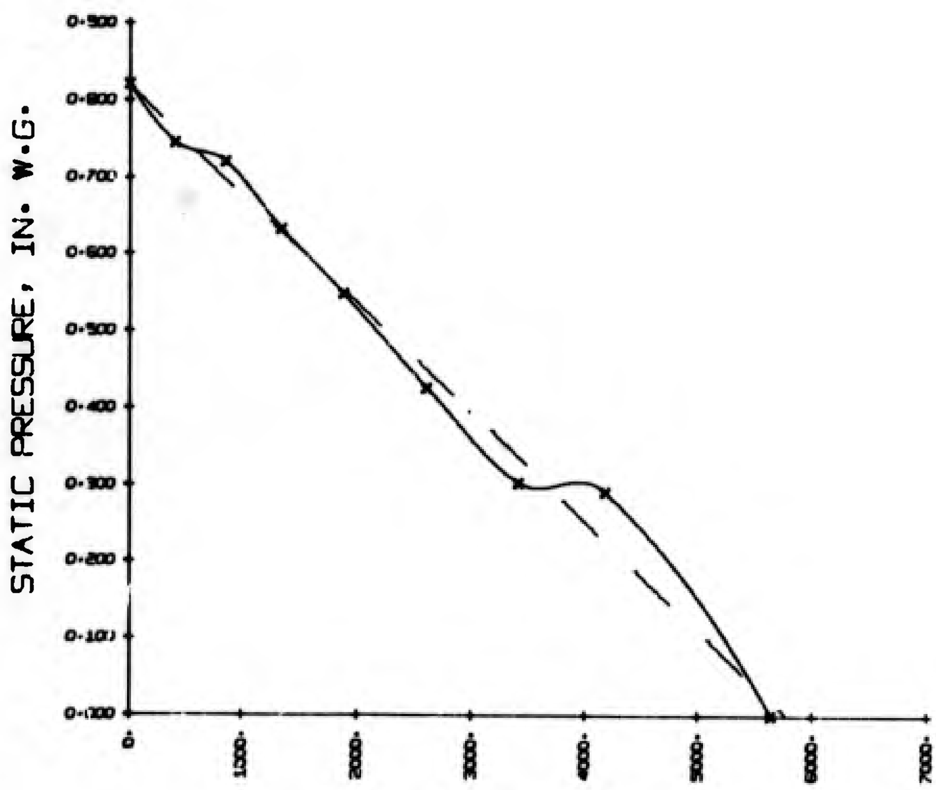


FAN PERFORMANCE CURVE FOR 2 E-2424-4



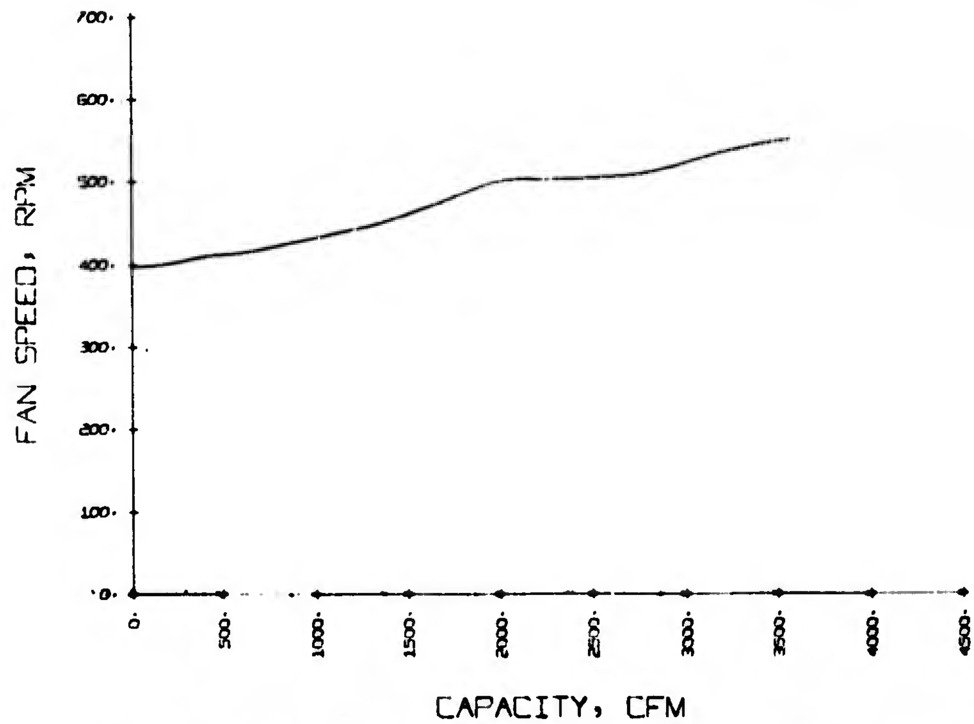
CAPACITY, CFM

FAN SPEED CURVE FOR 4 E-2424-4

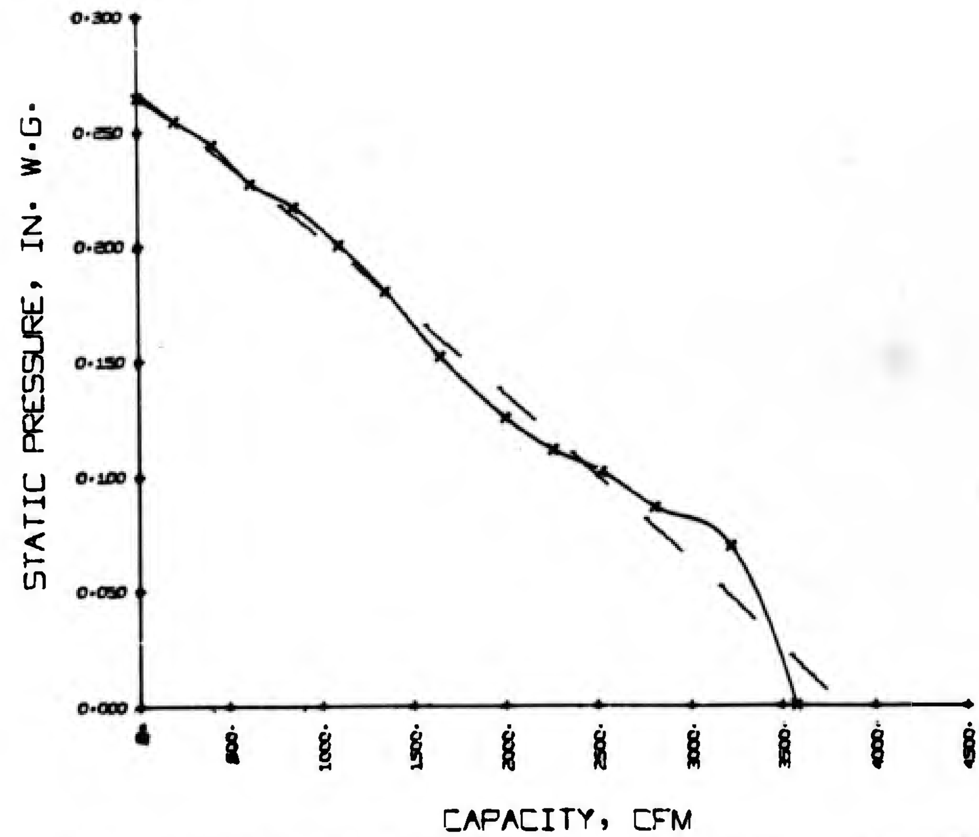


CAPACITY, CFM

FAN PERFORMANCE CURVE FOR 4 E-2424-4



FAN SPEED CURVE FOR 1 N-2624-4



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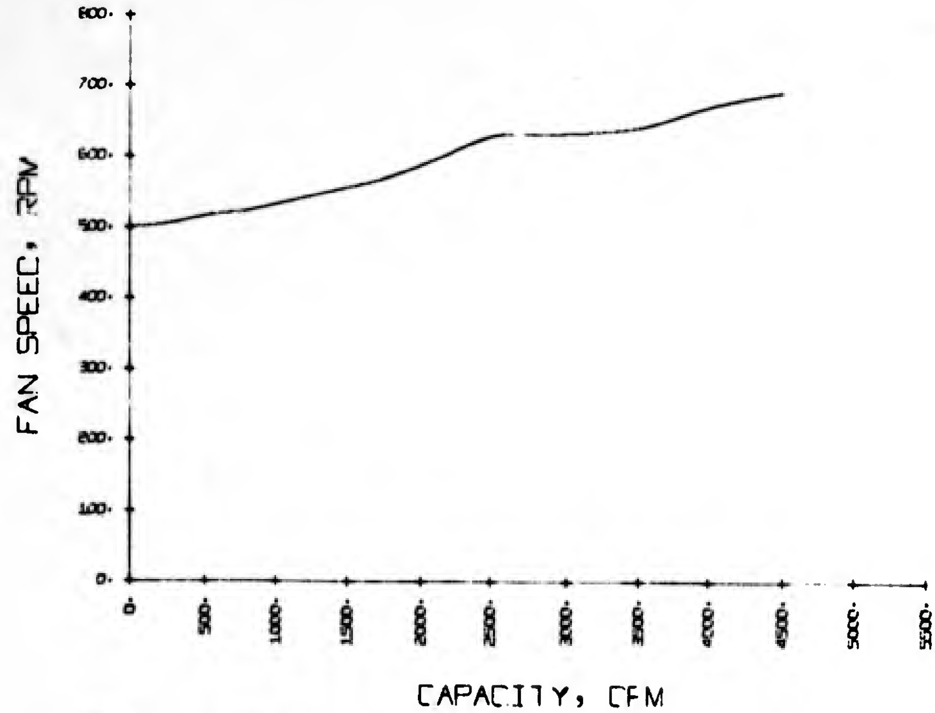

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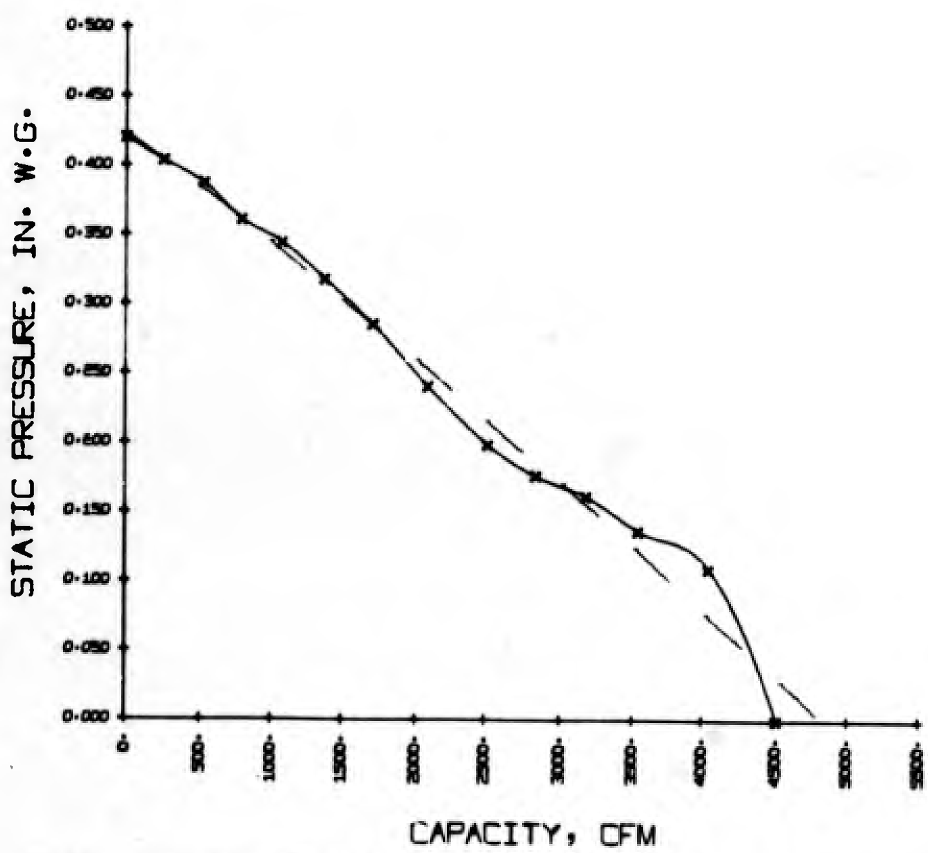

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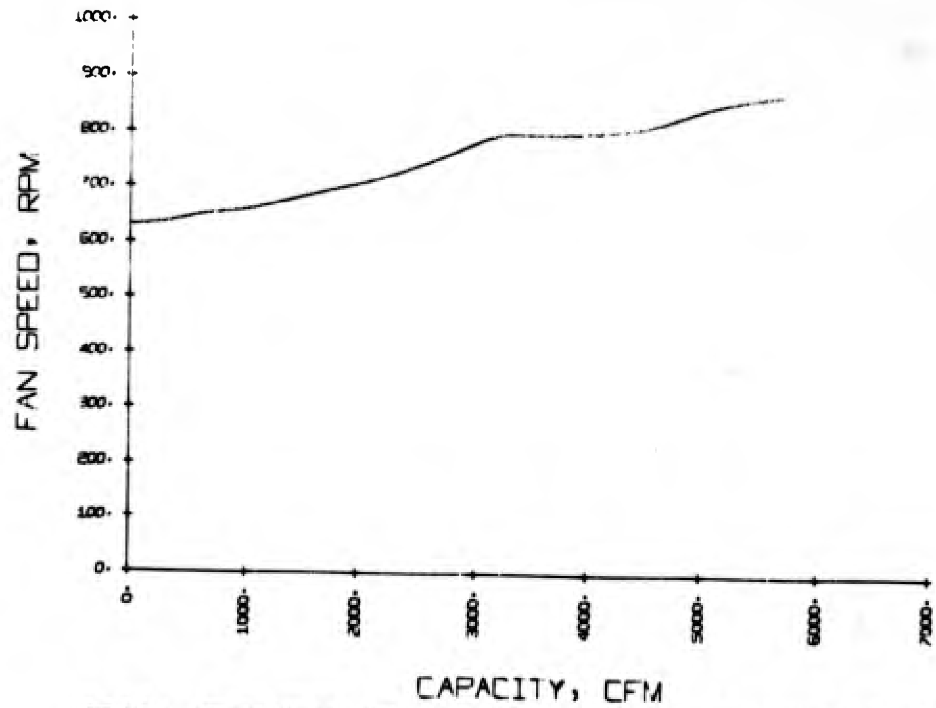

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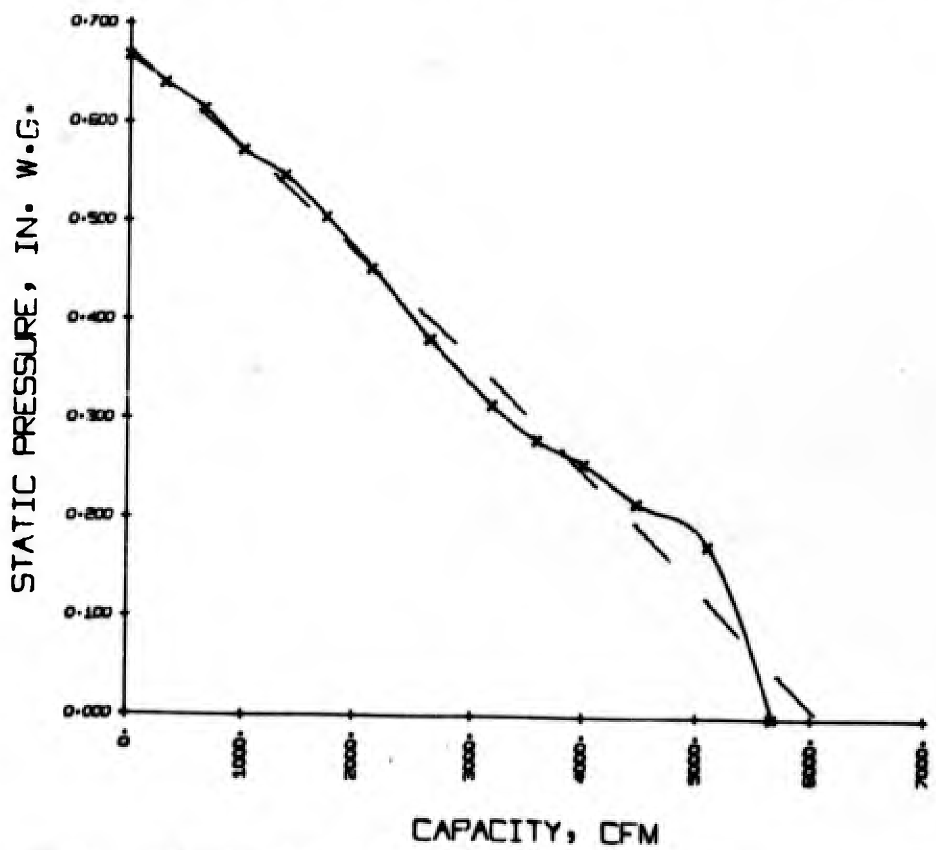

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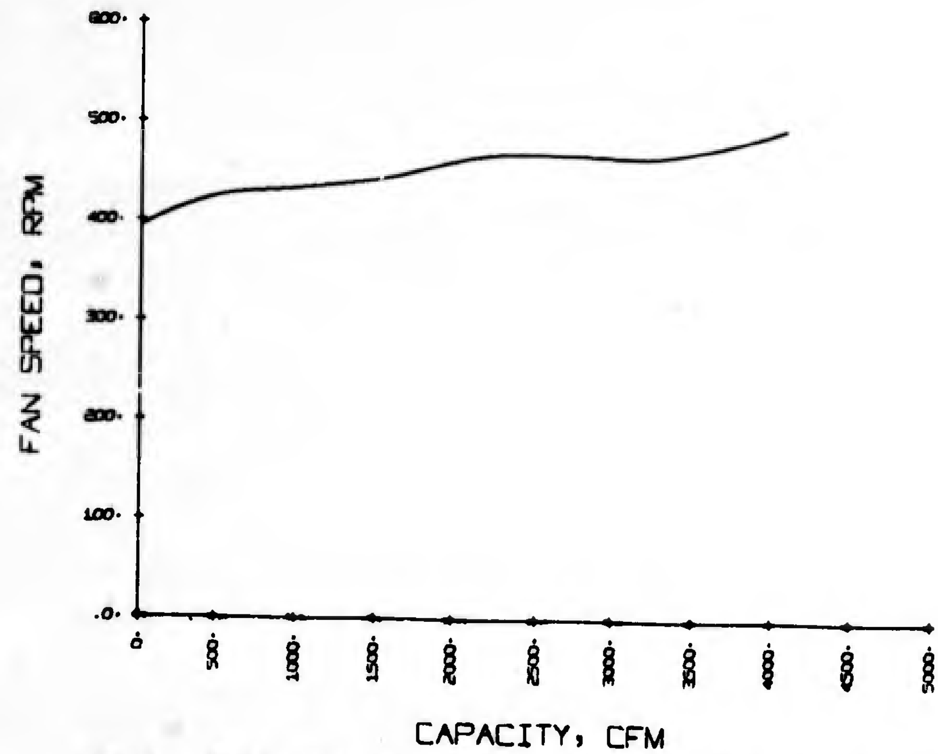

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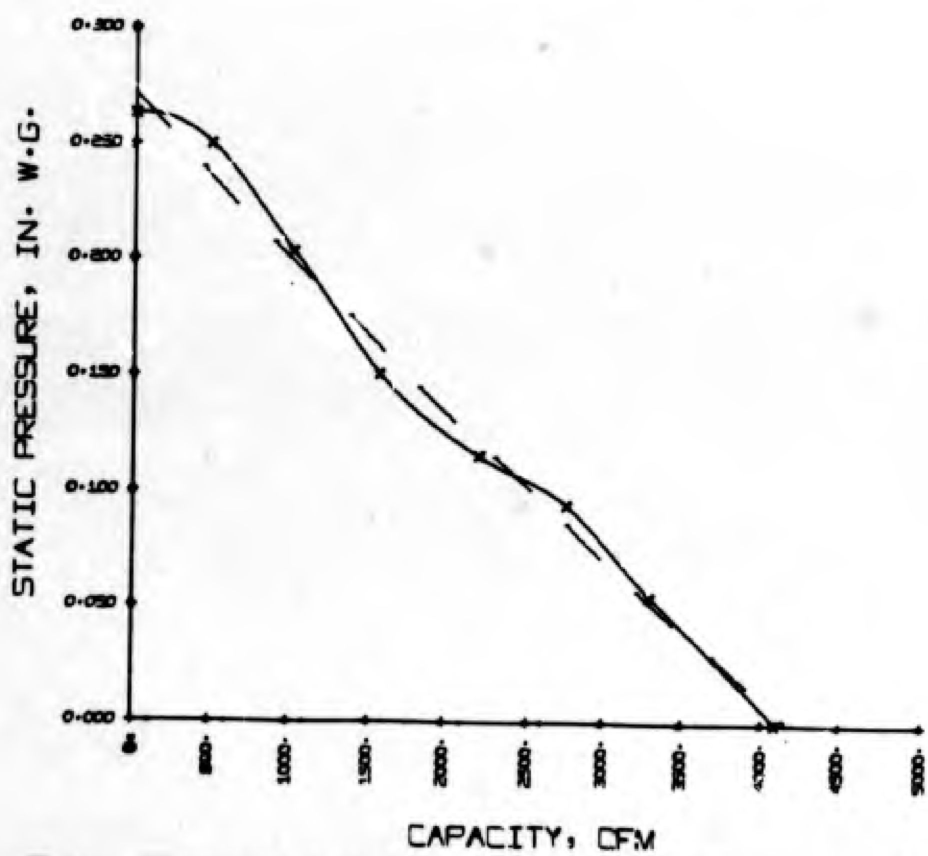

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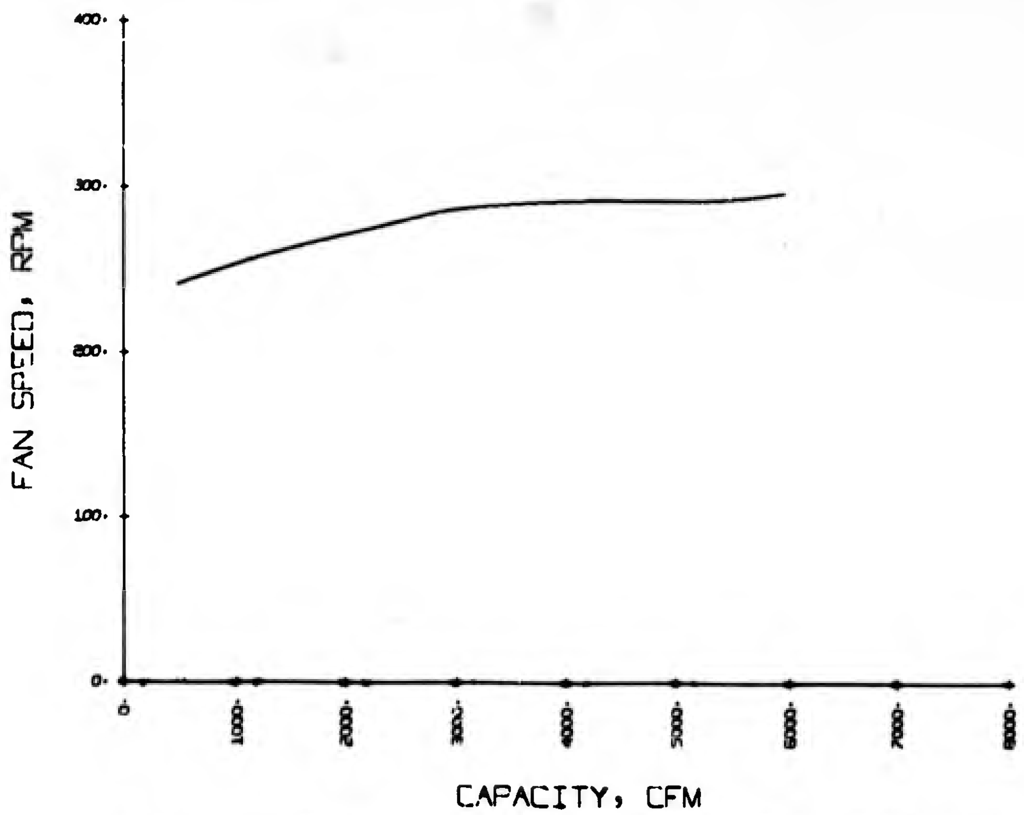
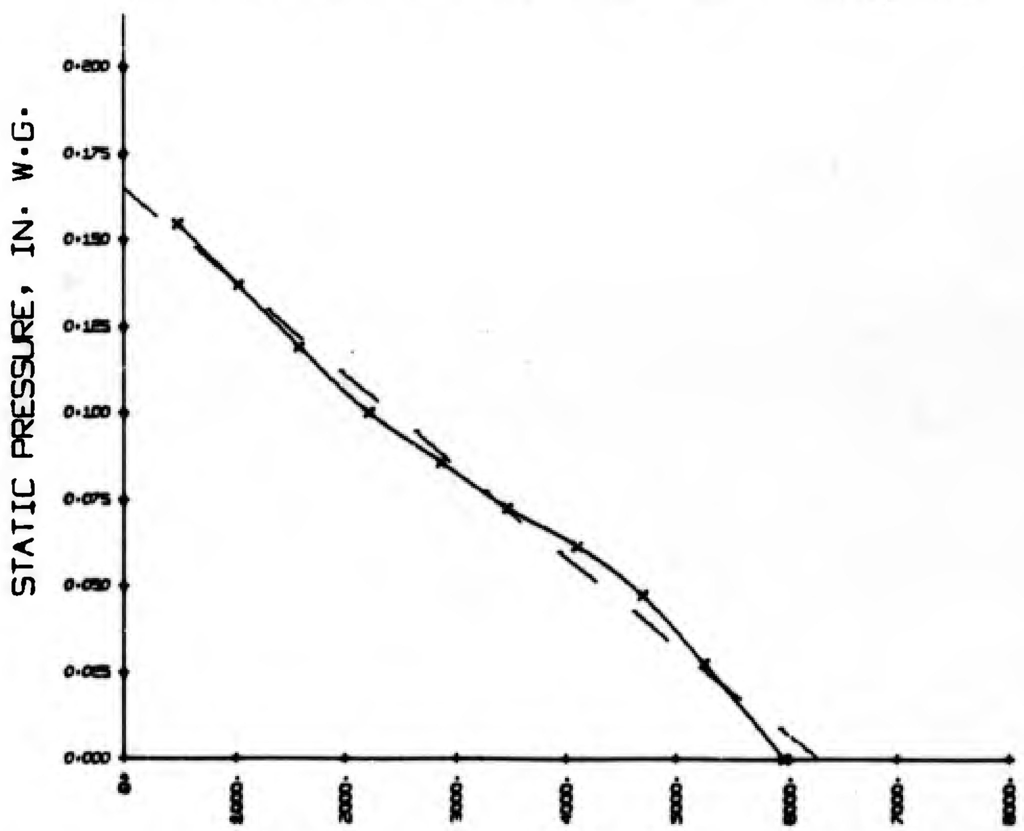


FAN SPEED CURVE FOR 1 R-3627-4



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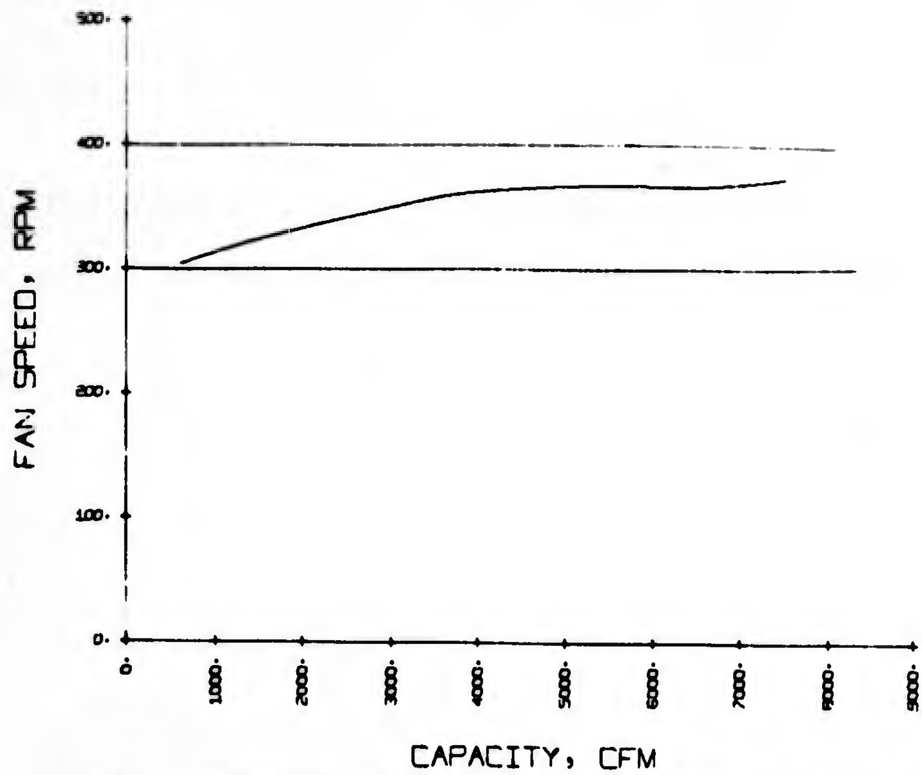

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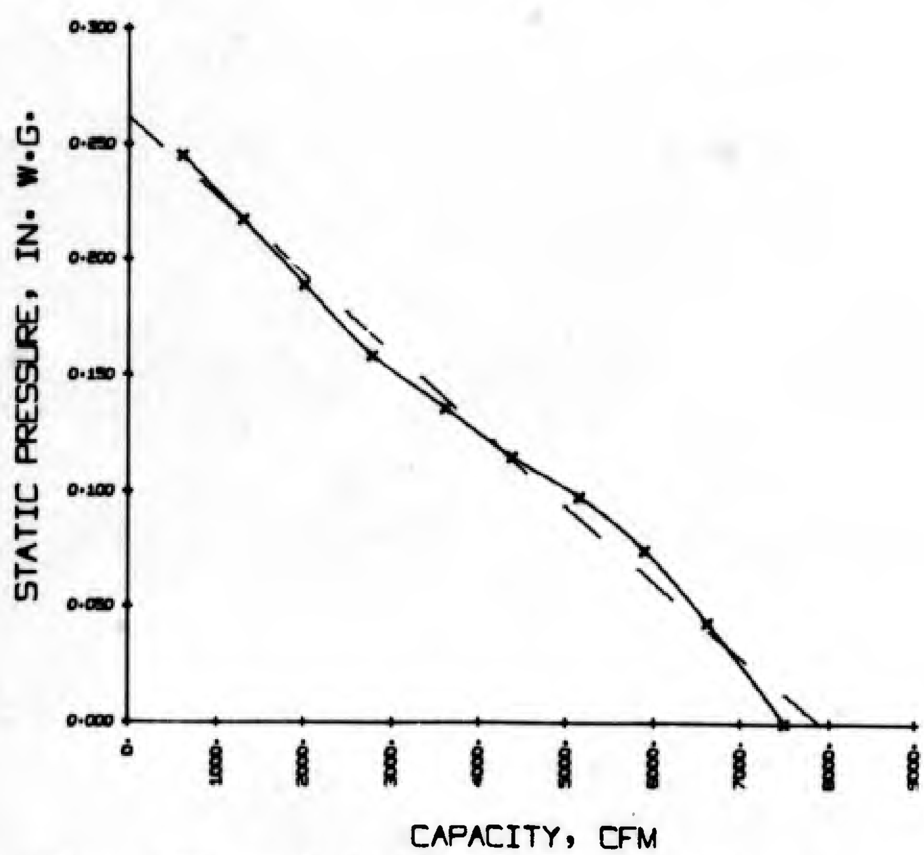

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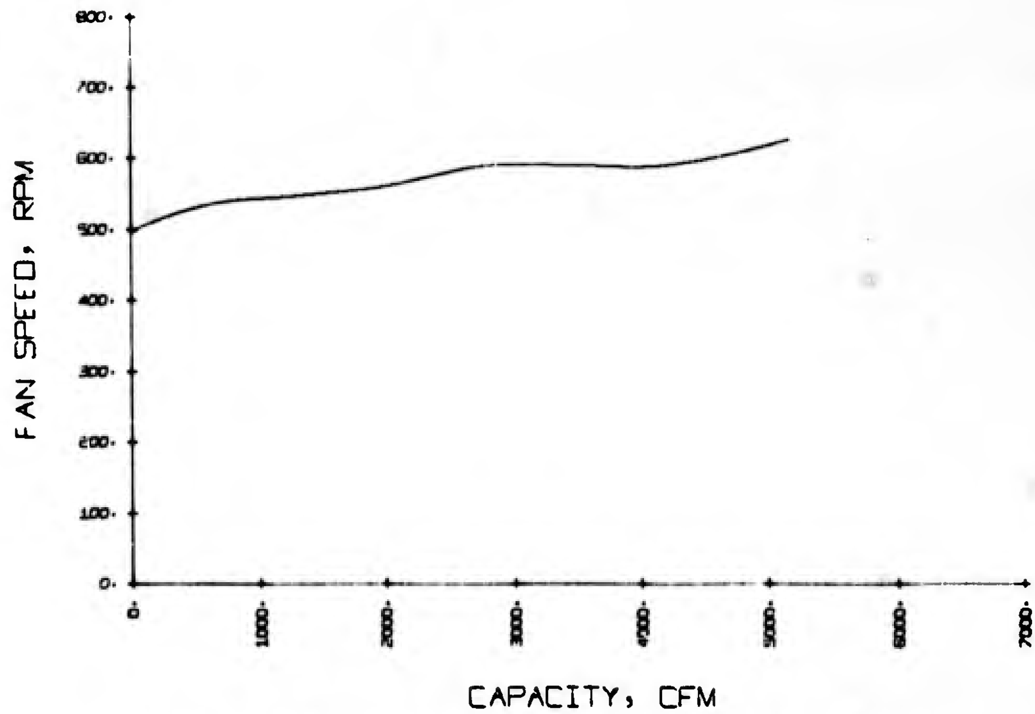

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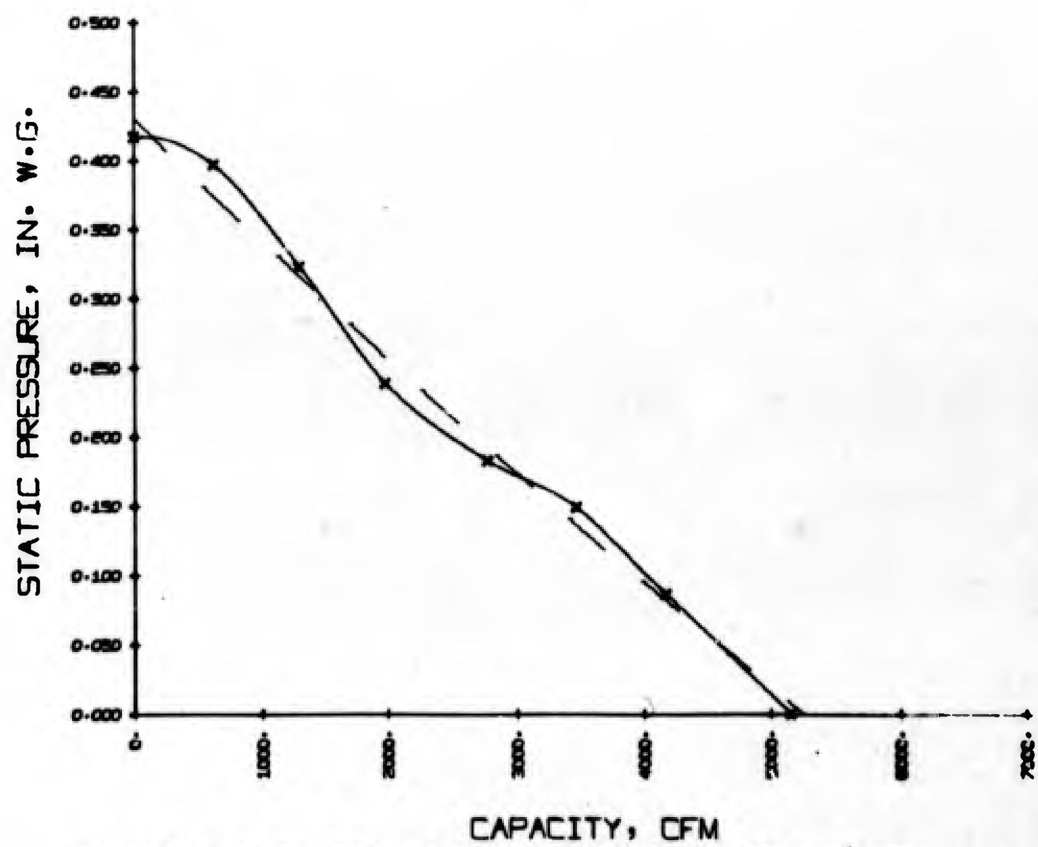

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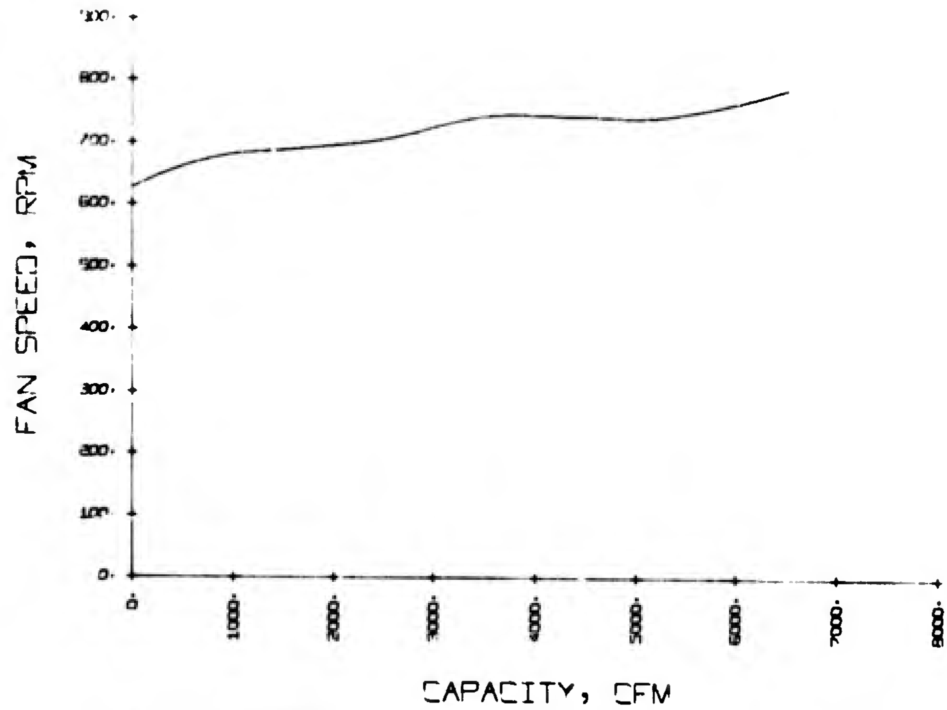

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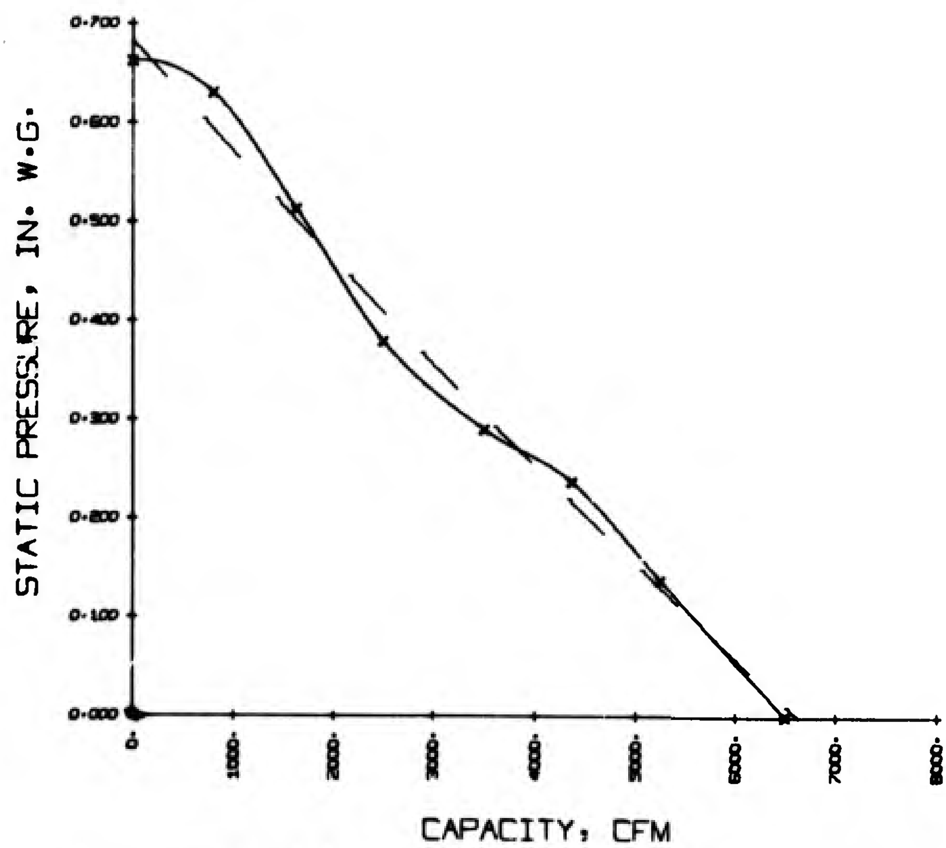

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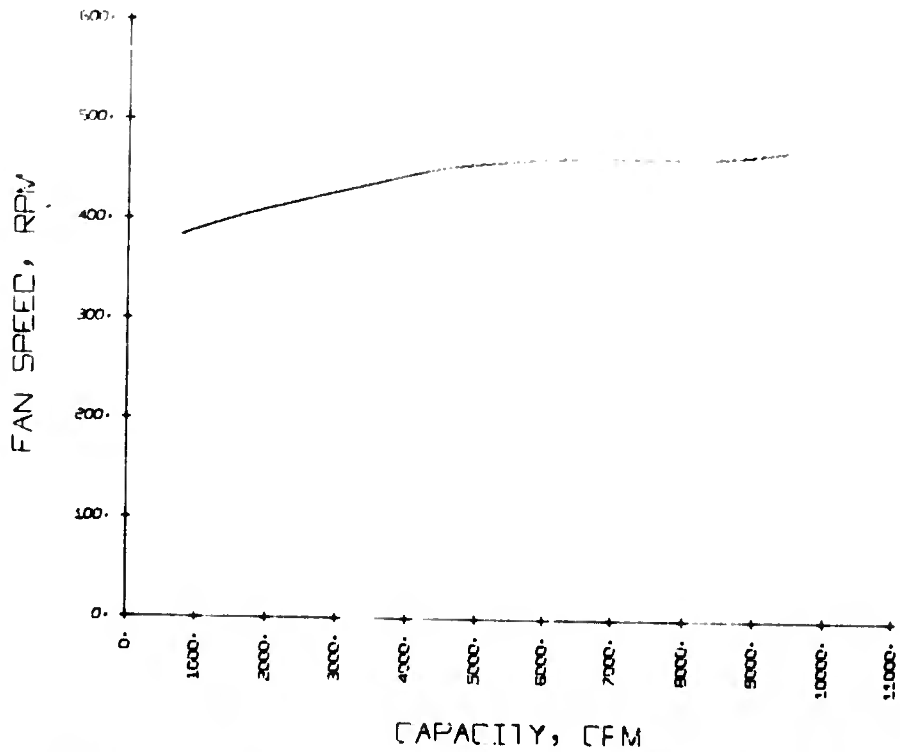

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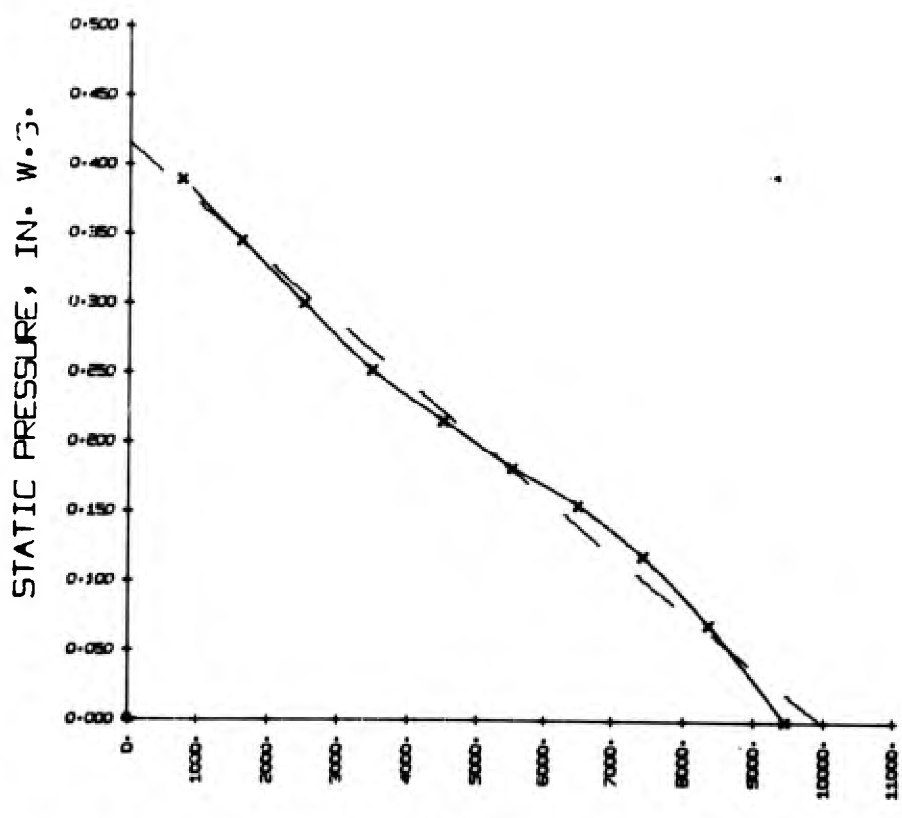

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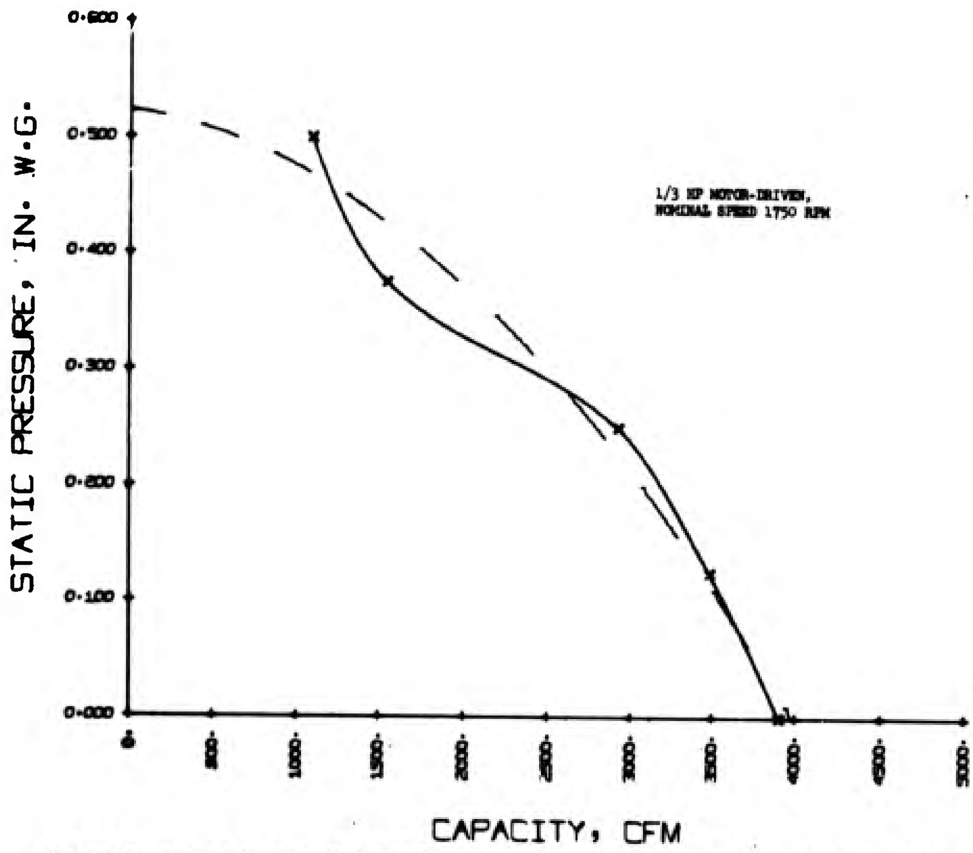
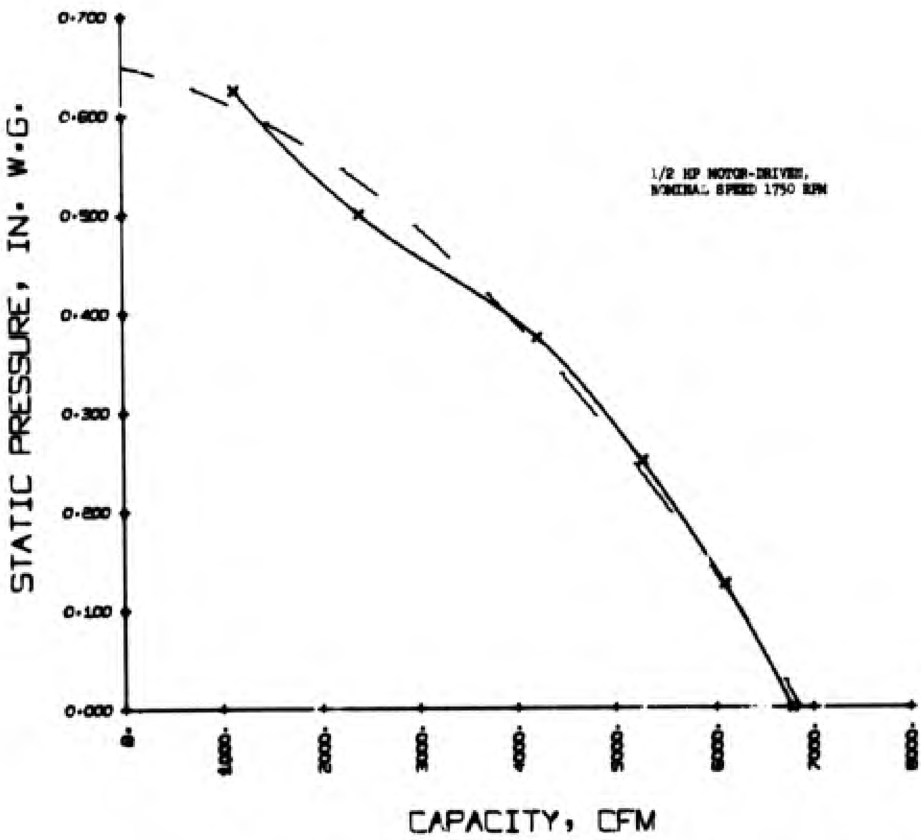


FAN PERFORMANCE CURVE FOR 185-18-1/3



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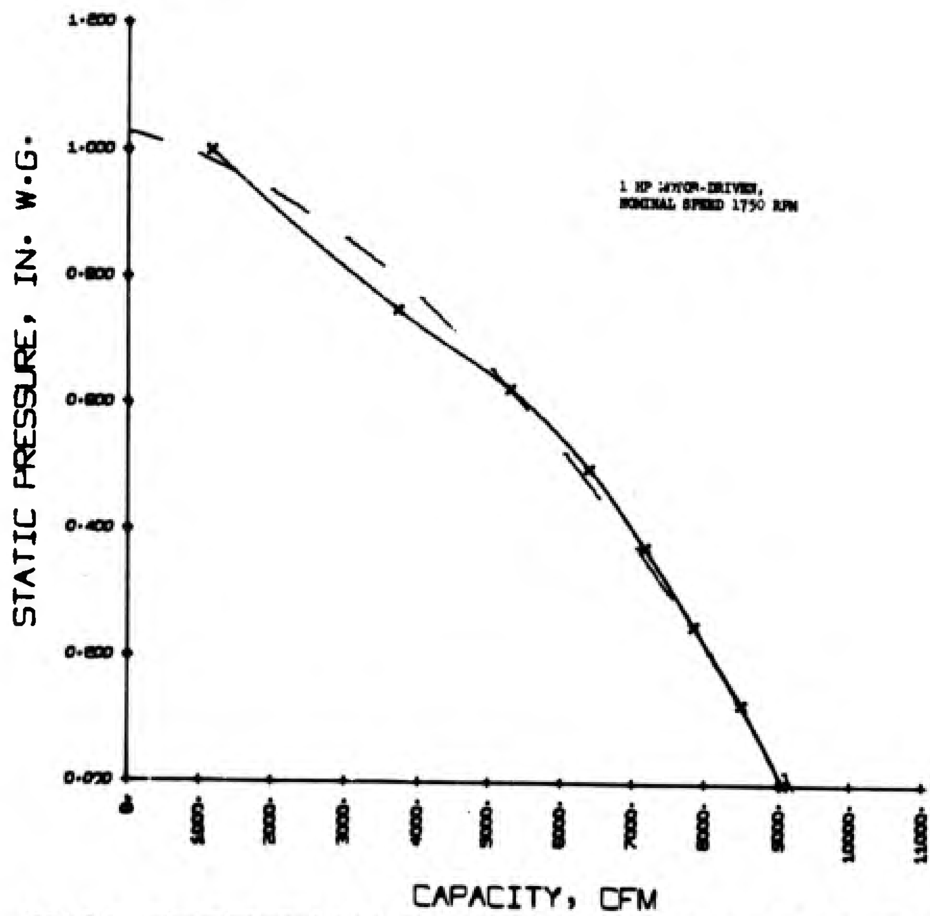

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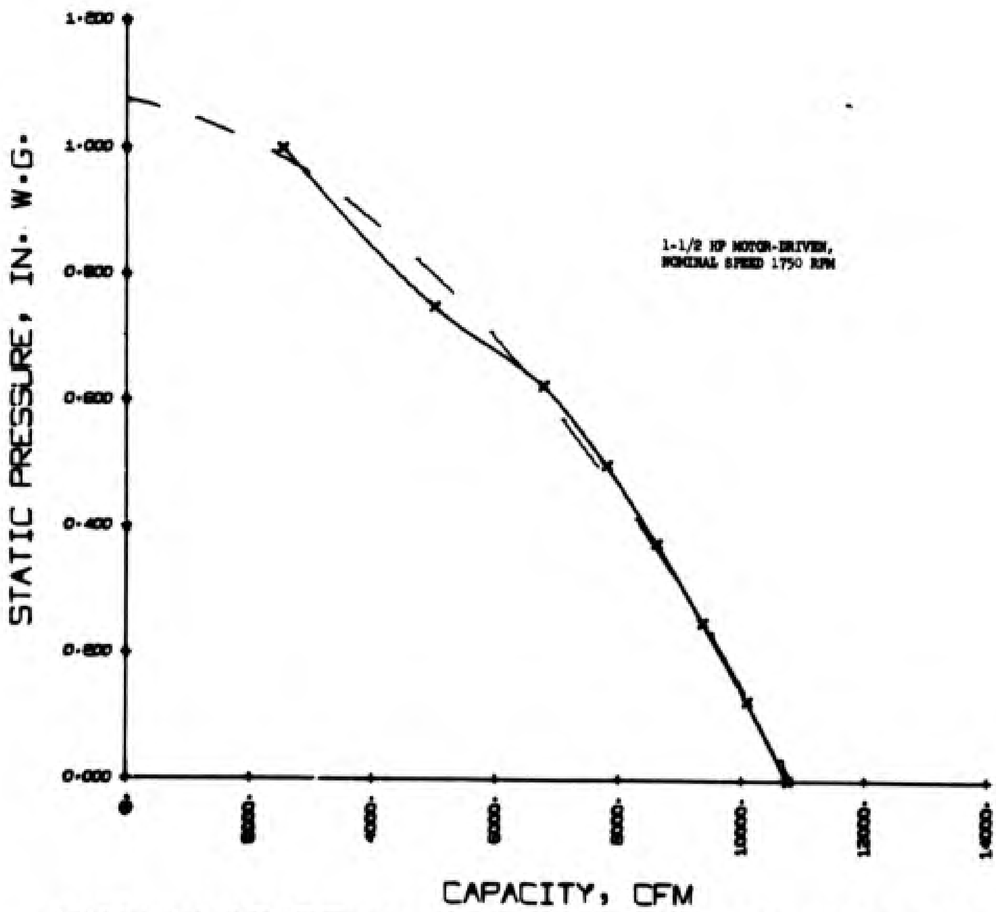

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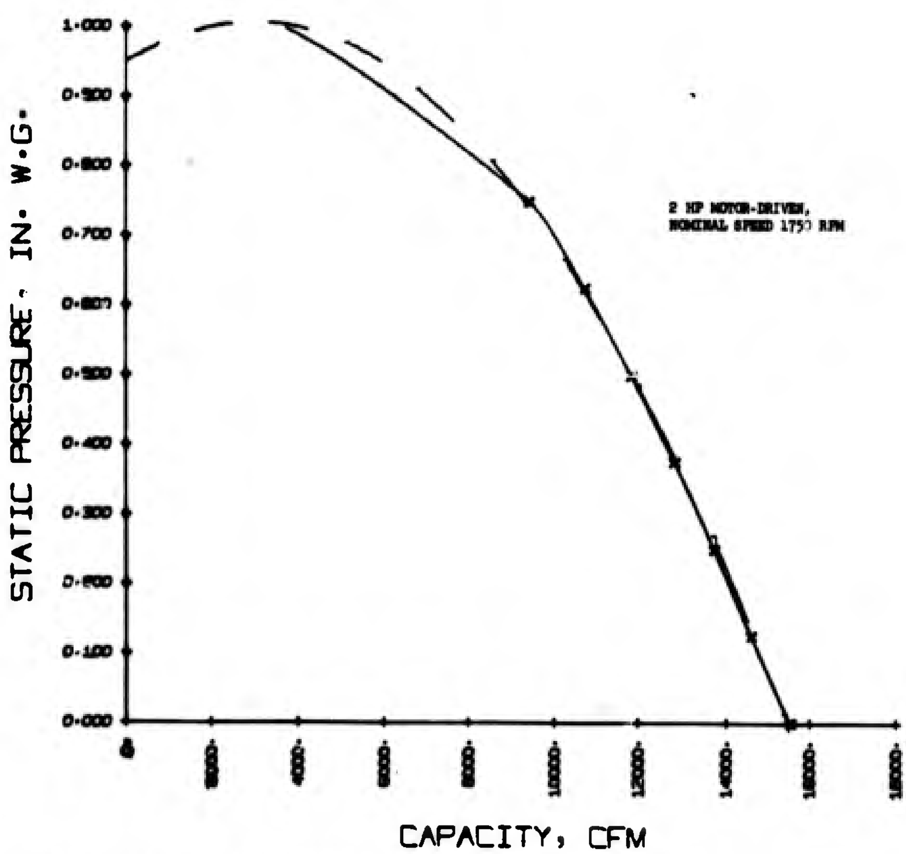

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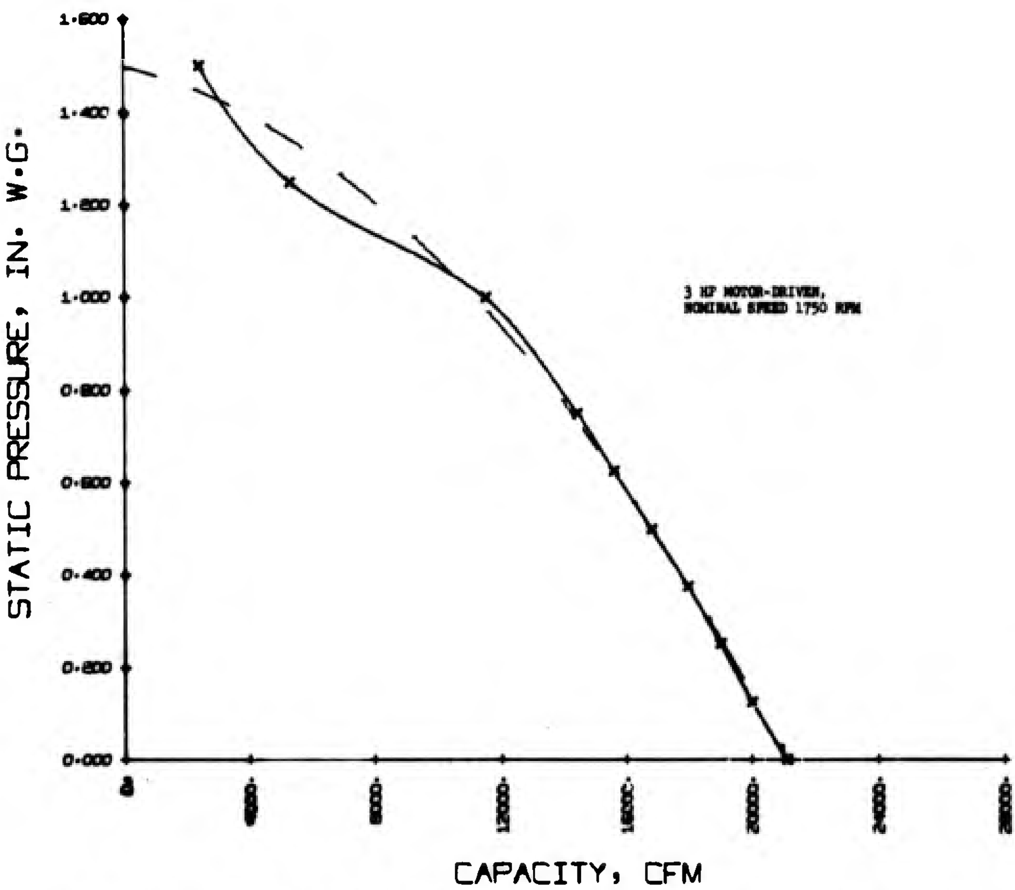
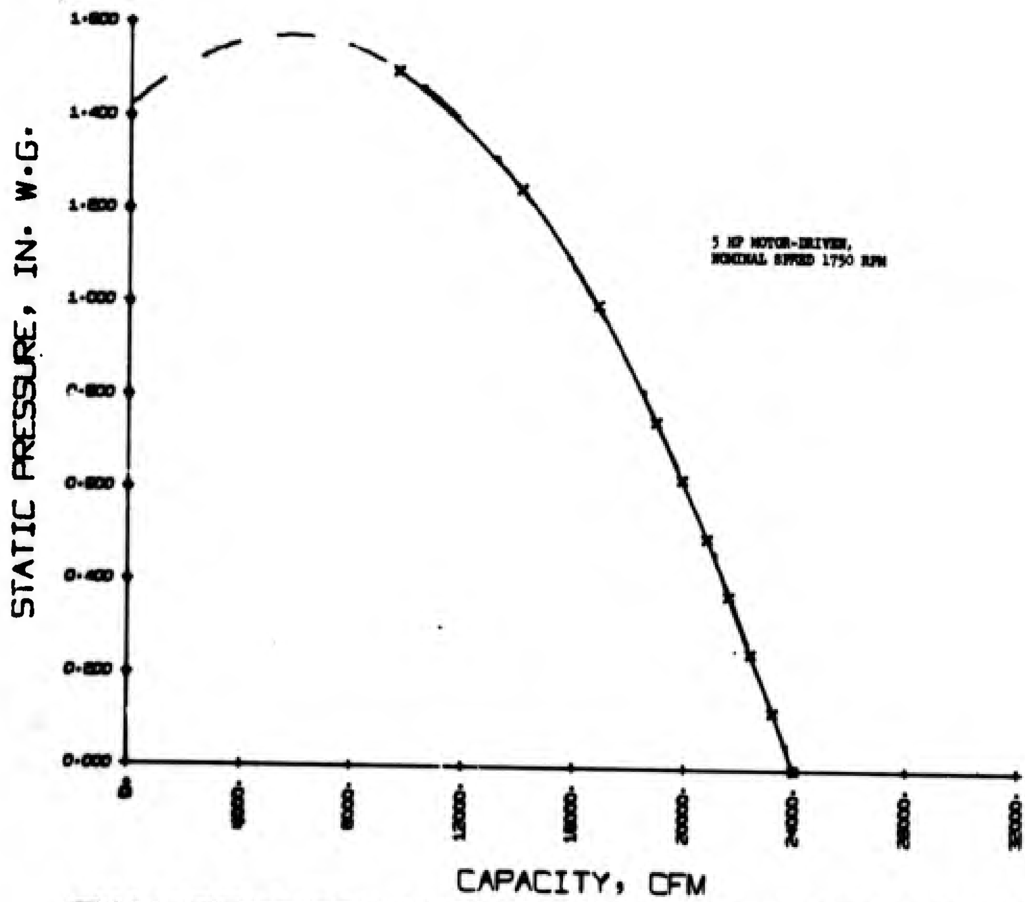


FAN PERFORMANCE CURVE FOR 368-36-3



FAN PERFORMANCE CURVE FOR 375-36-5

GENERAL AMERICAN TRANSPORTATION CORPORATION, NILES, ILLINOIS

Ventilation Equipment Analysis for Basement Shelters
OCD Work Unit 1423A
Final Report 1278
By S. J. Lis and H. F. Behls
February 1968 (UNCLASSIFIED) pp. 364

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CIVIL DEFENSE SYSTEMS, FALLOUT SHELTERS, NATIONAL FALLOUT SHELTER SURVEY, SYSTEMS ENGINEERING, STATISTICAL ANALYSIS, SHELTER IMPROVEMENT, VENTILATION, COOLING AND VENTILATING EQUIPMENT, PORTABLE, PROCUREMENT

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Prepared for
Office of Civil Defense
Office of the Secretary of the Army
under
SRI Subcontract No. B70925(4949A-28)-US

SUMMARY
OF
RESEARCH REPORT

VENTILATION EQUIPMENT ANALYSIS FOR BASEMENT SHELTERS

OCD Work Unit 1423A

GARD Final Report 1278 February 1968

General American Research Division
General American Transportation Corporation

REVIEW NOTICE

This is a summary of a report which has been reviewed in the Office of Civil Defense and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Office of Civil Defense.

INTRODUCTION

Shelter and ventilator equipment analyses were performed to determine the best ventilator kits for the 138,000 below-grade fallout shelters identified during the second phase of the National Fallout Shelter Survey (NFSS). The basis for the study was a random sampling of 160 facilities. Sketches of these shelters were analyzed for basic characteristics that define the ventilation requirements, and by matching the performance of 636 fans to the shelter requirements, the best kits were chosen based on a least-cost ventilation system.

SHELTER CHARACTERISTICS

In order to provide ventilation for identified fallout shelters throughout the country, a random sample of basement shelters was analyzed to determine the basic descriptors and the performance characteristics of ventilators, the equipment could be screened and the best units identified for further design analysis and human factors evaluation. To limit the number of shelters analyzed, a statistical random sample of 160 facilities was taken to represent the NFSS shelters. The statistical sample of facilities, designed and surveyed by the Research Triangle Institute was drawn from all of the facilities surveyed in Phase 2 of the NFSS in the 216 Standard Metropolitan Statistical Areas (SMSA*) of the United States. The master sample consisted of four SMSA's in each of the OCD Regions plus the New York City, Philadelphia, Chicago, and Los Angeles areas. Eight facilities were selected in each of two SMSA's for each OCD region and the four cities. Since entry was denied in two facilities in Seattle (no substitute facilities were available in the master sample), and

*An SMSA is generally an urban county or group of counties combined by the Bureau of Census for statistical purposes.

since one San Francisco building (Facility No. 103) was determined to have no usable fallout shelter space, the sub-sample finally consisted of 157 facilities. These 157 facilities consisted of 175 parts.

The sampling procedure insured the selection of buildings from all geographic areas of the United States. Moreover, the selection of facilities from different areas within the sample SMSA's was guaranteed. Results of this sample are adequate for making estimates on the National level; however, RTI points out that due to the small number of buildings in each OCD region and the resulting relative error, Regional estimates should not be made. GARD agrees that the sample when broken down by facilities in each region or isoventilation zone is too small for accurate shelter sampling; however, since larger samples in each region are not available, the entire RTI sample was applied to each isoventilation zone. It is therefore implied that the type of construction of shelters is similar throughout the United States, and the sample is representative of the type of basement shelters that exist in each isoventilation zone. These assumptions were necessary to provide a basis for defining the shelter descriptors to optimize the number and capacity of ventilation kits, and to estimate the total cost for the optimum ventilation kits.

Five methods of deploying ventilators were analyzed in detail using the 157 sample floor plans. The deployment approach which yielded the best coverage considered the shelter to be one open-area, although the partitions and arrangement of the rooms did define the duct system required with each ventilator. The apertures and their sizes were considered in the optimization program, since in the process of defining and analyzing ventilation systems, it was found that their shortage limited the number of ventilators which could be used in a shelter. This lack of openings resulted in designing and analyzing (performance and cost) larger capacity ventilators, such as the 4-, 6-, and 8-man pedal-driven units, and the motor-driven ventilators. The basic descriptors deduced from the sample shelters by this deployment approach are itemized below:

1. Shelter Floor Area of each shelter-part.

   NOTE: These shelter-parts are the same building story numbers as used during Phase 1, and also are the entries in Columns 13-14, Section B, of the Phase 2 Data Collection Form (DD Form 1356-1).

2. Total Aperture Area available to the outside air, including windows, stairwells, and elevator shafts.

3. Maximum Number of openings to be used for routing ducts to non-shelter areas within the building or the outside environment.

4. Remaining Aperture Area available for the air inlet.

5. Average Equivalent Duct Length (EDL) for each ventilator (excluding the pseudo-EDL resulting from an additional pressure-drop caused by a high air flow rate through the apertures allocated for the inlet air.

The location of ventilator units within each shelter is important from the standpoint of air distribution and ventilator performance. The location of units in the sample shelters was chosen such that the best air distribution could be obtained using the shortest duct system. This was done because long duct systems are difficult to implement and the pressure drop associated with the duct friction could increase the number of units necessary to ventilate the shelter. Whenever possible, the ventilators were located so that they would exhaust directly through an opening in the exterior wall. Existing openings and/or intentionally placed holes in the partitions were used to distribute the air. Where possible, elevator shafts and windows were used for the exhaust ducts from the ventilators, rather than relying on the doors and stairwells.

After selecting the openings which should be used for the ventilation equipment (actual floor plan layout required), the following guidelines were used to determine the maximum number of units which may be placed in the shelter.

1. Two units per door, stairwell, or elevator shaft.
2. One unit per window or opening if the minimum size is 36 inches by 36 inches and the horizontal dimension is less than 72 inches.
3. For garage doors, ramps, and other large openings, one unit-high only and spaced on 3-foot centers.

When a facility had shelter space on more than one story, the same stairwells and elevator shaft were used for either supply air or exhaust air.

The equivalent duct length (EDL) for each ventilator is the straight length of duct plus the equivalent length of any elbows used. Ducts which go through openings which are large enough to be used both as an air source and exhaust must be extended at least 35 feet from the openings to prevent recirculation of the exhaust air.

After deploying the maximum number of ventilators on the sample floor plans and laying out the duct systems, it was found that in 83 percent of the shelters, the difference between the largest and shortest EDL was 50 feet or less. Of the remaining 17 percent, none have minimum-to-maximum difference greater than 300 feet. The average minimum-maximum difference in these remaining shelters is less than 150 feet. This large difference generally occurs because one or two ducts are much longer or shorter than the rest. In fact, if the two ducts which deviate most from the average in each of these remaining shelters are deleted, only 2 percent of the shelters have a min-max EDL difference greater than 50 feet and none exceed 150 feet. Because the EDL's of the individual ventilators in each shelter vary only a small amount from their average, it is convenient to use this average equivalent duct length as the system characteristic for each ventilator from the maximum number of ventilators considered to the minimum possible of one in a given shelter. This fact was used in the equipment selection program.

VENTILATOR SCREENING

A total of 636 ventilator designs were screened using criteria of performance and cost. Using manufacturer's catalog data, performance of the man-powered impellers was determined for inputs of 0.1, 0.2, 0.4, 0.6 and 0.8 horsepower. The performance for electrically-powered impellers was determined for 0.3, 0.5, 2.0, 3.0 and 5.0 horsepower. The performance was determined for EDL's of 50, 300 and 700 feet. The cost of each of the units was also determined.

The units were listed by CFM in decreasing order for each of the three EDL's. The units yielding the maximum CFM for the least cost for each EDL were selected for further screening. Fifty-three units survived.

These survivors were then subjected to further screening. The 6- and 8-man units were eliminated because the physical size of the unit would occupy too much shelter floor space. Also, units were eliminated that contained similar cost and performance. Thus 18 ventilators remained at the end of the first screening.

Ten units were added by the end of the second screening. These were three 36-inch units, 1-,2- and 4-man, and seven electric motor-driven units, 1/3, 1/2, 1, 1-1/2, 2, 3, and 5 horsepower. Further, exact rather than approximate costs and exact duct friction values were used for the second screening.

Although two of the seven final electric units were eliminated in the second screening, they were retained on the master list of 28 so that the complete range of electric ventilators could be considered. These 28 designs were then subjected to the following cost minimization analysis.

The performance characteristics of each ventilator, the cost of each ventilator kit, and the unit length cost of the duct system were used in the cost analysis. The least-cost criterion is used in selecting the best ventilator for each shelter-part, but the minimum total cost varies with each changing group of ventilators considered. Starting with the master list of 28 fans, an equipment computer program produced solutions for each isoventilation zone as if the 175 RTI sample shelter-parts were located therein. The frequency of occurrence of the 28 units was summarized and the results were tabulated. Based on the frequency of occurrence, the 10 ventilators with a frequency of occurrence greater than 100 were retained. For the 10 remaining ventilators, it was decided to eliminate arbitrarily one ventilator in each of the low, moderate, and high capacity ranges. The performance curves for the remaining seven ventilators were used in selecting the optimum number of shelter ventilation kits for the NFSS basement shelters without any human factors considerations.

OPTIMIZATION OF VENTILATION KITS

The basis for matching and selecting the least-cost equipment is a file of the shelter characteristics for any combination of equipment size and any number of installed units (number of openings) from the maximum possible to a minimum of one. This summary of data is called the "surveyor file" and was generated by use of a computer program using as input the shelter descriptors. The output format of the computer program gives, for each shelter-part of the RTI survey, the equivalent duct length (EDL) as a function of (1) the possible duct diameters, and (2) the number of ventilators from the maximum possible to one unit. In determining the equivalent duct lengths, the total air flow (CFM) required was calculated for each of the isoventilation zones based on an occupancy density of 10 square feet per shelteree. The air flow per ventilator was determined simply by dividing the total ventilation requirement by the number of units from the maximum to one.

The predictions are made for all ventilation zones and the totals hown that out of 138,261 facilities or 154,160 shelter-parts, 98.6 percent of the shelter-parts are ventilable. The spaces available in these shelters are 90.2 percent (72,014,940) of the maximum possible (79,824,485). When the selections are made from 28, 10 and 7 ventilators, the total estimated cost for ventilation equipment is 32.7, 33.9 and 36.6 million dollars, respectively. For 7 ventilators, the estimated cost is only 3.9 million dollars more than when 28 units are possible; therefore, it is of definite advantage to reduce the number of kits in an operational system to no more than 7, and possibly less.

Table I shows cost, precent shelter parts covered, and percent people ventilated of total sheltered, as a function of various mixes of the seven selected ventilator units when power is available.

As indicated in Table II, the shelter coverage decreases significantly when eliminating the power units from the system. Roughly 82 percent of the identified spaces would be adequately ventilated; however, the best five kits would cover 93.6 percent of the identified shelter parts at an estimated cost of 27.7 million dollars. Reducing the number of kits from five to four and three, increases the cost slightly to 28.0 and 28.4 million dollars, respectively. We recommend stocking the 1R-3627-4 and the 4R-3627-4 kits. These units will provide ventilation for an estimated 65,353,075 people at an

TABLE I

OPTIMA VENTILATOR MIXES WITH POWER AVAILABLE

NUMBER OF UNITS	TOTAL NUMBER OF VENTILATORS	TOTAL COST	NUMBER OF SHELTER PARTS	NUMBER OF PEOPLE
7	333,806	$ 36.664 M	151,944 (98.6%)	72,014,940 (90.2%)
6*	332,321	37.593 M	151,944 (98.6%)	72.014,940 (90.2%)
5	332,321	37.890 M	151,944 (98.6%)	72,014,940 (90.2%)
4	329,670	38.326 M	151,944 (98.6%)	72,014,940 (90.2%)
3	325,708	40.534 M	151,944 (98.6%)	72,014,940 (90.2%)
2	292,422	50.729 M	151,944 (98.6%)	72,014,940 (90.2%)
6**	324,332	29.528 M	146,987 (95.3%)	66,825,132 (83.7%)
3 USING MIL-V-40645	296,385	48.521 M	151,944 (98.6%)	72,014,940 (90.2%)

*Unit 375-36-5 as the electric-powered unit.

**Unit 280-27-1 as the electric-powered unit.

TABLE II

OPTIMA VENTILATOR MIXES USING ONLY MANUAL UNITS

5	319,170	$ 27.689 M	144,258 (93.5%)	65,353,075 (81.9%)
4	319,170	27.986 M	144,258 (93.5%)	65,353,075 (81.9%)
3	316,519	28.422 M	144,258 (93.5%)	65,353,075 (81.9%)
2	312,556	30.630 M	144,258 (93.5%)	65,353,075 (81.9%)

estimated cost of 30.6 million dollars. Significantly, the same manual units are optimum for either a manual or power-manual system. In no case will a power unit be used in a shelter if it is possible to ventilate the shelter with the largest capacity manual unit available.

CONCLUSIONS AND RECOMMENDATIONS

The shelter ventilation equipment optimization study presented in this report provides the means for selecting from 28 ventilator designs the best ventilators to ventilate the NFSS below-grade fallout shelters. When power is available from an auxiliary engine-generator set, the optimum units are the 1-man, 36-inch diameter Unitary Ventilator; the 4-man, 36-inch diameter Modular Unit; and the 5-horsepower, 36-inch diameter Power Unit. These units will provide ventilation for an estimated 98.6 percent of the identified basement shelter-parts (see Table III). The shelters will accommodate an estimated 72,014,940 people or 90.2 percent of the maximum number of people which could be sheltered at a floor loading of 10 square feet per person. The cost for the equipment to ventilate these shelters is estimated at 40.5 million dollars or 56 cents per person. This dollar value does not include the expense of the survey, selection of equipment, instructions, warehousing, and freight.

If manual units only are feasible, the optimum units are again the 1R-3627-4 Unitary Ventilator, and the 4R-3627-4 four-man Modular Unit. These units will provide ventilation for an estimated 81.9 percent of the maximum number of people which could be sheltered in the 138,261 identified NFSS basement facilities. If the MIL-V-40645 PVK, 1- and 2-module units were applied to the RTI sample shelters according to the techniques described in the report, the results show that 122,669 shelter-parts or 79.6 percent of the total number of shelter-parts can be adequately ventilated. These shelters

TABLE III

SUMMARY OF THE RECOMMENDED VENTILATOR KITS
FOR THE NFSS BASEMENT SHELTERS

Type of System	Manually-Driven Ventilators	Manually- and Electric Motor-Driven Ventilators
Percentage of Estimated Shelter-Parts which can be ventilated	93.5%	98.6%
Percentage of the Maximum Number of People who can be protected with increased ventilation	81.9%	90.2%
Recommended Number of Kits	2	3
Style of Ventilators with Estimated Number of Kits Required	1R-3627-4: 250,743 and 4R-3627-4: 61,813	1R-3627-4: 250,745, 4R-3627-4: 61,811, 375-36-5: 13,152
Estimated Cost for Equipment, (dollars in millions)	$ 30.630	$ 40.534
Per Capita Cost for the Equipment	$ 0.47	$ 0.56

*Costs do not include the expense for the survey, selection of equipment, warehousing, instructions, and freight.

cover 55.6 percent of the maximum number of shelter spaces available or 44,436,023 shelter spaces.

During the program it was learned that large capacity units were required in order to get reasonable ventilation coverage when considering all of the NFSS basement shelters. This means that many rooms in these shelters are covered by one ventilator, and therefore the deployment of the ventilators will always significantly affect the distribution of air throughout the shelters. Since the air distribution within the shelters is highly dependent upon the placement of the ventilators, the geometry of the shelter, and the occupancy density throughout the shelter, it may be necessary to selectively seal doors and apertures, and intentionally put holes of various sizes in the interior partitions. Additional studies are necessary to define the minimum shelter air distribution requirements, and to determine if additional distribution devices and instruments (such as the punkah and a baffle kit and dry-bulb thermometers) should be incorporated into the system.

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13. ABSTRACT

Shelter and ventilator equipment analyses were performed to determine the best ventilator kits for the 138,000 below-grade fallout shelters identified during the second phase of the National Fallout Shelter Survey (NFSS). The basis for the study was a random sampling of 160 facilities. Sketches of these shelters were analyzed for basic characteristics that define the ventilation requirements, and by matching the performance of over 600 fans to the shelter requirements, the best seven kits were chosen based on a least-cost ventilation system. The final selection of kits to be stocked depends on considerations other than engineering, primarily human factors. Based on shelter conditions not exceeding a daily average effective temperature of 82°F for all but 10 percent of the days of the year, the best three ventilators, when power is available, are (1) the one-man, 36-inch diameter unit, (2) the four-man, 36-inch diameter unit, and (3) the one-man, 36-inch diameter power-driven unit. These units will provide adequate ventilation for 98.6 percent of the basement shelter-parts identified in the NFSS at an average per-capita cost of $0.56. For an exclusively manual system, the best two kits are again the one-man, 36-inch diameter unit and the four-man, 36-inch diameter unit. The best three kits would be these same two units plus the one-man, 20-inch diameter unit described by Specification MIL-V-40645. With this equipment, 93.5 percent of the shelter parts, accommodating 65,353,075 people can be adequately ventilated. These shelters accommodate 81.9 percent of the total shelter spaces available, as compared to 90.2 percent when the Power Unit is used. (U)

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
CIVIL DEFENSE SYSTEMS						
FALLOUT SHELTERS						
NATIONAL FALLOUT SHELTER SURVEY						
SYSTEMS ENGINEERING						
STATISTICAL ANALYSIS						
SHELTER IMPROVEMENT						
VENTILATION						
COOLING AND VENTILATING EQUIPMENT						
PORTABLE						
PROCUREMENT						