18c

PNL-2969
UC-62

The Effects of Noncontact Cleaners on Transparent Solar Materials

H. L. Hampton
M. A. Lind

April 1979

Prepared for the U.S. Department of Energy under Contract EY-76-C-06-1830

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy by Battelle Memorial Institute

Battelle

PNL-2969

PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
Under Contract EY-76-C-06-1830

Printed in the United States of America
Available from
National Technical Information Service
United States Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151

Price: Printed Copy $____*; Microfiche $3.00

*Pages	NTIS Selling Price
001-025	$4.00
026-050	$4.50
051-075	$5.25
076-100	$6.00
101-125	$6.50
126-150	$7.25
151-175	$8.00
176-200	$9.00
201-225	$9.25
226-250	$9.50
251-275	$10.75
276-300	$11.00

PNL-2969
UC-62

THE EFFECTS OF NONCONTACT CLEANERS ON TRANSPARENT SOLAR MATERIALS

H. L. Hampton
M. A. Lind

April 1979

Prepared for
U.S. Department of Energy
Under Contract EY-76-C-06-1830

Pacific Northwest Laboratory
Richland, Washington 99352

ABSTRACT

A brief study has been undertaken to evaluate the performance of non-contact cleaning agents for use on solar collectors. Several techniques are used to compare cleansing agents which have been recommended by their respective manufacturers for cleaning solar mirrors. Wetting and residue buildup properties are evaluated for over 50 of these commercially available cleaners. The wetting properties of each cleaner are evaluated by measuring the growth of the contact area of a constant volume drop as a function of time. Losses due to residue buildup are solar weighted and considered equally with the wetting parameters and cost figures to construct a figure of merit for cleaner comparison.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The problems associated with cleaning solar materials have been largely ignored. Dirt accumulations have been shown to reduce the transmittance of glass by as much as 50% in only 14 days.[1] The effects on plastic may be even worse due to the dust-attracting and adhesive properties of the polymeric surface constructions. Various strategies to overcome the problems of dirt and dust accumulations have been suggested. Options considered fall into three basic categories: 1) enlarging the collector field to compensate for the optical losses, 2) preventing the contaminants from depositing on the collector surface in sufficient quantities to significantly degrade performance, and 3) periodic removal of the atmospheric contaminants by cleaning.

This report focuses on one aspect of the third strategy, the comparison of cleaning agents which have potential application in noncontact cleaning schemes. The noncontact cleaning approach is desirable because of the advantages it offers when maintaining complex collector shapes and large surface areas characteristic of the solar industry. A noncontact cleaning strategy such as high pressure spray minimizes surfaces abrasions and is usually less manpower intensive and therefore less costly than conventional techniques which involve mechanical contact with the surface.

The evaluation of cleaning agents is subject to numerous interpretations, depending upon the point of view of the evaluator. A single unbiased test to compare or rank cleaning agents which relates to all applications has yet to be developed. As a practical concern, only a limited number of parameters can be investigated in an expeditious manner.

The surface chemistry between the cleaner and the material being cleaned is one of the factors that determine the overall effectiveness of the cleaner. One convenient way to evaluate this surface interaction without examining the chemistry in detail is to look at how the cleaner wets the surface to

---

[1] H. P. Garg, "Effect of Dirt on Transparent Covers in Flat Plate Solar Energy Collectors," Solar Energy 15:299-302 (1974).

which it is applied. The surface wetting can be characterized by using two parameters directly applicable to the cleaning process. These parameters are the maximum area wetted by a constant volume of the cleaner and the time it takes to obtain a given fraction of this area.

Two other important parameters for cleaner evaluation are the effects of repeated application and the cost of the product. Repeated applications of a cleaner may cause excessive residue buildup, resulting in solar absorption or scattering, thus reducing collector performance. High cost cleaners could add significantly to the life cycle operations and maintenance cost of the solar collector field.

In this report the wetting, residue buildup and cost parameters have been used to construct an arbitrary, but useful, figure of merit for comparing cleaners. The report, which is the result of a brief study conducted for DOE, is not intended to be a definitive study of the cleaners. Rather, its purpose is to present methods of evaluation that may be useful when comparing cleaning products. No attempt has been made to do an exhaustive study of all the available cleaning agents or to make definitive statements about any particular product.

As a word of caution, some discretion should be exercised when interpreting the results of the tests described in this report. The evaluation of any cleaning agent using these techniques may be influenced by any number of external parameters. Examples of these parameters include: 1) variations in the surface of the material to which the cleaner is applied, 2) non-uniform preparation of the surface before testing, and 3) batch variations in the cleaner being tested. Each of these parameters can cause errors which are large enough to invalidate the results obtained in many comparative types of studies. Although attempts have been made to minimize the effects of these parameters in this study, they cannot be totally eliminated.

A large number of firms manufacturing or distributing glass and plastic cleaners were contacted. The initial list of contacts was generated from the Thomas Register under the categories of "Cleaners: Glass" and "Cleaners: Plastic." A listing of the firms contacted is contained in Appendices A and B.

CONCLUSIONS

The wetting characteristics of a number of glass and plastic cleaners have been compared. The contact area of a fixed volume of the cleaning solution has been measured as a function of time on various substrate materials. The effects on the solar transmittance of the substrates after repeated application have been estimated. These parameters have been combined with the prepared cost per gallon to formulate a figure of merit for the cleaners based on a specific noncontact cleaning scheme for solar applications.

SURFACE WETTING STUDIES

Background

One method for comparing cleaning solutions is to determine their ability to wet the surface of the material to be cleaned. The wetting of a solid surface with a liquid is, with few exceptions, a function of the difference in surface energy between the liquid and the solid. Surface wetting is generally quantified by measuring the contact angle between the drop surface and the solid surface. The contact angle is defined as the exterior angle between the tangent to the drop surface, at the point of contact, and the plane of the solid surface on which the drop is placed.

Unfortunately, accurate measurements of contact angle are difficult to perform and the results become somewhat subjective. However, several alternative parameters can be measured when relative rather than absolute comparisons are desirable. One useful technique is to measure the diameter of the wetted surface for a given volume of applied liquid. This technique is easier to implement than contact angle measurements, but is still subject to error introduced when the contacted area is non-isotropic.

A preferred technique is to measure the area of the wetted surface for a given volume of applied liquid. With appropriate instrumentation, this measurement is rapid, accurate, and easy to perform. Such instrumentation is described later in this document.

The actual measurement of contact area is complicated by the fact that the area may vary with time. A given volume of liquid will tend to spread over the solid surface from the time it is placed on the surface until some equilibrium value is reached. The two parameters of interest for the wetting study are the time constant for this interaction and the final wetted area.

With a few exceptions, the time dependence of the area growth can be fit to the following exponential function:

$$A = (A_f - A_i)\left[1 - e^{-\beta t}\right] + A_i, \qquad (1)$$

where A is the drop area, t is the elapsed time, β is the inverse of the time constant for the process, A_f is the asymptotic value of the area reached at an infinite time, assuming no evaporation occurs, and A_i is the initial drop area at t = 0. Exceptions to the above equation include alcohol based cleaners that evaporate before an equilibrium value for the area is reached.

It is impractical to measure the actual values for the initial and final areas for most real cleaning agents. The initial areas are a strong function of the exact mechanism used to place the drops on the surface. The final area is unattainable in a reasonable evaluation period because time constants may be on the order of tens of minutes.

The time constant can be calculated from Equation (1) without reference to the actual initial and final areas by measuring the contact area of the drop at four intermediate times. One can see that

$$\frac{A_1 - A_2}{A_3 - A_4} = \frac{e^{-\beta t_2} - e^{-\beta t_3}}{e^{-\beta t_4} - e^{-\beta t_3}} \tag{2}$$

where A_1 to A_4 are the areas at times t_1 to t_4. If one assumes, in addition, that the four measurements are taken at equal time intervals, Δt, then Equation (2) reduces to:

$$\frac{A_1 - A_2}{A_3 - A_4} = \frac{e^{-\beta(t_1 + \Delta t)} - e^{-\beta t_1}}{e^{-\beta(t_1 + 3\Delta t)} - e^{-\beta(t_1 + 2\Delta t)}} \tag{3}$$

$$= \frac{e^{-\beta\Delta t} - 1}{e^{-3\beta\Delta t} - e^{-2\beta\Delta t}} \tag{4}$$

$$= e^{2\beta\Delta t} \; . \tag{5}$$

Solving for β, one finds

$$\beta = \frac{1}{2\Delta t} \ln\left(\frac{A_1 - A_2}{A_3 - A_4}\right) . \tag{6}$$

Once the time constant is known, the final area can be calculated. By rearranging Equation (1), one can write

$$A_f - A = (A_f - A_i)e^{-\beta t} . \tag{7}$$

It follows that

$$\frac{A_f - A_1}{A_f - A_2} = \frac{e^{-\beta t_1}}{e^{-\beta t_2}} . \tag{8}$$

If $t_2 - t_1 = \Delta t$, then,

$$\frac{A_f - A_1}{A_f - A_2} = e^{\beta \Delta t} \tag{9}$$

or

$$A_f = \frac{A_1 - A_2 e^{\beta \Delta t}}{1 - e^{\beta \Delta t}} . \tag{10}$$

For comparison purposes it is often informative to plot the area the drop will occupy when its growth is 90% complete versus the time that the drop takes to reach this area. This is done by setting

$$A = A_i + 0.9(A_f - A_i), \tag{11}$$

substituting this expression into Equation (1) and solving for t. Then

$$t_{90\%} = \frac{\ln(0.1)}{\beta} . \tag{12}$$

Instrumentation

An instrument has been developed to perform the drop contact measurements using electro-optic techniques. The instrument has been named SWAMI (Surface Wetting Area Measurement Instrument). It uses an optical shadowing technique in conjunction with a two-dimensional CCD array and additional processing electronics to produce a numeric display which is proportional to the area wetted. A block diagram of the measurement apparatus is shown in Figure 1. Photographs of the actual instrument and typical video display are shown in Figure 2 and Figure 3.

The instrument shown actually measures the relative cross-sectional area of any solid or liquid material placed on the transparent sample substrate to be wetted. Transparent liquid drops cast a shadow which is similar to that of an opaque object by virtue of their lens-like behavior. The instrument can be calibrated for absolute area measurements by placing opaque reference areas in the beam. The overall area measurement accuracy of the apparatus in the configuration shown is $\pm 2\%$. Further information on the characterization of the instrument and the design of the electronic interface will be forthcoming.

Using this apparatus, an investigator may rapidly obtain precise contact area information at predetermined time intervals. It should be noted, however, that by virtue of the shadowing technique used, the area measured is the maximum cross-sectional area of the drop and therefore is not representative of the contact area for substances which do not result in contact angles greater than 90°. This limitation does not affect the results for the materials used in this study.

Preliminary Wetting Investigations on Glass

As noted previously, the actual wetting characteristics of a solid surface by a liquid depend on the surface chemistry of both the liquid and the solid to which it is applied. Therefore, the selection of reference substrate materials for the wetting evaluations of various cleaning agents

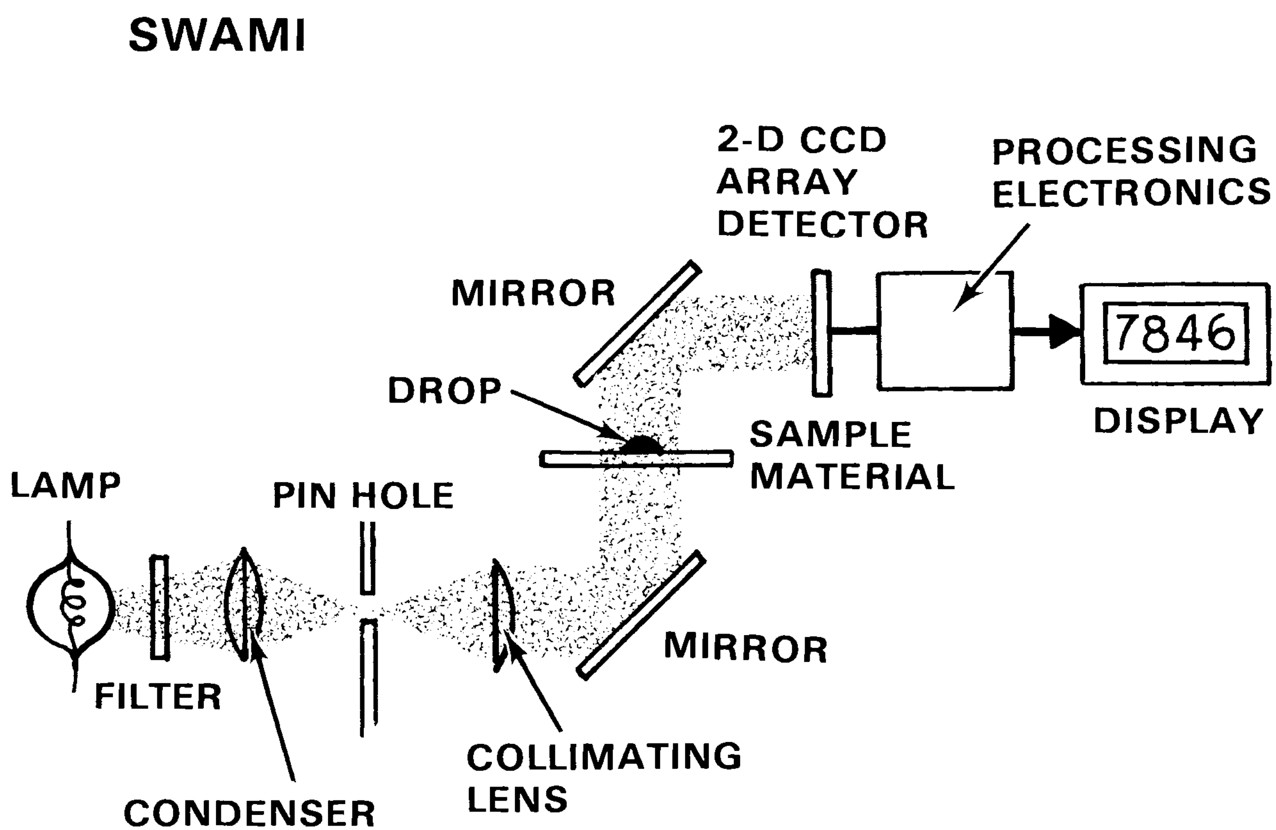

FIGURE 1. Block Diagram of Surface Wetting Area Measurement Instrument

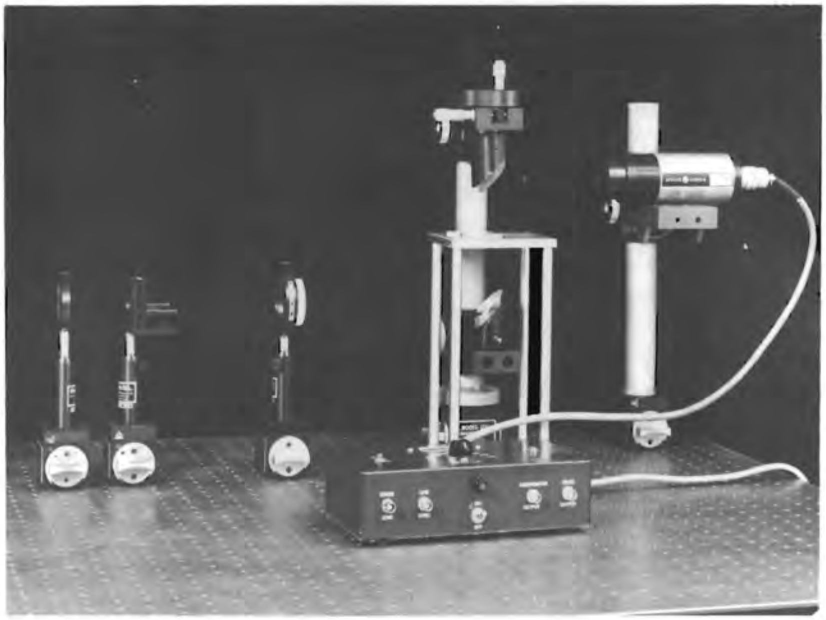

FIGURE 2. Optical Configuration for SWAMI. The light enters from the left of the photograph. The transparent substrates to be wetted are placed on the platform between the two mirrors of the periscope. The image of the shadow cast by the drop is projected onto the two-dimensional array detector shown at the right. The processing electronics are contained in the box in the foreground.

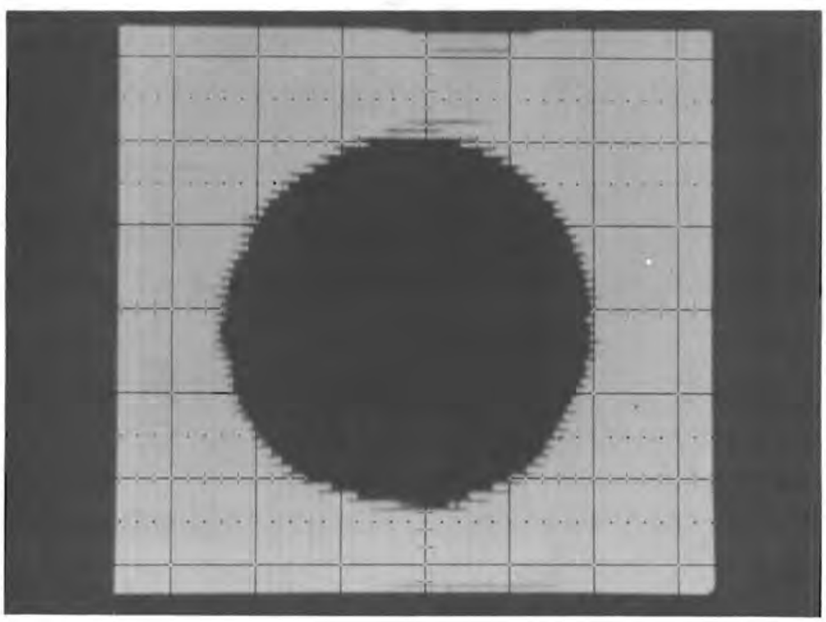

FIGURE 3. Typical Video Image of a Fairly Symmetrical Drop from the Array Detector, as Seen on a CRT Monitor

can influence the outcome of the tests significantly. In order the determine the extent to which surface variability affects the results of the wetting studies, several glass samples produced by different commercial processing techniques were used as substrates for the preliminary measurements.

The measurements were performed by placing fixed volume drops on the glass substrate surfaces and measuring the contact area using SWAMI. The distilled water drops were dispensed in 5 μl quantities using a metering pipette with a volumetric accuracy of ±1%.

Since water drops do not increase in size appreciably with time, only one measurement of each drop was necessary. A number of drops (5-10) were placed on each substrate to assure an adequate statistical sample.

At the onset of the study it was found that the results depended upon the preparation of the substrate surface prior to the actual evaluation. The method of cleaning the substrate significantly influenced the results.

A number of cleaning techniques were used which led to large deviations in the contact area for a given substrate. These techniques included cleaning with various commercial detergents and ultrasonic cleaning in a number of different solvents. In all cases the commercial detergents proved unsatisfactory, yielding highly scattered data. It was felt that the scatter may have been caused by residue left on the surface. Ultrasonic cleaning was discontinued after a review of the literature revealed that significant disruption of the surface was possible with glass substrates.

One technique that provided relatively consistent results was used for the remainder of the study on glasses. It entailed first gently wiping the substrate surface with a clean, lint-free cloth dipped in methanol. This was then followed by rinsing with distilled water and immediately blowing dry with freon gas. The substrates were then allowed to stand in a clean atmosphere for a minimum of 16 hours. Insufficient or accelerated drying led to consistently excessive wetting areas.

Once the samples were prepared, it was necessary to attach spacers on the surface to prevent contact with foreign surfaces. It was found that even casual contact with the aluminum support platform in the SWAMI would cause noticeable deviations in the results.

Glass surfaces produced by three different manufacturing processes were evaluated in the initial phase of the study. The substrates included annealed float, drawn and fusion glasses. Float glass is manufactured by floating the molten glass onto a bed of liquid tin and drawing off the sheet. Drawn glass is formed by drawing the sheet directly from the melt. Fusion glass is produced by overflowing a trough of molten glass to form a gr vity-drawn sheet. One might expect to see significant differences between the two surfaces of the float glass due to the infusion of tin and formation of tin oxides on the floated surface. These differences should not be present in the glasses manufactured by the other two processes.

The results of the study are shown in Tables 1 through 3. Each side of the samples was labeled for identification. For the fusion and drawn glass, the identifications were arbitrary. The tin bath side of the float glass was identified using ultraviolet fluorescence and labeled "A" in all cases. The mean area shown is a relative number based on the total unilluminated pixels on the detector array and is proportional to the actual contact area of the drop. The standard deviation of the five to ten sample average is also indicated. Two parameters of the standard t-test are also shown. Details of the test are discussed in Appendix B. "S" is the standard error of the difference between the two means, and "t" is defined as the ratio of the difference between the sample means to the standard error of the difference. The conclusion column indicates whether the two measurements are the same (S) or different (D), based on the observed deviations in the measurements. The percent difference in the means is also indicated for completeness.

The tables indicate that there is indeed a significant difference between the two sides of the float glass. The side of the glass which was in contact with the molten tin during processing does <u>not</u> wet as well as the atmospheric side in all cases, as shown in Table 1. Both sides of the drawn glass are statistically identical for the limited number of samples studied, as shown in Table 2.

TABLE 1. Wetting of Float Glass*

Sample No.	Side	Mean Area	Std. Dev.	s	t	Conc.	% Diff. in Means
51	A	1580	45	107.3	7.0	D	38.6
	B	2337	300				
52	A	2142	130	52	6.0	D	13.54
	B	2453	207				
53	A	1665	155	66.7	13.6	D	42.8
	B	2571	266				
66	A	1843	168	120.6	3.5	D	20.7
	B	2268	301				
67	A	1822	171	102.9	4.9	D	26.8
	B	2385	235				
68	A	1839	248	129.8	5.4	D	32.0
	B	2541	271				
57	A	1811	194	138.8	16.0	D	76.0
	B	4032	341				
58	A	2055	351	148.7	8.35	D	46.4
	B	3297	233				
59	A	1822	85	123.2	9.4	D	48.4
	B	2985	360				

*Side A on the float glass samples is the side that was in contact with the tin bath during processing.

TABLE 2. Wetting of Drawn Glass

Sample No.	Side	Mean Area	Std. Dev.	s	t	Conc.	% Diff. in Means
54	A	1371	70	47.0	1.91	S	6.8
	B	1281	115				
55	A	1759	140	55.2	1.76	S	5.7
	B	1662	71				
56	A	1606	141	57.0	0.03	S	0.12
	B	1608	57				

TABLE 3. Wetting of Fusion Glass

Sample No.	Side	Mean Area	Std. Dev.	s	t	Conc.	% Diff. in Means
61	A	1665	169	83.7	6.38	D	27.6
	B	2199	186				
62	A	2437	290	113.9	4.86	D	28.3
	B	1833	203				
69	A	2143	96	54	2.37	D	6.2
	B	2015	113				
70	A	2060	115	107.9	0.705	S	3.8
	B	1984	304				
71	A	2100	215	89.2	3.34	D	15.3
	B	1802	140				
63	A	1966	78	48.5	0.165	S	0.41
	B	1974	113				
64	A	2167	131	49.5	3.65	D	8.72
	B	1986	49				
65	A	2079	114	47.4	1.27	S	2.9
	B	2019	20				
153	A	2200	193	67.6	3.71	D	10.8
	B	2451	61				
154	A	2125	60	38.7	8.76	D	15.0
	B	2469	94				
155	A	2331	62	32.7	3.21	D	4.41
	B	2436	76				
156	A	2419	76	30.3	0.5	S	0.62
	B	2404	5				
157	A	2498	46	30.5	1.15	S	1.41
	B	2463	79				
158	A	2446	82	31.3	0.48	S	0.61
	B	2461	46				

The results on fusion glass were not as conclusive as the results on the other two glasses, as shown in Table 3. The t-test shows about half of the samples were statistically the same and half were different. No known differences in the manufacturing process would account for the observed results. However, local variations in the surface condition of the glass may be a contributing factor.

It should be noted that the magnification factors in the samples with numbers below 71 and above 153 were slightly different due to a change in the optical configuration of the SWAMI. Thus, the mean area numbers differ for the same drop contact area. However, this does not alter the conclusions discussed previously.

It can be concluded from the above tests that the results of wetting studies will be significantly affected by subtle changes in the surface chemistry and preparation of the substrate. It is therefore important to use identically prepared substrates for the wetting evaluation of the cleaning agents.

Cleaners on Glass Substrates

Thirty-one cleaners were tested for their ability to wet identically prepared glass substrates. The substrates were prepared as discussed previously and allowed to dry for a minimum of 36 hours. The cleaning agents were prepared as directed by the manufacturer. Measurements of contact area versus time were made at 15 second time intervals using the SWAMI.

Nine 3-μl drops of the cleaning agent were placed on the surface of the glass for each sampling. From the surface area measurement of these nine drops, the obvious outliers in the data were discarded. If more than two of the nine drops were outliers, the sampling was repeated. If no outliers were present, the high and low values of each sampling were discarded. The remaining seven drops of each sampling were averaged and the standard deviation of the measurement calculated. Samplings with exceptionally large (>20%) standard deviations were repeated.

In most cases the growth of the drop followed an exponential function, as discussed in the Introduction. The average growth curves for the cleaners tested are shown in Figures 4 and 5. The actual drop area (in square inches) can be roughly approximated by multiplying the relative area numbers in the figures by 10^{-5}. The magnitude of the experimental error bars associated with each curve vary greatly. They range from $\pm1\%$ to $\pm20\%$ of the relative drop area, depending upon the cleaner tested.

The curves should be compared with some degree of caution. The absolute magnitude of these curves depends greatly on the substrate preparation. Substrates that were dried for significantly less than 36 hours consistently led to larger values for the relative drop areas. The substrates dried for longer time periods yielded results comparable to those shown in the figures. In both cases the shape of the curves was similar.

The final area of the drop (A_f) and the time required for the drop to reach 90% of its final area ($t_{90\%}$) were calculated for each series of measurements as discussed previously. The results of these calculations are given in Table 4.

Interpretation of the results is straightforward. Cleaners numbered 88, 8, 91A and 18 started to evaporate before an equilibrium value for the contact area was reached. Therefore, the largest area attained was used as A_f. Cleaner No. 57B started evaporating immediately; therefore, the contact area at 15 seconds was used for A_f.

Figure 6 is a scatter diagram of the calculated data from Table 4. From this diagram it is possible to select a cleaner that would be most effective for a given cleaning strategy. If, for example, a cleaner that wets well in less than 15 seconds is desirable, then a logical choice would be No. 57B. If, on the other hand, the cleaning strategy would allow a relatively long time period to assure the best wetting, then Cleaner No. 59 would be a logical choice.

Cleaners on Plastic Substrates

Wetting studies were also performed on a small group of commonly used plastics. Substrates included a polycarbonate, a polyvinylfluoride, an acrylic, and a polyester. The cleaning agents that were used in the study are listed with their manufacturers or distributors in Appendix B. Again,

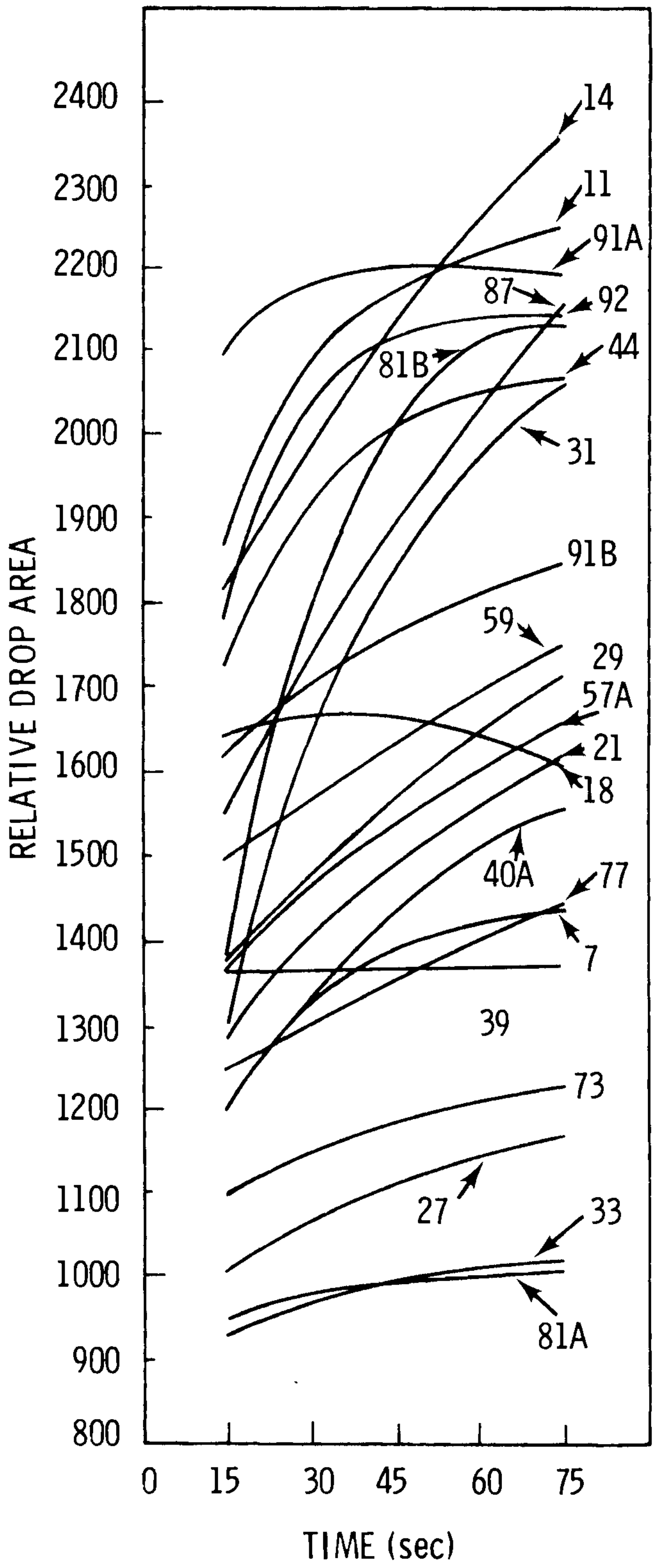

FIGURE 4. Wetting Characteristics for Selected Cleaners on Glass

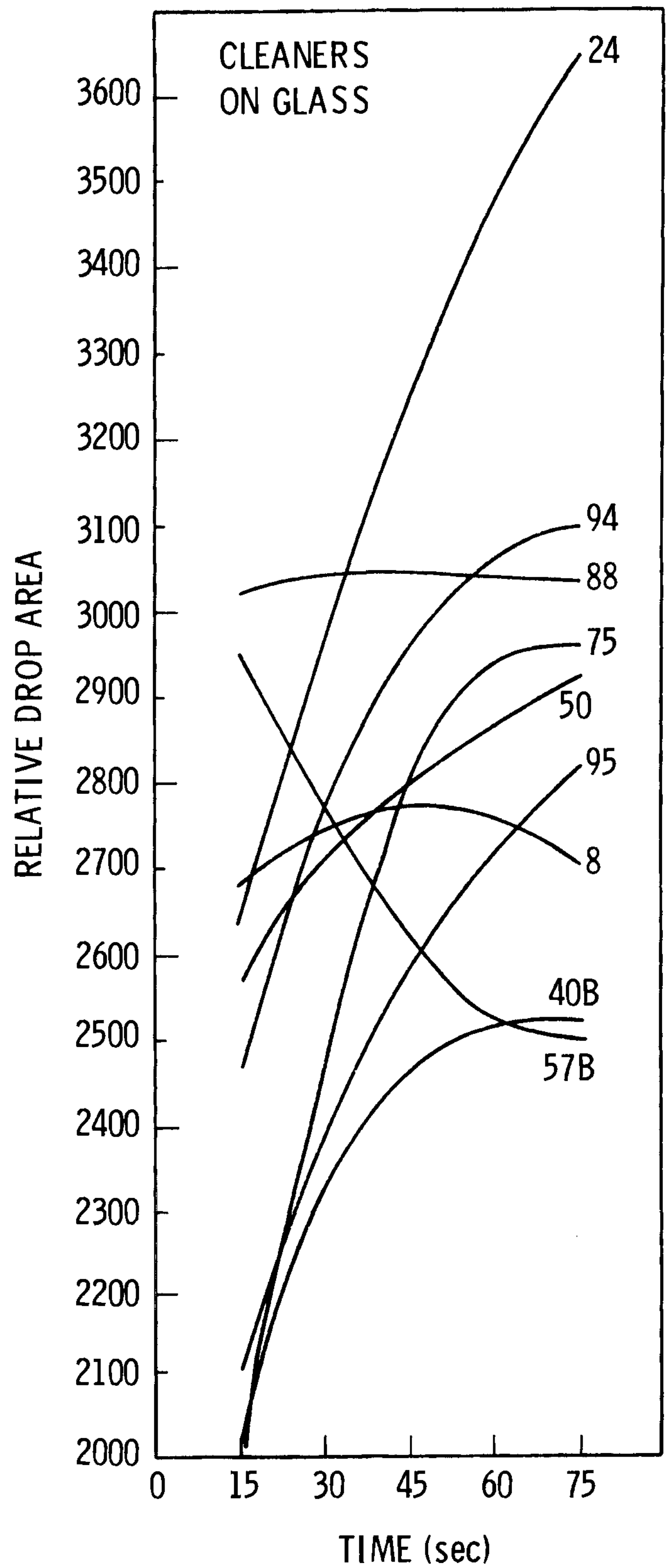

FIGURE 5. Wetting Characteristics for Selected Cleaners on Glass

TABLE 4. Relative Wetting Data for Selected Cleaning Agents on Glass

Cleaner Code	A_f	$t_{90\%}$
7	1453	51.3
8	2771	@45.0
11	2257	42.9
14	4235	573.3
18	1665	@39.0
21	1784	126.7
24	4517	180.5
28	1231	109.5
29	2687	464.1
31	2197	73.3
33	1055	114.0
39	1371	49.8
40A	1701	112.6
40B	2535	38.6
44	2081	47.5
50	3009	84.6
57A	1850	149.5
57B	>2945	<15.0
59	5684	2210.0
73	1255	83.3
75	3055	58.5
77	1974	439.5
81A	1019	64.9
81B	2183	52.2
87	2963	253.3
88	3210	@42.0
91A	2186	15.6
91B	1945	119.5
92	2141	29.5
94	3175	62.5
95	3011	90.7

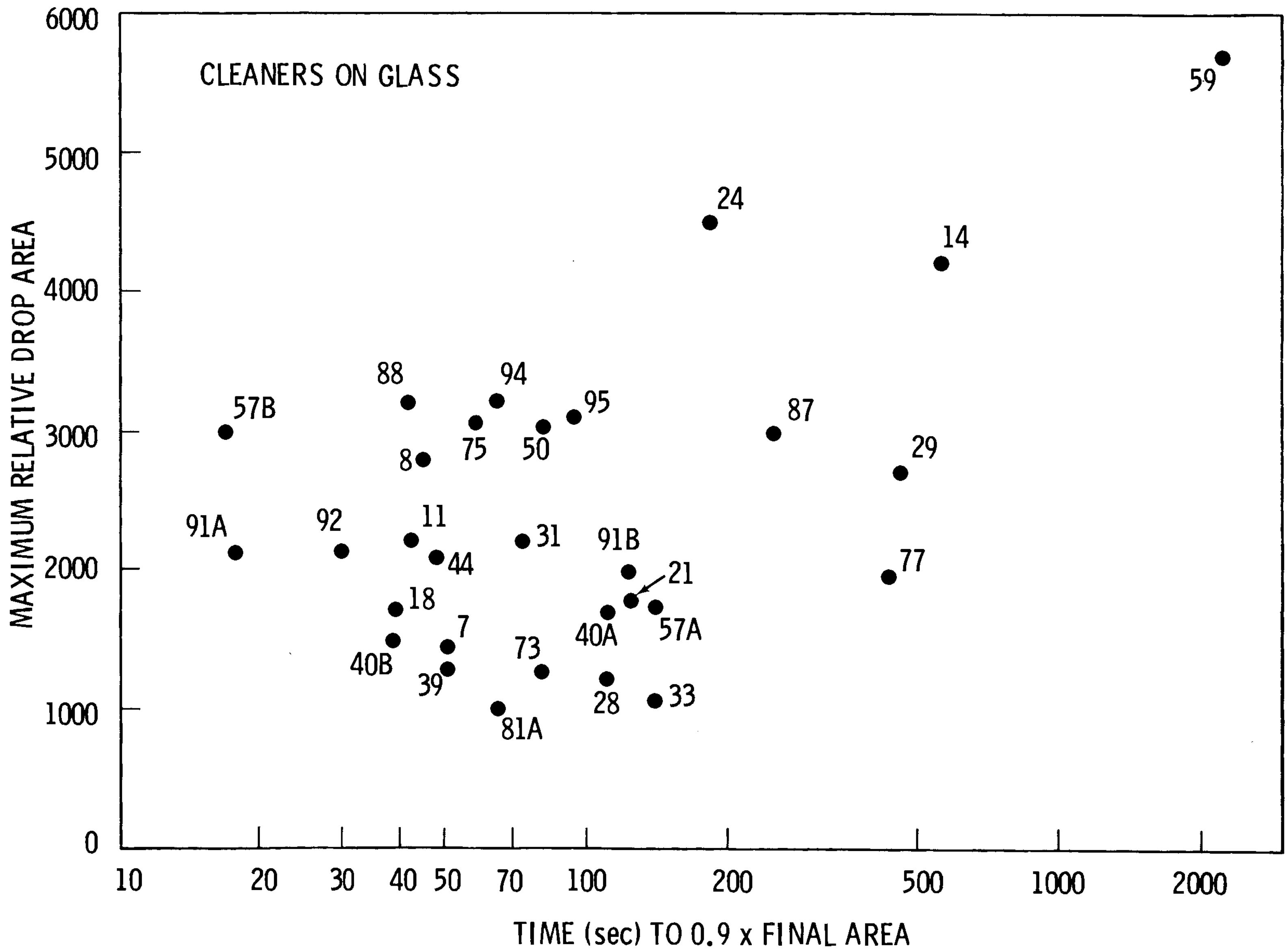

FIGURE 6. Scatter Diagram of Wetting Parameters for Selected Cleaners on Glass

no attempt was made to do an exhaustive study but only to screen selected commercially available agents recommended by the manufacturers.

The techniques used to perform the studies were nearly identical to those used in the section on glass cleaners, the only exception being in the pre-cleaning process. Since the surface of the plastic materials is considerably softer than glass, a cotton swab was substituted for the lint-free rag. Also, because some of the plastics are sensitive to alcohol, a detergent was substituted, followed by a lengthy rinse in deionized water.

The same caution should be applied in interpreting the wetting studies on plastics as was applied to the studies on glass. Large variability in the samplings is possible with small changes in the surface preparation. Substrates that were used repeatedly tended to wet better than the virgin material due to surface roughening and abrasion. Therefore, virgin material was used for the substrates whenever possible.

The wetting curves for the cleaners tested on each of the four plastic substrates are given in Figures 7-10. Tables 5-8 list the calculated values for the final area, A_f, and time necessary to reach 90% of that area, $t_{90\%}$. The scatter diagrams for A_f versus $t_{90\%}$ are given in Figures 11-14.

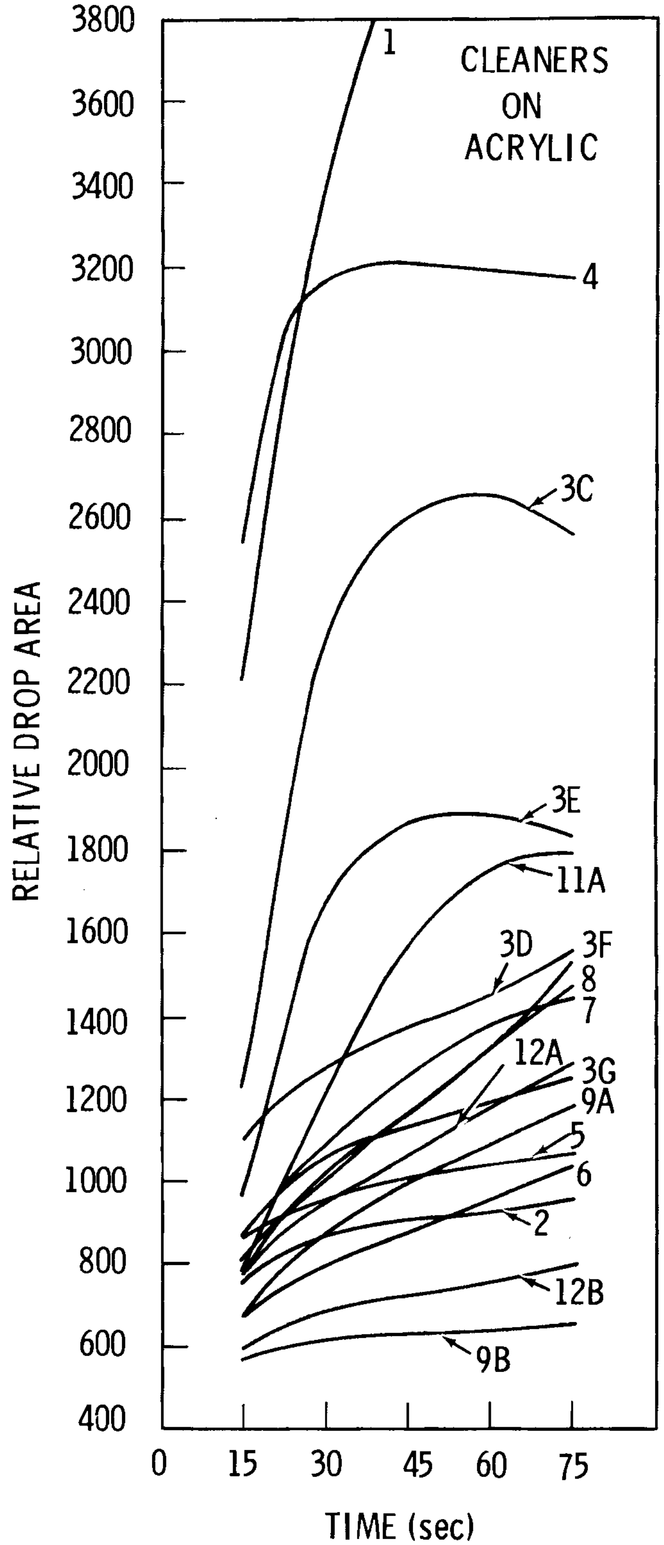

FIGURE 7. Wetting Characteristics of Selected Cleaners on Acrylic

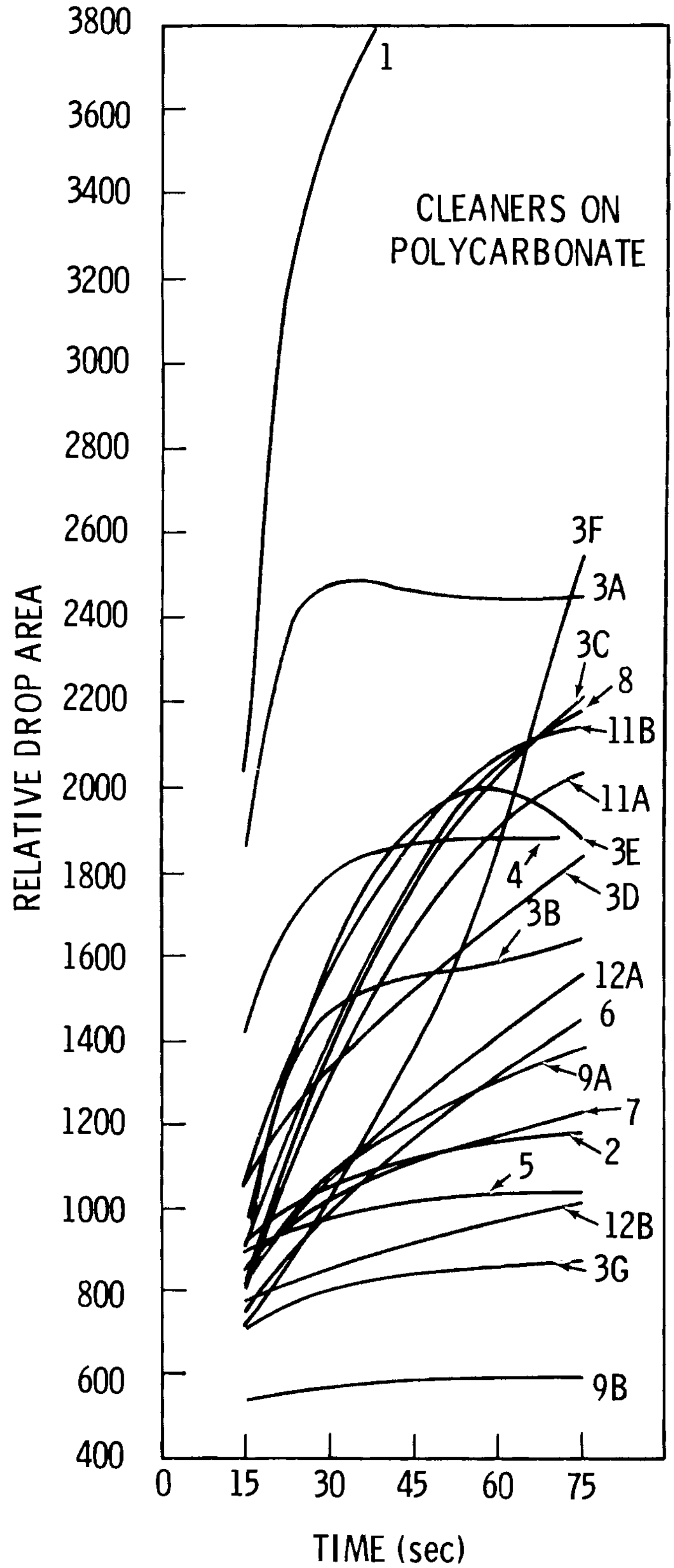

FIGURE 8. Wetting Characteristics of Selected Cleaners on Polycarbonate

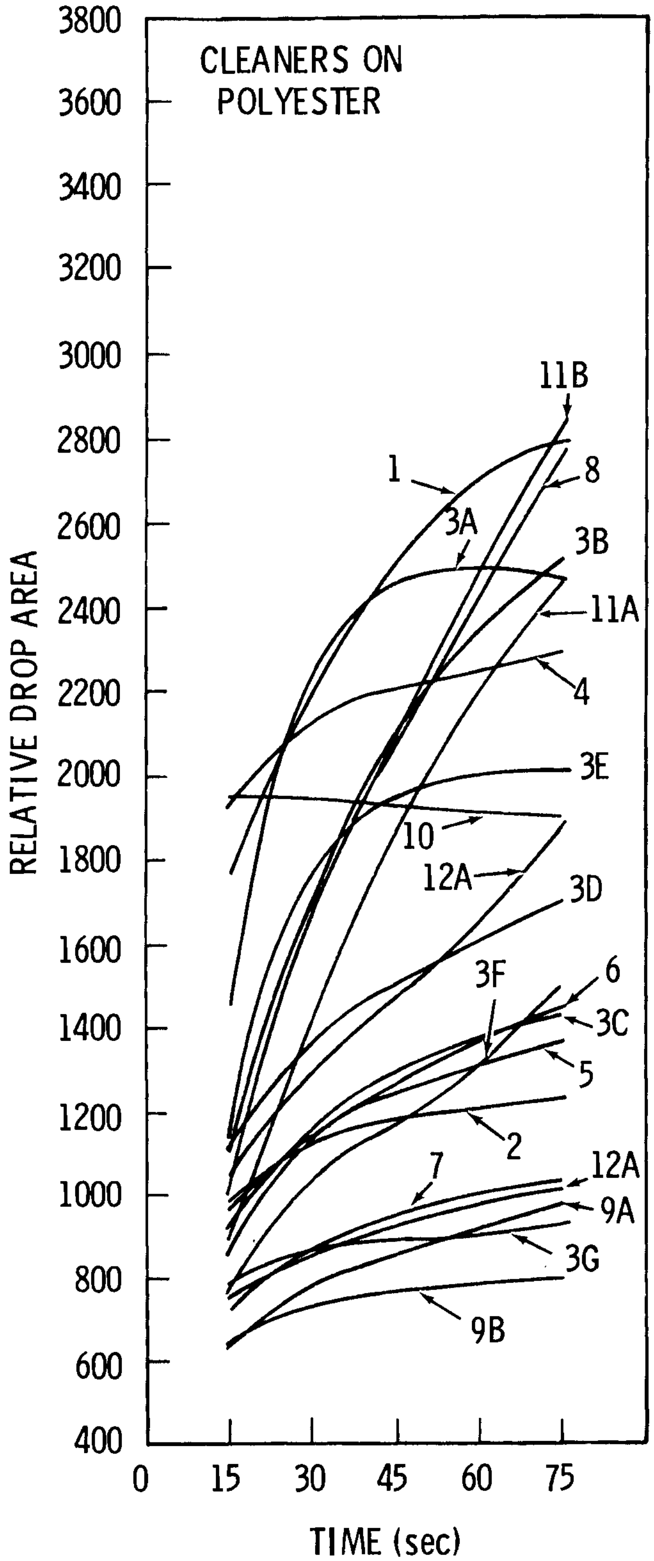

FIGURE 9. Wetting Characteristics of Selected Cleaners on Polyester

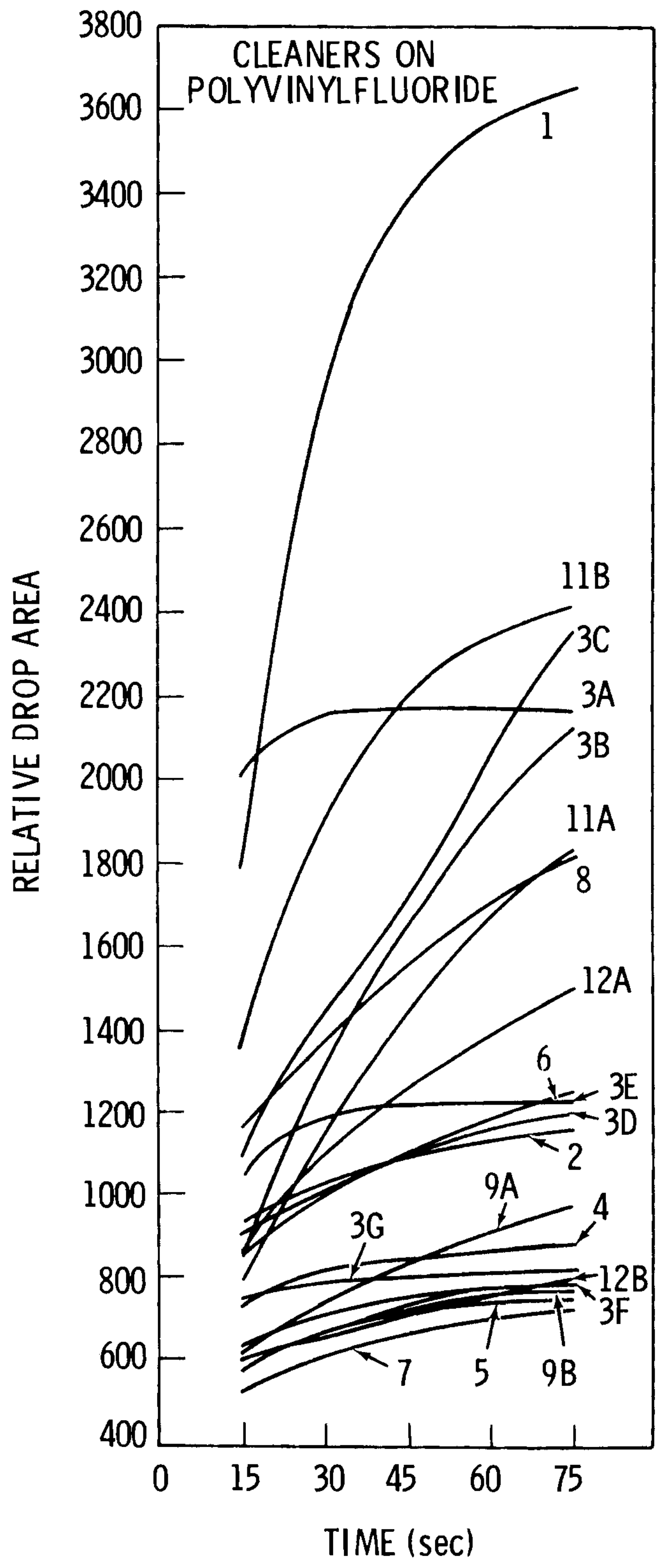

FIGURE 10. Wetting Characteristics of Selected Cleaners on Polyvinylfluoride

TABLE 5. Relative Wetting Data for Selected Cleaning Agents on Acrylic

Cleaner Code	A_f	$t_{90\%}$
1	4360	44.6
2	965	47.2
3A	2390	37.0
3B	2048	38.1
3C	2559	30.8
3D	1614	83.8
3E	1829	28.8
3F	1949	135.9
3G	1281	54.6
4	3198	50.0
5	1111	77.7
6	1350	177.5
7	1956	152.8
8	2499	278.9
9A	1314	86.7
9B	657	47.6
10	--	--
11A	2064	89.8
11B	2018	73.2
12A	1543	133.3
12B	850	99.7

TABLE 6. Relative Wetting Data for Selected Cleaning Agents on Polycarbonate

Cleaner Code	A_f	$t_{90\%}$
1	4141	33.0
2	1210	52.6
3A	2480	@30
3B	1642	28.8
3C	2636	98.3
3D	2315	139.8
3E	1880	37.4
3F	1010	@30
3G	888	50.2
4	1910	22.8
5	1039	38.3
6	2254	213.0
7	1304	71.6
8	2681	108.0
9A	1492	72.3
9B	598	52.3
10	--	--
11A	2485	104.0
11B	2338	67.2
12A	3041	344.0
12B	1294	211.6

TABLE 7. Relative Wetting Data for Selected Cleaning Agents on Polyester

Cleaner Code	A_f	$t_{90\%}$
1	3227	112.6
2	1241	36.7
3A	2470	29.4
3B	2693	67.8
3C	4184	59.1
3D	1830	80.5
3E	2022	32.4
3F	1766	105.5
3G	941	50.8
4	2304	44.6
5	1390	43.9
6	1701	129.2
7	1103	76.3
8	3473	112.1
9A	1064	84.3
9B	819	51.9
10	1950	15.0
11A	3730	174.1
11B	4378	186.3
12A	3124	268.2
12B	1138	113.6

TABLE 8. Relative Wetting Data for Selected Cleaning Agents on Polyvinylfluoride

Cleaner Code	A_f	$t_{90\%}$
1	3703	41.9
2	1159	80.9
3A	2167	@30
3B	2808	122.9
3C	1540	@30
3D	1338	99.7
3E	1222	20.6
3F	827	79.7
3G	799	33.2
4	892	50.8
5	763	54.4
6	998	@30
7	808	103.3
8	2403	187.9
9A	1199	146.0
9B	780	51.7
10	--	--
11A	2770	185.0
11B	2496	52.9
12A	1835	127.9
12B	981	210.0

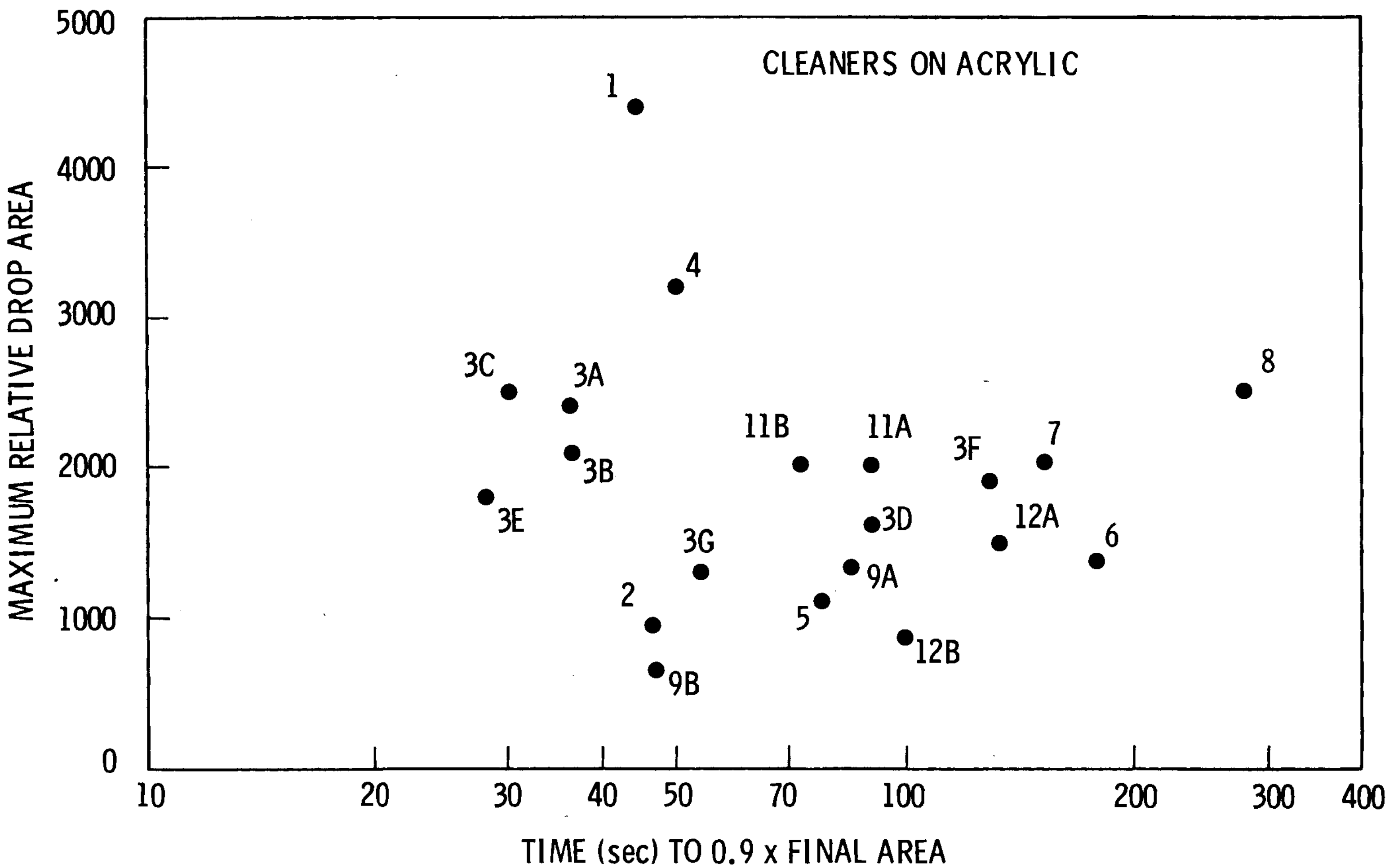

FIGURE 11. Scatter Diagram of Wetting Parameters for Selected Cleaners on Acrylic

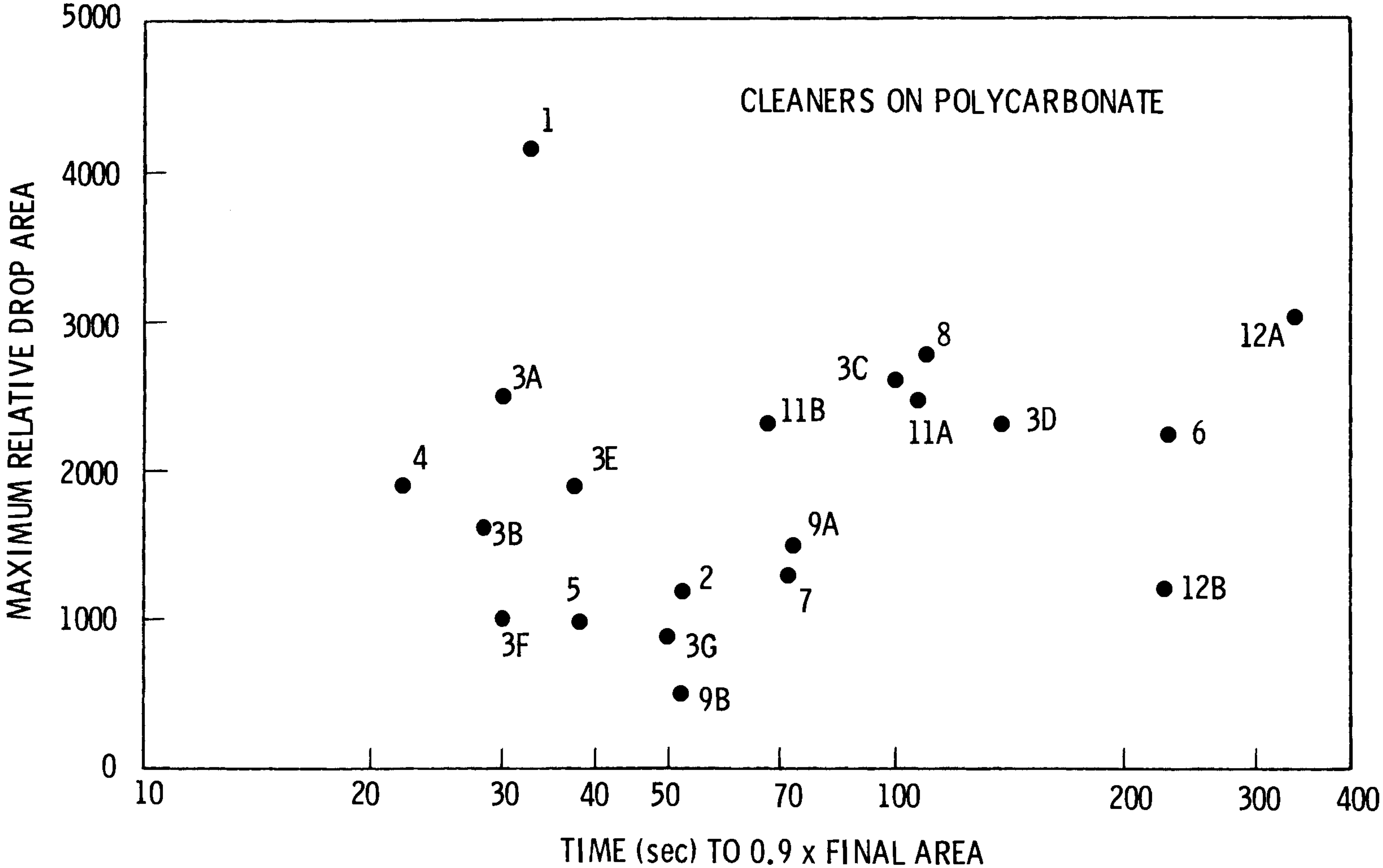

FIGURE 12. Scatter Diagram of Wetting Parameters for Selected Cleaners on Polycarbonate

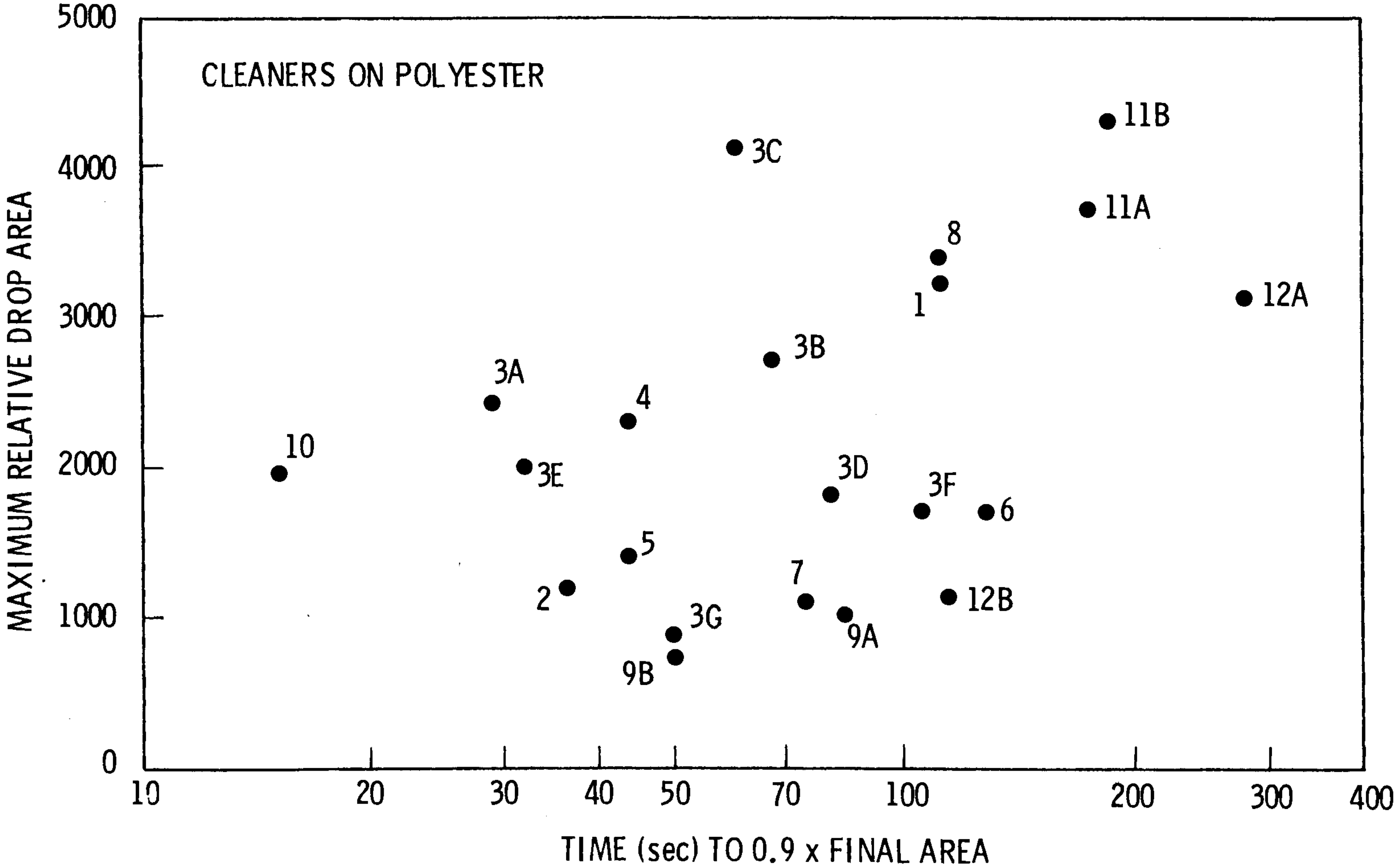

FIGURE 13. Scatter Diagram of Wetting Parameters for Selected Cleaners on Polyester

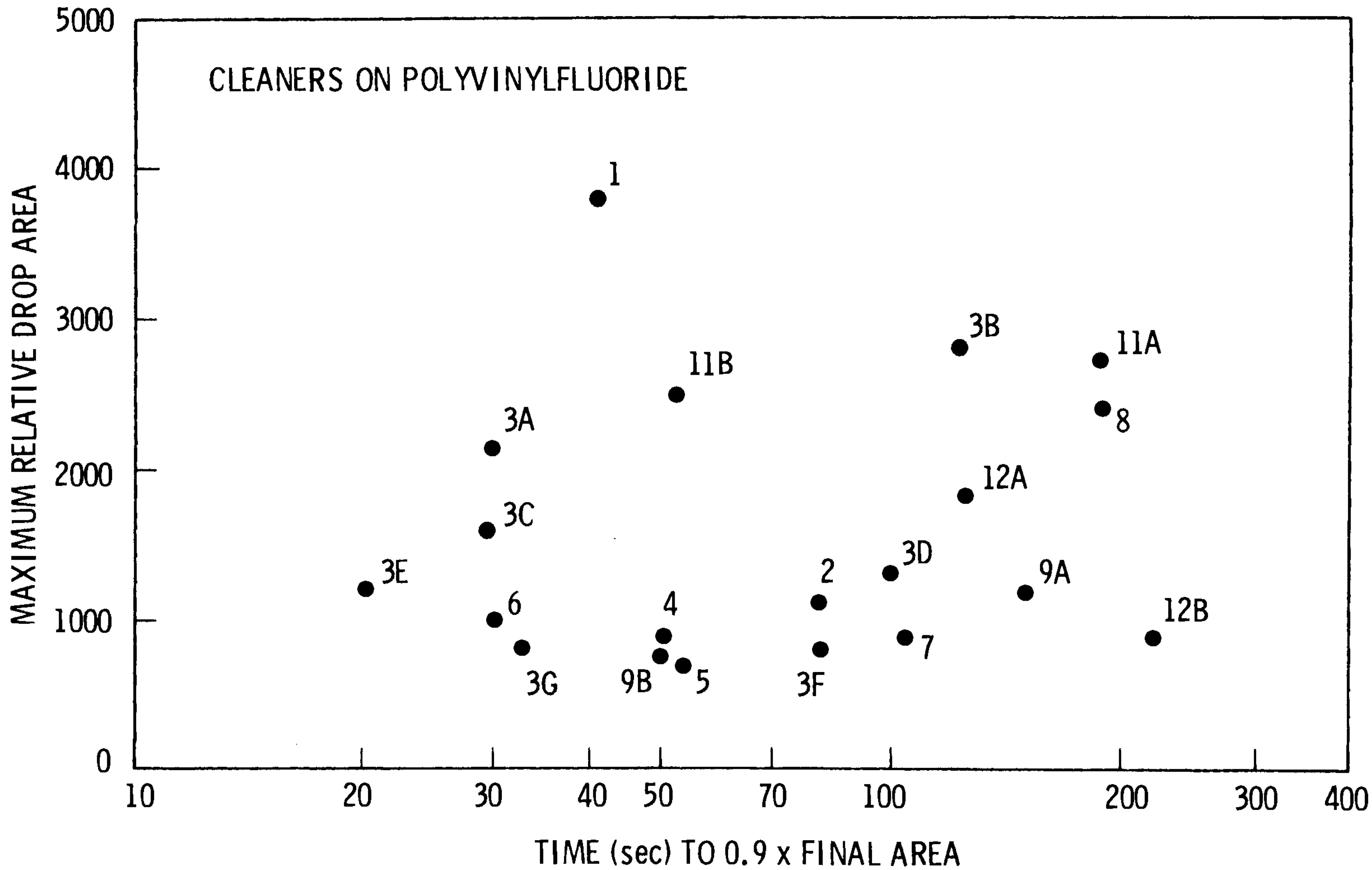

FIGURE 14. Scatter Diagram of Wetting Parameters for Selected Cleaners on Polyvinylfluoride

RESIDUE STUDIES

Background

The deleterious effects of the cleaning agents on the substrate after repeated application are also of concern when comparing the relative merits of cleaners. Residue buildup or changes in the surface of the substrate can cause losses in the transmittance or reflectance of the optical elements in a solar installation. The loss mechanisms are primarily due to absorption or scattering at the surface of the substrate.

Prospective cleaning agents should be screened for undesirable effects on the optical substrates to which they are applied. Keeping in mind a high pressure, noncontact cleaning strategy, a simple test apparatus was constructed to evaluate the effects of repeated applications of our group of glass cleaners under semi-realistic conditions. The basic idea was to spray on, rinse, and dry off the cleaning agent from a transparent substrate a few hundred times and compare the solar transmittance before and after the process.

Instrumentation

An apparatus was deisgned and constructed to spray rinse and air dry 2 inch x 2 inch samples with the cleaner of interest on a continuous basis. The device, which is shown in Figure 15, uses all glass sample holders and surroundings to eliminate the problem of residues formed by reactions with dissimilar materials. The apparatus can hold up to 13 samples on a 58 cm diameter rotating wheel. This wheel rotates at approximately 0.8 rpm, spraying each sample with cleaner for roughly 2.1 seconds/revolution. The rinse cycle occurs over the same period of time and in the same manner as the cleaner spray. For both cleaning and rinsing, an air brush type sprayer was used. Both sprayers are activated by N_2 at approximately 30 psi. It was felt that low pressure cleaning would produce the worst case conditions for residue buildup. Each sprayer is activated by a separate microswitch to avoid overspraying onto other samples and excessive use of cleaning solutions.

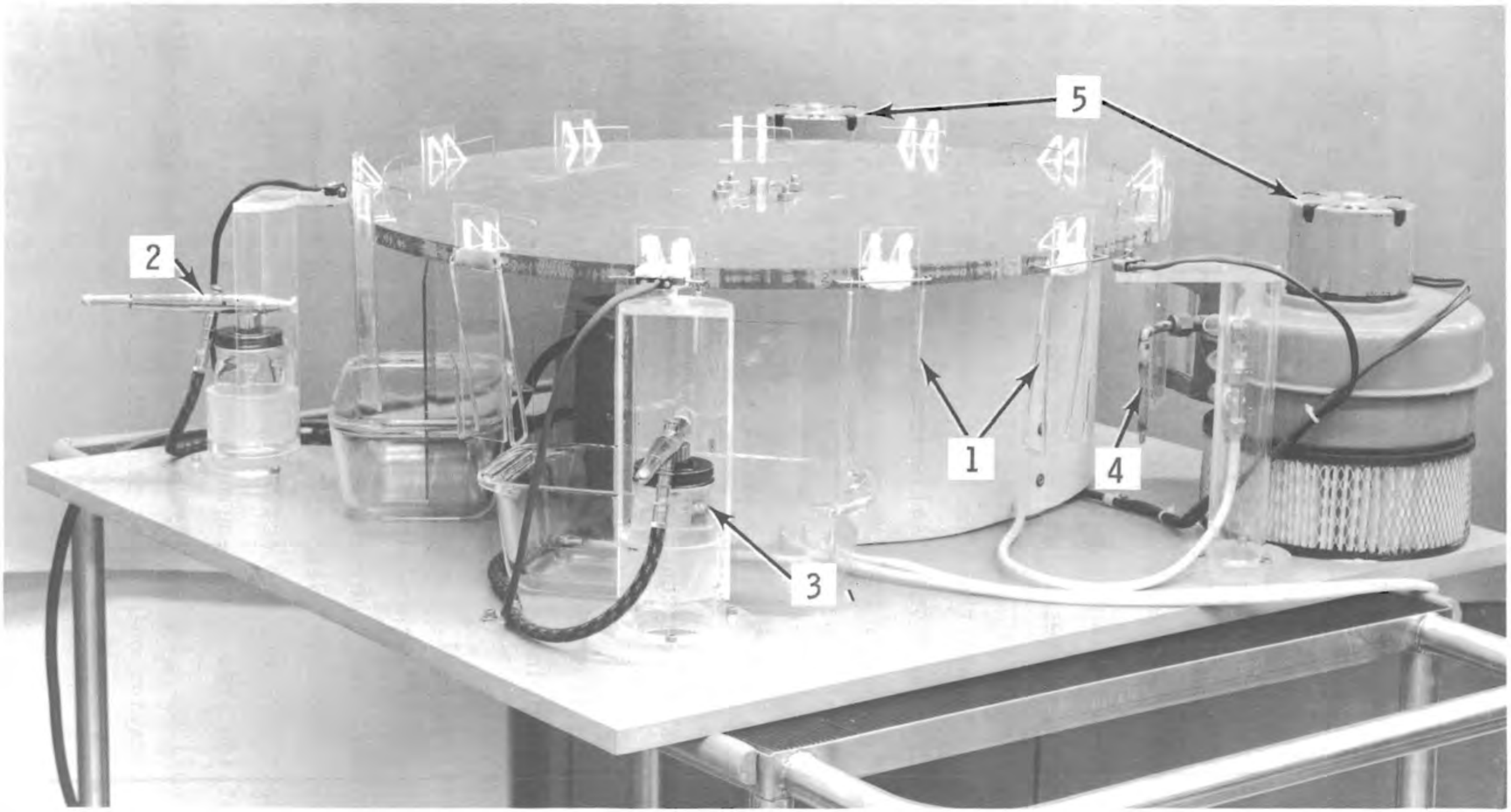

FIGURE 15. Photograph of Cleaner Residue Deposition Apparatus. Shown are: 1) the glass sample holders, 2) the airbrush liquid cleaner applicator, 3) the airbrush rinse applicator, 4) the airjet drying station, and 5) the filtered blower drying stations.

Drying of the samples may occur in three stages. The first (optional) stage is activated by a microswitch and blows N_2 at 30 psi onto the sample. This stage remove the larger droplets and sheets of rinse solution from the sample. The second and third stages of the drying process are identical and consist of two continuously running filtered blowers feeding air onto the samples at 160 cfm. The samples, after passing the drying stage, are then moved back to the spray wash stage. It should be noted that the spray wash, spray rinse and the first drying stage use 99.9% pure N_2 to avoid residue buildup due to the contaminants present in most compressed air sources.

The sprayers are adjusted so that roughly the top 70% of the sample is wetted by the direct spray and the lower 30% is wetted by runoff of the accumulated cleaning or rinsing agent. This positioning was chosen to enable the investigator to determine to what extent residue buildup in preceding cycles was removed by the force of the direct spray.

Residue on Glass Substrates

Only the glass cleaners previously evaluated for their wetting characteristics were examined for their residue buildup characteristics. Fusion glass was chosen for the substrate material.

The tests reported below were run without the use of the airjet first stage dryer since worst case conditions were of primary interest. The high pressure dryer removed most of the liquid from the substrate by displacement rather than evaporation. This results in a lower amount of residue being left by the cleaning agent than if the substrate was left to dry "naturally."

The cleaners were sprayed onto the glass substrates and air-dried for 200 cycles. The substrates were then removed and measured for their solar transmittance. The cleaning agents used in the tests were prepared according to the manufacturers' specifications. Neither the cleaning agents nor the rinse fluids were recycled during the tests.

Table 9 shows the loss in solar transmittance due to the buildup of cleaner residue. This loss was obtained by comparing the solar specular

TABLE 9. Transmittance Losses Due to Residue Buildup of Glass Cleaners After Repeated Application

Cleaner Code	ΔT (Average)	ΔT (Worst)
7	0.002	--
8	0.340	0.406
11	0.003	--
14	0.006	0.012
18	0.	--
21	0.	--
24	0.	--
28	0.003	--
29	0.	--
31	0.002	--
33	0.001	--
39	0.001	--
40A	0.008	0.016
40B	0.	--
44	0.004	--
50	0.002	--
57A	0.002	--
57B	0.003	--
59	0.	--
73	0.005	--
75	0.002	--
77	0.	--
81A	0.009	0.035
81B	0.007	0.035
87	0.045	0.102
88	0.001	--
91A	-0.007	--
91B	-0.007	--
92	0.003	--
94	0.002	--

($\sim$7°) transmittance of the substrate before and after the cleaning cycles. Moon's AM 2 spectral data[3] was used for the weighting.

The table shows both the average and worst case degradation observed for three substrates. The highest losses occurred in the lower 30% of the substrate where the spray was not directly incident on the surface. This implies that in many cases, the residue was prevented from reaching significant levels by the disruptive action of the direct spray.

The relative accuracy of the transmittance measurements is approximately $\pm$0.5%. Therefore, changes in transmittance on the order of 1% may be within the noise of the measurement. Only six of the tested cleaners (8, 14, 40A, 81A, 81B and 87) left any significant residue. Two cleaners (91A and 91B) left residues that actually increased the transmittance of the substrate slightly.

---

[3] P. Moon, "Proposed Standard Solar Radiation Curves for Engineering Use," Journal of the Franklin Institute 320:604, Table III, 1940.

FIGURE OF MERIT

Background

It is an interesting, although certainly speculative, exercise to construct a figure of merit for each of the cleaners in order to compare them. The formulation of a figure of merit must be sensitive to the cost and effectiveness of the cleaner, the cleaning strategy to be used, the cost of labor for application, and a large number of other variables.

The actual weighting given to the various parameters depends not only on the overall cleaning strategy, but also on the type and design of collector field. The figure of merit presented below is based on the following four assumptions.

- A heavy penalty should be paid by cleaning agents that reduce the solar transmittance of the sample. The argument can be made that in large central receiver reflector applications, the cost of adding additional heliostats to compensate for transmittance losses is proportional to $(1 - \Delta T)^{\alpha}$ where T is the transmission loss and $\alpha \geq 1$, depending on the size and configuration of the collector field.
- There is an optimum time in the cleaning strategy that the cleaner will be allowed to sit in order to achieve maximum wetting. A penalty should be assessed for cleaners whose optimum wetting time, $t_{90\%}$, is significantly different from the optimum time allotted in the cleaning scheme, t_{opt}.
- The performance of the cleaner is directly proportional to how well it wets the surface of the material to which it is applied at the optimum time. Thus, the figure of merit should be proportional to $A_f(t = t_{opt})$.
- The figure of merit should also be inversely proportional to the cost of the product, K.

Combining these factors and making some reasonable assumptions about the magnitude of α and t_{opt}, the figure of merit could be written as

$$M = \frac{[1 - \Delta T]^2 A_f(t = 20)}{K} . \qquad (13)$$

Results for Glass Cleaners

Based on Equation (13), the results of our previous investigations and the cost data supplied in Table 10, M can be calculated for the glass cleaners that were tested. The costs are for the diluted, ready-to-apply solutions. They are calculated from the manufacturer's suggested retail price for 55 gallon drums of concentrate supplied in large quantities FOB their point of origin. The values of M are displayed graphically in Figure 16. Given the previous assumptions, the largest values for M represent the most desirable cleaners.

Again, it should be emphasized that this figure of merit is somewhat arbitrary and should be viewed as such. The actual "best" cleaner will depend on the exact cleaning strategy that is employed.

TABLE 10. Cleaning Solution Cost and Relative Figure of Merit

Cleaner Code	K(¢/gal.)	M
7	1.96	636.22
11	8.42	231.62
14	175.00	10.57
18	168.00	9.83
21	138.00	9.65
24	5.37	551.02
28	0.63	1620.39
29	3.50	402.57
31	127.00	11.25
33	1.63	577.37
39	27.27	49.95
40A	9.70	127.02
40B	8.33	257.98
44	12.94	138.38
50	395.00	6.63
57A	1.28	1093.27
57B	21.18	135.44
59	71.78	21.16
75	3.51	314.78
75	1.08	2024.29
77	13.58	93.15
87	3.88	380.56
88	2.80	1081.05
91A	20.88	103.59
91B	26.50	63.10
92	38.70	48.72
94	505.00	5.10

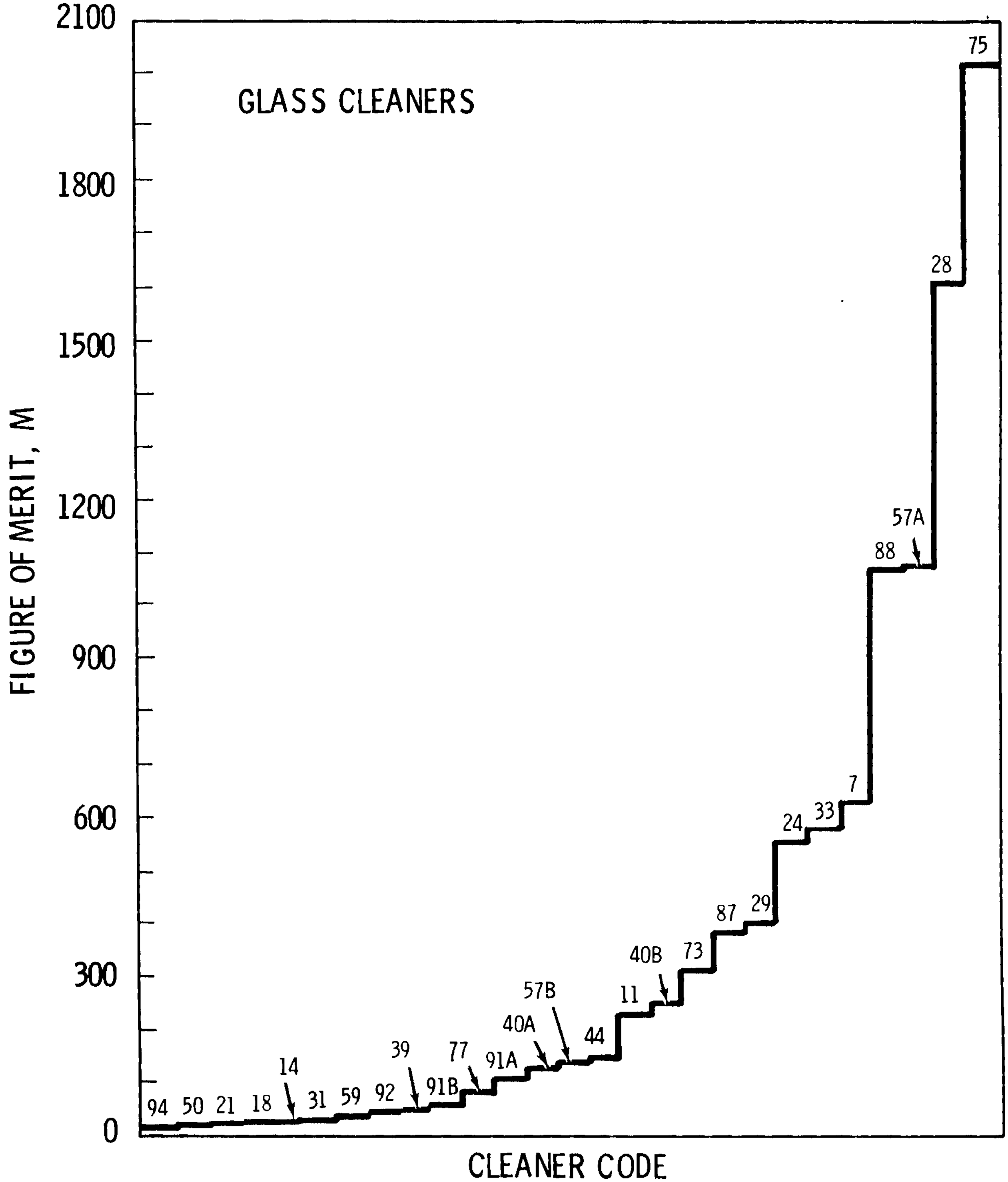

FIGURE 16. Figure of Merit for Glass Cleaners Used in Non-Contact Cleaning in Solar Application

ACKNOWLEDGMENTS

The authors wish to thank Tim Stewart and Mike Nordmeyer for their many long hours of data gathering and analysis.

APPENDIX A

MANUFACTURERS AND DISTRIBUTORS OF GLASS CLEANERS

Company Name and Address	Reply
Abso-Clean Chemical Co. 17325 Lamont Detroit, MI (313) 366-3820	No cleaner available to meet requirements (Not applicable)
Acme Chemical Co. 2506 N. 32nd St. Milwaukee, WI (414) 442-6321	Not applicable
Aero Wash Systems, Inc. Terry Industrial Park 336 Terry Dr. Trevase, PA (215) 355-8025	Not applicable
L. B. Allen Company, Inc. 9339 Bernice Ave. Schiller Park, IL (312) 678-3097	Their cleaner is an alcohol, ammonia and water mixture that would evaporate too rapidly and leave streaks, so is not applicable.
Amchem Products, Inc. Box 33 Ambler, PA (215) 628-1000	Company no longer at this location.
Ames Chemical Co. 31780 Franklin Fairway Farmington, MI (313) 851-2690	Not applicable
Angler Chemical Co. 100 Messenger St. Plainville, MA (617) 695-9311	Chempol 104 is a cleaner for Kilben Glass Co. It is slightly acidic and non-alcohol based. It is good for Coilzac. A sample will be sent.
Argo & Company, Inc. 178 Ezell St., P.O. Drawer 2747 Spartanburg, SC (803) 583-9766	Argosheen is a synthetic, non-alcohol based rug cleaner with emulsifier and 10% petroleum content. A sample will be sent.
Barco Chemical Products Co. 703 S. LaSalle St. Chicago, IL (312) 427-2916	A mixture of agents similar to Windex is made by Procter & Gamble. Calling Procter & Gamble in Cincinnati concerning their Arvus wetting agent was suggested.

Company Name and Address	Reply
Bernard's Laboratories, Inc. 1632 Walnut St. Cincinnati, OH (513) 621-6924	Not applicable
Bestline Non-Polluting Prod., Inc. 1100 Touhy Ave. Elk Grove Village, IL (312) 437-2555	B-15, a synthetic cleaner with chelating agents, various surfactants and drying agents, will be sent.
Boston Chemical Industries, Inc. 168 A St. South Boston, MA (617) 269-0555	Not applicable
Boyer Chemical Co. 1609 Church St. Evanston, IL (312) 475-1005	They no longer carry glass cleaners; not applicable.
CMC Laboratories Co., Inc. 122 W. Houston St. New York, NY (212) 675-8210	A synthetic detergent that is sprayed on, let stand, and followed with a rinse was suggested. A sample will be sent.
Carhoff Co. 13404 St. Claire Ave. P.O. Box 10480 Cleveland, OH (216) 541-4835	Not applicable
Cello Chemical Company, Inc. 968 Easton Rd. Warrington, PA (215) 343-1250	A brief outline of the problem was requested in order to work up solutions in the laboratory.
Chemclean Corporation 128-05 18th Ave. College Point, NY (212) 445-2330	A mildly alkaline water-based butyl was suggested. No. 101, which is a mixture of amides, sodium, LAS salt, and complex phosphates, will be sent. (Glycol ether solvents need wetting agents in rinse; perhaps 0.01% rinse additive formulated with cleaner.)

Company Name and Address	Reply
Chemical Products Co. 1213 Jackson Omaha, NB (402) 345-5432	A windshield cleaner concentrate that lowers surface tension was suggested. Kleenmaster, a cleaner used to clean large buildings, will be sent. The cleaner is sprayed on and does not have to be rinsed off.
Chemtronics, Inc. 45 Hoffman Ave. Hauppauge, NY (516) 582-3322	It was suggested that chandelier cleaner with antistatic ingredients be used. This was also felt to be economically feasible.
Claire Manufacturing Co. 7620 S. Harvard Chicago, IL (312) 543-7600	Not applicable
Classic Chemical Co. 16th and Nickel Sts. Camden, NJ (609) 964-7006	It was suggested to use a wetting agent in the rinse or lower the surface tension of the rinse with non-ionic surfactants and follow with a rinse of demineralized water. A sample will be sent.
Crescent Chemical Corp. 460 Market St. Perth Amboy, NJ (201) 826-3630	Not applicable
The Drackett Co. 5020 Spring Grove Ave. Cincinnati, OH (513) 632-1500	Not applicable
Du Bois Chemicals Division of Chemed Corp. 1314 Du Bois Tower Cincinnati, OH (513) 762-6795	Flow, a Lectro-Safe solvent in which no rinsing is required, will be sent.
Dytex Chemical Co. 372 Central Ave. Pawtucket, RI (401) 724-6300	Not applicable
Easterday Supply Co. 901 E. 61st Los Angeles, CA (213) 231-9131	Not applicable

Company Name and Address	Reply
Edison Chemical Co. 71 Amory Boston, MA (617) 442-0270	An alcohol-based cleaner will be sent.
Emulso Corp. 299 Ellicott St. Buffalo, NY (716) 854-2889	No. 999 dishwashing liquid, a non-phosphate, synthetic cleaner, will be sent. Our problem was thought to be similar to cleaning glass in dishwashers.
Environmental Control Sys., Inc. 409 Washington Ave. Baltimore, MD (301) 296-7859	A sample of non-streak, non-film synthetic cleaner will be sent.
Epic Chemical, Inc. 93 Coffey St. Brooklyn, NY (212) 625-3180	Not applicable
Essential Chemicals Corp. 28391 Essential Rd. Merton, WI (414) 691-3000	Cleaner No. 103, an isopropyl-based cleaner with a wetting agent, will be sent.
Federal International Chemicals 1191 S. Wheeling Rd. Wheeling, IL (312) 541-9000	Not applicable
Alex C. Fergusson Co. Spring Mill Dr. Frazer, PA (215) 647-3300	A sample of synthetic cleaner Lance will be sent.
Fuld-Stalford 1354 Old Post Rd. Havre De Grade, MD (301) 939-1234	See Cello Co.
A. J. Funk & Company, Inc. 1471 Timber Dr. Elgin, IL (312) 741-6760	Not applicable

Company Name and Address	Reply
Gail Industries 621 4th Ave. SE P.O. Box 1864-T Cedar Rapids, IA (319) 366-6241	Not applicable
Golden Star Polish Mfg. Co., Inc. 400 E. 10th Ave. North Kansas City, MO (816) 842-0233	Produce foam cleaner only; not applicable.
Gold Seal Co. P.O. Box 1698 Bismark, ND (701) 223-4880 NJ: (201) 273-4990	Chandelier cleaner recommended (see Hylon-Hoburn Chemicals, Inc.).
Haviland Products Co. 421 Ann St. NW Grand Rapids, MI (616) 361-6691	A sample will be sent.
Hillyard Chemical Co. 302 N. 4th St. St. Joseph, MO (816) 233-1321	A synthetic to buffer minerals in water and get rid of hydrocarbons was suggested. Synthetic cleaners No. 153 and Topclean will be sent.
Holbrook Industries, Inc. 604-T River St. Grand River, OH (216) 352-2411	No cleaner was available to meet requirements at present, but one could be designed.
Howell Bros. Chemical Labs 5414 W. Sirard Ave. Philadelphia, PA (215) 477-0260	A glass detergent, One-Step Cleaner, will be sent.
Phillip A. Hunt Chemical Corp. Organic Chemical Division Massasoit Ave. P.O. Box 4249 East Providence, RI (201) 944-4000	Not applicable
International Products P.O. Box 118 Trenton, NJ (609) 394-5480	A sample of Micro, an EDTA synthetic cleaner with a chelating agent, will be sent.

Company Name and Address	Reply
Hylon-Hoburn Chemicals, Inc. 20 S. 2300 W. A Salt Lake City, UT (801) 364-6580	They represent Sparkle-Plenty Co.
J. Chemical Works 602 W. 37th St. New York, NY (201) 656-5238	Not applicable
Jacks Manufacturing Co. B St. Mendota, MN (612) 452-1474	To avoid the problem of streaks resulting from the use of ammonia, a mixture of 30-40% isopropyl, 60% soft water, and a small amount of Triton X-100 wetting agent was suggested.
Jasco Chemical Corp. Terra Bella at Linda Vista Mountain View, CA (415) 968-6005	Not applicable
Kano Laboratories, Inc. 1079 Thompson Lane Nashville, TN (615) 833-4101	Not applicable
Klean Strip Division P.O. Box 1879 Memphis, TN (901) 775-0100	A sample of an alcohol-based cleaner that uses ethyl glycol to increase wetting time will be sent.
Knicks Mend-Rite Co. 1443 Gentry North Kansas City, MO (816) 842-0233	Not applicable
Lan-O-Sheen, Inc. 1 W. Water St. Paul, MN (612) 224-5681	Not applicable
Mac's, Inc. P.O. Box 391 Dubuque, IO (606) 329-3743	Mac's 8000 glass cleaner concentrate for autos, which contains phosphates and must be diluted 1 qt./20 gal. water, is suggested. It can be purchased at NAPA auto stores.

Company Name and Address	Reply
Magnuson Products Corp. 50 Court St. Brooklyn, NY (212) 625-0190	Not applicable
Maintenance Products, Inc. 797 W. Commercial St. Lowell, IN (219) 696-6411	Not applicable
Manostat Corp. 519 8th Ave. New York, NY (212) 594-6262	Not applicable
Mellocraft Co. 1320 Locust P.O. Box 567 Toledo, OH (419) 243-6100	A sample of No. 346 Sprazit, an alcohol, glycol and ether cleaner, will be sent.
Memer, Inc. 1830 Ellsworth Andus Dr. NW Atlanta, GA (404) 355-4580	Most of the cleaners carried are alcohol-based and will leave a film if not wiped. A sample will be sent.
Merix Chemical Co. 2234 E. 75th St. Chicago, IL (312) 221-8242	Merix 100 gal. wash concentrate with 100:1 dilution and desynthesizing agent will be sent.
Michelman Chemicals, Inc. 9090 Shell Rd. Cincinnati, OH (513) 793-7766	Not applicable
Midland Laboratories, Inc. 210 Jones St. Dubuque, IO (319) 743-3226	Produce foam cleaner only; not applicable.
Mitchell Manufacturing Corp. P.O. Box 65 Wood River Junction, RI (401) 364-7731	Not applicable

Company Name and Address	Reply
Mohawk Finishing Prod., Inc. Perth Rd. Amsterdam, NY (518) 843-1380	Not applicable
National Cleanser Prod. Co., Inc. 437 11th Ave. New York, NY (212) 563-6377	See J. Chemical Works
National Laboratories Lehn & Fink Indus. Prod. Div. 225 Summit Ave. Montvale, NJ (201) 391-8500	Not applicable
New Haven Heat Treating 454 Grand Ave. New Haven, CT (203) 787-1269	Not applicable
Nyco Products Co. 3021 W. 36th Chicago, IL (312) 847-3484	Not applicable
Oakite Products, Inc. 50 Valley Rd. Berkeley Heights, NJ (201) 464-6900	Oakite Surfcon 300 organic acid cleaner will be brought in when available by local sales representative.
Octagon Process, Inc. 12 Archer Ave. Edgewater, NJ (201) 945-9400	Cleaner No. 3677, which was sent to us for plastics, was suggested for use on glass also. Feedback on how it performs was requested, with the formula to be modified accordingly.
Penetone Corp. 70 Hudson Ave. Tenafly, NJ (201) 567-3000	Not applicable
Puritan Chemical Co. 916 Ashby St. NW Atlanta, GA (404) 872-0721	Glint Cleaner in a dilution of 10:1 with water will be sent.

Company Name and Address	Reply
Reefer-Galler, Inc. 105 Hudson Jersey City, NJ (201) 434-1300	Not applicable
Reily Chemical Co. 450 Mandeville St. P.O. Box 50372 New Orleans, LA (504) 488-0889	Foampak Formula 200 will be specially formulated for us with wetting agents reduced since surface has no grease. A cationic wetting agent is used to eliminate electrostatic adhesion force.
Riverside Chemical Co., Inc. River & Rasch Rds. North Tonawanda, NY (716) 692-1350	A fluorinated solvent, Genosolve (triflorotrichloromethane - liquid freon), will be sent.
Rosenthal Cleans-Quick Corp. 30995 Industrial Rd. Livonia, MI (313) 341-2880	An alcohol-based cleaner will be sent.
Rothlan Corp. P.O. Box 5074 St. Louis, MO (314) 383-5254	Not applicable
Sanivan Laboratories, Inc. 222 Liberty Camden, NJ (609) 966-0660	A sample containing two types of alcohol and a small amount of detergent will be sent.
Stan Sax Corp. 5659 Lauderdale Ave. Detroit, MI (313) 366-3820	Not applicable
Sentinel Soap & Chemical Co., Inc. 3819 Emerson Ave. S. Minneapolis, MN (612) 824-5100	Not applicable
E. B. Snyder Laboratories 1218 20 Shackamaxon Philadelphia, PA (215) 426-9585	Not applicable

Company Name and Address	Reply
Solar Kinetics, Inc. 147 Parkhouse St. P.O. Box 10764 Dallas, TX (214) 747-6519	Samples of SKI-500 Solar Reflector Cleaner and SKI-5001 Solar Reflector Rinse Agent will be sent.
Solventol Chemical Prod., Inc. 13177 Huron River Dr. Romulus, MI (313) 941-3800	GL Spray, a concentrated synthetic glass cleaner with a wetting agent and a solvent, will be sent.
Sparkle Plenty 625 N. Michigan Chicago, IL (312) 266-1700	A one-qt. sample of chandelier cleaner will be sent.
Sprayaway, Inc. 484 Vista Ave. Addison, IL (312) 628-0998	Not applicable
State Chemical Manufacturing Co. 3100 Hamilton Ave. Cleveland, OH (216) 861-7114	Synthetic Cleaners Nos. 222, 174, or 999, which have cationic wetting agents, will be delivered by local sales representative. (Filtering rinse water with activated charcoal to remove dissolved minerals was suggested.)
Stoners Ink Co. Quarryville, PA (717) 786-7355	Not applicable
Sunshine Chemical Corp. P.O. Box 17041 West Hartford, CT (203) 232-9227	A synthetic that has a high-performance wetting agent, a chelating agent, and is synergistic, will be sent.
Texo Corp. 2801 Highland Ave. Cincinnati, OH	Car Wash AD, a synthetic-based cleaner, will be sent.
Trico Products Corp. 817 Washington St. Buffalo, NY (716) 852-5700	Not applicable

Company Name and Address	Reply
Trio Chemical Works, Inc. 345 Scholes St. Brooklyn, NY	Not applicable
Turco Products Division 24600 S. Main St. P.O. Box 6200 Carson, CA (213) 835-8211	Samples of the cleaning concentrates Turco 5366 LPH and Turco Rinse will be sent.
Twin Specialties Corp. Suite 154 111 Presidential Blvd. Bala-Cynwyd, PA (215) 664-1744	A sample of Twin Super Wash will be sent.
U. S. Chemical Corp. 5400 E. 59th St. Kansas City, MO (816) 333-5900	Not applicable
U. S. Aviex Co. 1056 Huntley Rd. Niles, MI (616) 683-6767	A sample of an ammoniated alcohol-based cleaner will be sent.
Universal Shellac & Supply Co., Inc. 495-T W. John St. Hicksville, NY	A sample of GTC-59, a water repellant, anti-static, anti-fog cleaner that produces a protective coating on glass, will be sent.
Water Soluble Products Div. 725 County Line Rd. Deerfield, IL (312) 675-1566	Not applicable
Western Chemical Co. 417 S. 4th St. Joseph, MO (816) 279-1681	Not applicable
Williams Chemical Corp. 3950 NW 31st Ave. Miami, FL (305) 633-0148	A sample of Will-Clear cleaner will be sent.

Company Name and Address	Reply
Wis-King, Inc. 14 Spielman Rd. Fairfield, NJ (201) 227-3710	Not applicable
Zep Manufacturing Co. 3008 Olympic Indus. Blvd. Atlanta, GA (404) 355-3120 WA: (206) 228-2100	Samples will be sent.
Zoned Soap Co. 824 W. Main Fort Wayne, IN (219) 424-8188	Not applicable
Zophar Mills, Inc. 100 26th St. Brooklyn, NY (212) 768-0907	Not applicable

APPENDIX B

MANUFACTURERS AND DISTRIBUTORS OF PLASTICS CLEANERS

Company Name and Address	Samples Sent
Brulin & Co., Inc. P.O. Box 270B Indianapolis, IN 46206	Laminade
Chemical Products Co. 1213 Jackson Omaha, NB	Kleenmaster
E.I. DuPont de Nemours & Co, Inc. Wilmington, DE 19898	Alkanol WXN, Duponol WA, and ZOYNL-FCS, ZOYNL-FSN, ZOYNL-FSB
Herbert Stanley Co. Skokie, IL 60076	Weiman Chandelier Rinse
Kleen Chemical Manufacturing Co. 2501 N. Sheffield St. Chicago, IL 60614	Space-B-Kleen
Kodak 343 State St. Rochester, NY 14650	Photo-Flo
Merix Chemical Co. 2234 E. 75th St. Chicago, IL	Merix Cleaner
Nokomis International, Inc. P.O. Box 4815 Hayward, CA 94540	Nokomis 3
Octagon Process, Inc. 12 Archer Ave. Edgewater, NJ 07020	Octagon 3677 in dilutions of 1/2 oz/gal and 1/4 oz/gal
Schwartz Chemical Co., Inc. 50-01 2nd St. Long Island City, NY	Rez-N-Cleen
TEXO Corporation 2801 Highland Ave. Cincinnati, OH 45212	TEXO 481 and TEXO APC

APPENDIX C

THE t-TEST

The t distribution test was used to evaluate the significance of the difference between the mean drop areas on a single sample. The t-test is a statistical test which takes into account both the extent of the difference between the means as well as the variability of the samples. The parameter t may be defined as the ratio of the difference between the sample means to the standard error of this difference. The t-test is generally used for tests with fewer than 30 samplings per mean.

There are many methods for calculating t. The one used in this study is given for different sample sizes as:

$$t = \frac{\bar{x}_1 - \bar{x}_2}{S(\bar{x}_1 - \bar{x}_2)}$$

where $S(\bar{x}_1 - \bar{x}_2)$ is the standard error of the difference between the two means and is defined as:

$$S(\bar{x}_1 - \bar{x}_2) = \sqrt{S^2 \frac{N_1 + N_2}{(N_1 \times N_2)}}$$

where

$$S^2 = \left(\frac{\Sigma x_1{}^2 + \Sigma x_2{}^2}{N_1 + N_2 - 2} \right) .$$

Here S^2 is the variance and N represents the sample size.

Once t has been calculated, the value is compared to values given in a t-table, and a decision is made to either accept or reject the null hypothesis. In this case the null hypothesis indicates that the means are the same. The criterion used in this analysis is to reject the null hypothesis if p (found from table) is equal to or less than 0.05, and regard the hypothesis as tenable if p is larger than 0.05. This corresponds to a 95% confidence interval for the data.

DISTRIBUTION

No. of Copies

OFFSITE

1 DOE Chicago Patent Group
9800 South Cass Ave.
Argonne, IL 60439

A. A. Churm

6 DOE Division of Solar Technology
20 Massachusetts Ave.
Washington, DC 20545

G. Braun
M. U. Gutstein
G. M. Kaplan
L. Melamed
J. E. Rannels
J. Weissinger

1 DOE Office of Solar Application
20 Massachusetts Ave.
Washington, DC 20545

A. C. Min

27 DOE Technical Information Center

(UC 62)

1 Haviland Products Co.
421 Ann St. NW
Grand Rapids, MI 49504

2 Jet Propulsion Laboratory
4800 Oak Grove Dr.
Pasadena, CA 92647

M. Adams
W. Carroll

No. of Copies

OFFSITE

2 McDonnell Douglas Astronautics Co.
5301 Bolsa Ave.
Huntington Beach, CA 92647

C. R. Easton
M. Sheratle

8 Sandia Laboratories
Box 5800
Albuquerque, NM 87115

D. Arvisue - STTF
E. Beauchamp
R. Champion
J. Leonard
B. Marshall
J. Otts - STTF
R. Pettit
L. Rainhart

4 Sandia Laboratories
Livermore, CA 94550

C. Mavis
A. Skinrood
W. Wilson

6 Solar Energy Research Institute
1536 Cole Blvd.
Golden, CO 80401

B. Butler
P. Call
T. Coyle
A. Czanderna
K. Masterson
S. Pullman

1 U.S. Avinex Co.
1056 Huntley Rd.
Niles, MI 49120

DISTRIBUTION (contd.)

No. of Copies

OFFSITE

1 Mr. Applebaum
International Products
P.O. Box 118
Trenton, NJ 08607

1 D. Argo
Argo & Company, Inc.
P.O. Drawer 2747
Spartanburg, SC 29304

1 P. Bender
Ford Motor Co.
Glass Division
P.O. Box 43343
Detroit, MI 48243

1 F. Bradley
Classic Chemical
16th & Nickel Sts.
Camden, NJ 08105

1 L. Brothers
Dubois Chemicals
Div. of Chemed Corp.
1314 Dubois Tower
Cincinnati, OH 45202

1 N. Cantos
Essential Chemicals Corp.
28391 Essential Rd.
Merton, WI 53056

1 C. Catacchio
Bestline Non-Polluting Products, Inc.
1100 Touhy Ave.
Elk Grove Village, IL 60007

1 W. Durkin
Universal Shellac & Supply Co., Inc.
495-T W. John St.
Hicksville, NY 11803

No. of Copies

OFFSITE

1 R. A. England
Martin Marietta
MS S0403
P.O. Box 179
Denver, CO 80201

1 H. E. Felix
Solaramics, Inc.
1301 El Segundo Blvd.
El Segundo, CA 90245

1 D. Flesher
Economics Lab
840 Sibley Memorial Highway
St. Paul, MN 55118

1 C. R. Frownfelter
PPG Industries, Inc.
One Gateway Center
Pittsburgh, PA 15222

1 R. Gillett
Boeing Eng. & Construction
MS 9A-46
P.O. Box 3707
Seattle, WA 98124

1 C. Guss
Chemical Products Co.
1213 Jackson
Omaha, NE 68102

1 E. Heinzelman
Solventol Chemical Products, Inc.
13177 Huron River Dr.
Romulus, MI 48174

1 J. S. Herbert
ASG Industries, Inc.
P.O. Box 929
Kingsport, TN 37662

DISTRIBUTION (contd.)

No. of Copies	
OFFSITE	
1	P. L. Hoffman Prog. Planning & Analysis Battelle Energy Program Battelle-Columbus Labs. 505 King Ave. Columbus, OH 43201
1	D. Holdridge Swedlow, Inc. 12122 Western Ave. Garden Grove, CA 92645
1	R. H. Horton Energy Systems One River Rd. Schenectady, NY 12345
1	J. Houghtby Rosenthal Cleans-Quick Corp. 30995 Industrial Rd. Livonia, MI 48150
1	S. Kaufmann Sunshine Chemical Corp. P.O. Box 17041 West Hartford, CT 06117
1	E. Korte Texo Corp. 2801 Highland Ave. Cincinnati, OH 45212
1	W. Larsson Angler Chemical Co. 100 Messenger St. Plainville, MA 02762
1	Ms. McHugh Sanders Associates MS MER12-1214 95 Canal St. Nashua, NH 03061

No. of Copies	
OFFSITE	
1	W. D. Mitchell Solaramics, Inc. 1301 El Segundo Blvd. El Segundo, CA 90245
1	G. R. Morgan Rocketdyne AA95 6633 Canoga Ave. Canoga Park, CA 91304
1	R. P. Mozzer Insolar, Inc. P.O. Box Z Port Jervis, NY 12771
1	E. Nelson ACUREX Corp. 485 Clyde Ave. Mountain View, CA 94042
1	S. Petrosky Twin Specialities Corp. Suite 154 111 Presidential Blvd. Bala-Cynwyd, PA 19004
1	Mr. Richmond Klean Strip Div. P.O. Box 1879 Memphis, TN 38101
1	I. B. Rickling Florida Solar Energy Center Library 300 State Rd. 401 Cape Canaveral, FL 32920
1	W. Rogers Dept. of Mech. Engineering Rensselaer Poly. Inst. JEC 2049 Troy, NY 12181

DISTRIBUTION (contd.)

No. of Copies	
OFFSITE	
1	J. Ross Hillyard Chemical Co. 302 N. 4th St. St. Joseph, MO 64501
1	Mr. Schwartz Alex C. Fergusson Co. Spring Mill Dr. Frazer, PA 19355
1	A. F. Shoemaker Corning Glass Works Corning, NY 14830
1	G. Siegle CMC Laboratories Co., Inc. 122 W. Houston St. New York, NY
1	M. Sine Environmental Control Systems, Inc. 409 Washington Ave. Baltimore, MD 21227
1	E. Sommeman Merix Chemical Co. 2234 E. 75th St. Chicago, IL 60649
1	G. Sturgen Emulso Corp. 299 Ellicott St. Buffalo, NY 14203
1	H. R. Swift Libby Owens Ford Co. Technical Center 1701 E. Broadway Toledo, OH 43605
1	R. Taylor Arizona Public Service Co. P.O. Box 21666 Phoenix, AZ 85036

No. of Copies	
OFFSITE	
1	K. Thompson Reily Chemical Co. P.O. Box 50372 New Orleans, LA 71078
1	W. Tomlinson Environmental Library University of Montana 758 Eddy St. Missoula, MT 59812
1	L. Van Pyke Sanivan Laboratories, Inc. 222 Liberty Camden, NJ 08104
1	R. R. Walters E. Systems P.O. Box 6118 Dallas, TX 75222
1	M. Weast Turco Products Div. P.O. Box 6200 Carson, CA 90749
1	C. Wienfield Edison Chemical Co. 71 Amory Boston, MA
1	J. Wiggan Mellocraft Co. 1320 Locust P.O. Box 567 Toledo, OH 43601
1	S. Zwerdling Northeast Solar Energy Center 70 Memorial Dr. Cambridge, MA 02142

DISTRIBUTION (contd.)

No. of Copies	
ONSITE	
2	DOE Richland Operations Office
	H. E. Ransom
	R. Stewart
40	Pacific Northwest Laboratory
	W. J. Coleman
	K. Drumheller
	H. L. Hampton (5)
	M. A. Lind (25)
	J. M. Rusin
	Publishing Coordination (2)
	Technical Information (5)