1. A. P. Metzger, EDC to F. C. DeWolf, Sept. 16, 1975.

2. A. P. Metzger, Technical Report, Sept. 15, 1975.

3. M. M. O'Mara and A. P. Metzger, Technical Report, August 18, 1975.

4. G. F. Smith, Technical Report, December 10, 1975.

5. A. P. Metzger, EDC to J. R. Goots, November 3, 1975.

6. A. P. Metzger, EDC to J. R. Goots, October 2, 1975.

7. A. P. Metzger, Technical Report, December 3, 1974.

8. C. A. Daniels, EDC to F. E. Krause, December 4, 1975.

9. C. A. Daniels, EDC to J. R. Goots, December 16, 1975.

10. C. A. Daniels, EDC to A. P. Metzger, December 19, 1975.

11. C. A. Daniels, EDC to A. P. Metzger, January 26, 1976.

12. C. A. Daniels, EDC to J. R. Goots, January 28, 1976.

BFG TECHNICAL DOCUMENT

P

B. F. Goodrich Chemical Company

A DIVISION OF THE B. F. GOODRICH COMPANY

DEVELOPMENT CENTER

MIGRATION OF RESIDUAL SOLVENTS IN CPVC POTABLE WATER SYSTEMS

40532

by A. P. Metzger

February 17, 1976

DISTRIBUTION:

Cleveland
- R. D. Scott
- R. A. Krueger
- B. M. G. Zwicker
- M. E. Koha
- K. Greene
- E. G. Schwaegerle
- J. L. Nelson - E. W. Herrington
- * E. J. Sehm - J. C. Healy-P. J. Donat
- * E. B. Osborne
- J. F. Malone
- * G. S. Ramsey
- R. W. Tennehill
- F. C. Dulle[illegible]
- R. A. Secu[illegible]
- R. C. Wil[illegible]
- R. J. Cu[illegible]
- H. R. Cale[illegible]

Akron
- J. Hughes Powell, Jr.
- E. K. Bean
- J. A. Brandhurst
- W. C. Bechtel

Independence
- ITC Technical Files (2)

ALTC
- J. R. Coots
- * R. M. Kreager - A. L. Schultz
- * R. R. Bloor-J. A. TePas
- P. E. Krause - R. K. Schlatzer
- L. B. Crider
- E. G. DeCapita
- C. A. Daniels
- R. J. Mayer
- CTF/Int'l. (4) ← COPY FOR

Brecksville
- * E. J. Powell
- * G. E. Thompson
- * C. E. Lafter
- * D. E. Lay
- A. R. Berens
- T. W. Boyer - E. A. Grulke
- R&D File (2)

ALCC
- R. N. Rylands - R. S. Mather

Louisville
- P. H. Lawrence - S. S. Michels

Pedrickstown
- A. R. Webber

Henry
- C. B. Cooper - A. W. Otto

*Indicates modified copy.

2225902

BFG19825

Summary

Potable water pipe made from Geon CPVC compounds frequently contains more than 0.5% of residual carbon tetrachloride. It has been shown that a portion of this "solvent" will migrate into water which remains in contact with the pipe.

Attempts to determine the migration rate of the "solvent" under specific conditions have yielded inconsistent results. For example, extractions carried out in an oven indicated that the amount of carbon tetrachloride which migrated into water did not depend on the amount in the pipe. The data also suggested that reducing the temperature (from 160 to 140°F) enhanced the migration. However, there was evidence that the pipe was somewhat heterogeneous and this probably influenced the migration.

In other extraction work, a temperature gradient was maintained across the pipe wall. Under those conditions, smaller amounts of "solvent" were extracted and the concentration in the water decreased with increasing exposure time. Apparently some of the carbon tetrachloride reacted with other ingredients in the system. Obviously, it is not possible to predict the concentration of fugitive carbon tetrachloride.

A typical CPVC hot water system was installed to provide "real-life" samples. Temperature measurements demonstrated that the CPVC pipe was at an elevated temperature only a small percentage of the time. Analysis of the water samples, collected over a 9 week period, showed that about 60% of them contained measurable amounts of "solvent". The concentration varied widely but in a random pattern. There was evidence that water trapped in certain portions of the system contained high concentrations of carbon tetrachloride. Occasionally, some of that water mixed into the sample and caused the analysis to be unexpectedly high (> 100 ppb). Presumably, that would also occur in most existing systems.

Consequently, if the risk of carbon tetrachloride migration is to be reduced, the amount in the resin must be greatly decreased. Although no acceptance criteria have been established, it seems likely that the residual carbon tetrachloride should be reduced from the current levels of about 5000 ppm to perhaps a maximum of 100 ppm.

Introduction

There has been concern about the possible migration of residual CCl_4 from potable water pipe fabricated of Geon CPVC. Last year, samples of water were collected from operating CPVC lines installed at various locations at ALTC. Analysis of the water showed that CCl_4 was present and that the amount increased with longer residence time[1]. Those results confirmed that migration does occur.

There is no criteria for an acceptable level of CCl_4 in water but it is generally agreed that it should be less than 0.05 ppm. Extraction studies have demonstrated that amounts far in excess of 0.05 ppm will migrate under certain conditions[2]. Those investigations also indicated, as expected, that the amount of CCl_4 which migrated increased with higher temperature, longer extraction time and larger surface-to-volume ratios. There was some criticism of those studies because sections of pipe had been immersed in water and in normal use extraction could occur only from the interior. Irrespective of that fact, there were a number of inconsistencies in the data and therefore it was not possible to develop a mathematical relationship which would predict the migration of CCl_4.

Subsequently, sections of pipe were filled with distilled water and stored in ovens. Periodic analysis of the samples stored at about 105°F indicated that the CCl_4 content increased with time and the migration rate was similar to that observed in the earlier extraction work with immersed samples. However, analyses of the pipe samples stored at 180°F were confusing because the CCl_4 content reached a maximum and then decreased with continued storage[3]. There was speculation that the long term decrease was evidence of a chemical reaction involving the CCl_4. The disappearance of the CCl_4 was studied (by G. F. Smith) in a series of experiments carried out in glassware. There was evidence that CCl_4 had reacted with the brass fittings used to cap the pipe sections[4]. Obviously, any further investigation of the migration of CCl_4 should not be conducted in the presence of brass. The study indicated that CCl_4 did not react with stainless steel.

It was evident that further extraction studies were needed to define the migration problem and clarify the contradictions in the previous work. This report describes the additional work.

Experimental

Most of the previous extraction studies have involved immersion of pipe sections in water and storage at 180°F. The migration of CCl_4 from potable water pipe is our main concern and therefore it was decided that any further investigations should more closely simulate that application. Consequently, in this work we will extract only from the interior pipe surface at somewhat lower temperatures. Of course, in actual systems the water is in contact with the pipe for varying time, dependent on specific use conditions. It is difficult to interpret data from a flowing system and therefore both static and dynamic systems were planned. Each system is described below.

Oven Tests

As already mentioned, in the initial effort to extract from the pipe interior, analyses of the water indicated that the CCl_4 content decreased with increased storage time, presumably because of reaction with the brass fittings. Nevertheless,

that experimental arrangement had merit and therefore it was modified to eliminate contact between the water and metal. This was accomplished by machining CPVC parts to form closures for the pipe sections. Septums were attached to the closures so that a hypodermic needle could be inserted and water removed from the inside of the pipe. Figure 1 shows a sketch of the arrangement. The pipe samples selected for this study (163-17-50-1 and 163-17-50-2) had been extruded at ALTC in December, 1974. They had been stored at ambient temperature (Bldg. 427) prior to initiation of the extraction study (November, 1975). The pipe sections (8") were not cleaned before being filled with distilled water and stored in a constant temperature oven. Periodically, samples of water were removed and analyzed for $CHCl_3$ and CCl_4.

Heat Exchanger Tests

Of course, in normal use the pipe in a hot water system has a temperature gradient across the pipe wall. There was some speculation that this gradient influenced migration of the solvents. Therefore, a static test arrangement was devised to simulate the gradient. This experiment was described earlier[5], but basically it required the use of metal components to cap the pipe sections and supply the heat. Since the previous work[4] had shown that stainless steel did not react with CCl_4, it was used for the metal parts. The end caps were drilled and tapped so that tubing (¼") could be extruded through the plastic pipe. An external water bath was maintained at an elevated temperature and this water was pumped through the tubing to heat the water in the annular space (between the CPVC pipe and S.S. tubing) to the desired temperature. Thermocouples in the static water and on the pipe surface were used to record the temperature gradient. A "saddle" around the plastic pipe held a septum which permitted sampling of the water in contact with the CPVC. The experimental arrangement is shown in Figure 2. The material used in the heat exchanger experiments were the same as those used in the oven tests. Samples, about 14" long, of 163-17-50-1 and 163-17-50-2 were installed and maintained at temperature for several days. Water samples were removed periodically and analyzed for $CHCl_3$ and CCl_4.

Simulated Hot Water System

Although the static tests described above should provide data for predicting the amount of CCl_4 migrating under a given set of conditions, it was decided that water from a "real-life" system should also be analyzed. Consequently, a "typical" hot water system was installed and operated on a schedule which presumably represented the habits of a 4-member family. Although this system has been described previously[6], the essential details will be repeated, for convenience. Commercial pipe (1/2" and 3/4" CTS) made about August, 1975, and fittings produced about May, 1975, were obtained from Genova Products. The system, which was fabricated from these components, consisted of approximately 32 feet of 3/4 inch pipe and 46 feet of ½ inch pipe (see Figure 3). Solenoid valves at 8 locations were actuated by timers which allowed flow to the drain on a prearranged schedule. Orifices downstream from the valves controlled the flow rate. These facts are tabulated below.

Location	Representing	Rate (gal./draw)	Frequency	Total (gal./day)
1	Bath #1 Lav.	1½	7	10½
2	Bath #1 Show	10	1	10
3	Bath #2 Lav.	2	8	16
4	Bath #2 Tub	15	3	45
5	Laundry Tub	20	2	40
6	Clothes washer	5	3	15
7	Kitchen sink	1½	19	28½
8	Dish washer	10	2	20

It should be noted that about 185 gallons of hot water was flushed through this system each day. An electrically heated hot water tank supplied the system. Thermocouples were located at 6 points (see Figure 4) so that the temperature of the water, pipe surface and ambient air could be recorded continuously (3 minute intervals).

The installation of this system was completed in early October, 1975. During the following month, it remained filled with water (at ambient temperature) while being checked for leaks and adjustment of flow rates. The system was then given three 5-minute flushes with hot water and placed in service. At weekly intervals, water samples were collected at each location and analyzed for $CHCl_3$ and CCl_4. After 9 weeks (about 7260 gallons of water flow) the experiment was terminated.

In addition to the hot water system described above, a second loop was installed for cold water. This consisted of about 15 feet of 3/4 inch pipe and 14 feet of ½ inch pipe. The solenoid valve on this loop operated at the same frequency as location #7 on the hot water system. Thus, flow through the cold water line was about 28½ gallons per day. This loop was sampled and the water analyzed on the same schedule as the hot water system.

Discussion

Oven Tests

The pipe samples used in this experiment contained different amounts of residual "solvents". The sample identified as 163-17-50-1 was based on our standard CPVC resin (6038560) while a "stripped" resin was used in 163-17-50-2. The residual "solvent" levels were:

	$CHCl_3$ (ppm)	CCl_4 (ppm)
163-17-50-1	172	5179
163-17-50-2	138	570
End plugs	233	5663

It was expected that the CCl_4 level in the water samples would reflect the nearly 10 fold difference in CCl_4 content of the pipe sections. Furthermore, since the same water remained in contact with the pipe throughout the experiment, it would be expected that each successive analysis (with increasing extraction time) would show increased amounts of residual solvent.

In the first trial, the samples were stored in a 160°F oven for 10 days. The control water contained no CCl_4, but after contact with the pipe section for only 24 hours analysis showed that water contained 800 ppb (Table I). There were further increases in CCl_4 with longer extraction time but the migration rate was much slower. It required 9 days for an additional 800 ppb of CCl_4 to migrate into the water. It should be noted that in some cases, water samples analyzed after longer exposure time appeared to have lost CCl_4. Subsequently, the concentration of CCl_4 would then increase again. It is doubtful that there would be intermittent leakage from the system and therefore it can be speculated that the random discrepancies are a reflection of overall sampling and analytical errors. A plot of the data (Figure 5) suggests that after the initial surge, the migration rate of CCl_4 is about 3 or 4 ppb per hour. It was surprising to find that the amount of residual CCl_4 in the pipe seemed to have little effect on the amount of CCl_4 which migrated into the water. At least in this experiment, reducing the CCl_4 content of the pipe did not decrease the amount which migrated into the water.

In the second trial, new sections of the pipe (163-17-50-1 and 163-17-50-2) were filled with distilled water and stored in a 140°F oven. Water samples were removed after very short exposure times to determine the initial migration rate. The extraction was continued for a total of 15 days. Analyses of the water samples are shown in Table II. Once again, a few of the samples appeared to lose CCl_4 but in general the amount of CCl_4 which migrated increased continuously with time. The initial rate (first 24 hours) at 140°F appears to be about one half that at 160°F (see Figure 5). However, the migration rate at 140°F during the remaining extraction period is actually greater than that at 160°F. It should also be noted that the pipe section containing low residual CCl_4 (163-17-50-2) lost as much "solvent" as the sample which contained nearly 10 times as much CCl_4 (163-17-50-1).

The observations that:

(a) the migration of CCl_4 at 160°F is not linear in short time intervals

(b) the migration rate at 140°F is greater than that at 160°F and

(c) the amount of CCl_4 which migrates is not dependent on the residual quantity in the sample

are inconsistent with expectations from diffusion theory. There was speculation that the interior surface of the pipe was not uniform and that this led to the anomalous results. It was postulated that the lubricant in the compound tended to concentrate on the interior surface during extrusion of the pipe and that CCl_4 was trapped in this layer. As a result the extraction of CCl_4 from both pipe sections would be relatively rapid and not influenced greatly by differences in the pipe wall. If that rationalisation were valid, then removal of the surface layer before extracting should result in (a) decreased migration of the CCl_4 and (b) differences in the amount of CCl_4 which migrated from pipe sections containing "high" and "low" levels of residual solvent.

In the third trial, approximately 5 mils of the interior surface was machined from (6") lengths of 163-17-50-1 and 163-17-50-2. The machined surface appeared

to be as smooth as the original surface. These sections were capped, filled with distilled water and stored in a 140°F oven. Water samples were removed after 24, 48 and 72 hours and analyzed for $CHCl_4$ and CCl_4. Comparison of those results, Table III, with the corresponding values for the pipe "as extruded" (Table II) demonstrates that there is increased migration of residual solvents from the machined surface. The increase is greater for the pipe section containing the larger amount of residual solvent. As already pointed out, when the "as extruded" pipe sections were extracted nearly the same amount of CCl_4 migrated from both (Table II). However, when new samples were machined and then extracted, the amount of CCl_4 which migrated depended on the amount that was in the pipe. Obviously, the pipe walls are not uniform in terms of CCl_4 content and it seems inevitable that extraction results will very widely. Thus, it would be very risky to use such data to predict the migration of the residual solvents in any use application.

Heat Exchanger Tests

Since the pipe sections selected for this experiment were the same materials as used in the oven tests, it was expected that the extraction results would also be similar. In the first trial, the pipe sections were filled with tap water and extracted over a 10 day period. The water temperature was maintained at 160°F and the resulting surface temperature was 125°F (when the ambient air temperature was 79°F). Thus, there was a 35°F gradient across the pipe wall (80 mils). Analysis of the tap water (control) indicated that it contained 79 ppb of $CHCl_3$ but no CCl_4. Periodic analysis of the water samples showed that the CCl_4 content was at a maximum after 1 or 2 days and then decreased with longer exposure time (Table IV). As noted earlier, a decrease in CCl_4 with increased exposure time had also been observed at 180°F[3]. Since there was no brass metal in contact with the water in the current study, the decrease in CCl_4 can not be attributed to a reaction with brass[4]. Apparently, other chemical reactions are occurring. This heat exchanger experiment and the previously described oven test have common characteristics. The same materials were used in both and the water temperature in contact with the CPVC surface was the same. However, comparison of the data in Table I and Table IV show dramatically different extractions. For example, in the oven test after 24 hours the water contained about 800 to 900 ppb of CCl_4 irrespective of the residual solvent level in the pipe. However, in the heat exchanger experiment, after 24 hours water from 163-17-50-1 contained only 117 ppb of CCl_4 and there was only 22 ppb in the water from 163-17-50-2. It was speculated that either the use of tap water or the presence of a temperature gradient across the pipe wall was responsible for the decreased extraction in the heat exchanger test.

In the second trial, new sections of pipe (163-17-50-1 and 163-17-50-2) were installed and filled with distilled water. The temperature of the water (in the annular space) was 136°F and the surface temperature of the pipe was 114°F with an ambient air temperature of 79°F. Thus, there was a 24°F temperature gradient across the pipe wall. Water samples were removed after short time intervals and analyzed to determine how rapidly a maximum extraction was reached. The experiment was continued over a 19 day period. The analyses (Table V) show that the amount of CCl_4 in the water reached a maximum in 12 to 24 hours and then gradually decreased with continued exposure. These results, like those obtained at 160°F, are in sharp contrast to comparable data from the oven test.

For example:

	CCl_4 (ppb) in water			
	Heat Exchanger		Oven	
Time (hrs.)	50-1	50-2	50-1	50-2
24	313	3	314	385
48	389	37	601	595
72	355	35	566	664
192	283	11	1401	1519
364	114	8	1697	2002

It seems clear that different factors must be controlling the migration in the two experiments. The most obvious difference is the fact that there is a temperature gradient across the pipe wall in the heat exchanger experiment. However, it is difficult to explain why this gradient didn't affect both pipe samples the same way. The fact that the same general trends were observed at both 160°F and 140°F suggests that it was not an experimental fluke. Nevertheless, the inconsistencies in the results of these two experiments demonstrates that the migration of CCl_4 from CPVC can not be predicted.

Simulated Hot Water System

The CPVC materials used to fabricate this hot water system contained very high levels of residual "solvents":

	$CHCl_3$ (ppm)	CCl_4 (ppm)
3/4 inch pipe	229	6980
1/2 inch pipe	240	6938
1/2 inch fitting	240	6592

Although those values are somewhat higher than the "average" (77 ppm $CHCl_3$ and 4677 ppm CCl_4) found in previous analyses[7], it is likely that a portion of the CPVC compounds do contain similar high concentrations. Thus, this hot water system is probably typical of some existing installations.

As pointed out before, the water system was flushed three times before it was placed in service. Samples of water were collected at location #7 before and after each flush. There was a time delay (about one hour) between each flush so that the water in the tank could recover temperature. Consequently, the water sample removed before the flush had been in contact with the CPVC longer than the water sample taken immediately after the flush. Analyses showed that this residence time influences the amount of solvent which had migrated.

	$CHCl_3$ (ppb)	CCl_4 (ppb)
First Flush		
Before	47	99
After	32	4
Second Flush		
Before	71	381
After	<1	<1
Third Flush		
Before	91	179
After	4	4

It was surprising to find that significant quantities of CCl_4 migrated into the water in such short periods of time. In all three cases, the water which had been in contact with the pipe for about one hour contained more CCl_4 than the water removed immediately (after flushing). There had been conjecture that during extrusion a surface layer would accumulate on the interior surface of the pipe. Conceivably such a layer might be removed during use. The analysis cited above indicate that, if such a layer exists, it is not readily removed.

Although this system delivers hot water, the pipe is at elevated temperatures for relatively short periods of time. Obviously that exposure to elevated temperature depends on the amount of hot water flowing through the system. For example, at location #1 (see Figure 4) the thermocouple on the pipe surface indicated that the maximum temperature was about 110°F. Since that location was scheduled for 7 uses per day, the temperature of the pipe was above 100°F for about 5% of the time (as estimated from the recorded temperatures). On the other hand, at location #7 there were 19 uses per day and the thermocouples indicated that the water temperature reached 125°F while the pipe surface was about 115°F. The temperature charts showed that the pipe was above 100°F about 20% of the time. Of course, the section of pipe between the hot water heater and the first tee (see Figure 4) had the most exposure to high temperature. All the water flowing through the system (185 gallons per day) passed through this section. According to the thermocouples, the water temperature in this section was usually about 140°F (during each of the 45 uses) and the pipe surface was about 125°F. The recorded temperatures indicated that the pipe was above 100°F about 70% of the time.

In the typical home, there are frequent draws of water so that the contact time with the CPVC pipe is relatively short. In this hot water system, there were 45 draws per day for each week day. However, at two locations, representing the laundry, no draws were made on the weekend. Consequently, water removed on Monday morning from those locations had been in the pipe for about 68 hours. Analyses of those samples showed that the water contained relatively high values of CCl_4.

Location	$CHCl_3$ (ppb)	CCl_4 (ppb)
#5	110	55
#6	73	20

Presumably most of the samples removed from this system will contain less CCl_4 because they will have shorter residence times.

Since this experiment was designed to represent the migration encountered in a typical hot water system, there were no special precautions used when the water samples were removed. A valve was opened and the flowing water was directed into a glass vial which was capped after filling. At the time of analysis, the cap was removed and a portion of the water was removed with a hypodermic syringe and injected into the GC unit. Of course, there were opportunities for volatiles to escape during these transfers. The errors inherent in the sampling and analytical procedures were examined by taking multiple samples at two locations. The analyses were fairly consistent and therefore it can be concluded that the sampling errors were small.

		$CHCl_3$ (ppb)	CCl_4 (ppb)
Location #2	A	25	<1
24 hour contact time	B	34	<1
	C	25	<1
	D	27	<1
Location #6	A	21	4
68 hour contact time	B	61	4
	C	83	9
	D	70	<1

The samples with the longer residence time do have some scatter but all the values are in the low range where analytical problems are greatest. However, it was puzzling to recall (see above) that the previous sample collected under similar conditions contained somewhat more CCl_4.

The hot water system was placed in operation on 11/10/75 and the initial samples were taken after 42 hours. Sampling was continued over a 9 week interval. Since the samples were taken between 8 and 9 in the morning, the water from 4 locations had resided in the pipe for only 1 or 2 hours while the contact time at the other locations was about 20 hours. However, as pointed out above, the water remained at an elevated temperature for a relatively short time. The analyses of these water samples are shown in Tables VI and VII. It should be noted (Table VI) that the control water contained significant quantities of chloroform. The concentration ranged from 3 to 102 ppb with an average of about 45 ppb (during the 9 week test period). The control sample was taken from the inlet to the water heater and therefore did not necessarily represent the water that was in the CPVC pipe. However, due to the varying amount of $CHCl_3$ in the control water, it was not possible to correct the analysis of the water samples. Nevertheless, since most of the analyses (70%) show that the water which has been in contact with CPVC contains more $CHCl_3$ (than the control water), there must have been some migration.

Of course, the migration of CCl_4 is of great concern. During the 9 week interval, analyses showed that about half the time the control water contained a small, but measurable, amount (approximately 3 ppb) of CCl_4. The analyses of the water samples which were removed from the CPVC system were not corrected (for the amount in the control water) but the data (Table VII) indicate that, at times, there was considerable migration of CCl_4. It was surprising to find that, at each location, the amount of CCl_4 in the water varied widely even though there was no known change in residence time or temperature. About 40% of the samples contained non-detectable quantities (<1 ppb) of CCl_4 (see Table VIII) but the other samples contained relatively large amounts. The highest concentrations of CCl_4 were detected in water which had remained in contact with the CPVC pipe for the longer periods. Thus, water withdrawn from the system after 1 or 2 hours residence time contained from <1 ppb up to perhaps 20 ppb of CCl_4 but if the water remained in the pipe for 20 hours, it sometimes contained more than 100 ppb (Table VII).

The fluctuations in CCl_4 content appeared to be random with no evidence that the pipe surface was changing. It was difficult to rationalize the fact that large amounts of CCl_4 appeared to migrate in short periods of time at relatively low temperature (Table VII). At other times, samples collected from the same location after identical exposure contained more detectable amounts of CCl_4. The CPVC

system contained "stand pipes" upstream from each outlet (Figure 3). It is common practice to install these sections of pipe so that air will be trapped in the line. The air acts as a "cushion" when the water pressure fluctuates and thus prevents "water hammer". It was speculated that some of the water trapped in the "standpipes" remained in contact with the CPVC pipe for long periods of time and therefore contained high concentrations of CCl_4. Subsequently, during sampling (and depending on flow rate and pressure) some of that water mixed with the sample. This uncontrolled mixing could result in the random fluctuations. It was decided that these conjectures should be examined by collecting special samples. The automatic timers on the discharge valves were disconnected so that water could be removed from the system only by manual operation. The CPVC lines, including the "standpipes" were then emptied of essentially all water. The system was refilled with hot water and allowed to flush briefly so that all lines were filled with hot water. After closing the valves, the water remained in the lines for 6 hours and then was sampled and analyzed. Subsequently, the entire procedure was repeated three times except that the water remained in the lines for periods of 12, 18 and 24 hours before sampling. As shown in Table IX , only 2 of the 36 samples contained a detectable amount of CCl_4 and even then the concentration was very low. These data, although not conclusive, support the postulation that the random samples containing high concentrations are from "stagnant" water.

A somewhat more fundamental study of the migration of residual "solvents" from CPVC compounds has been undertaken by Staff Technical Services[8]. That work indicates that the diffusivity of CCl_4 decreases as the residual concentration is reduced[9]. There is also evidence showing that the diffusion coefficient of CCl_4 is influenced by the ingredients used in the CPVC compound[10]. Thus, any heterogeneity in the pipe could result in variability in the migration of residual CCl_4. The measured diffusion coefficient and its estimated activation energy were used to calculate the expected CCl_4 content of water after contact with CPVC pipe under prescribed conditions. These calculations provide values which are in reasonable agreement with the "averages" detected in the water samples taken from the hot water systems[11]. This consistency suggests that the CCl_4 content of water can be predicted for any desired use conditions. For example, if the acceptance criteria for migration of CCl_4 in a maximum of 2 ppb in a typical home, then the calculations indicate that the CPVC pipe should contain a maximum of 100 ppm of residual CCl_4[12].

Table I

Migration of Residual "Solvents" From CPVC Pipe

Oven Test

Extractant - distilled water
Temperature - 160°F

Time (hrs.)	163-17-50-1 $CHCl_3$ (ppb)	163-17-50-1 CCl_4 (ppb)	163-17-50-2 $CHCl_3$ (ppb)	163-17-50-2 CCl_4 (ppb)
24	59	897	49	812
48	88	1127	68	942
72	115	1281	76	897
96	112	1081	81	770
168	161	1317	119	1018
192	169	1322	127	1105
216	161	1376	127	1197
240	[illegible]	1656	121	1606

Table II

Migration of Residual "Solvents" From CPVC Pipe

Oven Test

Extractant - distilled water
Temperature - 140°F

Time (hrs.)	163-17-50-1 $CHCl_3$ (ppb)	163-17-50-1 CCl_4 (ppb)	163-17-50-2 $CHCl_3$ (ppb)	163-17-50-2 CCl_4 (ppb)
2	--	21	2	51
4	2	94	--	56
6	--	82	4	107
24	1	314	6	385
48	3	601	4	595
72	11	966	3	664
96	5	274	11	850
168	60	1263	21	1300
192	24	1401	25	1519
216	36	1716	25	1644
264	43	1697	31	2002
288	44	2528	34	2095
440	19	2604	22	1880

Table III

Migration of Residual "Solvents" From CPVC Pipe

Cross Test

Extractant - distilled water
Temperature - 140°F
Machined interior surface of pipe

Time (hrs.)	163-17-50-1		163-17-50-2	
	$CHCl_3$ (ppb)	CCl_4 (ppb)	$CHCl_4$ (ppb)	CCl_4 (ppb)
24	12	1276	15	528
48	94	4865	28	776
72	36	5422	11	939

Table IV

Migration of Residual "Solvents" From CPVC Pipe

Heat Exchanger Test

Extractant - tap water
Temperature - 160°F

Time (hrs.)	163-17-50-1 $CHCl_3$ (ppb)	163-17-50-1 CCl_4 (ppb)	163-17-50-2 $CHCl_3$ (ppb)	163-17-50-2 CCl_4 (ppb)
24	38	117	42	22
48	62	169	52	24
72	78	125	53	24
96	84	45	52	22
128	98	32	83	2
168	114	32	64	2
192	115	36	72	2
216	116	19	68	1
240	105	17	27	2

Table V

Migration of Residual "Solvents" From CPVC Pipe

Heat Exchanger Test

Extractant - distilled water
Temperature - 138°F

Time (hrs.)	163-17-50-1 $CHCl_3$ (ppb)	163-17-50-1 CCl_4 (ppb)	163-17-50-2 $CHCl_3$ (ppb)	163-17-50-2 CCl_4 (ppb)
2	<1	36	<1	<1
4	<1	101	<1	<1
6	4	165	<1	<1
12	4	318	<1	20
24	6	313	8	3
48	4	389	14	37
72	5	355	2	35
96	--	173	<1	17
168	13	332	7	21
192	8	283	4	11
222	13	232	--	8
366	6	114	8	8
460	<1	32	<1	1

Table VI

Extraction of $CHCl_3$ From a CPVC Hot Water System

Location	[redacted]	$CHCl_3$ (ppb) in water								
		1	2	3	4	5	6	7	8	Cold Water
Approximate Contact Time (hrs.)		2	24	1	2	20	21	1	14	1
Date	Time In Operation (hrs.)									
11/12	42	53	92	81	90	93	89	99	99	100	66
11/14	90	72	39	61	66	39	93	24	77	72	42
11/19	210	52	86	101	72	77	226	83	86	76	49
11/26	378	40	76	52	82	66	82	76	85	70	54
12/3	546	10	37	93	98	96	102	93	28	103	33
12/10	714	44	64	51	55	66	79	90	72	72	38
12/17	882	35	18	20	15	34	85	11	18	20	5
12/24	1050	3	3	9	3	96	7	17	7	105	75
12/31	1218	61	10	34	23	24	113	77	92	85	67
1/7	1386	102	123	125	84	89	108	84	99	155	23
1/14	1554	26	27	21	53	24	33	32	53	77	11
	AVERAGE	45	52	59	58	64	92	62	65	85	42

BFG19842

40539

22259019

Table VII

Extraction of CCl_4 From a CPVC Hot Water System

Date	Location	Sample Number	CCl_4 (ppb) in water								
			1	2	3	4	5	6	7	8	Cold Water
	Approximate Contact Time (hrs.)		2	24	1	2	20	21	1	14	1
	Time in Operation (hrs.)										
11/12	42	<1	1	181	<1	9	10	1	16	15	21
11/14	90	3	7	15	2	<1	82	3	2	3	2
11/19	210	2	2	2	<1	13	445	148	<1	3	8
11/26	378	2	2	10	<1	1	2	<1	<1	<1	<1
12/3	546	<1	15	129	<1	10	5	123	<1	<1	<1
12/10	714	<1	<1	<1	1	<1	7	20	<1	<1	<1
12/17	882	4	11	5	12	21	116	80	<1	4	9
12/24	1050	<1	<1	<1	<1	<1	<1	5	<1	<1	1
12/31	1218	5	<1	2	<1	<1	60	<1	<1	<1	5
1/7	1386	4	<1	4	<1	1	21	27	21	6	3
1/14	1554	<1	<1	<1	<1	<1	1	6	<1	<1	<1

Table VIII

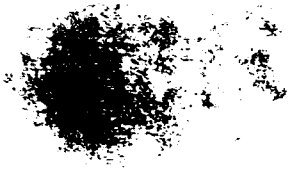
Summary of CCl_4 Analysis of Water Samples

Location	Residence Time (hrs.)	Number of Samples Containing: Low <1 ppb	Moderate >1 <50 ppb	Large >50 ppb	Range (ppb)	Average of Measurable Amount (ppb)
Control	--	5	6		<1 1	3
1	2	5	6		<1 15	6
2	24	3	6	2	<1 181	44
3	1	8	3		<1 12	5
4	2	5	6		<1 21	9
5	20	1	6	4	<1 445	75
6	21	2	6	3	<1 148	46
7	1	8	3		<1 21	13
8	14	6	5		<1 15	6
Cold	[illegible]	4	7		<1 21	7
TOTAL		42	48	9		

Table IX

Migration of Residual "Solvents" from CPVC Pipe After Controlled Time Intervals

	Residence Time (Hrs.)							
	6.5		12		17.5		24	
	Residual "Solvents" (ppb) in Water							
Location	$CHCl_3$	CCl_4	$CHCl_3$	CCl_4	$CHCl_3$	CCl_4	$CHCl_3$	CCl_4
1	102	<1	98	<1	62	<1	23	<1
2	<1	<1	4	<1	<1	<1	5	<1
3	108	<1	94	<1	18	<1	<1	<1
4	110	<1	2	<1	<1	<1	3	<1
5	<1	<1	11	<1	<1	<1	41	<1
6	<1	<1	20	<1	3	<1	7	<1
7	114	<1	<1	<1	4	<1	1	<1
8	<1	<1	108	<1	2	<1	1	<1
Cold	<1	<1	24	<1	71	5	93	8



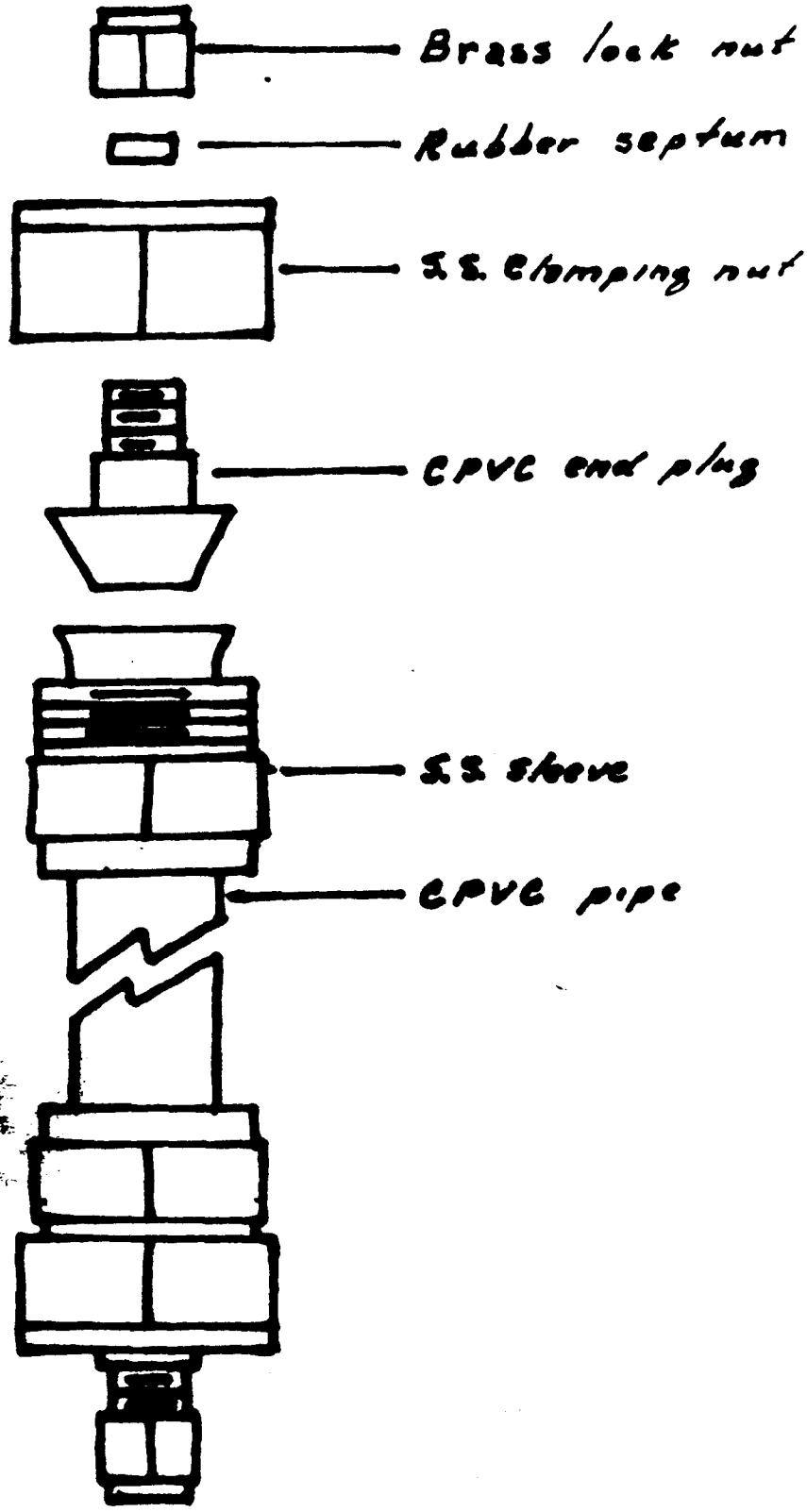


Figure 1

BFG19845

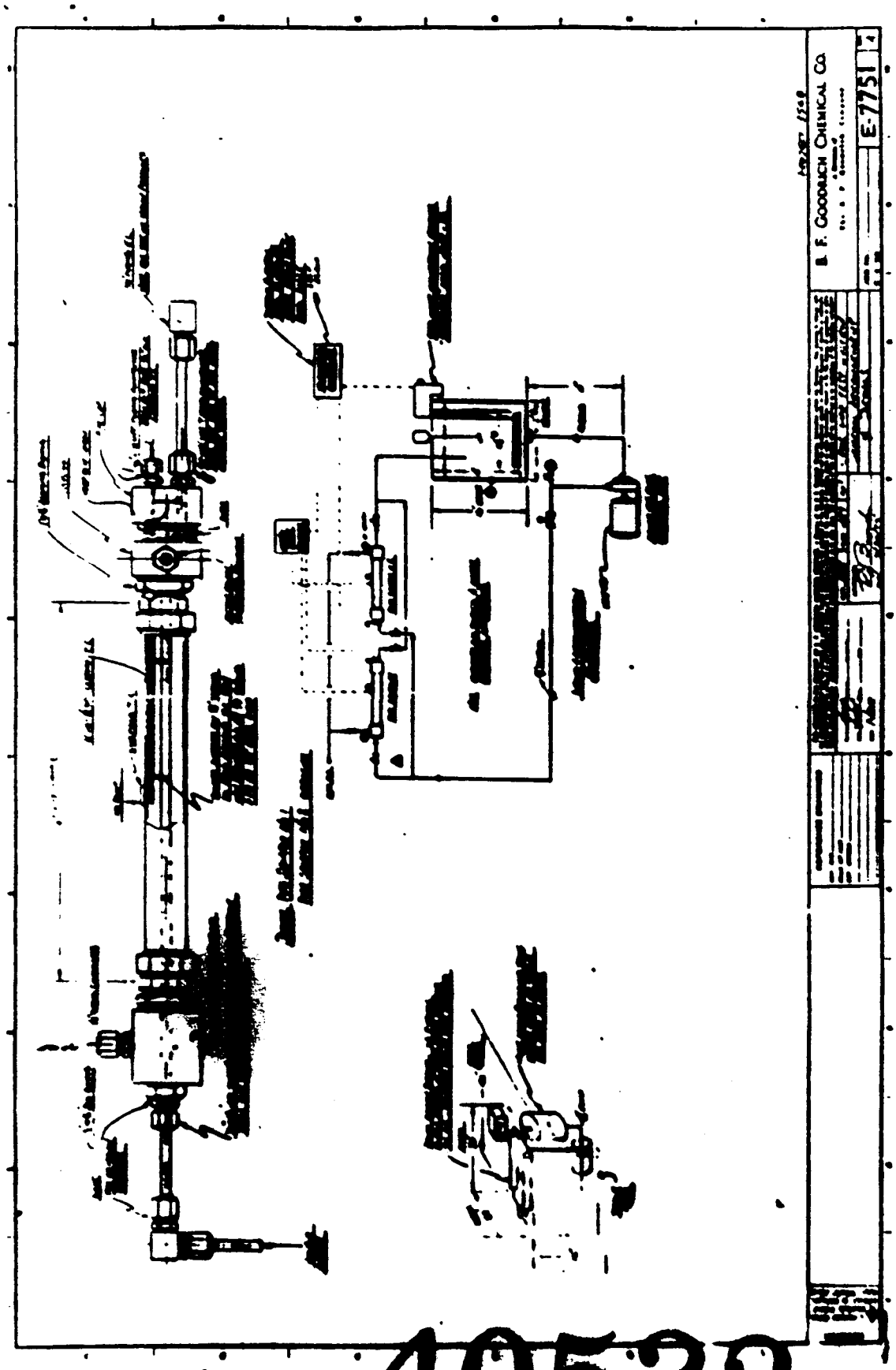


Figure 2

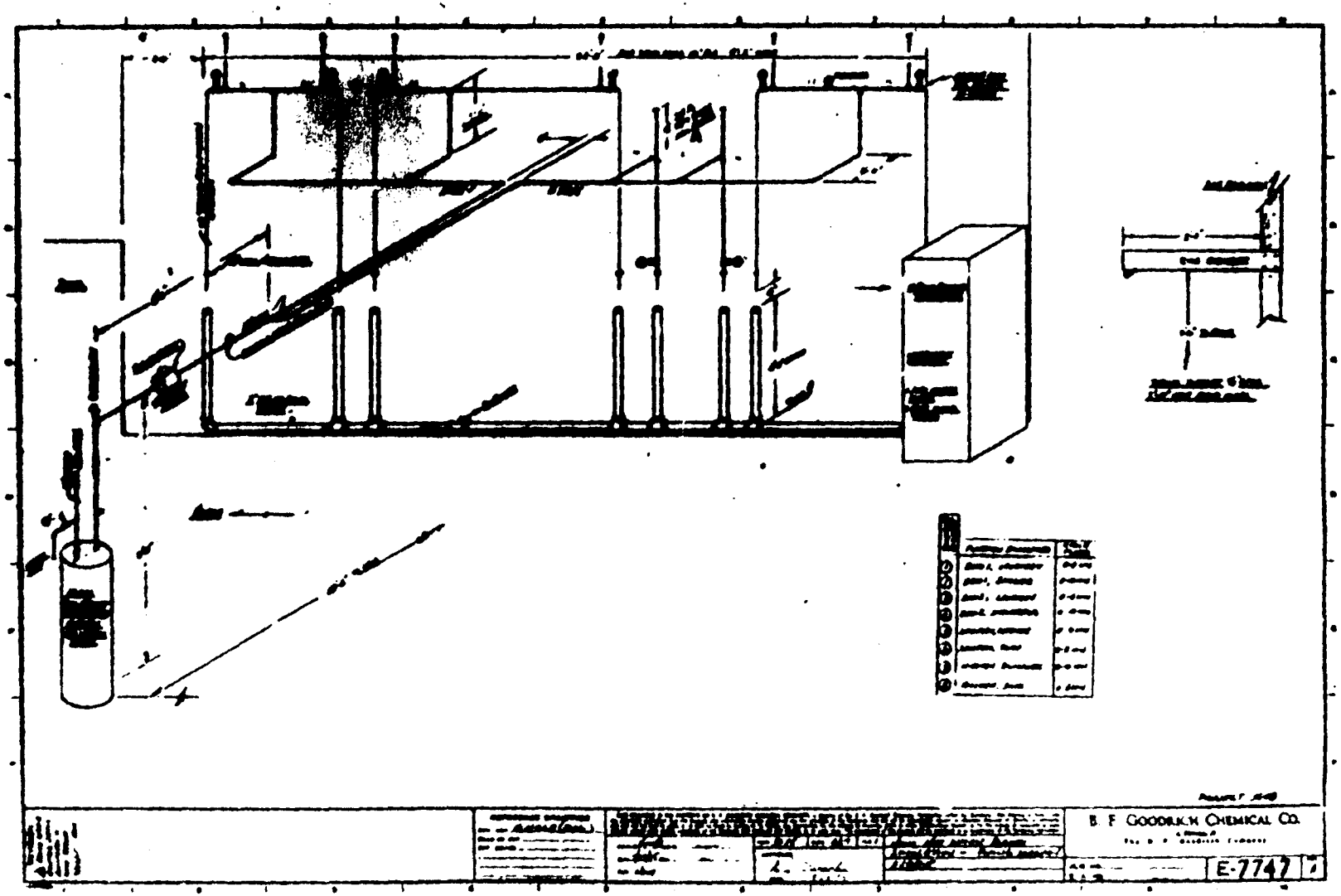


Figure 3

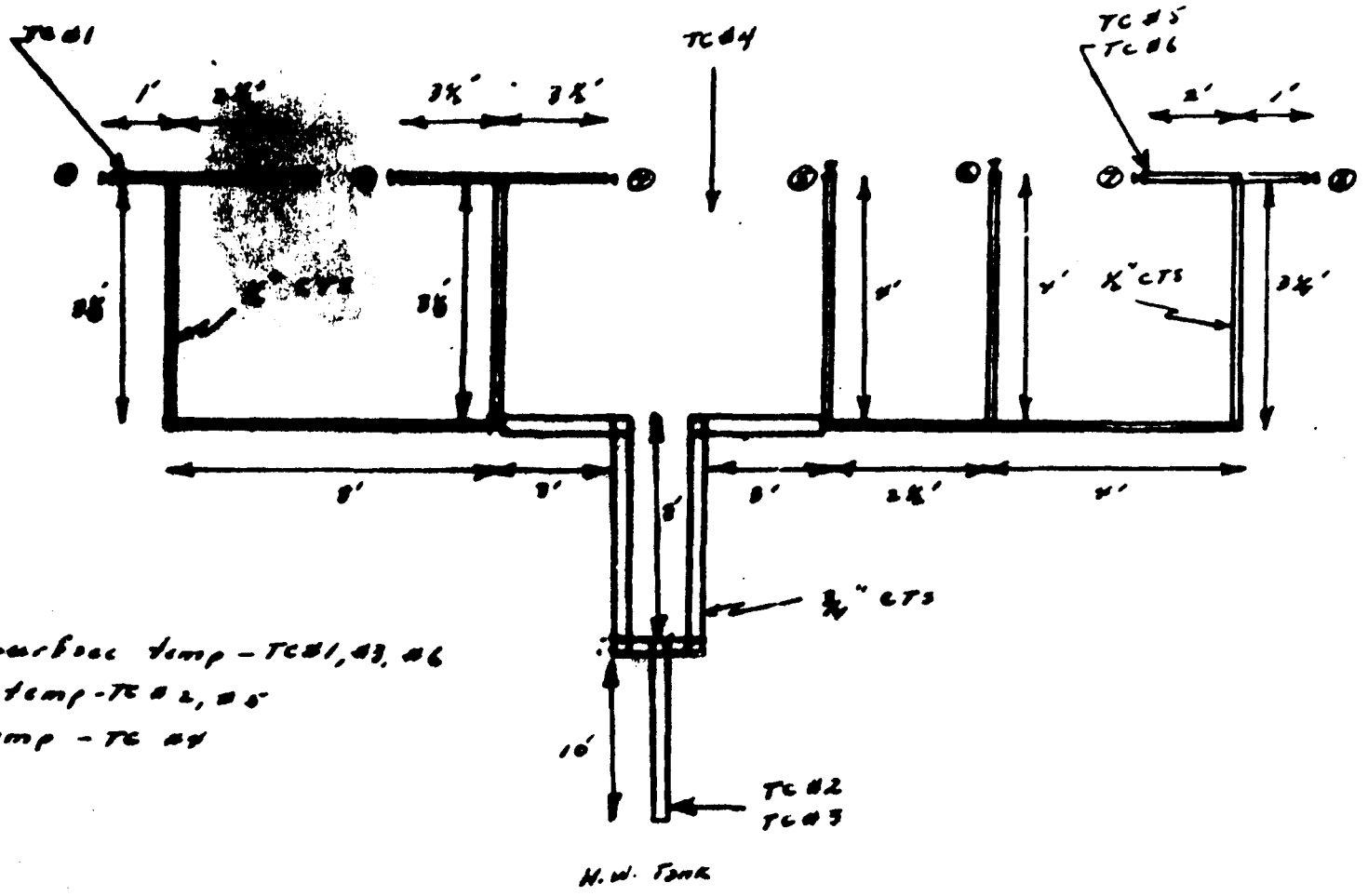


Figure 4

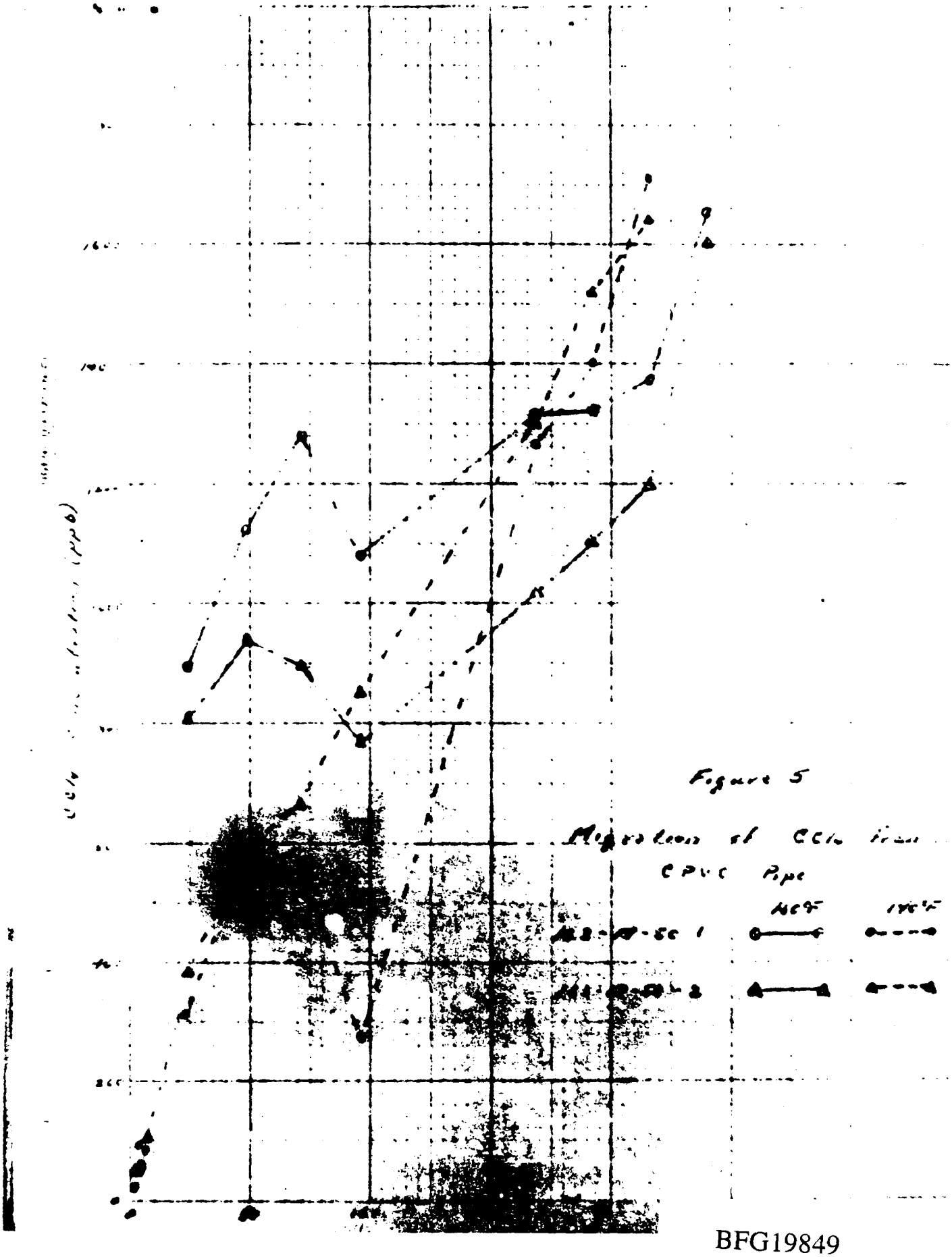


Figure 5

Migration of CCl4 from CPVC Pipe

140°F

160°F

SC 1

SC 2