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Products of Motor Burnout
Final Report

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NOTICE

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ABSTRACT

A program was developed to perform (a) identify and quantify the products of motor burnouts generated through pulsed electrical discharge on three fluids: a) R-22/mineral oil, (b) R134a/polyolester lubricant, and (c) R-507/polyolester lubricant (50:50 blend of 50% R-125 and 50% R-143). Test conditions were varied in an attempt to identify whether bench scale testing could be performed which would accurately simulate actual motor AC carryover conditions. Results of laboratory tests were compared with a simulated motor AC carryover. Fewer by products were observed after high temperature/high pressure testing than were seen at atmospheric pressure testing. The major breakdown products remained the same for all fluids tested. The number of minor breakdown products decreased slightly. Although the numbers of different breakdown products decreased, the total amount of breakdown products remained relatively constant when plotted as a function of energy deposited into the system. Data presented here shows that bench-scale electrical breakdown testing does not duplicate motor failure conditions. Examination of the literature, in conjunction with the limited testing described here, indicates that thermal breakdown testing also does not accurately predict breakdown products due to an AC carryover motor failure.

SCOPE

I.A. Background:

The Montreal Protocol of 1987 effectively banned a long list of chlorofluorocarbons (CFCs) traditionally used in air conditioning and refrigeration applications. The refrigeration and air conditioning industries have responded by developing and testing new, alternative refrigerants that are less damaging to the atmosphere upon release. Despite a reputation for quality and reliability, air conditioning systems do occasionally fail. One of the more common failure modes in a hermetic system is a motor burnout.

Motor burnouts can occur by various mechanisms. One of the most common scenarios is a locked motor rotor, which may result from a damaged bearing. The resulting electrical motor burnout is caused by overheating of the locked rotor and subsequent failure of the insulation. This is primarily a thermal breakdown process. A fewer number of systems which experience a motor burnout failure will do so as a direct result of an electrical short circuit in the motor. The refrigerant breakdown products formed as a result of an electrical arc in the fluid volume of a refrigeration system may differ from those products resulting from a thermal breakdown process. The products may differ in both type of compound and amount formed. Chemical products generated during motor burnouts in refrigeration systems may be highly toxic and/or damaging to system components. In some hermetic motor systems which cycle on and off (refrigerators, home air conditioning systems), a small electrical arc is generated within the motor by the electrical contacts engaging and disengaging each time the motor goes through a cooling cycle. Although the electrical energy deposited into the fluid by each small arc may be minimal, the cumulative effects on fluid breakdown may be important.

Lawrence Livermore National Laboratory (LLNL) began investigating the effects of electrical current discharges (arcing) in CFC's and CFC replacements in 1987. At that time, a replacement was being sought for the R-113 used in large quantities as a dielectric and heat transfer medium in pulsed power modulators for high power laser systems. Many of the candidate replacement fluids were hydrofluorocarbons (HFCs) and fluorocarbons (FCs). Data on the material safety data sheets indicated the possibility of formation of highly toxic by-products during thermal breakdown; however, formation of these by-products under electrical breakdown conditions was not addressed.

LLNL personnel have designed and constructed a special purpose electrical test stand to evaluate CFCs and CFC replacement fluids under simulated AC, DC, and pulsed breakdown conditions. The test stand includes an electrical diagnostic system which allows the measurement of breakdown voltage, discharge current, arc power and energy associated with each pulse. The appropriate data that is collected in order to correlate the quantity of by-products produced with the pertinent control variables, such as voltage, current, pulse-width, pulse-repetition-frequency, and energy. Along with the electrical test stand, LLNL has extensive chemical analysis facilities that enable us to perform gas chromatographic and gas chromatographic-mass spectrometric analysis of various fluids to identify and quantify the breakdown products formed under various scenarios of electrical energy deposition.

In July of 1994, Lawrence Livermore National Laboratory received funding from the Air Conditioning Research and Technology Institute (ARTI) to perform work associated with LLNL's proposal titled "Compatibility Problems Resulting from Products of Motor Burnout." The objectives of the proposed work were:

(1) To identify and quantify the products of motor burnouts in systems containing (a) R-22/mineral oil, (b) R134a/polyolester lubricant, and (c) R-507/polyolester lubricant. R-507 is a 50:50 blend of 50% R-125 and 50% R-143.

(2) To assess, based on the existing literature, the toxic nature of the identified products of motor burnout on humans.

(3) To assess, based upon existing literature, the corrosive effects of the identified products of motor burnout on the electrical feed through terminals.

(4) To assess, based upon existing literature, the efficacy of existing procedures which use filter driers to remove the residual burnout products

(5) To assess, based upon existing literature, whether HFC refrigerant/oil systems are likely to increase or decrease the incidence of motor burnouts as compared to HCFC/lubricant systems.

The principle focus of this effort has been in support of the first objective. A program was developed to perform pulsed electrical discharge on the three fluids in question. Initial electrical discharge experiments were performed on 100 mL samples of fluid held at atmospheric pressure and temperature. In the second phase of testing, a special test cell was constructed to perform electrical discharge testing at elevated temperatures up to 200°C (392°F) and elevated pressures up to 1380 kPa (200 psi). The final phase of testing was devised to simulate full scale compressor failure initiated by high electrical stress (arcing). As initially proposed, compressor motors were to be charged with the specific fluid and then intentionally caused to fail by applying a high-voltage impulse that would create a lasting arc fed by the normal AC power to the motor. After difficulties were encountered with induction of an AC carryover condition in hermetic motors, the final phase of the experimental work was modified so as to use the original test stand apparatus to simulate a possible AC carryover arc condition. These experimental difficulties are discussed in detail later in the report.

The breakdown products formed under the various test scenarios were analyzed by gas chromatography-mass spectrometry. By-products produced under electrical breakdown conditions were found to be significantly different in type and quantity from breakdown products produced under purely thermal conditions. After identification of breakdown products, a literature search was performed to determine potential health hazards of breakdown products.

METHODS

II. Electrical Breakdown Tests

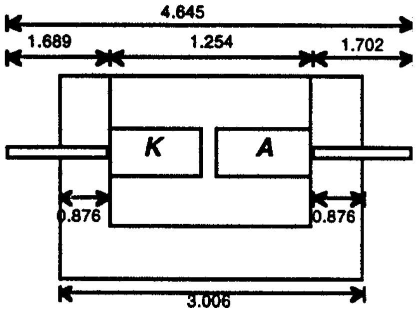
Three types of electrical breakdown tests were performed on each fluid. Tests were performed at atmospheric pressure and ambient temperature, at elevated temperature and pressure (temperature to 200°C, pressure dependent upon specific fluid), and under simulated motor breakdown conditions. Ambient temperature and pressure testing was performed because this was the method used previously to investigate breakdown product formation in CFCs and CFC replacements. Elevated temperature (up to 200°C) and elevated pressure tests (pressure determined by enthalpy conditions for each fluid) were performed in order to establish breakdown product creation under more realistic operating conditions. Finally, tests were planned to be performed under induced motor breakdown conditions in order to determine whether the rate of energy deposition might be a significant factor in the quantity and type of by-products produced.

Initial intentions were to perform actual motor breakdown tests, where a suitable hermetic motor would be charged with the fluid of interest, and then a high-voltage pulse introduced in such a way as to produce an electrical arc in the fluid space surrounding the motor. We were unable to introduce such a failure in actual electrical motors; the electrical input required to induce an internal electrical failure resulting in an arc was sufficiently high that external arcing occurred first. In order to determine the breakdown products resulting from high voltages which might occur, for example, as result of a lighting strike, a simulated motor burnout test was performed. Data from this test was compared with data from the elevated temperature/pressure and atmospheric pressure tests, and with data from the literature. However, we feel that, based upon the experiments described in this report, failure due to massive overvoltage is an unlikely failure mechanism.

II.A.1 Atmospheric Pressure Testing

Initial testing involved the use of high impedance impulse injectors to cause electrical breakdown in the gas or head pressure regions. The purpose of this approach was to establish the relationship between the amount of energy deposited (in Joules) and the amount of by-products produced for the selected fluids of interest. Similar injectors were used for the atmospheric testing and the high-temperature/high-pressure testing. The test configuration for all three tests are similar and explained in the following sections.

The test cell (device under test, DUT) is shown in Figure 1.



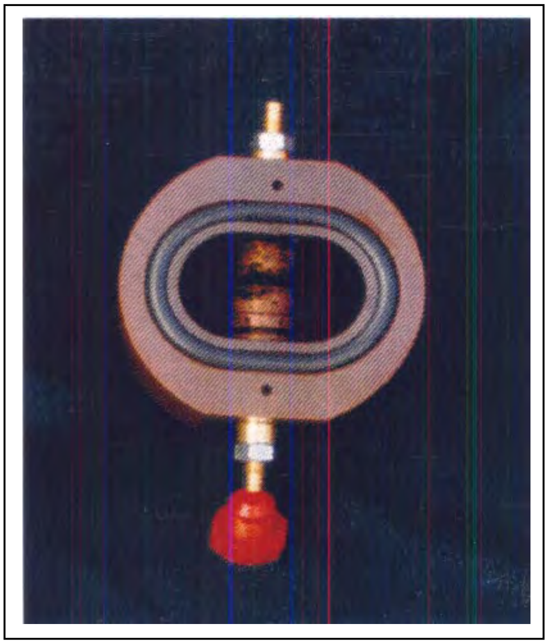


Figure 1 Block diagram (above) and photograph (right) showing electrode placement in test cell

As can be seen in Figure 1, the device under test (DUT; also referred to as the test cell) is a simple two electrode gap used to hold the selected gas specimen. The opposing electrodes are labeled A & K to represent anode and cathode respectively. The electrodes are made of brass, while the housing is constructed from a polyimide material capable of withstanding the required temperature and pressure. Total cell volume is 93 mL. The test cell was fitted with suitable ports and valves used to introduce and remove the fluid being test, as shown in Figure 2.

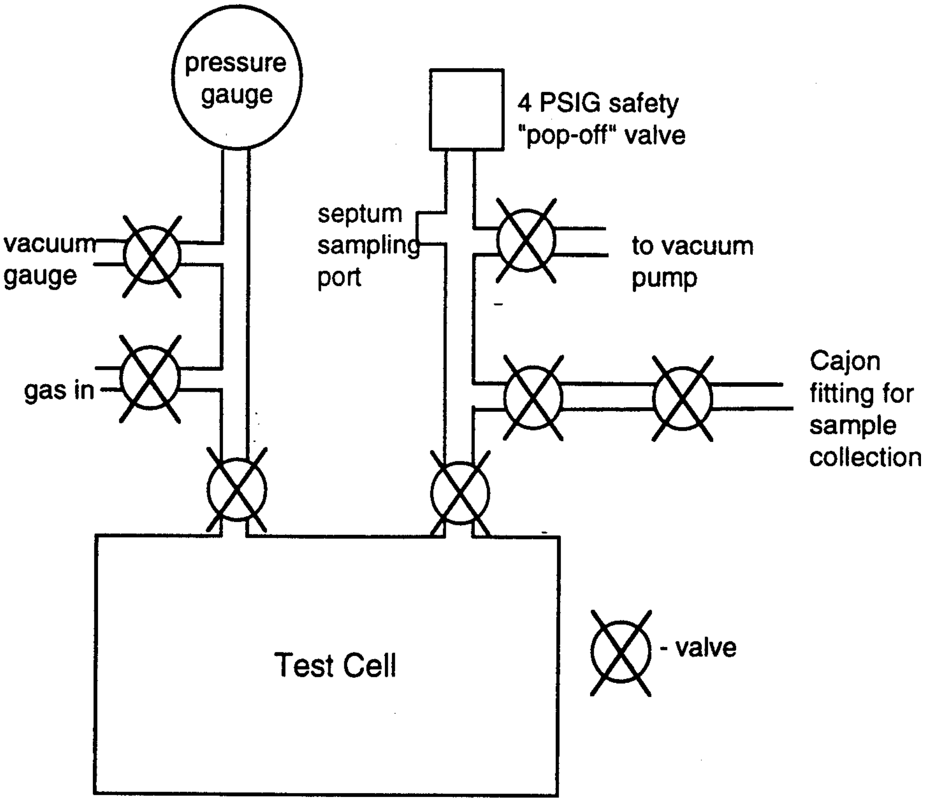


Figure 2 Schematic of ambient pressure/temperature test cell

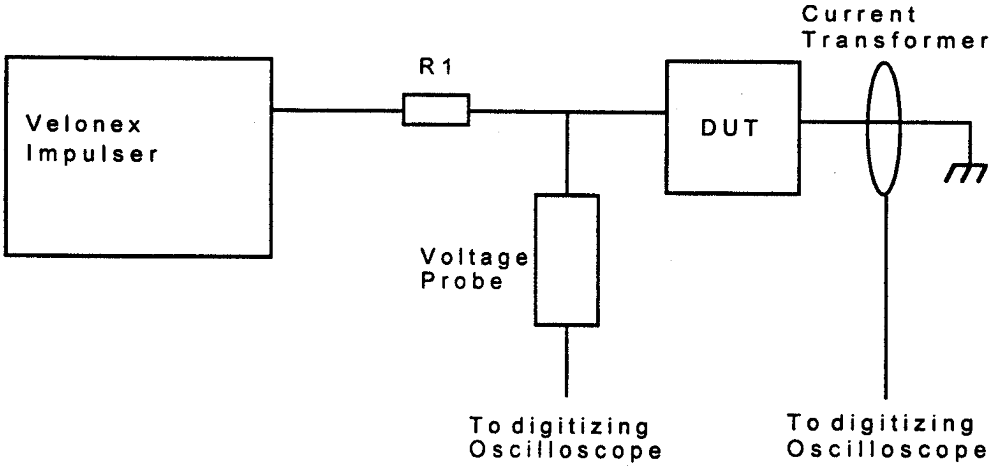


Figure 3 Block Diagram of test stand and diagnostics

Figure 3 is a block diagram that illustrates the relationship of the impulse generator, the device under test (DUT), and the associated diagnostics. A series resistor (R1) limits the available source current to the DUT and provides the short circuit protection to the impulse generator. Using the measured voltage and current signals, it is possible to determine the energy delivered to the DUT.

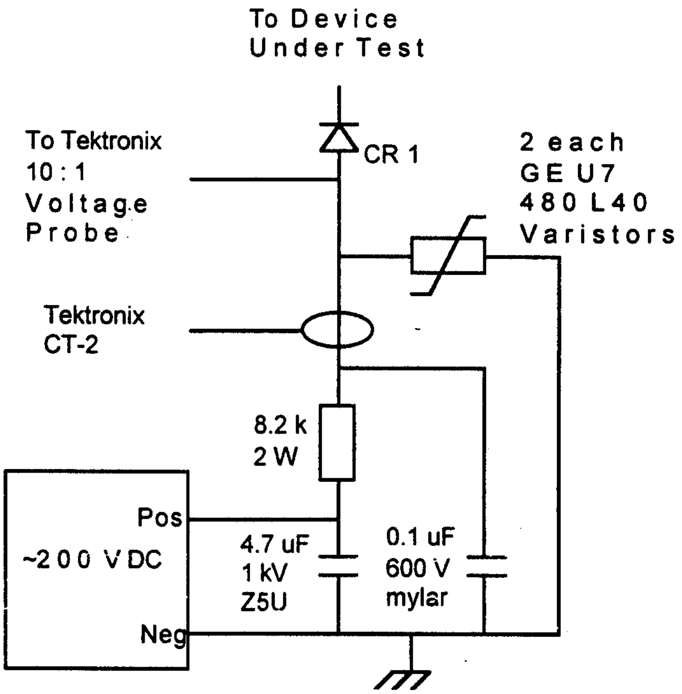


Figure 4 Voltage probe diagram

Figure 4 is a schematic representation of the voltage probe used to monitor the collapsed voltage drop across the DUT. A current rectifier (CR1) was used to block the injected high voltage source. CR1 was constructed from 30 fast recovery diodes, each having an estimated voltage drop of 0.7 volts. Representative electrical parameters were measured on the DUT during testing. An estimated 6% error was given to all electrical measurements. Appendix B.1 provides sample waveforms for each of the selected fluids.

II.A.2 Sampling and analysis: Prior to the beginning of each test, the test cell was cleaned with hexane and dried with air. The cell was then filled with the fluid to be tested and evacuated, using a vacuum pump, to approximately 50-100 millitorr. The cell was filled and evacuated once more before filling it to 100 kPa (15 psia) with the fluid to be tested. The fluid was then subjected to the specified number of pulses before a sample was drawn.

After each test, the fluid was collected in a 10 mL, stainless steel, sampling bottle with a valve and metal-seal fitting. The sampling bottle had been previously evacuated to 10^{-6} torr. The sampling bottle was placed on the sampling manifold and the region between the test cell and the sampling bottle was evacuated to 50-100 mtorr. First, the valve to the test cell and, then, the valve to the sample bottle were opened and the gas sample was collected. The sample bottle was fitted to a small manifold that contained a septum seal. The manifold was evacuated to 50-100 mtorr, the valve to the sample bottle was opened, and a gas tight syringe (Dynatech Precision Sampling Corp., Baton Rouge, LA) was used to pierce the septum seal and transfer the fluid into the gas chromatograph/mass spectrometer (GC/MS).

All samples were analyzed with a Hewlett-Packard GC/MS. A gas tight syringe was used to transfer 50 µL of gas from the sample bottle to the split/splitless injection inlet of the GC/MS. The breakdown products were separated using a 105 m, RTX-1 column (Restek Corp., Bellefonte, PA) with a 0.25-mm i.d. and a 1-µm film thickness. The analytes were separated using He carrier gas at 210 kPa (30 psig) head pressure. A splitless injection (0.75 min.) was used and the GC was started at -30°C (held for 13 min.), ramped at 5°C/min. to 150°C, and ramped at 10°C/min. to 300°C (held for 10 min.). The analytes were detected by electron ionization MS. The MS was scanned from 33 to 500 amu at a rate of 1.1 sec/scans.

Prior to sample analysis, an injection of 55 ng 1,1,2-trichlorotrifluoroethane (TCTFE) was made each day to verify that the GC/MS was functioning optimally. Quantitation of the analytes was accomplished by assuming that the mass spectral responses of the analytes were the same as that of TCTFE and by comparing the total ion chromatogram peak areas of analytes to that of the TCTFE external standard. It was assumed that the calibration curve for the analytes would be linear for the amounts of analyte detected (*i.e.* if the mass of analyte injected into the GC/MS is doubled, then the GC/MS response, measured as peak area in the total ion chromatogram, would also double). This assumption was valid for the measurement of the breakdown products formed.

However, the assumption of linear response was not valid for the quantitation of the starting material (parent fluid). Because- the parent fluid was often present at a concentration 500 to 1000 times greater than those of the breakdown products, its response exceeded the linear range of the GC/MS. Thus, a correction factor was needed to allow the quantitation of the parent fluid based on the GC/MS response of TCTFE. To correct for nonlinear behavior, the GC/MS response of dichloromethane, from its linear range to its non-linear range was determined. We assumed that the parent fluid would behave similarly to dichloromethane. A logarithmic fit described this curve. Next, we calculated the response that given amounts of dichloromethane would have, if the GC/MS behaved linearly for all amounts of dichloromethane. Comparison of these two curves yielded response factors which could be multiplied to peak areas of the total ion chromatogram which were outside the linear range of the GC/MS. The corrected peak area was then used, along with the response of the TCTFE standard, to calculate concentration. Because the approximate amount of parent fluid which was injected into the GC/MS could be estimated, it was possible to select appropriate correction factors (ranging from 10 to 40) to calculate the amounts of parent fluid that were actually present in the sample.

The concentrations of breakdown products were reported as parts-per-million in the presence of the parent fluid (*i.e.* micrograms of breakdown product per gram of parent fluid). Had the above correction factors not been applied, the concentrations of breakdown products would have been overestimated by factors of 10-50.

The reproducibility of the GC/MS method was determined by comparing four, 50 µL injections of a standard gas mixture containing 2.5 µg/mL each of chloromethane, vinyl chloride, bromomethane, chloroethane, trichlorofluoromethane, and dichlorodifluoromethane in nitrogen (Restek, Bellefonte, PA). The retention times for replicate injections of these compounds agreed within 2 seconds. The GC/MS response, as measured by area counts recorded by the detector, averaged 8% standard deviation. The standard deviation varied from 4% (for dichlorodifluoromethane and chloromethane) to 12% (for chloroethane), depending on the compound.

II.B Elevated Temperature and Pressure Testing

The design of the test cell used for the high temperature/high pressure tests was similar to that described above, with the exception of sampling. The elevated temperature/pressure test cell had a sample volume of 77 mL. A schematic of the test cell and sampling apparatus is shown Figure 5.

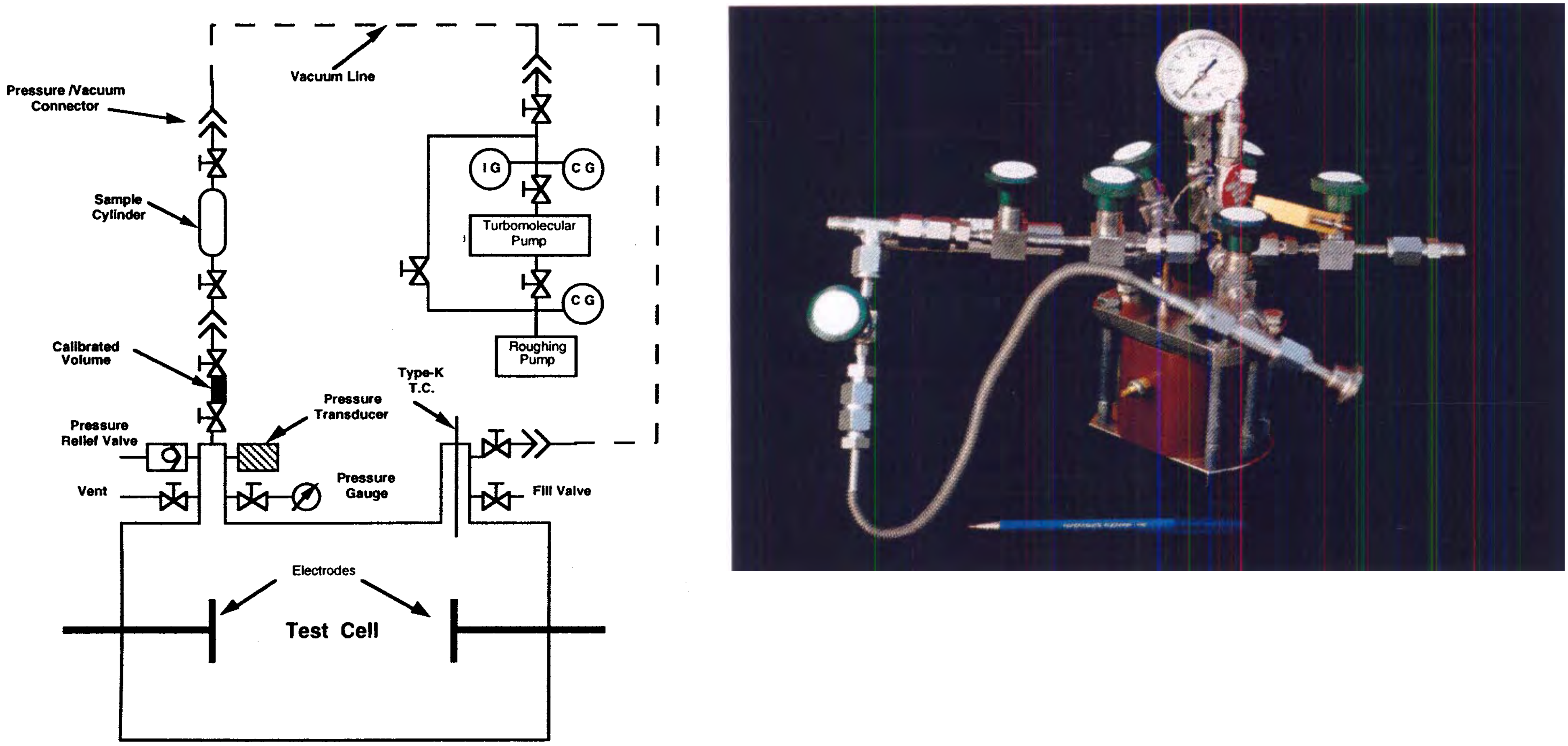


Figure 5. Schematic and Photograph of High Temperature/High Pressure Test Cell

II.B.1 Electrical measurements: Total electrical energy deposited into each of the fluids under test was measured as described for the ambient pressure/temperature tests, and is summarized in Table II in Section III. As in the ambient testing a 6% error is reflected in the electrical measurements. Selected waveforms representing typical measured electrical parameters are provided in Appendix B.2.

II.B.2 Elevated Temperature/Pressure sampling/analysis procedures: The cell was prepared and filled to the desired pressure as previously described. The cell was allowed to heat to 200°C and the test was begun. Because it took several hours for the cell to reach 200°C, five samples were taken from the same volume of parent fluid. Samples from the cell were taken at the beginning of the experiment, at 10K pulses, at 50K pulses, at 100K pulses, and at 200K pulses.

The fluid samples were collected in 10 mL, stainless steel, sampling bottles, as previously described. The fluid sampled was first collected in a smaller (3 mL) volume on the sampling manifold before it was expanded into the 10 mL sample bottle. This provided a reduced gas pressure in the sample bottle. The collected gas was then sampled, as described previously, with a gas tight syringe and injected into the GC/MS. Analysis and quantitation of the breakdown products and parent fluids was performed as described previously.

II.C Motor tests

The objective of the simulated motor AC carryover tests was to simulate AC-like faults within a refrigeration motor-compressor unit, and to quantify and identify the by-products produced. Previous tests conducted at LLNL, along with the ambient temperature/pressure and elevated temperature/pressure tests conducted for this work, indicated that the production of breakdown products was an approximately linear function of arc energy. The motor carryover tests were designed initially to provide data collected under realistic fault conditions to compare against the bench-scale data. The tests were designed to deposit the same amount of energy in a single (or a few) AC cycles of millisecond duration as was deposited in thousands of repetitive discharges of microsecond duration using the bench-top tester.

The intent of this series of tests was to impose sufficient over voltages on an energized motor to initiate an arc within the motor compressor housing and maintain the established arc with the motor's normal operating voltage. In pursuit of this effort, appropriate temperature range units were procured having internal construction characteristics allowing for the desired effect. The requirement for establishment of an internal electrical arc was that motors must have internally exposed electrical connections which might allow arcing within a vapor region. The focus of these tests was on electrical breakdown of the refrigerant fluid within an operating motor-compressor unit, in order to determine by-products produced as a result of electrical arcing within an operating motor. Other test scenarios which might result in thermal decomposition (i.e., overheating due to locked rotors) were not investigated.

A simulated AC test bed was used to investigate the effects of AC type of currents on the selected fluids. The High Voltage Test Facility at LLNL was initially designed to investigate transient type of impulses on active AC operating systems. The test system utilized an impulse generator to inject sufficient impulse voltage to over stress the motor winding in a reasonable time but not allow prime power currents to continue through the injector circuit. The impulse parameters originally estimated to be sufficient can be represented by a double exponential waveshape having a rise time of 10 ns to a peak of 20 kV and a fall time of 350 ns to a level that is one half the peak voltage. The initial peak value of 20 kV was selected to allow for simulator impedance mismatches. The injection level of a device under test (DUT) was limited to 5 kV. The 5 kV level was selected as below the representative flashover voltage of a typical duplex outlet (6 kV). The impulse rise time and fall time were estimated based upon previous work at LLNL in solid dielectric breakdown. Verification of these parameters was performed during shakedown tests using reclaimed excess refrigerator motors.

The initial phase of this effort characterized a representative unit using low level measurement techniques. Following this high voltage impulses were injected into the setup unit. An extensive effort was required to modify the unit so that it would not breakdown externally on the atmospheric side of the housing. The resulting internal spacing of the exposed electrical inside the test unit far exceeded the test units capability to withstand the related external fields generated during the initial testing. As a result the approach to access the AC effects were iterated.

However, after several attempts at exposing a representative test unit to typical transients without successfully inducing a fault, a simulated motor burnout test was developed. We believe that the frequency of occurrence of a transient-induced arc is not a credible environment and/or has a frequency of occurrence less than 1:1,000,000. The attempt to establish a probability of the selected occurrence takes the following things into consideration: As mentioned above, a typical AC connector will flashover at a nominal 6 kV. The DUT used to characterize a typical unit flashed over externally at 9 kV and flashed over internally at 15 kV. Continued attempts to induce internal AC carryover by extending the impulse duration were not sufficient to cause the unit to fail. Past experience on highly stressed electrical cables indicate that this type of environmental exposure to a given system did not induce failure even after 70,000 exposures. Internal motor construction is not meant to operate at these levels and insulation degradation would be anticipated. Allowing for a representative system fail frequency of 1:100, and an impulse exposure rate of 1:1000 provides an accumulative frequency of occurrence of 1:100,000,000. We use a conservative estimate of 1:1,000,000 for this type of environment causing AC carryover. As a result of this effort contact to a local vendor to access the observed electrical failure scenarios was made. Other failure mechanisms in the electrical insulation might provide close enough electrical paths that may induce the operating voltage to go into an arc phase. One example of this failure mechanism would be overheating scenarios that might be brought on by a locked rotor or a mechanical wearing scenario of electrical insulation.

II.C.1 Test cell modifications: To investigate AC-type failure current effects a modification to the initial test plan was made. The initial two electrode test fixture was taken from the original test stand and inserted into the LLNL AC test bed. Figure 6 illustrates the test configuration used to acquire the data reported for the simulated motor AC carry over tests; Figure 7 is a photograph of the high voltage test facility at LLNL, with the test cell installed in the facility.

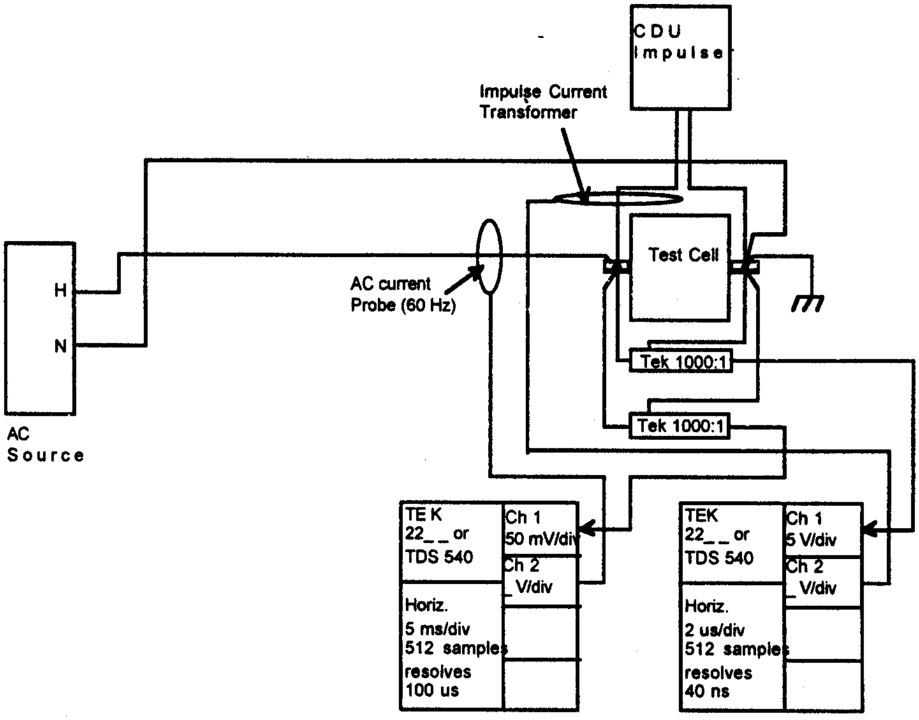


Figure 6. Simulated AC carry-over test configuration.

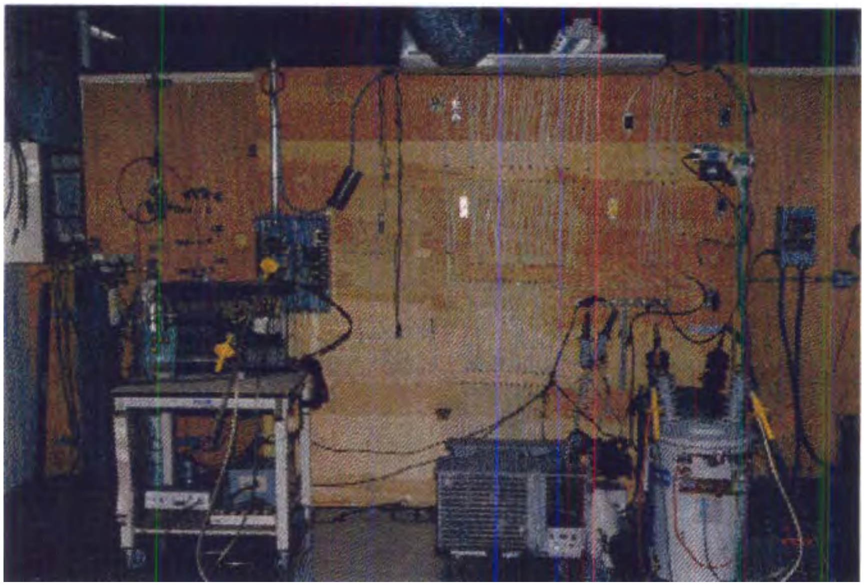
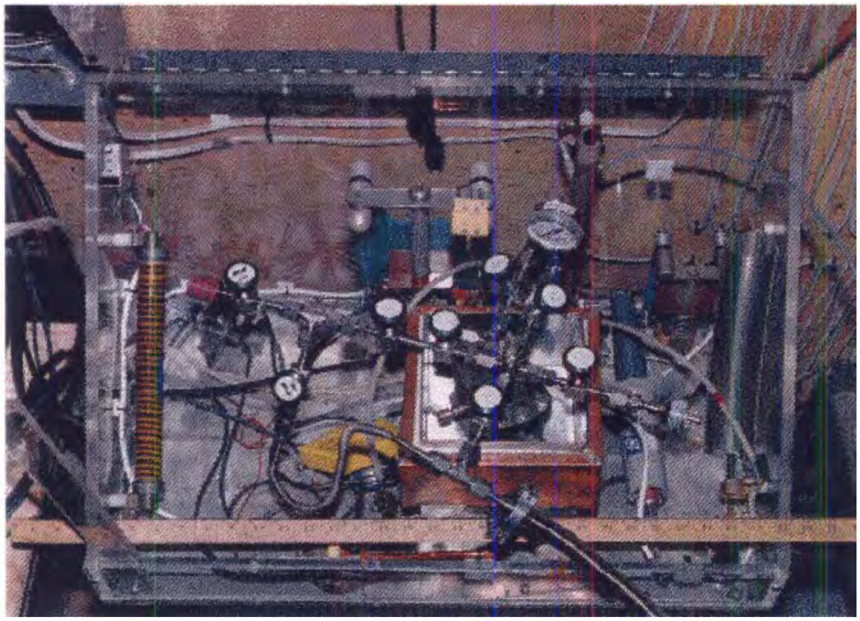


Figure 7. LLNL High Voltage Test Facility (top); test stand installed in facility (right)



The motor simulation design included the initiating impulser, the two electrode test cell, two voltage probes to record high and low voltage characteristics, current probes on selected sources, a 60 Hz AC power source capable of typical current levels, and recording instruments. This test configuration provides the means to assess the level of energy (joules) typically experienced by operating systems during AC arcing.

As in the ambient testing, a 6% error is reflected in the electrical measurements. Selected waveforms representing typical measured electrical parameters were collected and are provided in Appendix B. Incomplete testing on R507 restricts the reporting of that specimen for this environment.

II.C.2 Motor Tests (Modified test stand) sampling/analysis: After the completion of each test, the resulting fluid was collected in a 10 mL, stainless steel sampling bottle, analyzed, and the breakdown products and parent fluids were quantified as described previously.

SIGNIFICANT RESULTS

III.A. Energy Deposition

Electrical testing was divided into three different areas of interest. All testing involved initiating an impulse pulse. Initial testing was performed with fluids at ambient temperature and pressure. The second phase of testing involved arcing with fluids held at elevated pressure and at a temperature of 200°C. The final testing included a continuing current typical in active AC power circuits. A summary of the injected electrical energy in joules is given in Table I. Table I shows the amount of electrical energy injected into the test specimen in joules per impulse, average one half cycle 60 Hz AC, and single exposure with multiple breakdowns in 60 Hz AC. Notice that under AC conditions an increase of 4 orders of magnitude in energy is delivered to the device under test. Additional information on the electrical parameters specific to each test is given in the preceding sections.

Table I Electrical energy (Joules) deposited into each fluid during testing*

	R22	**R134a**	**8507**	**Units**
Ambient temperature/pressure	1.56 E-03	1.80 E-03	3.31 E-03	J/pulse
High temperature/pressure	2.54 E-03	3.73 E-03	1.93 E-03	J/pulse
AC single half-cycle exposure	2.53 E+01	2.29 E+01	no test	J total
AC multiple cycle exposure	3.80 E+02	3.89 E+02	no test	J total

* - note: the ambient T/P and high T/P energy per pulse must be scaled according to the number of pulses to determine the total energy deposited.

III.B. Atmospheric Pressure/Temperature Testing: A wide variety of breakdown products were identified in all test scenarios. Identification of breakdown products is performed by comparison of mass spectra obtained with mass spectra contained in the following mass spectral libraries:

a. The Wiley/NBS Registry of Mass Spectral Data, F. W. McLafferty and D. B. Stauffer, John Wiley & Sons, New York, 1989.---112,300 compounds

b. Mass Spectral Library: DuPont Fluorochemicals, personal communication from Pat Kaczarel, February 11, 1991.---126 compounds

c. The Eight Peak Index of Mass Spectra, 4th Ed., The Mass Spectrometry Data Centre, The Royal Society of Chemistry, Thomas Graham House, Science Park, Cambridge, UK, 1991.---81,123 compounds

d. NIST/EPA/NIH Mass Spectral Database, PC Version 4.0, US Department of Commerce, NIST, Gaithersburg, MD, May 1992. >100,000 compounds.

The electrical arcing experiments described in this work produced highly complex mixtures of breakdown products. In general, few breakdown products were formed which were lighter than the original material. In both the atmospheric pressure and elevated temperature and pressure tests, the compounds produced were generally heavier (higher molecular weight and less volatile) than the starting material. Chlorodifluoromethane (R-22) was identified in all samples taken, at widely varying levels. Although the sample cell was cleaned thoroughly between each test and evacuated prior to filling, the source of the R-22 could not be identified. Formation of chlorinated breakdown products from R-22 is reasonable; however, R-134a and R-507 do not contain chlorine sources, so that detection of R-22 in these fluids after testing can only be due to contamination from carry over or other sources, which we were not able to identify. No other chlorinated breakdown products were identified in R-134a or R-507 tests.

For all test scenarios, R-22 produced the largest number and variety of breakdown products; compounds ranged from chlorotrifluoromethane (R-13) to long-chained chlorinated and/or fluorinated hydrocarbons. R-134a produced the least complex breakdown products in terms of numbers of different compounds. Table II lists the compounds produced by each of the fluids during atmospheric pressure testing, with an indication of the relative amount produced at 100K pulses, or a total energy deposition 156-331 Joules. Amounts are indicated as high, med, or low, as measured relative to the parent fluid µg compound/µg parent fluid). High indicates relative concentrations in the 10^{-3} range (0.1% or greater when compared to the parent fluid), medium indicates relative compound concentrations in the 10^{-4} range, and low indicates compounds produced at relative concentrations of 10^{-5} or lower (<100 ppm). A complete listing of all compounds identified in each test, along with the quantity relative to the parent fluid, is given in Appendix C.

Table II. Compounds Produced under atmospheric pressure/ambient temperature electrical discharge

Compound	R-22	R-134a	R-507
Chlorodifluoromethane (R22)*	High[@]	High	Low
1,1,1,2-tetrafluoroethane (R-134a)		High[@]	Med
R-507			High[@]
tetrafluoroethene (R-1114)	High	High	High
hexafluoroethane (R-116)		High	High
1,1-difluoroethene (R-1132a)			High
1,1-dichloro-2,2-difluoroethene (R-1112a)	High		
1,2-dichloro-1,1,2,2-tetrafluoroethane (R-114)	High		
dichlorodifluoromethane (R-12)	High		
hexafluoropropene	High		
trifluoroethene		High	
1,1,2-trichloro-1,2,2-trifluoroethane (R-113)	Med		
1,1,3,3-tetrachloro-2,3-difluoropropene	Med		
1,2,2-trichloro-1,1,3,3,3-pentafluoropropane	Med		
1,2-dichloro-1,2-difluoroethene[#] (R-1113)	Med		
1,2-dichloro-1,3,3,3-tetrafluoro-1-propene[#]	Med		
1,2-dichloro-tetrafluorocyclobutene[#]	Med		
1-chloro-1,1,2,2,-tetrafluoroethane (R-124a)	Med		
2-chloro-1,1,3,3,3 - pentafluoro-1-propene	Med		
3-chloro-1,1,2,3,3-pentafluoro-1-propene	Med		
C4F3Cl	Med		
1,3-dichloro-1,1,2,2,3,3-hexafluoropropane (R-216ca)	Med		
CF3CFClCF2Cl	Med		
chlorinated aromatic compound	Med		
chlorinated hydrocarbon (2 Cl; mw=145?)	Med		
chlorinated hydrocarbon (2 Cl; mw=156?)	Med		
chlorofluorohydrocarbon[#]	Med		
chlorohexafluoropropane	Med		
chloropentafluorobenzene	Med		
Cl-CCCF3	Med		
dichloroethyne	Med		
fluorinated alkane	Med		
hexafluorochlorobutene	Med		
mw=152? mono Cl aromatic?	Med		
tetrachloroethene	Med		
trans- 1,3,3-trichloro-1-propene	Med		
trichlorofluoroethene	Med		
trichlorofluoromethane (R-11)	Med		

(Table II continued)

Compound	R-22	R-134a	R-507
trichloropropene	Med		
unknown[#]		Med	
1,1,3,3,3-pentafluoro-1-propene			Med
3,3,3-Trifluoro-1-propyne			Med
1,1,1,6,6,6-hexafluoro-2,4-diyne		Low	Low
1,2,3,4,5,5-hexafluoro-1,3-cyclopentadiene[#]		Low	Low
1,3-Butadiyne	Low		
dichlorofluoromethane (R-21)	Low		
C5F5H		Low	
octafluoro-1,3,5-Hexatriene		Low	
1,1,2,3,3,3-hexafluoropropane			Low
3 chloro-1,1,3,3-tetrafluoro-1-propene			Low
4 - (difluoromethylene)-2,3,3-trifluorocyclobutene			Low
CH3-substituted pentafluorocyclopentadiene			Low
fluorinated hydrocarbon (aliphatic) [#]			Low
hexafluoro-cyclobutene			Low
monochlorinated, CH3-substituted hydrocarbon			Low

* - no chlorine source for R-134a or R-507; detection of R-22 must be suspect.

[@] - in all cases the parent fluid was the major constituent present (>97%).

[#] -multiple isomers detected; highest concentration reported

ASHRAE R-designations are provided where known for compounds listed in Table II; where the specific isomer is unknown, the parent R-number is listed. A complete listing of compounds identified with relative concentrations is given in Appendix C.

Tetrafluoroethene (R-1114) was the only common compound detected in all three fluids under electrical breakdown at atmospheric pressure and temperature. With the exception of R-22, the major breakdown products produced for all fluids were two-carbon molecules. Hexafluoroethane (R-116) was produced by both R-134a and R-507. Tetrafluoroethene was the major breakdown product produced by R-22, followed by R-12 (dichlorodifluoromethane); both these compounds were produced at percent levels (1.2-1.9%). Dichlorotetrafluoroethane (R-114) was the next most abundant breakdown product from R-22, found at levels of approximately 0.4%. Hexachloropropene and dichlorodifluoroethene (R-1112a) were the next most abundant breakdown products for R-22, present at levels of from 0.1-0.3%. Figure 8 shows the relative amounts of the major breakdown products produced as a function of energy deposition for R-22.

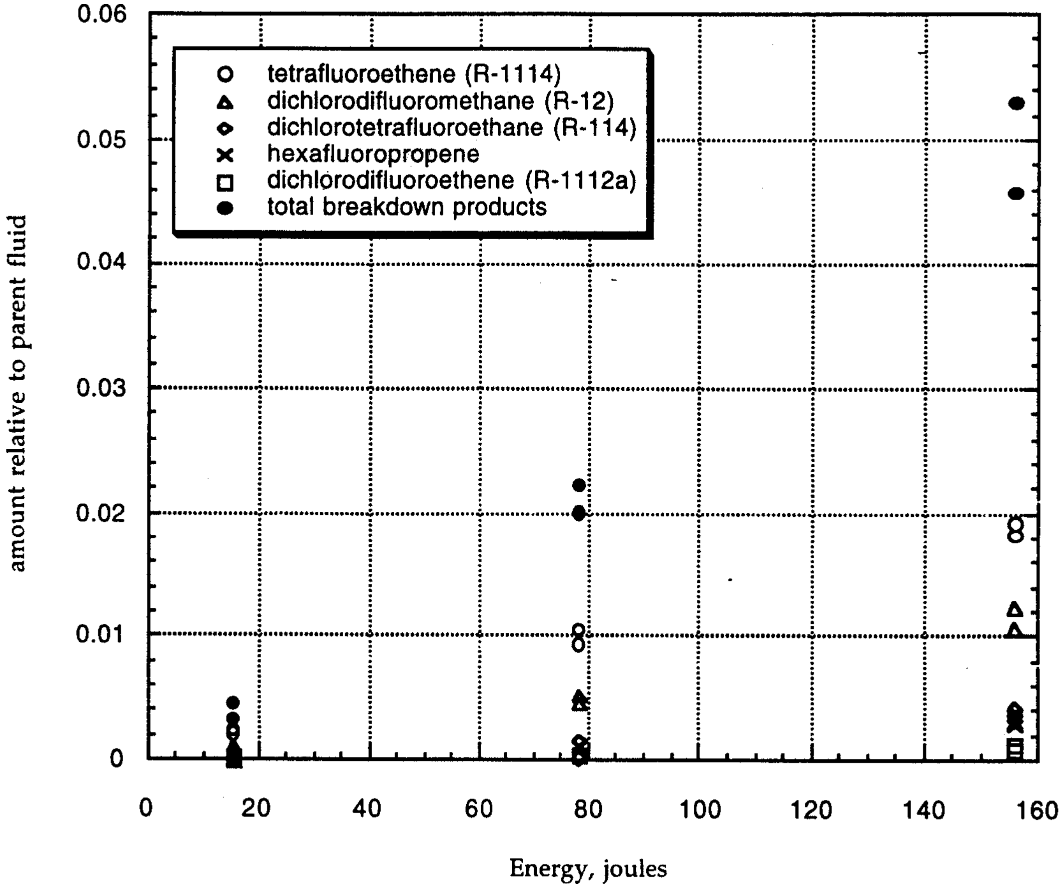


Figure 8. Major Breakdown products for R-22 as a function of energy, atmospheric pressure/ambient temperature testing.

R-134a and R-507 produced both lesser amounts of breakdown products, and less complex mixtures than R-22 when tested at ambient temperature and pressure. In the case of R-134a, tetrafluoroethene (R-1114; 0.4-0.7%), hexafluoroethane (R-116; 0.2%) and trifluoroethene (0.2%) were the major breakdown products. For

R-507, tetrafluoroethene was again the major breakdown product, present at 0.4-0.5%. 1,1-difluoroethene (R-1132a) and hexafluoroethane (R-116) were present at around 0.2%. Figures 9 and 10 are graphic representations of the amounts of these breakdown products as a function of energy for R-134a and R-507.

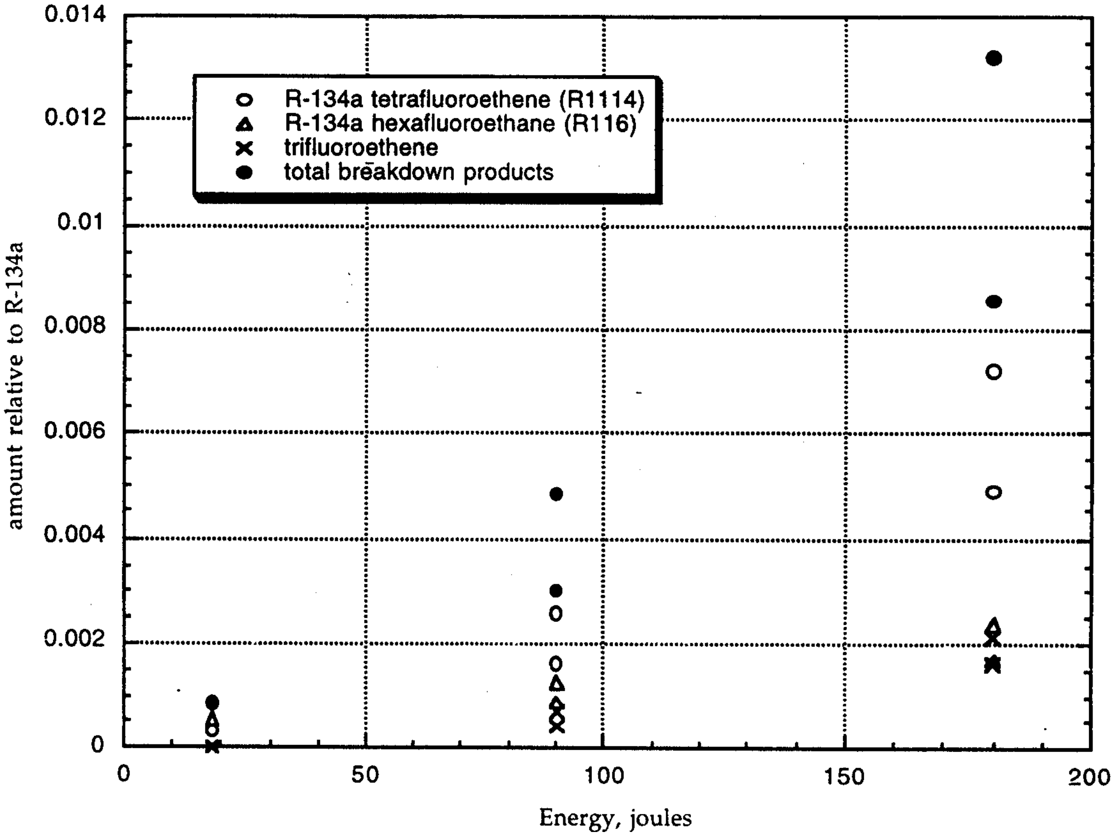


Figure 9. Major Breakdown products for R-134a as a function of energy, atmospheric pressure/ambient temperature testing.

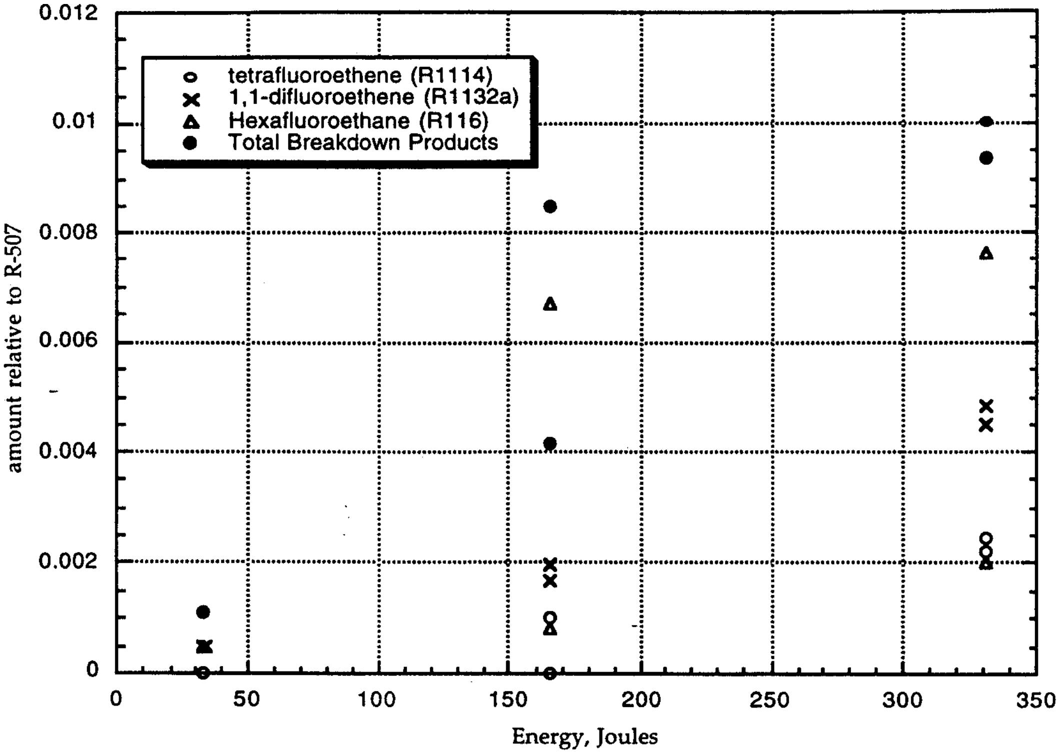


Figure 10. Major Breakdown products for R-507 as a function of energy, atmospheric pressure/ambient temperature testing.

III.C. Elevated Temperature/Pressure Testing: Elevated temperature/pressure testing with electrical discharges to 200,000 pulses was conducted on R-22 and R-134a. We were unable to complete electrical breakdown testing of R-507 to these levels due to conductance by R-507. Although R-507 was found to carry over quickly when pulsed, it was not able to sustain an arc. R-507 testing was successful only to 77K arcs, at which time the test stand was found to conduct. When disassembled after sampling, deposits of carbon were observed between the electrodes. These deposits served as a conductive bridge between the electrodes, preventing the pulsed breakdown of the fluid. Similar behavior was seen in the simulated motor AC carryover tests, which prevented the testing of R-507 under these electrical conditions. R-134a was also found to produce carbon upon high temperature/pressure testing, although carbon production did not interfere with the electrical discharge breakdown.

Final pressure of each fluid under test varied. Pressure was measured through the use of a pressure transducer mounted on the cell (see figure 5). The high temperature cell was initially filled to a pressure at equilibrium with the source cylinder. The cell was then heated to 200°C, and the resulting pressure measured. Fluid test pressures were 1860 kPa (270 psi) for R-507, 1380 kPa (200 psi) for R-22, and 830 kPa (120 psi) for R-134a. Once the test cell had reached 200°C, the electrical breakdown testing was initiated.

Fewer by-products were observed after high temperature/high pressure testing than were seen at atmospheric pressure testing. The major breakdown products remained the same for all fluids tested. The number of minor breakdown products decreased slightly. Although the numbers of different breakdown products decreased, the total amount of breakdown products remained relatively constant when plotted as a function of energy deposited into the system. Figure 11 is a plot of the total amounts of breakdown products produced for all fluids as a function of energy. With the exception of R-22 at ambient temperature and pressure, the amount of breakdown products produced appears to be approximately linear with respect to energy deposition. One possible explanation for the anomalous R-22 data is that multiple discharge arcs may have occurred during breakdown testing which were incorrectly counted as single events. When the electrical waveforms collected during the R-22 atmospheric pressure testing were analyzed, multiple arcing was observed on at least one waveform. Waveform data was not taken for every pulse due to instrument limitations, so the actual amount of multiple arcing cannot be accurately estimated.

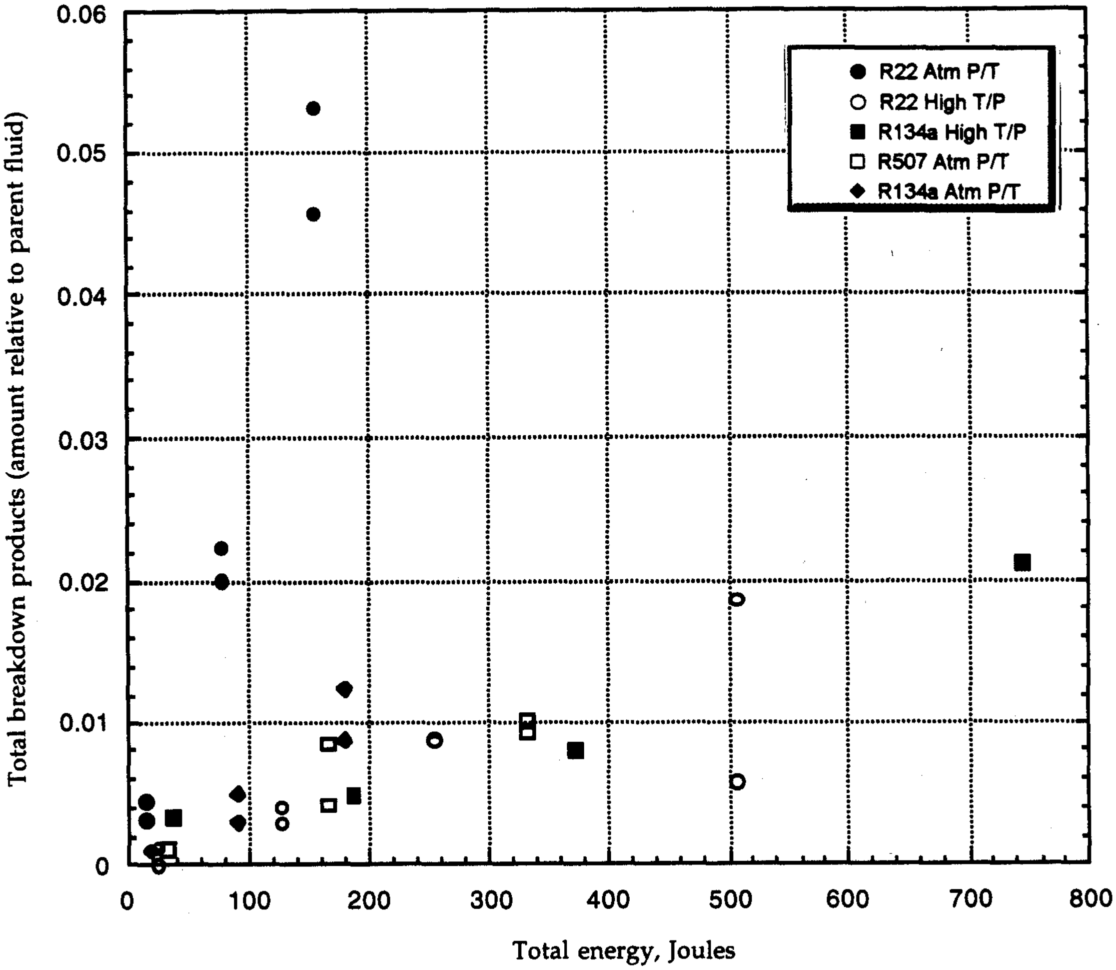


Figure 11. Comparison of total breakdown products as a function of energy for atmospheric pressure and elevated temperature/pressure testing of R-22, R-134a and R-507.

Figure 12 is a plot of the relative amounts of specific breakdown products for R-22 and R-134a produced under testing at ambient temperature / pressure and at elevated temperature / pressure. With the exception of the high levels of R-1114 (tetrafluoroethene) and R-12 (dichlorodifluoromethane) found in the atmospheric pressure testing of R-22, a general trend of increasing production with increasing energy deposition can clearly be seen. When the data for figure 12 is replotted without the ambient temperature and pressure R-22 data, a clearer link between energy deposition and breakdown product formation can be seen (Figure 13).

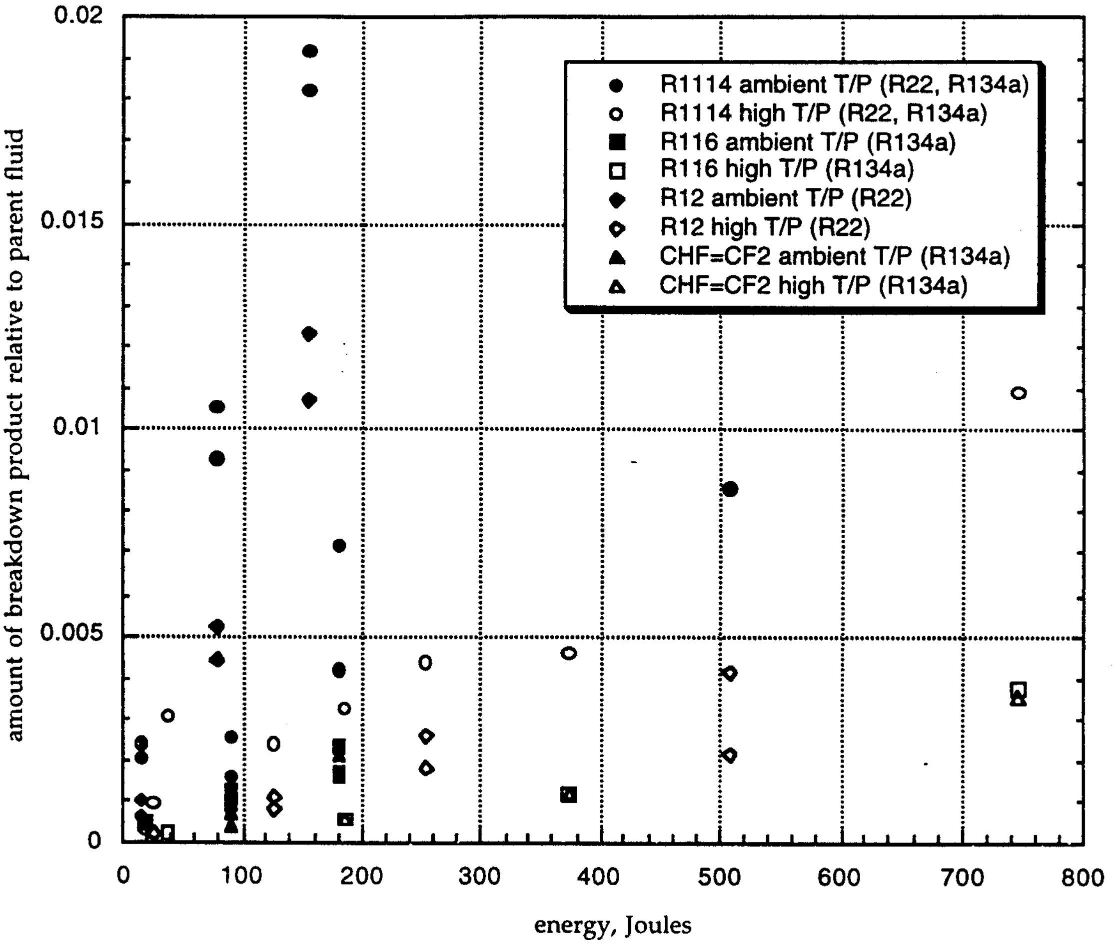


Figure 12. Relative amounts of specific breakdown products from R-22 and R-134a; solid markers indicate products from ambient temperature and pressure tests, while open markers indicate elevated temperature and pressure tests.

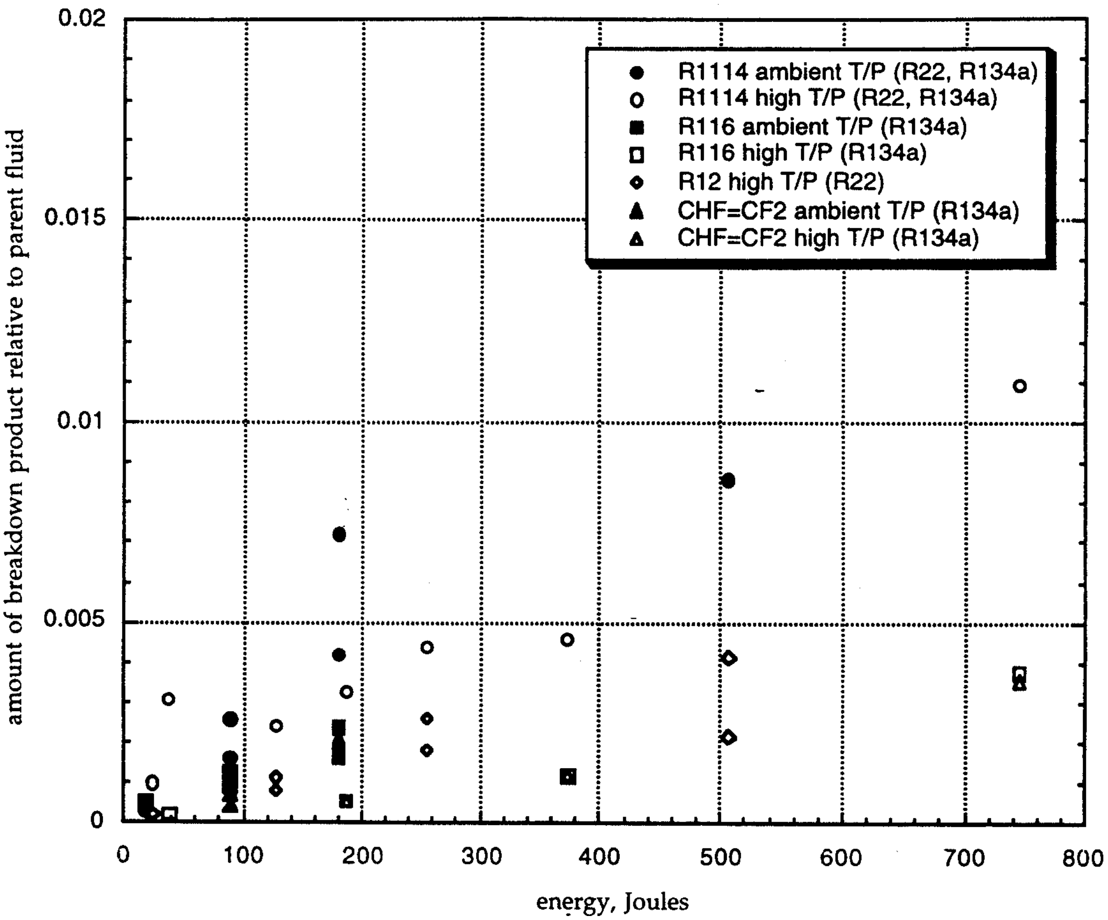


Figure 13. Same as Figure 12 but data from ambient pressure testing of R-22 is not plotted.

III.D. Simulated Motor AC Carryover Experiments: Two experiments were performed to simulate an AC carryover overvoltage event on an electrical motor. R-22 and R-134a were chosen for these experiments. R-507 was not studied due to the difficulty in inducing non-conductive arcing in an elevated pressure environment. The high temperature /pressure test cell was moved to the pulsed power laboratory and connected to high voltage transformers as described previously (section II.C). The system was charged with fluid to a pressure that would be expected in a typical operating system. A single half-cycle current injection was performed, and the fluid sampled and analyzed.

The total energy injected into the system was comparable to the maximum energy injected during both the ambient temperature/pressure tests and the high temperature/pressure fluid testing. Maximum energy deposition in R-22 ranged from approximately 150 to 500 Joules; for R-134a, maximum energy deposition ranged from approximately 180 to 750 joules. The total amount of breakdown products produced showed the same dependence upon energy that had been observed in previous ambient and elevated temperature/pressure tests. Figure 14 is a graph of total breakdown products for all tests.

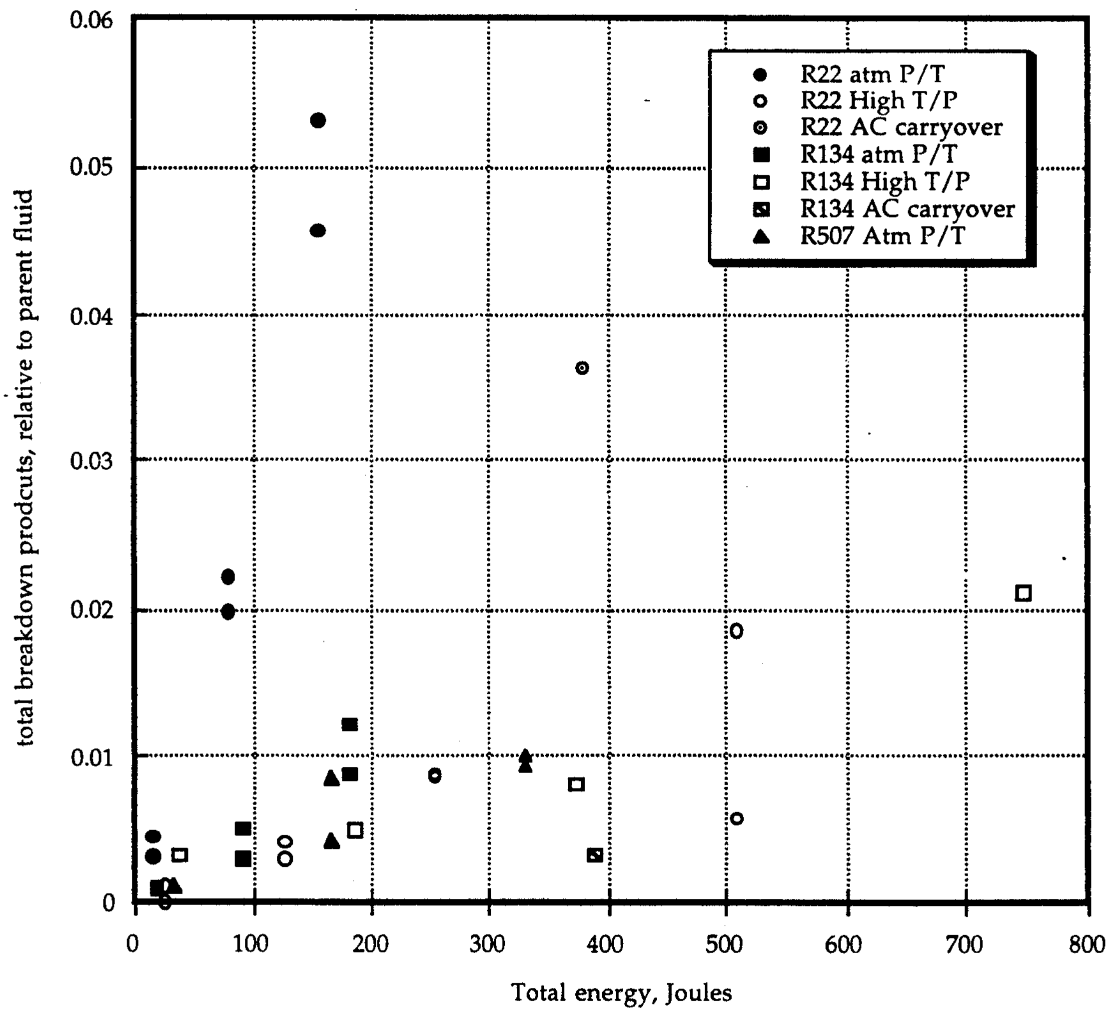


Figure 14. Total breakdown products produced as a function of energy deposition, all fluids, all tests

Although the total amounts of breakdown products formed under AC carryover testing was consistent with the apparently linear relationship of energy deposition with by-product formation, there were important differences in the by-products formed under AC carryover. The by-products seen in both R-22 and R-134a were less complex mixtures than had been obtained in previous tests. Only five major by-products were identified for both R-22 and R-134a. In each case, only one of those by-products had been identified in previous testing; the other four were new. The by-products observed and the amounts relative to the parent fluid are given in Table III.

Table III. Breakdown products formed during AC carryover testing.

	amount relative to parent fluid	
compound	**R-22**	**R-134a**
dichlorodifluoromethane (R-12)	0.000733	
chlorotrifluoromethane (R-13)	0.00510	
pentafluoroethane (R-125)	0.00232	0.000146
trifluoroethane (R-143)	0.00415	0.000359
tetrafluoroethane (R-134)	0.0241	
hexafluoroethane (R-116)		0.0000454
trifluoroethene		0.000242
difluoroethene (R-1132a)		0.0000190

It is interesting to note that products which were major breakdown products under ambient and elevated temperature and pressure tests are seen at very low concentrations under simulated AC carryover tests. For example, for R-22, R-12 (dichlorodifluoromethane) was the major breakdown product under bench-scale testing. Under simulated AC carryover conditions, R-12 is the least abundant breakdown product, and is present at approximately 733 ppm. If we extrapolate the bench-scale results for R-12 production to a similar energy deposition (380 joules), we would expect levels of 2500 ppm (elevated T/P) to almost 3% (ambient T/P). Hexafluoroethane (R-116) was identified as a breakdown product of R-134a under both bench-scale and simulated AC carryover testing; again, at levels in the AC carryover sample that were much lower than what would be expected from previous tests. For an energy deposition of 389 joules (AC carryover), we would expect formation of 1700 ppm (elevated T/P) to 4000 ppm (ambient T/P) of R-116, rather than the actual amount detected of 45 ppm. These expectations are shown graphically in Figure 15.

The differences in types of breakdown products, combined with the different levels observed, suggest that different mechanisms are controlling the final breakdown products. Previous work on thermal and shock-wave decomposition of CFCs has indicated that formation of free radicals is a mechanism by which halocarbon decomposition occurs (Foon, Millward, Schug, Kargamanov, Xavier). The wide variety and high levels of breakdown products observed under low pressure conditions suggests that collisions of free radical species with other free radicals and/or unreacted starting material is an important process for formation of various breakdown products.

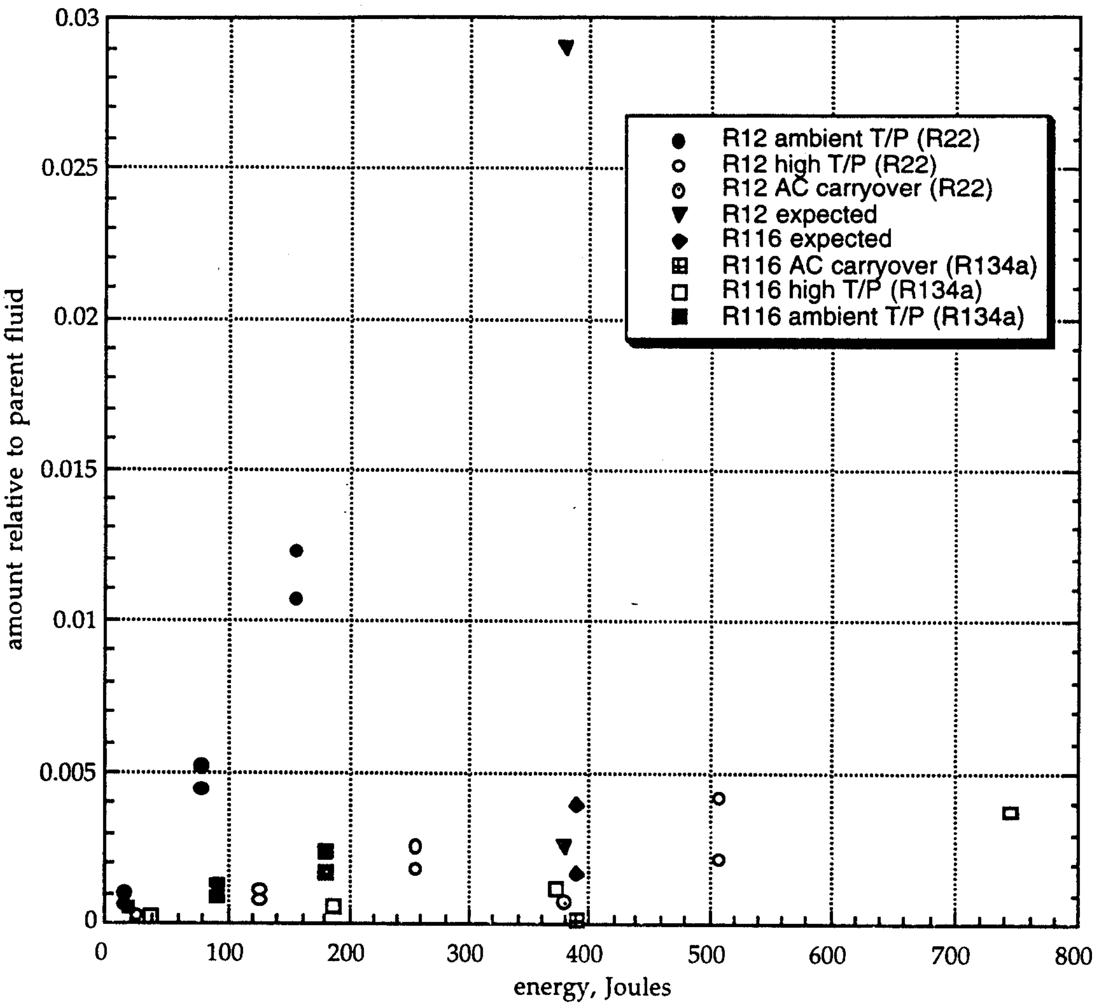


Figure 15. Variation in production of dichlorodifluoromethane (R-12, circles) and hexafluoroethane (R116, squares) as a function of electrical breakdown test. Triangles indicate expected R-12 formation; diamonds indicate expected R-116 formation.

In both the ambient temperature/pressure and elevated temperature/pressure tests, electrical energy was deposited into the system through pulsing at 100 Hz. This repeated pulsing provides a steady source of radicals, which can then react through collisions with other radicals or unreacted molecules, to generate new species. This steady-state free radical formation would suggest that by-product formation is dependent upon free-radical collision frequency. A continual influx of radicals may allow an equilibrium to be established. Under ambient temperature and pressure conditions, the radicals formed have relatively fewer collisions with other radicals or molecules than in the elevated temperature and pressure condition. The radicals formed under ambient temperature and pressure conditions may have lifetimes long enough to allow rearrangement to more stable radicals. This suggests the possibility of thermodynamic control of reaction products. The observation that both smaller amounts and fewer compounds are formed under elevated temperature and pressure conditions supports the hypothesis that product formation under these conditions is controlled by collision rate. In a higher pressure system, radicals are likely to collide and react relatively soon after formation, and before they can rearrange to more stable (thermodynamic) isomers. With a relatively constant influx of radicals, there is opportunity for multiple reactions over a relatively long period of time; conditions that would be expected to favor formation of a variety of reaction products.

In the AC carryover tests, an equivalent amount of energy is deposited into the system in a relatively short period of time, suggesting that the observed reaction products are governed by kinetics. The system is at high pressure (relative to the ambient temperature and pressure bench scale tests). Radicals have relatively short lifetimes, reacting soon after they are formed. By-products are formed quickly; there is not a continual input of additional radicals that can allow continued reaction and rearrangements to more complex products.

III.E. Thermal Breakdown of Refrigerants (literature data): CFC and HCFC degradation, as determined in the laboratory, is dependent on many factors including the experimental set-up, temperature, the presence of varying types of metal catalysts, and the presence of various oils (Parmelee, Huttenlocher, Kauffman, Broyer, Chinoy, Gozzo, DiFelice). Tests of R22 and R134a conducted in sealed tubes at 150-200°C for 14 days showed that these fluids were stable;

although various oils mixed with these fluids showed some degradation (Huttenlocher). Several authors cited in a literature review (Kauffman) demonstrated that R22 and R134a were stable below 200°C.

However, thermal breakdown of R-22 has been observed under certain conditions. R-32 (CF_2H_2), R-23 (CF_3H), carbon monoxide, carbon dioxide, methane, and hydrogen were produced as R-22 (mixed with lubricant) decomposed at 200-250°C in sealed tubes in the presence of metals; the log of the percentage of R-22 decomposed increased linearly with temperature up to 250°C (Spauschus). HCl, C_2F_4, hexafluoropropylene, C_4F_8, and CF_2ClCF_2H (R-124a) have also been observed at temperatures of 800-950°C (Broyer). The presence of C_2F_4 as a decomposition product is not surprising--pyrolysis of R-22 is used to make this monomer, which is used in the synthesis of Teflon. R-22 pyrolysis at 500-750°C produced HCl, C_2F_4, C_4F_8, C_2F_3Cl, C_2HF_4Cl, and trace amounts of perfluoroisobutylene (DiFelice). Bar graphs showing the major products formed when R22 is thermally degraded are shown in Figures 16 and 17. Note that both of these experiments were performed at very different conditions than those present in our reactor--the major differences being the flow cell configurations and the short residence times of the R-22 in the experimental cells. In both experiments C_2F_4 was observed to be a major by-product. No detailed information was found in the open literature describing the thermal breakdown products of R-134a and R-507.

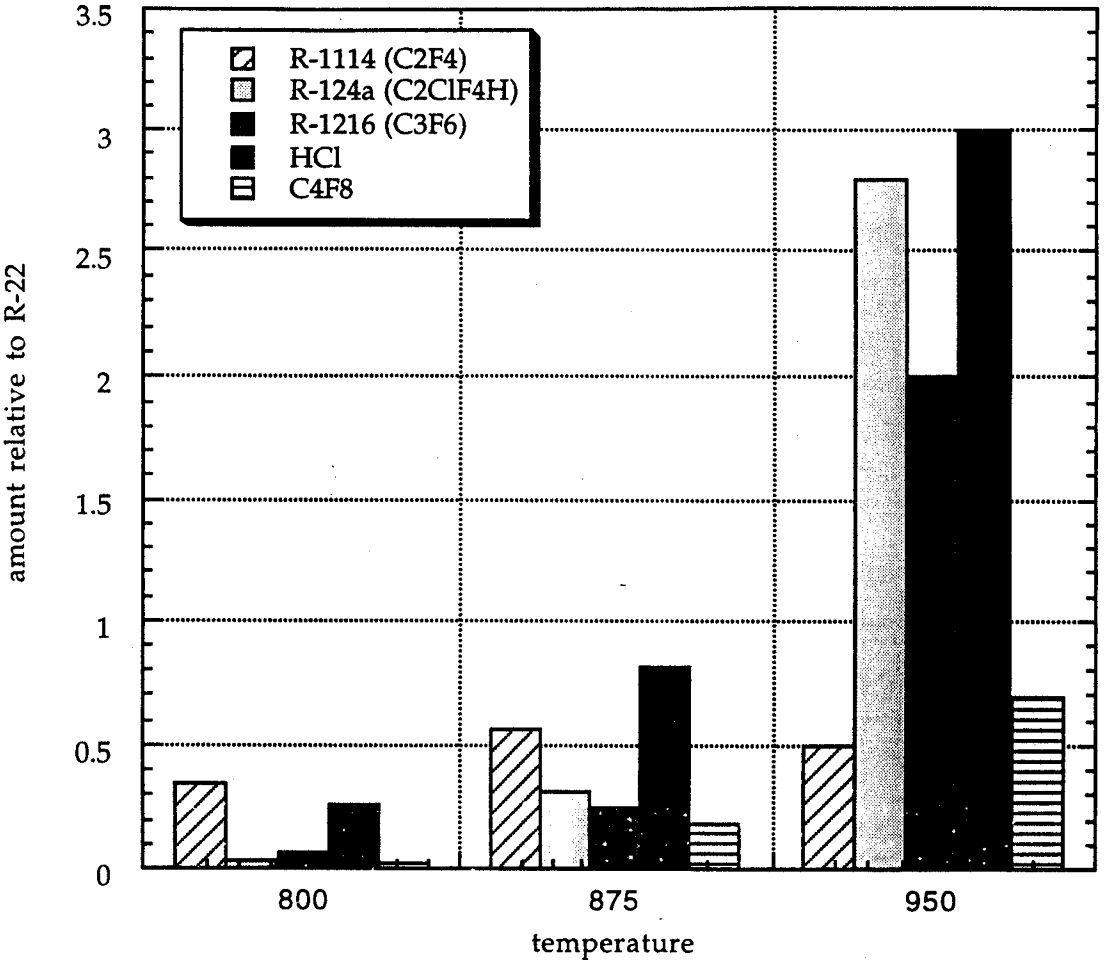


Figure 16. Major break-down products of R22; adapted from Figure 4, ref. Broyer. Experimental conditions: tubular reactor, 4 psig of R22, 0.25 s residence time in the test reactor; (equivalent energy deposited into R-22 approximately 28 joules).

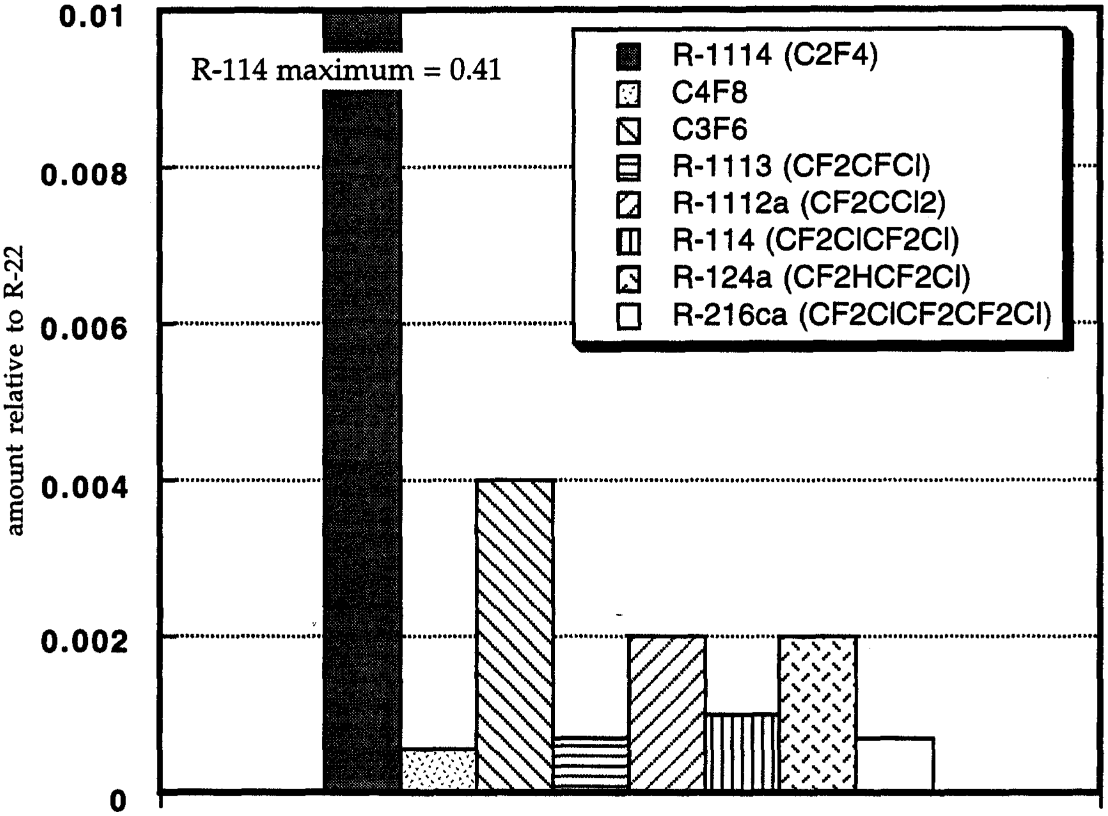


Figure 17. Major break-down products of R22; adapted from Table 3, ref. Gozza. Experimental conditions: flow system, 742 mm Hg, reactant mixture of 9.5% R22 and 90.5% He, reaction time 0.09 s; equivalent energy deposited in to R22 approximately 0.27 joules).

In order to verify that the breakdown products observed in the high temperature/ high pressure electrical breakdown experiments were not due to both thermal and electrical breakdown of the fluids, thermal breakdown tests were performed. R-22 and R-134 were chosen for the thermal tests. The high temperature/pressure cell was filled and treated as for a normal high temperature/pressure test, but no electrical breakdown was initiated. After 4.5 hours (the usual time required to fill the cell, bring it to temperature, and conduct an electrical breakdown test of 200,000 pulses), a sample was withdrawn using the standard method, and analyzed. R-22 produced five compounds under thermal breakdown condition; only one of these (dichlorodifluoromethane, R-12) was also identified in electrical breakdown tests. Table IV lists the compounds and approximate amounts formed.

Table IV. Compounds identified in R-22 due to thermal breakdown

compound	amount (relative to R-22)
difluoromethane (R-32)	0.000164
trifluoromethane (R-13)	0.000199
tetrafluoroethane (R-134)	0.00453
dichlorodifluoromethane (R-12)	0.0000298
benzene	0.000281

The only breakdown product detected from R-134a was trifluoroethane, which was detected at a concentration of approximately 170 ppm, relative to R-134a. Trifluoroethane was not detected in R-134a as a by-product of electrical breakdown at elevated temperatures. When combined with the observation that the breakdown products detected under the elevated temperature and pressure conditions differed only from atmospheric pressure and temperature breakdown products in having a lesser variety of compounds, this confirms that no by-products due to purely thermal breakdown were detected in the elevated temperature/pressure tests.

IV. Breakdown Products Materials Compatibility

Data on the compatibility of breakdown products observed with hermetic motor elements is available through the Air Conditioning and Refrigeration Technology Institute (ARTI) Refrigerants Database. Several extensive studies of materials compatibility with various refrigerants have been performed with financial support from ARTI and the refrigeration and air conditioning industry. Extensive references were found in the database describing swell and softening data for various elastomer and refrigerant combinations (Cavestri, Doerr, Atwood, Hamed). Private corporation publications also detailed the reactions of various fluorocarbons with a variety of materials, including metals, elastomers, lubricants and plastics (E.I. duPont de Nemours). Data was not available for all of the principle breakdown products formed; for example, no swell or softening data was found for R-1132a, R-1114, or R-116 (major products observed in R-507 and R-134a), hexafluoropropene, or R-1112a (major products observed in R-22 under bench scale testing). Studies have been conducted to investigate materials compatibility between various CFCs and CFC-replacements with metals, elastomers, polymers, lubricants, lubricant additives. As an example, R-12 and R-22 have been observed to cause embrittlement of polyethylene phthalate found in Mylar and Melinex sheet and sleeving insulation, and separation of varnish from metal surfaces, although the condition of the metal surface may have contributed to the varnish separation. Certain plastics have been found to be generally incompatible with refrigerants; these include acrylonitrile-butadiene-styrene terpolymers, polyphenylene oxide, and polycarbonate.

Although specific analyses for free chloride and fluoride were not performed as a part of this work, previous experiments at LLNL have shown that HF is formed upon electrical breakdown of fluorocarbons fluids. Concentrations as high as 11 ppm for fluoride and 50 ppm chloride were measured in R-123 after 90,000 pulses; the total energy deposition is unknown but is estimated at approximately 150 Joules (similar to R-134a ambient temperature/pressure tests, this work). The formation of HF from fluorocarbons, and (by analogy) HF and HCl from chlorofluorocarbons, is expected to have a larger effect upon materials compatibility and motor lifetimes than is the formation of low percent to ppm levels of breakdown products which are also refrigerants.

V. Literature Searches

An initial literature and patent search (1965 - 1995) was conducted using the computer-based Chemical Abstracts and Envirochem databases; a manual search of the Chemical Abstracts database was performed for the time period 1955-1965. Through the use of key words and CAS numbers, references related to of "pyrolysis" or "thermal degradation" of R-22, R-134a, R-125 and R-143a, as well as other CFC-replacements (R-124, R-142B, R-32, R-134, R-152, R-502) were searched. Approximately 75 articles and patents were identified. Brief abstracts or complete copies of the articles of interest were obtained. The focus of the many these articles was flash or shock-wave pyrolysis combined with laser spectroscopy for kinetics studies, or pyrolysis of various precursors as a route to the formation of tetrafluoroethylene. Very few articles on thermal stability were identified. Several articles discussing reaction mechanisms of Freons® in the upper atmosphere were also identified in the literature search. Some of the articles (Gozzo & Patrick, 1966; Martin & McGee, 1968; Yasuhara & Morita, 1990) covering kinetic reactions contained tables listing various degradation products identified by GC, GC/MS, or IR spectroscopy. Many of the kinetics references postulated the formation of CF_2 radicals from one- and two-carbon halogenated starting materials.

The most useful source of information on thermal decomposition of HCFCs was found in the ARTI Refrigerant Database. Most of the experiments described were from sealed-tube tests containing mixtures of lubricants and refrigerants with metal catalysts (steel, iron, copper, aluminum). Temperatures were in general rather low (200°C or less). Compatibility tests with other materials (lubricants, motor materials and elastomers) were also conducted at elevated temperatures; however, decomposition of motor materials or elastomers was generally the primary concern. Several references described potential methods for the destruction of CFC's (passing over catalysts of various metals at elevated temperature, microwave induced plasma, RF-plasma); however, chemical analysis was usually aimed at detection of CO, CO_2 HCl, HF (for one-carbon species) or dehydrohalogenation products.

Health and exposure data was taken from the Toxicology, Occupational Medicine & Environmental Series (TOMES) Plus database. The TOMES system is a comprehensive collection of proprietary and government databases. The TOMES plus system includes the databases listed in Table V. Animal test data and human exposure guidelines were not available for many of the compounds we identified as breakdown products. The data has been summarized in individual sheet form and is included in Appendix A.

Table V. Databases included in the Toxicology, Occupational Medicine & Environmental Series (TOMES) Plus System

Database	Description
MEDITEXT™	designed for use by health care professionals in treating exposure range of toxicity physicochemical parameters
HAZARDTEXT™	information for emergency response and safety personnel clinical effects range of toxicity
INFOTEXT™	General Health & Safety information for industrial hygiene personnel regulatory information
SARATEXT®	Acute & chronic effects of chemicals listed on the SARA title III Hazardous substance list clinical effects of exposure range of toxicity .
Hazardous Substance Data Bank (HSDB; from National Library of Medicine)	Information on impact of >4000 chemical substances on health and environment exposure standards and regulations monitoring and analysis methods

(Table V. continued)

Database	Description
Chemical Hazard Response Information System (CHRIS; form U.S. Coast Guard)	primarily information useful for response to aquatic incidents involving hazardous materials
Oil and Hazardous Materials/Technical Assistance Data System (OHMS/TADS; from U.S. EPA)	primarily information useful for response to aquatic incidents involving hazardous materials
Integrated Risk Information System (IRIS; from U.S. EPA)	contains U.S. EPA health risk assessment information used in determining safe levels of human and environmental exposure
Registry of Toxic Effects of Chemical Substances (RTECS; from NIOSH)	toxicity data on >100,000 substances extracted from worldwide scientific literature carcinogenicity, mutagenicity, reproductive hazards acute & chronic toxicology
NIOSH Pocket Guide	critical industrial hygiene data for approximately 675 chemicals
New Jersey Fact Sheets (from New Jersey Dept. of Health)	generic, non-technical worker safety and training information
DOT Emergency Response Guides	primarily for spill response; contains information necessary to identify a substance, isolate and contain it

VI. Conclusions and Recommendations

The principle focus of this work has been to identify and quantify the products of motor burnouts in systems containing (a) R-22, (b) R134a, and (c) R-507. Test conditions were varied in an attempt to identify whether bench scale testing could be performed which would accurately simulate actual motor AC carryover conditions. Results of laboratory tests were compared with a simulated motor AC carryover. Simulated motor AC carryover was done because we were unable to directly induce an AC carryover failure in a hermetic motor as originally expected. Although we believe that AC carryover failures are still possible in hermetic motors, the likelihood and frequency of these failures is unknown.

Data presented here has shown that bench-scale electrical breakdown testing does not duplicate motor failure conditions. Examination of the literature, in conjunction with the limited testing described here, indicates that thermal breakdown testing also does not accurately predict breakdown products due to an AC carryover motor failure. Although some common breakdown products were observed in all tests conducted, the majority of the by-products and the relative amounts formed under simulated AC carryover conditions are significantly different than in bench-scale electrical breakdown tests or from thermal breakdown only. Laboratory bench-scale breakdown experiments produced highly complex mixtures. Both thermal and simulated AC carryover experiments produced relatively few by-products. By-products from bench-scale testing ranged from two carbon to six carbon molecules, with few single carbon species. AC carryover produced only one and two carbon species, as did thermal breakdown; however, R-12 was the only by-product observed in both thermal and electrical breakdown of R-22.

An assessment of the probability and mechanism of purely electrical breakdown with resulting AC carryover in hermetic motors is required before additional testing should be undertaken. If a likely mechanism for this type of failure is identified, a more accurate simulation can be designed. The by-products produced from this simulation can then be compared with actual motor breakdown events.

COMPLIANCE WITH AGREEMENT

Modifications from the original scope of the proposed work have been discussed in section II.C. Due to funding limitations, no action was taken to assess the efficacy of cleanup procedures using filter driers for the removal of by-products. Based upon the research reported herein, it was not possible to formulate any conclusions concerning whether HFC refrigerant/oil systems are likely to increase or decrease the incidence of motor burnouts as compared to HCFC/lubricant systems.

PRINCIPAL INVESTIGATOR EFFORT

The principal investigator, Ms. Ruth Hawley-Fedder, Ph.D., has directed and performed the necessary activities for the completion of this contract.

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18. T. Atwood, E.M. Clark, R.C. Downing, M.O. Mc Linden, *Refrigerants, ASHRAE Handbook D Fundamentals*, published by the American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Atlanta 16.1-16.10 (1989) and updates (1993)

19. R.G. Doerr, S.A. Kujak, *ASHRAE Journal* 35(8) 42-47 (1993)

20. G.R. Hamed, R.H. Seiple, O. Taikum, "Compatability of Refrigerants and Lubricants with Elastomers", report DOE/CE/23810-14 Jan. 1994

21. *Freon® Fluorocarbons Properties and Applications, bulletin G-1,* E.I. duPont de Nemours and Company, Inc., Wilmington, DE, March 1985

Appendix A. Health and Exposure Data for Selected Breakdown Products

Exposure data was not available for all compounds identified by mass spectral analysis. Data was investigated only for breakdown products present at medium to high concentrations (above 100 ppm). The table below lists the compounds for which industrial hygiene data were sought and the file name used to identify the data. For those files where no data is indicated, no exposure data was identified in the TOMES database.

Compound Name	FileName	Comments	Registry #
1,2-dichloro-1,1,2,2-tetrafluoroethane (R-114)	CHEMl		76-14-2
1,1,1-trifluoroethane (R-143a)	CHEM2	RTECS no data	420-46-2
tetrafluoroethene (R-1114)	CHEM3		116-14-3
1,1,1,2-tetrafluoroethane (R-134a)	CHEM4		811-97-2
pentafluoroethane (R-125)	CHEM5		354-33-6
hexafluoroethane (R-116)	CHEM6		76-16-4
hexafluoropropene	CHEM7		116-15-4
dichlorodifluoromethane (R-12)	CHEM8		75-71-8
chlorodifluoromethane (R-22)	CHEM9		75-45-6
1,1-dichloro-2,2-difluoroethene (R-1112a)	CHEM10	RTECS Only	79-35-6
1,2-dichloro-l,2-difluoroethene	CHEM11	Not In TOMES	
chloropentafluoroethane (R-115)	CHEM12		76-15-3
1,1,-difluoroethene (R-1132a)	CHEM13		75-38-7
trifluoroethene	CHEM14	HSDB;no data	359-11-5
1,2-dichloro-hexafluoropropane	CHEM15	Not In TOMES	
1,2,2-trichloro-pentafluoropropane	CHEM16	RTECS Only	1599-41-3
1-chloro-3,3,3-trifluoro-propyne	CHEM17	RTECS Only	460-35-5
3-chloropentafluoropropene	CHEM18	RTECS Only	79-47-0
dichloroethyne	CHEM19		7572-29-4
trichlorofluoroethene	CHEM20	Not In TOMES	
trichlorofluoromethane (R-11)	CHEM21		75-69-4
1-chloro-1,1,2,2-tetrafluoroethane (R-124a)	CHEM22	RTECS Only	354-25-6
1,1,3,3,3-pentafluoropropene	CHEM23	Not In TOMES	
2-chloropentafluoropropene	CHEM24	Not In TOMES	
1,2-dichlorotetrafluorocyclobutene	CHEM25	Not In TOMES	
trichloropropene	CHEM26	Not In TOMES	
1,3-dichloro-hexafluoropropane	CHEM27	Not In TOMES	
1,1,2-trichloro-1,2,2-trifluoroethane (R-113)	CHEM28		76-13-1
chloropentafluorobenzene	CHEM29	RTECS Only	344-07-0
1,1,3,3-tetrachloro-2,3-difluoropropene	CHEM30	Not In TOMES	
1,2-dichloro-1,3,3,3,-tetrafluoropropene	CHEM31	Not In TOMES	
chlorohexafluoropropane	CHEM32	Not In TOMES	
3,3,3-trifluoropropyne	CHEM33		75-43-4
dichlorofluoromethane (R-21)	CHEM34	Not In TOMES	
1,1,1,6,6,6-hexafluoro-hexa-2,4-di-yne	CHEM35	Not In TOMES	
1,1,1,3,3,3-hexafluoropropane	CHEM36	Not In TOMES	

CHEM 1

(CRYOFLUORANE)
ETHANE, 1,2-DICHLORO-
1,1,2,2-TETRAFLUORO-

TDLO/TCLO

LOWEST PUBLISHED TOXIC DOSE/CONC (inhalation)

A. HUMAN

LDLO/LCLO

LOWEST PUBLISHED LETHAL (inhalation)

A. GUINEA PIG

B. DOG

LD50/LC50

LETHAL DOSE/CONC 50% KIL (inhalation)

A. RAT

DOSE: 72 pph/30M

B. MOUSE

DOSE: 70 pph/30M

C. GUINEA PIG

D. RABBIT

DOSE: 75 pph/30M

OTHER LD/LC

OTHER LETHAL DOSE/CONC (inhalation)

A. RAT

C. GUINEA PIG

DOSE: >20 pph/8H

MUTATIONS IN MICROORGANISMS

A. BACTERIA - S TYPHIMURIUM

4.2 MAXIMUM TOLERATED EXPOSURE

long term

No clinical, biochemical, or histological effects were seen in dogs exposed to 5,000 ppm or rats exposed to 10,000 ppm 6 hours daily for 90 days.

4.3 WORKPLACE STANDARDS

A. TLV-TWA: 1,000 parts per million (approximately 6,990 milligrams per cubic meter) (ACGIH, 1993)
B. TLV-STEL: Not listed (ACGIH, 1993)
C. IDLH value: 50,000 parts per million (NIOSH, 1990)
D. OSHA PEL-TWA Transitional Limit: 1,000 parts per million (approximately 7,000 milligrams per cubic meter) (OSHA, 1989)
E. OSHA PEL Final Rule Limits (OSHA, 1989)
1. PEL-TWA Final Rule Limit: 1,000 parts per million (approximately 7,000 milligrams per cubic meter); no STEL or Ceiling Limit.

CHEM 2	**MUTATIONS IN MICROORGANISMS**
ETHANE, 1,1,1-TRIFLUORO-	**A. BACTERIA - S TYPHIMURIUM**
	DOSE: 50 pph/48H;
TDLO/TCLO	
LOWEST PUBLISHED TOXIC DOSE/CONC (inhalation)	**4.2 MAXIMUM TOLERATED EXPOSURE**
A. HUMAN	**long term**
LDLO/LCLO	
LOWEST PUBLISHED LETHAL (inhalation)	
A. GUINEA PIG	**4.3 WORKPLACE STANDARDS**
B. DOG	
LD50/LC50	
LETHAL DOSE/CONC 50% KIL (inhalation)	
A. RAT	
B. MOUSE	
C. GUINEA PIG	
D. RABBIT	
OTHER LD/LC	
OTHER LETHAL DOSE/CONC (inhalation)	
A. RAT	
C. GUINEA PIG	

Appendix A

CHEM 3

ETHYLENE, TETRAFLUORO-

TDLO/TCLO

LOWEST PUBLISHED TOXIC DOSE/CONC (inhalation)

A. HUMAN

LDLO/LCLO

LOWEST PUBLISHED LETHAL (inhalation)

A. GUINEA PIG

B. DOG

LD50/LC50

LETHAL DOSE/CONC 50% KIL (inhalation)

A. RAT

DOSE: 40000

EFFECTS: LUNGS, THORAX, OR RESPIRATI

B. MOUSE

DOSE: 143 g

EFFECTS: BEHAVIORAL - Somnolence (ge activity); LIVER - Other changes; KI BLADDER -Other changes;

C. GUINEA PIG

DOSE: 116 g

EFFECTS: BEHAVIORAL - Somnolence (ge activity); LIVER - Other changes; KI BLADDER -Other changes;

D. RABBIT

OTHER LD/LC

OTHER LETHAL DOSE/CONC (inhalation)

A. RAT

C. GUINEA PIG

MUTATIONS IN MICROORGANISMS

A. BACTERIA - S TYPHIMURIUM

4.2 MAXIMUM TOLERATED EXPOSURE

long term

Cancer Hazard - not tested

Reproductive Hazard - not tested

Other Long-Term Effects

Very high or repeated overexposures may damage the kidneys and/or liver and irritate the lungs.

4.3 WORKPLACE STANDARDS

WORKPLACE EXPOSURE LIMITS

No occupational exposure limits have been established for Tetrafluoroethylene.

CHEM 4

1,1,1,2-TETRAFLUOROETHANE

TDLO/TCLO

LOWEST PUBLISHED TOXIC DOSE/CONC (inhalation)

A. HUMAN

LDLO/LCLO

LOWEST PUBLISHED LETHAL (inhalation)

A. GUINEA PIG

B. DOG

LD50/LC50

LETHAL DOSE/CONC 50% KIL (inhalation)

A. RAT

LC50 (4 hr) in rat higher than 5000,000 ppm (v/v).

B. MOUSE

C. GUINEA PIG

D. RABBIT

OTHER LD/LC

OTHER LETHAL DOSE/CONC (inhalation)

A. RAT

C. GUINEA PIG

MUTATIONS IN MICROORGANISMS

A. BACTERIA - S TYPHIMURIUM

4.2 MAXIMUM TOLERATED EXPOSURE

long term

4.3 WORKPLACE STANDARDS

CHEM 5	**MUTATIONS IN MICROORGANISMS**
PENTAFLUOROETHANE	**A. BACTERIA - S TYPHIMURIUM**
TDLO/TCLO	
LOWEST PUBLISHED TOXIC DOSE/CONC (inhalation)	**4.2 MAXIMUM TOLERATED EXPOSURE**
A. HUMAN	
No information available on health effects of inhalation exposure in humans and no adequate long-term inhalation or oral studies have been conducted in laboratory animals	**long term** no clinical signs of toxicity
LDLO/LCLO	
LOWEST PUBLISHED LETHAL (inhalation)	
A. GUINEA PIG	
	4.3 WORKPLACE STANDARDS
B. DOG	To our knowledge, this agent has not been evaluated for reproductive effects.
LD50/LC50	
LETHAL DOSE/CONC 50% KIL (inhalation)	
A. RAT	
The 4-hour LC50 of pentafluoroethane was determined to be greater than 709,000 ppm in rats (Panepinto, 1990; 2 groups)	
B. MOUSE	
C. GUINEA PIG	
D. RABBIT	
OTHER LD/LC	
OTHER LETHAL DOSE/CONC (inhalation)	
A. RAT	
C. GUINEA PIG	

CHEM 6

HEXAFLUOROETHANE

TDLO/TCLO

LOWEST PUBLISHED TOXIC DOSE/CONC (inhalation)

A. HUMAN

LDLO/LCLO

LOWEST PUBLISHED LETHAL (inhalation)

A. GUINEA PIG

B. DOG

LD50/LC50

LETHAL DOSE/CONC 50% KIL (inhalation)

A. RAT

B. MOUSE

C. GUINEA PIG

D. RABBIT

OTHER LD/LC

OTHER LETHAL DOSE/CONC (inhalation)

A. RAT

C. GUINEA PIG

MUTATIONS IN MICROORGANISMS

A. BACTERIA - S TYPHIMURIUM

4.2 MAXIMUM TOLERATED EXPOSURE

long term

4.3 WORKPLACE STANDARDS

A. No ACGIH-TLV, OSHA PEL or IDLH values have been established for this agent (ACGIH, 1993; OSHA, 1989; NIOSH, 1990).

B. ODOR THRESHOLD: Not listed (CHRIS, 1989)

C. Hexafluoroethane is listed in the 1986 EPA TSCA Chemical Inventory (RTECS, 1989).

No occupational exposure limits have been established for Hexafluoroethane

CHEM 7
HEXAFLUOROPROPENE
TDLO/TCLO
LOWEST PUBLISHED TOXIC DOSE/CONC (inhalation)
A. HUMAN
LDLO/LCLO
LOWEST PUBLISHED LETHAL (inhalation)
A. GUINEA PIG
B. DOG
LD50/LC50
LETHAL DOSE/CONC 50% KIL (inhalation)
A. RAT
11,200 mg/m(3) for 4 hours
B. MOUSE
750 ppm for 4 hours
C. GUINEA PIG
D. RABBIT
OTHER LD/LC
OTHER LETHAL DOSE/CONC (inhalation)
A. RAT
C. GUINEA PIG

MUTATIONS IN MICROORGANISMS
A. BACTERIA - S TYPHIMURIUM
4.2 MAXIMUM TOLERATED EXPOSURE
long term
4.3 WORKPLACE STANDARDS
A. No ACGIH-TLV, OSHA PEL or IDLH values have been established for this agent (ACGIH, 1993; OSHA, 1989; NIOSH, 1990). B. ODOR THRESHOLD: Not listed (CHRIS, 1989) C. Hexafluoropropene is listed in the 1986 EPA TSCA Chemical Inventory (RTECS, 1989). D. Hexafluoropropene meets criteria for the proposed OSHA Medical Records Rule (RTECS, 1989).

CHEM 8
METHANE, DICHLORODIFLUORO-
TDLO/TCLO
LOWEST PUBLISHED TOXIC DOSE/CONC (inhalation)
A. HUMAN
TCLo DOSE: 200000 ppm/30M; TOXIC EFFECTS: SENSE ORGANS AND SPECIAL SENSES - Conjunctive irritation; LUNGS, THORAX, OR RESPIRATION - Fibrosing alveolitis; LIVER - Other changes;
LDLO/LCLO
LOWEST PUBLISHED LETHAL (inhalation)
A. GUINEA PIG
B. DOG
LD50/LC50
LETHAL DOSE/CONC 50% KIL (inhalation)
A. RAT
B. MOUSE
DOSE: 3348 gm/m3/3H; TOXIC EFFECTS: BEHAVIORAL - Sleep; Tremor; BEHAVIORAL - Excitment; REFERENCE: 76 parts per hundred for 30 min
C. GUINEA PIG
DOSE: 80 pph/30M; REFERENCE:
D. RABBIT
DOSE: 80 pph/30M; REFERENCE:
OTHER LD/LC
OTHER LETHAL DOSE/CONC (inhalation)
A. RAT
DOSE: >5600 ug/kg; REFERENCE:
C. GUINEA PIG

MUTATIONS IN MICROORGANISMS
A. BACTERIA - S TYPHIMURIUM
4.2 MAXIMUM TOLERATED EXPOSURE
long term Chronic Animal Exposure No adverse effects
4.3 WORKPLACE STANDARDS
OSHA: The legal airborne permissible exposure limit (PEL) is 1,000 ppm averaged over an 8-hour workshift. (Final Rule, January 1989). ACGIH: Recommended airborne exposure limit is 1,000 ppm averaged over an 8-hour workshift. A. TLV-TWA: 1000 parts per million (approximately 4950 milligrams per cubic meter); no STEL (ACGIH, 1993) B. IDLH value: 50,000 parts per million (NIOSH, 1990) C. OSHA PEL-TWA Transitional Limit: 1,000 parts per million (approximately 4,950 milligrams per cubic meter) (OSHA, 1989)

CHEM 9

METHANE,
CHLORODIFLUORO-

TDLO/TCLO

LOWEST PUBLISHED TOXIC DOSE/CONC (inhalation)

A. HUMAN

LDLO/LCLO

LOWEST PUBLISHED LETHAL (inhalation)

A. GUINEA PIG

DOSE: 30 pph/2H; TOXIC
EFFECTS: BEHAVIORAL - General anesthetic; BEHAVIORAL - Somnolence (general depressed activity); BEHAVIORAL - Convulsions or effect on seizure threshold; REFERENCE:

B. DOG

DOSE: 70 pph; TOXIC EFFECTS:
LUNGS, THORAX, OR RESPIRATION - Other changes;

LD50/LC50

LETHAL DOSE/CONC 50% KIL (inhalation)

A. RAT

DOSE: 35 pph/15M; TOXIC
EFFECTS: BEHAVIORAL - Altered sleep time (including change in righting reflex); BEHAVIORAL - Ataxia; LUNGS, THORAX, OR RESPIRATION - Respiratory depression;

B. MOUSE

DOSE: 28 pph/30M; TOXIC
EFFECTS: BEHAVIORAL - Change in motor activity (specific assay); BEHAVIORAL - Muscle weakness; LUNGS, THORAX, OR RESPIRATION - Cyanosis; REFERENCE:

C. GUINEA PIG

D. RABBIT

OTHER LD/LC

OTHER LETHAL DOSE/CONC (inhalation)

A. RAT

C. GUINEA PIG

MUTATIONS IN MICROORGANISMS

A. BACTERIA - S TYPHIMURIUM

4.2 MAXIMUM TOLERATED EXPOSURE

long term
no significant known effects
carcinogenic ; genetic ; reproductive effects
no significant effects

4.3 WORKPLACE STANDARDS

A. TLV-TWA: 1,000 parts per million (approximately 3,540 milligrams per cubic meter) (ACGIH, 1993)
B. TLV-STEL: Not listed (ACGIH, 1993)
C. No IDLH value has been established for chlorodifluoromethane (NIOSH, 1990).
D. OSHA PEL-TWA Transitional Limit: Not listed (OSHA, 1989)
E. OSHA PEL Final Rule Limits (OSHA, 1989)
1. PEL-TWA Final Rule Limit: 1,000 parts per million (approximately 3,500 milligrams per cubic meter)
2. PEL-STEL Final Rule Limit: Not listed
3. PEL-CEILING Final Rule Limit: Not listed
4. The effective date for the Final Rule Limits is March 1, 1989

CHEM 10

ETHYLENE,
1,1-DICHLORO-2,2-DIFLUORO-

TDLO/TCLO

LOWEST PUBLISHED TOXIC DOSE/CONC (inhalation)

A. HUMAN

LDLO/LCLO

LOWEST PUBLISHED LETHAL (inhalation)

A. GUINEA PIG

B. DOG

LD50/LC50

LETHAL DOSE/CONC 50% KIL (inhalation)

A. RAT

DOSE: 505 mg/m3/4H; TOXIC
EFFECTS: BEHAVIORAL - Somnolence (general depressed activity); LIVER - Other changes; KIDNEY, URETER, AND BLADDER - Other changes; REFERENCE: Gigiena Truda i

B. MOUSE

DOSE: 610 mg/m3/4H; TOXIC
EFFECTS: BEHAVIORAL - Somnolence (general depressed activity); LIVER - Other changes; KIDNEY, URETER, AND BLADDER - Other changes; REFERENCE: Gigiena Truda i

C. GUINEA PIG

DOSE: 700 mg/m3/4H; TOXIC
EFFECTS: BEHAVIORAL - Somnolence (general depressed activity); LIVER - Other changes; KIDNEY, URETER, AND BLADDER - Other changes; REFERENCE: Gigiena Truda i

D. RABBIT

OTHER LD/LC

OTHER LETHAL DOSE/CONC (inhalation)

A. RAT

C. GUINEA PIG

MUTATIONS IN MICROORGANISMS

A. BACTERIA - S TYPHIMURIUM

4.2 MAXIMUM TOLERATED EXPOSURE

long term

4.3 WORKPLACE STANDARDS

CHEM 12

ETHANE, CHLOROPENTAFLUORO-

synonym

-CHLORO-1,1,2,2,2-PENTAFLUOROETHANE

TDLO/TCLO

LOWEST PUBLISHED TOXIC DOSE/CONC (inhalation)

A. HUMAN

Human evidence for systemic toxicity from chloropentafluoroethane is generally lacking.

LDLO/LCLO

LOWEST PUBLISHED LETHAL (inhalation)

A. GUINEA PIG

B. DOG

LD50/LC50

LETHAL DOSE/CONC 50% KIL (inhalation)

A. RAT

FLUORINATED HYDROCARBONS

6.5 LD50/LC50

A. LD50 (rats - inhalation): 50,000 ppm for 4 hours (Tech Info, 1987a).

B. MOUSE

C. GUINEA PIG

D. RABBIT

OTHER LD/LC

OTHER LETHAL DOSE/CONC (inhalation)

A. RAT

DOSE: >20 pph/2H; REFERENCE:

C. GUINEA PIG

MUTATIONS IN MICROORGANISMS

A. BACTERIA - S TYPHIMURIUM

4.2 MAXIMUM TOLERATED EXPOSURE

long term

Cancer Hazard

Reproductive Hazard

Other Long-Term Effects

no significant effects were noted

large body of research on animal species indicates minimal or no significant health effects

4.3 WORKPLACE STANDARDS

A. TLV-TWA: 1,000 parts per million (approximately 6,320 milligrams per cubic meter) (ACGIH, 1993)

B. TLV-STEL: Not listed (ACGIH, 1993)

C. No IDLH value has been established for chloropentafluoroethane (NIOSH, 1990)

D. OSHA PEL-TWA Transitional Limit: Not listed (OSHA, 1989)

E. OSHA PEL Final Rule Limits (OSHA, 1989)

1. PEL-TWA Final Rule Limit: 1,000 parts per million (approximately 6,320 milligrams per cubic meter)
2. PEL-STEL Final Rule Limit: Not listed
3. PEL-CEILING Final Rule Limit: Not listed
4. The effective date for the Final Rule Limits is March 1, 1989
5. PELs specified in Final Rule Limits shall be achieved by any reasonable combination of engineering controls, work practices and personal protective equipment effective September 1, 1989, through December 30, 1992.

CHEM 13

ETHYLENE, 1,1-DIFLUORO-

TDLO/TCLO

LOWEST PUBLISHED TOXIC DOSE/CONC (inhalation)

A. HUMAN

LDLO/LCLO

LOWEST PUBLISHED LETHAL (inhalation)

A. GUINEA PIG

B. RAT

DOSE: 128000 ppm/4H; TOXIC

EFFECTS: LUNGS, THORAX, OR RESPIRATION - Other changes;

LD50/LC50

LETHAL DOSE/CONC 50% KIL (inhalation)

A. RAT

B. MOUSE

C. RABBIT

OTHER LD/LC

OTHER LETHAL DOSE/CONC (inhalation)

A. RAT

C. GUINEA PIG

MUTATIONS IN MICROORGANISMS

A. BACTERIA - S TYPHIMURIUM

DOSE: 50 pph/24H;

TUMORIGENIC EFFECTS

A. RAT

1. ROUTE: Oral; DOSE: 1930 mg/kg/52W-I; TOXIC EFFECTS: TUMORIGENIC - Neoplastic by RTECS criteria; SENSE ORGANS AND SPECIAL SENSES - Tumors; SKIN AND APPENDAGES -

4.2 MAXIMUM TOLERATED EXPOSURE

long term

No data are available in humans. Inadequate evidence of carcinogenicity in animals.

4.3 WORKPLACE STANDARDS

Threshold Limit Values:

1. Time Weighted Avg (TWA) 2.5 mg/cu m (1977) ACGIH, 1992.22
2. Excursion Limit Recommendation: Excursions in worker exposure levels may exceed three times the TLV-TWA for no more than a total of 30 min during a work day and under no circumstances should they exceed five times the TLV-TWA, provided that the TLV-TWA is not exceeded. ACGIH, 1992.5
3. BEI (Biological Exposure Index): Fluoride in urine prior to shift is 3 mg/g creatinine. ACGIH, 1992.64
4. BEI (Biological Exposure Index): Fluoride in urine at end of shift is 10 mg/g of creatinine. ACGIH, 1992.64

Appendix A

CHEM 16	
PROPANE, 1,2,2-TRICHLOROPENTAFLUORO-	
TDLO/TCLO	**4.2 MAXIMUM TOLERATED EXPOSURE**
LOWEST PUBLISHED TOXIC DOSE/CONC (inhalation)	
A. HUMAN	**long term**
LDLO/LCLO	
LOWEST PUBLISHED LETHAL (inhalation)	**4.3 WORKPLACE STANDARDS**
A. GUINEA PIG	
B. RAT	
LCLo; ROUTE: Inhalation; DOSE: 8000 ppm/	
LD50/LC50	
LETHAL DOSE/CONC 50% KIL ( )	
A. RAT	
LD50; ROUTE: Oral; DOSE: 15 gm/kg;	
B. MOUSE	
C. GUINEA PIG	
D. RABBIT	
OTHER LD/LC	
OTHER LETHAL DOSE/CONC (inhalation)	
A. RAT	
C. GUINEA PIG	
MUTATIONS IN MICROORGANISMS	
A. BACTERIA - S TYPHIMURIUM	

CHEM 17	
PROPANE, 3-CHLORO-1,1,1-TRIFLUORO-	
TDLO/TCLO	**4.2 MAXIMUM TOLERATED EXPOSURE**
LOWEST PUBLISHED TOXIC DOSE/CONC (inhalation)	
A. HUMAN	**long term**
LDLO/LCLO	
LOWEST PUBLISHED LETHAL (inhalation)	**4.3 WORKPLACE STANDARDS**
A. RABBIT	
DOSE: 2300 mg/m3/2H;	
B. RAT	
DOSE: 1800 mg/m3/2H;	
LD50/LC50	
LETHAL DOSE/CONC 50% KIL ( )	
A. RAT	
B. MOUSE	
1. LD50; ROUTE: Oral; DOSE: 62 mg/kg; TOXIC EFFECTS: BEHAVIORAL - Sleep; BEHAVIORAL - Somnolence (general depressed activity); BEHAVIORAL - Ataxia; 2. Inhalation; DOSE: 800 mg/m3/2H	
C. GUINEA PIG	
OTHER MULTIPLE DOSE	
TOXICITY DATA	
A. RAT	
ROUTE: Oral; DOSE: 1062 mg/kg/30W-I; TOXIC EFFECTS: BEHAVIORAL - Alteration of classical conditioning;	
C. RABBIT	
ROUTE: Oral; DOSE: 1062 mg/kg/30W-I; TOXIC EFFECTS: BLOOD - Change in clotting factors; BLOOD - Other CHANGES	
MUTATIONS IN MICROORGANISMS	
A. BACTERIA - S TYPHIMURIUM	

CHEM 19

ACETYLENE, DICHLORO-

TDLO/TCLO

LOWEST PUBLISHED TOXIC DOSE/CONC (inhalation)

A. HUMAN

LDLO/LCLO

LOWEST PUBLISHED LETHAL (inhalation)

A. RABBIT

DOSE:307 ppm/1H;TOXIC EFFECTS: LIVER-Fatty liver degeneration KIDNEY, URETER, AND BLADDER - Chgs in tubules (inc acute renal failure, acute tubular necrosis

B. RAT

-

LD50/LC50

LETHAL DOSE/CONC 50% KIL (inhalation)

A. RAT

B. MOUSE

DOSE: 19 ppm/6H; TOXIC EFFECTS: BEHAVIORAL - Change in motor activity (specific assay); LUNGS, THORAX, OR RESPIRATION - Dyspnea; SKIN AND APPENDAGES - Hair;

C. GUINEA PIG

OTHER LD/LC

OTHER LETHAL DOSE/CONC (inhalation)

A. RAT

MUTATIONS IN MICROORGANISMS

A. BACTERIA - S TYPHIMURIUM

DOSE: 4000 ppm;

TUMORIGENIC EFFECTS

A. RAT

Inhalation; DOSE: 14 ppm/6H/77W-I; TOXIC EFFECTS: TUMORIGENIC - Carcinogenic by RTECS criteria; VASCULAR - Tumors; KIDNEY, URETER, AND BLADDER - Kidney tumors;

B. MOUSE

Inhalation; DOSE: 2 ppm/24H/77W-I; TOXIC EFFECTS: TUMORIGENIC - Carcinogenic by RTECS criteria; KIDNEY, URETER, AND BLADDER - Kidney tumors; BLOOD - Tumors;

4.2 MAXIMUM TOLERATED EXPOSURE

long term

A SPECIFIC REVIEW on the clinical effects and treatment of individuals exposed to this agent HAS NOT YET BEEN PREPARED.

IARC CANCER REVIEW:ANIMAL LIMITED EVIDENCE

IARC CANCER REVIEW:HUMAN NO ADEQUATE DATA

4.3 WORKPLACE STANDARDS

MSHA STANDARD:air-CL 0.1 ppm (0.4 mg/m3)

OSHA PEL FINAL:CL 0.1 ppm (0.4 mg/m3)

NIOSH REL TO DICHLOROACETYLENE-air:CA CL 0.1 ppm

ACGIH TLV-CL 0.1 ppm

CHEM 21

METHANE, TRICHLOROFLUORO-
TRICHLOROMONOFLUOROMETHANE (FC 11)

the most toxic of the fluorocarbons

TDLO/TCLO

LOWEST PUBLISHED TOXIC DOSE/CONC (inhalation)

A. HUMAN

DOSE: 50000 ppm/30M; TOXIC EFFECTS: SENSE ORGANS AND SPECIAL SENSES - Conjunctive irritation; LUNGS, THORAX OR RESPIRATION - Fibrosing alveolitis; LIVER - Other changes;

LDLO/LCLO

LOWEST PUBLISHED LETHAL (inhalation)

A. GUINEA PIG

LD50/LC50

LETHAL DOSE/CONC 50% KIL (inhalation)

A. RAT

DOSE: 13 pph/15M; TOXIC EFFECTS: BEHAVIORAL - Tremor; BEHAVIORAL - Convulsions or effect on seizure threshold; LUNGS, THORAX, OR RESPIRATION - Respiratory depression

LD50 Rat inhalation 100,000 ppm/30 min

B. MOUSE

LC50 DOSE: 10 pph/30M;

LD50; ROUTE: Intraperitoneal; DOSE: 1743 mg/kg; TOXIC EFFECTS: BEHAVIORAL - Convulsions or effect on seizure threshold;

C. GUINEA PIG

LC50; ROUTE: Inhalation; DOSE: 25 pph/30M;

LD50 Guinea pig inhalation 250,000 ppm/30 min

D. RABBIT

LD50 Rabbit inhalation 250,000 ppm/30 min

LC50; ROUTE: Inhalation; DOSE: 25 pph/30M;

E. HAMSTER

LC50 Hamster inhalation 571 g/cu m/4 hr

OTHER LD/LC

OTHER LETHAL DOSE/CONC (inhalation)

A. RAT

C. GUINEA PIG

MUTATIONS IN MICROORGANISMS

A. BACTERIA - S TYPHIMURIUM

AMBIENT WATER QUALITY CRITERIA

Aquatic Organisms

Freshwater:
Acute LEC -- 1.1E+4 ug/L
Chronic -- None
Marine:
Acute LEC -- 1.2E+4 ug/L
Chronic LEC -- 6.4E+3 ug/L

4.2 MAXIMUM TOLERATED EXPOSURE

long term

large body of research of health effects in humans indicates no significant effects

CNS & coronary disease potentials noted.

carcinogenic & reproductive hazards not evaluated

no genetic effects noted

Repeated exposure may damage a special substance in the lungs called "surfactant".

large body of research of health effects in animals indicates no significant effects; carcinogenic potential noted

carcinogenic potential noted; not officially tested

4.3 WORKPLACE STANDARDS

MSHA STANDARD-air:TWA 1000 ppm (5600 mg/m3)
OSHA PEL:8H TWA 1000 ppm (5600 mg/m3)
OSHA PEL FINAL:CL 1000 ppm (5600 mg/m3)
OSHA Standards:
1. 8 hr Time-Weighted avg: 1,000 ppm (5,600 mg/cu m)
NIOSH Recommendations:
1. Ceiling value: 1,000 ppm (5,600 mg/cu m)
Threshold Limit Values:
1. Ceiling Limit 1,000 ppm, 5,620 mg/cu m (
Immediately Dangerous to Life or Death:
1. 10,000 ppm
Threshold Limit Values:
1. Ceiling Limit 1,000 ppm, 5,620 mg/cu m
CERCLA; TSCA; RCRA; FIFRA; FDA Requirements noted
IDLH: 10,000 ppm
ACGIH:recommended airborne exposure limit: 1,000 ppm

CHEM 28

ETHANE, 1,1,2-TRICHLORO-1,2,2-TRIFLUORO-

TDLO/TCLO

LOWEST PUBLISHED TOXIC DOSE/CONC (inhalation)

A. HUMAN

LDLO/LCLO

LOWEST PUBLISHED LETHAL (inhalation)

A. RAT

DOSE: 87000 ppm/6H; TOXIC EFFECTS: BEHAV -somnolence (general depressed activity) - convulsions or effect on seizure thrshld; LUNGS,THORAX, or RESPIRATION - acute pulmonary edema

B. MOUSE

DOSE: 25 pph/90S

C. GUINEA PIG

50000 PPM/1 HR

LD50/LC50

LETHAL DOSE/CONC 50% KIL (inhalation)

A. RAT

Oral; DOSE: 43 gm/kg; TOXIC EFFECTS: BEHAVIORAL - Somnolence (general depressed activity); GASTROINTESTINAL - Other changes; SKIN AND APPENDAGES - Hair;

B. MOUSE

C. GUINEA PIG

D. RABBIT

OTHER LD/LC

OTHER LETHAL DOSE/CONC (inhalation)

A. RAT

C. GUINEA PIG

MUTATIONS IN MICROORGANISMS

A. BACTERIA - S TYPHIMURIUM

4.2 MAXIMUM TOLERATED EXPOSURE

long term

no evaluation for carcinogenic effect

no significant findings

isolated indication or coronary disease assoc

CNS effect

4.3 WORKPLACE STANDARDS

MSHA STANDARD-air:TWA 1000 ppm (7600 mg/m3)

OSHA PEL:8H TWA 1000 ppm (7600 mg/m3)

OSHA PEL FINAL:8H TWA 1000 ppm (7600 mg/m3);STEL 1250 ppm

15 min Short-Term Exposure Limit: 1,250 ppm (9,500 mg/cu m)

Immediately Dangerous to Life or Death: 4,500 PPM NIOSH

NIOSH 10 hr Time-Weighted avg: 1,000 ppm (7,600 mg/cu m).

15 min Short-Term Exposure Limit: 1,250 ppm (9,500 mg/cu m)

ACGIH (TWA) 1,000 ppm, 7,670 mg/cu m; Short Term Exposure Limit (STEL) 1,250 ppm, 9,590 mg/cu m

IDLH: 2000 ppm*

Other rqmts: Atmospheric STDS.; TSCA; RCRA; FDA

CHEM 29

BENZENE, CHLOROPENTAFLUORO-

TDLO/TCLO

LOWEST PUBLISHED TOXIC DOSE/CONC (inhalation)

A. HUMAN

LDLO/LCLO

LOWEST PUBLISHED LETHAL (inhalation)

A. GUINEA PIG

B. DOG

LD50/LC50

LETHAL DOSE/CONC 50% KIL (inhalation)

A. RAT

Oral; DOSE: >5 gm/kg;
Inhalation; DOSE: >4840 mg/m3/4H;

B. MOUSE

C. GUINEA PIG

D. RABBIT

OTHER LD/LC

OTHER LETHAL DOSE/CONC (inhalation)

A. RAT

C. GUINEA PIG

MUTATIONS IN MICROORGANISMS

A. BACTERIA - S TYPHIMURIUM

4.2 MAXIMUM TOLERATED EXPOSURE

long term

REPRODUCTIVE EFFECTS

A. RAT

1. ROUTE: Oral; DOSE: 10500 mg/kg; DURATION: female 6-15D of pregnancy; TOXIC EFFECTS: EFFECTS ON EMBRYO OR FETUS - Fetotoxicity;

3.4 GENETIC EFFECTS

3.4.3 UNSCHEDULED DNA SYNTHESIS

A. RAT

1. CELL TYPE: liver; DOSE: 10 mg/L;

3.4.7 CYTOGENETIC ANALYSIS

A. HAMSTER

1. CELL TYPE: ovary; DOSE: 30 mg/L;

3.4.8 SISTER CHROMATID EXCHANGE

A. HAMSTER

1. CELL TYPE: ovary; DOSE: 62500 ug/L;

3.4.17 ONCOGENIC TRANSFORMATION

A. MOUSE

1. CELL TYPE: other cell types; DOSE: 100 mg/L;

4.3 WORKPLACE STANDARDS

OEL-RUSSIA:STEL 2 mg/m3 JAN93.
OEL IN BULGARIA, COLOMBIA, JORDAN, KOREA check ACGIH TLV.
OEL IN NEW ZEALAND, SINGAPORE, VIETNAM check ACGIH TLV.

Appendix A

CHEM 34

METHANE, DICHLOROFLUORO-

TDLO/TCLO

LOWEST PUBLISHED TOXIC DOSE/CONC (inhalation)

A. HUMAN

LDLO/LCLO

LOWEST PUBLISHED LETHAL (inhalation)

A. GUINEA PIG

DOSE: 10 pph/1H;

B. RAT

TCLo (INHL) RAT: 1 pad per hundred for 6 hours

LD50/LC50

LETHAL DOSE/CONC 50% KIL (inhalation)

A. RAT

DOSE: 49900 ppm/4H

B. MOUSE

DOSE: >800 gm/m3/2H; TOXIC EFFECTS: BEHAVIORAL - tremor; ataxia; LUNGS, THORAX, OR RESPIRATION - Other changes

C. GUINEA PIG

D. RABBIT

OTHER LD/LC

OTHER LETHAL DOSE/CONC (inhalation)

A. RAT

C. GUINEA PIG

MUTATIONS IN MICROORGANISMS

A. BACTERIA - S TYPHIMURIUM

4.2 MAXIMUM TOLERATED EXPOSURE

long term

HUMAN no significant findings

IN HIGH CONCN, IT MAY CAUSE CENTRAL NERVOUS DEPRESSION.
ATTENTION /HAS BEEN DRAWN/ TO PROMINENT CARDIOTOXIC EFFECTS, MANIFESTED IN ARRHYTHMIAS.

REPRODUCTIVE EFFECTS: rat

Inhal; DOSE: 1 pph/6H; DURATION: female 6-15D of pregnancy
TOXIC EFFECTS: EFFECTS ON FERTILITY preimplantation mortality

OTHER MULTIPLE DOSE TOXICITY DATA rat

1. ROUTE: Inhalation; DOSE: 1 pph/6H/2W-I; TOXIC EFFECTS: LIVER - Other changes; REFERENCE: Toxicology and Applied Pharmacology 41(1):199, 1977. <CODEN TXAPA9>
2. ROUTE: Inhalation; DOSE: 1000 ppm/6H/90D-I; TOXIC EFFECTS: SKIN AND APPENDAGES - Hair; DEATH;

Three cases of leukemia were observed in high dose male rats

Repeated exposures have produced marked hepatic damage or failure

4.3 WORKPLACE STANDARDS

(TWA) 10 ppm, 42 mg/cu m (1980)
Excursion Limit Recommendation:
may exceed three times the TLV-TWA for no more than a total of 30 min during a work day and under no circumstances should they exceed five times the TLV-TWA, provided that the TLV-TWA is not exceeded.
ACGIH TLV-TWA: 10 parts per million (approximately 42 milligrams per cubic meter); no STEL (ACGIH, 1993)
IDLH value: 50,000 parts per million (NIOSH, 1990)
OSHA PEL-TWA Transitional Limit: 1,000 parts per million (approximately 4,200 milligrams per cubic meter) (OSHA, 1989)

OSHA PEL Final Rule Limits (OSHA, 1989)

1. PEL-TWA Final Rule Limit: 10 parts per million (approximately 40 milligrams per cubic meter); no STEL or Ceiling Limit.

MSHA Standard: 1000 ppm (4200 mg/m(3)) (TWA) (RTECS, 1989)

Dichlorofluoromethane is listed in the 1986 EPA TSCA Chemical Inventory (RTECS, 1989).

H. Dichlorofluoromethane meets criteria for the proposed OSHA Medical Records Rule (RTECS, 1989).

Other: wzter stds; FDA;

Appendix B

This appendix provides the electrical measurements used to determine the electrical characteristics used in the Final Report.

B.1 The following section provides representative electrical data on selected ambient gas exposures to impulse arcing.

Figure B.1.1 The amount of voltage measured across the device under test (DUT) represents a voltage drop across a gap during the high current conduction phase. A typical waveform measured across a DUT of R22 during atmospheric testing is illustrated in the adjacent figure. The horizontal dimension is 20 µs per division and the vertical displacement is 50 volts per division.

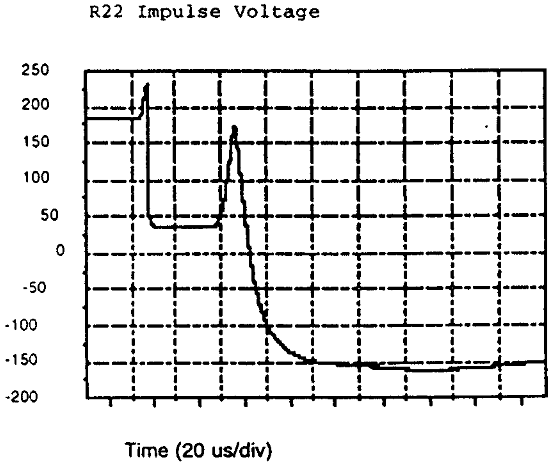


Figure B.1.2 The amount of current measured through the DUT represents the increased current observed during the conduction phase. A typical waveform indicating current as measured by a current transformer through R22 during atmospheric testing is illustrated in the adjacent figure. The horizontal dimension is 20 µs per division and the vertical displacement is 0.5 amperes per division.

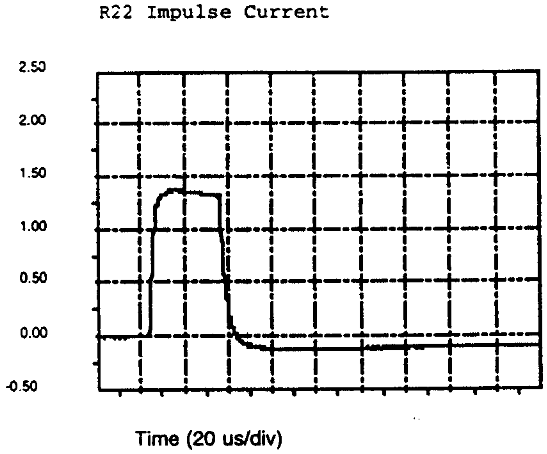


Figure B.1.3 The resulting product of the voltage and current represents the power across the DUT. Illustrated in the adjacent figure is a functional view of the power as a function of time across a DUT specimen of R22. The horizontal dimension is 20 µs per division and the vertical displacement is 50 watts per division.

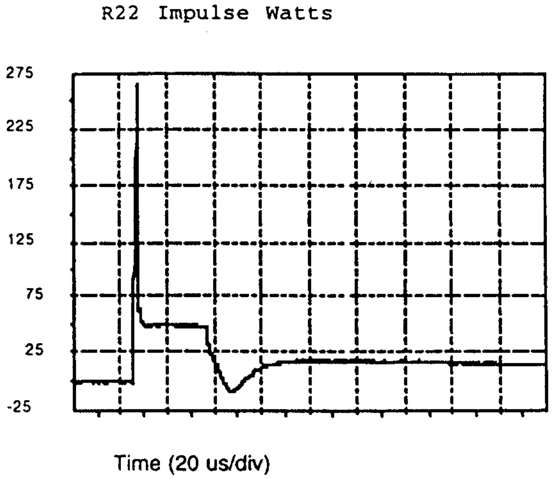


Figure B.1.4 Integrating the power delivered to the specimen an energy per breakdown can be measured. A typical resulting waveform is illustrated in the adjacent figure. Shown is the energy in joules as a function of time for R22 under initial ambient conditions. The horizontal dimension is 20 µs per division and the vertical displacement is 0.001 joules per division.

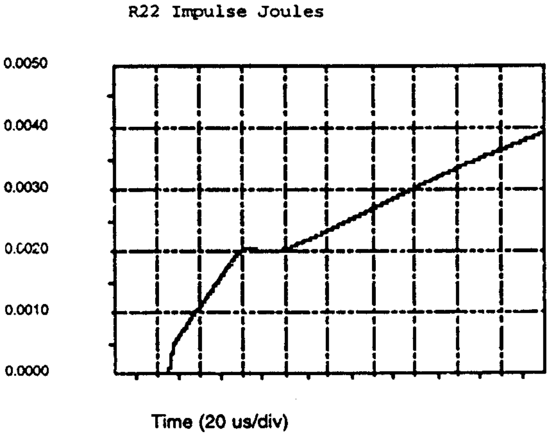


Figure B.1.5 The amount of voltage measured across the device under test DUT represents a voltage drop across a gap during the high current conduction phase. A typical waveform measured across a DUT of R134a during atmospheric testing is illustrated in the adjacent figure. The horizontal dimension is 20 µs per division and the vertical displacement is 50 volts per division.

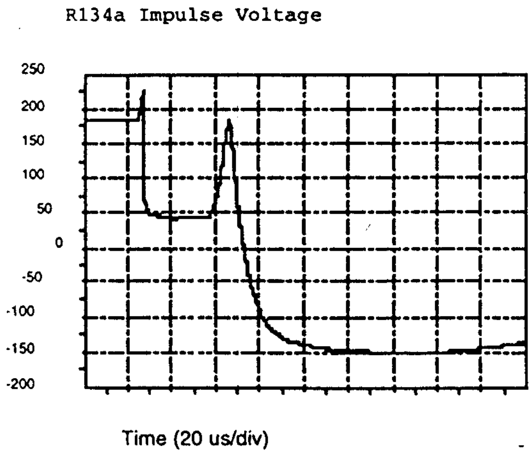


Figure B.1.6 The amount of current measured through the DUT represents the increased current observed during the conduction phase. A typical waveform indicating current as measured by a current transformer through R134a during atmospheric testing is illustrated in the adjacent figure. The horizontal dimension is 20 µs per division and the vertical displacement is 0.5 amperes per division.

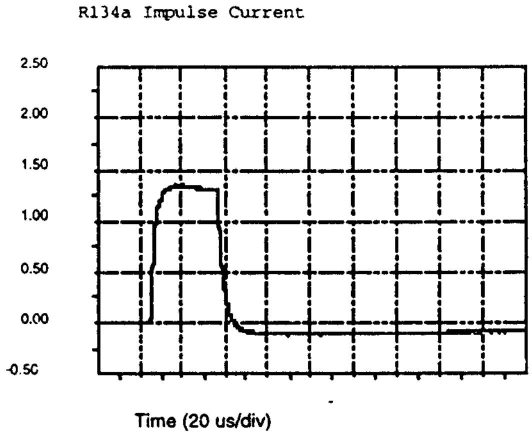


Figure B.1.7 The resulting product of the voltage and current represents the power across the DUT. Illustrated in the adjacent figure is a functional view of the power as a function of time across a DUT specimen of R134a. The horizontal dimension is 20 µs per division and the vertical displacement is 50 watts per division.

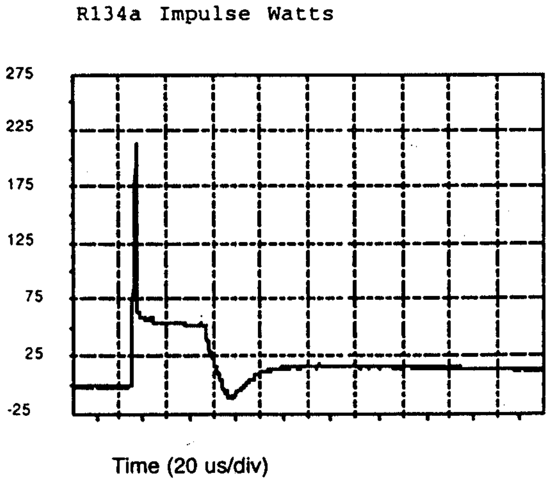


Figure B.1.8 As above by integrating the power delivered to the specimen an energy per breakdown can be measured. A typical resulting waveform is illustrated in the adjacent figure. Shown is the energy in joules as a function of time for R134a under initial ambient conditions. The horizontal dimension is 20 µs per division and the vertical displacement is 0.001 joules per division.

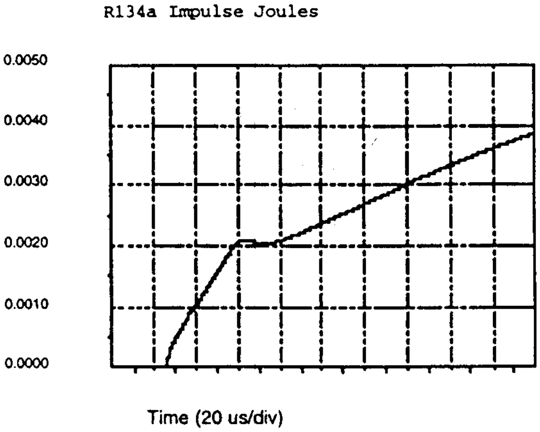


Figure B.1.9 The amount of voltage measured across the DUT represents a voltage drop across a gap during the high current conduction phase. A typical waveform measured across a DUT of R507 during atmospheric testing is illustrated in the adjacent figure. The horizontal dimension is 20 µs per division and the vertical displacement is 50 volts per division.

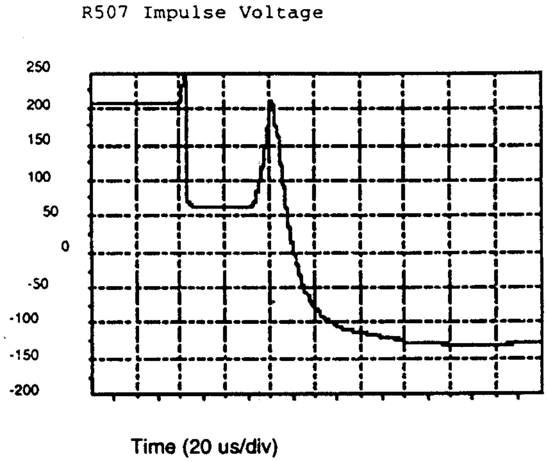


Figure B.1.10 The amount of current measured through the DUT represents the increased current observed during the conduction phase. A typical waveform indicating current as measured by a current transformer through R507 during atmospheric testing is illustrated in the adjacent figure. The horizontal dimension is 20 µs per division and the vertical displacement is 0.5 amperes per division.

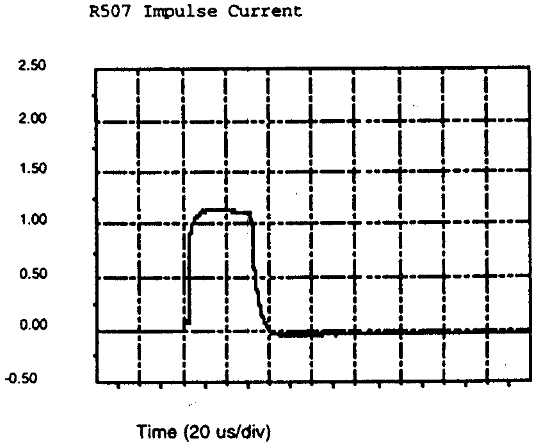


Figure B.1.11 The resulting product of the voltage and current represents the power across the DUT. Illustrated in the adjacent figure is a functional view of the power as a function of time across a DUT specimen of R507. The horizontal dimension is 20 µs per division and the vertical displacement is 50 watts per division.

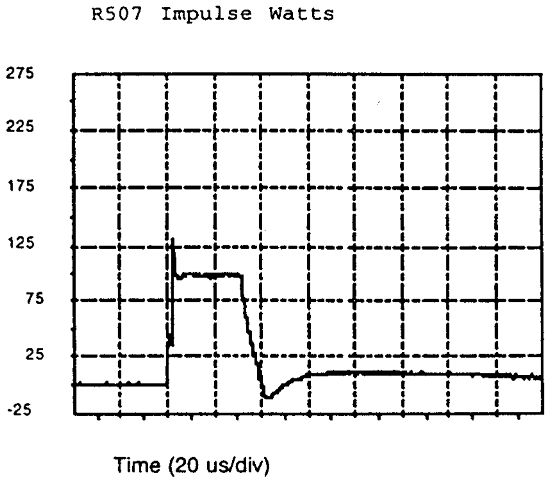


Figure B.1.12 As above by integrating the power delivered to the specimen an energy per breakdown can be measured. A typical resulting waveform is illustrated in the adjacent figure. Shown is the energy in joules as a function of time for R507 under initial ambient conditions. The horizontal dimension is 20 µs per division and the vertical displacement is 0.001 joules per division.

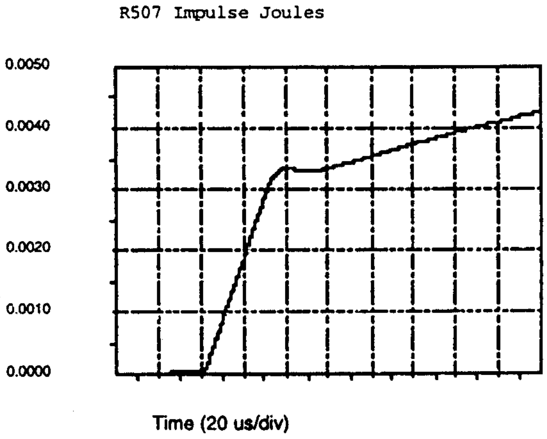


Figure B.2 Test performed at elevated temperature and pressure are reported and include the following electrical parameters.

Figure B.2.1 The amount of voltage measured across the DUT represents a voltage drop across a gap during the high current conduction phase. A typical waveform measured across a DUT of R22 during elevated temperature and pressure testing is illustrated in the adjacent figure. The horizontal dimension is 20 µs per division and the vertical displacement is 100 volts per division.

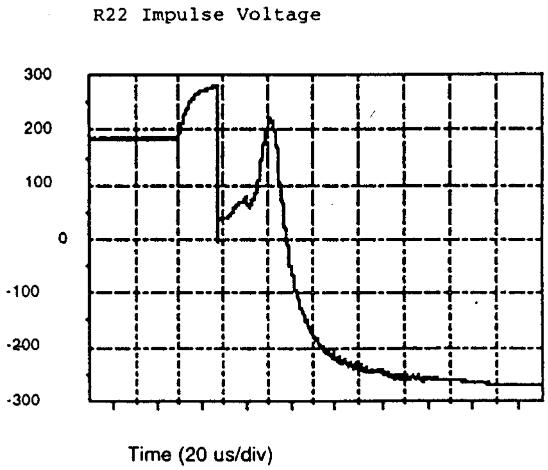


Figure B.2.2 The amount of current measured through the DUT represents the increased current observed during the conduction phase. A typical waveform indicating current as measured by a current transformer through R22 during elevated temperature and pressure testing is illustrated in the adjacent figure. The horizontal dimension is 20 µs per division and the vertical displacement is 0.5 amperes per division.

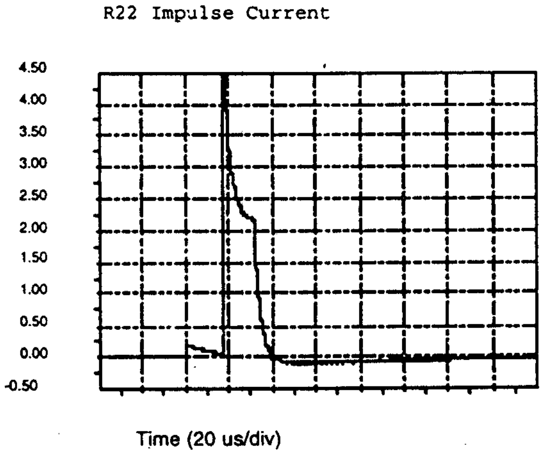


Figure B.2.3 The resulting product of the voltage and current represents the power across the DUT. Illustrated in the adjacent figure is a functional view of the power as a function of time across a DUT specimen of R22. The horizontal dimension is 20 μs per division and the vertical displacement is 50 watts per division.

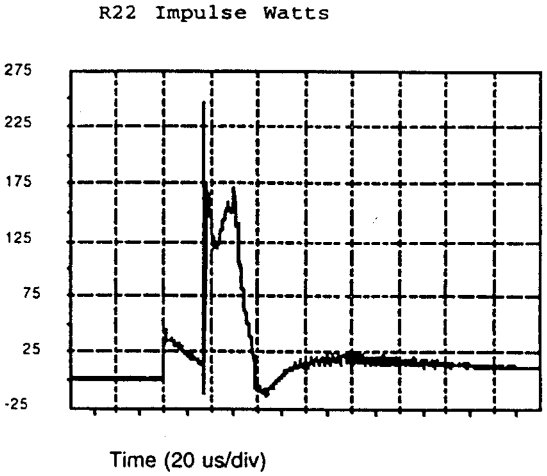


Figure B.2.4 Integrating the power delivered to the specimen an energy per breakdown can be measured. A typical resulting waveform is illustrated in the adjacent figure. Shown is the energy in joules as a function of time for R22 under elevated temperature and pressure conditions. The horizontal dimension is 20 μs per division and the vertical displacement is 0.001 joules per division.

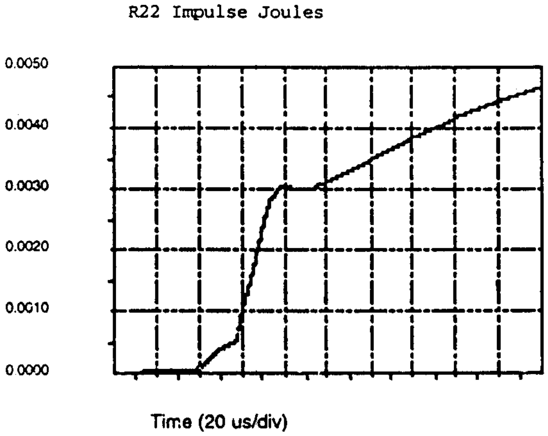


Figure B.2.5 The amount of voltage measured across the DUT represents a voltage drop across a gap during the high current conduction phase. A typical waveform measured across a DUT of R134a during elevated temperature and pressure testing is illustrated in the adjacent figure. The horizontal dimension is 20 μs per division and the vertical displacement is 100 volts per division.

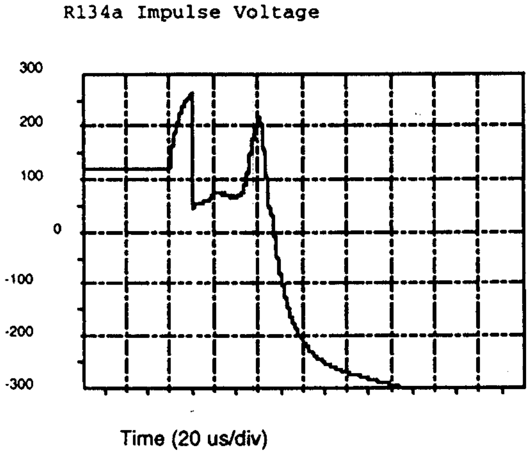


Figure B.2.6 The amount of current measured through the DUT represents the increased current observed during the conduction phase. A typical waveform indicating current as measured by a current transformer through R134a during elevated temperature and pressure testing is illustrated in the adjacent figure. The horizontal dimension is 20 µs per division and the vertical displacement is 0.5 amperes per division.

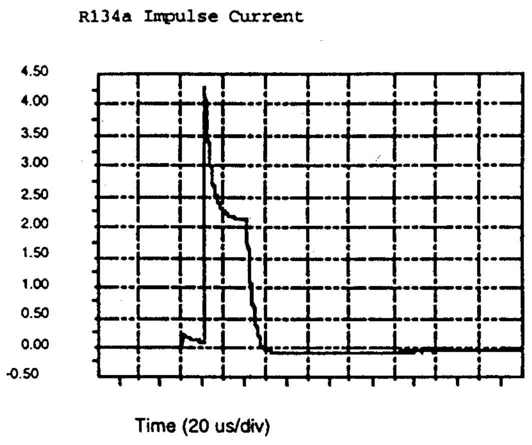


Figure B.2.7 The resulting product of the voltage and current represents the power across the DUT. Illustrated in the adjacent figure is a functional view of the power as a function of time across a DUT specimen of R134a. The horizontal dimension is 20 µs per division and the vertical displacement is 50 watts per division.

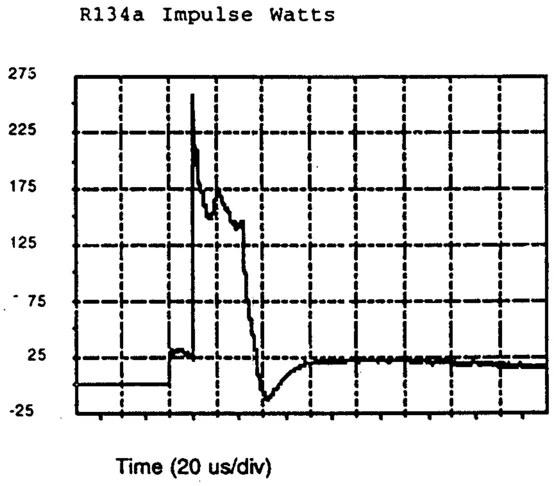


Figure B.2.8 As above by integrating the power delivered to the specimen an energy per breakdown can be measured. A typical resulting waveform is illustrated in the adjacent figure. Shown is the energy in joules as a function of time for R134a under elevated temperature and pressure conditions. The horizontal dimension is 20 µs per division and the vertical displacement is 0.001 joules per division.

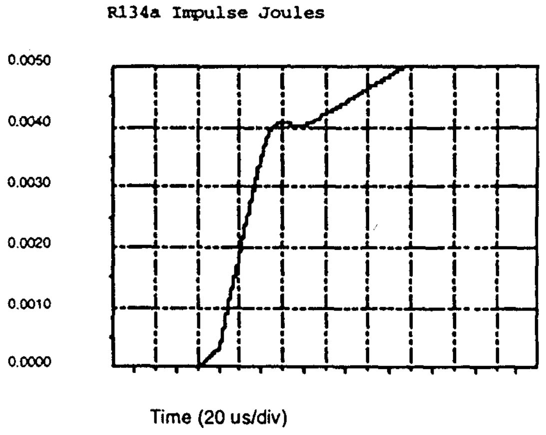


Figure B.2.9 The amount of voltage measured across the DUT represents a voltage drop across a gap during the high current conduction phase. A typical waveform measured across a DUT of R507 during elevated temperature and pressure testing is illustrated in the adjacent figure. The horizontal dimension is 20 µs per division and the vertical displacement is 100 volts per division.

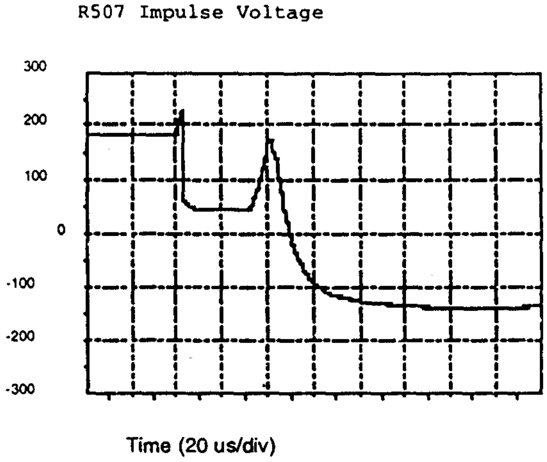


Figure B.2.10 The amount of current measured through the DUT represents the increased current observed during the conduction phase. A typical waveform indicating current as measured by a current transformer through R507 during elevated temperature and pressure testing is illustrated in the adjacent figure. The horizontal dimension is 20 µs per division and the vertical displacement is 0.5 amperes per division.

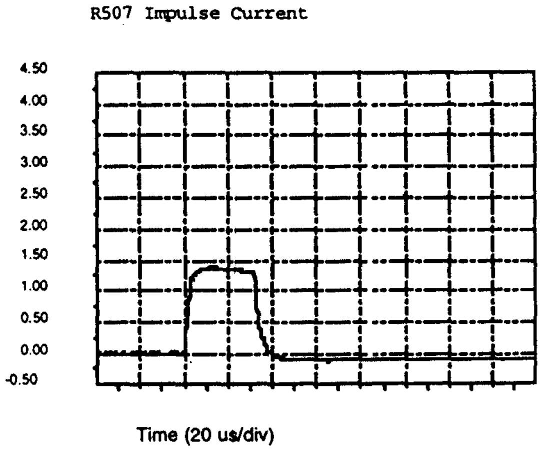


Figure B.2.11 The resulting product of the voltage and current represents the power across the DUT. Illustrated in the adjacent figure is a functional view of the power as a function of time across a DUT specimen of R507. The horizontal dimension is 20 µs per division and the vertical displacement is 50 watts per division.

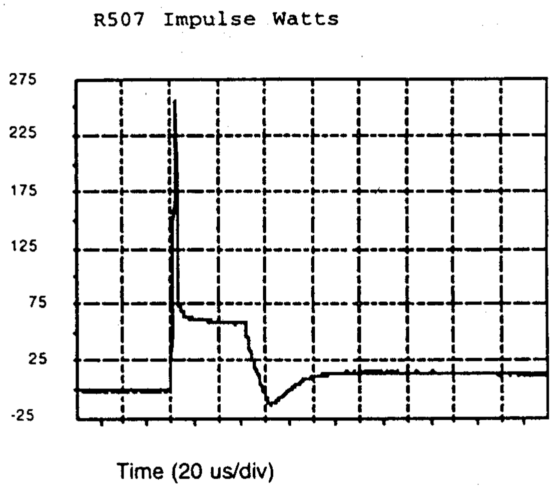
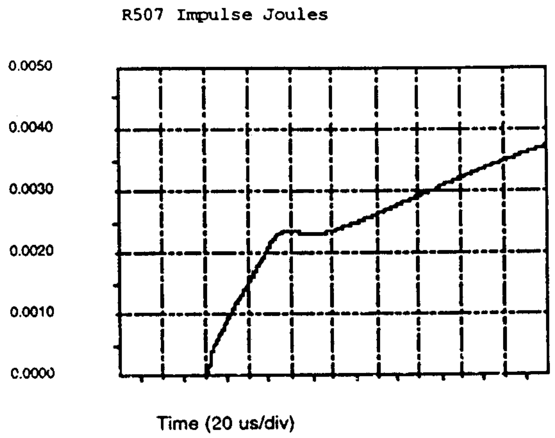


Figure B.2.12 As above by integrating the power delivered to the specimen an energy per breakdown can be measured. A typical resulting waveform is illustrated in the adjacent figure. Shown is the energy in joules as a function of time for R507 under elevated temperature and pressure conditions. The horizontal dimension is 20 µs per division and the vertical displacement is 0.001 joules per division.



	ASHRAE	ATM P					
	number	950109b	950111b	950105f	950110C	950111b	950109a
	designation	10K #2	10K #3	50K #1	50K #2	100K #2	100K #1
ENERGY DEPOSITION (Joules)		15.6 J	15.6 J	78 J	78 J	156 J	156 J
COMPOUND ID		amt, relative to R22					
Chlorodifluoromethane	22	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Tetrafluoroethene	1114	2.40E-03	2.06E-03	9.28E-03	1.05E-02	1.92E-02	1.82E-02
dichlorodifluoromethane	12	9.86E-04	5.83E-04	4.45E-03	5.22E-03	1.23E-02	1.07E-02
Hexafluoropropene		2.01E-04	9.93E-05	9.34E-04	1.08E-03	3.13E-03	2.84E-03
1,2-dichloro-1,1,2,2-tetrafluoroethane	114	2.54E-04	1.26E-04	1.28E-03	1.44E-03	4.19E-03	3.59E-03
1,1-dichloro-2,2-difluoroethene	1112a	7.36E-05	5.66E-05	3.33E-04	3.75E-04	1.09E-03	8.88E-04
1,1,2,2-tetrafluorochloroethane	124a						
3-chloro-1,1,2,3,3-pentafluoro-1-propene				1.79E-04	1.98E-04	6.70E-04	4.83E-04
trichlorofluoroethylene		3.96E-05	2.11E-05	1.30E-04	1.72E-04	4.95E-04	4.35E-04
CF2ClCF2CF2Cl	216ca			7.82E-05	7.80E-05	2.44E-04	2.12E-05
1,2-dichloro-1,3,3,3-tetrafluoro-1-propene		2.56E-05		1.03E-04	1.12E-04	3.01E-04	1.98E-04
2-chloro-1,1,2,2,2-pentafluoropropene Cl-CCCF3			3.10E-05	1.74E-04	1.87E-04	6.29E-04	4.76E-04
trichlorofluoromethane	11	2.56E-05		1.19E-04	1.75E-04	4.81E-04	3.69E-04
monochlorinated fluorocarbon chlorine & fluorine containing hydrocarbon		3.23E-05	1.97E-05	1.65E-04	1.85E-04	5.77E-04	4.07E-04
1,2-dichlorotetrafluorocyclobutene		4.31E-05		1.16E-04	1.36E-04	3.35E-04	3.21E-04
1,2-dichloro-1,3,3,3-tetrafluoro-1-propene				5.20E-05	6.25E-05	1.43E-04	1.31E-04
1,1,2-trichloro-1,2,2-trifluoroethane	113	4.04E-05		8.28E-05	7.30E-05	2.11E-04	1.87E-04
1,2-dichloro-1,2-difluoroethene		2.92E-05	4.01E-05	1.77E-04	2.41E-04	6.56E-04	5.47E-04
trichloroethene	1120						
1,1,2-trichloro-3,3,3-trifluoro-1-propene							
1,2-dichloro-1,2-difluoroethene		3.03E-05	2.53E-05	1.61E-04	2.16E-04	5.48E-04	4.58E-04
chlorohexafluoropropane				3.60E-05	7.01E-05	1.23E-04	8.33E-05
2-chloro-1,1,2,2,2-pentafluoropropene CF3CFClCF2Cl		5.31E-05	2.47E-05	2.75E-04	3.04E-04	9.30E-04	7.84E-04
1,2,2-trichloro-1,1,3,3,3-pentafluoropropane		5.59E-05		2.87E-04	1.51E-04	6.95E-04	6.10E-04
tetrachlorethene		4.44E-05		1.92E-04	9.29E-05	3.01E-04	2.16E-04
chloropentafluorobenzene				6.73E-05	4.13E-05	1.77E-04	1.04E-04
1,2-dichlorotetrafluorocyclobutene				2.74E-05		3.38E-04	1.90E-04
dichlorofluoromethane	21					7.31E-05	6.38E-05
trans-1,3,3-trichloro-1-propene		5.28E-05		1.86E-04	1.82E-04	5.83E-04	5.34E-04
chlorinated aromatic compound				5.51E-05	3.60E-05	5.24E-04	9.17E-05
dichloroethyne		3.89E-05	2.81E-05	1.43E-04	1.73E-04	5.00E-04	4.13E-04

	ASHRAE number designation	ATM P					
		950109b	950111b	950105f	950110C	950111b	950109a
		10K #2	10K #3	50K #1	50K #2	100K #2	100K #1
ENERGY DEPOSITION (Joules)		15.6 J	15.6 J	78 J	78 J	156 J	156 J
COMPOUND ID		amt, relative to R22					
mw=152? mono Cl aromatic?				4.11E-05	3.53E-05	4.38E-04	1.02E-04
fluorinated alkane				5.45E-05		3.89E-04	9.40E-05
chlorodifluoromethane	22			5.70E-05	4.81E-05	3.58E-04	3.14E-04
1-chloro-1,1,2,2,-tetrafluoroethane	124			9.17E-05	1.09E-04	3.54E-04	2.57E-04
2-chloro-1,1,3,3,3 -pentafluoro-1-propene				9.30E-05	1.04E-04	3.42E-04	2.50E-04
chlorine & fluorine containing hydrocarbon		3.81E-05		1.10E-04	1.25E-04	3.40E-04	2.83E-04
trichloropropene				4.09E-05		3.08E-04	1.30E-04
chlorine & fluorine containing hydrocarbon				7.70E-05	8.21E-05	2.55E-04	2.32E-04
chlorinated hydrocarbon (2 Cl; mw=145?)				2.90E-05		2.45E-04	7.03E-05
hexafluorochlorobutene				6.88E-05	4.03E-05	1.59E-04	1.19E-04
1,1,3,3-tetrachloro-2,3-difluoropropene					4.24E-05	1.56E-04	7.69E-05
C4F3Cl				5.57E-05	4.14E-05	1.34E-04	1.21E-04
1,2-dichlorotetrafluorocyclobutene				4.55E-05	3.32E-05	1.21E-04	1.01E-04
chlorinated hydrocarbon (2 Cl; mw=156?)				4.56E-05	5.03E-05	1.18E-04	1.31E-04
difluoromethane	32						
trifluoromethane	23						
benzene							
chlorotrifluoromethane	13						
pentafluoroethane	125						
trifluoroethane	143						
tetrafluoroethane	134						
1,3-Butadiyne							5.93E-05
TOTAL BREAKDOWN PRODUCTS (excluding R-22)		4.46E-03	3.12E-03	1.99E-02	2.22E-02	5.31E-02	4.57E-02

	ASHRAE number designation			HIGH T/P			
		950511C	950619	950511B	950619	950105E	950619
		0K #1	0K #1	10K #1	10K #1	50K #1	50K #1
ENERGY DEPOSITION (Joules)		0 J	0 J	25.4 J	25.4 J	127 J	127 J
COMPOUND ID		amt, relative to R22					
Chlorodifluoromethane	22	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Tetrafluoroethene	1114				9.33E-04		2.39E-03
dichlorodifluoromethane	12				1.85E-04	1.09E-03	8.02E-04
Hexafluoropropene						6.37E-04	
1,2-dichloro-1,1,2,2-tetrafluoroethane	114				4.41E-05	2.41E-04	2.13E-04
1,1-dichloro-2,2-difluoroethene	1112a				2.75E-05	9.72E-05	1.08E-04
1,1,2,2-tetrafluorochloroethane	124a					6.46E-05	7.09E-05
3-chloro-1,1,2,3,3-pentafluoro-1-propene						5.85E-05	5.21E-05
trichlorofluoroethylene						1.08E-04	5.99E-05
CF2ClCF2CF2Cl	216ca						4.37E-05
1,2-dichloro-1,3,3,3-tetrafluoro-1-propene						2.82E-05	3.10E-05
2-chloro-1,1,2,2,2-pentafluoropropene						3.09E-05	3.06E-05
Cl-CCCF3						2.73E-05	2.37E-05
trichlorofluoromethane	11					4.18E-05	2.58E-05
monochlorinated fluorocarbon						4.81E-05	2.96E-05
chlorine & fluorine containing hydrocarbon						3.07E-05	2.13E-05
1,2-dichlorotetrafluorocyclobutene						6.78E-05	2.89E-05
1,2-dichloro-1,3,3,3-tetrafluoro-1-propene						2.82E-05	2.15E-05
1,1,2-trichloro-1,2,2-trifluoroethane	113					4.15E-05	2.69E-05
1,2-dichloro-1,2-difluoroethene						6.86E-05	6.89E-05
trichloroethene	1120						
1,1,2-trichloro-3,3,3-trifluoro-1-propene							
1,2-dichloro-1,2-difluoroethene						5.27E-05	4.74E-05
chlorohexafluoropropane							
2-chloro-1,1,2,2,2-pentafluoropropene							
CF3CFClCF2Cl						4.01E-05	
1,2,2-trichloro-1,1,3,3,3-pentafluoropropane						4.37E-05	
tetrachlorethene						3.64E-05	
chloropentafluorobenzene							
1,2-dichlorotetrafluorocyclobutene						3.31E-05	
dichlorofluoromethane	21						
trans-1,3,3-trichloro-1-propene							
chlorinated aromatic compound							
dichloroethyne							

	ASHRAE number designation	HIGH T/P					
		950511C	950619	950511B	950619	950105E	950619
		0K #1	0K #1	10K #1	10K #1	50K #1	50K #1
ENERGY DEPOSITION (Joules)		0 J	0 J	25.4 J	25.4 J	127 J	127 J
COMPOUND ID		amt, relative to R22					
mw=152? mono Cl aromatic?							
fluorinated alkane							
chlorodifluoromethane	22						
1-chloro-1,1,2,2,-tetrafluoroethane	124						
2-chloro-1,1,3,3,3 -pentafluoro-1-propene							
chlorine & fluorine containing hydrocarbon							
trichloropropene							
chlorine & fluorine containing hydrocarbon							
chlorinated hydrocarbon (2 Cl; mw=145?)							
hexafluorochlorobutene							
1,1,3,3-tetrachloro-2,3-difluoropropene							
C4F3Cl							
1,2-dichlorotetrafluorocyclobutene							
chlorinated hydrocarbon (2 Cl; mw=156?)							
difluoromethane	32						
trifluoromethane	23						
benzene							
chlorotrifluoromethane	13						
pentafluoroethane	125						
trifluoroethane	143						
tetrafluoroethane	134						
1,3-Butadiyne							
TOTAL BREAKDOWN PRODUCTS (excluding R-22)		0.00E+00	0.00E+00	0.00E+00	1.19E-03	2.92E-03	4.09E-03

	ASHRAE	HIGH T/P				Heating Only	
	number	950510d	950619	950510c	950619	951106c.d	951106e.d
	designation	100K #1	100K #1	200K #1	200K #1	0 hours	4.5 hours
ENERGY DEPOSITION (Joules)		254 J	254 J	508 J	508 J		
COMPOUND ID		amt, relative to R22					amt, relative
Chlorodifluoromethane	22	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Tetrafluoroethene	1114		4.39E-03		8.56E-03		
dichlorodifluoromethane	12	2.57E-03	1.79E-03	2.14E-03	4.14E-03	1.88E-05	2.98E-05
Hexafluoropropene		1.12E-03		8.49E-04	1.61E-03		
1,2-dichloro-1,1,2,2-tetrafluoroethane	114	6.24E-04	4.77E-04	5.08E-04	1.23E-03		
1,1-dichloro-2,2-difluoroethene	1112a	2.34E-04	2.87E-04	2.27E-04	5.80E-04		
1,1,2,2-tetrafluorochloroethane	124a	2.34E-03	1.39E-04	1.06E-04	3.67E-04		
3-chloro-1,1,2,3,3-pentafluoro-1-propene		1.44E-04	1.06E-04	6.51E-05	2.79E-04		
trichlorofluoroethylene		1.65E-04	9.50E-05	2.14E-04	2.55E-04		
CF2ClCF2CF2Cl	216ca	3.49E-05	1.05E-04	4.71E-05	1.91E-04		
1,2-dichloro-1,3,3,3-tetrafluoro-1-propene		7.67E-05	2.08E-04	7.40E-05	1.81E-04		
2-chloro-1,1,2,2,2-pentafluoropropene		9.32E-05	6.30E-05		1.75E-04		
Cl-CCCF3		7.26E-05	5.42E-05	5.87E-05	1.74E-04		
trichlorofluoromethane	11	8.40E-05	1.21E-04	8.66E-05	1.53E-04		
monochlorinated fluorocarbon		4.94E-05	1.21E-04	6.66E-05	1.33E-04		
chlorine & fluorine containing hydrocarbon		4.88E-05	1.06E-04	5.00E-05	1.24E-04		
1,2-dichlorotetrafluorocyclobutene		7.54E-05	5.60E-05	8.15E-05	1.22E-04		
1,2-dichloro-1,3,3,3-tetrafluoro-1-propene		4.19E-05	6.20E-05	4.05E-05	9.14E-05		
1,1,2-trichloro-1,2,2-trifluoroethane	113	5.16E-05	1.07E-04	6.12E-05	8.44E-05		
1,2-dichloro-1,2-difluoroethene		1.50E-04	1.98E-04	1.43E-04	7.09E-05		
trichloroethene	1120	2.81E-05		6.77E-05	5.48E-05		
1,1,2-trichloro-3,3,3-trifluoro-1-propene		3.13E-05		6.49E-05	3.70E-05		
1,2-dichloro-1,2-difluoroethene		1.34E-04	1.43E-04	1.38E-04	2.76E-05		
chlorohexafluoropropane		8.98E-05		1.43E-04			
2-chloro-1,1,2,2,2-pentafluoropropene		4.20E-05		1.26E-04			
CF3CFClCF2Cl		9.31E-05		1.05E-04			
1,2,2-trichloro-1,1,3,3,3-pentafluoropropane		2.33E-04		6.69E-05			
tetrachlorethene		7.00E-05		6.59E-05			
chloropentafluorobenzene		3.96E-05		4.31E-05			
1,2-dichlorotetrafluorocyclobutene		3.09E-05		4.26E-05			
dichlorofluoromethane	21	3.22E-05		3.38E-05			
trans-1,3,3-trichloro-1-propene							
chlorinated aromatic compound							
dichloroethyne							

	ASHRAE	HIGH T/P				Heating Only	
	number	950510d	950619	950510c	950619	951106c.d	951106e.d
	designation	100K #1	100K #1	200K #1	200K #1	0 hours	4.5 hours
ENERGY DEPOSITION (Joules)		254 J	254 J	508 J	508 J		
COMPOUND ID		amt, relative to R22					amt, relativ
mw=152? mono Cl aromatic?							
fluorinated alkane							
chlorodifluoromethane	22						
1-chloro-1,1,2,2,-tetrafluoroethane	124						
2-chloro-1,1,3,3,3 -pentafluoro-1-propene							
chlorine & fluorine containing hydrocarbon							
trichloropropene							
chlorine & fluorine containing hydrocarbon							
chlorinated hydrocarbon (2 Cl; mw=145?)							
hexafluorochlorobutene							
1,1,3,3-tetrachloro-2,3-difluoropropene		2.49E-05					
C4F3Cl							
1,2-dichlorotetrafluorocyclobutene							
chlorinated hydrocarbon (2 Cl; mw=156?)							
difluoromethane	32					1.31E-05	1.64E-04
trifluoromethane	23						1.99E-04
benzene							2.81E-04
chlorotrifluoromethane	13						
pentafluoroethane	125						
trifluoroethane	143						
tetrafluoroethane	134					6.00E-05	4.53E-03
1,3-Butadiyne							
TOTAL BREAKDOWN PRODUCTS (excluding R-22)		8.83E-03	8.63E-03	5.72E-03	1.86E-02	9.19E-05	5.20E-03

	ASHRAE	Motor AC Carryover Simulation
	number	951204b.d
	designation	single 1/2 cycle
ENERGY DEPOSITION (Joules)		380 J
COMPOUND ID		to R22
Chlorodifluoromethane	22	1.00E+00
Tetrafluoroethene	1114	
dichlorodifluoromethane	12	7.33E-04
Hexafluoropropene		
1,2-dichloro-1,1,2,2-tetrafluoroethane	114	
1,1-dichloro-2,2-difluoroethene	1112a	
1,1,2,2-tetrafluorochloroethane	124a	
3-chloro-1,1,2,3,3-pentafluoro-1-propene		
trichlorofluoroethylene		
CF2ClCF2CF2Cl	216ca	
1,2-dichloro-1,3,3,3-tetrafluoro-1-propene		
2-chloro-1,1,2,2,2-pentafluoropropene		
Cl-CCCF3		
trichlorofluoromethane	11	
monochlorinated fluorocarbon		
chlorine & fluorine containing hydrocarbon		
1,2-dichlorotetrafluorocyclobutene		
1,2-dichloro-1,3,3,3-tetrafluoro-1-propene		
1,1,2-trichloro-1,2,2-trifluoroethane	113	
1,2-dichloro-1,2-difluoroethene		
trichloroethene	1120	
1,1,2-trichloro-3,3,3-trifluoro-1-propene		
1,2-dichloro-1,2-difluoroethene		
chlorohexafluoropropane		
2-chloro-1,1,2,2,2-pentafluoropropene		
CF3CFClCF2Cl		
1,2,2-trichloro-1,1,3,3,3-pentafluoropropane		
tetrachlorethene		
chloropentafluorobenzene		
1,2-dichlorotetrafluorocyclobutene		
dichlorofluoromethane	21	
trans-1,3,3-trichloro-1-propene		
chlorinated aromatic compound		
dichloroethyne		

	ASHRAE	**Motor AC Carryover Simulation**
	number	**951204b.d**
	designation	**single 1/2 cycle**
ENERGY DEPOSITION (Joules)		**380 J**
COMPOUND ID		**to R22**
mw=152? mono Cl aromatic?		
fluorinated alkane		
chlorodifluoromethane	22	
1-chloro-1,1,2,2,-tetrafluoroethane	124	
2-chloro-1,1,3,3,3 -pentafluoro-1-propene		
chlorine & fluorine containing hydrocarbon		
trichloropropene		
chlorine & fluorine containing hydrocarbon		
chlorinated hydrocarbon (2 Cl; mw=145?)		
hexafluorochlorobutene		
1,1,3,3-tetrachloro-2,3-difluoropropene		
C4F3Cl		
1,2-dichlorotetrafluorocyclobutene		
chlorinated hydrocarbon (2 Cl; mw=156?)		
difluoromethane	32	
trifluoromethane	23	
benzene		
chlorotrifluoromethane	13	5.10E-03
pentafluoroethane	125	2.32E-03
trifluoroethane	143	4.15E-03
tetrafluoroethane	134	2.41E-02
1,3-Butadiyne		
TOTAL BREAKDOWN PRODUCTS (excluding R-22)		3.64E-02

Appendix C

	ASHRAE	atmospheric P/T				
	number	9500119c	950119b	950118e	950117C	950118C
	designation	10K #1	50K #2	50K #1	100K #1	100K #2
ENERGY DEPOSITION (Joules)		18 J	90 J	90 J	180 J	180 J
COMPOUND ID		amount, relative to R-134a				
1,1,1,2-tetrafluoroethane	134a	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Tetrafluoroethene	1114	3.15E-04	1.60E-03	2.56E-03	7.18E-03	4.91E-03
Hexafluoroethane	116	5.23E-04	8.91E-04	1.26E-03	2.36E-03	1.69E-03
Trifluoroethene			4.13E-04	7.00E-04	2.09E-03	1.61E-03
chlorodifluoromethane	*22*		1.92E-05		1.31E-03	7.21E-03
1,1,2,2-tetrafluoroethane	134					[illegible]
?????		1.69E-04		2.19E-04	4.10E-04	2.85E-04
1,1,3,3-tetrafluoro-3-chloro-1-propene						
C5F5H			9.80E-06	2.35E-05	2.40E-05	3.03E-05
1,2,3,4,5,5-hexafluoro-1,3-cyclopentadiene			3.50E-05		4.02E-05	5.76E-05
1,1,1,6,6,6-hexafluoro-2,4-diyne			2.18E-05	1.53E-05	5.60E-05	7.64E-05
Octafluoro-1,3,5-Hexatriene					4.17E-05	1.99E-05
1,2,3,4,5,5-hexafluoro-1,3-cyclopentadiene				2.25E-05	3.95E-05	3.79E-05
?????				1.23E-05	2.83E-05	1.22E-05
?????				2.06E-05	2.66E-05	2.41E-05
?????					1.47E-05	2.07E-05
?????					1.44E-05	1.81E-05
?????					1.37E-05	
~~1,1-difluoroethene~~						
1,1,2,3,3,3-hexafluoro-1-propene				1.95E-04		
pentafluoroethane	125					
trifluoroethane	143 isomer					
C3F6 or larger (??)						[illegible]
benzene						
TOTAL BREAKDOWN PRODUCTS (excluding R134a AND R-22)		1.01E-03	2.97E-03	5.03E-03	1.23E-02	8.80E-03

	ASHRAE	**HIGH T/P**				
	number designation	**950622b**	**950622c**	**950628c**	**950628b**	**950622d**
		0K #1	**10K #1**	**50K #1**	**100K #1**	**200K #1**
ENERGY DEPOSITION (Joules)		**0 J**	**37.3 J**	**186 J**	**373**	**746 J**
COMPOUND ID		**amount, relative to R-134a**				
1,1,1,2-tetrafluoroethane	134a	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Tetrafluoroethene	1114	1.60E-03	3.05E-03	3.24E-03	4.57E-03	1.09E-02
Hexafluoroethane	116	6.23E-04	2.08E-04	5.71E-04	1.22E-03	3.73E-03
Trifluoroethene				5.36E-04	1.15E-03	3.54E-03
chlorodifluoromethane	*22*	1.10E-03		1.27E-03	1.17E-03	2.21E-03
1,1,2,2-tetrafluoroethane	134	6.74E-04				1.46E-03
?????					1.78E-04	4.58E-04
1,1,3,3-tetrafluoro-3-chloro-1-propene				2.68E-05	8.34E-05	2.83E-04
C5F5H					4.52E-05	2.66E-04
1,2,3,4,5,5-hexafluoro-1,3-cyclopentadiene						2.61E-04
1,1,1,6,6,6-hexafluoro-2,4-diyne					2.57E-05	1.93E-04
Octafluoro-1,3,5-Hexatriene						
1,2,3,4,5,5-hexafluoro-1,3-cyclopentadiene					4.39E-05	
?????						
?????						
?????						
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?????						
~~1,1-difluoroethene~~				4.58E-04	7.99E-04	
1,1,2,3,3,3-hexafluoro-1-propene		9.17E-05				
pentafluoroethane	125					
trifluoroethane	143 isomer					
C3F6 or larger (??)		4.91E-05				
benzene						
TOTAL BREAKDOWN PRODUCTS (excluding R134a AND R-22)		3.03E-03	3.26E-03	4.83E-03	8.12E-03	2.11E-02

Appendix C

	ASHRAE	High T/P Heated ONLY		Motor AC Carryover Simulation
	number	951107c.d	951107e.d	960223a.d
	designation	t=0	t=4.5 hrs	single cycle
ENERGY DEPOSITION (Joules)				389 J
COMPOUND ID		amount, relative to R-134a		
1,1,1,2-tetrafluoroethane	134a	1.00E+00	1.00E+00	1.00E+00
Tetrafluoroethene	1114			
Hexafluoroethane	116			4.54E-05
Trifluoroethene				2.42E-04
chlorodifluoromethane	*22*	1.02E-03	4.48E-02	2.44E-03
1,1,2,2-tetrafluoroethane	134			
?????				
1,1,3,3-tetrafluoro-3-chloro-1-propene				
C5F5H				
1,2,3,4,5,5-hexafluoro-1,3-cyclopentadiene				
1,1,1,6,6,6-hexafluoro-2,4-diyne				
Octafluoro-1,3,5-Hexatriene				
1,2,3,4,5,5-hexafluoro-1,3-cyclopentadiene				
?????				
?????				
?????				
?????				
?????				
1,1-difluoroethene				~~1.90E-05~~
1,1,2,3,3,3-hexafluoro-1-propene				
pentafluoroethane	125			1.46E-04
trifluoroethane	143 isomer	7.51E-05	1.77E-04	3.59E-04
C3F6 or larger (??)				
benzene			4.17E-05	
TOTAL BREAKDOWN PRODUCTS (excluding R134a AND R-22)		7.51E-05	2.18E-04	8.13E-04

Appendix C

	ASHRAE	ATM P				
	number	950124d	950124c	950124b	950119D	950123C
	designation	10K #1	50K #2	50K #1	100K #1	100K #2
ENERGY DEPOSITION (Joules)		33.1 J	165 J	165 J	331 J	331 J
COMPOUND ID		amount relative to R-507				
R-507	507	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Tetrafluoroethene	1114	4.68E-04	1.97E-03	1.70E-03	4.49E-03	4.34E-03
1,1-difluoroethene	1132a		9.79E-04		2.19E-03	2.46E-03
Hexafluoroethane	116	4.71E-04	8.20E-04	6.73E-03	1.60E-03	2.00E-03
1,1,3,3,3-pentafluoro-1-propene			1.32E-04	4.18E-05	3.35E-04	[illegible]
1,1,1,2-tetrafluoroethane	134a	1.36E-04	1.32E-04	3.04E-05	3.28E-04	[illegible]
3,3,3-Trifluoro-1-propyne		1.32E-05	4.59E-05		1.04E-04	[illegible]
1,1,1,6,6,6-hexafluoro-2,4-diyne			4.91E-06		6.88E-05	4.77E-05
1,1,2,3,3,3-hexafluoropropane					4.31E-05	
1,2,3,4,5,5-hexafluoro-1,3-cyclopentadiene			5.89E-06		3.60E-05	2.83E-05
1,2,3,4,5,5-hexafluoro-1,3-cyclopentadiene			1.49E-05		3.16E-05	[illegible]
fluorinated hydrocarbon (aliphatic)			7.45E-06		2.52E-05	1.91E-05
hexafluoro-cyclobutene					2.51E-05	
monochlorinated, CH3-substituted hydrocarbon		1.25E-05	5.56E-06		1.97E-05	8.60E-05
chlorodifluoromethane	*22*	2.12E-05	9.08E-06		1.75E-05	2.37E-05
CH3-substituted pentafluorocyclopentadiene					1.57E-05	1.47E-05
fluorinated hyrocarbon (aliphatic)					1.42E-05	
3 chloro-1,1,3,3-tetrafluoro-1-propene					9.76E-06	
4 - (difluoromethylene)-2,3,3-trifluorocyclobutene					6.27E-06	2.17E-05
TOTAL BREAKDOWN PRODUCTS (excluding R-507 AND R-22)		1.10E-03	4.12E-03	8.51E-03	9.34E-03	1.00E-02