Pilot Retrofit Test of Refrigerant R-134a for GDSCC

J. Albus
Ground Antennas and Facilities Engineering Section

B. Brown, M. Dungao, and G. Spencer
TDA Mission Support and DSN Operations Section

NASA has issued an interim policy requiring all of its Centers to eliminate consumption (purchase) of stratospheric ozone-depleting substances, including chlorofluorocarbons (CFCs), by 1995. Also, plans must be outlined for the eventual phaseout of their usage. The greatest source of CFC consumption and usage at the Goldstone Deep Space Communications Complex is refrigerant R-12, which is used in many of the facility's air-conditioning systems. A pilot retrofit test shows that retrofitting R-12 air-conditioning systems with hydrofluorocarbon R-134a would be a workable means to comply with the R-12 portion of NASA's policy. Results indicate acceptable cost levels and nearly equivalent system performance.

I. Introduction

Some researchers believe that the release of manufactured chlorofluorocarbons (CFCs) into the atmosphere plays a substantial role in depletion of the stratospheric ozone layer. This layer, located at an altitude of 15 to 55 km, shields our planet from harmful solar ultraviolet rays. In 1987, representatives of both industrialized and developing nations set forth a timetable for reduction and elimination of stratospheric ozone-depleting substances, including CFCs, in a document known as *The Montreal Protocol for Protection of Stratospheric Ozone*. Twenty-four nations signed the initial document, which has since been modified with stricter phaseout schedules for these substances. Today, *The Montreal Protocol* has been ratified by more than 100 nations.

NASA's policy calls for eliminating ozone-depleting substance consumption (purchase) and planning for the quickest practical phaseout of their usage at all Centers. The Goldstone Deep Space Communications Complex (GDSCC) annually consumes approximately 3086 kg of the CFC R-12 to maintain refrigerant charges on 20 R-12 air-conditioning systems.

The ozone depletion potential (ODP) of a chemical compares its tropospheric lifetime, upward atmospheric diffusion rates, and photolyzability into chlorine with that of CFC R-11 (reference ODP of 1.0). A chemical with an ODP of 0.5 has one-half the ozone-depletion potential of R-11 [1]. Refrigerant R-12 has an ODP of 1.0.

Closed R-12 systems may continue to operate past 1995 using in-house stocks of refrigerant. Stockpiling sufficient R-12 to operate the systems for their remaining lifetimes would be costly. Refrigerant R-12 cost approximately $3.30/kg in 1986, but in February 1994 it had increased in price to $27.90/kg, due in part to federal taxation on CFC compounds. Taxes on R-12 are $9.57/kg for 1994 and will rise to $11.77/kg in January 1995. Its production will cease in the United States in December 1995.

II. Alternatives to CFC R-12

The term "capacity" refers to the maximum amount of British thermal units (BTUs) that a refrigerant in a compressor of fixed displacement can remove from the air (or other medium) under a given set of conditions. "Efficiency" refers to the amount of energy required to remove a given amount of heat from the air (or other medium) under a given set of conditions.

Viable alternatives to CFC R-12 include hydrochlorofluorocarbon (HCFC) R-22, HFC R-134a, and MP39. These refrigerants were the only commercially available alternatives suggested by GDSCC compressor manufacturers and major refrigerant manufacturers (Allied Signal, Du Pont, and ICI). Each is classified as A1 for lower toxicity and no flame propagation by the American National Standards Institute—American Society of Heating, Refrigeration and Air Conditioning Engineers (ANSI-ASHRAE) standards. Class A is a designation for refrigerants whose toxicities have not been identified at concentrations less than or equal to 400 parts per million. Class 1 is a designation for refrigerants showing no flame propagation when tested in air at one atmosphere and 18.3 deg C.

A. The R-22 Retrofit

R-12 systems may be modified to use HCFC R-22, an "interim solution" refrigerant with a complete phaseout date of 2030. R-22 has a low 0.05 ODP. Its present cost of $4.03/kg is considerably less than that of R-12. An R-12 system can gain capacity when retrofitted to use R-22. Conversion to R-22 usually requires expensive and time-consuming modifications (downsizing refrigerant lines, compressor replacement, etc.) due mainly to R-22's significantly higher operating pressures (a condensing pressure higher than 1548 kPa) and a condensing temperature of 38 deg C.

B. System Replacement

R-12 systems may be removed and replaced with those using acceptable refrigerants. This is advantageous when the current R-12 system requires greater capacity or is scheduled for replacement in the near future. It would allow installation of the most energy-efficient system design available. Removing and replacing a system, however, is costly, time-consuming, and usually very disruptive to operations.

C. The R-134a Retrofit

R-12 systems may be retrofitted to hydrofluorocarbon (HFC) R-134a with less disruption and cost than with R-22. As R-134a contains no chlorine, its ODP is 0. Usually, no major components in a reciprocating compressor system need replacement. R-134a's present cost of $14.00/kg (as of February 1994) is less than that of R-12 and should decline somewhat as commercial production capacity increases. System capacity and efficiency should be equivalent to R-12 in systems running evaporator temperatures above −6.7 deg C (GDSCC's R-12 systems operate above −1.1 deg C). Special procedures must be followed, however, to ensure lubricant and materials compatibility with R-134a.

D. The MP39 Retrofit

R-12 systems may be retrofitted to use MP39 (Du Pont) with little or no modification other than an oil change to an alkylbenzene lubricant. Efficiency should be equivalent to R-12 and R-134a. Because of higher operating pressures (than with R12), some GDSCC systems, however, may require receiver tank replacement. MP39 is a blend of HCFC R-22, HCFC R-124, and HFC R-152a, with an ODP of 0.03. MP39's current price of $12.78/kg (as of February 1994) is similar to that of R-134a. An R-12 system may gain capacity when retrofitted with MP39. MP39 is an acceptable alternative refrigerant that should not be phased out until 2030.

E. The Field Retrofit Test

Because of its good characteristics, R-134a was chosen to replace R-12 in an air-conditioning system at the Echo site's building G-38. This provided experience and data involving a refrigerant conversion. R-22 was not chosen because of the anticipated complexity and expense of system modifications. MP39 was not chosen because of two concerns. First, MP39 contains R-22, and at the time there was concern that the phaseout date of 2030 might be moved up. Second, performance of MP39 can change if significant leakage occurs on a repeated basis. While such performance changes are considered within acceptable ranges for most commercial uses, it was decided that no changes would be acceptable in systems supporting NASA mission-critical operations.

III. The R-12 to R-134a Retrofit Test

An R-12 air-conditioning system at building G-38 was retrofitted to use R-134a. Selected variables were monitored to compare qualitative and quantitative system performance with both refrigerants. A Fluke 2620A hydra data acquisition unit, a personal computer (PC), and an Elcontrol energy analyzer were used to collect and record information.

The variables monitored included current, voltage, suction-line pressure, discharge-line pressure, suction-line temperature, liquid-line temperature, cold-deck temperature, discharge-line temperature, mixed return-air temperature, second-stage suction temperature, compressor-head temperature, first-stage suction temperature, hot gas bypass temperature, ambient temperature, subcooling temperature, second-stage expansion valve temperature, return air temperature, air handler temperature, air off of condenser coils, pre-evaporator coil humidity, and post-evaporator coil humidity.

Allied-Signal Technical Services Corporation, Du Pont, GDSCC, and Trane maintenance personnel assisted in determining these variables. Measurements were made point-in-time with the interfaced hydra 2620A and PC, usually at 1- or 5-min intervals. The energy analyzer recorded (on demand) the kilowatt consumption rate.

Temperatures were measured with JPL-made thermocouples; pressures were measured with Fluke pressure transducers; voltage was read directly from a compressor transformer; current was measured with a Fluke current transducer; and relative humidity was measured with Omega humidity transducers. All output was fed to the 2620A. The energy analyzer monitored energy consumption directly from the system's 3-phase 480-V panel. All measuring devices were either calibrated and/or tested alongside portable instruments to ensure accuracy.

IV. Retrofit Considerations

A. Lubricants

Prior to converting from R-12 to R-134a, the compressor lubricant must be changed from the mineral oil commonly used in R-12 systems to a synthetic polyol ester oil. Mineral oils are not miscible with R-134a. Nonmiscibility, resulting in oil pooling in various parts of the system, can impede performance. In the worst case, such pooling can result in compressor oil starvation and severe damage or failure. The heating, ventilation, and air conditioning (HVAC) industry, lubricant manufacturers, and refrigerant manufacturers recommend a maximum of 3- to 5-percent mineral oil contamination of the new polyol ester oil before converting to R-134a.

Manufacturers, such as Castrol and ICI, offer synthetic polyol ester lubricants that are well suited for use with R-134a. Lubricant additive packages ensure good lubricity of the HFC R-134a/oil mixture, even though it lacks the chlorine found in CFCs (chlorine forms metal chlorides which provide a significant measure of lubrication).

The oil change procedure is as follows:

(1) The mineral oil is drained from the compressor.

(2) The compressor is filled with polyol ester oil and run for 24 hr or more. A longer run time provides better flushing of the oil from the system.

(3) A sample of the oil is removed and tested either by the oil manufacturer or by HVAC personnel (with a test kit) for contamination levels of mineral oil. The manufacturer can test the oil for metal wear and other factors that most test kits cannot test.

(4) The system is again drained, refilled, and run with fresh polyol ester oil for 24 hr or longer. Contamination levels are once again determined.

This procedure is repeated, if necessary, until mineral oil contamination is under 5 percent (usually 2 or 3 oil changes in total). The system may then be evacuated of R-12 and charged with R-134a, assuming that all necessary modifications have been made. The G-38 system required three oil changes to reach a 2-percent contamination level (industry consensus at the time had not yet agreed upon 5-percent maximum allowable contamination). Two changes would have been sufficient to reach a sub-5-percent level.

B. Material Compatibility

Refrigerant and lubricant manufacturers have tested R-134a and polyol ester lubricants for a variety of factors, such as material swell, material shrinkage, hardening, elasticity changes, refrigerant permeation, and so on. Published results are usually noted without a generic approval for a material to be used in all applications. In general, the following applies:

(1) Metals. R-134a and polyol esters are compatible with all metals typically found in air-conditioning systems.

(2) Plastics. R-134a and polyol esters are compatible with most plastics found in R-12 systems. Acrylics and celluloses are among those that should not be used with R-134a.

(3) Elastomers (seals, gaskets, o-rings, etc.). R-134a and polyol esters are compatible with many elastomers found in R-12 systems. Adiprene L and Viton A should not be used with R-134a. Because Buna S and butyl rubber exhibit borderline characteristic changes, their use with R-134a is not recommended. Styrenated butadiene (SBR) exhibits a high swell with polyol ester and is not recommended for use with the lubricant.

An inventory was made of all system components (hoses, solenoids, compressor, etc.) for the G-38 system. Component manufacturers were contacted to determine material compatibility of their parts with R-134a and polyol ester lubricants. All materials in the G-38 system were determined to be compatible. According to Trane, Carrier, and Vilter (manufacturers of the GDSCC air-conditioning system compressors), all GDSCC compressors should be compatible with R-134a.

C. Equipment Modifications

The air-conditioning equipment requiring compatibility evaluation before being converted to another type of refrigerant includes compressors, expansion valves, hot gas valves, condensor coils, evaporator coils, filter-driers, capillary tubes, pressure switches, and system piping. Centrifugal R-12 compressors often experience significant capacity loss as impeller design and rotational speed are exactly matched to the properties of R-12. Replacement of the impeller and/or pulley is usually required to regain lost capacity. Reciprocating R-12 compressors in systems operating above evaporator temperatures of −6.7 deg C usually experience equivalent performance with R-134a. The GDSCC R-12 compressor systems are reciprocating and operate at evaporator temperatures above −1.1 deg C. No piping material or diameter changes are required when retrofitting with R-134a because its physical characteristics are similar to those of R-12.

Some expansion valve manufacturers may recommend replacing the expansion valves because of somewhat higher operating pressures with R-134a. ALCO and Sporlan manufacture most of the expansion valves found in the GDSCC R-12 systems. ALCO recommended that the expansion valve power heads be changed for the G-38 retrofit. Sporlan states that its expansion valve assemblies are compatible with R-134a unless the system is already running a significantly oversized valve. The solenoid valves, pressure switches, and hot gas valve for the G-38 system were determined to operate satisfactorily with R-134a (confirmed by manufacturers). The expansion valve power heads were replaced at the recommendation of the manufacturer. Filter driers were replaced with an R-134a-compatible type. No compressor modifications were required.

D. Capacity

According to Du Pont, at evaporator temperatures over −6.7 deg C, R-134a exhibits an equivalent capacity compared with R-12.[1] Some systems running at these temperatures may show slightly higher capacities with R-134a because of its higher heat of vaporization (ability of a liquid to absorb heat prior to vaporizing to a gas).

E. Energy Efficiency Ratio

The energy efficiency ratio (EER) is the ratio of the net cooling capacity of a device, in BTU/hr, to the electric power input to that device, in watts, under designated operating conditions. Based on computer modeling by Du Pont, R-134a has a slightly lower EER than R-12 (1.5 percent and 0.5 percent less at evaporator temperatures of −40 and +4.4 deg C, respectively).[2] In actual practice, however, R-134a's greater heat transfer value provides better temperature transfer at the evaporator and condensor, resulting in an EER as good as with R-12.

F. Coefficient of Performance

The coefficient of performance (COP) is the ratio of heat removed to the energy used. Theoretically, the COP of R-134a is roughly 3 percent less than that of R-12. Both the G-38 retrofit and discussions with manufacturers indicate, however, that R-134a's greater heat transfer value can provide an equivalent or slightly higher COP in systems operating at evaporator temperatures over −6.7 deg C.

V. Retrofit of the G-38 Air Conditioning System to R-134a

The retrofitting of building G-38's air conditioning system to R-134a is summarized as follows:

(1) The Trane 8-cylinder reciprocating compressor was completely overhauled to standard specifications, including replacement of all elastomeric parts, such as gaskets, seals, and o-rings. Rebuilding allowed testing with a "new" compressor, eliminating potential confounding variables introduced by worn equipment.

(2) The compressor was reinstalled, filled with polyol ester oil, and run for more than 24 hr. Two more oil changes and runs with polyol ester were performed, which resulted in a residual mineral oil contamination below 2 percent. All samples were sent to Castrol for contamination analysis. As previously mentioned, a higher contamination level could have been tolerated.

(3) Baseline data were recorded on the R-12 charged system.

(4) The R-12 refrigerant was evacuated with a Thermoflow refrigerant recovery unit.

(5) The 660 kg of recovered R-12 was recycled and stored for use in other R-12 systems.

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[1] Personal communication with R. Dlugopolski, Technician, Du Pont Technical Services, Wilmington, Delaware, January 1994.

[2] Ibid.

(6) The following parts were changed: ALCO power heads were changed to an R-134a-compatible model of the manufacturer's recommendation and desiccant filter blocks were replaced with an R-134a-compatible model.

(7) The system was evacuated to a vacuum of 500 μm.

(8) The system was charged with R-134a and run. Superheat was checked and adjusted.

(9) Data were recorded on the retrofitted system.

VI. Retrofit Comments and Observations

No gasket or o-ring leakage has been observed in the converted G-38 system. The mechanical shaft seal cannot be observed without compressor tear down. Vilter reported that similar mechanical seals remained leak-free in laboratory extended-run testing with R-134a.

Oil samples analyzed by Castrol showed no unusual compressor wear or undesirable lubricant chemistry in the R-134a charged system. Flushing the system with polyol ester oil to a contamination level of under 5-percent mineral oil is a fairly simple procedure with about 4 to 6 hours of system downtime per oil change. Polyol ester oil is an expensive synthetic lubricant costing about $14/liter (as of February 1994). The G-38 compressor uses approximately 23 liters of oil per change ($320 oil cost). The drained oil cannot be reused and is disposed of as a hazardous waste. Disposal of used oil should not add extra expense to the GDSCC's current hazardous waste disposal costs. The R-134a/polyol-ester oil mixture foamed considerably less than the R-12/mineral oil mixture.

Changing the power-head assemblies of the ALCO expansion valves required minimal effort due to their design. Changing power heads in other systems may require significantly more time if they are not as easily disassembled. Some systems will not require power-head changes if fitted with Sporlan power heads.

Trane reviewed the performance data and noted that the first- and second-stage suction pressures wander more than expected. As measurements were taken point-in-time, either when the compressor was loading or was unloading, readings gave the appearance of random wandering. It was also noted that R-134a exhibited cooler discharge temperatures than with R-12. The different enthalpy values of the two refrigerants likely caused the temperature differences, which are within expected ranges. All other variables indicate that the G-38 system is operating satisfactorily with both refrigerants.

The time and cost for the retrofit are as follows:

(1) Labor time: Approximately 95 hr were required to complete the retrofit to R-134a. This works out to a $2,850 labor cost. Table 1 shows the labor breakdown.

(2) Materials cost: Materials for the retrofit to R-134a cost approximately $3,152. Table 2 shows the materials cost breakdown.

VII. Retrofit Performance Results

Quantitative comparisons were made among 5- to 15-minute performance runs with both refrigerants. Pairs, each consisting of an R-12 run and an R-134a run, were selected for similar running conditions (less than 4-percent variation in ambient and pre-evaporator air temperature). The pairs were then separated into their own refrigerant categories, providing two comparable groups of 10 each. COPs were calculated and plotted from lowest to highest values in each group (Fig. 1). Because of the lack of controlled heat and ventilation loads, these factors were not included in the calculations. As the G-38 test retrofit building was unoccupied, the system was run under low loading conditions. Compressor efficiency is usually measured at high load conditions in the laboratory. Thus, this field test shows the relative performance with each refrigerant, rather than actual system COP.

The efficiency and capacity of R-134a and R-12 appear to be comparable. Slightly more energy was used with R-134a (Fig. 2) to remove moderately more heat from the air (Fig. 3). R-134a exhibited an average postevaporator temperature that was −2.2 deg C lower than that of R-12. The R-134a group runs and the R-12 group runs exhibited COPs of 3.21 and 3.06, respectively. Thus, the relative COP of R-134a was 5 percent greater than that of R-12 for these specific data. When retrofitting to R-134a, some impurities were found to have accumulated in the liquid line filter, which may have somewhat impeded the performance with R-12.

Table 1. Labor time for the G-38 retrofit to R-134a.

Task	Time, hr
System materials listing and compatibility research	8
Drain mineral oil and recharge with polyol-ester oil (2 oil changes to <5% contamination—6 hr each)	12
Remove 600 kg R-12 refrigerant to 0 gauge pressure	16
Replacement of hardware (power head, etc.)	13
Vacuum system to 500 μm	12
Recharge system with 660 kg R-134a	8
Run system and make adjustments	12
Change filter driers and check in-line screens	5
Take system readings and evaluate performance	6
Leak check and repair	3
Total labor time: (equivalent cost = $2,850 at $30/hr)	95

Table 2. Materials cost for the G-38 retrofit to R-134a.

Material	Cost, dollars
660 kg Du Pont R-134a refrigerant (adjusted to retail price 2/94)	$1,908
2 cases Castrol Icematic SW-68 lubricant (adjusted to retail price 2/94)	631
2 ALCO XB1014MV-1B power assemblies	108
1 Henry 3-way dual shutoff valve	146
2 Henry relief valves	92
1 Henry seal cap valve	47
2 ALCO HX-48 desiccant blocks	40
Miscellaneous shop materials	200
Total materials cost:	$3,152

VIII. Other R-134a Retrofit Field Cases

In general, the G-38 retrofit results are similar to results observed in field and laboratory tests of other R-12 air-conditioning systems.

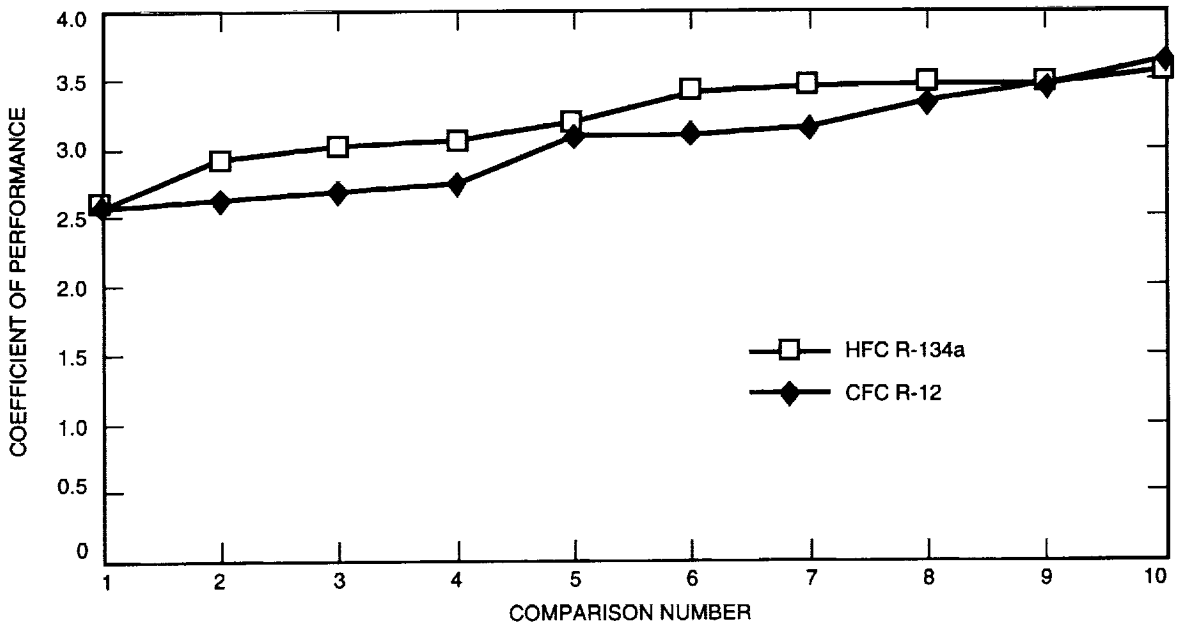

Fig. 1. Coefficient of performance.

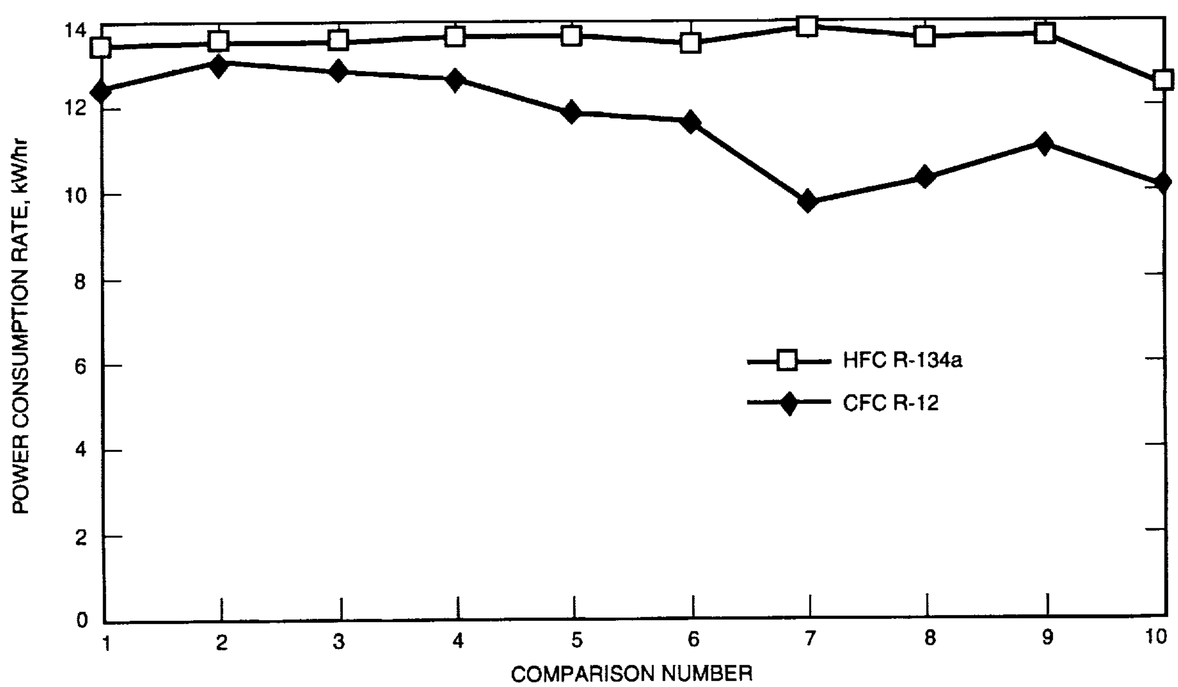

Fig. 2. Power consumption rate (kW/hr).

Vilter Corporation has retrofitted a Unichiller system (similar to the two at building G-86) to R-134a under laboratory conditions. Their test system exhibited capacities and efficiencies nearly identical to both refrigerants. Internal components and seals were in satisfactory condition after an extended run test. The main shaft seal exhibited a slight, but acceptable, swelling.

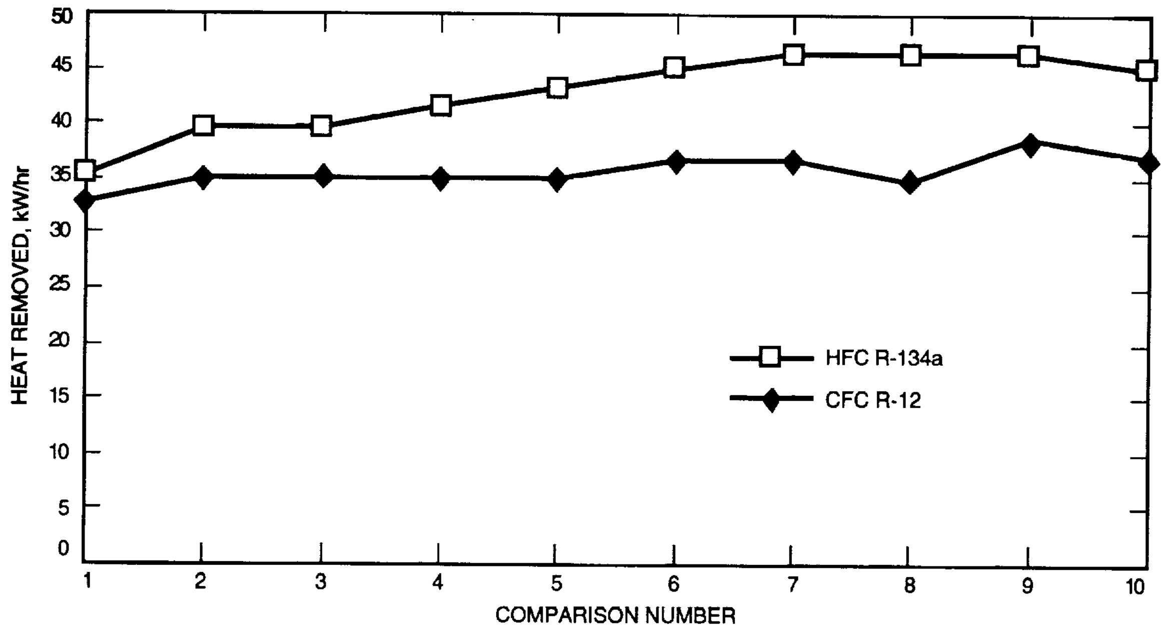

Fig. 3. Heat removed (kW/hr).

Trane has retrofitted an R-12 8-cylinder reciprocating compressor (similar to the G-38 unit) to R-134a under laboratory conditions and has run it in a 1-year endurance test. The unit has operated satisfactorily with no significant deviation from the reliability, capacity, or efficiency experienced with R-12. ICI, a major producer of R-134a, has published results of several R-12 to R-134a retrofits showing very similar performance for both refrigerants in all instances [2].

IX. Alternative Refrigerant MP39

Prior to the pilot retrofit, MP39 was assessed as a replacement for R-12. In most retrofits, no mechanical or material changes are required when converting to MP39. Usually only the oil must be changed once to an inexpensive alkylbenzene lubricant. In contrast, two or three changes with an expensive polyol ester oil are required when converting to R-134a.

Two concerns prevented MP39 from being chosen for the pilot retrofit: First, MP39 contains HCFC R-22, which is scheduled for phaseout in 2030. There was concern that this date may occur sooner. There has yet to be any indication, however, that the date will change (probably because of R-22's low ODP of 0.05). Second, MP39 is a near-azeotropic blend of three components: HCFC R-22, HCFC R-124, and HFC R-152a. They form a physical mixture (no new chemical compounds are formed) that has distinct vapor pressures corresponding to each component. An azeotrope's components have consistent vapor pressures. When a nonazeotrope leaks from a system in the gaseous phase, the components leak at different rates, altering the original ratio. There was concern that after several cycles of refrigerant leakage and refill (most air-conditioning systems leak to some extent), the composition of MP39 would change enough to affect system performance. Du Pont has run 20 leak (gaseous state) and recharge cycles with MP39 to find the effect on system capacity. Four such cycles caused a capacity loss of about 9 percent, resulting in overall capacity equivalent to that with R-12. Six more cycles caused a further 5-percent loss and 10 more cycles caused only a 1-percent further loss. Several substantial leaks (i.e., a broken fitting leaking overnight) in a system operating at or near maximum capacity levels may require that the remaining refrigerant be evacuated and replaced with fresh MP39 to maintain capacity.

Observations by a Du Pont refrigerant distributor and retrofit specialist have indicated capacity gains averaging 6 to 8 percent in R-12 air-conditioning systems retrofitted to MP39.[3] Du Pont confirms that up to 10-percent system-capacity gains can be expected. Thus, MP39 can provide system capacity gains as long as leakage is maintained within limits. As MP39's capacity decreases with sustained leakage and/or refill cycles, its EER increases. A computer simulation of leak recharging shows that a slight gain in efficiency is observed, as shown in Table 3.

Table 3. Energy efficiency ratios (at 1.7 deg C evaporator temperature).

Refrigerant	EER	EER after 20 percent refrigeration loss
MP39	15.823	15.985
R-12	15.992	15.992 (same)
R-134a	15.896	15.896 (same)

Du Pont claims that charging an R-12 system with MP39 requires only 80 to 85 percent of the usual R-12 charge by weight. Some field observations have shown even lower average numbers of 75 percent.[4] Using less refrigerant would save money. It is estimated that retrofitting the G-38 R-12 system with MP39 would incur a materials cost of $2,097 versus $3,152 for R-134a (using an estimated 85-percent charge for the MP39). Labor for retrofitting with MP39 is estimated at 84 hr versus 95 hr for R-134a. Material and labor costs may be higher with MP39, depending on the system configuration. Some GDSCC R-12 systems would require an expensive receiver tank replacement to accommodate MP39's higher pressures.

X. Systems Not Included

Not included in this retrofit plan and schedule are a walk-in refrigerator, walk-in freezer, and five small food-cooling units at the Echo site cafeteria; several small wall air conditioners; and the complex water fountains. Those units have shown insignificant R-12 consumption and, as sealed systems, pose very low leakage potential. A small supply of in-house R-12 stock would ensure sufficient refrigerant for their remaining lifetimes. The time and cost of converting these units to R-134a is not justified.

The Carrier system in G-38 (room 115) does not contain any refrigerant. As the building is vacant and has no known occupancy plans, the system is not included in this retrofit plan and schedule. The Carrier system in G-52 (Venus antenna) and the rooftop unit in G-33 (Photo Lab) are no longer being used and are not included either.

XI. Potential R-12 Replacement Plan and Schedule

A. Plan

The following plan could allow the GDSCC to meet NASA's interim policy with respect to consumption and use of CFC R-12. It is recommended that the GDSCC R-12 air-conditioning systems be retrofitted with R-134a. Several factors justify the possible additional costs of converting to R-134a (as compared with MP39). In some systems, the higher operating pressures of MP39 (and R-22 as well) would necessitate installation of higher pressure receiver tanks, eliminating or reversing projected cost savings. Table 4 shows some pressure comparisons of refrigerants referred to in this article. At higher discharge temperatures, relief valves in 172-kPa receiver tanks (found in some GDSCC R-12 systems) could vent

[3] Personal communication with R. Sazewicz, Air Cold Supply, Irwindale, California, January 1994.

[4] Ibid.

refrigerant to the atmosphere. A system audit would be required to determine the number of tanks needing replacement. R-134a should operate within the relief valve limit.

Table 4. Comparison of refrigerant pressures.

Temperature, deg C	Pressure, kPa			
	R-12	R-134a	MP39	R-22
10	322	312	499	579
24	530	542	749	912
38	808	856	1083	1351
52	1166	1272	1521	1916
66	1618	1812	2075	2632

Using a blend of refrigerants, such as MP39, would require training and maintenance procedures different from those of the single-component refrigerants used at GDSCC. Systems must be liquid-charged instead of gas charged, as usual. Two sets of subcooling and superheat calculations must be used in routine servicing (as opposed to using one set with R-12 or R-134a) to account for "temperature glide." As the liquid refrigerant boils into a gas, the components will boil at different rates, depending on their vapor pressures. This causes a change in the mixture's composition, which results in a temperature glide or change for the boiling point.

Recycling MP39 recovered from systems is not as straightforward as with a single-component refrigerant. Short of a chemical analysis, component ratios in the recovered refrigerant cannot be accurately estimated if an exact leakage record is kept because of the differing leakage rates of the components. Additionally, some refrigerant reclaimers will not accept used-blend refrigerants. This presents a disposal issue not normally encountered with single-component refrigerants. Du Pont will accept used blends, however, in its Refrigerant Reclamation Program.

B. Schedule

This plan and schedule attempts to reduce the risk of equipment problems with air-conditioning units used to cool critical locations. No indications of problems have been seen in either the pilot test, other field retrofits (reported by refrigerant manufacturers), or equipment manufacturers retrofit experiences with R-134a. The retrofit process should proceed cautiously by first converting equipment less critical to tracking support. This would give more experience and run time in each system type before converting critical units. Using a small data-acquisition unit and laptop computer (included in the total cost estimate), systems would be monitored for performance before and after converting to R-134a. This would provide detailed information for optimizing performance of the retrofitted systems.

A five-phase, 1-year retrofit schedule (Fig. 4) would be performed by Allied Signal Technical Services Personnel if an additional temporary workforce is provided. Three units per phase would be retrofitted, with the flexibility of rearranging the schedule within the phase. Completion in 1 year is suggested, but that period may be extended considerably while still complying with the interim NASA policy directive.

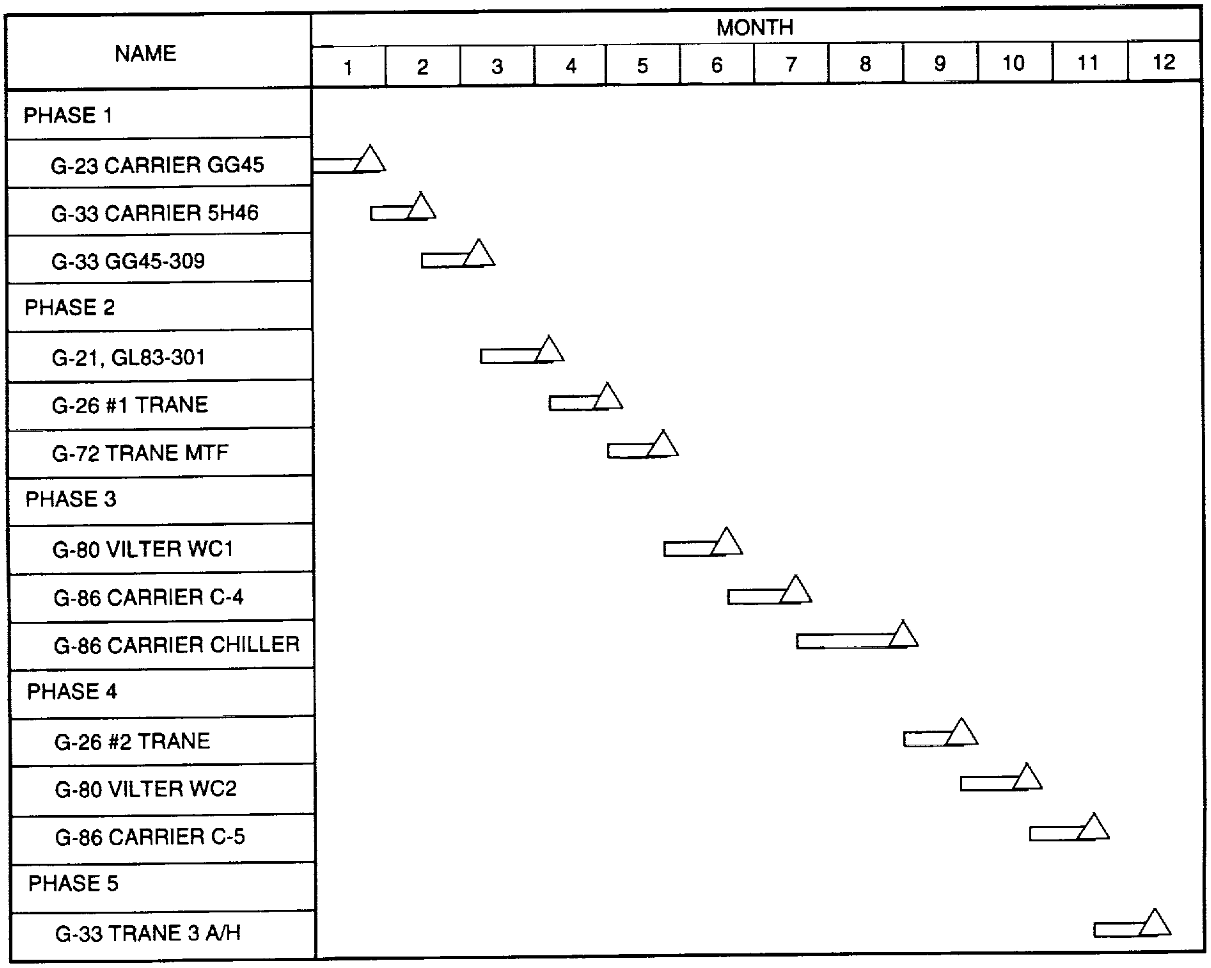

Fig. 4. Potential GDSCC R-12 replacement schedule.

XII. Cost Estimate of Potential R-12 Replacement

The total estimated cost for retrofitting the GDSCC R-12 systems to R-134a is approximately $136,000 (Fig. 5). Labor and material costs were itemized for each system. Included in the total cost estimate are recovery and recycling equipment, data-acquisition and recording equipment, and R-12 recovery certification training required by the Environmental Protection Agency (EPA).

XIII. In-House R-12 Stocks

Approximately 3080 kg of R-12 are consumed annually by the 20 GDSCC R-12 systems. As systems are converted to R-134a, the recovered R-12 would be recycled and stored in-house to meet the progressively decreasing consumption demand. The accumulating stock (Table 5) would be more than sufficient to maintain operation of the unconverted systems.

BUILDING	No. 274 kg CYLINDERS R-134a	KILOGRAMS OF R-134a	LITERS OF POLYOL ESTER OIL	No. FILTER DRIERS	No. POWER ASSEMBLIES	No. TEST VALVE DRAINS	No. OIL TESTS	No. REFRIGERANT TESTS	No. OIL FILTERS	MATERIAL COST	No. 3-WAY VALVES	No. RELIEF VALVES	LABOR HOURS	LABOR COST	TOTAL COST
G-21 GL83-301	3	142	114	4	2	1	3	2	1	$6,815	1	2	175	$5,250	$12,065
G-26 #1 TRANE	4	160	57	4		1	3	2		$5,070	1	2	127	$3,810	$8,880
G-26 #2 TRANE	3	160	57	4		1	3	2		$5,070	1	2	128	$3,840	$8,910
G-23 CARRIER GG45-469	1	36	34	2	1	2	3	2	1	$2,141	1	2	123	$3,690	$5,831
G-33 CARRIER 5H46	3	159	27	4		2	3	2	1	$3,967	1	2	112	$3,360	$7,327
G-33 GG45-309	1	45	34	2		2	3	1		$2,037	1	2	141	$4,230	$6,267
G-72 TRANE MTF	2	91	38	2		1	3	2		$3,108	1	2	129	$3,870	$6,978
G-80 VILTER WC1	4	205	80	1	2	2	3	2		$5,996			138	$4,140	$10,136
G-80 VILTER WC2	4	205	80	1	2	2	3	2		$5,996			138	$4,140	$10,136
G-86 CARRIER C-4	4	227	38	4	4	2	3	2	1	$5,550	1	2	169	$5,070	$10,620
G-86 CARRIER C-5	4	227	38	4	4	2	3	2	1	$5,550	1	2	169	$5,070	$10,620
G-86 CARRIER CHILLER #1	5	284	83	4		4	3	2	3	$7,154	1	2	230	$6,900	$14,054
G-33 TRANE 3 A/H	2	114	57	4	1	4	3	2		$3,485	1	2	162	$4,860	$8,345
TOTALS:	40	2056	734	40	16	26	39	25	8	$61,939	11	22	1941	$58,230	$120,169
RECOVERY UNITS (2)	$9,000														
TECHNICIAN TRAINING AND CERTIFICATION	$3,000														
DATA COLLECTION AND ANALYSIS UNIT	$4,000														
GRAND TOTAL	$136,169														

Fig. 5. Estimates for retrofitting the GDSCC R-12 systems to R-134.

Table 5. R-12 inventory as GDSCC systems are retrofitted to R-134a.

System	Cumulative R-12 recovered, kg
G-23 Carrier GG45-469	142
G-33 Carrier 5H46	302
G-33 Carrier GG45-309	463
G-21 GL83-301	499
G-26 #1 Trane	658
G-72 Trane MTF	704
G-80 Vilter WC1	795
G-86 Carrier C-4	999
G-86 Carrier chiller #1	1204
G-26 #2 Trane	1431
G-80 Vilter WC2	1658
G-86 Carrier C-5	1942
G-33 Trane 3 A/H	2056

XIV. Conclusion

To comply with NASA's policy, HVAC systems at GDSCC must be retrofitted with an alternative refrigerant. Retrofitting with HFC R-134a would require fewer work hours, less system downtime, and would be less expensive than retrofitting with HCFC R-22 or replacing entire systems. It is preferable to retrofit with R-134a rather than with MP39 for factors discussed previously. Most of MP39's advantages (compared with R-134a) are not anticipated to be substantial with respect to the GDSCC's systems. All systems recommended for retrofitting operate in the temperature ranges best suited for R-134a performance. The efficiency and capacity with R-134a are expected to be equivalent to those with R-12. Compatibility of system materials and equipment does not appear to be a concern. Retrofitting the GDSCC R-12 air-conditioning systems with R-134a is a workable means of complying with the NASA policy directive while maintaining equivalent systems performance.

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