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ARI's R-22 ALTERNATIVE REFRIGERANTS EVALUATION PROGRAM (AREP)

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Introduction

Background

The refrigerants primarily used in the U.S. air-conditioning and refrigeration industry are CFC-11, CFC-12, HCFC-22, and R-502 (an azeotropic blend of CFC-115 and HCFC-22 – 51.2/48.8% by weight). Although CFC phase-out dates have been continually accelerated, industry has endeavored to exceed the deadlines. As an example, three manufacturers (SnyderGeneral Corporation, The Trane Company, and York International Corporation) have announced that they will no longer produce CFC chillers after 1 January 1993, three years ahead of President Bush's 1 January 1996 deadline for halting all CFC production.

Attention is now focused on limiting the use of long-life hydrochlorofluorocarbons, especially HCFC-22. In December 1991, the National Resources Defense Council (NRDC) submitted a petition to the U.S. Environmental Protection Agency (EPA) requesting a phase-out of HCFC-22 in new equipment by the year 2000 and a ban on HCFC-22 production by 2005.

The use of new refrigerants, and the establishing of refrigerant phase-out dates, must be based on energy efficiency measurements, global warming potentials (GWPs), toxicity data, materials compatibility information, availability of suitable lubricants, flammability data, reliability statistics, serviceability requirements, ease of refrigerant production, and a host of other issues, not just ozone depletion potentials (ODPs). It takes time to deal effectively with these issues.

Wide-scale testing must be completed before new chemicals can replace existing refrigerants. The tasks to be performed include optimizing compressors and investigating their performance over a broad range of operating conditions. The material compatibility characteristics of the new refrigerants must be evaluated. On the manufacturing side, time is needed for equipment and component design, field testing, new tooling, and, finally, equipment production. Industry estimates that approximately 14 years are required to satisfy these issues and to introduce new equipment to the marketplace (refer to Figure 1). However, the clock starts <u>after</u> suitable alternative refrigerants have been identified.

After discussions with leaders in the HVAC&R industry, ARI ascertained that HCFC-22 must be available until at least the year 2010 for new equipment. ARI, the Alliance for Responsible CFC Policy, and industry leaders from Canada, Europe, and Japan have endorsed this date. Due to its excellent safety, energy efficiency, and operating characteristics, the continued availability and usage of HCFC-22 is essential for a successful CFC phase-out policy.

Furthermore, industry leaders realized that they needed to take an active role in identifying replacements for HCFC-22. In response to this requirement, industry has initiated the R-22 Alternative Refrigerants Evaluation Program (AREP). ARI is coordinating this effort.

Purpose of AREP

The goal of AREP is to identify candidate fluids that can potentially replace HCFC-22 in ARI product categories, establish testing protocols to evaluate the performance of the candidates, conduct the tests, and present the results objectively.

No attempts will be made at prioritizing the alternative refrigerants, nor in ranking the alternative refrigerants for various applications. Rather, AREP is an industry-wide cooperative program to focus research on HCFC-22 alternatives, accelerate industry's response, and avoid duplicative work. The overall objective is to perform a broad screening of the alternative candidates, while eliminating unnecessary duplication of work and wasting of limited resources. Selecting the alternative fluid(s) most appropriate for a specific application and the designing of optimized equipment are tasks left to individual manufacturers.

Organization of AREP

In December 1991, ARI formed a Task Force of senior executives from member companies (refer to Exhibit A) to launch a cooperative research effort to identify possible alternatives to HCFC-22. In turn, a Technical Committee (refer to Exhibit B) was created to advise the Task Force. The Technical Committee oversees research that is done by the participating companies – organizations that have agreed to perform research tasks under this program and to share their results with the public.

Subsequent to the establishment of the ARI AREP effort, Canadian, European, and Japanese companies (refer to Exhibit C) volunteered to collaborate in the program and to share their resultant data. As a result, over 35 companies are cooperating in an unprecedented international effort to accelerate the introduction of alternative refrigerants for HCFC-22 applications. Research activities of the European companies will be coordinated by the European Committee of Manufacturers of Refrigeration Equipment (CECOMAF), while the Japanese companies will coordinate their activities under the direction of the Japan Refrigeration and Air Conditioning Industry Association (JRAIA).

Also involved as observers to the AREP effort are many government agencies, independent associations, and private and public companies. Some of these entities, although not conducting research under the AREP effort, have agreed to share the results of their research with ARI and the world community.

Initial Identification of AREP fluids

The protocol for selecting the HCFC-22 replacements for the AREP effort was totally open. Government officials, chemical producers, and others were encouraged to nominate candidates for consideration. The Technical Committee considered these recommendations in addition to their own suggestions. In all, nearly 30 compounds were nominated for AREP consideration.

Ten candidates were selected for further investigation and are shown below:

Candidate Fluids	Composition (% by wgt)
possible HCFC-22 alternatives[a]:	
HFC-32/HFC-125[b]	60/40
HFC-32/HFC-134a	25/75[c]
HFC-32/HFC-125/HFC-134a	10/70/20
HFC-32/HFC-125/HFC-134a/R-290	20/55/20/5
HFC-32/HFC-125/HFC-134a	30/10/60
HFC-134a	---
R-290 (propane)	---
R-717 (ammonia)	---
possible R-502 alternatives[a]:	
HFC-125/HFC-143a[b]	45/55
HFC-125/HFC-143a/HFC-134a[d]	45/50/5

Notes:
(a) candidates are listed in no particular ranking order
(b) azeotrope
(c) was changed from 30/70%
(d) Du Pont HP-62, a near-azeotrope

Three of the ten AREP candidates are single constituent fluids – HFC-134a, propane, and ammonia:

- A key advantage of HFC-134a is that it, like all the AREP fluids, has zero ODP. Another advantage is that it is non-toxic and non-flammable. Preliminary material compatibility and lubrication work has been done; however, a few questions remain to be resolved. HFC-134a has some disadvantages as well. Compared to HCFC-22, its efficiency is low for low-temperature applications. In addition, the need for much greater compressor volumetric displacement may add to the size and cost of the equipment, and may also require overhauling compressor manufacturing facilities{3}.
- Propane is an efficient refrigerant, has well known material compatibility characteristics, zero ODP and near-zero GWP. Additionally, finding a suitable lubricant may not be a problem{5}. One shortcoming of propane is that an increase in compressor displacement is required to obtain capacities similar to HCFC-22. Its major disadvantage, of course, is flammability. Manufacturers will be challenged to develop acceptable containment for this, or any other flammable refrigerant.
- Ammonia is a well-known fluid in our industry. It is efficient and also has zero ODP and zero GWP. However, ammonia is classified by ASHRAE standard 34-1992 as a B2 fluid – toxic and moderately flammable. In

addition, the servicing infrastructure to support a large increase in usage of ammonia equipment may take years to develop.

Several azeotropic and near-azeotropic mixtures are being evaluated:

- HFC-32/HFC-125 is a non-toxic, non-flammable azeotrope with zero ODP. However, its coefficient of performance (COP) is not as good as that of HCFC-22{1,2,3}. Also, it operates at a higher pressure than HCFC-22, which could limit its utilization in a number of applications.
- HFC-125/HFC-143a/HFC-134a is a zero ODP near-azeotrope being considered as a replacement for R-502. Although preliminary results look good{4}, its temperature glide characteristics, and questions related to fractionation (e.g., selective leaking), need to be fully resolved. The relatively high GWP characteristics of the HFC-143a constituent may limit its future use. Additionally, toxicity testing on HFC-143a needs to begin so that the fluid can become listed under the U.S. Toxic Substances Control Act (TSCA).
- HFC-125/HFC-143a is an azeotrope with zero ODP. It is anticipated to have minimal problems associated with fractionation or heat exchanger design considerations. Again, the HFC-143a constituent requires toxicity testing and its high GWP may limit future use of the mixture.

The other four refrigerants are zeotropic blends. If their temperature glides can be utilized, these blends offer the potential for improved energy efficiency. All four contain HFC-32, which is flammable. However, the blends are formulated with adequate amounts of the nonflammable constituents to suppress the HFC-32 flammability. Fractionation and heat exchanger design considerations need to be resolved to realize potential efficiency gains.

Refrigerant Availability

Most of the chosen blends contain HFC-32, which, in the past, has been difficult and expensive to obtain. However, several chemical companies have supplied testing quantities of HFC-32 so that the program could commence. ARI is working with chemical manufacturers to facilitate acquisition of the quantities of refrigerants needed. Commercial quantities are expected to be available in the near future.

Other Candidate Fluids

To allow for a periodic review of new and interesting candidates, nomination periods are built into the program. The latest nomination period was at the end of August 1992 (subsequent to the submittal of this paper).

AREP Testing Program

The evaluation protocol consists of compressor calorimeter tests, heat transfer coefficient measurements, refrigerant drop-in tests in existing equipment, system simulations, and tests on slightly-optimized systems (refer to Figure 2).

Compressor Calorimeter Tests

Compressor calorimeter tests are designed to provide an understanding of how well a given compressor operates with a particular working fluid. Different types of compressors will be tested: reciprocating, scroll, rotary, screw, and centrifugal.

Compressor performance maps will be created from the data obtained during the calorimeter tests utilizing ARI Standard 520-90 for positive displacement compressors and the American Society of Mechanical Engineers (ASME) Performance Test Code PTC-10 for centrifugal compressors. Results will be reported relative to HCFC-22 or R-502.

Heat Transfer Tests

The Electric Power Research Institute (EPRI) is funding heat transfer coefficient research, an integral part of AREP. The purpose of this investigation is to measure refrigerant-side heat transfer coefficients of the HCFC-22 and R-502 alternatives in enhanced tubes. These measurements will be performed with pure refrigerant and with a 1% and 5% (by weight) lubricant charge. The results will be compared to baseline HCFC-22 and R-502 tests.

The heat transfer testing will be performed inside and outside of tubes in both the condensing and evaporating modes as a function of mass flow and heat flux. Four quadrants of heat transfer research will be performed (refer to Figure 3 for a schematic of the testing protocol):

Evaporator, Inside Tube	Condenser, Inside Tube
Evaporator, Outside Tube	Condenser, Outside Tube

An advisory committee, composed of industry and other experts, will assist EPRI in the technical direction of the research. Results from the EPRI-sponsored research is anticipated in the second quarter 1993.

Drop-in Tests

Drop-in tests will be performed on representative existing systems, with no modifications made to the equipment. The alternative fluids will be run under ARI standard conditions for the equipment under evaluation. The performance of these fluids will be evaluated relative to HCFC-22 or R-502.

System Simulations

After data from the compressor calorimeter and heat transfer tests are obtained, individual manufacturers will perform system simulations. These simulations will permit the companies to make educated assumptions on how equipment components can be partially optimized for each candidate replacement.

System Tests

Computer simulations will be useful in preliminary system design work. Refrigerant-specific systems will be designed, built, and tested. Some system optimization (*soft-optimization*) is likely to be performed; however, development and fine-tuning of optimized systems will be left to individual companies.

All tests preceding the system tests are, in actuality, in preparation for these system tests. It is the full-systems results that are of most interest since these tests will yield the best indication of how specific equipment categories will perform with a candidate fluid.

Dissemination of Results

All data generated through this investigation will be published and shared with industry and other interested parties. Each fluid will have its performance shown relative to that of HCFC-22 or R-502. Solutions to some of the pressing management and infrastructure concerns may also be learned. It is anticipated that final results will be available by the spring of 1994 and, after review by the AREP Technical Committee, released publicly by late summer.

The results will be disseminated through technical literature, conferences, final reports, and through the Air-Conditioning and Refrigeration Technology Institute (ARTI) Refrigerant Database. Additionally, information will be shared with JRAIA and CECOMAF for subsequent dissemination to their members and others. Similarly, ARI will share information from JRAIA and CECOMAF with interested U.S. entities.

References

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{3} Mark W. Spatz (Allied-Signal Incorporated), *Performance of Alternative Refrigerants from a System's Perspective*, Proceedings of the International CFC and Halon Alternatives Conference (Baltimore, MD), Alliance for Responsible CFC Policy, Arlington, VA, pages 352-361, December 1991

{4} Sonny G. Sundaresan (Copeland Corporation), *Near Azeotrope Refrigerants to Replace R-502 in Commercial Refrigeration*, Proceedings of the 1992 International Refrigeration Conference – Energy Efficiency and New Refrigerants, edited by D. R. Tree, Purdue University, West Lafayette, IN, pages 1-13, July 1992

{5} David W. Treadwell (Lennox Industries Incorporated), *Application of Propane (R-290) to a Single Packaged Unitary Air-Conditioning Product*, Proceedings of the International CFC and Halon Alternatives Conference (Baltimore, MD), Alliance for Responsible CFC Policy, Arlington, VA, pages 348-351, December 1991

Exhibit A: Members of the R-22 AREP Task Force

Mr. David Goldberg (Chairman)	Standard Refrigeration Company
Mr. William E. Dalton	Inter-City Products Corporation
Mr. Todd W. Herrick	Tecumseh Products Company
Mr. David Kelly	Carrier Corporation
Mr. William A. Klug	The Trane Company
Mr. John W. Norris, Jr.	Lennox International, Inc.
Mr. Robert J. Novello	Copeland Corporation
Mr. Robert N. Pokelwaldt	York International Corporation
Mr. Charles J. Tamborino	SnyderGeneral Corporation
Mr. Gary L Tapella	Rheem Manufacturing Company
Mr. J. L. Vowell	Hussmann Corporation
Mr. Thomas Zacaroli	Dunham-Bush, Inc.

Exhibit B: Members of the R-22 AREP Technical Committee

Mr. Earl B. Muir (Chairman)	Copeland Corporation
Mr. Warren L. Beeton	The Trane Company
Mr. Gary W. Cole	Matsushita Compressor Corporation
Mr. Jimmy Cox	Rheem Manufacturing Company
Mr. Warren Dillenbeck	Dunham-Bush, Inc.
Dr. Kenneth E. Hickman	York International Corporation
Mr. Kevin Kiefer	Thermo King
Mr. Edward D. Lawler	SnyderGeneral Corporation
Mr. Peter W. Likes	Hussmann Corporation
Mr. Alexandria T. Lim	Inter-City Products Company
Dr. Keshav S. Sanvordenker	Tecumseh Products Company
Mr. Howard W. Sibley	Carrier Corporation
Mr. David Treadwell	Lennox Industries, Inc.

Exhibit C: International Organizations Participating in the R-22 AREP Program

<u>Canadian Company</u>
National Research Council

<u>European Companies</u>	<u>Japanese Companies</u>
Aerzener Maschinenfabrik GmbH	Daikin Industries, Ltd.
Aspera Srl	Hitachi, Ltd
Bitzer Kuhlmaschinebau GmbH	Kobe Steel, Ltd
Bock & Company GmbH	Matsushita Electric Industrial Co.
Grasso Stacon B.V.	Mayekawa Manufaturing Company, Ltd
Necchi and Campiglio SpA	Mitsubishi Electric Corporation
L'Unite Hermetique S.A.	Mitsubishi Heavy Industries, Ltd
Sabroe Refrigeration A.S.	Sanden Corporation
Sulzer Brothers Limited	Sanyo Electric Company, Ltd
Zanussi Elettromeccanica SpA	Toshiba Corporation

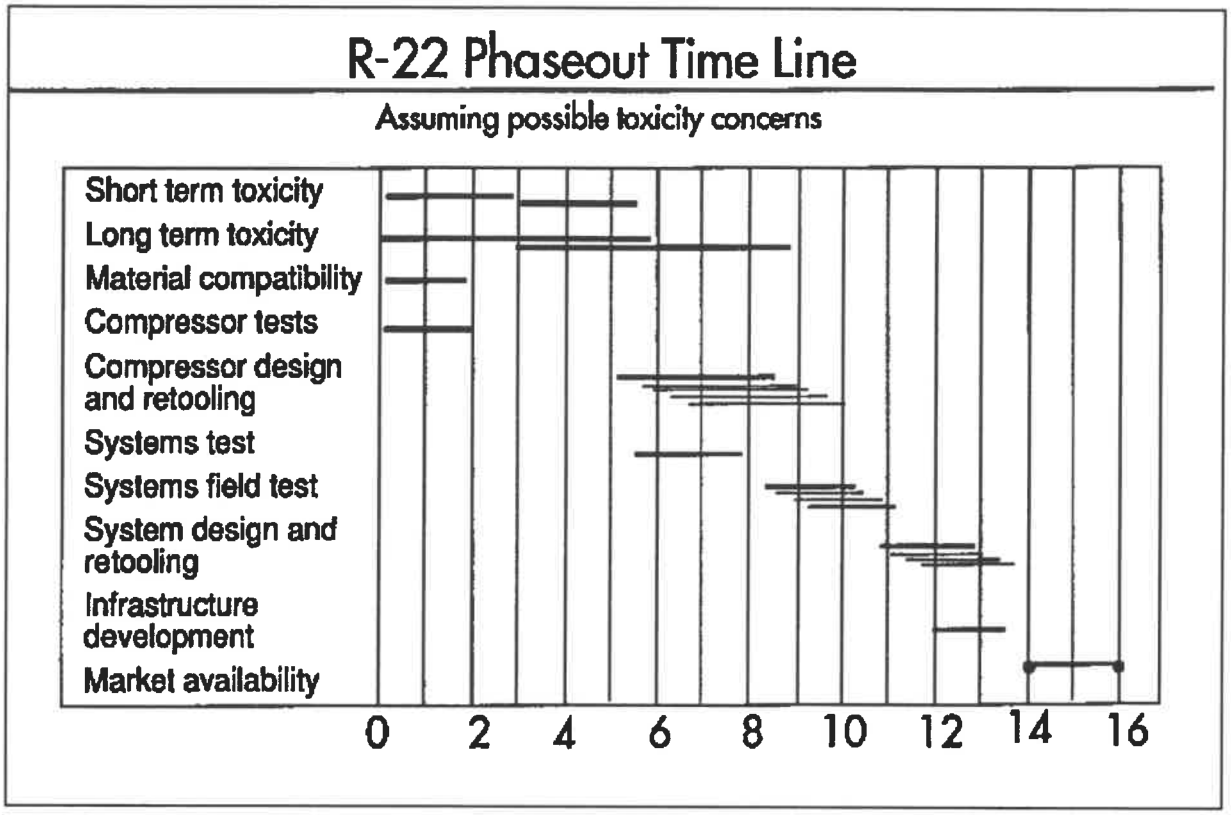

Figure 1: R-22 Phaseout Time Line

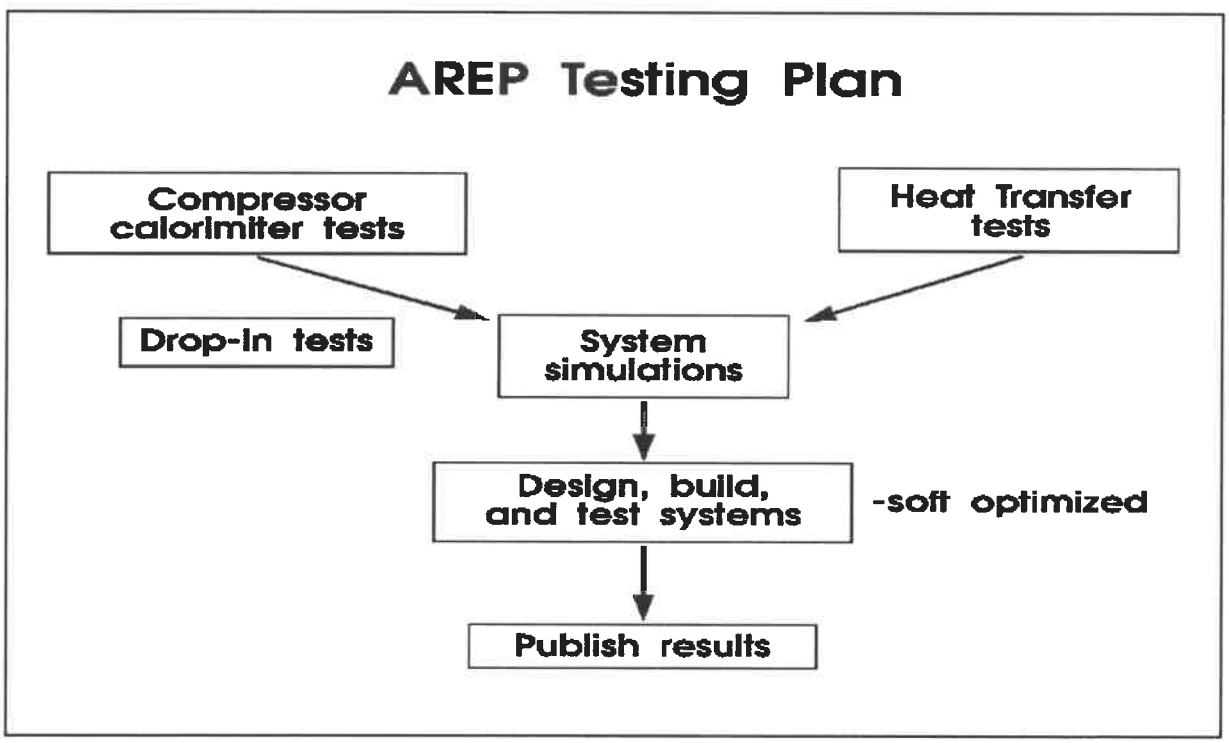

Figure 2: R-22 AREP Testing Plan

Heat Transfer Testing

	Inside Tubes	Outside Tubes
Evaporation	$h_{local}(q,m)$ minimum three sections | $h_{avg}(q,m)$ for at least 4 mass rates at more than one heat flux Relative to R-22 (40F) and R-502 (-30F) 3/8" OD microgroove (Wolverine Turbo A) Non-electric heat addition Tests to encompass 2 ranges: *IN* — *OUT* *1: quality from expansion of 105F liquid* — *90% quality* *2: quality from expansion of 105F liquid* — *10F superheat* *OIL**: *none, 1% by mass*	$h_{avg}(q)$ for a minimum of 6 heat fluxes Relative to R-22 only (40F) 3/4" OD Wolverine Turbo B-2 500 <= q <= 3000 BTU/hr/ft Non-electric heat addition encouraged *OIL**: *none, 1%, 5% by mass* *If temperature glide is significant: propose tests to cover composition change*
Condensation	$h_{local}(q,m)$ minimum three sections | $h_{avg}(q,m)$ for a range of heat fluxes and at least 4 mass rates Relative to R-22 and R-502 (both at 125F) 3/8" OD microgroove (Wolverine Turbo A) Tests to encompass 2 ranges: *IN* — *OUT* *1: 20F superheat* — *5% quality* *2: 20F superheat* — *10F subcool* *OIL**: *none, 1% by mass* *tube length (in air-cooled condensers) up to 100 ft*	$h_{avg}(q)$ for a minimum of 6 heat fluxes Relative to R-22 and R-502 (both at 100F) 3/4" OD Wolverine Turbo C-2 1000 <= q <= 3000 BTU/hr/ft No measurements with oil are required *If temperature glide is significant: propose tests to cover composition change*

* *oil to use is Mobil EAL 346R (46 cSt)*

Figure 3: R-22 AREP Heat Transfer Testing Protocol