Report No. 90-01

A Report of the

Office of Energy
Bureau for Science and Technology
United States Agency for International Development

VACCINE REFRIGERATION TECHNOLOGIES AND POWER SOURCES

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BST-5730-X-ER-5097-00

March 1990

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FIGURES AND TABLES

Unless otherwise specified, data on equipment cost and energy consumption were obtained from World Health Organization Expanded Program on Immunization (WHO/EPI) documents, particularly the *1988/89 Cold Chain Product Information Sheets.* WHO documents were also relied upon for information on requirements for vaccine refrigeration storage (i.e. number of systems and individual volume) and performance. Information on photovoltaic refrigerator system costs was obtained from the manufacturers and from WHO. A list of relevant publications, documents, and information sources is presented in the appendix.

SUMMARY

Adequate refrigeration of vaccines is an essential component of the worldwide child immunization effort sponsored cooperatively by such development assistance agencies as the World Health Organization, the United Nations Children's Fund, and the U.S. Agency for International Development (AID), and by developing countries. Unfortunately, the areas in most urgent need of effective immunization programs are often far from reliable refrigerated storage facilities or energy services. Selection of an appropriate energy supply and/or refrigeration technology has been seen as a limiting factor in effective immunization programs. In response to this problem, this document has been prepared to assist in the selection of reliable and affordable refrigeration systems. It provides information on refrigeration technologies and energy sources currently employed in the vaccine cold chain and discusses possible responses to a variety of energy-related problems, including intermittent or unreliable electric service, and unreliable supply, unavailability, or poor quality of fuels for refrigerators in health centers not served by the electric power grid.

Selection of appropriate vaccine refrigerators is relatively straightforward for clinics served by grid electricity. Equipment selection becomes somewhat more complex for off-grid clinics where absorption refrigeration is working satisfactorily, and becomes most complex for off-grid clinics where refrigeration costs are excessive or refrigerator reliability and performance are poor. The decision tools in this document can assist the reader interested in comparing the appropriateness of different refrigeration systems. These tools enable the reader to estimate, very roughly, life-cycle costs for various refrigerator systems, at different fuel costs. In addition to system cost, consideration must be given to how refrigerator reliability and performance may effect cost-effectiveness or appropriateness. A decision chart, and information in the text, indicate the types of situations where certain technologies can or cannot function effectively.

Where reliable or fairly reliable grid-electric power is available, compression refrigeration is the most reliable and cost-effective technology for vaccine cold-chain use. If electric service is reliable, but there are planned outages daily, or short unplanned outages are common, ice-lining refrigerators are recommended, assuming at least 8 hours of electricity per day. In areas where grid-electric service is not available, or where it is often unavailable for long periods, a choice will have to be made between kerosene and gas absorption systems, solar or photovoltaic (PV) systems, or cold-box outreach.

Photovoltaic (PV) systems can play a valuable role in immunization programs. In some cases, PV refrigeration appears to be the most cost-effective alternative; in other cases, PV systems may be the only type that can be effectively supported in the field. At present system costs, PV systems will be most cost-effective or programmatically justifiable in locations that are subject to poor fuel availability or quality, high fuel costs, severe logistical problems, and high vaccine spoilage rates. Bottled gas or kerosene refrigerators will often be the most cost-effective option for off-grid health clinics, if the fuel supply is reliable, of high quality, and reasonably priced. If both kerosene and gas are available, gas is generally highly preferable, even if fuel costs are higher. Provided that kerosene is of acceptable quality and kerosene refrigerators have functioned effectively for the Expanded Program on Immunization (EPI) in that region in the past, kerosene systems can be a cost-effective option.

The main purpose of this report is to identify the factors relevant to determining the most **reliable** and **cost-effective** refrigeration technologies and energy sources for the vaccine cold chain in a given environment. It is also intended to provide program officers and health officials with a summary of current cold-chain refrigeration technologies and energy sources, encourage comments and inquiries from the field, and discuss types of technical assistance and other support that the AID Office of Energy and other AID offices and projects can provide.

The material is organized as follows. The first section contains a general discussion of the vaccine cold chain, addressing both equipment needs and various cold chain constraints. The second section contains refrigeration equipment recommendations for different conditions, and advice on how to proceed with equipment selection. The third section consists of a more detailed discussion of technology selection, including region- and site-specific factors that must be taken into account; performance, reliability, and cost information on each of the technologies and power sources; and a description of the operation of each technology.

THE EXPANDED PROGRAM ON IMMUNIZATION

Immunization is widely recognized to be a highly cost-effective health care activity. The World Health Organization (WHO) initiated the Expanded Programme on Immunization (EPI) in 1974 and established a goal of universal childhood immunization by 1990. In 1984 and 1985, major donor countries and international organizations committed themselves to a greater level of effort in supporting the EPI in developing countries. WHO has been joined in EPI by the United Nations Children's Fund (UNICEF) and many other major development assistance donors, both public and private. The United States is a major contributor, primarily through the Agency for International Development (AID).

The EPI is characterized by a high degree of collaboration, cooperation, and integration between the international organizations, donor countries, and developing countries' health ministries. Both internationally and within recipient countries, there is often a recognized division of labor and financial burden-sharing. This cooperation extends to the cold-chain procurement area. The WHO/EPI Cold Chain office has primary responsibility for setting performance standards for, and testing and certification of, cold-chain equipment. This office also has primary responsibility for the development of training materials and programs for cold-chain equipment installers, maintainers, and operators.

THE VACCINE COLD CHAIN

The vaccine cold chain is the entire system of people, equipment, and material necessary to preserve vaccine at suitable storage temperatures from the point of manufacture until administration to a child or a woman of child-bearing age. Appropriate selection of vaccine refrigeration equipment is merely one of the vital tasks facing cold-chain managers. A large number of management, training, and other human resource issues affect the cold chain, no matter what type of refrigeration equipment is used, and must be dealt with effectively.

The refrigeration technology, energy source, and specific model selected, however, can have important impacts on program costs and effectiveness. Vaccine refrigerators differ considerably in terms of capital and operating costs, reliability, precision of temperature control, tolerance of poor quality fuel or electricity, and amount of operator intervention (adjustment and maintenance) required. These factors impact program effectiveness through vaccine spoilage or availability rates, cold-chain sustainability (high recurrent costs), increased staff work-loads, and other effects.

TEMPERATURES REQUIRED FOR VACCINES

Exposure to heat causes deterioration and loss of potency of vaccine. Both the magnitude of the temperature and the length of time of exposure at elevated temperatures are contributing factors to vaccine deterioration. As shown in Figure I, vaccines must usually be stored at 0 to 8°C (32 to 46.4°F). At higher levels of the cold chain, such as regional or provincial health centers, measles, yellow fever, and oral polio vaccine should be stored in freezers at -25 to -15°C (-13 to 5°F). Vaccines should be transported in insulated containers with a sufficient number of frozen ice packs to keep vaccines at 0 to 8°C. In health installations requiring large numbers of ice packs, separate ice-pack freezers may be required. Ice-pack freezers must be capable of maintaining a temperature of -10°C or below, in order to rapidly freeze ice packs.

NUMBERS AND CAPACITIES OF REFRIGERATORS NEEDED

The refrigerator volume required for vaccine storage in clinics is fairly low. One small refrigerator of 20- to 30-liter capacity can hold one month's supply of vaccines for a population of 100,000 (Based on the vaccination rate of 9600 vaccinations per 100,000 people). In rural areas, the actual number of refrigerators required for a given population will often exceed this ratio of 1 per 100,000 people, depending on a number of local factors, including population dispersion, the relative emphasis given fixed-site and mobile-team vaccination strategies, and whether lower-level health clinics are equipped with refrigerators or rely upon cold-box outreach. (In some cases, it is possible to transport vaccines and frozen ice packs to clinics weekly, allowing for use of a well-insulated cold box or ice chest at some clinics instead of a refrigerator.) WHO/EPI estimates typical vaccine refrigerator requirements for a population of ten million at over six hundred refrigerator-freezers, freezers, and refrigerators, with one hundred of these at the district level and five hundred at the health center (clinic) level. These are typical or average figures only and differ considerably from country to country, due to the impact of local factors.

COLD-CHAIN COSTS

Capital costs are normally a fairly modest component of cold-chain lifetime costs. WHO/EPI estimates that, on average, equipment capital costs account for 24% of cold-chain lifetime costs, energy costs account for 25%, equipment delivery accounts for 6%, and recurrent costs such as spare parts account for 44%. These figures are based primarily on experience with compression equipment connected to the electric grid (power line) and with kerosene and bottled gas absorption equipment. Solar, or photovoltaic (PV), refrigerators differ from other cold-chain equipment in that they have higher capital costs, no energy costs, and generally lower maintenance costs. It should be noted that energy costs are often far higher in remote regions. In these regions the lifetime cost of energy can greatly exceed the capital cost. Energy costs are presented in more detail in the discussion of absorption refrigeration in the technology selection section. Capital costs for refrigerators differ considerably, ranging from approximate average costs of $450 for grid powered vapor compression units; to $800 for absorption refrigerators; to $3600 for solar photovoltaic refrigerator systems. Table I contains information on capital costs and energy consumption of a number of vaccine refrigerators.

ENERGY REQUIREMENTS FOR VACCINE REFRIGERATION

The amount of energy required for vaccine refrigeration is relatively modest, and insignificant in terms of any developing country's overall energy consumption. Higher energy efficiency can be important for off-grid systems, however, by lowering capital and recurrent costs and reducing fuel delivery requirements. Energy consumption varies considerably based on ambient temperature, size of refrigerator/freezer, ice-pack freezing load, insulation and design factors, and refrigeration process efficiency. On average, absorption systems working on electric power require two to three times as much energy as compression systems for a given refrigeration load. Electric compression refrigerators use from 0.3 kilowatt-hour to 3.6 kilowatt-hours per day; electric compression ice-pack freezers use 1.8 to 8.6 kilowatt-hours per day; electric compression refrigerators employed in PV systems use 0.3 to 1 kilowatt-hour per day; and absorption refrigerators use between 1 to 5.3 kilowatt-hours of electricity, 0.13 to 1.5 kilograms of bottled gas, or 0.5 to 2.5 liters of kerosene per day. These figures are for WHO approved refrigerants. See Table I for energy consumption figures for a number of vaccine refrigerators.

CONSTRAINTS ON THE COLD CHAIN IN DEVELOPING COUNTRIES

Cold-chain planners and managers in developing countries must often overcome severe climatic, geographic, and institutional constraints. High ambient temperatures common to many developing countries increase cooling loads, often beyond the capability of equipment in place. Rainy seasons can render roads impassable for months at a time, hindering deliveries. Long distances between health centers, lack of roads, and geographical barriers also impede the movement of fuel, vaccines, ice, and other supplies. The vaccine cold chain is further hampered by the scarcity of skilled personnel, trained managers, and efficacious institutions that is common to many developing countries.

The cold chain also faces numerous financial and economic constraints. Although the EPI is a relatively favored recipient of development assistance from bilateral and multilateral donor organizations, the magnitude of the programs, ambitious coverage targets, and poverty of the developing countries often result in a relative scarcity of resources for immunization programs. Expenditures to support the rural cold chain must compete with other immunization/child survival expenditures, which in some cases may have larger or faster payoffs. The low level of economic development in many rural areas hinders the cold chain, due to poorly developed energy markets; energy prices are often high, supply is frequently unreliable, and the quality of available fuel or electric service is often extremely poor.

TABLE I. Typical vaccine refrigerators

Manufacturer and model	Volume (liters)	Energy type	Price (U.S. dollars excluding shipping)[a]	Annual energy consumption[b]
		Absorption		
Electrolux RCW 42 EG	Refrigerator 40, freezer 1.6	Electricity (AC) or gas	\$690-\$770	365-584 kWh, 47-73 kgs[f]
Electrolux RCW 42 EK[c]	Refrigerator 40, freezer 1.6	Electricity (AC) or kerosene	Approximately \$700-\$800	365-584 kWh, 110-146 liters[f]
Electrolux RCW-65	Refrigerator 105, freezer 21	Bottled gas, or kerosene	\$1803-\$2001 \$1914-\$2216 (gas)	164 kgs, 657-913 liters
Sibir V 240 GE (gas) and V 240	Refrigerator 240, freezer 33	Bottled gas, kerosene, or electric (AC)	\$766-\$812 (gas) \$985-\$1100 (kerosene)	1497 kWh, 164 kgs, 328-365 liters
		Compression		
Electrolux TFW 791, ice-pack freezer	Freezer 234	Electricity (AC)	\$1043-\$1159	657-1059 kWh
Polar Products E-3	Refrigerator 100, freezer 27[d]	Electricity (AC)	\$896-\$1195	438-1314 kWh
Vestfrost MK 140, ice-lining	Refrigerator 134 or freezer 134	Electricity (AC), 8 hours/day	\$325	183-438 kWh

Table I (continued)

Manufacturer and model	Volume (liters)	Energy type	Price (U.S. dollars excluding shipping)[a]	Annual energy consumption[b]
		Compression/Photovoltaic		
Polar Products RR-50L	Refrigerator 19, freezer 17[d]	Electricity (DC)	\$660-\$995, \$3525-\$4345 for PV system	110-255 kWh
Polar Products RR-2	Refrigerator 100, freezer 27[d]	Electricity (DC)	\$1496-\$1995[e], \$4607-\$5421[e] for PV system	146-400 kWh
Sunfrost RFV-4	Refrigerator 51, freezer 34	Electricity (DC)	\$1450, \$3400 for PV system	110-329 kWh

[a] Price ranges reflect manufacturers' practice of quoting different prices based on the number of units ordered.

[b] Energy consumption is based on WHO tests at 32 and 43°C, respectively. Average energy consumption in most developing countries will be closer to the 32°C (i.e., lower) consumption figure, assuming equipment is well maintained and performing well.

[c] This model is not currently approved by WHO nor listed in 1988/89 EPI Cold Chain Product Information Sheets, due to performance problems with kerosene fuel.

[d] Refrigerator and freezer compartment divider can be moved, changing compartment sizes.

[e] Polar Products RR-2 has two redundant compressors and refrigeration circuits for added reliability and efficiency. A one-compressor model, the RR-1, is available for approximately \$600 less per unit or per PV system.

[f] Gas sold by kg; kerosene by liter.

Source: Cold Chain Product Information Sheets 1988/89. World Health Organization Expanded Programme on Immunization, May 1988. Price data for PV systems were provided by manufacturers. Data on Electrolux RCW 42 EK are from Development of Better Kerosene Refrigerators for Storing Vaccines, World Health Organization Expanded Programme on Immunization, May 1986.

EQUIPMENT RECOMMENDATIONS

Selection of appropriate vaccine refrigerators is straightforward for clinics served reliably by grid electricity. Equipment selection becomes somewhat more complex for off-grid clinics where absorption refrigeration is working satisfactorily, and becomes most complex for off-grid clinics where refrigeration costs are excessive or refrigerator reliability and performance are poor.

A number of tools are presented below to assist in selection of vaccine refrigeration equipment. The decision charts illustrated in Figures I and II recommend specific technology and equipment types based on sequenced decisions about the quality and availability of electric service, the quality and availability of fuel, and the level of the cold chain. There are separate decision charts for health clinics and for larger, higher level health centers. A simple life-cycle cost comparison of absorption and PV refrigerators for off-grid clinics is given in Figure IV.

Readers interested in reviewing or using these selection tools should first read the decision chart. If the appropriate technology choice is clear (for example, a grid-electric compression refrigerator/freezer for a small clinic with reliable electric service), the next step is to consult the WHO/EPI Product Information Sheets and select refrigeration equipment of appropriate type and size. For off-grid clinics where the choice is much more complex, due perhaps to the unavailability of bottled gas or high-quality kerosene, or the high price of these fuels, the reader should consult the life-cycle cost comparison in Figure IV. This will give information on relative system costs at different fuel prices. Consideration should also be given to how refrigerator reliability may affect cost-effectiveness. Precise cost-effectiveness comparisons may not be possible, but it should be kept in mind that a less expensive system cannot be considered cost-effective if it is chronically out of order, resulting in costly vaccine losses.

Where reliable or fairly reliable grid-electric power is available, compression refrigeration is without a doubt the most reliable and cost-effective technology and is the undisputed choice for vaccine cold-chain use. The primary decisions to be made concern the size and model of refrigerator. Other decisions include whether to select ice-lining equipment for higher-level health centers (due to the large amounts of vaccine stored) and whether refrigerators and freezers need to be equipped with voltage regulators due to line voltage variations.

If electric service is reliable, but there are planned outages daily, ice-lining refrigerators are recommended, assuming at least 8 hours of electricity per day. If unplanned outages are frequent, but usually of short duration, ice-lining equipment will usually still be the most appropriate choice.

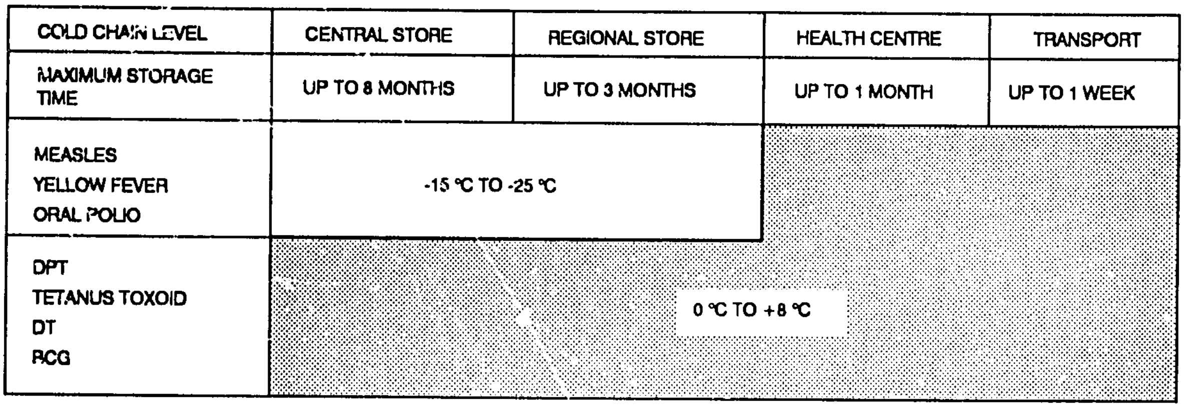
In areas where grid-electric service is not available, or where it is often unavailable for long periods, a choice will have to be made between kerosene and gas absorption systems, PV systems, or cold-box outreach. For intermediate and higher levels of the cold chain, consideration of small diesel or wind generators may also be appropriate. If intermittent electric service is available, or if there is a possibility of the grid being extended to an area, a combination gas/electric or kerosene/electric absorption system may be the most appropriate choice.

In certain locations and situations, PV refrigeration may appear to be the most cost-effective alternative, and suitable equipment alternative. At present system costs, PV systems may be more cost-effective than kerosene and bottled gas systems in locations that are subject to poor fuel

FIGURE I

ORNL-DWG 89-6593

VACCINE STORAGE TEMPERATURES



COLD CHAIN LEVEL	CENTRAL STORE	REGIONAL STORE	HEALTH CENTRE	TRANSPORT
MAXIMUM STORAGE TIME	UP TO 8 MONTHS	UP TO 3 MONTHS	UP TO 1 MONTH	UP TO 1 WEEK
MEASLES YELLOW FEVER ORAL POLIO	-15 °C TO -25 °C		0 °C TO +8 °C	
DPT TETANUS TOXOID DT BCG	0 °C TO +8 °C			

Note:

- Never freeze DPT or Tetanus (they both freeze at tempertures below -3°C)
- Storage times are recommended maximum figures.
- Remember to check expiration dates.

FIGURE II

ORNL-DWG 89-6624

REGIONAL LEVEL REFRIGERATION DECISION TREE

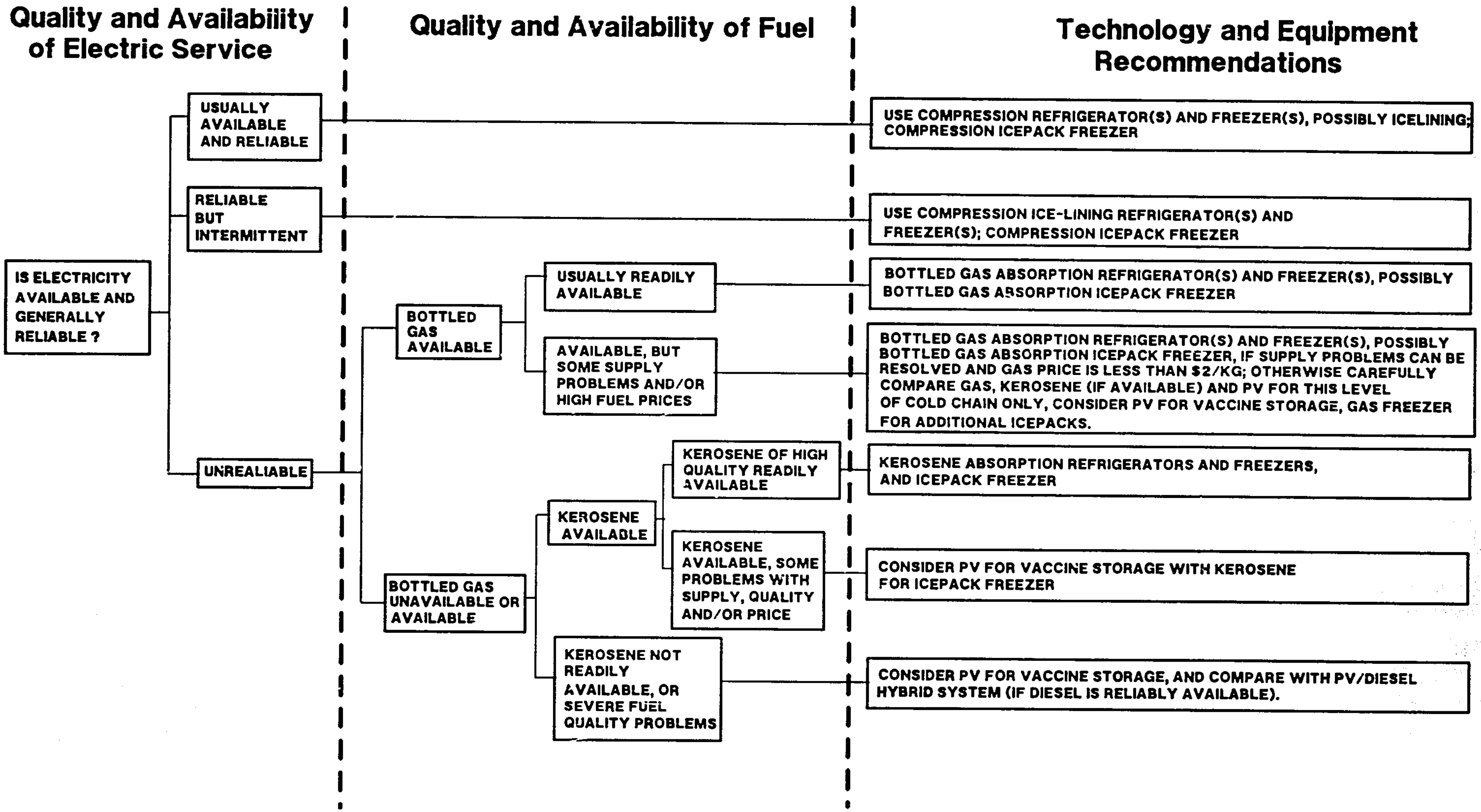


FIGURE III

ORNL-DWG 89-6625

HEALTH CLINIC LEVEL REFRIGERATION DECISION TREE

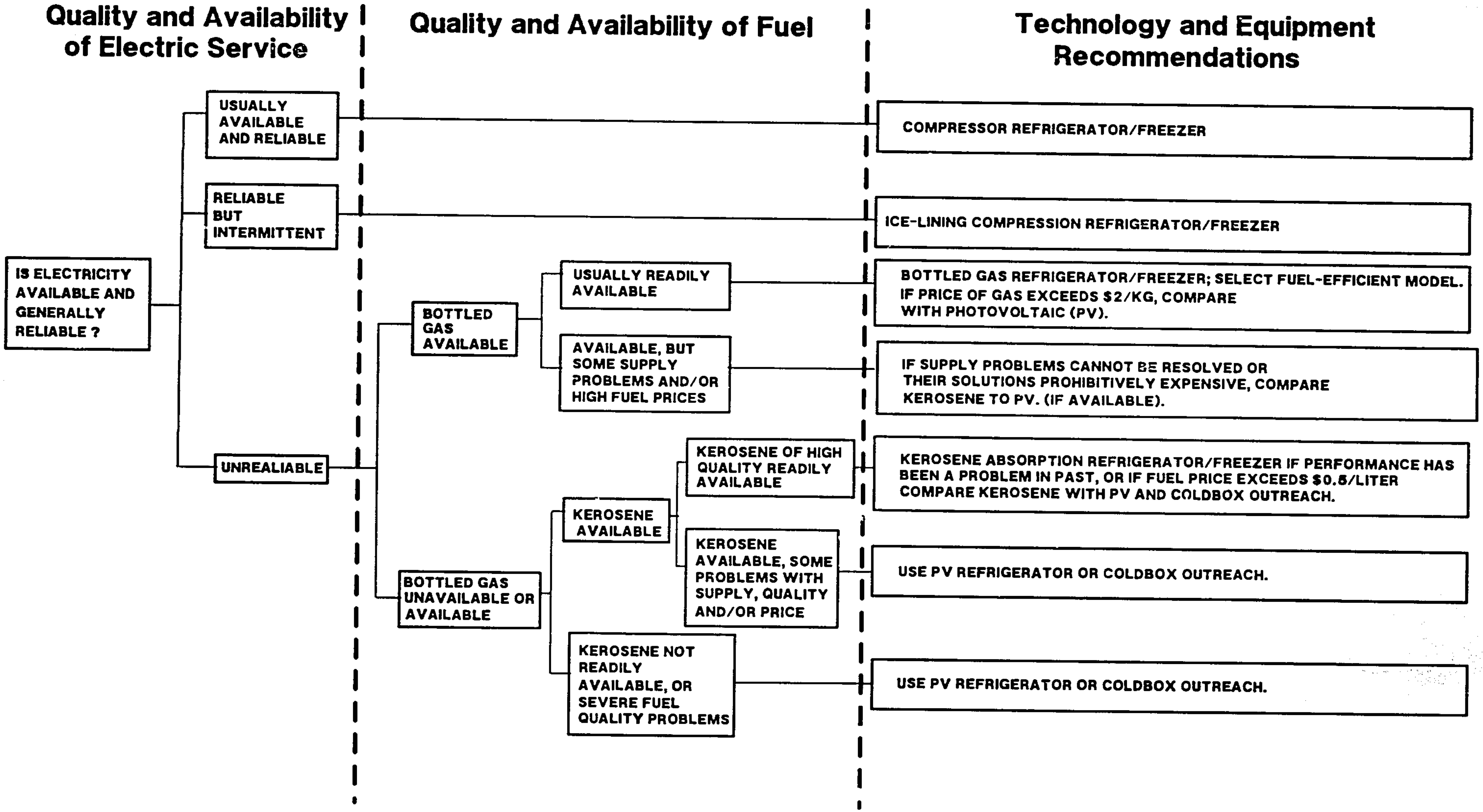
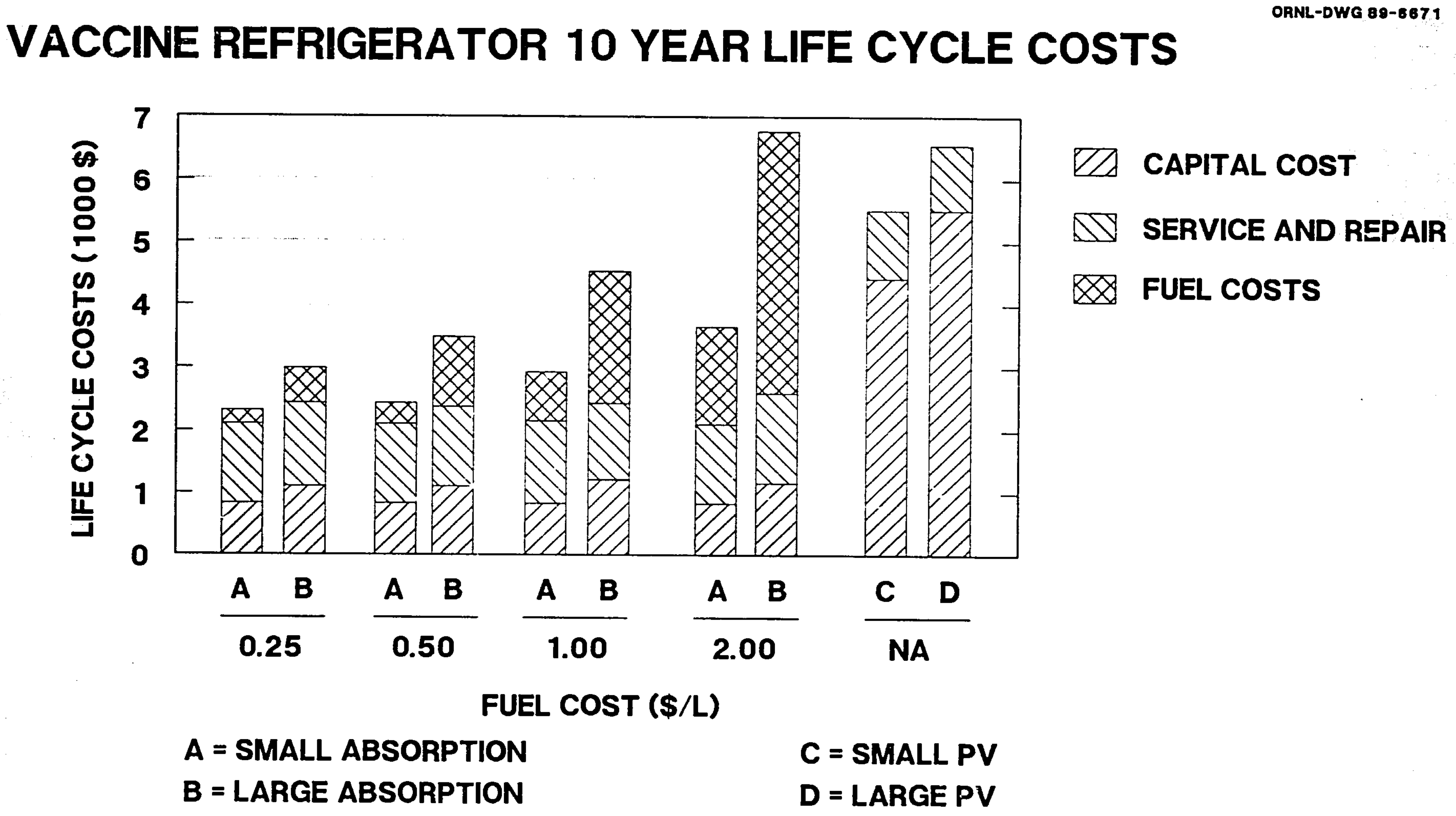


FIGURE IV



Refrigerator A refers to a small 24 liter capacity (net) absorption system; refrigerator B refers to a large absorption system with 68 liter net capacity; C refers to a small PV system with 17 liter net capacity; and D refers to a PV system with 80 liter net capacity. Capital cost includes shipping and installation. Service and repair includes routine maintenance.

FIGURE III

ORNL-DWG 89-6625

HEALTH CLINIC LEVEL REFRIGERATION DECISION TREE

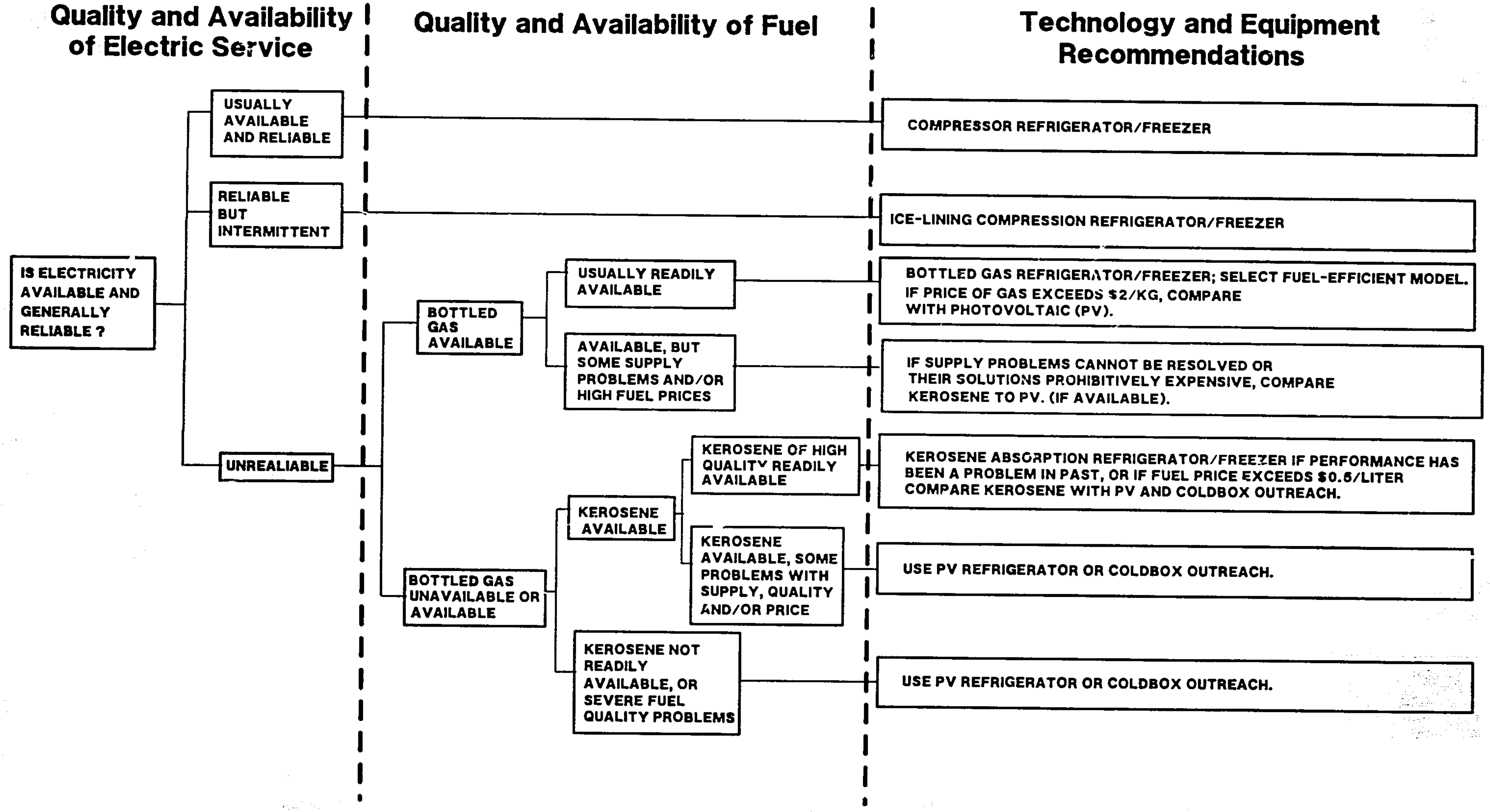
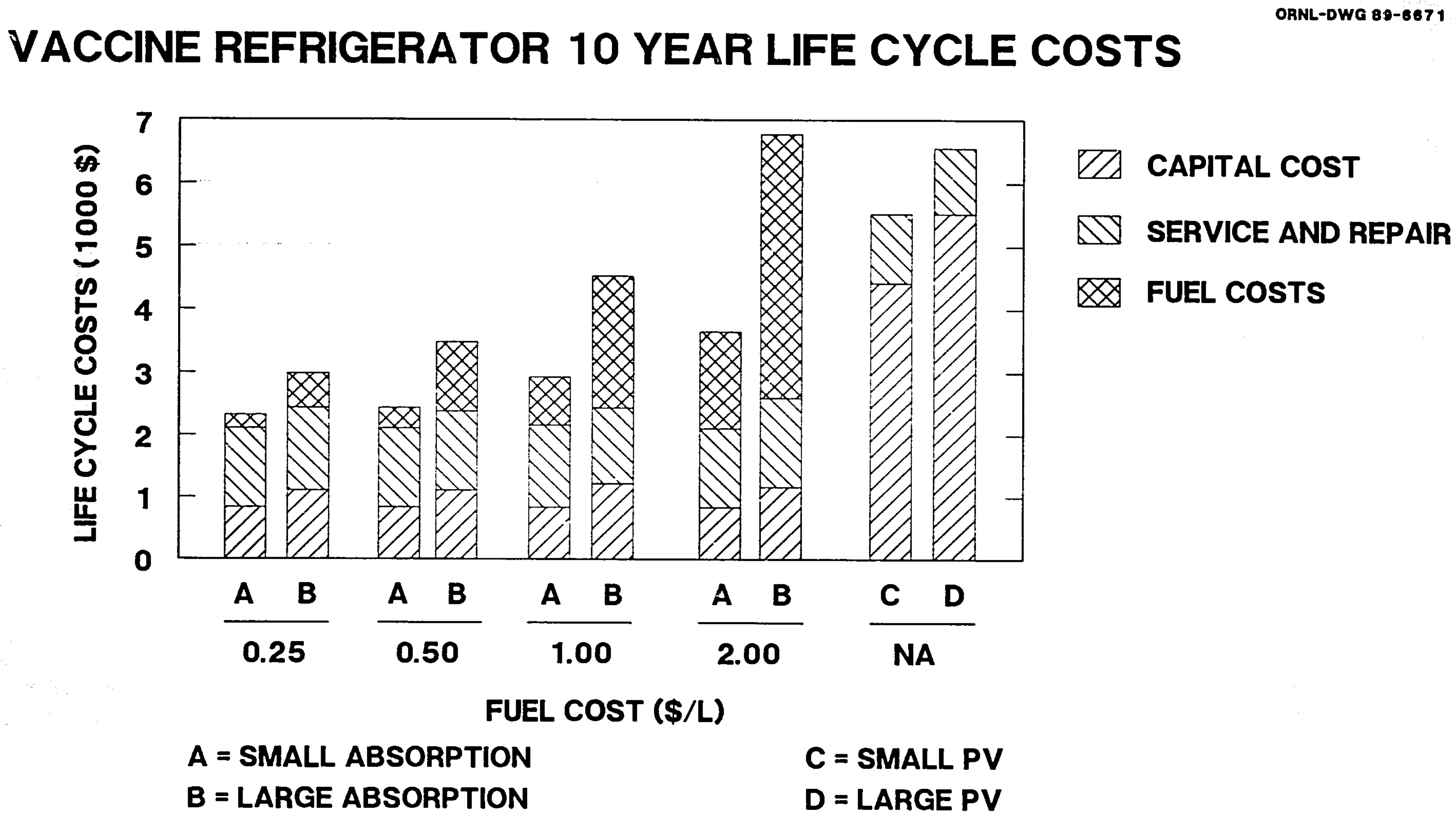


FIGURE IV



Refrigerator A refers to a small 24 liter capacity (net) absorption system; refrigerator B refers to a large absorption system with 68 liter net capacity; C refers to a small PV system with 17 liter net capacity; and D refers to a PV system with 80 liter net capacity. Capital cost includes shipping and installation. Service and repair includes routine maintenance.

availability, low quality, and high fuel costs. In very poor countries, PV vaccine refrigeration may be appropriate for widespread use throughout many of the rural areas. In countries with a higher level of development and better rural access to grid electricity, bottled gas, or kerosene, PV refrigeration (at present PV costs) will likely be more appropriate for use in specific regions or niches that are remote from or must pay a prohibitively high price for, such commercial energy sources. Where PV systems are being given serious consideration, the WHO/EPI Solar Refrigerator Pre-Feasibility Study Guide (forthcoming) should be consulted. Final determination of choice among absorption and PV refrigerators and cold-box outreach may require technical assistance from cold-chain specialists.

Where fuel supply is reliable, uncontaminated, and reasonably priced, bottled gas or kerosene refrigerators will often be the most cost-effective option for off-grid health clinics. If both kerosene and gas are available, gas is generally highly preferable, even if fuel costs are higher. Experience has shown that kerosene refrigeration should only be considered when the quality and availability can be assured. Contaminated or diluted kerosene will likely result in costly vaccine loss and interuption of immunization programs. However, if kerosene quality can be assured, kerosene systems will be an attractive option and may be the most cost-effective option. The nature of any existing kerosene refrigerator problems should be investigated, as some problems involving kerosene refrigerators may be easily resolved through training and provision of spare parts or funding for fuel purchases.

When selecting cold-chain options for regions with high fuel prices, PV systems and cold-box outreach should be explicitly considered, and any gas or kerosene refrigerators selected should be chosen with fuel efficiency and reliability in mind. The WHO/EPI Product Information Sheets include fuel consumption test results.

TECHNOLOGY SELECTION

Two basic decisions must be made when selecting refrigeration equipment for the cold chain: whether specific clinics should have a refrigerator or rely upon cold-box outreach; and the technology and model of refrigerator to select.

Cold-box outreach approach lowers equipment requirements at peripheral clinics and eliminates many fuel quality and availability problems. On the other hand, this approach increases vaccine storage and ice-making requirements at the higher-level health center, increases transport costs, and requires a higher degree of management or oversight. The cost-effectiveness of cold-box outreach depends to a large extent on the cost and feasibility of weekly transport of vaccines to the clinics. In regions where the cold chain has been hindered by refrigerator problems, cold-box outreach is one of the options that should be considered, along with PV or gas systems, and any possible measures to safeguard fuel availability and quality.

REGION- AND SITE-SPECIFIC FACTORS TO BE CONSIDERED

A variety of site- and region-specific information is required in order to undertake careful selection of cold-chain equipment and vaccination delivery methods. This is the case whether or not a change in refrigerator technology is being considered; the EPI is often hindered by cold chain failures resulting from selection of inappropriate models of refrigerators, or from failure to provide items such as spare parts, ice-packs, fuel, or fuel-cost funds. Gathering site-and region-specific information on the cold chain will identify easily resolvable problems such as these, in addition to identifying regions where refrigerator technology comparisons are advisable. In general, it is preferable to gather the necessary information in the course of broader cold-chain or immunization program reviews. This is likely to be more cost-effective than a specialized study of vaccine refrigerators, and it can produce valuable information on cold-chain performance, logistics, and management issues that can be used to improve the performance of equipment already in place.

For health centers where grid electricity is available, electric service availability and reliability at specific health centers should be examined, including hours of service per day, common duration of power outages, and incidence of voltage fluctuations.

For health centers where grid electricity is not available, a much larger number of factors should be examined, including:

1. kerosene and gas availability, including reliability of kerosene and gas supply;

2. actual fuel cost in specific regions either market cost, if procured locally by the clinic, or total cost including transport, if supplied by EPI;

3. kerosene quality, including incidence of low-grade (under-refined) kerosene and/or of contamination with other fuels or water (fuel quality problems will be indicated by burner smoking, inability to freeze sufficient ice packs or maintain temperatures, or need for frequent adjustment);

4. direct and indirect costs of vaccine spoilage caused by malfunctioning refrigerators, and costs and program performance reductions resulting from spoiled vaccines (if reliable cost data are unavailable, which is likely, an attempt should be made to ascertain if vaccine spoilage or unavailability due to refrigerator malfunction is a problem in specific regions);

5. historical performance and costs of different refrigeration technologies and energy sources in specific regions;

6. comparison of cost of cold-box outreach with cost of furnishing all clinics with refrigerators;

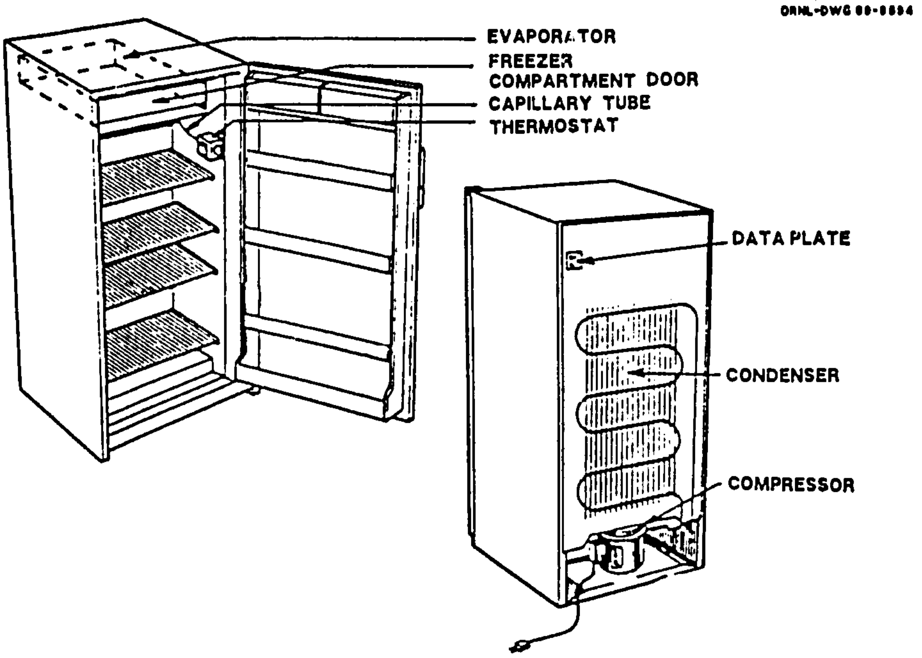
7. local solar energy resources, if PV systems are one of the options being considered. Some data will often be available from energy ministries, weather records, and other sources. If data are not available in-country, it will probably be available from scientific institutions in the United States and elsewhere. WHO/EPI Product Information Sheets contain a simple solar resource map.

In addition to examining energy, several other factors are important. First, maintenance and repair issues should be examined, including whether a lack of routine maintenance has resulted in poorly performing or inoperative refrigerators, and whether there is an adequate repair network with skilled technicians and spare parts. Second, one should look at the extent to which existing vaccine refrigerator problems appear to be resolvable through relatively simple measures such as providing recurrent-cost funding, providing needed spare parts and repair services, training operators and technicians, and converting kerosene refrigerators to operate on gas. Third, vaccine storage (volume) and ice-pack freezing requirements should be evaluated based on population size and distribution, immunization delivery methods, and logistical factors. (i.e. distance and travel time from a higher-level health center that supplies vaccines and transportation costs) Finally, for regions not covered by EPI or served by an insufficient number of clinics, one should ascertain if any regions have intentionally not been served by the immunization program or provided with clinics due, largely or in part, to an actual or anticipated inability to provide a reliable cold chain.

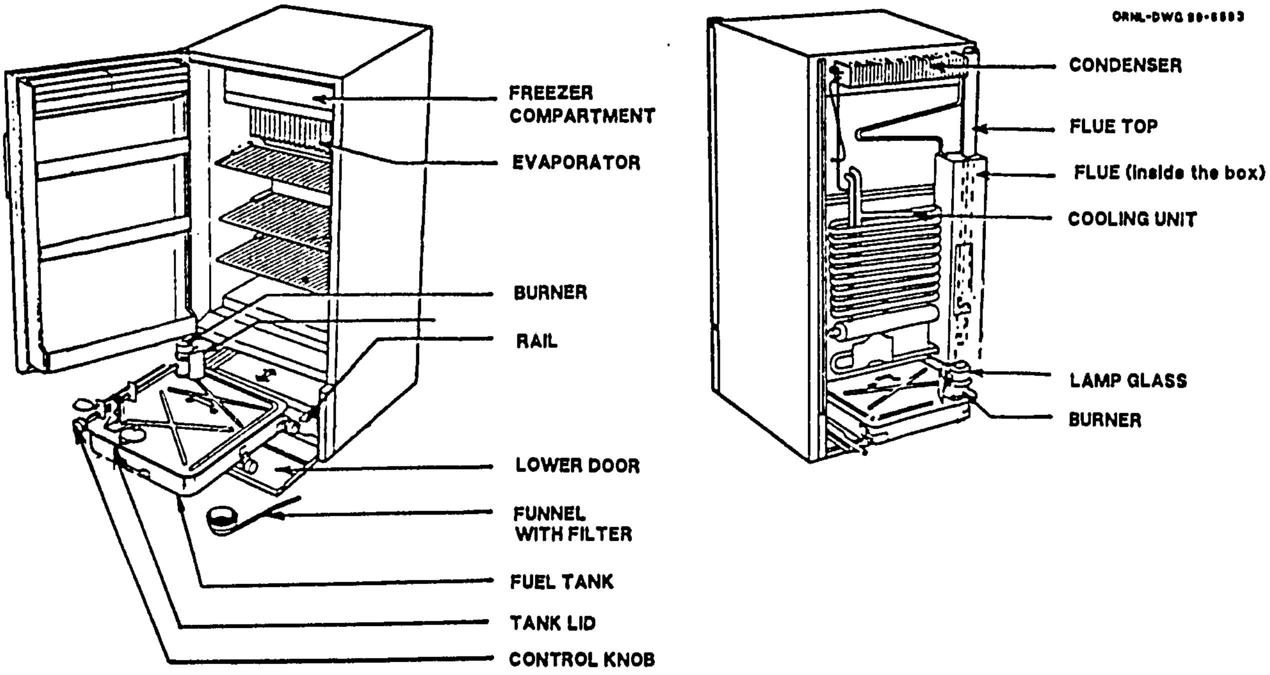
REFRIGERATION EQUIPMENT FACTORS

The refrigeration technologies commonly used for the cold chain are compression refrigeration and absorption refrigeration. Compression refrigerators are powered by electricity, usually from an electric grid, but sometimes from solar (PV) panels or a small diesel generator. Absorption refrigerators are normally powered by kerosene, bottled gas, or electricity. The operation mechanics of compression, absorption, and PV refrigeration technologies are described on the sidebar following this section. Figure V provides a visual description of the operating components of abosorption and vapor compression systemss. The performance and reliability of each of these refrigeration technologies are discussed below, along with the cost-effectiveness of various absorption and PV systems.

FIGURE V



ELECTRIC (AC or DC) COMPRESSION REFRIGERATOR



ABSORPTION (gas or kerosene) REFRIGERATOR

Compression Refrigeration

Vapor-compression refrigeration (more commonly known simply as compression refrigeration) is the technology employed in most household and commercial refrigerators and freezers. The compression refrigerators approved by WHO for EPI employ mechanical components similar to those of household refrigerators. They differ mainly in that they are more heavily insulated to achieve longer holdover times and reduce energy consumption through reduced cooling losses, and are much more precise in temperature control, in order to maintain safe vaccine-storage temperatures.

In areas with unreliable or intermittent electric service, ice-lining refrigerators can often provide safe vaccine storage. An ice-lining refrigerator is a type of compression refrigerator with a built-in ice (water or chemical) reservoir -- usually a network of vertical water-filled tubes lining the refrigerator or freezer compartment. When frozen, these tubes provide sufficient cold thermal mass (ice) to maintain safe refrigerator temperatures for up to 78 hours in the event of a power outage. Ice-lining refrigerators can maintain safe temperatures with as little as 8 hours of electricity a day, with some models requiring 12 hours.

Performance and Reliability

Properly designed and selected compression refrigerators and freezers are capable of maintaining the low temperatures necessary for storing vaccines (0 to 8°C or -25 to -15°C) and freezing ice packs (-10°C). These units are capable of responding quickly and automatically to temperature changes caused by external temperature variations or placement of warm materials in the refrigerator or freezer compartment.

Compression refrigerators are normally very reliable and durable and can be expected to last more than ten years, on average. The electric motor can be damaged by large voltage variations, which may be common in many developing countries' electric systems. Voltage stabilizing/protecting equipment to remedy this situation is available, at a cost of from $175 to over $400.

Absorption Refrigeration

Absorption refrigerators and freezers are the most common option for cold-chain use where electricity is not available. Absorption systems are powered by a heat source and do not have a motor or compressor; although they do not require electricity, electric resistance heat can be used as the heat source. Most absorption refrigerators use kerosene or bottled gas (propane or compressed natural gas); many can use both kerosene and electricity or both gas and electricity. Absorption freezers and refrigerators that use solar heat as the heat source are being developed, but these have not yet proven reliable or appropriate for vaccine storage.

Performance and reliability

Although gas and kerosene refrigerators employ the same basic refrigeration technology and the capital costs are similar, there are several important differences in performance and reliability.

Bottled gas has proved to be far superior to kerosene as a refrigerator fuel for the cold chain, as it burns much more cleanly, requires less burner adjustment and maintenance, and is not prone to contamination or dilution like kerosene. Current kerosene absorption systems are not thermostatically controlled and do not automatically respond to temperature changes. Bottled gas systems are available with thermostats. Thus, kerosene absorption systems require more operator intervention to maintain appropriate temperatures.

Kerosene refrigerators can perform effectively if the kerosene is of sufficiently pristine quality and if the operator adjusts and maintains the refrigerator adequately. The refrigerator temperature has to be monitored often; if it is too high or low, the burner flame must be adjusted. The tank must be refilled with kerosene at least weekly (in many cases daily), and the kerosene must be filtered by the operator. The burner must be cleaned weekly, and the flue and baffle cleaned weekly or whenever the burner has been smoking. If the kerosene is of high quality and if this maintenance schedule can be adhered to by trained, motivated staff, kerosene refrigerators can function effectively. This higher degree of reliance on trained, motivated staff is vital, and should be taken into account.

Kerosene fuel in remote regions is often of very low quality, however. Some developing countries import or refine less expensive low-grade kerosene, which is suitable for cooking and industrial use but smokes heavily in refrigerator burners. Kerosene is often contaminated in transport, because it is stored in containers previously used for diesel fuel, gasoline, and other substances. Contamination with water, either accidental or from intentional cutting, is also a significant problem. WHO/EPI testing has consistently found kerosene unacceptable for cold-chain use, because it is of too low quality to enable refrigerators to maintain required temperatures.

There are a variety of actions that can be taken to address kerosene quality problems. If bottled gas is reliably available, or can be made available, conversion of kerosene refrigerators to operate on gas is possible. Actions can also be taken to safeguard kerosene supplies from contamination, such as delivering kerosene in sealed containers to clinics along with other EPI supplies or installing large kerosene storage tanks at clinics, instead of relying on market supply in rural areas.

Large stores of kerosene could create an almost irresistible temptation to divert or misuse fuel, however; and if the national kerosene supply is low-grade to begin with, these delivery or storage actions will not solve the problem of kerosene quality. There have been extensive efforts by WHO/EPI and others to develop refrigerators that can utilize low-quality kerosene, but these efforts have not yet proven successful.

It is important to be aware of recent experience with kerosene refrigerators in the specific remote regions under consideration and to have information on kerosene quality when selecting vaccine refrigerators. This will help to avoid selection of inappropriate technology or of refrigerators especially intolerant of low-quality fuel.

Photovoltaic Refrigeration Systems

PV vaccine refrigeration is an alternative to kerosene- or gas-fueled absorption refrigeration for the vaccine cold chain in off-grid health centers. PV panels convert solar insolation (sunlight) to direct current (DC) electricity, which can be used to power a DC compression refrigerator. They contain no moving parts, are highly reliable, and can last over twenty years. PV-generated electricity is much more expensive than electricity from the grid. Where grid-supplied electricity is unavailable, however, PV is often the least-cost power source for low-power, high-value applications such as communications equipment (radio, telephone, and television repeaters and radios for remote facilities); navigation aids (aircraft beacons, buoys); lighting; and cathodic protection (application of low-power current for anticorrosion protection of bridges, pipelines, and towers). In these applications, PV replaces batteries, which must be replaced or recharged often, or diesel generators. In addition, the higher reliability and lower maintenance requirements of PV relative to batteries or diesel generators are often vital in unattended applications such as communications equipment and navigation aids.

Research and development of PV refrigeration for the vaccine cold chain has been supported over the past decade by a number of donor and technical organizations, in an effort to provide a more reliable refrigeration technology than kerosene absorption systems. Over one thousand PV cold-chain refrigerator systems have been installed worldwide.

Research, development, and demonstration of PV vaccine refrigeration were undertaken in the early to mid-1980s. Early demonstrations and field tests of prototypes achieved mixed results and contributed to a negative impression of PV vaccine refrigeration among many program officers and health officials. These programs involved first-generation systems, whose performance and reliability were surpassed as early as 1984; current (third-generation) systems are far superior. Also, as there were usually only one or two prototype systems per country in these early programs, it was not feasible to set up in-country service, repair, and parts networks. Major or minor system faults consequently often resulted in long periods of equipment downtime.

Performance and Reliability

Current PV refrigerator systems designed for vaccine cold-chain use and meeting WHO/EPI requirements perform well and are reliable, assuming careful equipment selection and maintenance. As a result of lessons learned from the above mentioned demonstrations, and as a result of advances and improvements in system components, newer systems have exhibited higher reliability. Many of the newer DC refrigerators used with PV are more energy efficient because of improved designs and reductions in size. The increased energy efficiency of refrigerators, which reduces the size of the PV array and battery bank needed, and significant reductions in the price of PV modules have led to system cost reductions. The experience gained through operational testing and demonstration has also led to improvements in system design that ease installation, operation, maintenance, and repair. The lessons learned from earlier programs have been incorporated into the training materials and programs of WHO/EPI, resulting in standardized training programs and recommendations for the effective introduction of PV refrigeration into a country's or region's cold chain.

One of the most important advantages of PV refrigerators over absorption systems is their ability to maintain much more precise temperature control. The temperature fluctuations common to many absorption systems can degrade vaccines, without any obvious sign of cold chain failure. This type of vaccine degradation can be much worse than the loss of vaccine potency due to spoilage, resulting in children being vaccinated but not immunized, a waste of resources, and defeating the objectives of the program.

PV refrigerator systems must be carefully selected, and system suppliers should meet WHO/EPI requirements. Installation programs must be carefully planned, and training provided for installers, technicians, and operators.

The most trouble-prone components of PV refrigeration systems to date have been batteries and charge controllers, which regulate the current flow between the PV modules and the battery. The charge controllers are the weakest link in the system. Many of the battery failures, especially those in recent years, have in fact been caused by poorly matched or malfunctioning charge controllers.

Several steps can be taken to avoid these difficulties. Careful matching of the charge controller to the specific battery being used is imperative. The most straightforward step one can take is to use industrial-grade deep-cycle batteries rather than the consumer-grade deep-cycle batteries that have been used in PV cold-chain systems. Industrial-grade batteries are much more robustly constructed and have much larger acid reservoirs. They are capable of withstanding many conditions and events--such as repeated deep discharges, overcharging, and various charge-controller-related problems--that would severely shorten the life of normal deep-discharge batteries. Because of the large acid or electrolyte reservoir, industrial-grade batteries have to be checked, and possibly topped off, only two or three times a year. Industrial-grade batteries should last well over ten years, and usually fail from sheer calendar life; consumer-grade deep-discharge batteries usually last four or five years in most applications, but can and often do fail much sooner in harsh tropical environments. Industrial-grade batteries cost 2 to 2-1/2 times more than consumer-grade deep-cycle batteries.

Batteries are normally rated on the basis of the number of discharge and recharge cycles they can withstand, at specific depths of discharge (DOD), described as a percentage of the battery's capacity. Consumer-grade deep-cycle batteries are rated at approximately 500 cycles at 80% DOD, 800 to 1000 cycles at 50% DOD, and 1200 to 1400 cycles at 20% DOD. Industrial-grade deep-cycle batteries are rated at 1500 to 1800 cycles at 80% DOD and over 4000 cycles at 20% DOD.

TECHNOLOGY DESCRIPTION

COMPRESSION REFRIGERATORS

Compression refrigerators operate as follows: Freon vapor is circulated through the system by a compressor driven by an electric motor. The Freon leaving the compressor passes through a condensing coil (a network of bent tubing on the back of most household refrigerators), condensing the Freon to a liquid state and releasing heat to the atmosphere. The Freon then passes through an expansion valve and into the evaporator coil located inside the refrigerator or freezer compartment. The liquid Freon expands to a vapor state, absorbing heat from the refrigerated compartment and its contents. The Freon then returns to the compressor, and the process is repeated. When the refrigerator reaches the appropriate temperature, a thermostat switches the compressor motor off.

ABSORPTION REFRIGERATORS

Although absorption refrigerators can use a variety of refrigerants, ammonia is used almost exclusively. The basic cooling process is similar to that of compression refrigerators: the refrigerant boils and evaporates at low temperature (-12°C for ammonia) in the evaporator coil, capturing and transferring heat from the refrigerator or freezer compartment.

Ammonia refrigerant is usually paired with water, which is the absorbent. The ammonia-water absorption cycle works as follows: Heat is supplied to an absorbent (NH_3+H_2O) in a boiler , releasing ammonia as it evaporates from the mixture. The ammonia gas enters a condensing coil, where heat is released and the ammonia is condensed to a liquid state. The liquid ammonia then enters the evaporator coil in the refrigerator or freezer compartment, where it evaporates, absorbing heat and cooling the contents of the refrigerator compartment. The ammonia next enters an absorber, where heat is dissipated into the atmosphere and the ammonia is absorbed back into the absorbent (water). The absorbent returns to the boiler.

PV REFRIGERATOR SYSTEMS

PV cells and modules (assemblies of cells) convert sunlight directly into electricity. They contain no moving parts, are highly reliable, and can last over twenty years. PV-generated electricity is much more expensive than electricity from the grid. Where grid-supplied electricity is unavailable, however, PV is often the least-cost power source for low-power, high-value applications.

Most compression refrigerators operate on alternating current (AC) of either 220 or 110 volts, the type of current supplied by an electric grid. Compression refrigerators are also available that operate on 12- or 24-volt DC, the form of electric current supplied by batteries. DC refrigerators for cold-chain use are very energy efficient, consuming between 0.3 and 1 kilowatt-hour per day, in order to minimize the capital cost of PV and other generator systems and the size and cost of the battery bank required. These refrigerators are suitable for off-grid use with PV, small diesel or gas generators, wind turbines, and other small power sources that charge battery banks.

COST COMPARISONS

In areas where on-grid electricity is reliably available, compression refrigeration is always the most cost-effective option. The relative cost-effectiveness of the different cold chain refrigeration technologies for off-grid locations is much more complicated to determine. Assessing cost-effectiveness is complicated by the need to address site- and region-specific factors including: fuel costs, refrigerator reliability and vaccine spoilage rates (those due solely to refrigerator malfunction) for kerosene or gas systems, maintenance and repair costs, and associated transport costs. There is also a relative lack of cost data for PV refrigeration systems operated as part of larger programs, as opposed to stand-alone demonstrations. It is only in the past several years that PV cold-chain programs have been undertaken involving significant numbers of systems within any one country.

Special efforts may have to be undertaken to obtain data on the performance of existing kerosene and gas refrigerators. EPI managers are often aware of the existence of cold-chain problems and attempt to address them, but do not attempt to quantify the severity of problems or the costs involved. Fuel availability and quality problems may simply be seen as one of the myriad problems to overcome in rural regions; if EPI managers assume there is no viable alternative to gas or kerosene refrigerators, attempting to quantify the extent and cost of problems may not seem worthwhile.

Absorption Systems

The capital cost of kerosene and gas refrigerator units ranges from approximately $700 to over $2000, depending on the model and on the number of units ordered. Capital cost of absorption equipment is generally higher than that of equivalent (size and function) compression equipment, but significantly lower than that capital cost cf complete PV systems.

Operating costs include fuel, maintenance, repair, and operator labor costs. Operating costs of gas and kerosene refrigerators are heavily dependent on local fuel costs, which vary considerably in developing countries, and on kerosene quality, which greatly affects the amount of maintenance required. Refrigerator size is also an important factor, as smaller refrigerators tend to consume less energy. Table II contains information on estimated energy consumption of various refrigerators, and Figure III portrays energy and other costs for a number of absorption refrigerators, at four different fuel prices.

Official kerosene prices are usually fairly low, ranging from $0.04 to $0.50 per liter. In urban and other easily served areas, kerosene and bottled gas may be available at, or close to, official prices. High transportation costs and scarcity often result in very high fuel costs in remote regions. For example, kerosene costs in rural Zaire run as high as $2 a liter, and bottled gas costs in Bolivia range from $2.50 a bottle (15-day supply) to $25 a bottle. These fuel costs would result in daily energy costs of $0.80 to $4 a day for kerosene, depending on the model, and up to $1.60 a day for gas. Although average fuel costs will be much lower than these, it should be kept in mind that prices may be high in certain regions, to the point where fuel cost per year may approach or exceed the capital cost of the refrigerator.

Use of low-quality kerosene in refrigerators results in a need for much more frequent adjustment, cleaning, and other maintenance. The additional labor cost and other costs incurred in such situations should be recognized. Low-quality fuel can also increase fuel consumption as soot deposits reduce efficiency.

It is important to be aware of high-fuel-price regions when making cold-chain procurement and planning decisions, to ensure that health centers in high-fuel-price regions are allocated additional funds to cover higher recurrent costs, and that local costs are taken into account in refrigerator technology selection decisions. Failure to provide funding for recurrent costs is one of the major problems hindering the cold chain in many countries. This is true even where fuel costs are not higher than average. Also, high fuel prices often reflect scarcity and occasional unavailability of fuel; where fuel prices are very high, reliability of supply should be investigated as a matter of course.

Photovoltaic Systems

To a certain extent, appropriate selection of PV systems depends on qualitative factors as much as on comparative costs. PV is most appropriate at sites where the following conditions are met: kerosene refrigerators are not performing well, and significant improvement does not appear possible because of logistical or fuel quality problems; bottled gas is not reliably available; and cold-box outreach is unfeasible or prohibitively expensive. In sites where cold-chain difficulties prevent or severely constrain the immunization program, use of PV systems may be the only feasible option that will allow the program to function effectively. Currently, it is in these types of situations that PV can contribute most to EPI--not in sites where current programs operate fairly well, and where PV systems could only slightly improve performance or reduce recurrent costs.

PV refrigerator system costs (not including shipping) for WHO-approved systems range from $3000 to $8000. The majority of systems appropriate for rural health clinics cost between $3400 and $5000. The systems costing between $6000 and $8000 are generally larger or less efficient systems and/or designed for areas with less insolation. Transportation and installation costs can add $500 to $1000. Continuing reductions in PV module costs should lead to reductions in system costs; lower-priced modules will also allow for the use of larger PV arrays and lower-capacity battery banks, reducing battery costs. PV refrigerator systems without freezers are available, at significant cost savings. Use of these systems in the vaccine cold chain is controversial, however. See the sidebar discussion of this issue.

PV systems do not use any fuel, or any electricity beyond what the PV panels produce. PV systems incur some of the recurrent costs that other systems do, such as maintenance and repair costs, and they also incur costs for battery replacement. Battery replacement costs can be significant, from $300 to $1000, depending on the size of the battery bank and type of batteries used. The frequency of battery replacement is also important. Batteries have expected lifetimes of five to ten years or more, depending on the type, but consumer-grade batteries (expected to last five years) often fail after two to three years as a result of the problems discussed above.

Figure III (shown earlier) contains a simple analysis of estimated life-cycle costs for several PV, kerosene, and gas vaccine refrigeration systems, at several different fuel prices. This analysis does not include consideration of relative benefits or system reliability, due to the great variability in reliability and performance of kerosene refrigerators from one region to another. At present, if refrigerator reliability and effectiveness is not taken into account, the life-cycle cost of PV refrigeration systems exceeds that of kerosene or gas refrigerators in the majority of cases. In regions with very high fuel prices, the cost gap between kerosene or gas and PV is narrow, and kerosene or gas systems are in some cases more expensive, on a cost per refrigerator basis. Note that the costs discussed here are cost per refrigerator, not cost per vaccination, nor any other measure of cost-effectiveness.

In some regions, as a result of fuel quality or availability problems or other factors, kerosene or gas refrigerators have proved to be unreliable. Inability to maintain safe temperatures, freeze ice packs, or simply keep refrigerators operating is quite common. These problems impact immunization programs significantly through vaccine spoilage or necessity to halt vaccination activities. To judge the relative cost-effectiveness of kerosene, gas and PV refrigerators, one must compare the relative life-cycle costs of PV and kerosene or gas refrigerators and then assess the benefits or program improvements possible with PV systems. If data on vaccine spoilage rates, percentage of time that vaccination activities were halted, and other factors can be obtained, it may be possible to develop estimates of refrigerator cost per vaccination or refrigerator cost per immunized child. Such cost estimates would allow for a direct comparison of cost-effectiveness of PV, kerosene, and gas refrigerators.

In practice, reliable data are often hard to come by, and a cruder assessment of cost-effectiveness may be necessary. This involves estimating refrigerator life-cycle costs, identifying where refrigerator problems have significantly hampered the immunization program, and judging where the additional investment in PV would improve the performance of the immunization program.

It is important to remember that refrigerator costs are usually a small portion of overall EPI costs. In instances where it appears PV refrigerators can improve program performance, any increase in refrigerator costs should be examined as a percentage of total EPI costs, including overhead, and not just compared to alternative refrigerator costs.

Refrigerator-Only PV Systems

Much of the energy consumed by vaccine refrigeration is due to ice-pack freezing, which imposes significantly higher energy demand. This higher demand has a major impact on PV system design and capital cost, due to the need for additional PV panels and batteries. Small PV vaccine refrigerators without freezers are available for approximately $1800 (FOB); the least expensive PV vaccine refrigerator/freezers cost approximately $3400-3500.

The appropriateness of these refrigerator-only systems for EPI use is a subject of contention. The significant capital cost savings possible with these systems has led to advocacy of their use in health clinics that do not have any ice-pack freezing requirements, perhaps due to reliance on a static immunization strategy with no outreach teams. The refrigerator-only systems do not meet WHO/EPI requirements, however, which specify ice-pack freezing capability, and are not listed in the Product Information Sheets. The WHO/EPI/Cold Chain Office is not in favor of their use, contending that health clinics will always have a need to transport vaccine for outreach immunization or shipment to other sites, and stressing that vaccines must always be packed with ice-packs when transported.

If it can be verified with certainty that a specific clinic has no ice-pack freezing requirements, a refrigerator-only PV system may well be the least-cost option. There will be few sites with no freezing requirements, however; and those that do exist are more likely to be operated by missions and other PVOs, and less likely to be under a ministry of health, or otherwise an integrated component of the EPI. The vital importance of verifying the lack of ice-pack freezing requirements cannot be underestimated.

FURTHER ASSISTANCE AND INFORMATION

A number of organizations, especially WHO produce materials and developing programs that are useful tools for health personnel who wish to investigate the suitability of PV refrigeration in their country programs, desire assistance in procuring or implementing PV refrigerators for the cold chain.

The World Health Organization is producing two documents: Solar Refrigerators for the Cold Chain: Pre-Feasibility Study; and Guidelines for Solar Cold Chain Installation and Infrastructure. The prefeasibility document will provide guidelines on how and when to select PV refrigeration, and it will provide guidance on program design if PV is selected, including budgeting, procurement, recruitment, and training. The guidelines on installation and infrastructure will be designed to compliment the first document; it will cover operational components of the solar refrigerator program, from a managerial rather than a technical point of view.

The A.I.D. Office of Energy (S&T/EY) initiated this investigation of vaccine refrigeration technologies in order to determine the current technical, operational, and economic status of PV vaccine refrigeration; and to do so in a technology unbiased manner that took EPI operational issues and other relevant factors into account. The Office of Energy is prepared to advise and assist USAID Missions and other offices with regard to PV cold chain information, technology selection, pre-feasibility studies, and project implementation. S&T/EY is interested in obtaining information on: current, planned, or contemplated PV cold chain activities; questions, problems, and resources needed. Comments, questions, and information can be sent directly to the Office of Energy, at the following address:

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The Office of Energy

The Agency for International Development's (A.I.D.) central Office of Energy plays an increasingly important role in providing innovative mechanisms and approaches for solving the growing energy and environmental crisis in A.I.D.-assisted countries. Situated in A.I.D.'s Bureau for Science and Technology, the Office helps to set energy policy direction for the Agency, while making its projects available to meet the generic and short-term needs of A.I.D.'s field offices in assisted countries.

Three problems drive the Office's programs: high rates of energy demand and economic growth accompanied by a lack of energy, especially power in rural areas; severe financial problems, including a lack of investment capital, especially in the electricity sector; and growing energy-related environmental threats, especially global climate change, acid rain, and urban air pollution.

To address these problems, the Office of Energy leverages financial resources of multilateral development banks such as the World Bank and the Inter-American Development Bank, the private sector, and bilateral donors to increase energy efficiency, expand energy supplies, and enhance the role of private power. The Office strategy involves implementing novel energy sector approaches through research, adaptation, and innovation. These approaches include improving power sector investment planning ("least-cost" planning) and encouraging the application of cleaner technologies that use both conventional fossil fuels and renewable energy sources. Promotion of greater private sector participation in the power sector and a wide-ranging training program also help to build the institutional infrastructure necessary to sustain cost-effective, reliable, and environmentally sound energy systems that are integral to broad-based economic growth.

Much of the Office strategy focuses on abatement of the increasingly severe environmental problems associated with the energy cycle, especially those involving fossil fuels, which pollute land and water during the extraction stage and cause atmospheric degradation--air pollution, acid deposition, and global CO_2 buildup--principally from power plant emissions during the conversion process. The Office's environmentally related assistance efforts have also anticipated and support recently enacted congressional legislation directing the Office and A.I.D. to undertake a "Global Warming Initiative" to mitigate the increasing contribution of key developing countries to greenhouse gas emissions. This strategy includes the following elements: expanding least-cost planning activities conducted in collaboration with the multilateral development banks to incorporate environmental concerns; increasing support for feasibility studies in renewable energy, end-use energy efficiency, and cleaner fossil energy technologies that focus on site-specific commercial applications; launching a multilateral global energy efficiency initiative; and enhancing training of host country nationals and A.I.D. staff in areas of energy that can help to reduce expected global warming and other environmental problems.

To pursue all of its activities, the Office of Energy implements the following seven projects: (1) The Energy Policy Development and Conservation Project (EPDAC); (2) The Biomass Energy Systems and Technology Project (BEST); (3) The Renewable Energy Applications and Training Project (REAT); (4) The Private Sector Energy Development Project (PSED); (5) The Energy Training Project (ETP); (6) The Conventional Energy Technical Assistance Project (CETA); and (7) its follow-on Energy Technology Innovation Project (ETIP).

Further information regarding the Office of Energy's projects and activities is available in our Program Plan and our Office Directory (both updated annually), which can be requested by using the following address:

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