PROGRAMMATIC ENVIRONMENTAL
ASSESSMENT OF THE DOE
SOLAR AGRICULTURAL AND INDUSTRIAL
PROCESS HEAT PROGRAM

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Chicago Operations and Regional Office
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Division of Solar Applications
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and Solar Applications
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EXECUTIVE SUMMARY

This document is a Programmatic Environmental Assessment (EA) of the Department of Energy's (DOE) Solar Agricultural and Industrial Process Heat (AIPH) Program. Its purpose is to evaluate the program's potential environmental impacts to ensure that environmental issues are considered at the earliest meaningful point in the decision-making process. The document is in keeping with both the letter and the spirit of the National Environmental Policy Act (NEPA) requirements.

DESCRIPTION OF PROGRAM AND TECHNOLOGY

The primary goal of the solar AIPH program is to substitute solar thermal energy for fossil fuel heat in agricultural and industrial process applications. The two specific objectives are:

- To develop and demonstrate agricultural solar energy technology which could provide significant amounts of heat energy required for:
 - grain drying
 - crop drying (peanuts, forage, and tobacco)
 - livestock shelter heating
 - food processing
 - greenhouse heating
- To apply state-of-the-art solar components and technology to industrial processes, to demonstrate their ability to supply industrial energy requirements, and to recommend a federal incentives program to promote the early commercialization of AIPH solar systems.

The DOE has established a series of research, development, and demonstration (RD&D) projects to meet these program goals. Each project will be conducted in three phases: design and analysis, fabrication and installation, and operation, data collection, and reporting. The USDA Science and Education Administration is conducting agricultural technology experiments at land grant colleges across the country. Promising

solar technologies will be tested further on private farms. The DOE fully funds industrial experiments that require less than 20,000 square feet of collector area; larger experiments share funding. Industrial experiments also are grouped by temperature requirements: low temperature ($<212^{\circ}\text{F}$), intermediate temperature (212° to 350°F), and high temperature ($>350^{\circ}\text{F}$).

The basic concept of solar process heat systems is the conversion of solar energy to thermal energy and the application of the thermal energy to agricultural or industrial processes. Typically, a solar collector is used to absorb incoming solar radiation and convert it to thermal energy. The thermal energy then heats a working fluid (liquid or air) as it passes through the collector. The heated working fluid then is transported to the point where it is applied to a process by direct contact or through heat exchangers. The heat also can be stored for use during periods when sunlight is unavailable. Auxiliary conventional energy sources often are employed as backup units during prolonged periods of insufficient sunlight.

OVERVIEW OF ENVIRONMENTAL AND SOCIAL/INSTITUTIONAL IMPACTS

Air Quality

Solar Collectors employing organic insulation materials may discharge toxic or corrosive fumes when they are overheated. This phenomenon is known as "outgassing". Outgassing can be reduced during operation by proper system design, careful selection and/or pretreatment of insulation materials, and proper equipment operation and maintenance. However, outgassing remains a problem in the event of fire.

Use of solar energy rather than fossil fuel energy will improve air quality. The use of fossil fuels in auxiliary equipment will continue to contribute to emissions. However, these emissions should be within the limits of the Clean Air Act.

Water Quality

Potentially toxic heat transfer fluids may be released into surface and groundwater systems and/or sewage treatment facilities as a result of leaks, spills, or backflow. Water contamination could be caused by working fluids (i.e., glycols, paraffinic hydrocarbons, or silicone oils) or various system additives used as corrosion inhibitors, dispersants, and biocides. Significant leakage and spillage are not expected during normal operations and could be controlled by proper maintenance procedures. Selection of least toxic fluids, fluid dilution, and adequate chemical/fluid management may reduce serious water quality impacts. In addition, regulatory laws, although not related specifically to solar system fluids, should control water degradation. If a significant accident did occur, isolation and cleanup activities would be required. Additional information on these procedures can be found in Section 3.2.

Ecosystems

Generally, concentrations of hazardous substances resulting from the use of solar energy will be low and will not affect animal and plant life. Leaks and spills should be minimal, and scattered over a number of isolated locations. In addition, proper system design, maintenance, and adequate chemical/fluid management will reduce serious impacts.

However, the release of toxic heat transfer fluids and storage media due to improper disposal or leakage and spillage could affect soil systems, local surface and groundwater systems, and local flora and fauna. The presence of these fluids may destroy microfauna vital to soil fertility, which is of particular concern in agricultural areas. Various bacteria, plants, and animals contaminated by the fluids could spread toxic substances through the food chain. Similarly, the release of heat-transfer liquids into local surface and groundwaters may prove harmful to aquatic life and other animals dependent on these water resources.

Health and Safety

The growth of bacteria and fungi in warm moist atmospheres such as rock-bed storage bins could produce allergic reactions in personnel. Insufficient heating of products may result in bacterial growth or product spoilage. Significant leaks of working fluids can contaminate products. While these factors may pose a hazard, operating experience to date has shown that their probability is low. Should they arise, careful maintenance procedures and fumigation with fungicides and bactericides would mitigate the problem. Pest control in integrated greenhouse/rural residences is a problem which needs further attention. Commercial strength pesticides may prove hazardous to humans, but chemicals which are safe for household use have not controlled the pests effectively. Currently, alternate mechanical and biological methods of pest control are being tested.

Safety impacts of solar AIPH systems may be difficult to control. Accidents can occur during installation, maintenance, and operation. Some components are flammable and may be potential fire hazards. Good design practice, safety measures, and user education can alleviate many of these problems.

Land Use

Solar AIPH applications can require large tracts of land. Farming and grazing land may be converted for agricultural applications. Land use impacts may be greater in the industrial sectors where applications may require solar industrial parks. These requirements could affect land values and zoning plans significantly. Mounting collectors on rooftops will reduce land use requirements.

Esthetics

The visual effects and noise levels of solar AIPH systems will vary. Systems will be adapted to local visual tastes. Solar systems are not

expected to contribute significantly to ambient noise levels for agricultural or industrial applications.

Social and Institutional Impacts

Widespread deployment of solar energy systems for agricultural and industrial process heat may affect the existing social/ institutional framework significantly. Conflicts may arise with existing laws and regulations. Solar access regulations, zoning and land use controls, and government and/or industry standards to accommodate solar AIPH use may be required to prevent conflicts and protect against fraud. The need for auxiliary power may create land management problems for utility companies. Increased tax incentives, insurance coverage, and loan money may be required. Most social and institutional impacts result from the technology's novelty. It is expected that through education and consumer acceptance and use, these impacts will be reduced significantly.

Secondary Impacts

Increased use of copper, glass, and aluminum in solar AIPH systems may impact resources and manufacturers negatively. However, improved technology and use of recycled material should offset the negative impact.

Unavoidable and Long-term Environmental Concerns

Solar process heat systems can be essentially non-polluting energy sources. As evidenced in the earlier discussions of environmental, health, and safety impacts, there appear to be no significant adverse impacts which are unavoidable.

Alternatives

The current DOE Solar AIPH program emphasizes industrial applications. The effects of several other approaches were considered, including:

- Eliminating Federal involvement in Solar AIPH work
- Accelerating the DOE Solar AIPH program
- Delaying the DOE Solar AIPH program
- Switching program emphasis to agricultural applications.

Elimination of Federal involvement is in direct conflict with Congressional mandates. Also, the loss of Federal funds could handicap further research and development. Acceleration of the current program could increase energy savings but also might encourage use of inferior products and leave environmental issues unresolved. Delaying the current program could improve product quality and environmental impacts but would postpone energy savings. The primary environmental impacts of solar AIPH programs are in the industrial area. Emphasis on agricultural applications may not address all industrially related impacts adequately.

1. PROPOSED ACTION

1.1 THE DEPARTMENT OF ENERGY PROGRAM FOR SOLAR AGRICULTURAL AND INDUSTRIAL PROCESS HEAT

Introduction

Federal legislation has enabled the Department of Energy (DOE) to organize the Solar Agricultural and Industrial Process Heat (AIPH) program. The overall goal of the program is to direct, fund, and manage projects applying the direct conversion of solar energy to useful output for agricultural and industrial processes. In addition, DOE's AIPH program provides the means for the private sector to undertake government-funded experiments and cost-shared prototype systems to demonstrate the technical and commercial viability of such systems at less risk than if all the costs of research, development, and demonstration (RD&D) had to be provided by private capital. This section describes the DOE solar AIPH program plan, including:

- Enabling legislation
- Program objectives and strategies
- Program management
- Proposed FY 1979-FY 1984 program schedule
- Commercialization

1.1.1 Enabling Legislation

Legislative authority for the Department of Energy (DOE) Solar Agricultural and Industrial Process Heat (AIPH) Program is found in five Congressional acts:

- The Solar Heating and Cooling Demonstration Act of 1974 (PL 93-409)

- The Solar Energy Research, Development, and Demonstration Act of 1974 (PL 93-473)
- The Federal Nonnuclear Energy Research and Development Act of 1974 (PL 93-577)
- The Energy Reorganization Act of 1974 (PL 93-438) and
- The Department of Energy Organization Act (PL 95-91)

The DOE is mandated to conduct technical, economic, social, and environmental projects relevant to solar process heat systems and to demonstrate the commercial applicability of such systems in agricultural and industrial processes.

1.1.2 Program Objectives and Strategy

The primary goal of the solar AIPH program is to substitute solar thermal energy for fossil fuel heat in agricultural and industrial process applications. The two specific objectives are:

- To develop and demonstrate agricultural solar energy technology which could provide significant amounts of heat energy required for:
 - grain drying
 - crop drying (peanuts, forage, and tobacco)
 - livestock shelter heating
 - food processing
 - greenhouse heating
- To apply state-of-the-art solar components and technology to industrial processes, to demonstrate their ability to supply industrial energy requirements, and to recommend a federal incentive program to promote the early commercialization of AIPH solar system.

The DOE has structured the Solar AIPH Program to attract potential users of solar energy systems. The agricultural and industrial sectors can undertake DOE-funded experiments in solar process heat and can share in the costs of larger prototype systems to demonstrate the technical and

commercial viability of solar process heat systems at less risk than if all the RD&D costs were met with private capital. DOE's sponsorship of experiments and prototype systems also aims to provide incentives for the commercial production of necessary system components. DOE's participation should stimulate the growth of solar applications in agriculture and industry at a rate beyond normal industrial and commercial expectations.

Once the DOE experiments and prototype systems have demonstrated that solar process heat systems are competitive economically with fossil fuel systems, the private sector gradually should assume the initiative for the solarized systems. The Federal role will diminish as the transition from prototype systems to full-scale systems occurs.

1.1.3 Program Management

The AIPH Program is managed by the AIPH Branch of the Office of the Assistant Secretary for Conservation and Solar Applications, DOE Division of Solar Applications. The AIPH Branch works with DOE laboratories and private industry to develop solar energy applications for industrial processes.

DOE has delegated management of the program's agricultural aspects to the United States Department of Agriculture (USDA), but continues to monitor its progress closely. The USDA, through the Science and Education Administration (SEA, formerly the Agricultural Research Service), works with State Agricultural Experiment Stations, SEA Laboratories, universities, and industry in conducting experiments and designing prototype systems for various agricultural applications of solar energy.

1.1.4 Proposed FY 1979-FY 1984 Program

The AIPH program is an applications program in that it applies established technologies to process heat systems. The general strategy of

the program is to develop experimental projects followed by larger scale prototype systems. To expedite the commercialization process, research and demonstration projects are scheduled in overlapping cycles, so operating prototype systems may benefit from ongoing experimentation and technology developments.

1.1.4.1 Agricultural Applications

Agricultural solar research began in 1974 at land grant colleges across the country. There are approximately fifty active projects within the program which are distributed among the five agricultural applications: crop drying, grain drying, greenhouse heating, livestock shelter heating, and food processing. Activities under each application are broken down into yearly cycles of proposal solicitation and contract awards. As a result, 15 to 20 percent of the projects are new to the program each year. In the commercial (or demonstration) phase, the technology is transferred from the land grant colleges to private farms. USDA manages the program, and DOE monitors activities and provides funding for both research and demonstration.

Each on-farm application is scheduled to complete six RD&D cycles. A project report will be submitted at the end of the commercial phase. Table 1-1 shows current status and scheduling for agricultural applications.

1.1.4.2 Industrial Applications

Industrial applications are divided into two types: experimental and prototype. Experimental systems, using less than 20,000 square feet of solar collectors, are funded fully by DOE. Within this program area, experiments are grouped by process heat temperature requirements: low temperature ($<212^{\circ}\text{F}$), intermediate temperature (212° to 350°F), and high temperature (350° to 550°F). The application of the technology is experimental in the high temperature group; the system itself is composed of state-of-the-art components.

TABLE 1-1 AGRICULTURE PROCESS HEAT PROGRAM

Phase I: Research at Land Grant Universities

Phase II: On-Farm Prototype Demonstrations

		Cycle Completed in FY						
		78	79	80	81	82	83	84
<u>Phase 1</u>								
(3)*	{ Grain drying	4	5	6			Individual	
	{ Crop drying	3	4	5	6		Application	
(1)	Greenhouse heating	3	4	5	6		Reports	
(2)	Livestock shelter heating	3	4	5	6			
(5)	Food processing	2	3	4	5	6		
<u>Phase 2</u>								
(1)	Greenhouse heating	C	O				Reports	
(2)	Livestock shelter heating	D	C	O				
(3)	Grain/crop drying		D	C	O			
(4)	Multi-use applications			D	C	O		
(5)	Food processing				D	C	O	

D = Design

C = Construction

O = Operation

*Order of expected commercial operation.

Source: DOE Solar Agricultural and Industrial Process Heat Branch. October 12, 1978. Personal Communication.

Each project within the program is carried out in three phases:

- Design and analysis
- Fabrication, installation, and checkout
- Operation, data collection, and reporting

Currently, there are seven low temperature projects and four intermediate temperature projects ongoing in either the construction or operation stages. Seven new contracts for the design of high temperature systems recently were awarded.

Prototype (or demonstration) systems, requiring less than 50,000 square feet of solar collectors, are divided into two groups using the boiling point of water (212°F) as the separation point. For these demonstrations, the costs are shared by DOE and the system user. No demonstration projects currently are ongoing; however, in early FY 79, two general RFP's were issued, and funds were appropriated to begin system design and analysis (see Table 1-2).

This work is expected to continue during FY 79-84. New programs incorporating large scale demonstrations of mass production collectors (100,000 to 250,000 ft²), advanced high temperature systems (>550°F), and hybrid system applications are planned for FY 79-84. However, the development of these programs is uncertain, as the design, construction, and operational phases are not funded at this time. If funding becomes available, the industrial process heat program also will work with the Solar Thermal Power Systems program on the feasibility of using concentrating collectors to generate steam for enhanced oil recovery.

1.1.5 Commercialization

The role of the Federal government is expected to diminish as success in specific agricultural and industrial process heat applications creates

TABLE 1-2 INDUSTRIAL PROCESS HEAT PROGRAM

Phase 1: Experimental ($< 20,000 \text{ Ft}^2$ collectors, fully funded)Phase 2: Prototype demonstrations ($< 50,000 \text{ Ft}^2$ collectors, shared funding)

	Begun in FY						
	78	79	80	81	82	83	84
<u>Phase 1</u>							
Low temperature (<212°F)	C ⁽⁶⁾	O ⁽⁶⁾ /C ⁽¹⁾	O ⁽¹⁾				
Intermediate temperature (<350°F)	D ⁽³⁾ /C ⁽¹⁾	C ⁽³⁾ /O ⁽¹⁾	O ⁽³⁾				
High temperature (<550°F)		D ⁽⁷⁾	C ⁽⁷⁾	O ⁽⁷⁾			
<u>Phase 2</u>							
Low temperature (<212°F)		D ⁽⁶⁾	C ⁽⁵⁾	O ⁽⁵⁾			
Intermediate/high temperatures (≥212°F)		D ⁽⁶⁾	C ⁽⁵⁾	O ⁽⁵⁾			

D = Design

C = Construction

O = Operation

() = Number of projects

Source: DOE Solar Agricultural and Industrial Process Heat Branch, October 12, 1978.

intensified participation by the private sector. The ultimate goal of the AIPH program is to bring solar process heat systems to the open marketplace. Then normal market forces and competitive market conditions will take control of the growth and distribution of the technology.

1.2 DESCRIPTION OF SOLAR PROCESS HEAT TECHNOLOGY

1.2.1 Basic Concepts

The basic concept behind solar AIPH systems is the conversion of solar radiative energy into thermal energy, and the application of this thermal energy to the heating of products or commodities. Figure 1-1 shows the essential components of solar process heat systems. The solar collector absorbs incoming solar radiation and converts it to thermal energy. The thermal energy heats a working fluid which passes through the collector. The heated working fluid is transported for use in process heating either directly or through heat exchangers. The heat-transfer fluid also can be routed through a storage system containing some heat-retaining material such as rocks or water, where thermal energy can be held for use when no sunlight is available. An auxiliary heat source such as a fuel-fired furnace or boiler may be required to supplement the storage system during prolonged periods of insufficient sunlight.

Technologies for solar process heating systems vary with the specific agricultural or industrial application. Several solar collectors, heat transfer media, and storage systems are described in the following sections. Also, five solar AIPH systems are described to show how the components work together.

1.2.2 Solar Collectors

Agricultural and industrial collector designs range from simple greenhouses that heat air fifty or sixty degrees to high-performance concen-

FIGURE 1-1 BASIC COMPONENTS OF SOLAR PROCESS HEATING SYSTEM

trating collectors that generate 600°F process steam. The desired process temperature, available space, and component cost are factors in collector selection. The following are the major collector designs in use today; more complete descriptions are included in Appendix A.

- Greenhouses are simple collectors that heat inside air up to 150°F.
- Solar ponds operate as horizontal collectors, with water as the heat-collecting medium. Shallow ponds (less than one foot deep) are most common; these can achieve water temperatures up to 150°F.
- Flat plate collectors employ a flat metallic absorption plate and either air or water as the working fluid. Glass or clear plastic cover sheets are used to reduce heat loss. Typical exit temperatures for the working fluid range from 150 to 200°F.
- Evacuated tube collectors use glass tubes arranged in parallel rows over a reflective metal backing sheet. Each tube contains a smaller absorber tube through which the working fluid flows, the space between the two tubes being evacuated to decrease convective and conductive heat losses from the working fluid. Working fluid temperatures of 140 to 340°F are achieved in present designs.
- Parabolic trough collectors concentrate sunlight by means of a reflective parabolic surface onto a small absorber tube through which the heat-transfer fluid flows. Tracking mechanisms usually are built into the collector to keep sunlight focused precisely on the absorber tube. Design temperatures range from 175 to 660°F.

Several other concentrating collector designs are being developed for high-temperature applications, all of which employ single- or double-axis tracking systems. Maximum working fluid temperatures achieved by these collectors range up to 1100°F.

1.2.3 Heat Transfer Media and Thermal Storage Systems

Transfer media and storage systems are discussed together because in many solar systems one fluid performs both functions. There are two common approaches to storing thermal energy generated by solar collectors:

- Sensible-heat storage: A liquid or solid that does not change physical state during heating will contain thermal energy in proportion to the material's temperature. Sensible-heat storage simply involves heating a material through contact with a hotter heat-transfer fluid, and holding the heat in that material until it is removed to the process.
- Latent-Heat storage: In the process of melting, materials absorb thermal energy without exhibiting a change in temperature. This absorbed energy (the latent heat of fusion) is retained in the material until the opposite phase change occurs (from liquid to solid), during which the latent heat is released as sensible heat.

1.2.3.1 Sensible heat storage

Water is the most common transfer and storage medium for low and intermediate temperature liquid heat-transfer systems; rock, most common in air heat-transfer systems. At temperatures above 390°F, solid storage media such as rocks, steel bars, or refractory bricks can be used in conjunction with a heat-transfer fluid such as steam, various hydrocarbon oils (e.g., Therminol), and liquid salt compounds (e.g., HITEC).

1.2.3.2 Latent Heat Storage

A variety of phase-change materials have been examined for possible use in low-temperature storage systems. These materials generally are either inorganic salt compounds or complex organic chemicals. Inorganic salt compounds, due to their high latent heat of fusion, have the potential for storing up to 100 times as much thermal energy as sensible-heat water systems. Several organic compounds, such as paraffin, acetamide, naphthalene and propionanamide, offer similarly high capacities for latent heat storage. Latent heat storage for high-temperature systems may involve inorganic compounds such as sodium hydroxide and potassium nitrite/sodium nitrite, or eutectic salts such as lithium fluoride, sodium fluoride, and magnesium fluoride, all of which have melting points above 300°C (570°F).

In storage systems using eutectic salts or organics, the storage medium is encapsulated in small plastic or metal containers and arranged in a storage tank through which the heat-transfer fluid flows to exchange heat with the storage material. The storage material is chosen so that the temperature of the heat-transfer fluid returning from the collectors during operation will be sufficient to melt the storage compound.

Latent heat storage generally is not found in existing AIPH systems, due to economics and the relative complexity of latent storage systems. Since latent materials can store much greater amounts of heat per unit volume than sensible materials, though, latent heat storage may find future use in large AIPH systems where there are constraints on the space available for storage tanks.

1.2.4 Solar Systems for Process Heat

To illustrate how the various components of solar process heat systems work together, schematic diagrams for five generalized systems, representative of a broad range of agricultural and industrial systems, are included in this section along with a brief description of each. In existing AIPH applications, the fraction of process energy supplied by solar typically is small, due to economic constraints on experimental AIPH systems. The storage component often is eliminated altogether, particularly in systems where loads are fairly constant and the solar contribution is relatively small, thus reducing cost, space requirements, and complexity of the system. Each of the following systems can be designed without storage, but storage components have been included to show how they are integrated into the systems.

1.2.4.1 System to Provide Process Hot Water

Figure 1-2 shows the basic design for a once-through hot water system. The system uses potable water as the thermal storage medium and heat-

FIGURE 1-2 SOLAR SYSTEM TO PROVIDE PROCESS HOT WATER

transfer fluid. During normal operation, water is drawn from storage (through valve 2) or from city water lines (through valve 1), and pumped through the collector, where it absorbs solar heat. The hot water flows back to the storage tank, and then is pumped as needed to the process through valve 4. The auxiliary heating unit boosts water temperature when solar collection is insufficient.

1.2.4.2 Process Heated Liquids Using Indirect Heat Exchange

Figure 1-3 shows a solar system that heats or preheats a process liquid which becomes part of the final product. This system differs from the preceeding one in that the heat-transfer fluid used between collectors and storage is kept separate from the process liquid: the process liquid often is something other than water, and is unsuitable for use as a collector heat-transfer fluid or storage medium. A heat exchanger in the storage tank transfers heat from the collector fluid to the process liquid.

1.2.4.3 Process Hot Air

Figure 1-4 shows an air-based solar system that heats outside air for dehydration, resin curing, or any operation which requires large amounts of heated outside air. This system operates in several modes. Outside air can be heated and sent directly to the process, drawn from storage and sent to the process, or heated and sent into storage. The various modes are chosen by opening and closing different combinations of vent dampers, as shown in the diagram.

1.2.4.4 Indirect Heating of Process Gas

Figure 1-5 shows a liquid-based solar system that can be used to heat process gas (sometimes other than normal air) beyond the temperatures attainable in the preceding system. A heat exchanger located in the process gas duct transfers heat from collector fluid to process gas.

FIGURE 1-3 SOLAR SYSTEM TO PROVIDE PROCESS HEATED LIQUIDS
USING INDIRECT HEAT EXCHANGE

FIGURE 1-4 SOLAR SYSTEM TO PROVIDE PROCESS HOT AIR

FIGURE 1-5 SOLAR SYSTEM TO HEAT PROCESS GAS BY INDIRECT HEAT EXCHANGE

Applications include processes where heated gas is used as a reactant, as in petroleum refining, and where process gas is used to dry or cure a product.

1.2.4.5 Process Steam

Figure 1-6 shows a solar system that generates steam by heating a working fluid in concentrating collectors and running it through a simple boiler. When the heat transfer fluid is not hot enough to evaporate all the boiler feedwater (labeled "condensate return"), an auxiliary fuel-fired boiler handles the difference.

FIGURE 1-6 SOLAR SYSTEM TO PROVIDE PROCESS STEAM

2. THE EXISTING ENVIRONMENT

2.1 INTRODUCTION

The objective of this section is to provide an understanding of the existing social/environmental structure so that changes resulting from the AIPH program may be observed and assessed. The term "existing environment" is interpreted broadly, to include an aggregate of factors (geographical regions, industry characteristics, etc.) that may affect or be affected by AIPH systems deployment. This assessment is confined to factors relevant to the AIPH program as a whole, or to basic components of it (such as agricultural vs industrial elements) and, particularly, to areas that may be especially significant in assessing cumulative program-wide impacts. A brief summary of the current DOE solar AIPH program efforts as well as a general description of existing projects is provided in the previous section.

This chapter is divided into three sections. The first identifies the geographical regions of solar agricultural process heat systems deployment, and briefly describes current process methods and fuel use patterns. The second section considers these same factors for industrial systems. The third section discusses relevant existing social/institutional factors, including characteristics of the solar industries.

2.2 THE AGRICULTURAL ENVIRONMENT

2.2.1 Grain Drying

Grain must have a low moisture content in order to avoid spoilage during storage and shipment. In the United States, five types of grain predominate: wheat, soybean, grain sorghum, corn, and rice. The first three

generally are permitted to dry on the stalk before harvest, thus they require little or no artificial drying before storage. Corn and rice, however, are harvested with high moisture contents and require substantial amounts of energy for drying.

Corn is grown in almost every part of the country and employs more acreage than any other grain crop in the nation. The greatest concentrations of corn production are in the North Central region where eight States account for over 70 percent of the country's total production. (See Figure 2-1)

Corn presently is dried by forced hot air heaters (batch, bin, or continuous flow). The predominant fuel is LP gas. The majority of the remaining energy needs are supplied by natural gas (USDA, 1974). The Council for Agricultural Science and Technology estimates that corn drying consumes energy at the rate of approximately 5.6×10^{13} Btu/yr. This is the equivalent of 609 million gallons of LP gas/year.

The South Central States and California are the leaders in rice production. (See Figure 2-2) Like corn, rice is dried by forced hot air heaters using both natural and LP gas. Energy consumption is estimated at 2.30×10^{12} Btu/yr, based on the 1970 crop (Lukes, 1974).

2.2.2 Crop Drying

Drying is important in the production of tobacco, peanuts, and various forage crops. Several varieties of tobacco are grown in the United States in several different geographical areas. However, overall tobacco production is concentrated heavily in the Southeast (see Figure 2-3); six States account for more than 90 percent of the total harvested acreage and production (Bender et al., 1976).

FIGURE 2-1

Corn Harvested for Grain: 1974
(All Farms—County Unit Basis)

FIGURE 2-2

Rice Harvested: 1974
(Farms With Sales of \$2,500 and Over—County Unit Basis)

Most of the tobacco is either air or flue cured. Air curing generally refers to curing under natural conditions, although supplemental heat may be required during periods of unfavorable weather. Flue curing is used more commonly. In flue curing, heat is used during the entire curing period. According to estimates by the Council for Agricultural Science and Technology, flue curing requires 32×10^{12} Btu every year which is the equivalent of 348×10^6 gallons of LP gas (Bender et al., 1976).

Peanut production is concentrated in the Southeast and South Central regions (see Figure 2-4); six States account for over 90 percent of both acreage and production (U.S. Bureau of the Census, 1978). Currently, natural and LP gas are used widely in peanut drying processes. The 1.7 million ton peanut crop of 1973 required approximately 6.3×10^{11} Btu's for drying (Bender et al., 1976). If the harvesting of green peanuts becomes an accepted practice, as some trends indicate, then the energy requirement will increase substantially.

"Forage" is a term used to classify several different crops used for livestock feed. As a result, forage cannot be classified regionally. Forage crops are found in almost every part of the country.

2.2.3 Livestock Shelter Heating

Heated shelters are necessary to ensure the health and growth of broilers (i.e., chickens 8 to 10 weeks old). Although every State is involved in some broiler production, the Southeast is the major area of concentration. (See Figure 2-5) The five largest producers account for approximately 60 percent of the total production. LP gas is the predominant source of fuel for broiler housing (especially for heating). Some regions rely on fuel oil, natural gas, and electricity to provide lighting and ventilation (Brewer and Dunn, 1975). Annual LP gas requirements for broiler production are estimated at 135 million gallons (12×10^{12} Btu).

FIGURE 2-3

Tobacco Harvested: 1974
(All Farms—County Unit Basis)

FIGURE 2-4

Peanuts Harvested for Nuts: 1974
(All Farms—County Unit Basis)

FIGURE 2-5

Concentrations of hog production coincide with the primary corn producing area because of the availability of feed. (See Figure 2-6) Efficient hog production depends strongly on housing, equipment, and management methods that increase baby pig survival. Oil- and gas-fired, forced-air, and electric radiants have been used to supply heat. Estimates of these supplemental heat requirements indicate an annual use of approximately 9×10^{11} Btu which is equivalent to about ten million gallons of propane or 2.6×10^8 kWh of electric energy (Bender et al., 1976).

2.2.4 Food Processing

Agricultural food processing refers to farm activities such as drying and dehydration of fruits and vegetables, milk processing, etc. Such activities vary widely and take place throughout the nation.

2.3 THE INDUSTRIAL ENVIRONMENT

Solar energy systems can be used in a number of industries to provide process heat. The industries listed below were selected on the basis of their process heat requirements (in terms of overall energy demand and process temperature requirements), their current fuel consumption, and the potential benefit of using solar process heat technology to meet these needs (Battelle, 1977 and Intertechnology Corporation, 1977). Currently, the process heat requirements of these industries are met by coal, petroleum, natural gas, LP gas, and nuclear energy. The industries are grouped into the major Standard Industrial Classifications (SIC's):

- Food and kindred products
- Textile mill products
- Lumber and wood products
- Paper and allied products
- Chemicals and allied products
- Petroleum refining and related industries
- Stone, clay, and glass products
- Primary metals industries

FIGURE 2-6

Hogs and Pigs—Inventory: 1974
(All Farms—County Unit Basis)

The industry locations are presented in Figure 2-7. These were determined through analysis of detailed production and energy consumption figures for each SIC (U.S. Bureau of the Census, 1972).

2.3.1 Food and Kindred Products

In the food industry, solar energy systems can be used for washing, drying, cooking, and dehydration processes. California is the leading producer of food and kindred products. Food processing activity is concentrated in the North Central and Mid-Atlantic regions of the country.

2.3.2 Textile Mill Products

The textile industry offers potential for solar process heat use in preparing, dyeing, and drying fabrics. Heat requirements for mercerizing and finishing also can be met, in part, by solar energy systems. The South Atlantic States, New York, and Pennsylvania are the leaders in textile production.

2.3.3 Lumber and Wood Products

Solar process heat can be used for log conditioning, kiln drying, and hot pressing of fiberboard products. The majority of the activity in this industry occurs in the three Pacific Coast States. Significant production also occurs in the South Central and South Atlantic regions.

2.3.4 Paper and Allied Products

In the paper products industry, solar process heat can be used in pulping, bleaching, and evaporation processes. The industry is widespread, with concentrations in the Pacific, East North Central, Mid-Atlantic, and South Atlantic regions of the country.

FIGURE 2-7

MAJOR PRODUCTION AREAS

FOOD AND KINDRED PRODUCTS

TEXTILE AND MILL PRODUCTS

LUMBER AND WOOD PRODUCTS

PAPER AND ALLIED PRODUCTS

FIGURE 2-7 (continued)

MAJOR PRODUCTION AREAS

CHEMICALS AND ALLIED PRODUCTS

PETROLEUM REFINING AND
RELATED INDUSTRIES

STONE, CLAY, AND GLASS PRODUCTS

PRIMARY METALS INDUSTRIES

2.3.5 Chemicals and Allied Products

The chemical industry requires high-temperature process heat for drying, leaching, distillation, and purification processes. The highest concentrations of industrial activity are in the West South Central, East North Central, and Mid-Atlantic regions.

2.3.6 Petroleum Refining and Related Industries

The petroleum industries have the highest process heat requirements of all industries considered here. Solar energy systems may be used in refining, extraction (enhanced oil recovery), and storage heating operations. These industries are concentrated in four areas of the country: West South Central, East North Central, Mid-Atlantic, and California.

2.3.7 Stone, Clay, and Glass Products

Solar process heat can be used to cure concrete blocks and brick products. Solar energy systems also can provide heat for washing, rinsing, laminating, and decorating processes for various glass products. California and Texas are among the leaders in stone, clay, and glass production; however, the largest concentrations of activity are found in the East North Central and Mid-Atlantic regions.

2.3.8 Primary Metals Industries

Calcining, smelting, and digestion procedures require large quantities of process heat which may be supplied, in part, by solar heating systems. The primary metal industries are concentrated in the East North Central and Mid-Atlantic regions of the country.

2.4 SOCIAL/INSTITUTIONAL FACTORS

2.4.1 Solar AIPH Users

Solar energy users will vary widely in organizational type and size. In general, low temperature applications will be most common for small agricultural and industrial operations; higher-temperature applications are more suited to larger industrial groups.

This analysis will not characterize user groups in detail because the groups are so varied. However, the environmental impact analysis (Section 3.1.7) will identify special concerns of various user groups where applicable.

2.4.2 The Solar Energy Industry

New technology industries usually follow a pattern of development. The first stage is characterized by fragmentation and diversity: a number of small companies manufacture a wide variety of systems. The survival and acceptance of the technology are emphasized in this stage. In the second stage, technology, production, and marketing become more sophisticated as the industry develops an identity and trade associations are organized. During this stage, concern for product quality leads to the development of uniform standards. This stage is followed by a period in which competition, experience, and continued development combine to eliminate inferior products (Energy and Environmental Analysis, 1978).

Current development of the solar industry combines elements of the first two stages of industry growth. A trade organization, the Solar Energy Industries Association (SEIA), has been in operation for several years. SEIA has 600 members, of which 150 are manufacturers. However, there is great fragmentation and diversity of products, services, and data, and little communication on technical matters within the industry.

Eighty-five percent of the solar system manufacturers are small businesses. In 1978, 3.5 million square feet of collectors were sold. Due to the variable nature of solar applications, particularly in terms of size and application, the actual number of units sold is unknown. However, the majority of applications were for hot water and swimming pool heating.*

The sophistication of manufacturing and marketing systems also varies greatly. Some farmers devise their own low-cost solar systems from readily available materials; industrial applications are dependent on manufactured systems. Consensus standards are being developed. The industry recognizes that standards are essential for market acceptance, comparison between systems, and for elimination of substandard equipment and fraudulent or misleading advertising which may damage the public image of the solar energy industry.

Several solar industry members were contacted concerning the future of the industry. They offered the following opinions:

- The promotion and enactment of government incentives (the National Energy Conservation Policy Act of 1978 and the Energy Tax Act of 1978) are likely to promote widespread application and acceptance of solar technology.
- The expansion of the solar energy industry will prompt the development of consensus standards, standardized testing and accreditation systems.
- The solar industry will experience a "weeding out" period beginning with the availability of industry standards.
- Manufacturing and installation/maintenance may become two distinct sectors, since installation/maintenance problems are site-specific rather than general manufacturing concerns.
- Trends in manufacturing include mass production and modularization to reduce on-site assembly and installation costs.

* Dyer, Randy (SEIA). 1979. Personal communication.

- Established firms (both HVAC corporations and exclusively solar-oriented companies) are likely to have the greatest advantage in manufacturing and distribution due to their superior capital, production capacity, and existing marketing networks.
- Small local firms may dominate the installation/maintenance sectors, due to the localized nature of on-site procedures.
- Installation and maintenance, product quality, and cost reduction of solar systems may be stressed in the industry to avoid substandard products. Temporarily, education and promotion of solar applications to builders, potential solar users, lenders, and code administrators may become more important than direct competition among specific solar products.

2.4.3 Other Groups

Solar AIPH development also is expected to impact:

- Federal, State, and local regulatory agencies
- Electric and gas utilities
- Construction industry
- Insurers
- Financial institutions

These groups are discussed in Section 3.1.7.

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3. ENVIRONMENTAL IMPACTS OF THE PROPOSED ACTION

Introduction

This section identifies the significant potential impacts of the AIPH program. This information will be used as a reference point in the preparation of site-specific EA's and EIS's as the program evolves and specific applications are defined.

Impact data were collected from literature, site visits and consultations with industry and government experts. The data were evaluated for the extent of their adverse effects and social/institutional response.

Assessment of adverse effects considered:

- constituents and quantities of residuals, effluents, and other by-products
- resultant environmental, climatic, health, and safety effects
- materials demand
- the scope and shape of existing and future environmental regulations

Assessment of social and institutional response included public, industry, and government reaction to adverse effects and the social/institutional adjustments required as a result of action to avert adverse effects.

Impacts were divided into two groups: primary and secondary. Primary impacts are those occurring on-site or as a direct consequence of the AIPH program. Secondary impacts occur off-site as a result of materials production requirements.

Twenty-four primary impacts have been included, grouped by environmental area affected (Table 3-1). The identified impacts are not uniformly

TABLE 3-1. ENVIRONMENTAL IMPACTS OF THE SOLAR AIPH PROGRAM

Impacts	Significance		
	High	Medium	Low
<u>Air Quality</u>			
Outgassing			X
Auxiliary Unit Emissions			X
<u>Water Quality</u>			
Solar Energy System Effluents		X	
Auxiliary Unit Emissions			X
<u>Ecosystems</u>			
		X	
<u>Health and Safety</u>			
Installation/Maintenance			X
Fire Hazards		X	
Glare/Misdirected Radiation		X	
Bacterial and Fungal Growth in System Components			X
Greenhouse Pests			X
Product Quality			X
<u>Land Use</u>			
		X	
<u>Esthetics</u>			
Visual			X
Noise			X
<u>Social/Institutional Impacts</u>			
Solar Industry Regulation and Product Quality Control		X	
Compliance with Federal Regulations			X
Taxes	X		
Insurance		X	
Building Codes		X	
Zoning and Land Use Controls		X	
Utility Company Impacts	X		
Building Industry Response			X
Availability of Financing			X
Consumer Acceptance	X		

significant. Therefore, a preliminary ranking system was developed applying the screening criteria more stringently and weighting factors associated with AIPH-unique components. Several secondary impacts also are included. Each impact is described to the extent needed to establish its significance. Additional details are included in Appendix B.

3.1 PRIMARY IMPACTS

3.1.1 Air Quality

3.1.1.1 Outgassing

Solar collectors commonly employ organic materials in insulation, sealants, plastic glazing and pipes, and heat transfer fluids. When solar collectors overheat, organic compounds may be discharged. This phenomenon is known as "outgassing," and often is evidenced by a thin film on the underside of the collector glazing.

The primary causes of outgassing are stagnant, or "no-flow" conditions which occur when the working fluid is not circulating and cooling the collector. These conditions can result from a control or system failure, a power failure, delay between installation and operation of the system, and periods, such as the summer months, when the system is not in use. The temperature of a stagnating collector can reach 400°F (Searcy, 1978).

Fumes from outgassing rarely are hazardous; they are primarily a collector-efficiency concern since their filmy condensation on glass reduces transmittance. However, isocyanurate and polyurethane foams outgas trichlorofluoromethane at 400°F. This substance poses a moderate toxicity hazard if inhaled, and exposure may lead to slight local irritation (Durham, 1975). However, significant decomposition of sealant materials occurs at temperatures below 400°F, and the quantity of sealant

material is so small that any environmental effects of sealant outgassing are expected to be minimal. Plastic glazing and pipes outgas at normal operating temperatures and will emit small amounts of either hydrochloric acid or hydrofluoric acid depending on the variety of plastic used. Exposure to either of these substances may produce highly toxic effects (see Appendix B). Heat transfer fluids (e.g., Dowtherm A, Therminol 66, and Mobil-Therm 603) are relatively stable at 450°F: hydrogen and methane gases are produced in small quantities. However, the extent of outgassing at normal operating temperatures is undetermined (Searcy, 1978). The fumes discharged during outgassing may prove harmful if inhaled in large quantities or over long periods of time. Hydrogen and methane gases may produce slightly toxic systemic effects (see Appendix B for specific toxicity data).

Selection of insulation, sealant, glazing and pipe material, and heat transfer fluids that are thermally and chemically stable under maximum collector temperatures will reduce the danger of outgassing. Table 3-2 shows the upper temperature limits for a number of insulation materials commonly used in solar systems. Certain types of insulation may be pretreated by heating to expel volatile material before being installed in collectors. The upper temperature limit of fiberglass insulation with organic binders may be increased somewhat as a result of such pretreatment. Also, circulating water or cool air through an inactive collector will prevent overheating.

3.1.1.2 Auxiliary Unit Emissions

Auxiliary process heat systems vary widely. In facilities where solar technology is retrofitted into an existing process, the existing energy system usually will be maintained as the auxiliary heat source. Emissions and effluents from the existing conventional energy system will decrease by the fraction of heat generated by the retrofitted solar system. The fraction of solar process heat is likely to be somewhat

TABLE 3-2. UPPER TEMPERATURE LIMITS FOR
INSULATION MATERIALS

Insulation Material	<u>Density</u>		<u>Upper Temperature Limit</u>	
	lb/ft ³	(Kg/m ³)	°F	(°C)
Fiberglass with organic binder	0.6-3.0	(9.6-48.1)	350	(177)
Fiberglass with no binder	1.5	(24.0)	850	(454)
Ceramic fiber blanket	3.0	(48.1)	2300	(1260)
Mineral fiber blanket	10.0	(160.2)	1200	(649)
Calcium silicate	13.0	(208.3)	1200	(649)
Urea-formaldehyde foam	0.7	(11.2)	210	(99)
Urethane foam	2-4	(32-48)	250-400	(121-204)

SOURCE: Teonjes, R. (Los Alamos Scientific Laboratory). November 1975.
Integrated Solar Energy Collector, Final Summary Report.

greater in new facilities than in retrofit applications, since the facility's buildings can be designed to hold collectors in optimal positions. Collector components also can function, in some cases as roofing elements, thus economizing on building materials.

Particulate matter, sulfur dioxide and trioxide, carbon monoxide, hydrocarbons such as methane, and nitrogen oxides are emitted from oil- and gas-fired boilers and furnaces and from electric power plants which use coal, oil, or natural gas. While emission controls generally are stricter for electric power plants than for industrial boilers and furnaces, these stricter controls are offset by the fact that electric power systems require more than twice as much fuel to deliver a given unit of process heat to the point of application. Table 3-3 compares emissions from an industrial boiler and an electric power plant, both burning residual grade fuel oil.

It is difficult to predict the mix of oil-fired, gas-fired, and electricity-powered auxiliary energy systems that will be used with solar ALPH systems in new facilities. Decisions will be based on the future economics and environmental impact of those energy sources, rather than on factors related to solar technologies.

3.1.2 Water Quality

The introduction of solar process heat working fluids into the environment may degrade water quality. No real hazards exist at present due to the small quantities of fluids in use. However, as the use of solar energy systems becomes more widespread, the impacts may become significant.

3.1.2.1 Solar Energy System Effluents

The following fluids represent a cross-section of fluids commonly used in solar energy systems (Searcy, 1978):

TABLE 3-3. EMISSIONS FROM TWO ENERGY
SYSTEMS USING FUEL OIL (RESIDUAL GRADE)

	CENTRAL ELECTRIC GENERATION AND DISTRIBUTION		DIRECT COMBUSTION IN INDUSTRIAL BOILERS	
	Emission Control Efficiency	Controlled Emissions (lb/10 ³ Btu of delivered process heat)	Emission Control Efficiency	Controlled Emissions (lb/10 ³ Btu of delivered process heat)
Particulates	90%	0.047	90%	0.021
SO ₂	90%	0.062	--	2.842
CO	--	0.114	--	0.052
HIC (as CH ₄)	--	0.023	--	0.012
NO ₂	50%	1.172	--	0.621

NOTES: Overall electric system efficiency assumed to be 32%; industrial boiler efficiency 70%.

SOURCE: U.S. Environmental Protection Agency (Office of Air and Waste Management/Office of Air Quality Planning and Standards). 1976. Compilation of Air Pollutant Emissions Factors, Second Edition. AP-42.

- Glycol/water solutions (Ethylene glycol, Propylene glycol, Polyethylene glycol)
- Silicone oils (polydimethylsiloxanes)
- Hydrocarbon oils (paraffinic)
- Additives (corrosion inhibitors, dispersants, biocides, etc.)

3.1.2.1.1 Surface and Groundwater Systems

Working fluids may be released as a result of system leaks and spills. Ruptures and leaks around fittings represent the classical failure modes of solar systems. In addition, structural failure may result in rupturing of piping. In each case, working fluids may escape to contact environmental water systems.

Collector subsystems are so varied that it would be impossible to characterize each one's probable failure modes in the space available. However, a general discussion of the subject will be presented with as much detail as is practical.

To evaluate the potential of working fluid spillage, one must have sufficient information on component reliability to allow a fault tree analysis. This type of analysis will yield an estimate of the probability of major spillage. Although the approach is widely accepted in the reliability analysis of large systems (such as a nuclear power plant), it may not prove practical for solar ALPH systems which are varied in design and construction. Therefore, the factors which enter into such an analysis will be discussed qualitatively.

When evaluating the potential for major fluid spills, one must consider system characteristics. After an initial check-out period, the probability of failure typically will increase over time due to the effects of age hardening, wear, and corrosion. Detection devices, location of valves, location of high or low pressure areas, containment methods, and

fluid types all can play important roles in the potential for damage from a major fluid spill.

Detection devices can be used to monitor the volume or pressure of fluid in the system. Sensitivities of such methods are limited due to the natural variations of the two variables. If external detection devices are used (such as temperature sensing probes below the collectors), unnecessary system shutdowns may occur. In all instances a trade-off occurs between safety and operation reliability.

The location of valves in the fluid transport subsystem can play an important role in determining the severity of a fluid spill. If valves are too far apart, substantial drainage can take place after the system has been shut off. If valves are too close together, cost and reliability suffer. Therefore, a judicious distribution of valves is warranted.

High pressure areas in a system are the most likely points for leakage due to seal or coupler failure. If these areas are kept at a higher elevation than the rest of the system, then leakage after shutdown may be minimized.

Containment methods are necessary to prevent the fluid from spreading over large areas. Catch basins and dikes should be employed and sized based on the "maximum credible accident" at each point in the system. By proper containment of the spillage, clean up is facilitated and future leaking problems into nearby water sources are avoided. A more detailed analysis of working fluid spillage based on a hypothetical Solar AIPH installation can be found in Appendix C.

Fluid types determine to a large extent the potential damage of major spills. For water systems, the extent of damage would be limited since the fluid is not toxic. Other fluids, however, possess properties which could result in environmental damage.

Ethylene and propylene glycols biodegrade in water (David and Evans, 1974); glycols and polyethylene glycols are biodegraded by microorganisms in soil. The rate at which this biodegradation occurs is important when considering the potential of harmful impacts. A commonly used indication of biodegradation, the Biochemical Oxygen Demand (BOD), is the amount of oxygen consumed by the biochemical oxidation of a material. Nearly all organic materials will biodegrade but large differences exist in the rates of degradation and resistance to degradation depending upon factors such as temperature, pH, the amount of available oxygen, local biological activity, and the chemical nature of the material. In the unlikely event that large quantities of glycols should be released simultaneously, the expected BOD could place an extraordinary demand on treatment facilities, degrading the efficiency of the treatment process and the quality of effluent. Disposal of glycol fluids into sewer systems is acceptable for limited quantities.* A reasonable procedure is to dilute the glycol-water mixture with five parts water to one part glycol-water before discarding into the sewer. Another five parts of water should be poured into the system after the diluted mixture (Searcy, 1978). The oxygen demand placed on a treatment facility is substantial. While the glycols are rated as slightly toxic, it appears unlikely that concentrations in water bodies could reach dangerous levels unless large amounts of fluids are released simultaneously from a number of sources. For example, ethylene glycol, potentially the most hazardous of these fluids, has an aquatic toxicity ($TL_{m:48}^{96}$) in the range of 100 to 1000 ppm. To reach a concentration of 100 ppm in a small 10 million gallon lake would require the release of approximately 1000 gallons of pure ethylene glycol fluid. A spill of this magnitude is highly unlikely (see Appendix C) as is the probability that hazardous concentrations will be attained as long as proper disposal procedures are followed. Therefore, fluids must be held in catchment basins, diluted, and released in small quantities over time or alternative disposal methods must be used. Properly controlled landfill disposal and high temperature incineration represent additional removal options for larger quantities (Searcy, 1978). Dis-

* Barbereau; R. (U.S. EPA). 1979. Personal communication.

posal by private contractors is recommended for users with inadequate disposal capability.

Silicone oils possess few toxic characteristics and are quite free of hazardous properties (Lisk and Young, 1977). Although oxidation and decomposition do occur, silicone oils are very resistant to biodegradation and, therefore, are likely to persist for an undetermined length of time. However, no evidence has been obtained that would indicate a large water quality hazard. Presently, silicone oils generally are mixed with waste organic solvent and disposed of through carefully controlled incineration. This is an acceptable means of disposal but special equipment is required to control the particulate emissions. Landfill disposal also is acceptable for small quantities; however, a more attractive alternative would be to collect the silicone oils until the quantities become large enough for recycling (Searcy, 1978).

Hydrocarbon oils may foul water reserves to the point that they are no longer potable and are even unfit for a great number of industrial applications (Searcy et al., 1978). In surface water systems, hydrocarbon oils float, contaminating the surface and preventing proper aeration. The oils degrade slowly and clearly present a hazard if released in great quantities (DeBerger et al., 1975). Current methods of waste hydrocarbon oil disposal include recycling and incineration. The release of oils, particularly by industries, is controlled by Federal regulations. Title 40 CFR, Parts 109 and 110, establish criteria to minimize damage resulting from accidental oil discharge into navigable waters. Parts 122 to 125 of the same act establish criteria for permitting and controlling the release of industrial oils into water systems. Working fluids disposal procedures may be subject to compliance with these regulations, thereby reducing some potential hazards associated with their release.

Most fluid additives are used in very low concentrations and generally are released in small quantities in a diluted form. It is difficult to determine the potential hazards of these additives because product

compositions often are considered proprietary information by the manufacturers; however, generic chemical substances which are used commonly as fluid treatment additives can be identified. These include chromium compounds, nitrates, nitrites, and boron compounds. See Appendix B for more detailed information on generic fluid treatment chemicals and related toxicity data.

In some cases, the designer, in an attempt to protect the solar system, inadvertently will impose a personnel or environmental hazard. For example, a relief valve installed to protect the system from excessive pressures may represent a human hazard if improperly located or an environmental hazard if discarded liquids and vapors are not directed properly to catch basins.

These considerations should be coupled with an assessment of the surrounding environment. If the solar installation is near a water source or the water table is near the surface, extreme caution should be taken to avoid toxic fluid spillage and resulting water contamination. In these situations, it may be unacceptable to allow the installation of fluid lines over unprotected ground.

The potential for fluid spillage should not be ignored, as illustrated by the following case. A receiver tube in a fixed-receiver parabolic trough collector collapsed during a test at Sandia Laboratory Solar Total Energy System Test Facility in New Mexico. The failure was due to a missing "Jack pin." The structural design was so rigid that the absence of one small pin caused an accident that could have injured personnel or equipment. Within 30 seconds, some 30 gallons of Therminol-66 (T-66) at 600°F flowed from the receiver. Due to proper area management, no injuries were incurred. The system now has a minicomputer monitoring the weight of fluid in the storage tanks. If a significant reduction in weight is detected, the system is shut down. T-66 is virtually non-toxic

and poses no special handling problems. Although no special precautions appear necessary, manufacturers recommend the use of good industrial practices for housekeeping, personal hygiene, and avoidance of prolonged and repeated exposure if spillage should occur. Limited studies indicate that Therminol 66 undergoes primary biodegradation and that it is not a persistent aquatic pollutant.

It is difficult to assess the likelihood of fluid spills from AIPH systems, but a few general observations can be made. The components of fluid transfer -- piping, joints, and valves -- generally should be no more prone to failure than equipment used in conventional process systems. One exception is the moving mechanical joint that connects tracking collector tubes to stationary supply and return pipes. Since this joint would be subject to frequent motion, failure rates might increase. However, periodic inspection and replacement of worn joints should reduce the possibility of fluid spills.

Because of collector spacing and, in some cases, the necessity of locating the collector field away from the storage tanks or the process, Solar AIPH systems require substantially more piping than do conventional process systems. As the length of piping and number of piping joints increase, so does the possibility of pipe failure and fluid spill. In this respect, solar AIPH systems generally will have a greater chance of fluid spills than will conventional process heat systems.

The Environmental Protection Agency (EPA) has primary responsibility for environmental quality protection; however, at the present time, no specific regulations exist pertaining to heat transfer and other solar system fluids. Disposal of glycol, silicone oil, and hydrocarbon oil is not recognized currently by regulatory agencies as a problem requiring specific attention (Searcy et al., 1978). Laws administered by EPA that seem most applicable include the Federal Water Pollution Control Act, Toxic Substances Control Act, Safe Drinking Water Act, and the Resource Conservation and Recovery Act.

3.1.2.1.2 Sewage Treatment Facilities

Liquid working fluids may be flushed through existing sanitary sewage facilities and enter local sewage treatment plants. Most glycols appear to be biodegradable. Ethylene glycol is expected in concentrations sufficient to affect the treatment plants. The oxygen demand imposed on a treatment facility by the introduction of ethylene glycol is substantial. Estimates reveal that the Biological Oxygen Demand (BOD) from the disposal of 1000 gallons of ethylene glycol in one day would be equivalent to that imposed on a treatment plant by an additional population of 41,000 people (Searcy et al., 1978). If the biochemical oxidation capacity of the system is exceeded, partially degraded ethylene glycol may be released to receiving waterways. This effluent may possess a high BOD as a result of incomplete oxidation and may strain oxygen supplies in the receiving waters, leading to adverse aquatic effects. However, releases of this magnitude are very unlikely. Large spills may be contained in catchment basins or other holding facilities to be released gradually over time or disposed of by alternate methods discussed earlier.

Silicone oils float and form a layer of low cohesivity, some of which may be skimmed off and transferred to the anaerobic digester at the plant. That which is not removed is released in the plant effluents. Hydrocarbon oils which are not removed in the skimming process may be degraded, trapped with the settled sludge, associated with suspended particulate matter, or present in the dissolved state (Farrington and Quinn, 1973). These are discharged with the plant effluents. If a trickling filter is used, these oils may degrade the performance of slime growths temporarily. The concentration of these materials in sewage treatment facility effluents may vary greatly depending upon the facility, the time of day, and the season of the year.

Fluid additives are used in low concentrations and are diluted further in wastewaters. Therefore, it is unlikely that the operation of the sewage treatment facilities will be affected by their use.

Chlorine is used commonly in sewage treatment plants and in the treatment of drinking water. While chlorine is an effective disinfectant, it also is quite reactive with organic chemicals. These reactions may lead to the formation of chlorinated hydrocarbons which are very stable and not readily biodegradable. Even in low concentrations, these substances may be unacceptable for release as some may be toxic and carcinogenic (Searcy et al., 1978). These organic compounds persist in water bodies, thus the potential for human exposure is great. Chlorinated hydrocarbons in drinking water have been suggested as a contributing factor in the increased incidence of cancer in New Orleans (Carlisle et al., 1975). Of the fluids and additives considered, the glycols appear to have the greatest potential for forming harmful chlorinated hydrocarbons.

Fluids degrade and must be replaced periodically; some may be suitable for reprocessing, reclamation, chemical treatment, or incineration. However, at the present time, those processes may not be feasible for solar fluids due to the small quantities in use. Control measures and regulations for fluid release from sewage treatment facilities are the same as those listed for surface water.

3.1.2.2 Auxiliary Unit Effluents

Most effluents associated with conventional auxiliary systems result from cleaning and equipment maintenance operations and will be intermittent in most cases. Boilers accumulate calcium and magnesium salts on evaporative surfaces in normal operation. These salts are removed by precipitation with sodium phosphates during boiler blowdown.

Boiler blowdown water contains dissolved solids (10-500 mg/liter), phosphate (5-50 mg/liter), and hydroxide alkalinity (10-100 mg/liter). If hydrazine is used instead of phosphate, blowdown water contains ammonia (0-2 mg/liter). Nuclear-fired power plants use ultrafine quality boiler water, so blowdown impurities are lower than in fossil fuel plants and industrial boilers.

Boiler maintenance also includes periodic thorough cleaning of the equipment. Cleaning wastes may contain boiler scale (salts), corrosion products (iron and copper oxides, various trace metals), by-products from alkaline cleaning mixtures (ammonium ion, oxidizing agents, high alkalinity), and by-products from acid cleaning mixtures (acidity, phosphates, fluorides, and organic compounds).

The effluents mentioned here represent the general types of wastes encountered. Effluent control measures vary among systems; in general, the effluents are not produced in quantities large enough to pose serious water quality problems. Increasing use of solar process heat systems will help to further reduce effluent related impacts.

3.1.3 Ecosystems

In soil systems, fluids may be absorbed by soil particles, diffused through the soil, or carried along with water moving through the soil (Searcy et al., 1978). The presence of these fluids may kill soil microfauna which contribute to soil fertility, an especially important consideration in agricultural regions. Glycols and polyethylene glycols are biodegraded by microorganisms in soil systems; the extent of biodegradation depends on the soil type and fluid concentration. Large spills of hydrocarbon oils may poison the surface soil layer and disturb its macro- and microecology (DeBerger et al., 1975). Biodegradation in soil systems can be accelerated somewhat by adding nitrogen and phosphorus fertilizers and aerating the soil through discing and ploughing.

Flora and fauna may be affected directly by fluid leaks and spills or indirectly through contact with contaminated ground and surface water systems. Various bacteria, plants, and animals can bioaccumulate harmful substances and pass them on into food chains. Silicone oils are absorbed most readily; however, whether the absorbed material is metabolically transformed is unknown. Tests involving silicone oils showed that vegetation in the area of a spill may be damaged severely, and in

one case, growth remained sparse at the end of a two year evaluation (Lisk and Young, 1977). The destruction of vegetation is attributed mainly to the water repellent properties of silicone compounds. Silicone oils form a film on the water surface which may interfere with the respiration of small organisms and retard the dissolution of atmospheric gases into the water. Silicon oils have little direct impact on microorganisms (Searcy et al., 1978). The glycols are somewhat toxic to some species of fish but their impacts on microorganisms are undetermined. Hydrocarbon oils are potentially harmful in that relatively small amounts can damage or destroy affected vegetation. They also hinder proper water aeration while contaminating everything which comes in contact with the water surface.

Fluid additives used in solar systems also contain substances which may prove harmful to ecosystems (see Appendix B). In some cases, compounds containing phosphorus, nitrogen, and sulfur may be used directly by plants as primary nutrients in protein synthesis, resulting in blooms of plankton and algae. Additional problems associated with ecosystem eutrophication may result, including a reduction in dissolved oxygen content with consequent harmful impacts on fish and other aquatic organisms. Some aquatic invertebrates are quite sensitive to chromium contamination, and sulfate and sulfite effluents may increase aquatic salinities, which may affect some species.

In general, the concentrations of harmful materials reaching the environment will be much smaller than those known to affect plant and animal life, particularly where the working fluids are diluted by entering a body of water. Potential leaks and spills are likely to be small and scattered over a number of isolated locations, so that significant cumulative adverse impacts are not likely to occur. The potential for such impacts may be further mitigated through the use of catchment basins or retention dikes to reduce the amount of fluids released. In

the case of periodic working fluid disposal, conscientious use of disposal methods will reduce adverse impacts. Federal legislation administered by the Environmental Protection Agency allows regulation of these potentially harmful releases.

3.1.4 Health and Safety

3.1.4.1 Installation And Maintenance Of Solar Process Heat Systems

Because of their decentralized nature, agricultural and industrial solar process heat system applications will be constructed, installed and maintained by many companies and individuals throughout the nation. Workers involved in any phase of installation or operation of solar process heat systems potentially will be exposed to hazards from accidents such as collector glass breakage, burns from overheated collectors or misdirected radiation, exposure to toxic fumes or leaking heat transfer fluids, and structural damage from improperly installed solar systems.

Solar equipment handling during installation poses two potential worker safety hazards. Mounting angled rooftop collectors requires that installers climb onto steep roofs and work in precarious situations. Generally, rooftops which are coated with heat absorbing materials such as black asphalt expose workers to high temperature work environments. This is of concern in solar AIPH applications since collectors often are mounted on plant rooftops.

Collector glass breakage is another potential hazard of solar AIPH systems. Breakage could be caused by thermal cycling, vandalism, adverse weather conditions, and accidents during shipping and installation (Energy and Environmental Analysis, 1978a). The hazards of broken glass often can be minimized by using heat-tempered glass which "beads" rather than shatters when broken, surrounding ground level collectors with fences, and employing persons familiar with glass work.

General contractors often are employed to install solar agricultural and industrial process heat systems. Experienced construction workers usually are apprised of the working conditions involved which should not differ radically from other types of installation work except for the handling of heat transfer fluids. Therefore, general safety procedures, detailed installation manuals, and careful supervision at the construction site for each particular system should address these concerns.

During installation and maintenance, workers will be handling potentially toxic heat transfer fluids. Leaks and spills of heat transfer fluids or outgassing may be hazardous to maintenance workers and to other employees exposed through dermal contact and/or inhalation of fumes. Although toxicity has been established for heat transfer fluids as pure chemical substances, little is known about the toxicity of specific products and solutions used in solar process heat systems (see Appendix B). If highly toxic chemicals are used or if prolonged exposure occurs, precautionary measures such as protective clothing, and training in proper handling and disposal methods may be necessary. For industrial facilities with trained engineers on site, frequent maintenance activities will be performed. System failure in these facilities will be less likely, thereby avoiding some potentially hazardous accidents. If an accident should occur, immediate action should be taken to contain the spill and cleanup operations should commence. The proper authorities also should be notified. This may involve contacting private disposal firms, local fire officials, and regulatory officials. If fluids are to be released into sewage systems, sewage plant operators should be informed of the additional load. Industrial facilities generally are familiar with quality control procedures; however, additional training and guidance may be required at agricultural locations.

Burns and glare caused by misdirected and reflected solar radiation could be significant safety hazards in certain AIPH applications (see

Section 3.1.4.3). For non-focusing collectors the problem is relatively minor and easily controlled through careful site selection and operation and construction of barriers. Misdirected radiation from focusing systems can cause burns and possible eye damage from glare. A fire hazard situation also may occur (see Section 3.1.4.2). Although ongoing damage from glare is unlikely due to the likelihood of early detection and prompt correction, plant maintenance personnel in industrial operations may be required to wear protective goggles and gloves particularly when work is done on collectors during no-flow or over temperature conditions. Provisions for stowing focusing collectors in face-down positions may alleviate potential accidental burns resulting from misdirected radiation. Such provisions typically are included in system design, and few problems have occurred (Energy and Environmental Analysis, Inc., 1978b).

Rooftop collectors could have significant implications for the safety of both workers and building inhabitants. Collectors could prove too heavy for certain roof structures, particularly in retrofit systems. In addition, collectors themselves may be damaged by hail, snow, ice or wind. This is a problem particularly for systems which use fixed collectors which cannot be stowed during periods of adverse weather. Careful attention to design, wind, snow, hail, and seismic loads during planning, and mounting rooftop collectors in such a way as to allow access for maintenance purposes may avoid accidents (EEA, 1978a). In some situations roof reinforcement and installation of stairs and safety railings may be required. Building codes and standard system design procedures generally mitigate these potential problems.

The widespread deployment of solar agricultural and industrial process heat systems could affect the health and/or safety of untrained workers engaged in solar system construction, installation and maintenance.

Accidents during installation and maintenance often are unavoidable. At present there are no formal safety standards or regulations specifically for solar AIPH systems. However, safety measures adopted in the Department of Housing and Urban Development Intermediate Minimum Property Standards for Solar Heating and Domestic Hot Water Systems address these potential problems by: developing vocational training programs; requiring proper labeling of all solar components, equipment, and hazardous substances such as certain heat transfer fluids; and requiring the inclusion of detailed installation, operation, and maintenance manuals with all solar systems (NBS, 1976). These regulations may serve as a guideline for the development of similar standards applicable to process heat systems. In addition, conformance to general safety standards for construction and building plant maintenance may help to alleviate some of the safety hazards. Additional information concerning the risks associated with materials acquisition and system construction may be found in Risk of Energy Production, a study performed by Herbert Inhaber of the Atomic Energy Control Board of Canada (Inhaber, 1978).

3.1.4.2 Fire Hazards

The identification of fire hazards and related safety issues for solar AIPH systems involves reviewing the potential flammability of component materials and the operating conditions under which solar systems may function. The component materials include heat transfer fluids, insulation, sealants, glazing, and heat storage media. During no-flow or overtemperature conditions, heat transfer fluid temperatures could rise to flash point and autoignite. The location of collectors, wood building structures, non-hostile heat sources such as pilot flames, heaters, welding and soldering, and industrial and agricultural oils and dust can reduce the fire resistance of a structure. Heat transfer fluids, heat storage media, insulation, sealants and some glazings will enhance flame spread of an existing fire. Direct contact with a pilot flame or other heat source will cause most component materials to burn. This section will discuss the potential impacts of solar AIPH systems in these fire

hazard situations; fire hazard data for specific solar system components are presented in Appendix B.

Heat transfer fluids seem to pose the most serious potential fire hazards. The exact nature of potential impacts depends on many variables, including the type of heat transfer medium employed, its relative combustibility, and the types of materials used in the building structure. Some of the fluids proposed for solar process heat systems (i.e., paraffinic oils, silicon fluids, aromatic hydrocarbons, and glycols) have flash point values which indicate the potential hazard of the fluid. Flash point values generally are determined for pure samples. If these fluids are used in water-based solutions, water will boil off before the remaining fluids reach their flash points.

Under no-flow or over-temperature conditions, the temperature of the working fluid may increase to its autoignition point. Leakage of heat transfer liquids or vapors which are hotter than ambient temperatures could cause fires if the leaks occur near pilot flames and other heat sources. During a fire, the rupture of storage tanks or pipes carrying heat transfer fluids could promote surface flame spread and outgassing.

Insulating materials in solar process heat systems also pose potential fire hazards: plastic foam, cellulose fiber and organically treated fiberglass are flammable. These materials usually are treated with fire retardants which protect them from ignition but do not prevent the insulation from becoming a medium for surface spread of fire. Thus, the insulation used in solar process heat systems can enhance flame spread during a fire. The flammability of insulation will increase if it is saturated with leaking heat transfer fluids, thereby increasing the possibility of ignition during over-temperature conditions.

Sealants and glazing materials pose relatively small fire hazards. Sealants are used only in small quantities in solar process heat systems, and potential toxic gas emissions from them during combustion are

low in comparison to other collector materials. Glass glazing materials are non-flammable; however, plastic materials do burn. Potential hazards include toxic gas production and the contribution of fuel to existing roof-top fires. In fact, these materials generally ignite more readily than common roofing materials (Searcy, 1978). Plastic piping will burn and outgas in a fire, but there is little possibility of autoignition. Coating materials used to protect metal and glass surfaces may be flammable also.

Thermal storage media hold very high temperatures, and have high flash points. They usually are well insulated and isolated from ignition points. Therefore, there is little potential for accidental ignition. However, like other collector component materials, thermal storage media could supply fuel for an existing fire.

Consideration of fire and safety hazards in agricultural and industrial processes extends to the operating conditions and environment surrounding the solar process heat system. The presence of a solar system may reduce the fire resistance of the structure. One possibility is the creation of pyrophoric conditions through continual heating and drying of wooden structures used to support solar system components. Wooden support structures used to transport heat fluids are exposed to moderately high temperatures for long periods of time and will undergo slow and cumulative decomposition. Eventually, combustible residues may be produced. Thermal degradation also adversely affects the structural strength of the wood, leading to the possible collapse of the structure (Underwriters Laboratory, 1959). Pressure treatment and surface treatment with flame retardants will delay this process and temper flame spread. However, neither process is a totally effective method of fire prevention. Another possible hazardous operating condition is the accumulation of oils and dusts from industrial and agricultural processes, which can trigger explosions and fire during no-flow or over-temperature conditions.

Although solar systems could block emergency exits, particularly in retrofit systems, the situation is avoidable. Furthermore, in industrial regions, compliance with building and fire codes should obviate the problem. However, the location or position of the collector could increase the potential of fire hazards. During windy conditions, a rooftop collector can be blown over, spilling flammable heat transfer fluids. In industrial operations where non-hostile and/or incidental heat sources are likely to be present, the hazards are increased if the spilled fluids ignite and spread the fire to other portions of the host structure or surrounding buildings. Outgassing also may occur in this situation.

In agricultural and industrial processes using solar heat, the risks of fire hazards are equated with the occurrence of accidents. Under normal operating procedures, fire conditions are not present. There is, however, the possibility that leaks of combustible heat-transfer fluids will occur* (EEA, 1978b).

Fire hazards and related safety issues are a primary concern in industrial operations. High process heat temperatures, use of the more combustible heat-transfer fluids, and the presence of non-hostile and/or incidental ignition sources potentiate fire conditions. In most cases, industrial operations are maintained by professional engineers having experience with potentially flammable conditions. In addition, insurance inspection and adherence to established fire and safety codes mitigate some fire hazards. Solar agricultural processes commonly use air or water-based solutions for heat transport and transfer, so operating temperatures are somewhat lower than in industrial processes. These media are unlikely to cause ignition, but may contribute to the spread of an existing fire.

* Walton, W.D. (National Bureau of Standards). 1978. Personal communication.

To date, there are no fire standards or criteria for solar AIPH systems. Industrial and commercial fire codes are well established, as are HUD's Intermediate Minimum Property Standards and NBS's Interim Performance Criteria for the residential solar heating and cooling of buildings. Although modification of existing standards would be required, they generally can be viewed as a guide for the control of solar AIPH fire hazard situations.

To mitigate concerns surrounding the flammability of fluids in solar collectors, both the NBS and HUD (in its Intermediate Minimum Property Standards) stipulate that temperatures attained by fluids in solar energy systems shall not exceed a temperature of 100°F below the flash point value of the fluid. This conforms to the National Fire Protection Association's classification of flammable and combustible liquids (NFPA No. 321). The NFPA distinguishes between flammable and combustible liquids: combustibles are defined as those flammable substances whose flash point temperatures equal or exceed 100°F. Nearly all of the heat transfer fluids (with methanol a notable exception) are classified as combustible liquids. Most working fluids have flash points in the 200°F to 380°F range (see Appendix B).

The Center for Building Technology at NBS has developed interim performance criteria for solar heating and cooling systems to address potential fire hazards of various materials. The criteria specify that, with materials such as wood, "consideration be given to the combustibility of materials adjacent to high temperature components in determining the clearance and/or insulation required." NBS also has noted in its criteria that if the collector system requires penetration into fire-rated walls, partitions, and roofs, these penetrations shall not reduce the fire resistance required by local codes and ordinances. This ensures that in areas where system components pass through fire-rated materials, the area will not lose its fire endurance and resistance. Additional considerations may be required in rural areas where such codes do not exist.

3.1.4.3 Glare/Misdirected Radiation

Glare and misdirected radiation from collector fields may present a nuisance and, possibly, health and safety problems. Glare, as used here, refers to light reflected off collectors; redirected radiation to the accidental redirection of the concentrated radiation beam from parabolic troughs or other dual axis concentrating collectors in the event of a system failure. Glare may result from flat-plate collector glass or from the metallic (aluminum) backing of parabolic troughs in the stowed position. The intensity of the glare is a function of the angle of incidence, intensity of sunlight, and the reflectivity of the collector surface (which is a function of the collector material and collector coating, if any). Glare from flat-plate collectors is similar to window glare; glare from stowed parabolic troughs is equivalent in intensity to glare from a metallic surface such as a car bumper. Glare problems may be less significant for rooftop collector systems in industrial settings, where the probability of human exposure is minimized. Also, glare from stowed parabolic troughs should not occur normally, as parabolic troughs typically would be operating during insolation periods. Glare problems would occur only in the event of a system shutdown.

The most apparent glare problem is nuisance glare, which may occur if collector fields are located near roads, buildings, parking lots, or small air fields. Glare could prove a significant hazard if motor vehicle or small plane operators are blinded temporarily. It has been suggested that potential glare hazards are less serious for aircraft operators than passing motorists (Brannan et al., 1977) because pilots have longer reaction times before hitting obstructions, more flexibility in altering their course of direction, and often wear polarized sunglasses. Proper placement of the collector fields and other precautionary measures, such as walling off collector areas, should minimize potential glare problems of this nature.

The possibility of high levels of UV radiation in the collector area may be more significant than nuisance glare. The wavelength composition of glare radiation probably has a smaller total fraction of UV radiation than does sunlight. Of the UV radiation, a larger proportion probably is UV-A (315 to 400 nanometers) and UV-B (280 nm to 315 nm) because some of the shorter wavelength radiation is likely absorbed and converted into longer wave radiation and heat. However, glare radiation wavelengths have not been characterized, and UV radiation levels in the collector area have not been monitored. Short-term acute exposure to UV-B and UV-C radiation can cause sunburn; chronic exposure, as could be experienced by plant personnel in the collector area, has been implicated in the cause of melanoma, the most common fatal form of skin cancer (EPA, 1977). UV-B is more effective than UV-C in producing tumors (non-melanoma skin cancers) in laboratory animal populations (Ham and Sliney, 1978). Coating collector surfaces of parabolic troughs would almost totally eliminate potential UV radiation hazards.

Misdirected radiation could occur when axis tracking collectors, such as parabolic dishes or heliostats, are not focused properly. These collectors will be used in high temperature industrial process applications such as petroleum refining. The misalignment of parabolic dishes or heliostats should not occur under usual circumstances, but might occur during a system malfunction, or as collectors are brought from the stow position in the morning. In an unfocused parabolic dish, a "smeared out beam" would result*, i.e., a beam that is somewhat less concentrated than the regular beam (although still capable of generating temperatures at the focus in excess of 1000°F), with a focal length up to one and a half times longer than usual. Typical parabolic dishes have focal lengths of around 10 ft; a smeared out beam would have a focal length of around 15 ft, and the energy density would be sufficient at three times this length to equal one sun**/+ (This is considered a conservative estimate.)

* Leonard, S. (Sandia Laboratories). 1978. Personal communication.

** One sun is equivalent to energy density of radiation striking the collector surface.

+ Leonard, S. (Sandia Laboratories). 1978. Personal communication.

Hence, the range of potential high temperature would extend 60 feet from the collector (15 ft. from collector to focus plus 3 focal lengths beyond); actual temperatures generated would depend on properties of any object exposed, such as specific heat, length of exposure time, and the point in the high temperature range that the exposure occurs (the nearer to the focus, the higher the potential temperatures). Plant personnel could be burned severely by an unfocused collector, and leaking working fluids, which may have flash point as low as 132°F (for Dowtherm J) and commonly have flash points in the 200 to 380°F range (see Appendix B). Also, petroleum refining involves a number of flammable substances. Careful safety procedures will be needed to ensure the safety of plant workers in the collector vicinity and to avoid flammability problems.

Misdirected radiation also might cause eye damage to personnel in the collector area. UV radiation may affect the lens and cornea; cataract formation in response to UV radiation has been observed in experiments. Visible light may pass through the cornea and to the retina, causing solar retinitis, i.e., inflammation of the retina, which may be temporary if the tissue is not burned (Ham and Sliney, 1978). Since the eye has a lower physiological damage threshold than skin or other parts likely exposed to misdirected radiation, safe levels established to protect against eye damage should ensure protection in all cases. Possible physiological damage by misdirected collector radiation has been investigated theoretically (Ham and Sliney, 1978 and Young, 1977). These studies concluded that the eye blink response of the typical person likely would preclude adverse physiological effects of acute exposure to misdirected radiation. Possible lenticular, corneal, and iris damage from chronic exposures were not considered. The use of protective goggles by plant personnel and restricted access in the collector area probably would mitigate potential adverse physiological effects of misdirected radiation. In general, proper collector placement and safety procedures should minimize the problems identified for collector glare and redirected radiation.

3.1.4.4 Bacterial And Fungal Growth In System Components

A potential concern associated with solar AIPH systems is the growth of bacteria and fungi in system components. These organisms thrive in warm, moist atmospheres, such as rockbed storage bins, or shaded areas between the structure and rooftop mounted collectors. Generally, they do not exhibit any seasonal growth pattern. The presence of fungi and/or bacteria in the process heat system may pose hazards to worker health due to possible allergic reactions.

Although bacterial and fungal growth pose a potential environmental hazard, few problems have been reported (EEA, 1978b). Diurnal fluctuations in circulating air temperatures and the high temperatures of the rocks appear to prevent growth of these organisms.*

Static water in solar ponds may promote bacterial growth. This can be remedied by water chlorination (EEA, 1978a). Bacterial or fungal growth under rooftop collectors can be avoided through proper system design, including flush mounting on a water-tight membrane (EEA, 1978b). However, such contamination has not been evidenced in DOE solar process heat demonstrations (EEA, 1978b).

3.1.4.5 Greenhouse Pests

Integrated solar greenhouse-rural residence systems share heat, heat storage, and ventilation systems. Thus, the control of pests which naturally breed in greenhouse plants and soils is a concern for these systems. Whitefly, spider mites, mealy bugs, and thrips are common pests infesting greenhouse plants. They are detrimental to plant growth and annoying to humans. Greenhouse soils also produce microorganisms and bacteria which can weaken the soils and prevent optimum plant growth

* Mears, D.R. (Biological and Agricultural Engineering Department, Rutgers University) and Smith, C.C. (Solar Energy Applications Laboratory, Colorado State University). 1978. Personal communication.

(McCollagh, 1978). Infestations of pests may damage or kill plants. Also, pests may enter living areas, thereby causing a nuisance to residents.

Pests must be controlled in these integrated systems, yet no effective means have been demonstrated. Traditionally, pesticides have been used in commercial greenhouses. However, commercial pesticides can pose potential hazards to the human environment, since noxious sprays and fumes may enter the integrated ventilation system and contaminate the residential environment.* In addition, humans may be exposed to hazardous chemicals through direct contact while working in the greenhouse or through ingestion of vegetables containing pesticide residues.

Pesticides such as malathion, pyrethrum, and diazinon, which are readily available to consumers on the retail market, have not proved effective when used repeatedly in greenhouses. With continued use, pests build resistance to these chemicals, and the levels of toxic fumes increase. If the greenhouse is constructed in a manner to allow complete isolation from the residence, it would be possible to close it off, fumigate, and air it out before reopening (Thompson et al., 1978).

Alternate methods of pest control have been and are being tested. It has been found that insects are attracted to various light frequencies and color. Experiments with electronic insect eradicators are being conducted at Colorado State University.** The beams attract the insects and trap them in a screen or electrocute them. Other mechanical methods include vacuuming, cold fumigation, and topical applications of vinegar, salt, and soapy water. Various biological controls such as garlic, marigolds, and praying mantids (Fisher and Yanda, 1976) can be used on a

* Smith, C.C. (Colorado State University). 1978. Personal communication.

** See Note above.

small scale but become expensive and labor-intensive in larger systems. These methods also pose nuisances to the residents.

Thus, the control of pests in greenhouse-residence combinations is an issue which has yet to be resolved. Further research is needed to develop a safe, effective means for pest control.

3.1.4.6 Product Quality

3.1.4.6.1 Insufficient Heating or Cooling

A concern unique to solar AIPH is possible product contamination or deterioration due to: 1) insufficient heating/ cooling, leading to bacterial/fungal infestation and other adverse effects or 2) leakage of and contamination by the chemical constituents of heat transfer/ storage media, or by the chipping and/or volitalization of absorber paint and binders used as coatings in air systems collectors. Solar systems may operate at temperatures as low as 100° to 150°F. This temperature range is favorable to bacterial/fungal growth. The most likely mode of contamination is in direct heating or drying applications for products such as tobacco, grain, grapes, etc.; spoilage of these products would be costly to the producer (costs which would be passed on to the consumer) and could pose health problems to livestock or consumers. Milk spoilage is another possibility, in the event that solar systems are unable to generate and maintain required temperatures for milk pasturization (i.e. 145°F) for at least 30 minutes. USDA requires that milk be stored at temperatures of 40°F or less. Inadequately pasturized or improperly stored milk can cause various forms of food poisoning and, possibly, tuberculosis. A related possibility is that lower temperatures may not be optimal for curing or processing, resulting in products of inferior quality and lower profit margins for producers or distributors.

While product contamination is possible, limited operating experience to date indicates that it is unlikely. In tobacco curing, lumber drying, raisin drying, and grain drying experiments, no evidence of bacterial, fungal, or other forms of spoilage were observed; solar treated products generally were of the same quality as products processed conventionally. In fact, in the case of grain drying, potential contamination problems may be of less concern in solar systems than in conventional high temperature drying procedures which expose the grain to combustible products such as CO, NO_x, etc. Recent evidence indicates that corn dried at lower temperatures has significantly fewer "stress cracks" than corn dried at higher temperatures (Shove and White, 1977). Stress cracks increase the probability of kernel breakage during handling (a significant economic liability) and may increase the chances of bacterial and/or fungal infection. Despite favorable operating experience to date, systems difficulties are more likely in early developmental/commercialization stages and the problems identified should be considered possible.

3.1.4.6.2 Chemical Contamination

Solar heating systems use a variety of compounds (working fluids, working fluid additives, and storage media) which may be harmful if accidentally ingested by humans or livestock (see Appendix B). Non-food products, such as lumber or textiles, might be degraded or soiled in the event of accidental exposure. Chemical contamination should not occur during normal systems operation; limited operational experience indicates that systems function with a fair degree of reliability. Use of double wall heat exchangers, and careful systems monitoring can minimize accidental leakage. FDA regulates many activities in food processing. Sanitary codes in some states require double wall heat exchangers for milk pasteurizing operations. Despite these factors, systems failures are possible in the early stages of commercialization.

Collectors often are coated with inorganic compounds (e.g., nickel, chromium, lead, zinc, and iron) and organic substances used as a binder for the coatings. They include polypropylene, polyethylene, and others. Degradation, flaking, or volatilization of these compounds is possible due to high collector temperatures. Subsequent air dispersal could create contamination problems, although the extent or likelihood of such an occurrence is unknown. Toxicities of the organic binders are not well known. The toxicities of the inorganic coating compounds vary and they are not considered harmful in small quantities. Iron and zinc, in fact, are important trace elements. Zinc typically occurs in drinking water at levels up to 7 ppm, nickel at levels of around 0.4 ppm; chromium, at 0.05 ppm; and iron below 3 ppm. It is unlikely that these materials will pose a significant hazard in collector coatings because they are not very volatile and because coatings are engineered to withstand collector temperatures. Lead flaking, while not likely, is possible. Lead ingestion hazards have received widespread public recognition following the many news accounts of lead poisoning, including those of children who had ingested flakes of lead-based wall paint.

3.1.5 Land Use

Since solar energy is relatively diffuse, solar AIPH collectors will require significant areas of land or building rooftops. Large-scale industrial solar applications, in particular, may require the conversion of surrounding land from previous uses to collector fields. The amount of land used for collector fields at a particular facility will depend on the type of collector used, the cost and availability of land, and the level of solar insolation available at the site. If land is not a constraining factor, collectors will be spaced to minimize shadowing by adjacent collectors; typical ground cover ratios (total area of collector aperture divided by the ground area used for the collector field) for tracking parabolic troughs or dishes range from 30 to 40 percent. As land for collector fields becomes more expensive or less available,

economics may justify closer packing of collectors. Ground cover ratios of 50 percent are possible with only a 5 to 10 percent loss of collection efficiency from shadowing.

Sandia Laboratories in Albuquerque, New Mexico has been developing a solar AIPH system using parabolic troughs that will supply roughly 6000 MWth/year (depending upon geographical location) from 50,000 square feet of collectors. Assuming a 35 percent ground cover ratio for illustrative purposes, the Sandia system would cover 3.3 acres of land. In Shenandoah, Georgia, a 42,000 square-foot knitwear factory will obtain at least 60 percent of its energy requirements (electricity as well as process heat) from a solar total energy system utilizing parabolic dish collectors that cover 5.7 acres of land.

These examples show that solar collector fields for industrial facilities will require substantial amounts of land. On a national scale, approximately 100 square miles of land area could be involved in meeting the AIPH program goals for 2000 (assuming a 35 percent average ground cover ratio and 930 million square meters of collector area - see Section 3.2.1 for collector area calculations.) Improvements in collector efficiencies will reduce the number of collectors, and thus the amount of land needed to supply a given level of output, but it is unlikely that efficiency improvements in the near future will substantially reduce land requirements.

The alternative to ground-level collector fields is to place collectors on building rooftops or on spanning frames over parking lots. In most cases, though, the added expenses associated with roof top systems, particularly for retrofit applications, will preclude their use where land is available. In addition, rooftop areas of industrial facilities will rarely be large enough to collect more than a minor fraction of the industry's process heat needs. For industrial plants with suitably

oriented parking lots, it may be less expensive to "roof over" the parking areas with spanning frames and collectors. This approach has been used successfully at the Honeywell headquarters in Minneapolis, Minnesota, as well as at other locations. Again, though, many if not most industries have process heat requirements beyond what could be collected over the existing parking areas or buildings, so that full-scale solar ALPH systems would require additional land.

Covering a field with solar collectors may exclude other land uses, but does not necessarily prevent the land from supporting vegetation. It is doubtful that crops could be harvested successfully under collector arrays for a number of reasons (difficulty in harvesting, insufficient sunlight, etc.) However, even with ground cover ratios of 50 percent or more, some form of ground cover should be able to thrive under collector arrays where the soil and available moisture are conducive. This will allow the use of this land for limited livestock grazing at some agricultural sites.

3.1.6 Esthetics

3.1.6.1 Visual

The visual effects of solar process heating will vary greatly. The greatest visual impact will be the collector and storage system. In industrial areas, the plant generally will fit in well, appearing as an industrial installation of some sort. In residential or rural areas, the plant may contrast somewhat with the surrounding scenery. Experience and research have shown, however, that solar systems can be adapted to existing visual tastes and esthetic restrictions; a study of solar users by the American Institute of Architects (AIA) Research Corporation concludes that visual esthetics appear to be among the least significant potential constraints to solar development (AIA, 1976).

3.1.6.2 Noise

The normally operating solar process heating system is not expected to cause significant noise problems. While the systems may include a series of pumps and blowers, proper design and insulation materials should minimize system noise to acceptable levels. In rural or residential areas, the system is not expected to contribute significantly to the ambient noise level, although there may be some slight effect depending on the area. The already high noise levels in industrial areas will not be affected significantly.

3.1.7 Social and Institutional Impacts

Social and institutional impacts of solar AIPH applications fall into three major areas:

- Potential conflicts with provisions of existing laws and regulations (e.g., building code violations)
- Need for expansion of existing practices and procedures (e.g., extension of insurance coverage, loan availability)
- Need for creation of new social and institutional structures (e.g., solar access regulations)

Most social and institutional impacts will occur during the planning and construction phases of AIPH projects. Issues at this stage include system evaluation and selection, siting and design of visually obtrusive components, financing, labor management, building code and zoning compliance, insurability, and safeguarding future access to sunlight. During system operation, system performance, insurability, product quality, and solar access impacts (if not resolved earlier) will apply; new issues will include impacts arising from tax and utility policies. No special social/institutional impacts related to decommissioning solar AIPH systems are foreseen.

Because the majority of potential social/institutional impacts result from the technology's novelty, impacts are expected to decrease substantially as solar energy use increases and existing institutions are adapted to accommodate it.

Social and institutional issues raised by solar energy development have been studied extensively in recent years. Although research efforts have focused on residential heating and cooling rather than process heat, many of their findings can be applied to AIPH. Based on the research literature, documented experience, and AIPH site visits and interviews, the following issues have been identified and evaluated for this EA:

- Solar industry regulation and product quality control
- Compliance with Federal regulations
- Taxes
- Insurance
- Building codes
- Zoning and land use controls
- Utility company impacts
- Building industry response
- Availability of financing
- Consumer acceptance

A comprehensive treatment of solar energy impacts on these areas is impossible within the space of this document. Instead, this section provides a brief, issue-by-issue summary of potential impacts, the degree to which they have been or may be experienced in actual solar applications, and their implications for eventual widespread solar deployment.

3.1.7.1 Solar Industry Regulation and Product Quality Control

Equipment safety, performance, resource requirements, and appearance are factors influencing product acceptability. These concerns have been institutionalized for solar systems in general; however, no formal criteria exist for solar agricultural and industrial process heat systems. The spread of solar AIPH systems will be accompanied by the development of mechanisms to ensure solar system quality, reliability, and safety. These may include changes in existing structures and development of new regulations and standards specifically for solar process heat. This will be necessary because existing regulations may impose irrelevant requirements on unconventional systems while failing to address special problems arising from their unique characteristics. Perhaps more importantly, product controls commonly are used as a basis for determining loan and insurance acceptability. Similarly, availability of standardized product information, standards, and warranties will be an important factor in influencing builders and designers, regulatory personnel, and financial decisionmakers to accept solar AIPH applications.

The pressing need for product standards, testing and accreditation systems, and operating data is widely recognized by solar manufacturers, builders, and potential solar users, lenders, code administrators, etc. In the absence of such controls, uncertainty about equipment quality, performance, and reliability slows general institutional acceptance of the technology. Second, the lack of standardized methods of testing and data presentation hinders product evaluation and comparison.

A number of strategies for solar product testing, certification, and guarantees currently are being pursued. Many States have passed legislation to establish performance standards for solar energy systems, but few specify the criteria to be used. To date, only California and Florida have testing and certification policies for solar systems. The Solar Energy Industries Association (SEIA) will be publishing certification

standards for solar collectors in early 1979 based on ASHRAE 93-77. These standards will relate only to the thermal performance of collectors. In addition, DOE has contracted with the Solar Energy Research and Education Foundation (SEREF) to develop a solar collector rating, certification, and labeling program. They will establish standards for collector reliability and thermal performance (Meeker, 1978).

Solar system certification and quality control also may be accomplished through the inclusion of product standards in established building codes. The National Bureau of Standards, with funds from DOE, has awarded contracts for the development of model code provisions for solar heating and cooling. The awards went to BOCA, ICBO, SBCC, the National Conference of States on Building Codes and Standards (NCSBCS), the Council of American Building Officials, the National Institute of Building Science, the American Institute of Architects Research Corporation, and the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE). This effort is to result in uniform code provisions covering safety and health requirements to be adopted by states and localities (Meeker, 1978).

Presently, criteria for solar systems in building codes concern only thermal performance of collectors and storage (ASHRAE 9377 and 9477). No guidance is given for health, safety, durability, reliability, structural strength, system materials, equipment or installation (Meeker, 1978). Because of the variability of building codes, general safety and durability standards and specific collector performance criteria are applicable only within specific jurisdictions. In addition, enforcement of building codes usually is delegated to local officials who are unfamiliar with solar systems. In some cases, because of tax incentives, it is tax officials who certify solar systems for compliance with standards.* Therefore, although building codes may mitigate some problems, some temporary measures may be required to ensure product regulation and quality control.

* Dyer, R. (SEIA). 1979. Personal communication.

Other possible interim solutions include independent testing, certification, strong product warranties, data dissemination on the part of manufacturers, and consumer education about solar technology and its applications.

3.1.7.2 Compliance with Federal Regulations

Solar AIPH applications must comply with Federal environmental laws and regulations. Relevant Federal laws include: the Resource Conservation and Recovery Act; Toxic Substances Control Act; Occupational Safety and Health Act; Clean Air Act; Safe Drinking Water Act; and other appropriate Federal agricultural and industrial regulations. The dominant impacts of regulatory standards are in the areas of fluids and waste handling, but standards for food production and processing also must be satisfied. The Clean Air Act and Safe Drinking Water Act are not anticipated to cause regulatory difficulties. Included below are summaries of the regulatory impacts of Federal laws pertaining to solar agricultural and industrial process heat applications (U.S. DOE, 1978).

Resource Conservation and Recovery Act (RCRA) (P.L. 94-580)

Under proposed new standards of RCRA, solar heat transfer fluids may be labeled as hazardous wastes. (E250:12-13, E3001). In this situation, compliance with hazardous (subtitle C) disposal regulations would be required. Special techniques for removal and disposal of used system fluids and wastes from auxiliary units may be necessary.

Toxic Substances Control Act (TSCA) P.L. (94-469)

Potentially toxic heat transfer fluids and additives may be used in solar AIPH systems. The release of toxic vapors as a result of fire or outgassing is possible. Use of these chemicals may be controlled by TSCA if their use in solar applications is determined to be a "significant new use", and then a pre-manufacture notice will be necessary (E5).

Testing of the fluids also may be required. Regulation under both TSCA and RCRA, though possible, is considered unlikely by EPA.

Occupational Safety and Health Act (OSHA)

Workers involved in the production of heat transfer fluids and maintenance of solar AIPH systems may be exposed to toxic gases or fire resulting from insulation outgassing and the autoignition or combustion of working fluids. OSHA regulates the use of flammable and combustible liquids under Sec. 1910.106. In addition, the General Industry Health Standards limit allowable exposure to hazardous substances.

Clean Air Act Amendments of 1977 (P.L. 95-95)

Operational air quality impacts of solar agricultural and industrial process heat systems are relatively insignificant. However, air quality could be impacted indirectly by auxiliary unit emissions. Auxiliary units with the capacity to combust heat input of 250 million Btu/hr or greater are subject to existing New Source Performance Standards (NSPS) and the Prevention of Significant Deterioration of Air Quality Standards (PSD) for fossil fuel-fired steam generators (E111).

Federal Water Pollution Control Act as amended by Clean Water Amendments of 1977 (P.L. 92-500, P.L. 95-217)

Flushing, disposal, and leakage of hazardous heat transfer fluids and auxiliary unit residuals may have adverse effects on water quality. The discharge of toxic heat transfer fluids or residuals into navigable waters requires National Pollutant Discharge Elimination Systems (NPDES) permits. Pretreatment standards apply to fluids entering publicly owned treatment works.

Safe Drinking Water Act of 1974 (P.L. 93-523)

Some solar AIPH applications will be subject to compliance with the National Interim Primary Drinking Water regulations under the Safe

Drinking Water Act. In addition, standards for best management practices applicable to fluid leaks are being considered. Applications which may be subject to compliance include any in which potentially hazardous fluid releases or disposal may enter into and contaminate public water systems.

Other Regulations

Product contamination during food processing and production often is the subject of regulation. In solar AIPH applications, fluid leakage and insufficient heating may promote product contamination. Food and Drug Administration regulations control chemical levels in foods. Food products which are processed through solar agricultural and industrial process heat also must meet the requirements of the Food and Drug Administration (FDA) Good Manufacturing Practice in Manufacturing, Processing, Packing or Holding Human Foods; Food Standards; and Low Acid Canned Foods regulations (21 CFR Parts 100-199).

U.S. Department of Agriculture (USDA) regulations govern the levels of process heat required in food preparation. Title 9, CFR, Chapter III, Animal, and Plant Health Inspection Service regulations control labeling and define quality standards for agricultural products with which solar AIPH systems applications must comply. Some applications of solar process heat, such as can washing, bottling, fruit and crop drying, or dairy production are subject to the USDA Food, Drug, and Beverage Equipment regulations.

Operators of DOE solar AIPH demonstration projects surveyed for the assessment were aware of applicable regulatory standards and felt that compliance with them would not be constrained by solar system use. In addition, on-site inspection of some demonstration projects by Federal officials showed them to be in compliance with existing regulations (EEA, 1978b).

3.1.7.3 Taxes

Solar energy development already has led to modification of a number of existing tax laws, and this impact is likely to grow in the future. Tax law changes have two purposes: to reduce tax assessment for existing solar installation and to provide incentives for increased use of solar energy. The degree to which existing tax structures have penalized users of solar energy systems is difficult to establish, particularly since many solar installations and monitoring studies have not been in operation long enough for comparative tax burdens to be known. However, a number of solar AIPH users interviewed for this assessment indicated that their property tax assessments either had or were expected to increase as a result of the solar installation. In another case, a farmer felt that despite its higher cost, his solar-equipped grain drying facility would be assessed at the same rate as a conventional one because a local tax assessor would not be qualified to apply any special value or rate (EEA, 1978b).

Tax incentives are considered necessary and desirable by most elements of the financial, industrial, and consumer communities if widespread market penetration is to occur. Such incentives may include:

- Sales tax exemption
- Income tax credit or deduction
- Property tax credit or deduction
- Rapid amortization of solar equipment costs
- Investment tax credit

Federal and state tax incentives as of 1978 are summarized in Table 3-4.

Current information on the monetary impacts of such laws to date is limited. The number of individuals taking advantage of State solar tax incentives for heating and cooling has varied from practically none to hundreds. Among individuals interviewed for this assessment, awareness

TABLE 3-4. STATE FINANCIAL INCENTIVES FOR SOLAR USE
(Exclude Provisions Limited to Residential Applications)

TAX MEASURES						
Credit	Exemption	Deduction	Refund	Amortization	Special Assessment	Financial Measures
FEDERAL (for industrial investment in alternative energy property, such as non-boiler burners for alternate fuels, heat conservation equipment, and recycling equipment)	Arizona (S) Connecticut (S) Georgia (R) Hawaii (R) Maine (R) Massachusetts (R) Michigan* (business tax) Michigan (excise tax) Michigan (R) Montana (R) New Hampshire (R) New York (R) North Dakota (R) Oregon (R) Texas (S) Texas* (business tax) Vermont (R) Virginia (R) Washington (R)	Indiana (R) Kansas* (amortization) Kansas (I) Kansas (I) (cost of system) Massachusetts* (I) New Jersey (R) Idaho (I) Arizona (S) Connecticut (S) Texas (S) Maine (S)	Georgia (S) Kansas* Maine (S)	Arizona Massachusetts Texas	Colorado Connecticut Illinois Maryland Nevada No. Carolina	Massachusetts Montana Oregon

Key: (I): Income
(R): Real estate, personal property
(S): Sales
* : Laws specifically aimed at business or agriculture.

Sources: Energy Tax Act of 1978

National Solar Heating and Cooling Information Center. January 1978. Personal Communication.

Swain, J.R. April 1978. "State Focus on Tax Incentives, Lag Behind on Sun Rights, Codes," Solar Engineering (3):4:22-25.

TABLE 3-4, continued

<u>Total by Type of Measure</u>		<u>Total by Type of Tax</u>	
Credit:	6	Income:	8
Exemption:	19	Real Estate/ Property:	17
Deduction:	10	Sales:	9
Amortization:	3	Excise:	<u>1</u>
Special Assessment:	6	Total	37
(Total Tax):	(46)		
Financing:	<u>3</u>		
Total	50		

and use of applicable tax incentives also varied widely (EEA, 1978b). Some were unaware that incentives were available to them. Others planned to use any available incentives, but were not sure how much money would be saved.

Tax law changes also will provide publicity and promote solar technologies (Booz, Allen, and Hamilton, 1976). Indeed, literature suggests that the second benefit may greatly outweigh the first. Most State taxes would not be reduced substantially even if the full cost of solar energy equipment were deducted (Arthur D. Little, 1976). Large dollar commitments are required to provide tax incentives which will affect the economics of solar use significantly. These commitments may be beyond the resources of most States (Arthur D. Little, 1976). In some States, incentives probably will not be worth their administrative costs (Ruegg, 1976). They also are more expensive than low cost loan programs and may be more difficult to phase out (Booz, Allen, and Hamilton, 1976).

3.1.7.4 Insurance

Insurance availability and cost are important for any relatively new or rare technology. The insurance industry generally takes five years to develop loss experience on which eligibility and rates are based (Whatmore, 1977). However, impacts on user insurance should be minor (Whatmore, 1977 and EEA, 1978a). In fact, the adjustment period for solar energy systems may be shorter than for some other new technologies because solar systems use conventional hardware and because most share a similar "theme of construction," within which the marketplace will determine the merits of specific products (Whatmore, 1977). Similarly, AIPH applications will benefit from insurance experience developed as a result of solar building heating and cooling systems. In summary, although there may be some uncertainty in the initial years of DOE's Solar AIPH program, long term adverse impacts on either the insurance industry or its clientele are not likely.

3.1.7.5 Building Codes

Because there is little express provision for solar energy use in existing building codes, solar systems are subject to a wide range of general provisions and discretionary powers. It has been suggested that application of building codes to solar systems could cause building delays, adversely affect solar economics by applying irrelevant and overly stringent provisions, or restrict collector size, configuration, or placement (especially on roofs) (Solar Engineering, 1977 and Meeker, 1978). Building code-related impacts will not pose a significant barrier to solar energy development in general or to AIPH systems in particular. Few, if any, code-related problems have occurred in connection with solar heating and cooling and even fewer in AIPH applications to date (EEA, 1978). Furthermore, many agricultural and industrial establishments are located in rural areas where building codes are not in effect. In some States, agriculture is specifically exempted from building code application (EEA, 1978b). However, building code impacts may increase in the future as solar applications become more widespread (Meeker, 1978).

Modification of building codes and regulations to include solar energy applications currently is underway at both the national and State levels. The National Bureau of Standards has awarded contracts for model solar code development to a number of groups including BOCA, ICBO, SBCC, the National Council of States for Building Codes and Standards (NCSBCS), the Council of American Building Officials (CABO), the National Institute of Building Sciences (NIBS) and the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE). Another trade organization, the International Association of Plumbing and Mechanical Officials (IAPMO) already has produced a "model solar code" which has been the subject of some controversy and criticism (Meeker, 1978). National Standards for solar equipment rating, certification, and labeling also will play a role in future building code modification and application to solar systems.

Most States and localities are likely to adopt model solar code provisions for use in their jurisdictions. Minnesota already requires solar installations to comply with the latest Federal standards (Meeker, 1978). Several other States have taken actions to minimize future building code barriers and related problems by requiring (or allowing jurisdictions to require) new construction to facilitate future installation of solar devices and/or providing for certification of solar system performance to meet code requirements (NSHCIC) (Meeker, 1978).

3.1.7.6 Zoning and Land Use Controls

Zoning and land use impacts of solar AIPH applications will depend largely on the degree of existing control. Most agricultural applications will not be subject to formal zoning controls, although they may be affected by overall land use plans at the county, metropolitan, or State level. Industrial applications, if regulated, likely will fall in industrial, commercial, or mixed zones. Regulations in such areas focus on potential nuisances such as noise, odor, etc., which will not be affected by solar system use. No esthetic objections to solar systems are likely to arise in industrial zones (Hayes et al., 1978). AIPH applications could occur in the "Garden Factory District" in which research and light manufacturing activities are combined in a campus-like setting (Hayes et al., 1978). In this zone type, esthetic considerations are more important, but should not preclude solar system use.

A second zoning/land use issue in AIPH development is that of solar access (preventing shading of structures or vegetation by collectors). Agricultural and industrial solar collectors should encounter few problems in this area. A number of potential remedies have been proposed or are available now for specific cases (such as easements, restrictive covenants, and solar zoning) and a number of States have enacted laws expressly providing for their use (Table 3-5) (Hayes et al., 1978).

TABLE 3-5. STATE SOLAR ACCESS LAWS

<u>STATE</u>	<u>BILL</u>	<u>DESCRIPTION</u>
Colorado	CH. 326 Laws of 1975	Provides procedures for recording voluntary solar easements.
Kansas	CH. 227 Laws of 1977	Provides procedures for creation of voluntarily negotiated solar easements between property owners.
Maryland	CH. 934 Laws of 1977	Provides that negotiated restriction on the use of land or water for the purpose of protecting solar access shall be enforceable in law and equity. Restrictions can be created by voluntarily negotiated easements, covenants, restrictions, or conditions between property owners.
New Mexico	CH. 169 Laws of 1977	Declares that access to sunlight is a transferable property right. Provides that disputes over solar access shall be resolved by prior appropriation rule modified by court decisions. Effective 7/1/78.
North Dakota	CH. 425 Laws of 1977	Provides procedures for the creation of voluntary solar easements.
Oregon	CH. 153 Laws of 1975	Adds solar energy considerations to comprehensive planning. Allows city and county planning commissioners to recommend ordinances governing building height for solar purposes.

SOURCE: National Solar Heating and Cooling Information Center, January 1978.
Personal Communication.

No cases of adverse zoning, land use controls, or access impacts were encountered in the interviews and project reviews conducted for this assessment. The literature suggests that solar access may be a greater concern as solar system use becomes more widespread. Adverse impacts from collector shading will be more likely in the short term, decreasing as legal remedies become established and routine.

3.1.7.7 Utility Company Impacts

General Issues

The potential impacts of widespread solar energy use on utility operations, revenues, and pricing policies are varied and complex. In some cases, widespread solar energy use could benefit the utilities by using more power at off-peak periods, thus acting as a load leveler enabling the utility to reduce expensive peak generating capacity. However, solar energy use also could reduce overall demand (and revenues) while still exerting heavy peak demands during periods of extended adverse weather when solar collection and thermal storage systems are inoperative. The construction and maintenance of little-used generating capacity to meet such peak demands is an expensive proposition and could strain the financial capabilities of utility companies. However, pricing schemes designed to recover the cost of service to intermittent users by charging for peak demand as well as capacity usage may discourage solar energy usage. Although a number of measures have been proposed to promote solar use through utility pricing and policies and to cover the costs of utility service to solar customers, these may be conflicting goals in some cases. Consequently, careful attention must be given to the development of alternative rate structures which would not penalize solar system users and, at the same time, would enable utilities to maintain sufficient revenues and profits. All of these issues are complicated by the fact that the utility industry already is regulated extensively on both the Federal and State levels, especially in terms of energy pricing schemes.

There is no formal industry-wide policy on solar energy. Many utility officials see solar energy use as only one of many factors with the potential to unbalance loads and, thereby, adversely affect revenues. There is little immediate concern about solar impacts or utility responses because it is presumed that many years will be required for solar users to make up a significant portion of electric consumers. Although current trends toward demand pricing may be seen as unfavorable to solar use, solar energy issues are not likely to be a forcing factor in such decisions.

Several studies indicate that widespread solar energy use may reduce utility revenues during some periods. This effect will be greater for winter peaking than for summer peaking utilities, but summer peaking utilities also may experience a gradual decline in revenues.

Availability of Service

Although utilities may be expected to react negatively to decreased overall energy use and fluctuating demand that could result from widespread use of solar energy systems, it is unlikely that they will respond by refusing to provide backup service. Such action would be precluded by Federal antitrust laws, and by common law and statutory mandates for public service by utilities (ELI, 1978).

Rate Changes

Usual rate structures include:

- Declining Block Rate - Rate declines as power use increases; favors large energy users
- All-electric rate - special rate for all-electric users
- Interruptible Service Rate - mostly used by industries where continuous service is not required

Rate structures which could be adapted in response to solar energy include:

- Demand/Energy Charge - Combines a total energy charge per kW used with a higher charge based on maximum demand in a given period. This system has been used for large commercial and industrial customers whose consumption justifies the cost of extra metering, but could be extended to solar users.
- Time of Day Pricing - Applies higher charge for energy used during periods of peak demand
- Promotional Rates - Sometimes used to attract customers to a given area; could be adopted to promote solar energy use
- Rate Inversion - Reverses declining-block structure, increasing cost of higher energy consumption; favors smaller energy users

The impacts of utility rate restructuring will vary greatly depending on individual utility operating characteristics. Rate inversion is seen as a potential mild incentive. Time-of-day pricing could encourage use of thermal storage systems, but could be quite expensive to utilities because it would require special metering and controls. Conversely, it allows utilities to better use the equipment they have rather than invest in new equipment, and special off-peak tariffs induce the public to level out peak hour use and get maximum use from alternative energy systems (Inside DOE, 8/21/78). Energy demand systems may increase backup energy costs. DOE's Economic Regulatory Administration (ERA) has recommended that utilities avoid "rate discrimination" in backup charges. However, ERA has no power to overturn rates discriminating against alternative energy users.

None of the agricultural or industrial solar energy users contacted in developing this assessment has experienced any change in availability or cost of backup power. In several cases, however, utility suppliers were reported as "disapproving" the idea of supplying solar users, and users felt that utility resistance would increase as solar use grew. Private farmers showed the least concern, indicating that natural gas for crop drying often is supplied by a dealer who also provides many other farm

products and services, and who could not afford the loss of goodwill that would result from any discrimination against solar system use (EEA, 1978b).

In summary, although there has been little impact on utility operations and rates by solar energy use to date, some change in rate structures and power costs to solar users is likely in the future.

3.1.7.8 Building Industry Response

The decision to use a solar system in an agricultural or industrial setting usually will be based on factors other than building industry marketing. Furthermore, many small solar AIPH systems may be installed by in-house labor or by small contractors, requiring little contact with the building industry at large. While higher degrees of craftsmanship may be required for solar energy system installation than conventional HVAC equipment, it uses skills already existing in the construction industry. Solar system construction is inherently labor intensive and is expected to create new jobs for the construction industry. Cumulative labor requirements for solar AIPH applications to the year 2000 have been estimated from .46 (base case) to 1.39 (maximum case) million labor years. (DPR, 1978).

Most AIPH systems surveyed for this assessment were installed by general contractors and/or in-house labor. In some cases solar system designers or suppliers provided special supervision. No major labor-related problems arose during construction. However, jurisdictional disputes between labor unions have been suggested as a potential source of conflict at solar construction sites. Two of the major unions potentially involved in solar equipment handling and installation, the United Association of Plumbers (UAP) and the Sheet Metal Workers Association (SMWA) have reached a formal agreement on work crew composition and job assignments to prevent future jurisdictional disputes. Other unions (carpenters and electrical workers) anticipated no jurisdictional problems arising from solar installation.

Although labor and construction problems probably will be resolved as they occur, it is difficult to generalize based on the limited experience to date. Some site-specific problems could delay construction as solar AIPH use becomes more widespread.

3.1.7.9 Availability of Financing

Capital availability appears to be less of an issue for solar AIPH than for heating and cooling applications, because industrial and agricultural operations usually have sources of capital for operating equipment which can be applied to solar systems. Research focused on savings and loan association policies toward solar financing indicates a trend toward increasing acceptance which is likely to be reflected in solar AIPH financing (Solar Engineering, January 1978). None of the projects surveyed for this assessment had experienced any difficulty obtaining financing.

3.1.7.10 Consumer Acceptance

System cost, performance, and reliability are major factors in user acceptance of solar AIPH systems. Cost is the overwhelming factor; even many current solar users interviewed indicated that they would not invest further, and did not expect others in their industries to do so, due to high costs. Cost-effectiveness and near-term consumer acceptance are most likely in relatively small, simple systems such as grain-drying applications. A final factor that has affected consumer acceptance of solar energy in recent years has been the climate of uncertainty as to Federal support and incentives for the technology. This was brought up consistently in AIPH project interviews as a cause of general hesitation and delay in entering the solar field. Presumably, passage of the National Energy Act will resolve this problem.

3.2. SECONDARY IMPACTS

Since solar radiation is a relatively diffuse form of energy, large areas of collectors are needed to capture significant amounts for agri-

cultural and industrial processes. As a consequence, solar AIPH systems are more materials-intensive than most conventional fuel-fired energy systems. This section will explore the resources requirements for solar AIPH systems, along with the pollutants resulting from the production of materials used in the systems. The basis for this analysis is a study performed by Battelle Memorial Institute at the Pacific Northwest Labs on possible resource supply constraints resulting from large scale deployment of solar systems. Three existing solar AIPH systems were examined in the study and described in terms of materials requirements: a shallow solar pond system to provide process heat water for a uranium mining and milling complex at Bibo, New Mexico, a water-based flat plate collector system for a lumber kiln in Canton, Mississippi, and a parabolic trough concentrating collector system for textile drying at the Westpoint Pepperell Mill in Fairfax, Alabama. The Battelle analysis included all system components.

It is assumed here that the AIPH program goals for the year 2000 -- solar providing 10 percent of industrial and 50 percent of agricultural process heat -- will be met with an equal mix of the three systems examined in the Battelle study. The three-system scenario will provide a general, if rough, indication of resource requirements for future solar AIPH systems. It is difficult to predict exactly which solar AIPH technologies will be used most extensively, but the three systems examined in the Battelle study represent technologies that likely will be among the more widely employed.

3.2.1 Resource Requirements

The growth of solar process heat applications will result in the diversion of large quantities of materials for the manufacture of solar system components. Table 3-6 shows the major materials requirements: carbon steel, aluminum, tempered glass and foam glass (a rigid insulation product). Battelle's study concluded that no significant supply

TABLE 3-6. MATERIALS AND ENERGY REQUIREMENTS FOR SOLAR AIPH SYSTEMS: THREE-SYSTEM SCENARIO

Material	Material Requirements				Energy Required for Production	
	(1)*	(2)*	(3)*	(4)	(5)	(6)
	Lumber Kiln System (kg/m ²)	Westpoint-Pepperell Textile Mill (kg/m ²)	Solar Pond System (kg/m ²)	3-System Scenario to Provide 10% of Industrial Energy Needs in 2000: (930 million m ² collectors) (metric tons)	Btu/metric ton final product	Total Btu's (column (4)x(5))
Carbon steel	91.0	25.9	7.1	38.4x10 ⁶	54x10 ⁶	2.08x10 ¹⁵
Aluminum	11.1	7.0	0	5.6x10 ⁶	196x10 ⁶	1.10x10 ¹⁵
Copper	2.5	1.1	0	1.1x10 ⁶	108x10 ⁶	0.12x10 ¹⁵
Tempered glass	14.9	0.6	0	4.6x10 ⁶	11.2x10 ⁶	0.05x10 ¹⁵
Fiberglass	4.2	2.3	0	2.1x10 ⁶	18.6x10 ⁶	0.04x10 ¹⁵
Foam glass	0	0	2.6	0.7x10 ⁶	?	?
Concrete	0	0	72.7	21.8x10 ⁶	1.3x10 ⁶	0.03x10 ¹⁵
Softwood lumber	76.0	0	0	23.6x10 ⁶	3.8x10 ⁶	0.09x10 ¹⁵
Sand	0	0	68.2	21.0x10 ⁶	0.06x10 ⁶	0.001x10 ¹⁵
Total						3.5x10 ¹⁵

NOTES: Included are materials required in amounts greater than 2 kg/m² of collector area for any or all of the 3 systems (4 lb/ft²).

* Columns 1-3 list actual materials used in three solar AIPH systems (see Battelle report).

SOURCES: California State Energy Resources Conservation and Development Commission, June 12, 1978. Final Impact Report: Residential Insulation Program.

Hannon, B. et al. November 1978. "Energy and Labor in the Construction Sector," Science (202):837-847.

Hayes, E.T. February 1976. "Energy Implications of Materials Processing," Science (191):661-665.

Watts, R.L. et al. (Battelle Pacific Northwest Laboratory). September 1978. Some Potential Material Supply Constraints in Solar Systems for Heating and Cooling of Buildings and Process Heat. Draft Report.

constraints would be encountered in manufacturing one billion square meters of solar collectors and associated system components over the next twenty years, which is slightly more than will be needed to meet the AIPH program goals (assuming that industrial and agricultural uses grow to roughly 50 quadrillion Btu's per year by 2000*).

Table 3-6 also shows the energy required for producing and manufacturing the major materials of the solar AIPH systems. The total figure of 6.8 quadrillion Btu's represents a cumulative use of energy over the fifteen years from 1985 to 2000; assuming a steady production rate, the yearly energy consumption would equal 0.6 percent of the total U.S. energy use in 1972. Solar AIPH systems in the three-system scenario will require roughly 1½ years of operation to generate as much energy as is used in the manufacture of their materials. Additional information concerning materials requirements for various solar technologies may be found in Risk of Energy Production, a study performed by Herbert Inhaber of the Atomic Energy Control Board of Canada (Inhaber, 1978).

* Of the 50 quadrillion Btu's ('quads') of energy that industry is projected to consume in 2000, approximately 30 quads will be used for generating process heat and process steam. These 30 quads will be supplied by electricity and fossil fuels in a ratio of roughly 1:3. Assuming that the various fossil fuel technologies (using coal, fuel oil, or natural gas) generate process heat and process steam with an overall average efficiency of 85 percent, and that electricity is converted to heat with 100 percent efficiency, the actual amount of process heat produced by 30 quads of fuels and electricity will be 26.5 quads.

AIPH program goals call for solar technologies to provide 10 percent of industrial process heat and steam by 2000. Ten percent of 26.5 quads is 2.6 quads, and using Battelle's calculations of energy output from the three AIPH systems, approximately 930 million square meters of collector area will be required to generate that amount of process heat. This total collector area represents an equal mix of the three AIPH systems.

3.2.2 Emissions, Effluents and Solid Wastes Associated with Production of Materials

The most significant environmental impacts associated with the production of the materials in Table 3-6 will result from increased air pollutant emissions and solid waste generation. To the extent that air pollutant emissions and solid waste generation may be significant (greater than 250 tons per year), AIPH system production will be subject to New Source Performance Standards (NSPS) and the Prevention of Significant Deterioration of Air Quality Standards (PSD) of the Clean Air Act Amendments of 1977 (P.L. 95-95). Additionally, any potentially harmful chemical substances and hazardous wastes generated during production will be regulated under the guidelines of the Toxic Substances Control Act (P.L. 94-469) and the Resources Conservation and Recovery Act (P.L. 94-580). The increase in water pollutant effluents will be minor, partly due to the mandatory use of best available effluent control technology for the iron and steel, aluminum, copper, glass, fiberglass, and concrete industries after 1983 (pursuant to the Federal Water Pollution Control Act as amended by the Clean Water Act of 1977).

Table 3-7 summarizes the air emissions from production of the major materials required in the three-system scenario. Pollutants resulting from combustion of fuels in the manufacturing processes are not included; assuming control technology comparable to that used for the listed process emissions, fuel combustion emissions will not be unacceptably high.

Table 3-8 lists the water pollutant effluents from materials productions. Since solar AIPH applications will not grow significantly until after 1985, it is assumed that all the industries listed in Table 3-8 will be using the best available control technology as required by law before 1983. On a national scale, these effluents are minor, and represent no significant environmental impact.

TABLE 3-7. AIR EMISSIONS RESULTING FROM PRIMARY MATERIALS MANUFACTURE FOR SOLAR AIPH SYSTEMS:
THREE-SYSTEM SCENARIO
(930 MILLION OF M² COLLECTORS)

Material	Emissions (exclusive of fuel combustion) (metric tons)						Flourides	
	Total Particulates	CO	SO (as SO ₂)	NO (as NO ₂)	Hydrocarbons (as CH ₄)	Ammonia	Gaseous (HF)	Particulates (CaF ₂)
Carbon steel	6.7x10 ⁴	1.6x10 ⁴	5.0x10 ⁴	0.05x10 ⁴	0.05x10 ⁴	0.2x10 ⁴	--	Neg.
Copper	0.2x10 ⁴	--	10.8x10 ⁴	--	--	--	--	--
Aluminum	4.4x10 ⁴	--	--	--	--	--	7.2x10 ⁴	0.4x10 ⁴
Concrete	2.5x10 ⁴	--	3.4x10 ⁴	--	--	--	--	--
Glass	0.5x10 ⁴	--	--	--	--	--	4.6x10 ⁴	--
Fiberglass	0.6x10 ⁴	0.3x10 ⁴	1.0x10 ⁴	0.7x10 ⁴	--	--	0.05x10 ⁴	--
Totals	14.9x10 ⁴	1.9x10 ⁴	20.2x10 ⁴	0.8x10 ⁴	0.1x10 ⁴	0.2x10 ⁴	11.9x10 ⁴	0.4x10 ⁴
Totals per Year (assuming constant produc- tion rate from 1985 to 2000)	9,900	1,300	13,400	460	40	20	4,800	270

NOTE: See Appendix F for emissions factors and control assumptions.

Source: U.S. Environmental Protection Agency (Office of Air and Waste Management/Office of Air Quality Planning and Standards). 1976. Compilation of Air Pollutant Emissions Factors, Second Edition. AP-42.

TABLE 3-8. EFFLUENTS RESULTING FROM MATERIALS MANUFACTURE FOR SOLAR AIPH SYSTEMS:
THREE-SYSTEM SCENARIO

Material	Total Suspended Solids	Oil and Grease	Phos- phorus	Effluents (metric tons)				
				Ammonia	Phenol	Sulfide	Fluoride	Cyanide
Carbon Steel	0.9×10^3	0.3×10^3	--	0.2×10^3	10.0	4.0	0.6×10^3	4.0
Copper	--	--	--	--	--	--	--	--
Aluminum	0.6×10^3	--	--	--	--	--	0.3×10^3	--
Concrete	50mg/liter	--	--	--	--	--	--	--
Glass	3.3×10^3	6.5×10^3	0.3×10^3	--	--	--	--	--
Fiberglass	--	--	--	--	--	--	--	--
Softwood Lumber	--	--	--	--	--	--	--	--
Totals	4.8×10^3	6.8×10^3	0.3×10^3	0.2×10^3	10.0	4.0	0.9×10^3	4.0
Totals per Year (assuming constant production rate from 1985 to 2000)	310	450	20	10	Neg.	Neg.	60	Neg.

NOTE: See Appendix F for effluent factor and control assumptions, as well as sources.

Various types and quantities of solid wastes will result from production of the materials in Table 3-6. Some of these wastes are generated during the manufacturing processes; some are generated by removal of pollutants from flue gases and process waste water. Many forms of solid waste are recycled within the manufacturing process; others are used elsewhere. Slag from copper smelters, for instance, can be granulated and used for concrete conglomerate or road surface material.

Solid wastes which may cause disposal problems are listed below:

- Nonrecyclable kiln dust from concrete manufacture: Controlling emissions from cement kilns results in quantities of dust material, some of which cannot be recycled to the kiln because of high alkalinity. Therefore, disposal of the potentially hazardous dust may be subject to compliance with regulations established by the Resource Conservation and Recovery Act (P.L. 94-580). In addition, landfill disposal of the high alkaline dust may limit future land use.
- Lime sludge from neutralization of process water in copper smelting operations: Neutralizing process waters with lime produces sludge which usually is disposed of by landfill. At one copper smelting and refining facility, neutralizing 68,400 cubic meters of process waste water (one day's output) is calculated to produce 36 metric tons of sludge (dry weight). Other industries may generate similar sludges. In general, proper landfill disposal of these sludges will not be a major problem.
- Brine residue from total process water recycle systems in glass plants: Brine residue must be disposed of in expensive lined storage basins to prevent groundwater contamination. Satisfactory effluent control can be achieved with systems that are less expensive than the total recycle system, so brine disposal may never be a problem.

In general, the major environmental impacts of producing solar ALPH systems will be those associated with mining and manufacturing the materials used in the systems. Fabrication and assembly of the system components will result in relatively little environmental damage, although residuals associated with these processes include metal tailings,

solvent and paint vapors, airborne particulates from insulation materials, and metal ion effluents from selective coating applications.

3.2.3 Energy Savings and Air Pollutant Reductions Resulting from Solar AIPH

It is expected that solar AIPH technologies will displace an increasingly significant fraction of conventional fuels consumption for industrial and agricultural process heat after 1985. Taking the solar AIPH program goal (10 percent of industrial process heat supplied by solar in 2000) as an initial assumption, Tables 3-9 through 3-13 illustrate the energy savings and pollutant reductions that will result from displacing fossil fuel and electricity consumption with solar energy. Whereas the energy consumption and pollutant releases associated with the manufacture of materials for solar systems will occur only once over the system's lifetime, the energy savings and pollution reductions from displacing conventional fuels will accrue as long as the system operates.

Since the air pollutant emissions described in the previous section do not include pollutants resulting from fuel combustion in the materials manufacturing industries, the quantities in Table 3-7 are not strictly comparable to those in Table 3-13. The energy figures in Tables 3-6 and 3-11, however, are comparable; as mentioned earlier, solar AIPH systems will generate as much energy as is used in production of their materials in $1\frac{1}{2}$ years of operation. One quad of solar AIPH energy will displace approximately 1.75 quads of fossil fuels in on-site combustion and electricity generation. Therefore, the "payback period" for fuels used in materials manufacture will be even less: roughly $\frac{3}{4}$ of a year.

Table 3-9. FUEL CONSUMPTION IN THE INDUSTRIAL
PROCESS HEAT AND PROCESS STEAM SECTORS
PROJECTED FOR 1995

<u>FUEL TYPE</u>	<u>CONSUMPTION FOR INDUSTRIAL PROCESS HEAT AND STEAM (10¹⁵ BTUs)</u>	<u>CONSUMPTION AS PERCENT OF TOTAL</u>
Coal	6.8	25%
Fuel Oil { Residual	2.2	8%
Distillate	0.9	3.5%
Natural Gas	10.1	37.5%
Electricity ¹	7.0	26%
TOTALS	27.0	100%

NOTES: ¹ Table 5 details projected fuel mix for electricity generation

SOURCE: EEA, Inc., preliminary unpublished data

Table 3-10. FUEL MIX IN THE ELECTRICITY
GENERATING INDUSTRY PROJECTED FOR 1990

<u>FUEL TYPE</u>	FUEL	ELECTRICITY
	INPUT (10 ¹⁵ BTU's)	OUTPUT (10 ⁹ KWH)
Coal	19.2	1,859.5
Fuel Oil	2.8	280.8
} Residual	0.2	
} Distillate		
Natural Gas	1.8	167.9
Nuclear	---	935.8
Hydro/Geothermal	---	370.5
TOTAL		3,614.5

SOURCE: Medium supply/medium demand projection from Department of Energy, Energy Information Association, Annual Report to Congress, Vol. II-1977.

Table 3-11. ENERGY SAVINGS RESULTING FROM
DISPLACEMENT OF CONVENTIONAL PROCESS HEAT
AND STEAM TECHNOLOGIES BY SOLAR AIPH ⁽¹⁾

FUEL TYPE	SAVINGS OF FUELS CONSUMED ON-SITE (10 ¹⁵ BTU's)	SAVINGS OF FUELS USED FOR ELECTRICITY (10 ¹⁵ BTU's)	TOTALS
Coal	0.76	1.21	1.97
Fuel Oil	Residual 0.24	0.18	0.42
	Distillate 0.10	0.01	0.11
Natural Gas	1.12	0.13	1.25
Hydro/Geothermal		0.24 ⁽²⁾	0.24
Nuclear		0.63 ⁽³⁾	0.63
TOTALS	2.22	2.40	4.62

NOTES: ¹This analysis is based on a displacement of 10% of projected industrial fuel consumption for process heat and steam in 2000, which represents a savings of roughly 3.0 quads. Since one-quarter of this amount is in the form of electricity, the production of which consumes approximately three units of fuel for every unit of electrical output, actual primary fuel savings will be significantly higher (as shown in the Table).

²Hydroelectric/geothermal input is figured at a heat rate of 10,383 BTU's/KWH of electric output.

³Nuclear input is figured at a heat rate of 10,660 BTU/KWH of electric output.

It is assumed that solar AIPH technologies will displace conventional fuels in direct proportion to their projected use in 1995 (see Tables 4 and 5).

Table 3-12. Emissions Factors Used in Calculating Air Pollutant Reductions Resulting from Displacement of Conventional Process Heat Technologies by Solar AIPH

Air Pollutant	Fuel			
	Coal (KO/Metric Ton)	Fuel Oil (KO/10 ³ Liters) Residual Distillate	Natural Gas (KO/10 ³ Cubic Meters)	
Industrial Boilers	Particulates	9.1	1.80	0.18
	SO _x (asSO ₂)	45.6	33.7	30.2
	CO	1.0	0.63	0.63
	HC(asCH ₄)	0.5	0.12	0.12
	NO _x	6.75	6.75	2.52
Electricity Generating Plants	Particulates	2.98	1.03	0.25
	SO _x (asSO ₂)	5.7	3.37	3.02
	CO	0.5	0.63	0.63
	HC(asCH ₄)	0.15	0.12	0.12
	NO _x	12.0	10.1	4.8

NOTES: Emissions factors expressed as kilograms per unit fuel burned, assuming use of typical emissions control technologies

SOURCE: U.S. Environmental Protection Agency (Office of Air and Waste Management/Office of Air Quality Planning and Standards). 1976. Compilation of Air Pollutant Emissions Factors, Second Edition. AP-42.

Table 3-13. REDUCTIONS IN AIR POLLUTANT EMISSIONS
 RESULTING FROM DISPLACEMENT OF CONVENTIONAL
 PROCESS HEAT TECHNOLOGIES BY SOLAR AIPH.
 (10^3 metric tons/year)

AIR POLLUTANT	INDUSTRIAL ON-SITE REDUCTIONS	REDUCTIONS AT ELECTRIC POWER PLANTS	TOTALS
Particulates	279.6	142.0	421.6
SO _x (as SO ₂)	1621.2	279.4	1900.6
CO	43.3	27.1	70.4
HC (as CH ₄)	17.0	7.6	24.6
NO _x	325.7	622.2	947.9

NOTES: Compiled from Tables 6 and 7.

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4. UNAVOIDABLE ADVERSE IMPACTS

Unavoidable adverse impacts associated with DOE's Solar AIPH program must be identified on two levels: impacts inherent in the technology or planned program elements, and cumulative and/or aggregate impacts of large-scale implementation of the technology.

Solar process heat systems seem to be benign environmentally. Where potential adverse impacts have been identified, viable mitigation strategies are available or can be developed in time for widespread solar AIPH deployment. Some adverse impacts and risks may be considered unavoidable in that there are likely to be some cases in which maximum mitigation strategies are not pursued, or in which design and/or operation of control measures is not completely effective. However, this is true for any technology and does not represent a risk specific to the AIPH program.

Similarly, few, if any, unavoidable adverse environmental impacts are expected to result from the cumulative or aggregate effects of large numbers of solar AIPH systems. Simultaneous discharge of ethylene glycol from several large systems to a single sewage treatment plant or waterway could have some adverse impact. However, such a configuration will not be common, and simultaneous discharges can be prevented by combining on-site controls (catchment basins, etc.) with coordinated flushing schedules among users sharing the same discharge facilities.

While widespread proliferation of solar energy systems will add a new visual element to agricultural and industrial facilities, actual esthetic impacts are likely to be local, with no significant cumulative adverse effects.

Conventional utility revenues may be reduced as a result of solar energy replacing electricity. As AIPH deployment becomes more widespread, cumulative adverse impacts on conventional utility revenues may become significant. However, this impact may be offset, to some degree, by modified pricing policies.

5. IRREVERSIBLE AND IRRETRIEVABLE COMMITMENT OF RESOURCES

Most AIPH system materials are recyclable. Recycling networks already exist for the major metals (copper, aluminum, and steel). Glass and insulation could be recycled if this becomes feasible from a supply/economic standpoint. Therefore, solar process heat utilization does not appear to involve extensive irreversible and irretrievable commitments of resources.

Nevertheless, there is a separation and transportation problem. Upon decommissioning, solar system components will have to be torn down, separated according to material, and transported to recycling centers. Certain of the materials will have to be cut down to suitable sizes and may have to have coatings or paints removed prior to recycling. For these reasons it is not clear whether materials recycling would be economical for an individual system. Hence, even though recycling is a feasible option, certain materials may not find their way into the recycling network. To the extent that this occurs, there may be an irreversible and irretrievable commitment of resources.

Another irreversible commitment of resources is in the use of petroleum in the manufacture of plastic cover plates and some types of insulation which currently are not recyclable. Figures show, however, that this commitment of petroleum represents only a tiny fraction of production.

The energy required by the processes and materials of solar process heat systems is substantial; yet, it appears that these energy requirements will be repaid by energy savings within the first few years of system operation.

6. SHORT-TERM VERSUS LONG-TERM ENVIRONMENTAL EFFECTS

Widespread use of solar energy systems to provide agricultural and industrial process heat initially may lead to adverse environmental impacts stemming from the novelty of solar process heat technology. Included in these impacts are potential surface and groundwater contamination as a result of working fluids release, visual impacts, and changes in utility block pricing. These environmental risks can be viewed as short-term since mitigation strategies are being developed. Furthermore, these impacts will be more than offset by the benefits realized through increasing use of solar energy in the place of non-renewable fuels. Specifically, by 1985, solar AIPH systems could replace up to one percent of current industrial and 10 percent of agricultural energy use (10 percent and 50 percent, respectively, by 2000). Replacing conventional energy sources with solar energy for process heat needs also will reduce adverse environmental impacts associated with fossil fuel extraction and combustion.

While physical and biological environmental impacts of widespread solar AIPH use will be few, long-term social and institutional shifts could occur. Existing laws and regulations may be modified as a result of widespread acceptance of solar process heat systems. In addition, financial, regulatory, and consumer judgements and evaluations on solar-related issues will be widened to include data and experiences related to solar process heat performance, costs, and reliability.

7. ALTERNATIVES

This section will examine options for the Federal solar agricultural and industrial process heat program which may be available to DOE as alternatives to current program strategies. For each alternative, social/institutional and environmental impacts will be discussed. The identification of social/institutional and environmental impacts resulting from the continuation of the present program forms the basis of the entire document. The purpose of this section is to compare the potential impacts of the existing solar AIPH program discussed herein with other available alternatives.

Five alternatives to the proposed action described in Section 2 have been identified. They are:

- No Action (discontinue the current DOE program)
- Accelerate the program schedule
- Delay the program schedule
- Emphasize agricultural applications of the program
- Emphasize industrial applications of the solar process heat program

7.1 NO ACTION

Under the No Action choice, the Federal involvement in solar agricultural and industrial process heat applications would be discontinued. Presently there are five congressional acts which authorize DOE to pursue research, development and demonstration (RD&D) programs aimed at effective utilization of solar process heat in agricultural and industrial applications (see Section 1.1.1). Ending Federal involvement with the solar AIPH program would be in direct contradiction of legislative mandates, and a special administrative or legislative action would be required to stop current programs.

A No Action choice also would hamper solar AIPH development and achievement of national energy goals. The absence of Federal support for demonstration programs would leave research and development reliant on private sponsorship. In the present stage of solar energy industry development (see Section 2.3), many solar manufacturers are small businesses which lack the capital and expertise for extensive R&D programs. The larger corporations, with sufficient R&D resources, in general have not committed enough funds to achieve widespread AIPH development pending secure indication of a developing market. Therefore, a No Action alternative may reduce the quantity and scope of solar AIPH systems applications. This may damage the fledgling solar industry as well as hinder the development and improvement of solar process heat systems.

Environmental impacts of the No Action alternative include the resource depletion and pollution associated with the continued use of non-renewable fossil fuels. Conventional oil- or coal-fired industrial boilers and power plants produce significant emissions of SO_2 , NO_2 and other pollutants, lowering air quality (Energy and Environmental Analysis, 1978). Displacing these plants with an equivalent capacity of solar process heat would reduce overall levels of air pollutants, particularly in industrial sectors. Water quality impacts also could be reduced with properly designed solar process heat systems. Acid drainage, increased sedimentation, temperature increase, and contamination of water are common to conventional fossil-fuel systems.

7.2 ACCELERATE THE PROGRAM

Under the current AIPH program, it is estimated that by 1985 solar energy could replace one percent of the present industrial energy and provide as much as 10 percent of agricultural process heat requirements. By accelerating the program schedule the positive impacts of earlier commercial acceptability may be realized. In addition, this would mean

earlier reduced dependence on conventional fossil fuels and imported fuels in the industrial and agricultural sectors. In general, acceleration would allow for energy savings in industry and agriculture by an earlier substitution of solar energy in feasible process heat applications. However, accelerating the program may have negative impacts in some social and institutional areas which could offset short-term gains. Present scheduling affords timely research, testing, development, and demonstration of solar systems components and applications. If accelerated, the program may suffer from the marketing of untested, uncontrolled, and/or inferior products.

Resource demands caused by accelerated solar AIPH system manufacture could increase costs and cause production delays. Adequate training and experience for manufacturers, installers, operators, and users is necessary, and accelerating the solar AIPH program may not allow time for expert training. This factor is particularly important in on-farm agricultural applications where engineering and technical expertise generally are not available. Also, reducing the time for environmental research may reduce opportunities to mitigate short-term health and safety impacts. In short, although earlier energy savings and decreased dependence on non-renewable resources may result from an accelerated program, associated social and institutional as well as site-specific environmental impacts may damage solar's image and delay widespread solar AIPH deployment.

7.3 DELAY THE PROGRAM

Delaying the program will result in continued reliance on depletable fossil fuels, imported resources, and related environmental impacts (i.e., air and water quality, land use, and costs). Energy savings and other benefits associated with solar energy use also will be delayed. Solar system commercialization would be hindered by continually rising

materials and labor costs. Many solar advocates feel that solar acceptance already has suffered from Federal delays in proposed incentives, budgeting, research, and development. Due to the present state of solar technology, it appears that the AIPH program would gain little by delay. Simply delaying the program may not assure the mitigation of engineering or installation/maintenance concerns, since they do not arise from inferior solar technology, but generally result from a lack of on-site experience and expertise. Therefore, program delays would most likely damage the solar image.

Delaying the program, however, may allow for further investigation of possible impacts of the solar AIPH program. In this respect, a delay could result in fewer impacts and greater public acceptance of AIPH use.

7.4 EMPHASIZE AGRICULTURAL APPLICATIONS

Agricultural uses of solar energy initially exceeded industrial applications in the Federal AIPH program, because of the ease with which agricultural solar systems may be applied. Generally, agricultural applications require lower temperatures and simpler systems. It is expected that by 1985 solar energy could account for 10 percent of agricultural energy use. Emphasizing agricultural applications may increase this percentage significantly, thereby increasing energy and financial savings in the agricultural sector. In addition, solar process heat applications would become widespread and, perhaps, more widely recognized and adopted for other small low temperature processes.

Although agricultural applications may be more amenable to solar process heat conversion, the overall effects of emphasizing agricultural applications as an alternative may not be beneficial. Agricultural processes account for only 2 percent of the nation's total energy use. Generally,

institutional standards and codes do not apply in the agricultural sector. Therefore, there may be less chance for product control and standards for equipment, installation, maintenance, and operation. Solar process heat applications in the agricultural sector are widely decentralized. Also, there is less technical expertise in the agricultural sector, allowing greater exposure to hazards associated with solar AIPH systems. Health, safety, and/or institutional impacts may not be mitigated adequately by emphasizing decentralized agricultural applications.

7.5 EMPHASIZE INDUSTRIAL APPLICATIONS

During 1976 and 1977, DOE shifted the relative emphasis of solar AIPH research and development from agriculture to industry. In doing so, intermediate temperature heat applications were accelerated, with expectations that by 1985 solar energy could replace one percent of industrial energy use. Emphasizing industrial applications may increase this percentage, energy savings, and the benefits associated with solar energy use.

Replacing fossil fuels in the industrial sector may, over time, reduce air and water pollution levels. In addition, since industry accounts for over 40 percent of the total energy used in the United States, the potential for overall energy savings through solar industrial applications may be more significant than in agricultural applications.

Industry typically employs on-site trained engineers with technical knowledge and expertise applicable to solar AIPH systems. Therefore, attention to and awareness of potential health, safety and other occupational problems may help mitigate hazards before widespread commercialization begins.

The industrial sector also is more subject than agriculture to compliance with Federal regulations, standards and codes. Solar AIPH appli-

cations concentrated in industrial applications will, therefore, undergo close scrutiny to meet existing production standards and perhaps encourage high product quality controls. New standards specifically related to solar process heat may result along with the elimination of low-grade equipment and inferior applications.

Summary

The major tradeoff represented by a No Action alternative is the avoidance of all environmental impacts associated with the DOE Solar Agricultural and Industrial Process Heat Program, which have been discussed throughout this Environmental Assessment. This, however, may be unacceptable not only in terms of DOE's mandate to conduct solar AIPH research, development and demonstration, but also in light of national energy policies and conservation goals.

Among the remaining alternatives, major tradeoff considerations include: energy savings, non-renewable resources, environmental impacts, product quality standards, social/institutional issues, and the public's view of solar AIPH commercialization. Given these considerations, the various solar AIPH program options may be compared.

The two options which call for a change in program scheduling may result in a more negative image of solar energy use. On one hand, acceleration will mean earlier commercialization and earlier energy savings, but may not address or resolve other environmental impacts adequately. On the other hand, delaying the AIPH program will allow enough time to mitigate environmental issues such as health, safety, solar rights, and regulatory codes and standards. In this case, however, delay will mean the continued use of depletable resources and reduced Federal stimulus for solar AIPH development and deployment.

The tradeoffs between agricultural and industrial applications already have been addressed by DOE in shifting to industrial emphasis. Although agricultural applications may allow earlier widespread use of solar process heat systems, they may not be amenable to timely mitigation of significant environmental impacts, since there is relatively little regulatory control. By emphasizing industrial applications, effective manufacturing, marketing, installation and maintenance strategies, and product quality controls and standards may be implemented, and health and safety and social/institutional impacts may be mitigated. However, industrial applications, being more geographically centralized, may not promote timely widespread acceptance and use of solar process heat.

Actual impacts of any of these alternatives will depend on the relative policy priority given to maximizing energy savings, minimizing cost, and minimizing potential environmental impacts. It should be noted that elements of various alternatives could be combined effectively within the existing DOE program. It also must be recognized that periodic program reviews in future years will reflect new conditions, technology advancements, and national priorities.

APPENDIX A. DESCRIPTION OF SOLAR COLLECTOR DESIGNS

Operating characteristics of each major collector type are described below, in ascending order of the working fluid temperatures they generate.

Greenhouses

Greenhouses are passive collection devices. Short-wave radiation from the sun and sky enter more efficiently than long-wave thermal radiation from materials inside escapes. Thermal energy accumulates inside until equilibrium is attained between the solar input and heat losses, particularly conductive losses through the greenhouse shell. Surplus heat can be removed by air ducts and used elsewhere or stored for use at night. Air temperatures of up to 150°F can be achieved.

Solar Ponds

There are two general types of solar ponds. Shallow solar ponds (see Figure A-1) typically are ten feet wide and no more than one foot deep. Water is contained in large, flat PVC plastic bags on a foundation of sand or gravel. Generally, the ponds are covered with bowed panels of rigid transparent plastic to protect the water bags from puncture and to increase energy retention by the greenhouse effect. Water temperatures of 150°F can be achieved.

Thermal-saline ponds (see Figure A-2), combine energy collection and storage functions. These ponds, generally around ten feet deep, are filled with a salt solution. The bottom half is a high density zone (approximately 15 percent sodium chloride solution) which absorbs solar short-wave radiation. From mid-depth to the pond surface, the brine concentration decreases to nearly 0 percent. This concentration gradient zone essentially is non-convective, thus insulating the bottom

absorptive zone from convective heat loss to the pond surface. Brine temperatures in the bottom zone can reach 175°F. Thermal-saline ponds can store solar energy for several months.

Energy is tapped by circulating the brine solution from the bottom zone through a heat exchanger. To maintain the brine concentration gradient, the top zone of the pond is disturbed as little as possible.

Flat Plate Collectors

Flat plate collectors (see Figure A-3) absorb solar radiation and convert it to thermal energy. The absorption plate (usually made of copper or aluminum) is painted black or coated to maximize absorption of short-wave solar radiation and minimize emissive losses of long-wave thermal radiation. Thermal energy is removed by a heat-transfer material moving along the plate. Where water is used, tubing is bonded thermally to the plate; where air is used, the air is blown over the front of the plate.

Thermal losses can be reduced by placing one or two sheets of glass or plastic several inches over the absorption plate and by placing a few inches of insulation under the plate. Flat plate collectors can be assembled on-site or purchased in finished form. Typical commercially manufactured collectors are three by seven feet. Working fluid exit temperatures usually reach 150°F but may reach 200°F.

Concentrating Collectors

A wide variety of collector configurations, most still being developed, operate by concentrating sunlight with mirrors or focusing lenses onto a small absorption element that carries the heat-transfer fluid. Most concentrating collectors employ mechanical tracking devices which keep the collector focused on the sun.

There are two stationary collector designs which focus at least some of the sunlight striking the collector over most of the day. These collectors -- the Stationary Tubular and Compound Parabolic Concentrator (see Figures A-4 and A-5) -- are less efficient but less expensive than tracking collectors. Design temperatures range from 160°F to 340°F.

Tracking collectors are single-axis or double-axis. Single-axis tracking collectors most commonly employ a reflective surface shaped in a parabolic trough (see Figure A-6) that focuses sunlight onto a one inch coated metal absorber tube above the reflector. In many designs the absorber tube is placed inside a larger glass tube, and the air between the two tubes is evacuated to insulate the absorber tube from convective and conductive heat loss. Solar energy concentrated onto the absorber tube is removed by a heat-transfer fluid (water, pressurized steam, or a hydrocarbon oil-based fluid).

The Linear Heliostat collector (see Figure A-7), has a stationary absorber tube mounted above a group of parallel mirrors, each of which tracks at a slightly different angle to reflect sunlight onto the absorber tube. The Stationary Stepped-Mirror collector (see Figure A-8), employs a fixed array of parallel mirrors over which a movable absorber tube tracks the changing collective focal axis of the mirrors. Several single-axis tracking collectors use linear fresnel lenses (see Figure A-9) instead of reflecting mirrors to concentrate sunlight onto absorber tubes.

Parabolic trough collectors generate fluid temperatures up to 212°F; most single-axis concentrators, in the 212°F to 660°F range. High performance stationary stepped-mirror and linear heliostat collectors can generate 780°F-1100°F process steam.

Double-axis collectors generally are more efficient than single-axis collectors, since they can maintain a precise orientation towards the sun all day. Three general types of double-axis tracking collectors are being developed. One is a series of parabolic trough collectors mounted on a carousel frame that rotates on a circular track. Combining the single-axis parabolic trough movement and the carousel rotation enables the collectors to face the sun throughout the day. The other two collectors employ more advanced designs. Large parabolic dish collectors (see Figure A-10) focus sunlight onto a single point. Heliostat/ central receiver collectors (see Figure A-11) employ a central receiver unit mounted on a tower, surrounded by a field of sun-tracking mirrors, or heliostats, which focus sunlight onto the receiver. An absorber element within the receiver converts solar radiative energy to thermal energy. A heat-transfer fluid (steam, molten salt, or hydrocarbon oil) carries the thermal energy down the tower and to the process. Working fluid temperatures can reach 790°F to 1100°F.

FIGURE A-1 SHALLOW SOLAR POND

Working Fluid: water

Design Temperature: 50-60°C (120-140°C) summer
30-35°C (85-95°C) winter

FIGURE A-2 THERMAL-SALINE SOLAR POND

Working Fluid: NaCl Brine

Design Temperature: 80°C (175°)

FIGURE A-3 FLAT PLATE SOLAR COLLECTOR

Working Fluid: water (as shown) or air

Design Temperature: 60-100°C (145-210°F)

FIGURE A-4 STATIONARY TUBULAR COLLECTOR

Working Fluid: water or steam

Design Temperature: 60-170°C (140-340°F)

FIGURE A-5 COMPOUND PARABOLIC COLLECTOR

Working fluid: water or steam

Design Temperature: 200°C (390°F)

FIGURE A-6 PARABOLIC TROUGH SOLAR COLLECTOR

Working Fluid: water, steam, or high-temperature heat-exchange fluid

Design Temperature: 40-100°C (100-210°F) low performance
60-200°C (140-390°F) high performance

FIGURE A-7 LINEAR HELIOSTAT COLLECTOR

Working Fluid: water, steam, or high-temperature heat-transfer fluid

Design Temperature: 500°C (930°F)

FIGURE A-8 STATIONARY STEPPED-MIRROR COLLECTOR

Working Fluid: same as above

Design Temperature: 500°C (930°F)

FIGURE A-9 LINEAR LENS CONCENTRATING COLLECTOR

Working Fluid: water, steam, or high-temperature heat transfer fluid
Design Temperature: 90-300°C (190-570°F)

FIGURE A-10 PARABOLIC COLLECTOR

Working Fluid: high temperature heat-transfer fluid
Design Temperature: 500-800°C (930-1400°F)

FIGURE A-11 HELIOSTAT/CENTRAL RECEIVER COLLECTION SYSTEM

Working Fluid: same as above
Design Temperature: 500-600°C (930-1100°F)

APPENDIX B
SOLAR ENERGY SYSTEMS MATERIALS
SURVEY OF HAZARDOUS PROPERTIES

1. INTRODUCTION

This appendix surveys the hazardous properties of materials suitable for use in solar process heat systems. The focus is on system components which may pose hazards to human health and the environment. The components examined are:

- Heat transfer fluids
- Insulation materials
- Seals and sealants
- Glazing and piping materials
- Heat storage media

The hazardous properties considered are those relating to thermal and thermoxidative stability, toxicity, and fire.

It is important to understand the distinction between a hazardous property and a hazard. A hazardous property of a material is one that can lead to personal harm or adverse environmental effects if the material is used improperly. Hazards result when the material is used in a manner that does not adequately protect against its potentially dangerous properties. This appendix details the properties of solar energy materials which, under certain conditions, may result in toxicity hazards or fire dangers. In general, these conditions will arise only during system upsets (e.g., leaks or stagnation) or if materials are handled or disposed

of improperly. Section 3 of the main text discusses the likelihood and consequences of such situations.

The materials included in this survey are either in use in solar process heat systems or are likely candidates for use. However, not every suitable material is discussed nor will every material considered be deemed appropriate for future solar energy systems. Furthermore, this survey does not attempt to rank materials with respect to efficacy or safety. It simply considers the hazardous properties of representative materials available for use in solar process heat systems.

The source of the data listed here is the Sandia Laboratories document entitled Hazardous Properties and Environmental Effects of Materials Used in Solar Heating and Cooling (SHAC) Technologies: Interim Handbook (hereafter referred to as the Interim Handbook).^{*} The handbook was prepared for residential solar energy technologies; however, since many of the materials used in residential systems also can be used in agricultural and industrial systems, the handbook is applicable to solar process heat materials. The data presented in the handbook were obtained mostly from surveys of published literature and manufacturer's brochures, although some chemical analyses of specific materials and some determination of chemicals produced in a high-temperature environment were performed by Sandia Laboratories. The handbook is an interim edition and is subject to change.

Before a discussion of the hazardous properties of solar process heat materials can be presented, the terms used must be defined and the limitations of the data outlined. This will allow the reader to

^{*} Searcy, J.Q., ed. August 1978. Hazardous Properties and Environmental Effects of Materials Used in Solar Heating and Cooling (SHAC) Technologies: Interim Handbook. SAND 78-0842. Prepared for the U.S. Department of Energy. Albuquerque: Sandia Laboratories.

interpret the data more accurately. The following sections provide the necessary background information.

1.1 THERMAL DEGRADATION AND THERMOXIDATIVE PRODUCTS

Health and environmental hazards can result from products of thermal degradation or partial oxidation of solar system materials. The information presented in this survey on degradation and thermoxidative products is applicable primarily to two abnormal conditions: collector stagnation (beginning at 205°C (400°F) for a flat plate collector) and fire. Since the gases emitted and the relative amounts of each primarily are a function of temperature, the data are characteristic only for the temperatures specified. Some of the data were obtained from literature and some were generated by Sandia Laboratories. The compilation is not complete. There are so many materials under consideration for solar process heat systems, and each material has so many possible degradation/oxidation modes and products, that an all-inclusive compilation of information was not feasible. Furthermore, many of the data were obtained for specific brand-name materials, but it cannot be assumed that the analyses conducted by Sandia are completely characteristic of the materials. This is because commercial products vary in chemical composition from one batch to the next and because the analyses were not repeated a sufficient number of times to ensure high accuracy.

The thermal stability of a material is its ability to remain chemically and physically intact when heated in the absence of oxygen or any other reactive gas. Thermoxidative stability relates to a material's stability when heated in the presence of oxygen or any other reactive gas. Both are important properties to consider in the selection of solar process heat materials since, depending on the system design, some components will be in contact with air (e.g., plastic glazings) while others will not (e.g., working fluids or insulations).

Sandia Laboratories measured the thermal and thermoxidative stabilities of solar system materials using a procedure known as thermogravimetric analysis (TGA). The material was heated in the presence of an inert gas or oxygen and a thermogravimetric analyzer measured the weight loss of the material. Sometimes the gas that evolved also was analyzed. In dynamic TGA, a sample of material was heated at a given temperature use rate (e.g., $10^{\circ}\text{C}/\text{min.}$), and the weight change of the sample at different temperatures was recorded. In solthermal TGA, a sample was heated rapidly to some specified temperature, and its weight monitored as a function of time. The tables in this appendix on the stabilities of various solar system materials specify the conditions under which the analyses were conducted.

1.2 TOXICITY

Most of the potential health effects of solar system materials will be toxic effects. Although the toxicity of most solar process heat materials has not been characterized completely, there are enough data to allow an initial estimation of the potential hazards likely to be associated with the use of many of the materials. Toxicity is the ability of a chemical molecule or compound to produce injury when it reaches a susceptible site in the body. Toxicity differs from a toxicity hazard in that toxicity is a property of a material, whereas a toxicity hazard results both from the properties of a material and the conditions of its use. Thus, the toxic effects of a chemical are dependent on the characteristics and conditions of exposure. They are related to the time and frequency of exposure, the dose delivered (including the physical and chemical form of the substance), and the route by which exposure occurs. A very toxic material may pose little hazard if it is used in a way that allows no exposure. Conversely, a moderately toxic material may pose a serious hazard if its use involves a high probability for human exposure.

Exposure to a toxicant may be acute or chronic. Acute exposure occurs when the dose is delivered in a single event and absorption is rapid; chronic exposure occurs when the dose is delivered at some frequency over a period of time. The effects depend on the toxicant delivered. For example, repeated exposure to a small amount of a carcinogen may be more dangerous than a single exposure to a large amount.

For any given route of exposure, toxicity will vary directly with the dose. However, while a dose may be low enough to produce no significant effects upon a single exposure, chronic exposure to the same dose may produce detectable effects.

The route of exposure to a toxicant will have a bearing on the effects observed due to differences in absorption and distribution. The most likely routes of exposure to solar process heat materials are inhalation and dermal (skin) contact. Toxicity data for ingestion also are included in this survey because of the possibility that toxic solar system materials or degradation products may contaminate food goods or drinking water supplies.

A common method for assessing the toxicity of a substance is to determine experimentally its toxic dose. The toxic dose defines the amount of a chemical required to produce some harm in an animal. It usually is given in units of mg/kg (milligrams (mg) of the substance administered per kilogram (kg) of the subject's body weight). The toxic dose may be expressed in a variety of forms; the two forms used here are:

- The LD_{Lo} (lethal dose low) - the lowest dose (other than the LD_{50}) introduced by any route over any given period of time which has been reported to cause death in humans.
- The LD_{50} (lethal dose fifty) - a calculated dose which is expected to cause the death of 50 percent of an entire experimental animal population.

In considering the toxicity data presented for solar process heat materials, several factors must be considered:

- A substance that in itself is highly toxic may not be of great concern because the system in which it is used minimizes or eliminates the probability of exposure.
- The hazard or even toxicity of a material may be changed by the conditions of its use, either "normal" or "abnormal." For example, conditions of high temperature and high pressure may convert a compound into a more or less toxic compound, or a fire may release very toxic combustion products which, when inhaled, may result in death or serious injury.

1.2.1 Toxicity Rating System

Two separate toxicity rating systems are used here to present toxicity information: one described by Durham*, and one described by Gosselin et al.**

Durham's system rates toxicity for four types of exposures and assigns numerical ratings to the toxic manifestations of a material. Definitions of the terms used in Durham's system are presented in Table B-1. It should be noted that Durham's system is not strictly quantitative. A material that is classified as slightly toxic for an acute systemic exposure can in fact cause death if it is ingested in large quantities.

Gosselin's numerical toxicity rating is based on the acute toxicity of a single dose taken orally. The system is presented in Table B-2. Although the Gosselin system uses the phrase "probable oral lethal dose (human)," assignment of a rating to a particular material usually is based on data obtained for laboratory animals.

* Durham, W.W. 1975. "Toxicology." In Dangerous Properties of Industrial Materials. Edited by N.I. Sax. New York: Van Nostrand Reinhold.

** Gosselin, R.E. et al., eds. 1975. Clinical Toxicology of Commercial Products. Fourth Edition. Baltimore: Williams and Wilkins.

Table B-1. DURHAM'S TOXICITY RATING SYSTEM

Type of Exposure	Severity of Toxic Effect
<ul style="list-style-type: none"> ● <u>Acute Local</u> - material contact in a localized area of skin or mucous membrane lasting seconds, minutes, or hours. ● <u>Acute Systemic</u> - introduction of a material into the body through inhalation, ingestion, or skin permeation over a time period of seconds, minutes, or hours. ● <u>Chronic Local</u> - repeated material contact in a localized area of skin or mucous membranes over a time period of days, months, or years. ● <u>Chronic Systemic</u> - repeated introduction of a material into the body through inhalation, ingestion, or skin permeation over a time period of days, months, or years. 	<ul style="list-style-type: none"> ● U - unknown, i.e., insufficient toxicity data are available. ● 0 - generally recognized as nontoxic under condition of normal use, or toxic only under unusually large exposures. ● 1 - slight toxicity; generally produce changes in the human body which are readily reversible and which will disappear following termination of exposure. ● 2 - moderate toxicity; may produce irreversible as well as reversible changes in the body, but the changes usually are not life-threatening and do not produce serious physical impairment. ● 3 - severe toxicity; produces irreversible, life-threatening changes in the human body.

Source: Durham, W.W. 1975. "Toxicology." In Dangerous Properties of Industrial Materials, edited by N.I.Sax. New York: Van Nostrand Reinhold

Table B-2. GOSSELIN'S TOXICITY RATING SYSTEM

Toxicity Rating or Class	Probable Oral Dose	LETHAL Dose (Human) For 70 Kg person (150 lb)
6 Super toxic	Less than 5 mg/kg	A taste (less than 7 drops)
5 Extremely toxic	5-50 mg/kg	Between 7 drops and 1 tsp.
4 Very Toxic	50-500 mg/kg	Between 1 tsp. and 1 ounce
3 Moderately toxic	0.5-5 gm/kg	Between 1 oz. and 1 pt. (or 1 lb.)
2 Slightly toxic	5-15 gm/kg	Between 1 pt. and 1 quart
1 Practically non- toxic	Above 15 gm/kg	More than 1 quart (2.2 lb)

Source: Gosselin, R.E.; Hodge; Smith; and Gleason, eds. 1976
Clinical Toxicology of Commercial Products. 4th edition.
 Baltimore: Williams and Wilkins.

1.3 Fire Hazard Properties

The fire hazard properties of solar system materials are an important consideration in assessing the safety of solar process heat systems. Since materials will be exposed to high temperatures, it is necessary to review the potential for autoignition of candidate materials as well as their behavior under fire conditions.

To aid in understanding the tables on fire hazard properties, a discussion of the terms used is given below. Descriptions of the various fire hazard tests can be found in the Sandia Interim Handbook. Caution should be used in interpreting the information presented, since there is no way to equate fire hazard with the data derived from tests. Each column in the tables gives an indication of relative hazard, which can be considered accurate only if all other parameters are equal. Consequently, all data must be considered if an assessment of the relative fire hazards of the different materials is to be meaningful.

1.3.1 Fire Hazard Properties Data for Solids

1.3.1.1 Ease of Ignition

Ease of ignition is defined as the facility with which a material or its pyrolysis products can be ignited under given conditions of temperature, pressure, and oxygen concentration. This property provides a measure of fire hazard in that a material having an ignition temperature significantly higher than that of another material is less likely to contribute to fire development, all other factors being the same in both cases. The column labeled ASTM D1929 in the tables gives the minimum air temperature necessary for the ignition (from a pilot flame) of the solid.

1.3.1.2 Surface Flame Spread

Data on surface flame spread provide a relative measure of the hazard associated with the transmission of flame along the surface of a given material. The numbers used in the tables to classify the flame spread of materials are relative indices. For example, red oak has a value of 100, while rigid urethane foam (polyester) has a value of 1000. This suggests that flame moves along the same size surface of the foam ten times faster than it does on red oak.

1.3.1.3 Heat Release

The heat release of a material is the rate at which heat is produced during burning of the material. The heat release rate is dependent on the external heat flux incident on the material, its configuration, the oxygen supply, and the nature of the material. Materials which release heat at a high rate will contribute to a greater fire intensity.

The Ohio State University test is a measure of the heat released from a surface that is exposed to radiant energy. The values under the column labeled ASTM E83 are measures of the heat released from a burning sample; the values are relative to the value for red oak (i.e., 100). Larger numbers mean a greater heat release (e.g., 200 would mean twice as much heat is released as from the same amount of red oak), and smaller numbers mean less heat is released. The column for total heat of combustion specifies the total amount of heat released for a given weight of material, regardless of the time involved.

1.3.1.4 Smoke Production

The tests for smoke production use a light beam that is attenuated by the smoke. The test is analogous to the visual effects caused by smoke. The NBS chamber test is conducted for a flaming sample and for a smoldering sample; large values indicate large amounts of smoke emitted.

1.3.2 Fire Hazard Properties Data for Fluids

In solar process heat systems, the fluid and fire points of the heat transfer fluids are the most indicative of the fire hazards encountered when there is a system failure resulting in large leaks.

1.3.2.1 Flash Point

The flash point of a liquid is the temperature at which a sample gives off enough volatiles to form an ignitable mixture with air. The flash point is an indication of the ability of a liquid to ignite; a lower temperature indicates easier ignition.

1.3.2.2 Fire Point

The fire point is that temperature of a liquid at which vapors are evolved fast enough to support continuous combustion. A higher temperature for the fire point indicates a lower degree of fire hazard.

1.3.2.3 Ignition Temperature

The third column on the tables for fluids gives the temperature at which a fluid in a nearly closed vessel will ignite spontaneously. In a solar process heat system, it is an indication of the hazards present when a liquid is contained but exposed to a high-temperature environment, such as a nearby fire. A higher ignition temperature indicates a lower hazard if two fluids are being compared.

1.3.2.4 Flammable Limits

Gases or vapors which form flammable mixtures in air or oxygen have a minimum concentration below which propagation of flame does not occur and a maximum concentration above which propagation does not occur. These borderline mixtures are known as "lower and upper flammable limits" and usually are expressed in terms of percentage by volume of gas or

vapor in air. A material with a wider flammable limit range (i.e., a small lower limit and a large upper limit) may be considered more fire hazardous than a material with a narrower limit range. A material with a lower low limit may be considered a greater fire hazard than a material with a higher low limit.

1.3.2.5 Vapor Density

Vapor density is the weight of a volume of pure vapor divided by the weight of an equal volume of dry air at the same temperature and pressure. A vapor density less than 1 indicates that the vapor is lighter than air and will tend to rise in a relatively calm atmosphere. A value greater than 1 indicates that the vapor is heavier than air and may travel at low levels for a considerable distance to a source ignition and flash back (if the vapor is flammable).

1.3.2.6 Boiling Point

Boiling point is the temperature at which the saturated vapor pressure of liquid equals atmospheric pressure. A flammable material with a lower boiling point generates more vapors at a lower temperature than does a flammable material with a high boiling point. Consequently, a material with a lower boiling point poses greater hazards during a fire.

1.3.2.7 Specific Heat

The specific heat of a material is defined as the quantity of heat absorbed (or released) when one unit of mass increases (or decreases) one degree of temperature. A material with a higher specific heat does not increase temperature as rapidly when abnormal heat sources are present; therefore, it does not produce vapors as rapidly as does a material with a lower specific heat. A material with a lower specific heat is a greater fire hazard if all other factors are equal.

1.3.2.8 Heat of Combustion

The total heat of combustion is the amount of heat released by one unit weight of a material during complete combustion. A material with a higher heat of combustion gives off more heat when burning than one with a lower heat of combustion and, thus, is more likely to sustain a fire if all other parameters are equal.

1.3.3 Suggested Fire Hazard Identification

The tables listing fire hazard properties of solar process heat materials include a column on suggested fire hazard identification. This warning system was developed by the National Fire Protection Association and is used by industry when large amounts of materials are stored. The hazard identification takes the form of a standardized decal placed on containers and buildings; its chief purpose is to warn firefighters of the dangerous conditions. Nevertheless, the rating system is of interest when considering materials used in solar process heat systems.

The system identified the hazards of a material in three categories: health, flammability, and reactivity. Only the latter two categories are included in this survey. The order of severity in each of the categories is indicated by five divisions, ranging from four, which warns of a severe hazard, to zero, which suggests no special hazard. The exact definitions for these indices are given below.

1.3.3.1 Flammability Hazard Identification for Firefighters

The basis for assigning risk indices within this category is susceptibility to burning. The hazard levels are defined as follows:

- 4 These materials are very flammable gases or very volatile flammable liquids. Shut off flow and keep cooling water streams on exposed tanks or containers.

- 3 These materials can be ignited under almost all normal temperature conditions. Water may be ineffective because of the low flash point.
- 2 These materials must be moderately heated before ignition will occur. Water spray may be used to extinguish the fire because the material can be cooled below its flash point.
- 1 These materials must be preheated before ignition can occur. Water may cause frothing if it gets below the surface of the liquid and turns to steam. However, water fog gently applied to the surface will cause a frothing which will extinguish the fire.
- 0 These materials will not burn.

1.3.3.2 Reactivity (Stability) Hazard Identification for Firefighters

The assignment of hazard levels in the reactivity category is based on the ability of materials to release energy either by themselves or in combination with water. The risk indices are as follows:

- 4 These materials are capable of detonation, explosive decomposition, or explosive reaction at normal temperatures and pressures. Such materials may be sensitive to mechanical or localized thermal shock. If a chemical with this hazard rating is in an advanced or massive fire, the area should be evacuated.
- 3 These materials are capable of detonation, explosive decomposition, or explosive reaction, but a strong initiating source or heating under confinement is necessary for initiation. Such materials are sensitive to thermal or mechanical shock at elevated temperatures and pressures, or they may react explosively with water without requiring heat or confinement. Fire fighting should be done from an explosion-resistant location.
- 2 These materials normally are unstable and readily undergo violent chemical change but do not detonate. Such materials can undergo chemical change with rapid release of energy at normal temperatures and pressures, or they can undergo violent chemical change at elevated temperatures and pressures. Also included are those materials which may react violently with water or which may form potentially explosive mixtures with water. In advanced or massive fires, fire fighting should be done from a protected location.

- 1 These materials normally are stable but may become unstable at elevated temperatures and pressures, or they may react with water with some nonviolent release of energy. Caution must be used in approaching the fire and applying water.
- 0 These materials normally are stable even under fire exposure conditions and are not reactive with water. Normal fire fighting procedures may be used.

2. HEAT TRANSFER FLUIDS

Heat transfer fluids suitable for solar process heat systems comprise five categories:

- Air
- Water
- Glycol-water solutions
- Hydrocarbon oils
- Silicone oils

The liquid heat transfer fluid often contains additives to inhibit corrosion and degradation (e.g., antioxidants, antifoaming agents, and corrosion inhibitors). For purposes of this discussion, additives are considered an additional category of heat transfer fluids. The chemical compositions of representative heat transfer fluids are given in the Sandia Interim Handbook.

2.1 Thermal Degradation and Thermoxidative Products

Sandia Laboratories tested the thermal stability of various liquid heat transfer fluids under conditions resembling system stagnation.* Table B-3 lists the outgassing products detected after seven days of heating at 232°C (450°F). These data indicate that the fluids tested are relatively stable in that none yielded outgassing products exceeding one percent of their weight.

* Arnold, C., Jr. and Trujillo, R.E. 1978. Composition, Stability, and Degradation Products of Selected Materials for Solar Heating and Cooling (SHAC). SAND-78-0681. Albuquerque: Sandia Laboratories. In preparation.

TABLE B-3. PERCENT COMPOSITION OF OUTGASSING PRODUCTS FROM
HEAT TRANSFER LIQUIDS AFTER AGING AT 232°C(450°F) FOR SEVEN DAYS

Decomposition Products	Silicone SF-96 50 (General Electric)	Ucon 50 HB-280 (Union Carbide)	Exxon Process, Oil 3029 (Exxon)	Caloria HT 43 (Exxon)	Dowtherm A (Dow Chemical)	Therminol 66 (Monsanto)	Mobil- Therm 603	Mobil Therm Light
Hydrogen	79	72	20	89	--	82	17	11
Methane	20	28	28	11	100	2	42	69
Ethene	Trace	--	3	--	--	--	2	--
Ethane	Trace	--	17	--	--	1	14	11
Water	Trace	--	8	--	--	15	5	2
Organics C ₂	--	--	--	--	--	--	19	6
Percent of liquid weight lost	0.044	0.05	0.45	0.07	0.5	0.04	0.45	0.17

SOURCE: Searcy, J.Q. 1978. Hazardous Properties and Environmental Effects of Materials Used in Solar Heating and Cooling (SHAC) Technologies: Interim Handbook. SAND 78-0842. Albuquerque: Sandia Laboratories.

Hydrogen and methane were the primary gases produced. These gases are quite flammable and potentially explosive. It is unclear whether the amounts of hydrogen and methane released during normal operations or stagnation conditions could create a fire or explosion hazard. Further testing is required. Inhalation of these gases generally poses little or no hazard to humans, however, the hazard may become more serious if the gases are allowed to accumulate in confined areas. In such an instance, the levels of hydrogen or methane may build up to the point that they act as asphyxiants. Proper ventilation practices should prevent the occurrence of such an event.

The thermoxidative stability of heat transfer liquids is an important consideration for systems where air may be in contact with the liquids due to leaks or system design. Oxidation of the liquids during stagnation conditions is a possible problem in such systems. To date, no testing on thermoxidative stability has been conducted.

2.2 Toxicity

The toxicity of heat transfer fluids is a significant concern since humans, livestock, and ecosystems may be exposed to these fluids. Installation and maintenance personnel working on solar process heat systems regularly will handle working fluids and inhale their vapors. Leaks, spills, and disposal of heat transfer fluids may contaminate working environments, food products, soils, and surface or groundwaters. Exposure to a particularly toxic liquid by any of these routes could result in serious health and ecological impacts.

The toxicity of a heat transfer liquid may be due to its main constituent (e.g., ethylene oxide) or to the treatment chemicals added to it (e.g., chromium compounds). A technical-grade liquid which in its pure form is nontoxic, may contain toxic residuals from the manufacturing process. Furthermore, nontoxic fluids may become toxic under certain conditions.

Although no systematic study of this phenomenon has been conducted, it is known that water standing in a metallic container for a long time can pick up toxic amounts of metals. Also, prolonged exposure of a fluid to other materials and elevated temperatures (conditions typical of solar energy systems) can cause chemical reactions and fluid degradation, possibly resulting in the formation of toxic substances.

Toxicity data for heat transfer fluids and fluid treatment chemicals are presented in Tables B-4 and B-5, respectively. The generic name of the material is given first, followed by the name of a typical product that has the chemical as its main constituent. LD₅₀ and LD_{L0} levels are given when known. The right-hand side of the table lists the toxicity rating for the chemical according to Gosselin's system and Durham's system. Table B-6 gives toxicity data for outgassing products from heat transfer fluids.

The data presented in these tables are based on values reported in the literature. It is important to realize that the toxicity ratings given are for pure chemical substances and not necessarily the product. If a named substance contains other substances (e.g., dyes, residuals from manufacturing, degradation products, or fluid treatment chemicals), the toxicity of the product may be greater than the toxicity indicated in these tables.

In order to determine the toxicity of specific products available for use as solar heat transfer fluids, the Lovelace Biomedical and Environmental Research Institute is conducting multi-tiered toxicological testing of representative fluids. The substances are evaluated for normal operating conditions and for stagnation and combustion conditions. To date, tests for mutagenicity, acute oral toxicity, and skin irritation have been conducted. Results indicate that most heat transfer fluids being considered for use have relatively low mutagenic activity, oral

TABLE B-4
TOXICITY OF HEAT TRANSFER FLUIDS

B-19

CHEMICAL SUBSTANCE (GENERIC)	COMMERCIAL PRODUCT	ACUTE TOXICITY (INGESTION)	TOXICITY RATING ^a GOSSELIN ^b	TOXIC HAZARD RATING ^a DURHAM ^c			
				ACUTE		CHRONIC	
				Local	Sys- temic	Local	Sys- temic
Diethylene glycol ^d Syn: diglycol $\text{CH}_2\text{OHCH}_2\text{OCH}_2\text{CH}_2\text{OH}$	--	Oral-human $\text{LD}_{50}=1000 \text{ mg/kg}^e$	3	Irritant	1	1	U
				Ingestion	2		U
				Inhalation	2		U
				Skin absorption			U
Dipropylene glycol Syn: 2,2-dihydroxy- isopropyl ether $(\text{CH}_3\text{CHOHCH}_2)_2\text{O}$	--	Oral-rat $\text{LD}_{50}=15 \text{ gm/kg}^e$	1	Irritant	U	U	
				Ingestion	U	2	2
				Inhalation	U	U	1
				Skin absorption	U	U	
Ethylene glycol Syn: 1,2-ethanediol; glycol; ethylene alcohol; glycol alcohol $\text{CH}_2\text{OHCH}_2\text{OH}$	Dowtherm SR-1; UCAR- thermofluid 17	Oral-human $\text{LD}_{50}=1500 \text{ mg/kg}^e$		Irritant	low	1	
		Oral-rat $\text{LD}_{50}=5840 \text{ mg/kg}^e$	2	Ingestion	low	3	2
				Inhalation	low		
				Skin absorption	low		
Ethylene oxide ^f Syn: 1,2-epoxy- ethane oxirane $(\text{CH}_2)_2\text{O}$	UCON 30	Oral-rat $\text{LD}_{50}=330 \text{ mg/kg}^e$	4	Irritant	3	2	U
				Ingestion			U
				Inhalation	2		U
				Skin absorption			U
Glycerine Syn: 1,2,3-propane- triol; glycerol $\text{CH}_2\text{OHCHOHCH}_2\text{OH}$	--	Oral-guinea pig $\text{LD}_{50}=7750 \text{ mg/kg}^e$	2	Irritant	1		
				Ingestion	1		

TABLE B-4 (cont'd.)
TOXICITY OF HEAT TRANSFER FLUIDS

CHEMICAL SUBSTANCE (GENERIC)	COMMERCIAL PRODUCT	ACUTE TOXICITY (INGESTION)	TOXICITY RATING ^a GOSSELIN ^b	TOXIC HAZARD RATING ^a DURHAM ^c			
				ACUTE		CHRONIC	
				Local	Sys- temic	Local	Sys- temic
Methanol Syn: methyl alcohol <chem>CH3OH</chem>	--	--	--	Irritant	1	1	
				Ingestion	3		2
				Inhalation	1	1	2
				Skin absorption	2		2
Phenyl ether-diphenyl mixture	Dowtherm A	Oral-rat $LD_{Lo}=4380$ mg/kg ^e	3	Not highly toxic but mild irritant			
Polyethylene glycol	UCON 50- HB-280-X E400 E600 E6000	Oral-rat $LD_{50}=6130$ mg/kg ^e	2 2 2 1				
Propylene glycol Syn: 1,2-propanediol; 1,2-hydroxy- propane <chem>CH2OHCHOHCH3</chem>	Dowfrost; UCAR Food Freeze 35	Oral-rat $LD_{50}=21$ gm/kg ^e Oral-mouse $LD_{50}=24$ gm/kg ^e	1 --	Irritant	1	1	
				Ingestion	1		1
				Inhalation			
				Skin absorption			
Propylene oxide ^f Syn: 1,2-epoxypro- pane; propene oxide; methyl oxirane <chem>OCH2CHCH3</chem>	UCON L20	Oral-rat $LD_{50}=930$ mg/kg ^e Oral-guinea pig ^g $LD_{50}=690$ mg/kg ^e	-- 3	Irritant	2	1	U
				Ingestion	2		U
				Inhalation	2		U
				Skin absorption			U

TABLE B-4 (cont'd.)
TOXICITY OF HEAT TRANSFER FLUIDS

CHEMICAL SUBSTANCE (GENERIC)	COMMERCIAL PRODUCT	ACUTE TOXICITY (INGESTION)	TOXICITY RATING ^a GOSSELIN ^b	TOXIC HAZARD RATING ^a DURHAM ^c			
				ACUTE		CHRONIC	
				Local	Sys- temic	Local	Sys- temic
Silicone oil Syn: Dimethyl polysiloxane	Dow Corning 200	No unequivocal toxic effects are recognized	--	--			
m-Terphenyl Syn: m-phenylbi- phenyl; benzene-1, 3-diphenyl (C ₆ H ₅) ₂ C ₆ H ₄	Therminol 66		--	Irritant	U	U	
				Ingestion	U	2	U
				Inhalation	U	2	U
				Skin absorption	U	U	
Triethylene glycol Syn: 2,2'-ethylene dioxydiethanol; glycol; bis(hydro- ethyl) ether (CH ₂ OCH ₂ CH ₂ OH) ₂	--	Oral-mouse LD ₅₀ =18500 mg/kg ^e	1	--			

^a Gosselin: 1 - practically nontoxic; 2 - slightly toxic; 3 - moderately toxic; 4 - very toxic; 5 - extremely toxic; 6 - super toxic.

Durham: 0 - none; 1 - slight; 2 - moderate; 3 - high; U - unknown.

^b Gosselin, R.E. et al., eds. 1976. Clinical Toxicology of Commercial Products. 4th edition. Baltimore: Williams and Wilkins Co.

^c Durham, W.W. 1975. Toxicology. In Dangerous Properties of Industrial Materials, edited by N.I. Sax. New York: Van Nostrand Reinhold Co.

^d Suspected carcinogen of bladder.

^e Christenson, H.E., ed. 1976. Registry of Toxic Effects of Chemical Substances. NIOSH 76-191. U.S. Department of Health, Education, and Welfare, National Institute of Occupational Safety and Health.

^f Carcinogen.

Source: Searcy, Jimmie Q., ed. August 1978. Hazardous Properties and Environmental Effects of Materials Used in Solar Heating and Cooling (SHAC) Technologies: Interim Handbook. SAND 78-0842. Albuquerque: Sandia Laboratories.

TABLE B-5
TOXICITY OF FLUID TREATMENT CHEMICALS

CHEMICAL SUBSTANCE (GENERIC)	COMMERCIAL PRODUCT	ACUTE TOXICITY (INGESTION)	TOXICITY RATING ^a GOSSELIN ^b	TOXIC HAZARD RATING ^a DURHAM ^c			
				ACUTE		CHRONIC	
				Local	Sys- temic	Local	Sys- temic
Arsenic compounds ^d	--	--	--	Irritant	2	2	
				Ingestion	3		3
				Inhalation			3
Benzotriazole	--	Oral-rat LD _{Lo} =500 mg/kg ^e	3	--			
Boron compounds	--	--	--	Irritant		U	0
				Ingestion	2	U	2
				Inhalation	2	U	2
				Skin absorption		U	2
Chlorinated phenols	--	--	--	Irritant	3	U	
				Ingestion	3	U	3
				Inhalation	3	U	3
				Skin absorption		U	3
Chromium compounds ^f	--	--	--	Irritant	3	U	3
				Ingestion	3	U	3
				Inhalation	3	U	3
				Skin absorption		U	
Hypochlorites	--	--	--	Irritant	2	U	U
				Ingestion		2	U
				Inhalation		2	U
				Skin absorption		U	U

TABLE B-5 (cont'd.)
TOXICITY OF FLUID TREATMENT CHEMICALS

CHEMICAL SUBSTANCE (GENERIC)	COMMERCIAL PRODUCT	ACUTE TOXICITY (INGESTION)	TOXICITY RATING ^a GOSSELIN ^b	TOXIC HAZARD RATING ^a DURHAM ^c			
				ACUTE		CHRONIC	
				Local	Sys- temic	Local	Sys- temic
Lithium chromate $\text{Li}_2\text{Cr}_4 \cdot 2\text{H}_2\text{O}$	--	--	--	See chromium compounds			
Lithium compounds	--	--	--	Irritant	2	U	
				Ingestion	3	U	2
				Inhalation	2	U	2
				Skin absorption		U	
Lithium nitrate LiNO_3	--	--	--	See nitrates			
Mercaptans	--	--	--	Irritant	3	U	
				Ingestion		U	
				Inhalation	3	U	2
				Skin absorption		U	
Mercury compounds, organic	--	--	--	Irritant	3	2	
				Ingestion	3		3
				Inhalation	3		3
				Skin absorption	2		2
Nitrates	--	--	--	Irritant	U	U	
				Ingestion	U	2	2
				Inhalation	U	2	2
				Skin absorption	U	U	

TABLE B-5 (cont'd.)
TOXICITY OF FLUID TREATMENT CHEMICALS

CHEMICAL SUBSTANCE (GENERIC)	COMMERCIAL PRODUCT	ACUTE TOXICITY (INGESTION)	TOXICITY RATING ^a GOSSELIN ^b	TOXIC HAZARD RATING ^a DURHAM ^c			
				ACUTE		CHRONIC	
				Local	Sys- temic	Local	Sys- temic
Nitrites	--	--	--	Irritant	U	U	
				Ingestion	U	3	3
				Inhalation	U	3	3
				Skin absorption	U	U	
Parathion	--	Oral-human	--	Irritant	U	U	
Syn: O,O-diethyl O-P-		LD _{Lo} =240 mg/kg ^e		Ingestion	U	3	3
nitrophenyl thio-		Oral-rat		Inhalation	U	3	3
phosphate; "Alkron";		LD ₅₀ =2 mg/kg ^e	6	Skin absorption	U	3	3
compound 3422;							
DNTP; DPP; E-605							
genithion; niran;							
paradust; paraflow;							
paraspray; parawet;							
penphos; phos-kil							
thiopos; vapophor;							
and many others							
C ₁₀ H ₁₄ NO ₅ PS							
Pentachlorophenol	Dowicide G	Oral-human		Irritant	3	2	
Cl ₅ C ₆ OH		LD _{Lo} =29 mg/kg ^e	4	Ingestion		3	2
		Oral-rat		Inhalation		3	2
		LD ₅₀ =50 mg/kg ^e		Skin absorption		3	2
Phenylmercuric	--	Oral-rat		See mercury com-			
triethanol		LD ₅₀ =30 mg/kg ^e	5	pounds, organic			
ammonium lactate							

TABLE B-5 (cont'd.)
TOXICITY OF FLUID TREATMENT CHEMICALS

CHEMICAL SUBSTANCE (GENERIC)	COMMERCIAL PRODUCT	ACUTE TOXICITY (INGESTION)	TOXICITY RATING ^a GOSSELIN ^b	TOXIC HAZARD RATING ^a DURHAM ^c			
				ACUTE		CHRONIC	
				Local	Sys- temic	Local	Sys- temic
o-Phenylphenol	Dowicide 1	Oral-rat LD ₅₀ =2700 mg/kg ^e	3	Irritant Ingestion	1	2	1 2
Phosphates, organic	--			See parathion			
Potassium arsenate ^f Syn: potassium dihydrogen arsenate; Macquer's salt KH ₂ AsO ₄	--			See arsenic compounds			
Potassium dichromate ^f Syn: potassium bi- chromate; red potassium chromate K ₂ Cr ₂ O ₇	--	Oral-human child LD _{Lo} =50 mg/kg ^e	5	See chromium compounds			
Potassium hydrogen phosphate Syn: potassium phosphate, dibasic K ₂ HPO ₄	--			Toxic hazard rating: U			
Sodium benzoate Syn: Benzoate of soda NaC ₇ H ₅ O ₂	--	Oral-rat LD ₅₀ =4100 mg/kg ^e		Irritant	0	0	0
		Oral-rabbit LD _{Lo} =2000 mg/kg ^e	3	Ingestion	0 1	0	0
				Inhalation	0	0	0
				Skin absorption	0	0	0

TABLE B-5 (cont'd.)
TOXICITY OF FLUID TREATMENT CHEMICALS

CHEMICAL SUBSTANCE (GENERIC)	COMMERCIAL PRODUCT	ACUTE TOXICITY (INGESTION)	TOXICITY RATING ^a GOSSELIN ^b	TOXIC HAZARD RATING ^a DURHAM ^c				
				ACUTE		CHRONIC		
				Local	Sys- temic	Local	Sys- temic	
Sodium borate Syn: Sodium tetra- borate Na ₂ B ₄ O ₇	--			See boron compounds				
Sodium chromate ^f Na ₂ CrO ₄	--			See chromium compounds				
Sodium hydroxide Syn: Caustic soda; Sodium hydrate; lye; white caustic NaOH	Drano	Oral-rabbit LD _{Lo} =500 mg/kg ^e	3	Irritant	3	U	2	U
				Ingestion	3	U		U
				Inhalation	2	U		U
				Skin absorption		U		U
Sodium hypochlorite NaClO	--			See hypochlorites				
Sodium metasilicate	--	Oral-rat LD ₅₀ =1280 mg/kg ^e	3					
Sodium nitrate Syn: Soda niter; nitratine NaNO ₃	--	Oral-rat LD _{Lo} =200 mg/kg ^e	4	See nitrates				
Sodium-o-phosphate Syn: trisodium phosphate Na ₃ PO ₄ :12 H ₂ O	--			Irritant	2		2	U
				Ingestion		2		U
				Skin absorption				U

TABLE B-5 (cont'd.)
TOXICITY OF FLUID TREATMENT CHEMICALS...

CHEMICAL SUBSTANCE (GENERIC)	COMMERCIAL PRODUCT	ACUTE TOXICITY (INGESTION)	TOXICITY RATING ^a GOSSELIN ^b	TOXIC HAZARD RATING ^a DURHAM ^c			
				ACUTE		CHRONIC	
				Local	Sys- temic	Local	Sys- temic
Sodium sulfate (Sol. Sulfate Salts of Sodium)	--	Amount of sulfate anion usually absorbed has no toxicological significance.					
Sodium 2,4,5- trichlorophenol	Dowicide B	Oral-rat LD ₅₀ =1620 mg/kg ^e	3	See chlorinated phenols			
2,3,4,6- trichlorophenol	Dowicide 6	Oral-rat LD ₅₀ =140 mg/kg ^e	4	See chlorinated phenols			
		Oral-guinea pig LD ₅₀ =250 mg/kg ^e	--				
2,4,5- trichlorophenol	Dowicide 2	Oral-rat LD ₅₀ =820 mg/kg ^e	3	See chlorinated phenols			
2,4,6- trichlorophenol ^f	Dowicide 2s	Oral-rat LD ₅₀ =820 mg/kg ^e	3	See chlorinated phenols			

^a Gosselin: 1 - practically nontoxic; 2 - slightly toxic; 3 - moderately toxic; 4 - very toxic;
5 - extremely toxic; 6 - super toxic.

Durham: 0 - none; 1 - slight; 2 - moderate; 3 - high; U - unknown.

^b Gosselin, R.E.; Hodge; Smith; and Gleason, eds. 1976. Clinical Toxicology of Commercial Products.
4th edition. Baltimore: Williams and Wilkins Co.

TABLE B-5 (cont'd.)
TOXICITY OF FLUID TREATMENT CHEMICALS

^c Durham, W.W. 1975. "Toxicology." In Dangerous Properties of Industrial Materials, edited by N.I. Sax. New York: Van Nostrand Reinhold Co.

^d Suspected carcinogen of bladder.

^e Christenson, H.E., ed. 1976. Registry of Toxic Effects of Chemical Substances. NIOSH 76-191. U.S. Department of Health, Education, and Welfare, National Institute of Occupational Safety and Health.

^f Carcinogen.

Source: Searcy, Jimmie Q., ed. August 1978. Hazardous Properties and Environmental Effects of Materials Used in Solar Heating and Cooling (SHAC) Technologies: Interim Handbook. SAND 78-0842. Albuquerque: Sandia Laboratories.

TABLE B-6

TOXICITY OF OUTGASSING PRODUCTS FROM HEAT TRANSFER LIQUIDS

OUTGASSING SUBSTANCE (GENERIC)	FROM COMMERCIAL PRODUCT		TOXIC HAZARD RATING ^a DURHAM ^b			
			ACUTE		CHRONIC	
			Local	Sys- temic	Local	Sys- temic
Argon A	SF 96, silicone; Exxon Caloria HT 43; UCON 500; Therminol 66; Mobiltherm Light; Dowtherm A	Irritant	0		U	U
		Ingestion	0		U	U
		Inhalation	0	1	U	U
		Skin absorption	0		U	U
Carbon dioxide CO ₂	SF 96, silicone; UCON 500; Exxon Process Oil 3029; Exxon Caloria HT-43; Dowtherm A; Therminol 66; Mobiltherm 603; Mobiltherm Light	Irritant	0		0	
		Ingestion	0		0	
		Inhalation	0	1	0	1
		Skin absorption	0		0	
Carbon monoxide CO	SF 96, silicone; UCON 500; Exxon Process Oil 3029; Exxon Caloria HT-43; Dowtherm A; Therminol 66; Mobiltherm 603; Mobiltherm Light	Irritant	0		0	
		Ingestion	0		0	
		Inhalation	0	3	0	1
		Skin absorption	0		0	
Ethane C ₂ H ₆	SF 96, silicone; Exxon Process Oil 3029; Mobiltherm 603; Mobiltherm Light	Irritant	0		0	
		Ingestion	0		0	
		Inhalation	0	2	0	1
		Skin absorption	0		0	
Ethene C ₂ H ₄	SF 96, silicone; UCON 500; Exxon Process Oil 3029; Therminol 66; Mobiltherm 603; Mobiltherm Light	Irritant	0		0	0
		Ingestion	0		0	0
		Inhalation	0	2	0	0
		Skin absorption	0		0	0

TABLE B-6 (cont'd.)
TOXICITY OF OUTGASSING PRODUCTS FROM HEAT TRANSFER LIQUIDS

OUTGASSING SUBSTANCE (GENERIC)	FROM COMMERCIAL PRODUCT		TOXIC HAZARD RATING ^a DURHAM ^b			
			ACUTE		CHRONIC	
			Local	Sys- temic	Local	Sys- temic
Hydrogen H ₂	SF 96, silicone; Exxon Process Oil 3029; Exxon Caloria HT-43; Therminol 66; Mobiltherm 603; Mobiltherm Light	Irritant Ingestion Inhalation Skin absorption	0 0 0 0	 1 	0 0 0 0	0 0 0 0
Methane CH ₄	SF 96, silicone; UCON 500; Exxon Process Oil 3029; Exxon Caloria HT-43; Dowtherm A; Therminol 66; Mobiltherm 603; Mobiltherm Light	Irritant Ingestion Inhalation Skin absorption	0 0 0 0	 1 	0 0 0 0	
Nitrogen N ₂	SF 96, silicone; Exxon Process Oil 3029; Exxon Caloria HT-43; Dowtherm A; UCON 500; Therminol 66; Mobiltherm 603; Mobiltherm Light	Toxicity: None				

^a Durham: 0 - none; 1 - slight; 2 - moderate; 3 - high; U - unknown.

^b Durham, W.W. 1975. "Toxicology." In Dangerous Properties of Industrial Materials, edited by N.I. Sax. New York: Van Nostrand Reinhold Co.

Source: Searcy, Jimmie Q., ed. August 1978. Hazardous Properties and Environmental Effects of Materials Used in Solar Heating and Cooling (SHAC) Technologies: Interim Handbook. SAND 78-0842. Albuquerque: Sandia Laboratories.

toxicity, and dermal toxicity*. Eye irritation tests have been initiated.

The information presented in Tables B-4 through B-6 and the data from the Lovelace study suggest that solar heat transfer fluids do not have significant toxic properties and that, given the conditions of their use and the routes of exposure, these fluids do not pose serious hazards to human health. However, additional risk assessment is necessary before the working fluids proposed for solar process heat use can be considered safe. Furthermore, only preliminary research has been conducted on the ecological effects of these fluids.

2.3 Fire Hazard Properties

Heat transfer fluids under consideration for solar process heat systems can pose potential fire hazards. When exposed to high temperatures or ignition sources, heat transfer fluids or their degradation products may cause fires and explosions or fuel existing fires; toxic gases may be emitted by burning fluids. Such conditions could occur, for example, if pipes containing the heat transfer fluids were welded or soldered, if fluids leaked near a heat source, or if fluid lines or storage tanks ruptured during a fire (see Section 3.1.4.2 of the text for further discussion).

In order to maximize the safety of solar process heat systems, the fire hazard properties of heat transfer fluids must be assessed. Data for these properties are presented in Table B-7; most of the information was provided by manufacturers. Since fluid treatment chemicals are a minor constituent of heat transfer fluids, no separate data for these chemicals are given.

* Clark, C.R. et al., 1978. "Toxicology of Solar Heating and Cooling Materials." Paper presented at the U.S. Department of Energy Review of Solar Heating and Cooling of Buildings and Agricultural and Industrial Process Heat, Ames, Iowa, October 4, 1978.

TABLE B-7. FIRE HAZARD PROPERTIES OF HEAT TRANSFER FLUIDS

Material	Flash Point (°F)	Fire Point (°F)	Ignition Temp. (°F)	Flammable Limits (% by vol)	Solubility in Water (ppm)	Vapor Density (Air=1)	Boiling Point (°F)	Sp. Heat Btu/lb (°F)	Heat of Comb. (Btu/lb)	Suggested Hazard Identification	
										Flammability	Reactivity
Mobiltherm 60J	380 ^a	--	--	--	--	--	--	0.51 ^a (@300°F)	--	--	--
Mobiltherm Light	250 ^a	--	--	--	--	--	>400	0.43 ^a (@300°F)	--	--	--
Dowtherm A (C ₆ H ₅) ₂ O(C ₆ H ₅) ₂ and diphenyl	241 ^b	275 ^b	1150 ^b	0.5-6.2 (@3500°F)	13.8 ^b (@60°F)	>1 ^b	494.8 ^b	0.50 ^a (@400°F)	15,500	--	polymerizes slowly
Dowtherm HP Paraffinic Oil	379 ^b	460 ^b	--	--	very low	>1 ^b	600-890 ^b	0.63 ^b	--	--	stable
Dowtherm J Alkylated aromatics	132 ^b	155 ^b	806 ^b	--	17 ^b	>1 ^b	358 ^b	--	--	--	stable
Dowtherm SR-1 CH ₂ OHCH ₂ OH based	240 ^b	250 ^b	--	--	infinite	>1 ^b	325 ^b	0.74 ^b (@300°F)	--	--	stable
Dowfrost CH ₂ OHCH ₂ OH	214 ^b	220 ^b	--	2.6-12.5 ^b	infinite	2.62 ^b	370 ^b	--	--	--	stable
Dow Corning 200 Dimethyl siloxane polymer	*	--	--	--	--	--	--	--	--	--	--
SF-96 (50) - Dimethyl siloxane polymer	>535 ^b	--	--	--	>10 ^c	--	305 ^b	0.36 ^b	--	--	--
Exxon Process Oil 3029 Naphthenic	300 ^d	--	--	--	--	--	--	--	--	--	--
Exxon Caloria HT 43	420 ^d	--	--	--	--	--	--	0.50 ^d (@212°F)	--	--	--
Suntemp 1	380 ^o	--	--	--	--	--	671 ^o	0.56 ^a	--	--	--
Therminol 66 Modified terphenyl	355 ^f	382 ^f	705 ^f	--	negligible	--	644 ^f	0.38 ^f (@100°F)	--	--	stable
Therminol 33	455 ^g	--	--	--	--	--	--	0.56 ^g (@300°F)	--	--	--
UCAR Thermafluid 17 Ethylene glycol based	260 ^h	--	--	(see ethylene glycol)	--	--	356 ^h	0.56 ^h	--	1 (ethylene glycol)	0 (ethylene glycol)
UCAR Food Freeze 35 Propylene glycol based	--	--	--	(see propylene glycol)	--	--	222 ^h (50% H ₂ O)	--	--	1 (propylene glycol)	0 (propylene glycol)
UCON 30	--	--	--	--	--	--	--	--	--	--	--
UCON L20	>500 ^h	--	--	--	--	--	--	--	--	--	--
UCON 50-HB-280-X	471	600 ^h	779 ^h	--	yes	--	--	0.51 ^h (@200°F)	--	--	--
Methanol CH ₃ OH	52	--	725	6.7-36	infinite	1.11	147	0.60 (@58°F)	9600	3	0
Ethylene Glycol CH ₂ OHCH ₂ OH	232	--	752	3.2-	infinite	2.14 ^f	387	0.573 (@67.3°F)	--	1	0
Propylene Glycol CH ₃ CH(OH)CH ₂ OH	210	--	700	2.6-12.5	infinite	2.62 ^f	370	--	--	1	0
Triethylene Glycol HOCH ₂ (CH ₂ CH ₂) ₂ -CH ₂ OH	350 (OC)	--	700	0.3-9.2	infinite	5.17 ^f	550	--	--	1	0
Glycerine HOCH ₂ CHOH-CH ₂ OH	320 (OC)	--	698	--	infinite	3.17 ^f	554	0.576 (@99-122°F)	7770	1	0
Water	--	--	--	non-flammable	infinite	0.62	212	0.999 (@68°F)	--	0	0
Air	--	--	--	non-flammable	0.0024 (@68°F)	1.0	--	0.25 (@100°F)	--	0	0

TABLE 8-7 (Continued)

Dow Corning 200:

Flash Point (F°)	Viscosity (centistokes)
30	.65
100	1.0
145	1.5
215	3.0
325	10.0
535	50.0
575	>100.0

^a Mobil Oil Corporation Technical Bulletins on Mobiltherm 603 and Mobiltherm Light.

^b Dow Corning Corporation. Technical Bulletin on Dow Corning 200.

^c General Electric Company. Technical Bulletin on SP-96(50).

^d Exxon Company. Technical Bulletins on Mobiltherm 603 and Oil 3029 and Exxon Caloria HT 43.

^e Resource Technology Corporation. Technical information on Suntemp 1.

^f Monsanto Chemical Corporation. Technical Bulletins on Therminol heat transfer fluids.

^g Union Carbide Corporation. Technical bulletins on UCAR Thermofluid 17, UCAR Food Freeze 35, UCON 30, L20, and UCON 50-HB-280-x.

SOURCE: Searcy, J.Q. ed. Hazardous Properties and Environmental Effects of Materials Used in Solar Heating and Cooling (SHAC) Technologies: Interim Handbook. SAND 78-0842. Albuquerque: Sandia Laboratories.

3. INSULATION MATERIALS

Insulation materials used in solar energy systems include glass and mineral wools, foamed plastics, and ceramic and refractory fibers; cellulose insulations generally are not used in solar applications. The Sandia Interim Handbook provides data on the physical properties of various insulating materials which are important from a functional standpoint. The physical and chemical properties of insulations that are important from a health and safety standpoint are discussed below.

3.1 Thermoxidative Stability and Outgassing Products

Under stagnation or fire conditions, the insulating materials suitable for solar process heat systems may degrade and emit toxic gases. This is a concern particularly for foam insulations and for fiberglass insulations using organic binders; the upper temperature limits of these materials are relatively low and can be exceeded easily during abnormal operating conditions (see Section 3.1.1.1 of the text for further discussion). Consequently, the thermoxidative stability of the various insulations and their gaseous products are important considerations in assessing the safety of solar process heat systems.

Sandia Laboratories measured the thermoxidative stability of five insulating materials using dynamic and isothermal thermogravimetric analysis (TGA). The data collected are presented in Table B-8. The percentage of weight loss observed is indicative of thermoxidative stability; the smaller the percentage, the less outgassing that occurred. The types of compounds emitted were determined by heating samples of the five insulations in high vacuum at 200°C and using a mass spectrometer to analyze the resulting products. The identified products are listed in Table B-8; the products labeled "degradation products" are unidentified species. This list should be used with caution since the qualities of the gases produced were not determined and the tests were done in high vacuum.

TABLE B-8

DYNAMIC AND ISOTHERMAL THERMOGRAVIMETRIC AND OUTGASSING ANALYSIS OF SELECTED INSULATING MATERIALS

Material	Dynamic TGA ^a in Air			Isothermal TGA in Air at 200°C		Outgassing Products ^b at 200°C in High Vacuum
	Percent Weight Loss 200°C	Percent Weight Loss 400°C	Percent Weight Loss 600°C	Percent Weight Loss 15 Min	Percent Weight Loss 30 Min	
Bead Board Polystyrene Foam, 1.5 lb/ft ³	1.0	99.0	100.0	0.4	0.6	Styrene, methylstyrene.
Isocyanurate Foam, ³ TF-600, ^c 2.0 lb/ft ³	1.2	27.7	86.6	3.3	3.3	H ₂ O, CO ₂ , HCl, trichlorofluoromethane, and other degradation products.
Rigid Polyurethane Foam, Suprathane 2.0 lb/ft ³	13.2	56.2	94.6	9.9	11.1	H ₂ O, CO ₂ , HCl, trichlorofluoromethane, chloro ethyl phosphate, and other degradation products.
Rigid Polyurethane Foam, Olin A602C5 ^e 2.0 lb/ft ³	4.2	33.7	63.3	6.2	7.5	H ₂ O, CO ₂ , HCl, trichlorofluoromethane, and other degradation products.
Fiberglass Batt, Owens Corning	0.0	2.7	5.3	0.0	0.0	Saturated Alkanes, H ₂ O, CO ₂

^a Thermogravimetric analysis.

^b Qualitative determination by mass spectroscopy.

^c Supplied by Celotex Building Products.

^d Supplied by United States Mineral, Inc.

^e Supplied by Olin Corporation.

Source: Searcy, Jimmie Q., ed. August 1978. Hazardous Properties and Environmental Effects of Materials Used in Solar Heating and Cooling (SHAC) Technologies: Interim Handbook. SAND 78-0842. Albuquerque: Sandia Laboratories.

3.2 TOXICITY

The toxicity hazards of insulating materials relate to their degradation products. All plastic foams and fiberglass material with organic binders emit toxic gases when overheated or burned. During system stagnation or fire, workers in a building that contains a solar process heat system could be exposed to such gases. However, no data are available to determine the exact nature of the gases evolved or the rates of gas evolution from the various insulations at different temperatures (i.e., above or below the maximum operating temperature). Thus, the severity of the health hazard posed by decomposing insulations in solar process heat systems still is uncertain.

Table B-9 presents toxicity data for the gases identified during the single Sandia experiment on outgassing products from selected insulations (see Section 3.1). These gases are representative of only this experiment; different temperatures and the close proximity of other materials might result in the evolution of other gases.

3.3 FIRE HAZARD PROPERTIES

Many insulating materials will burn, and some will burn quite vigorously. Plastic foam insulations and fiberglass with an organic binder can burn; mineral fiber insulations and fiberglass without a binder normally do not burn. The plastic foam insulations usually are treated with flame-retardant chemicals or are sandwiched between layers of some other flammable material. However, these insulations degrade rapidly when overheated and emit flammable products.

Insulations used in solar process heat systems may become saturated with leaked organic heat transfer liquids, resulting in another possible fire hazard. Such saturated insulation materials would offer a large fuel surface under poor dissipation conditions. An accidental spark or the

TABLE B-9

TOXICITY OF OUTGASSING PRODUCTS FROM INSULATIONS

CHEMICAL SUBSTANCE (GENERIC)	FROM COMMERCIAL PRODUCT		TOXICITY HAZARD RATING ^a DURHAM ^b			
			ACUTE		CHRONIC	
			Local	Sys- temic	Local	Sys- temic
Fluorotrichloromethane Syn: trichlorofluoromethane FCCl ₃	polyphenylisocyanurate foam with a urethane modifier; tan polyure- thane foam; Suprathane	Irritant Ingestion Inhalation Skin absorption	1	1 2	1	1 2
Hydrochloric acid Syn: muriatic acid Hcl	polyphenylisocyanurate foam with a urethane modifier; tan poly- urethane; Suprathane	Irritant Ingestion Inhalation Skin absorption	3	3 3	2	U U
Methyl styrene C ₉ H ₁₀	common white styrofoam	Irritant Ingestion Inhalation Skin absorption	2	3 2	U U U U	U U U U
Phenylethylene Syn: vinylbenzene, stryene (monomer), cinnamene C ₆ H ₅ CHCH ₂	common white styrofoam	Irritant Ingestion Inhalation Skin absorption	2	2 2	U U U U	2 2

a Durham: 0-none; 1-slight, 2-moderate; 3-high, U-unknown.

b Durham, W.W. 1975. "Toxicology." In Dangerous Properties of Industrial Materials, edited by N.I. Sax. New York: Van Nostrand Reinhold.

SOURCE: Searcy, J.Q. ed. August 1978. Hazardous Properties and Environmental Effects of Materials Used in Solar Heating and Cooling (SHAC) Technologies: Interim Handbook. SAND 78-0842. Albuquerque: Sandia Laboratories.

slow oxidation process that occurs when organic liquids fill insulation voids could cause ignition of the insulation.

Data for the fire hazard properties of flammable insulation materials are given in Table B-10.

4. SEALS AND SEALANTS

Rubber seals and gaskets are used in solar collectors to seal the glazing to the collector frame and to prevent leakage of heat transfer fluids from circulating pumps. The common generic types of rubbers or elastomers available for use in solar process heat systems are butyl, polysulfide, ethylene/propylene (EPDM), nitrite, silicone, fluorosilicone, fluorocarbon, and neoprene. There are many different formulations of these generic rubbers. The Sandia Interim Handbook contains data on the chemical composition and operating characteristics of commercially available seal and sealant materials.

4.1 THERMAL DEGRADATION AND THERMOXIDATIVE PRODUCTS

Tests conducted by Sandia Laboratories revealed that the thermal stabilities of selected sealants generally were lower than those for other plastic materials used in solar energy systems (see Table B-11). The polysulfide caulking materials (Novacalk 600 and GC-9) were the least stable of all the sealants tested. Significant decomposition occurred below 400°F, a moderate stagnation temperature for the collector surface. Although the seals and sealants probably would be at a lower temperature than the collector surface, all the materials listed (except the silicone rubber caulking compound) would decompose slowly if a temperature of 400°F were reached.

The thermal degradation products that would evolve from seals and sealants exposed to stagnation temperatures are listed in Table B-11; these are

TABLE B-10. FIRE HAZARD PROPERTIES OF INSULATION MATERIALS

Material	Ease of Ignition	Surface Flame Spread			Heat Release			Smoke Production			Maximum Continuous Service Temp °F	Relative Flammability
	ASTM D1929 Flash Ignition Temp. °F	ASTM E84 Tunnel Test	ASTM E162 Radiant Panel Test	Burning Rate (Horizontal) in/min	OSU Test ft ² /min.	ASTM E84 Tunnel Test	Heat of Combustion Btu/lb	NBS Chamber Test	Non-Flaming Da	ASTM E84 Tunnel Test		
Red Oak (for comparison)	--	100 ^a	99 ^b	--	--	100	8835 (wood) ^c	76-4 ^b	395-4 ^b	100 ^a	--	Moderate
INSULATORS												
Flexible Urethane foams:	--	--	--	--	--	--	--	20 ^b	156 ^b	--	--	--
Polyester, FR	--	--	1000 ^b	--	--	--	--	110-770 ^a	161 ^d	--	--	--
Polyether	--	--	1490 ^b	--	--	--	--	319 ^d	515 ^d	--	--	--
Polyether, FR	--	--	10 ^b	--	--	--	--	159-202 ^a 285	290 ^d	--	--	--
Rigid Urethane Foams:	--	--	--	--	210 (FR) ^a (82.5 Btu/sec-ft ²)	--	12000 ^c (gen. urethanes) 16000 (gen. urethanes)	--	--	--	180-190	Moderate
Polyester, FR	--	--	1440 ^b	--	--	--	--	525 ^d	454 ^d	--	--	--
Polyether	590 ^b	--	2220 ^b	--	--	--	--	--	--	--	--	--
Polyether, FR	--	--	880 ^b	--	--	--	--	196 ^d	119 ^d	--	--	--
Isocyanurate foam	--	--	--	--	--	--	--	--	--	--	284	--
Isocyanurate foam, FR	--	--	--	--	--	--	17970	225 ^d	300 ^d	--	--	--
Polystyrene foam, rigid	655	--	114 ^e	0.5-2.3 ^b	melts ^a on vertical liq. burns	--	17420 ^g	390 ^h	25 ^h	--	150-170	Moderate
Polystyrene foam, rigid, FR	--	--	13 ^b	--	--	--	--	260 ^b	10 ^b	--	--	--
TF-600 Board (Celotex Corp.)	850 ⁱ	25 ⁱ	--	--	--	5-10	--	--	--	75-145 ⁱ	--	--
Fiberglass (bonded)	--	20-40 (vinyl coated ^a)	--	--	--	10-25 (vinyl coated)	30-40 ^g	25 ^h	25 ^h	25-75 ^a (vinyl coated)	--	--
Fiberglass (unbonded)	--	--	--	--	--	10-25	--	--	--	0	--	--

^a Calbreath, M. Flame-Spread Performance of Common Building Materials. Technical Paper 170. Division of Building Research, National Research Council, Ottawa, Canada. April 1974.

^b Hilado, C.I. Flammability Handbook for Plastics. Westport, Connecticut: Technomic Publishing Co., Inc. 1969.

^c Klitgaard, P.S., and Williamson, R.B. The Impact of Contents on Building Fires. Consumer Product Flammability. 2:84. 1975.

^d Gaskill, J.R. Smoke Development in Polymers During Pyrolysis or Combustion. Journal of Fire and Flammability. 1:183-216. 1970.

^e Gage - Babcock and Associates, Inc. Evaluation of Release Rate Apparatus for Combustibility Testing. Report No. 7294-2.

^f Marcy, J.E. and Johnson, R. Flaming and Self-Extinguishing Characteristics of Aircraft Cabin Interior Materials. Report No. NA-6d-30 (DS-68888-13) Federal Aviation Administration.

^g U.S. Department of Commerce. Potential Heat of Materials in Building Fires. Technical News from the U.S. Department of Commerce, National Bureau of Standards. October 1960.

^h Lee, T.G. The Smoke Density Chamber Method for Evaluating the Potential Smoke Generation of Building Materials. National Bureau of Standards Technical Note 757. January 1973.

ⁱ Celotex Corporation. Technical bulletins on TF-600 Thermax insulation board.

SOURCE: Searcy, J.Q., ed. Hazardous Properties and Environmental Effects of Materials Used in Solar Heating and Cooling (SHAC) Technologies: Interim Handbook. SAND 78-0842. Albuquerque: Sandia Laboratories. August 1978.

TABLE B-11
THERMAL STABILITY AND THERMAL DEGRADATION PRODUCTS OF SEALANTS

Material (Supplier)	Sandia TGA Data			Thermal Degradation Products Reported in the Literature
	Temperature @ 3% Wt. Loss (°C)	Polymer Decomposition Temperature (°C)	Temperature of Maximum Rate of Wt. Loss (°C)	
Neoprene (DuPont and others)	235	297	315	Hydrogen chloride (major), 1,3 butadiene, benzene, toluene. ^{a,b,c}
D.C. 781 Silicone building sealant (Dow Corning)	420	462	550	Cyclic polysiloxanes $[(CH_3)_2SiO]_n$ where n=3 to 8. ^d
EPDM Rubber (Parker Seal)	340	427	467	Ethylene, propylene (major), longer chain hydrocarbons, methane, hydrogen. ^{e,f}
EPDM Rubber (Ball Rubber Co.)	240	428	465	As above. ^{e,f}
EPDM Rubber (Jasper Rubber Co.)	235	438	470	As above. ^{e,f}
Polysulfide, Novacalk 600 (Novagard Co.)	184	230	300	Diethyl disulfide, ethyl mercaptan, ethylthioethylmercaptan, ethylene, hydrogen sulfide (trace). ^g
Polysulfide, GC-9 (Pecora Co.)	185	220	300	As above. ^g
Butyl Rubber, Novacalk 420 (Novagard Co.)	170	360	412	Isobutene, isobutane, pentenes, neopentane, methane. ^h

TABLE B-11 (cont'd.)
THERMAL STABILITY AND THERMAL DEGRADATION PRODUCTS OF SEALANTS

- ^a Gardner, D.L., and McNeill, I.C. 1971. The Thermal Degradation of Poly Chloropene-I. European Polymer Journal, 7:569.
- ^b McNeill, I.C., and Neil, D. 1971. Thermal Degradation of Graft Copolymers of PVC Prepared by Mastication with Styrene and Methyl Methacrylate, and of Further PVC Mixtures and Vinyl Chloride Copolymers. European Polymer Journal, 7:453.
- ^c Swenker, R.F., and Beck, L.R. August 1960. Differential Thermal Analysis of Textile and Other High Polymeric Materials. Textile Research Journal, Vol. 624.
- ^d Hunter, M.J.; Hyde, J.F.; Warrick, E.L.; and Fletcher, H.J. 1946. Organo-Silicon Polymers: The Cyclic Dimethyl Siloxanes. Journal of the American Chemical Society. 68:667.
- ^e Seno, H., et al. 1972. Pyrolysis-gas Chromatographic Studies on the Structure of Ethylene/Propylene Copolymers. Makrom. Thermol. Chem. 161:195.
- ^f Wall, I.A., and Straus, S. 1960. Pyrolysis of Polyolefins. Journal of Polymer Science. 44:313.
- ^g Machon, J.P.; Nicco, A.; Mariage, A.; and Philippe, T. 1972. European Polymer Journal. 8:547-49.
- ^h William, L. 1949. J. Res. Natl. Bur. Std. 42:499.

Source: Searcy, Jimmie Q., ed. August 1978. Hazardous Properties and Environmental Effects of Materials Used in Solar Heating and Cooling (SHAC) Technologies: Interim Handbook. SAND 78-0842. Albuquerque: Sandia Laboratories.

based on reports in the literature. Sandia Laboratories attempted experimentally to detect the volatile additives present in selected seal and sealant materials. Dow Corning 781 silicone rubber caulking outgassed the least; only small amounts of water and siloxanes were detected. The largest amount of outgassing occurred with the butyl rubber products (Novacaulk 420 and Tremco 440). The outgassing products consisted primarily of low molecular weight aliphatic hydrocarbons.

In the presence of oxygen, seals and sealants that were tested generally decomposed at higher temperatures. Table B-12 presents the Sandia data on thermoxidative stability as well as the combustion products reported in the literature.

4.2 TOXICITY

The primary toxicity hazard associated with seal and sealant materials is the release of volatile compounds under over-temperature conditions. However, the quantity of sealant material used in a solar process heat system is so small that the hazard to health or environment is minimal.

4.3 FIRE HAZARD PROPERTIES

Seal and sealant materials in solar process heat systems do not pose significant fire hazards because of the small amounts used. Toxic gases are released when the materials burn, but in any fire involving a solar energy system, the toxic gas contribution from sealants would be insignificant compared with sources such as insulations.

5. GLAZING AND PIPING MATERIALS

Glazing materials used in solar process heat systems are either glass or plastic. The glass usually is a soda lime silicate glass which is tempered to increase its strength and to give it a fine breaking pattern. Several types of plastic glazing are suitable for solar process heat

TABLE B-12

THERMOXIDATIVE STABILITY AND COMBUSTION PRODUCTS OF SEALANTS

Material (Supplier)	Sandia TGA Data			Combustion Products Reported in the Literature
	Temperature @ 3% Wt. Loss (°C)	Polymer Decomposition Temperature (°C)	Temperature of Maximum Rate of Wt. Loss (°C)	
Neoprene (DuPont and others)	235	314	335	CO ₂ , CO, H ₂ O, H ₂ , CH ₄ , C ₂ H ₆ , ethylene, Cl ₂ , 1,2-butadiene, benzene, toluene ^a
D.C. 781 Silicone, building sealant (Dow Corning)	370	500	555	Formaldehyde, formic acid, CO, CO ₂ , cyclic polysiloxanes [(CH ₃) ₂ SiO] _n with n=3 to 8. ^{b,c}
EPDM Rubber (Parker Seal)	315	378	445	No references found on combustion products; combustion products should be similar to those obtained for thermal degradation of EPDM plus CO ₂ , CO, and acetylene.
EPDM Rubber (Ball Rubber Co.)	255	332	480	As above.
EPDM Rubber (Jasper Rubber Co.)	250	260	460	As above.
Polysulfide, Novacalk 600 (Novagard)	210	250	338	CO ₂ , CO, sulfoxides, H ₂ O, C ₂ H ₅ SH, CHO, HCHS, C ₂ H ₅ OH, thioformaldehyde. ^d
Polysulfide, GC-9 (Pecora Co.)	225	240	360	As above. ^d
Butyl Rubber, Novacalk 420 (Novagard Co.)	270	360	411	N/A; probable products are CO ₂ , CO, H ₂ O, H ₂ , isobutene, pentenes, acetylene.

TABLE B-12 (cont'd.)

THERMOXIDATIVE STABILITY AND COMBUSTION PRODUCTS OF SEALANTS

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- ^a Gross, D., et al. Smoke and Gases Produced by Burning Aircraft Interior Materials. Building Science Series, Vol. 18. February 1969.
- ^b Murphy, C.C.; Saunders, C.E.; and Smith, D.C. Ind. Engng. Chem. 42:2462 1950.
- ^c Atkins, D.C.; Murphy, C.M.; and Saunders, C.E. Ind. Engng. Chem. 39:1395. 1947.
- ^d Machon, J.P.; Mariage, A.; and Philippe, T. Reactions de Decomposition Thermooxydante de Polymers D'Episulfures. European Polymer Journal. 9:233. 1978.

Source: Searcy, J.Q., ed. Hazardous Properties and Environmental Effects of Materials Used in Solar Heating and Cooling (SHAC) Technologies: Interim Handbook. SAND 78-0842. Albuquerque: Sandia Laboratories. August 1978.

systems; for this discussion, Lucite, Teflon, and Tedlar will be used as representative examples. Important physical properties and the chemical compositions of the different glazing materials are given in the Sandia Interim Handbook.

Piping materials used to distribute heat transfer fluids generally consist of three types: copper, iron, and polyvinyl chloride (PVC or C-PVC).

5.1 THERMAL DEGRADATION AND THERMOXIDATIVE PRODUCTS

Plastic glazing and piping materials which are heated to temperatures beyond their maximum operating temperatures may degrade and emit toxic or combustible gases; their behavior during stagnation and fire conditions is similar to that of foam insulations. Table B-13 presents the thermal stabilities of the plastics under consideration for solar process heat systems. These values were determined by Sandia Laboratories using dynamic thermogravimetric analysis. The data indicate that at stagnation temperatures (400°F or higher) PVC, Lucite, and Tedlar likely would decompose slowly.

The thermal degradation products emitted by the plastics vary with temperature. For example, hydrochloric acid and hydrofluoric acid are the first gases evolved during degradation of PVC and Tedlar, respectively; both probably would evolve at temperatures near 205°C. At this temperature the other plastics listed in Table B-13 would be less likely to decompose, although some of the thermal degradation products listed in the last column of Table B-13 might form. At temperatures of 500°C or higher, and in the absence of sufficient oxygen, all of the plastics would decompose and evolve the products in Table B-13. No data are available on the rates of decomposition.

TABLE B-13
THERMAL STABILITY AND THERMAL DEGRADATION PRODUCTS OF PLASTIC GLAZINGS AND PIPES

Material (Supplier)	Sandia TGA Data			Thermal Degradation Products Reported in the Literature
	Temperature @ 3% Wt. Loss (°C)	Polymer Decomposition Temperature PDT°C	Temperature of Maximum Rate of Wt. Loss (°C)	
Teflon, PTFE (DuPont)	510	525	585	Tetrafluoroethylene (95%), carbon tetrafluoride (1.5%), hexafluoroethylene. ^a
Teflon, FEP (DuPont)	460	468	570	Tetrafluoroethylene (75-84%), hexafluoropropylene (16-25%). ^{b,c}
Teflon, PFA (DuPont)	--	--	--	NA
Tedlar (DuPont)	250	247	268	Hydrogen fluoride, butadiene, allyl fluoride, benzene, toluene, ^{d,e} naphthalene, vinyl fluoride, others.
Lucite (DuPont) Plexiglas (Rohm & Haas)	230	242	358	Methyl methacrylate (major), benzene (trace), H ₂ O (trace). ^{f,g}
PVC, Geon, Halon (B.F. Goodrich, Allied Chemical, and many others)	230	238	308	HCl, vinyl chloride, benzene, toluene, numerous saturated and unsaturated aliphatic and aromatic compounds. ^{h,i}

^a Straus, S., and Madorsky, S.L. Pyrolysis of Some Polyvinyl Polymers at Temperatures up to 1200°C. J. Res. Natl. Bur. Std. 66a:401. 1962.

^b Wall, L.A., and Straus, S. Pyrolysis of Fluorocarbon Polymers. J. Res. Natl. Bur. Std. 65a:227. 1961.

^c Morton, M., ed. Rubber Technology. Second edition. New York: Van Nostrand Reinhold Co. 1973.

TABLE B-13 (cont'd.)

THERMAL STABILITY AND THERMAL DEGRADATION PRODUCTS OF PLASTIC GLAZINGS AND PIPES

- d Madorsky, S.L.; Hart, V.E.; Straus, S.; and Sedlek, V.A. Thermal Degradation of Tetrafluoroethylene and Hydrofluoroethylene Polymers in a Vacuum. J. Res. Natl. Bur. Std. 51:327. 1953.
- e Ryan, R.W. Comparison of Flaming Combustion with Oxidative Degradation. Paper read at the Polymer Conference, July 7-11, 1975, at the University of Utah, Salt Lake City, Utah. 1975.
- f Cameron, G.G., and Kane, D.R. Thermal Degradation of Poly(benzyl acrylate). Polymer. 9:461. 1968.
- g Grassie, N., and Melville, H.W. Discussions of the Faraday Society. 2:378. 1947.
- h Ehlers, G.F.L. Structure Stability Relationships Based on Thermogravimetric Analysis Data, Part I. AFML - TR - 74. 1974.
- i Chatfield, D.A.; Einhorn, I.N.; Mickelson, R.W., and Futrell, J.H. The Combustion and Thermal Degradation of Two Aromatic Polyamide Polymers. Paper read at the Polymer Conference, July 7-11, 1975, at the University of Utah, Salt Lake City, Utah. 1975.

Source: Searcy, J.Q., ed. Hazardous Properties and Environmental Effects of Materials Used in Solar Heating and Cooling (SHAC) Technologies: Interim Handbook. SAND 78-0842. Albuquerque: Sandia Laboratories. August 1978.

Table B-14 lists the combustion products of plastics which are formed when excess oxygen is present. The thermoxidative stabilities of the various glazing and piping plastics also are listed in Table B-14. Sandia Laboratories detected higher decomposition temperatures for these plastics under thermoxidation conditions than under pyrolysis conditions.

5.2 TOXICITY

There are no data available to indicate that glazing or piping materials present any toxicity hazard during normal use. At temperatures normally attained by collectors, plastic glazings and pipes do outgas to some extent. These gases have not been well characterized, but some may be toxic. However, since most plastics in solar process heat systems are exposed to the outside atmosphere, human exposure to any outgassing products probably will be minimal. Nonetheless, solar system designs which could allow outgassed products to enter working areas should not utilize plastic glazings.

If the solar process heat system stagnates or burns, the gases evolved from decomposing plastic materials can pose a significant toxicity hazard. Table B-15 lists toxicity data for thermal degradation and combustion products. It should be noted that the gases listed are representative of only one experiment. Different temperatures and the close proximity of other materials might result in the evolution of different gases. There are no definitive data that allow a prediction of the quantities of gases produced or their relative amounts.

5.3 FIRE HAZARD PROPERTIES

Plastic glazings and pipes burn. Fire hazards associated with these materials include the toxic gases produced during combustion and the contribution of the materials to the spread of existing fires. The major fire hazard properties of plastic glazings and pipes are presented in Table B-16.

TABLE B-14

THERMOXIDATIVE STABILITY AND COMBUSTION PRODUCTS OF PLASTIC GLAZINGS AND PIPES

Material (Supplier)	Sandia TGA Data			Combustion Products Reported in the Literature
	Temperature @ 3% Wt. Loss (°C)	Polymer Decomposition Temperature PDT°C	Temperature of Maximum Rate of Wt. Loss (°C)	
Teflon, PTFE (DuPont)	525	535	588	CO ₂ , CO, COF ₂ , tetrafluoroethylene, SiF ₄ formed via reaction with glass. ^{a,b,c,d}
Teflon, FEP (DuPont)	470	490	540	NA; probably CO ₂ , CO, SiF ₄ , COF ₂ .
Teflon, PFA (DuPont)	--	--	--	NA; probably CO ₂ , CO, SiF ₄ , COF ₂ plus low molecular wt. fluoro- carbons.
Teflon (DuPont)	270	275	295	CO ₂ , benzene, HF, fluorobenzene, xylene, vinyl fluoride, others. ^e
Lucite (DuPont), Plexi- glas (Rohm & Haas)	262	270	330	Methylmethacrylate monomer, CO ₂ , CO, C ₂ H ₄ , H ₂ .
PVC, Geon, Halon (B.F. Goodrich, Allied Chem- ical, and many others)	267	281	345	HCl, CO ₂ , CP, vinyl chloride, benzene, toluene, methane, ethane, methyl chloride. ^{f,g,h}

^a Wall, L.A., and Michaelson, J.D. Thermal Decomposition of Polytetrafluoroethylene in Gaseous Atmospheres. J. Res. Natl. Bur. Stds. 56:27. 1956.

^b Matula, R.A. Combustion Kinetics of Tetrafluoroethylene. AD-664-088. September 1967.

^c Warren, P.C. How Plastics Burn. SPE Journal. 27:17. 1971.

^d Autian, J. Toxicologic Aspects of Flammability and Combustion of Polymeric Materials. Journal of Fire and Flammability. 1:239. 1970.

TABLE A-14 (cont'd.)

THERMOXIDATIVE STABILITY AND COMBUSTION PRODUCTS OF PLASTIC GLAZINGS AND PIPES

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- ^e Cameron, G.G., and Kane, D.R. Thermal Degradation of Poly(benzyl acrylate). Polymer. 9:461. 1968.
- ^f Boettner, E.A. Analysis of Volatile Degradation Products of Polymer Combustion. Paper read at the Polymer Conference, June 16-20, 1969, at University of Detroit, Michigan. 1969.
- ^g Palmer, T.Y. Combustion Sources of Atmospheric Chlorine. Nature. 263:44. 1976.
- ^h Morimoto, T.; Takeyana, K.; Konishi, F. Composition of Gaseous Combustion Products of Polymers. Journal of Applied Polymer Science. 20:1967. 1976.

Source: Searcy, J.Q., ed. Hazardous Properties and Environmental Effects of Materials Used in Solar Heating and Cooling (SHAC) Technologies: Interim Handbook. SAND 78-0842. Albuquerque: Sandia Laboratories. August 1978.

TABLE B-15

TOXICITY OF THERMAL DEGRADATION AND COMBUSTION GASES FROM PLASTIC GLAZINGS AND PIPES

CHEMICAL SUBSTANCE (GENERIC)	FROM COMMERCIAL PRODUCT		TOXIC HAZARD RATING ^a DURHAM ^b			
			ACUTE		CHRONIC	
			Local	Sys- temic	Local	Sys- temic
Benzene ^c Syn: Coal naphtha C_6H_6	Geon; Halon; Plexiglas; Lucite; PVC	Irritant Ingestion Inhalation Skin absorption	2 1 1	 2 2	0 0 0	 3 3 3
Carbon dioxide CO_2	Teflon, PTFE; Teflon, FEP; Teflon, PFA; Tedlar; Lucite; Plexiglas; PVC; Geon; Halon	Irritant Ingestion Inhalation	0 0 0	 1	0 0 0	 1
Carbon monoxide	Teflon, PTFE; Teflon, FEP; Teflon, PFA; Lucite; Plexiglas; PVC: Geon; Halon	Inhalation	0	3	0	1
Carbonyl fluoride Syn: fluoroformyl fluoride COF_2	Teflon, PTFE	Irritant Inhalation	3 3	U U	U U	U U
Carbon tetrafluoride Syn: tetrafluoro- methane CF_4	Teflon, PTFE	Irritant Ingestion Inhalation Skin absorption	 2	 2	U U U U	U U U U
Ethane C_2H_6	PVC; Geon; Halon	Inhalation	0	2	0	1

TABLE B-15 (cont'd.)

TOXICITY OF THERMAL DEGRADATION AND COMBUSTION GASES FROM PLASTIC GLAZINGS AND PIPES

CHEMICAL SUBSTANCE (GENERIC)	FROM COMMERCIAL PRODUCT	TOXIC HAZARD RATING ^a DURHAM ^c			
		ACUTE		CHRONIC	
		Local	Sys- temic	Local	Sys- temic
Hexafluoropropylene Syn: perfluoropropene CF CF:CF ₂	Teflon, FEP; Teflon, PTFE	Toxic hazard ratings: U Toxicity: animal experiments suggest moderate toxicity.			
Hydrochloric acid Syn: muriatic acid hydrogen chloride HCl	Tedlar; PVC; Neoprene; Geon; Halon	3		2	U
			3		U
			3		U
					U
Hydrocyanic acid Syn: hydrogen cyanide; prussic acid HCN	Nylon 6,6; Nylon HT-4	2		U	U
			3	U	U
			3	U	U
			3	U	U
Hydrofluoric acid Syn: hydrogen fluoride HF	Tedlar	3		2	
			3		3
			3		3
Hydrogen H ₂	EDPM rubber	0		0	0
		0		0	0
		0	1	0	0
		0		0	0

TABLE B-15 (cont'd.)

TOXICITY OF THERMAL DEGRADATION AND COMBUSTION GASES FROM PLASTIC GLAZINGS AND PIPES

CHEMICAL SUBSTANCE (GENERIC)	FROM COMMERCIAL PRODUCT		TOXIC HAZARD RATING ^a DURHAM ^c			
			ACUTE		CHRONIC	
			Local	Sys- temic	Local	Sys- temic
Methane Syn: marsh gas CH_4	PVC; Geon; Halon	Inhalation	0	1	0	1
Methyl chloride Syn: chloromethane CH_3Cl	PVC; Geon; Halon	Irritant Inhalation	1 1	3	U U	2
Methyl methacrylate (monomer) $\text{CH}_2\text{C}(\text{CH}_3)\text{COOCH}_3$	Lucite; Plexiglas	Irritant Ingestion Inhalation	1	2 1	U U	1 1
Silicon tetrafluoride Syn: tetrafluoro- silane SiF_4	Teflon, PTFE; Teflon, FEP; Teflon, PFA	Irritant Ingestion Inhalation	3	3 3	1	3 3
Toluene Syn: methylbenzene phenylmethane; toluol $\text{C}_6\text{H}_5\text{CH}_3$	PVC; Geon; Halon	Irritant Ingestion Inhalation Skin absorption	1	2 2 1	1	2 2 2
Vinyl chloride ^c Syn: chloroethylene; chloroethene CH_2CHCl	PVC; Geon; Halon	Irritant Inhalation	2	2	2	3

TABLE B-15 (cont'd.)

TOXICITY OF THERMAL DEGRADATION AND COMBUSTION GASES FROM PLASTIC GLAZINGS AND PIPES

CHEMICAL SUBSTANCE (GENERIC)	FROM COMMERCIAL PRODUCT		TOXIC HAZARD RATING ^a DURHAM ^c			
			ACUTE		CHRONIC	
			Local	Sys- temic	Local	Sys- temic
Vinyl fluoride Syn: fluoroethylene $\text{CH}_2\text{:CHF}$	Tedlar	Irritant Ingestion Inhalation	3	3 3	1	3 3
Xylene $\text{C}_6\text{H}_4(\text{CH}_3)_2$	Tedlar	Irritant Inhalation Skin absorption	1	2 2	1	2 2

^a Durham: 0 - none; 1 - slight; 2 - moderate; 3 - high; 4 - unknown.

^b Durham, W.W. Toxicology. In Dangerous Properties of Industrial Materials, edited by N.I. Sax. New York: Van Nostrand Reinhold Co. 1975.

^c Carcinogen.

Source: Searcy, J.Q., ed. Hazardous Properties and Environmental Effects of Materials Used in Solar Heating and Cooling (SHAC) Technologies: Interim Handbook. SAND 78-0842. Albuquerque: Sandia Laboratories. August 1978.

TABLE B-16. FIRE HAZARD PROPERTIES OF PLASTIC GLAZING AND PIPING MATERIALS

Material	Ease of Ignition	Surface Flame Spread			Heat Release			Smoke Production			Maximum Continuous Service Temp °F	Relative Flammability
	ASTM D1929 Flash Ignition Temp. °F	ASTM E84 Tunnel Test	ASTM E162 Radiant Panel Test	Burning Rate (Horizontal) in/min	OSU Test Btu/ft ² -min.	ASTM E84 Tunnel Test	Heat of Combustion Btu/lb	NBS Chamber Test Flaming Dm	Non-Flaming Dm	ASTM E84 Tunnel Test		
Tedlar	--	--	4 ^a	--	--	--	--	0.9-4 ^{b,c}	1 ^d	--	220-250 ^e	Low ^e
Plexiglas	536-572 ^f	--	118-360 ^a	0.6-1.6 ^f	--	--	--	59 ^b	328 ^d	--	140-200 ^e	Moderate ^e
Plexiglas, FR	--	--	376 ^g	--	--	--	--	283 ^b	--	--	--	Very low ^e
Teflon	986 ^f (self ign.)	--	--	nonigniting ^f	--	--	--	55-53 ^{g,h}	0 ^h	--	550 ^e	Low ^e
PVC, rigid	735 ^f	0-25	9.6 ^f	self extig- guishing ^f	200 (@ 2.5 gtu/ sec-ft ²)	--	7720 ^g	525-660 ^f 525-535 ^h	270-470 ^h 300-490 ^h	--	120-160 ^e	Low ^e
PVC, rigid, FR	--	--	3.2 ^f	--	--	--	9290 ⁱ	--	--	--	--	--
ABS (acrylo- nitrilebutadiene- styrene)	--	--	37-312 ^a	1.0-2.0 ^f 0.9-1.4 ^j	--	--	--	660 ^f 450 ^k	71 ^f 220 ^l	--	140-230 ^e	Moderate ^e
Polycarbonate (Lexan)	--	--	18 ^a	self extig- guishing ^f	--	--	13,300 ^h	324-174 ^f 100-248	21 ^h 12 ^f	--	250 ^e	Low ^e
Fiberglass, reinforced	655-750 ^a	50-85 ^m	--	--	--	0-25	--	395 ^f	350 ^f	>200	300-350 ^e	Low ^e
Polyester, 21% reinforced	--	--	30-56 ^f	--	--	--	--	--	--	--	--	--
Polyester, 27% reinforced	--	--	239 ^f	--	--	--	--	152 ^b	--	--	--	--
Polyester, 27% reinforced	--	--	154 ^f	--	--	--	--	--	--	--	--	--

^a Marcy, J.E., and Johnson, R. Flaming and Self-Extinguishing Characteristics of Aircraft Cabin Interior Materials. Report No. NA-68-30 (DS-68888-13). Federal Aviation Administration.

^b Sarkso, C.P. Measurement of Toxic Gases and Smoke from Aircraft Cabin Interior Materials Using the NBS Smoke Chamber and Calometric Tubes. Report No. FAA-RD-76-7. Federal Aviation Administration. March 1967.

^c Sumi, Y., and Sumi, K. Smoke Producing Characteristics of Materials. Journal of Fire and Flammability. January 1974.

^d Gross, D., et al. Smoke and Gases Produced by Burning Aircraft Materials. Building Science Series 18. National Bureau of Standards. February 1969.

^e Monsanto Chemical Corporation. Thermal Heat Transfer Fluids. Technical Bulletin No. IC/FF-31.

^f Hilado, C.J. Flammability Handbook for Plastics. Westport, Connecticut: Technomic Publishing Co. 1969.

^g Klitgaard, P.S. and Williamson, R.B. The Impact of Contents of Building Fires. Consumer Product Flammability. 2:84. March 1975.

^h Gaskill, J.R. Smoke Development in Polymers During Pyrolysis or Combustion. Journal of Fire and Flammability. 1:183-216. 1970.

ⁱ U.S. Department of Commerce. Potential Heat of Materials in Building Fires. Technical news from the U.S. Department of Commerce, National Bureau of Standards. October 1960.

^j Agrenoff, J. ed. Modern Plastics Encyclopedia, 1976-77. New York: McGraw-Hill Book Co. 1977.

^k Lee, T.G. The Smoke Density Chamber Method for Evaluating the Potential Smoke Generation of Building Materials. National Bureau of Standards Technical Note 757. January 1973.

^l National Fire Protection Association. Fire Protection Handbook. 14th Edition. 1976.

^m Galbreath, M. Flame-Spread Performance of Common Building Materials. Technical Paper 170. Division of Building Research, National Research Council, Ottawa, Canada. April 1964.

SOURCE: Searcy, J.Q. ed. Hazardous Properties and Environmental Effects of Materials Used in Solar Heating and Cooling (SHAC) Technologies: Interim Handbook. SAND 78-0842. Albuquerque: Sandia Laboratories. August 1978.

6. HEAT STORAGE MEDIA

Two classes of heat storage media are used in solar process heat systems, those which store sensible heat and those which store latent heat (i.e., heat-of-fusion). Common sensible heat storage media are rocks, concrete, and water. Latent heat storage media include a variety of hydrated salts, eutectic salts, paraffins, and other phase change media. Pertinent chemical and physical properties of these media are detailed in the Sandia Interim Handbook.

6.1 THERMAL DEGRADATION

Phase-change heat storage media used in low temperature solar process heat applications should prove completely stable over the short-term (months). The long-term (years) stability is unknown; accelerated aging experiments need to be performed. Generally, organic compounds do not degrade thermally until temperatures of about 200°C are reached. Since the heat generated for intermediate- and high-temperature industrial applications usually will exceed this temperature, caution should be used in selecting phase-change storage media for these systems. Testing is needed to determine the thermal stability and degradation products of candidate storage media, since the possible hazards of exposing these media to high temperatures are unknown.

6.2 TOXICITY

Many materials under consideration for heat storage are quite toxic, as is evidenced by the toxicity data presented in Table B-17. Routine exposure to these substances will be limited to manufacturers, installers, and maintenance personnel. The primary routes of exposure will be dermal contact and inhalation. The Lovelace Biomedical and Environmental Research Institute plans to conduct multi-tiered toxicological testing of candidate thermal storage media. Their tests will provide a more accurate assessment of the potential toxicity hazards associated with solar process heat storage systems.

TABLE B-17
TOXICITY OF THERMAL STORAGE MEDIA

CHEMICAL SUBSTANCE (GENERIC)	ACUTE TOXICITY (INGESTION)	TOXICITY RATING ^a GOSSELIN ^b	TOXIC HAZARD RATING ^a DURHAM ^c			
			ACUTE		CHRONIC	
			Local	Sys- temic	Local	Sys- temic
Ammonium bromide NH_4Br	--	--	See bromides			
Barium compounds (soluble)	--	--	Irritant	1	1	
			Ingestion	1	3	2
			Inhalation	1	3	2
Barium hydroxide Syn: barium hydrate; caustic baryta $\text{Ba}(\text{OH})_2 \cdot 8\text{H}_2\text{O}$	--	--	See barium compounds			
Benzamide	Oral-mouse $\text{LD}_{50}=1160 \text{ mg/kg}^d$	3	--			
Benzoic acid Syn: phenylformic acid $\text{C}_6\text{H}_5\text{COOH}$	Oral-rat $\text{LD}_{50}=3040 \text{ mg/kg}^d$ Oral-mouse $\text{LD}_{50}=2370 \text{ mg/kg}^d$	3 --	Irritant	1	0	
			Ingestion	1	1	1
			Inhalation	1	0	
			Skin absorption		0	
Biphenyl Syn: Diphenyl $\text{C}_6\text{H}_5\text{C}_6\text{H}_5$	Oral-rat $\text{LD}_{50}=3280 \text{ mg/kg}^d$ Oral-rabbit $\text{LD}_{50}=2410 \text{ mg/kg}^d$	3 --	Irritant	U	U	
			Ingestion	U	2	2
			Inhalation	U	2	2
			Skin absorption	U	U	
Bromides	--	--	Irritant	1	1	
			Ingestion	2	2	2
			Inhalation	2		2

TABLE B-17 (cont'd.)
TOXICITY OF THERMAL STORAGE MEDIA

CHEMICAL SUBSTANCE (GENERIC)	ACUTE TOXICITY (INGESTION)	TOXICITY RATING ^a GOSSELIN ^b	TOXIC HAZARD RATING ^a DURHAM ^c				
			ACUTE		CHRONIC		
			Local	Sys- temic	Local	Sys- temic	
Calcium bromide CaBr ₂ · 6H ₂ O	--	--	See bromides				
Calcium chloride CaCl ₂	Oral-rat LD ₅₀ =1000 mg/kg ^d Oral-rabbit LD _{Lo} =1384 mg/kg ^d	3 --	See calcium compounds				
Calcium compounds	--	--	Irritant	1	U	1	U
			Ingestion	1	U		U
			Inhalation	1	U		U
			Skin absorption		U		U
Caprylic acid Syn: octanoic acid CH ₃₃ (CH ₂) ₆ COOH	--	--	Experimental data suggested low toxicity				
Diphenyl oxide (CH ₅) ₂ O	Oral-rat LD ₅₀ =3370 mg/kg ^d	3	--				
Glaubers salt NaSO ₄ · 10H ₂ O	See sodium sulfate	--	--				
Lauric acid Syn: dodecanoic acid CH ₃ (CH ₂) ₁₀ COOH	--	--	--				

TABLE B-17 (cont'd.)
TOXICITY OF THERMAL STORAGE MEDIA

CHEMICAL SUBSTANCE (GENERIC)	ACUTE TOXICITY (INGESTION)	TOXICITY RATING ^a GOSSELIN ^b	TOXIC HAZARD RATING ^a DURHAM ^c			
			ACUTE		CHRONIC	
			Local	Sys- temic	Local	Sys- temic
Myristic acid Syn: tetradecanoic acid	Nontoxic by oral administration	--	--			
Naphthalene Syn: moth flakes; white tar; tar campher C ₁₀ H ₈	Oral-rat		Irritant	2	1	
	LD ₅₀ =1780 mg/kg ^d	3	Ingestion			2
	LD _{Lo} =100 mg/kg	4	Inhalation			1
			Skin absorption			2
Nitrates	--	--	Irritant	U	U	
			Ingestion	U	U	2
			Inhalation	U	U	2
			Skin absorption	U	U	
Paraffin wax	--	--	Irritant	0	0	
			Ingestion	0	0	
			Inhalation	0	0	
			Skin absorption	0	0	
Polyethylene glycol 400 HOCH ₂ (CH ₂ OCH ₂) _n CH ₂ OH (n varies from 8-10)	--	2	Toxic hazard rating: U			
Polyethylene glycol 600	--	2	--			
Polyethylene glycol 6000	Oral-rat LD _{Lo} =50 gms/kg ^d	1	Toxicity: U			

TABLE B-17 (cont'd.)
TOXICITY OF THERMAL STORAGE MEDIA

CHEMICAL SUBSTANCE (GENERIC)	ACUTE TOXICITY (INGESTION)	TOXICITY RATING ^a GOSSELIN ^b	TOXIC HAZARD RATING ^a DURHAM ^c			
			ACUTE		CHRONIC	
			Local	Sys- temic	Local	Sys- temic
Sodium sulfate	Amount of sulfate anion usually absorbed has no toxicological significance					
Stearic acid Syn: octadecanoic acid $\text{CH}_3(\text{CH}_2)_{16}\text{COOH}$						Toxicity: slight
Zinc nitrate $\text{Zn}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$	Oral-rat $\text{LD}_{50}=1190 \text{ mg/kg}^d$	3				See nitrates

^a Gosselin: 1 - practically nontoxic; 2 - slightly toxic; 3 - moderately toxic; 4 - very toxic; 5 - extremely toxic; 6 - super toxic.
Durham: 0 - none; 1 - slight; 2 - moderate; 3 - high; U - unknown.

^b Gosselin, R.E.; Hodge; Smith; and Gleason, eds. Clinical Toxicology of Commercial Products. 4th ed. Baltimore: Williams and Wilkins Co. 1976.

^c Durham, W.W. Toxicology. In Dangerous Properties of Industrial Materials, edited by N.I. Sax. New York: Van Nostrand Reinhold Co. 1975.

^d Christenson, H.E., ed. Registry of Toxic Effects of Chemical Substances. NIOSH 76-191. U.S. Department of Health, Education, and Welfare, National Institute of Occupational Safety and Health. 1976.

Source: Searcy, J.Q., ed. Hazardous Properties and Environmental Effects of Materials Used in Solar Heating and Cooling (SHAC) Technologies: Interim Handbook. SAND 78-0842. Albuquerque: Sandia Laboratories. August 1978.

6.3 FIRE HAZARD PROPERTIES

Heat storage media used in solar process heat systems usually are well insulated and isolated from ignition sources. Thus, there appears to be little probability that the media could ignite accidentally. In a fire situation, however, the phase-change heat storage media could add considerable fuel as well as produce toxic gases.

Table B-18 lists the fire hazard properties of candidate heat storage media. Most of the flammable media retain stored heat through latent heat of fusion (melting) or store energy in a hot liquid. Such materials must melt before they can burn, therefore they are treated as liquids when calculating their fire hazard properties.

TABLE 8-18. FIRE HAZARD PROPERTIES OF THERMAL STORAGE MEDIA

Material	Flash Point (°F)	Fire Point (°F)	Ignition Temp. (°F)	Flammable Limits (% by vol)	Solubility in Water (ppm)	Vapor Density (Air=1)	Boiling Point (°F)	Sp. Heat Btu/lb (°F)	Heat of Comb. (Btu/lb)	Suggested Hazard Identification	
										Flammability	Reactivity
Propionamide $C_2H_5CONH_2$	--	--	--	--	yes	--	--	--	--	--	--
Urea/ NH_4 Br	--	--	--	--	yes	--	--	--	--	--	--
Diphenyl oxide $(C_6H_5)_2O$	239	--	1148	0.8-1.5	slight ^a	5.86 ^b	498	--	--	1	0
Napthalene $C_{10}H_8$	174 (OC)	--	979	0.9-5.9	slight ^c	4.4 (sublines)	424	--	--	2	--
Lauric acid $CH_3(CH_2)_{10}COOH$	--	--	--	slightly flammable ^d	no ^a	--	268 ^e	--	--	1	1
Benzamide $C_6H_5CONH_2$	--	--	--	--	slight ^e	--	554 ^a	--	--	--	--
Benzoic acid C_6H_5COOH	250	--	1058	--	slight ^a	4.21	482 ^e	--	--	1	--
Barium hydroxide Octo-Hydrate $Ba(OH)_2 \cdot 8H_2O$	--	--	--	non- flammable	5.6 ^a (@59°F)	--	1436 ^e	--	--	0	--
Biphenyl $C_6H_5C_6H_5$	235 ^c	--	1004	0.6-5.8 (@232°F) ~(@322°F)	no	5.31 ^b	489	--	--	1 ^c	0
Stearic acid $CH_3(CH_2)_{16}COOH$	385 ^c	--	743	--	no ^a	9.8 ^b	721 ^b	--	--	1 ^c	0
Palmitic acid $C_{15}H_{31}COOH$	--	--	--	--	no ^d	--	332 ^d	--	--	--	--
Paraffin wax	390 ^f	--	473 ^f	--	no ^e	--	>734	--	--	1	0
Myristic acid $C_{13}H_{27}COOH$	--	--	--	--	no ^a	--	301 ^g	0.539 ^h (@212°F)	--	0	--
Zinc nitrate hexa-hydrate $Zn(NO_3)_2 \cdot 6H_2O$	--	--	--	non- flammable	184 ^c (@59°F)	--	221-268 ^g	--	--	0	--
Calcium bromide Hexa-hydrate $CaBr_2 \cdot 6H_2O$	--	--	--	non- flammable	594 (@59°F) ^e	--	300 ^g	--	--	--	0
Calcium chloride Hexa-hydrate $CaCl_2 \cdot 6H_2O$	--	--	--	non- flammable	279 (@59°F) ^e	--	392 ^g	--	--	--	0
Capric acid $CH_3(CH_2)_8COOH$	--	--	--	--	no ^e	--	518 ^g	--	--	--	--
Myristic/capric acid	--	--	--	--	--	--	--	--	--	--	--
Polyglycol E600	--	480 (OC)	--	--	--	--	--	--	--	--	--
Polyglycol E400	--	460 (OC)	--	--	--	--	--	--	--	--	2
Polyglyco E6000	--	495 (OC)	--	--	--	--	--	--	--	--	1
Caprylic acid $CH_3(CH_2)_6COOH$	--	--	--	--	slight ^e	--	230 ^g	--	--	--	--
Glauber's salt $Na_2SO_4 \cdot 10 H_2O$	--	--	--	non- flammable	11 (@59°F)	--	212 ^g	--	--	--	0
Rock	--	--	--	non- flammable (usually)	--	--	--	--	--	--	0

TABLE B-18 (Continued)

- ^a Gaskill, J.R. Smoke Development in Polymers During Pyrolysis or Combustion. Journal of Fire and Flammability. 1:183-216. 1970.
 - ^b Monsanto Chemical Corporation. Therminol Heat Transfer Fluids. Technical Bulletin IC/FP-31.
 - ^c Klitgaard, P.S. and Williamson, R.B. The Impact of Contents on Building Fires. Consumer Product Flammability. 2:84. March 1975.
 - ^d Celotex Corporation. Technical bulletins on TF-600 Thermax Insulation Board.
 - ^e Weast, R.C. ed. Handbook of Chemistry and Physics. 56th Edition. Chemical Rubber Co. 1976.
 - ^f Comsrow, T.J.; Glaser, F.M.; and Shaw, R.W., Jr. Potential Environmental Impacts of Solar Heating and Cooling Systems. EPA 600/7-76-014. Environmental Protection Agency. October 1976.
 - ^g Young, R.A., and Fisk, L.O. eds. New Silicon Transformer Fluid: An Environmental Review. Pollution Engineering, p. 41, August 1977.
 - ^h Perry, R.H., and Chilton, C.H. eds. Chemical Engineer's Handbook. 5th Ed. New York: McGraw-Hill Book Co. 1973.
- SOURCE: Searcy, J.Q. ed. Hazardous Properties and Environmental Effects of Materials Used in Solar Heating and Cooling (SHAC) Technologies: Interim Handbook. SAND 78-0842. Albuquerque: Sandia Laboratories. August 1978.

APPENDIX C
DETAILED ANALYSIS OF
SOLAR AIPH WORKING FLUID SPILLAGE

Introduction

There exists a wide variety of solar AIPH system configurations due to diverse applications, locations, costs, load profiles, etc. It would be impossible to provide a detailed analysis for each system configuration. It also is impossible to define a standard analysis which is representative of most systems. Therefore, this report describes an analysis of one particular system which represents at least a portion of solar AIPH systems. The method for performing the analysis and the evaluation of the resulting information are perhaps more important than the specific numbers used in the study.

In selecting a system for analysis, 23 AIPH systems (designed and/or installed) were considered. Of these, six were air or greenhouse systems which obviously do not pose a spillage problem. Of the remaining 17 liquid systems, 13 used water as the working fluid. Although spillage of a water system could result in some property damage or personnel injury, the potential hazard is not severe. Four systems used fluids which could degrade nearby ecosystems if large spills took place. One of these system designs had sufficient information to allow a detailed analysis.

The system chosen will not be referred to by name in this report for several reasons. First, the system may have been altered significantly since the report was written. Second, the control scheme has been changed to provide a more interesting analysis. In the original design, most valves were not closed at the time of system failure. Third, dimensions for all portions of the system were not available and there-

fore, required assumptions. Finally, little would be gained by tying the analysis to a particular installation since the methodology is the primary emphasis of this report. Therefore, the system described herein should be considered as a hypothesized design based on an actual system.

System Description

Figure C-1 illustrates the general system configuration being studied. The collector array consists of 72 parabolic collectors, each with an aperture area of 140 ft² yielding a total area of 10,080 ft². Each group of six collectors will have its own tracking mechanism resulting in 12 collector groups. The system will operate up to 250 psig and 500°F. The heat transfer is a hydrocarbon oil with a flash point of 430°F and an autoignition temperature of 675°F. The only storage in the system is contained in the expansion tank and piping capacity.

The system is meant to operate on a "supply what you can" basis. The heat transfer oil is passed through a steam generator. Via a heat exchanger, feed water at 220°F is converted to dry saturated steam at 375°F for use in processing.

The emergency control system consists of a level detection device and controlled valves. (This is not the same as the original system design.) If the system loses more than forty gallons of working fluid, a liquid level detector will sense the loss and shut the system down. This is accomplished by shutting off the working pump, closing the valves, and redirecting the collector orientation (to avoid excessive stagnation temperatures). The system also may be shut down manually if personnel detect the leak before the 40 gallon limit is reached.

Catch basins are not described since they do not affect the magnitude of the spill. However, it should be realized that the dikes and catch basins will affect the impact of such spills on the local environment.

FIGURE C-1 SOLAR IPH SYSTEM SCHEMATIC

Failure Analysis

Several assumptions must be made about the system and its operation before a failure analysis can be attempted. First, the study deals only with major spills. Minor leaks can be detected before the 40 gallon limit is reached and repairs accomplished with little loss of fluid. Second, the study will attempt to identify only the potential magnitude of spillage and not the probability of such occurrences. Third, the detection and control system is assumed to work properly. If not, the system could lose virtually the entire oil content (between 390 and 480 gallons). Such a case should be considered seriously in future studies since emergency control subsystems often have poor reliability. Periodic checking can reduce the probability of such a failure of the emergency control subsystem. Finally, if failure occurs, the system will drain all lines that are not sealed off by controlled valves. Although this assumption is somewhat conservative, it was necessary to define the worst possible spill for each failure mode.

With these assumptions in mind we now can define the various failure areas. Figure C-2 through C-8 illustrate the portions of the system which become isolated when all valves are closed. The crosshatched portion in each Figure represents the piping which would drain if a rupture occurred in that section of pipe. For example, if a break occurred on the inlet line to the collectors (prior to the gate valve) the crosshatched area in Figure C-2 would be drained (150 + 40 gallons). The actual location of the spill obviously would be a function of where the break occurs, but it should be noted that in this case the spill probably would occur outside of the building thus endangering nearby water supplies.

Figure C-3 illustrates the case for a collector failure. The shaded area could drain and represents approximately 27 gallons. Differences in elevations could reduce this value substantially. Again, the spill-

FIGURE C-2 LEAKAGE DUE TO FAILURE IN THE COLLECTOR INLET LINE

FIGURE C-3 LEAKAGE DUE TO FAILURE IN THE COLLECTOR PIPING

FIGURE C-4 LEAKAGE DUE TO FAILURE IN THE COLLECTOR OUTLET LINE

FIGURE C-5 LEAKAGE DUE TO FAILURE IN THE PIPING BETWEEN COLLECTOR AND STEAM GENERATOR

FIGURE C-6 LEAKAGE DUE TO FAILURE IN THE GENERATOR INLET OR OUTLET

FIGURE C-7 LEAKAGE DUE TO FAILURE IN THE PUMP INLET

FIGURE C-8 LEAKAGE DUE TO FAILURE IN THE EXPANSION TANK

age would occur outside and represent a threat to water supplies.

Figures C-4 through C-7 divide the remaining piping from the collector outlet to the working pump into four sections determined by the location of the various valves. The volumes of the sections are 58, 5.8, 10 and 9.6 gallons. Table C-1 presents this information in summary form. Also included are the temperatures of each section during normal operation conditions.

The final failure considered is a rupture below the expansion tank (Figure C-8). In this situation, whatever oil was in the tank at that time would be drained. This can be up to 90 gallons of low temperature oil.

It is not within the scope of this study to consider failures which include failure of the various valve combinations. However, by combining the information in Table C-1, one can obtain most of the permutations of interest.

Evaluation

The information presented above indicated that the potential magnitude of an oil spill is not insignificant and that the magnitude is very dependent upon the location of the rupture.

To fully appreciate the failure modes, it is necessary to discuss the possible impact of the ruptures. Most of the system fluids are contained in lines located outside of the building. Spillage in these areas can cause contamination of nearby water supplies via direct drainage or long term leaking. Hydrocarbon oils may foul water reserves to the point that they are no longer potable and are even unfit for a great number of

TABLE C-1 SUMMARY OF SPILLAGE ANALYSIS

<u>Figure #</u>	<u>Spillage Location</u>	<u>Approximate Leak Volume (gals)</u>	<u>Temperature Range-°F</u>
C-2	Outside	150 + 40 *	380-400
C-3	Outside	27 + 40	480-500
C-4	Outside	58 + 40	480-500
C-5	Equipment Room	5.8 + 40	480-500
C-6	Equipment Room	10 + 40	380-500
C-7	Equipment Room	9.6 + 40	380-400
C-8	Equipment Room	up to 90.0	380-400

* Note: The leak detection systems set to detect a leakage of 40 gallons before shutting the system down.

industrial applications*. In surface water systems, hydrocarbon oils float, contaminating the surface and preventing proper aeration. The oils degrade slowly and clearly present a hazard if released in great quantities.** Catch basins should be sized to accept the amount of spillage indicated in Table C-1. (The 40 gallons must be included.).

If spillage occurs inside the building, water supply contamination is not a significant hazard. However, it should be noted that if an indoor spillage occurred, substantial amounts of hydrocarbon vapors could be given off. These vapors may represent a toxic hazard if proper ventilation is not provided. The fluid in the lines coming from the collector to the generator (indoors) typically are operating above the 430°F flash point. Therefore, if a rupture occurs in these lines during operation, a significant fire hazard is created. Care should be taken to eliminate any heat sources capable of raising the spilled fluid (or portions of the fluid) above the 675°F autoignition temperature. Outside spills involve the same fire and toxic hazards but have less potential effect and are avoided more easily.

Conclusions

This analysis has demonstrated the potential magnitude of a major oil spill at one particular AIPH installation. One cannot extrapolate to

* Searcy, J.Q. et al. November 1978. A Survey of Potential Environmental Effects and Regulations Related to the Disposal of Solar Heating and Cooling (SHAC) Heat Transfer Liquids. SAND 78-1782. Albuquerque: Sandia Laboratories.

** Deborger, J.D. et al. 1975. "Soil and Groundwater Contamination by Oil Spills; Problems and Remedies," J. Environ. Studies (8):99-111.

all systems but it is possible to obtain a general appreciation of the problem.

For this particular site one may conclude that extreme caution should be taken to ensure that the fluid is contained in the event of a rupture. (Especially since a major water source is only 70 feet below the collector field.) Fire and inhalation hazards also are significant especially if the failure occurs within the building. Periodic checks should be made of the emergency control system so that no more than 40 gallons of oil are lost prior to detection.

APPENDIX D
ENGLISH/METRIC CONVERSION TABLE

English Units (abbreviations)	Conversion Factors ^{a/}	Metric Units (abbreviations)
foot (ft)	0.305	meter (m)
square foot (ft ²)	0.093	square meter (m ²)
cubic foot (ft ³)	0.038	cubic meter (m ³)
ounce (oz)	28.4	gram (g)
pound (lb)	0.454	kilogram (kg)
ton	0.909	tonne
gallons (gal)	3.79	liters
parts per million (ppm)	conversion factor depends on the substance	milligrams per liter (mg/l); milligrams per cubic meter (mg/m ³)
degrees Fahrenheit (°F)	$\frac{5}{9}(^{\circ}\text{F} - 32) = ^{\circ}\text{C}$	degrees Centigrade (°C)
British Thermal Unit (Btu)	1,055	joule (J)
quadrillion Btu (quad)	1.055	giga-gigajoule (GGJ)

DEFINITIONS OF METRIC PREFIXES

G (giga -) = billion = 10^9

M (mega -) = million = 10^6

k (kilo -) = thousand = 10^3

m (milli -) = thousandth = 10^{-3}

a/ Multiply the number of English units by the conversion factor to get the number of metric units. (Exception: for temperature use the formula.)

APPENDIX E

GLOSSARY

active solar system - a solar system which uses auxiliary energy such as electrically driven pumps or blowers to transfer the thermal energy collected by a solar collector to the point of use or to a storage tank.

AIPH - Agricultural and Industrial Process Heat

ASHRAE - American Society of Heating, Refrigeration, and Air Conditioning Engineers.

bioassay - a test to determine the toxicity of a substance with respect to a specific organism. The dosage or concentration of the substance, the length of exposure, and the environmental conditions of the test are controlled.

biocides - chemical substances used to prevent the buildup of biological growth (e.g., algae) in pipes or tanks through which fluid is flowing.

BOD (Biochemical oxygen demand) - a measure of organic material in water based on the amount of oxygen used in the biochemical oxidation of the organic matter in a specified time, at a specified temperature, and under specified conditions.

Btu (British Thermal Unit) - English unit of heat measurement; the amount of heat required to raise the temperature of 1 lb of water by 1°F at sea level.

conduction - the transfer of heat by adjacent molecular collisions throughout a material medium. The medium itself does not move.

convection - the transfer of heat from one part of a liquid or gas to another part by mixing of the liquid or gas particles.

COP (coefficient of performance) - a ratio which expresses the effectiveness of a heating or cooling device. For a solar powered Rankine engine,

$$\text{COP} = \frac{\text{heat absorbed by vaporizing collant}}{\text{solar heat incident on collector}}$$

The higher the COP, the greater the effectiveness of the device.

corrosion inhibitors - chemical compounds used to reduce corrosion in metals which are exposed to water and air.

covenant - (or restrictive covenant, personal covenant) - a private promise between two or more parties involving the use of land; usually found in a deed. Often used by developers to govern esthetic considerations in subdivisions.

declining block pricing - a utility rate structure which imposes a higher fee for the first "block" of energy purchased. This is the most common pricing system for residential utility customers, and was designed to encourage long-run growth in demand.

direct application of solar energy - use of solar energy for the heating and cooling of buildings or for agricultural or industrial process heat without first converting it to electricity. Generation of electricity is the other application of solar energy.

DOD - U.S. Department of Defense.

DOE - U.S. Department of Energy.

DOJ - U.S. Department of Justice.

easement - the right to use another's land for a narrowly defined purpose; may be created by grant, purchase, or other agreement between involved parties. Affirmative easements allow one party to use another's land in a given way; negative easements preclude specific uses by landowners that would otherwise be allowable. Solar easements to prevent collector shading are negative easements.

EEA - Energy and Environmental Analysis, Inc.

energy/demand pricing - a utility rate system having two components; an energy charge, reflecting total kilowatt-hours used, and a demand charge, based on the maximum kilowatt demand during any given time period (e.g., any 15 minutes). The demand charge reflects the cost of maintaining generating capacity as opposed to the cost of fuel.

EPA - U.S. Environmental Protection Agency.

EPRI - Electric Power Research Institute.

ERDA - U.S. Energy Research and Development Administration.

eutrophication - the over-enrichment of a water body by nutrients which results in increased levels of algae growth and, often, in lower levels of dissolved oxygen in the water.

FHA - Federal Housing Administration.

FY - fiscal year.

GSA - U.S. General Services Administration.

heat exchanger - a device for transferring heat from one fluid to another. In a solar system, a heat exchanger may be needed to transfer heat between the fluid circulated in the collectors and the storage fluid and/or between the storage and distribution components.

HUD - U.S. Department of Housing and Urban Development.

HVAC - heating, ventilation, and air conditioning.

J (joule) - metric unit of energy measurement, including heat measurement; corresponds to the English Btu.

latent heat - heat added to a substance which results in a change of phase (e.g., from solid to liquid) without any rise in temperature.

LC₅₀ (Lethal Concentration Fifty) - the concentration of a toxicant in air or water which is lethal (fatal) to fifty percent of the organisms tested in a specified time.

life cycle costs - the cost of buying, operating, and maintaining a machine or building over the entire period of its use.

mg/l (milligrams per liter) - used to denote the concentration of a substance in a liquid solution.

mg/m³ (milligrams per cubic meter) - used to denote the concentration of a substance in a gas mixture.

NASA - U.S. National Aeronautics and Space Administration.

NBS - U.S. National Bureau of Standards

NSF - National Science Foundation.

OSHA - Occupational Safety and Health Act.

passive system - a solar system which uses no auxiliary energy to transfer thermal energy. The building is designed, using methods such as proper window placement and building orientation, so that heat from the sun will be collected, stored, and distributed by natural convection, conduction, and radiation.

peak-off-peak pricing - see "time-of-day pricing."

pH - used to express both acidity and alkalinity on a scale whose values run from 0 to 14 with 7 representing neutrality, numbers less than 7 increasing acidity, and numbers greater than 7 increasing alkalinity.

plenum - a central distribution duct in an air distribution system.

ppm (parts per million) - used to denote the concentration of a substance in a gas or a liquid. For a gas, it refers to the ratio of the weight of the substance to the weight of a given volume of the gas mixture and corresponds to the metric unit, mg/m³. The ppm values in this report were determined using air as the gas mixture.

quad - one quadrillion (10^{15}) Btu's.

radiation - the transfer of heat from one body to another by electromagnetic waves passing through a separating medium.

rate inversion - a utility pricing system which charges less for the first "block" of energy purchased than for succeeding amounts; this is an inversion of the traditional declining block rate which charges more for the first block of energy than for subsequent energy use.

RCRA - Resource Conservation and Recovery Act.

RD&D - research, development, and demonstration.

retrofit solar system - a solar system which is installed in an already existing building.

sensible heat - heat added to a substance which results in a rise in temperature without a change in phase.

solar collector - a device which collects solar radiation, transforms it into usable thermal energy, and uses this to heat a liquid or gaseous working fluid.

sun rights - refers to the legal problem of ensuring access to sunlight for solar heating and cooling systems.

thermal capacity - the amount of heat absorbed or given off by a body of a given mass per unit of temperature change (for example, the thermal capacity of 1 pound of water is 1 Btu per Fahrenheit degree).

thermal cycling - expansion and contraction of a substance caused by changes in temperature. Sudden contraction of some substances (e.g., glass) can cause them to crack or break in this process.

thermosyphoning - natural circulation of liquid in an enclosed system without the use of a pump. With respect to a thermosyphone water heating system, this occurs when solar radiation heats the liquid in the collector and causes it to become less dense than the liquid in the storage tank above it. This density differential causes the liquid to flow, by the convection process, through the collector and up to the top of the storage tank.

TIC - ERDA Technical Information Center.

time-of-day pricing (peak and off-peak pricing) - a utility rate structure which charges more for power consumed during peak periods and less during other hours, such as late at night.

TL_m⁹⁶ - aquatic toxicity level - the concentration of a substance which will kill 50 percent of exposed test organisms within 96 hours after initial exposure.

TLV (Threshold Limit Value) - a guideline representing the highest airborne concentration of a substance to which workers may be repeatedly exposed in the working environment without adverse physical effects due to inhalation of the substance.

TSCA - Toxic Substances Control Act.

working fluid - the fluid (e.g., water, air) used to transport thermal energy in a solar heating and/or cooling system.

APPENDIX F

EFFLUENT FACTORS ASSOCIATED WITH THE MANUFACTURE OF KEY MATERIALS FOR SOLAR AIPH SYSTEMS

TABLE F-1
WATER POLLUTANTS ASSOCIATED WITH THE MANUFACTURE
OF KEY MATERIALS FOR SOLAR AIPH SYSTEMS
(BASED ON FEDERAL EFFLUENT CONTROL GUIDELINES)
USING BEST AVAILABLE TECHNOLOGY ECONOMICALLY ACHIEVABLE)

Material and Process	Pollutant Effluents (Kg/metric ton final product) 30-day average							
	Total suspended solids	Oil and grease	Phosphorus	Ammonia	Cyanide	Phenol	Sulfide	Fluoride
Steel								
• By-Product Coke	.0040	.0016	-	.0016	-	.0001	-	-
• Sintering	.0036	.0015	-	-	-	-	-	.0029
• Blast Furnace-Iron	.0091	-	-	.0036	.0001	.0002	.0001	.0072
• Basic Oxygen Steel Furnace (wet air pollution control methods)	.0052	-	-	-	-	-	-	.0042
• Continuous Casting	.0052	.0052	-	-	-	-	-	-
Copper								
• Primary and Secondary Smelting and Refining	-	-	-	-	-	-	-	-
Aluminum								
• Bauxite Refining	-	-	-	-	-	-	-	-
• Primary Smelting	0.1	-	-	-	-	-	-	.05
• Secondary Smelting	-	-	-	-	-	-	-	-
Concrete								
• Cement Manufacturing	-	-	-	-	-	-	-	-
• Materials Storage	≤50/mg/liter in rainwater runoff	-	-	-	-	-	-	-
Glass								
• Float Manufacturing	0.70	1.40	0.05	-	-	-	-	-
Fiberglass								
• Manufacturing	-	-	-	-	-	-	-	-
Softwood Lumber								
• Sawing & Milling	-	-	-	-	-	-	-	-

SOURCES: 40 CFR, Cement Manufacturing Guidelines and Standards
40 CFR, Effluent Guidelines and Standards for Iron and Steel Manufacture
40 CFR 421, Effluent Guidelines and Standards for Nonferrous Metals
40 CFR 426, " " for Glass Manufacturing
40 CFR 429, " " for Timber Products

TABLE F-2

EMISSIONS FACTORS FOR AIR POLLUTANTS ASSOCIATED WITH THE
MANUFACTURE OF KEY MATERIALS FOR SOLAR ALPH SYSTEMS

Material and Process	Emission Controls	Total Particulates	Emissions (Kg/metric ton of final product)					Fluorides	
			CO	SO ₂ (as SO ₂)	NO _x (as NO ₂)	Hydrocarbons (as CH ₄)	Ammonia	Gaseous (HF)	Particulates CaF ₂
Steel									
• Coking Operation (By-Product process)	none	1.12	0.41	1.29	0.012	1.35	0.058	-	-
• Pig-Iron Blast Furnace	Dry cyclone and electrostatic precipitators	0.35	-	-	-	-	-	-	-
• Steel Furnace (Basic oxygen type)	Venturi scrubber	0.26	-	-	-	-	-	-	0.001
Copper									
• Roasting	Electrostatic precipitators &								
• Smelting (reverberatory type furnace)	sulfuric acid plants with lime	1.35	-	93.75	-	-	-	-	-
• Converting	slurry scrubbing								
• Refining									
Concrete									
• Portland Cement Manufacture (dry process)	Electrostatic precipitators	1.10	-	1.58	-	-	-	-	-
• Concrete Batching	none	0.05	-	-	-	-	-	-	-
Aluminum									
• Bauxite Grinding	Electrostatic precipitators								
• Calcinating of Aluminum hydroxide	"	3.80	-	-	-	-	-	-	-
• Anode Baking Furnace	Dry electrostatic precipitation	0.57	-	-	-	-	-	0.47	-
• Prebaked Reduction Cell	"	2.64	-	-	-	-	-	12.37	0.66
• Materials Handling	Quench tower and spray screen	0.85	-	-	-	-	-	-	-
Glass									
• Soda Lime Manu.	none	1.0	-	-	-	-	-	2F?	-
Fiberglass									
• Manufacture	Electrostatic precipitator	2.3	1.13	5.0	3.2	-	-	0.13	-