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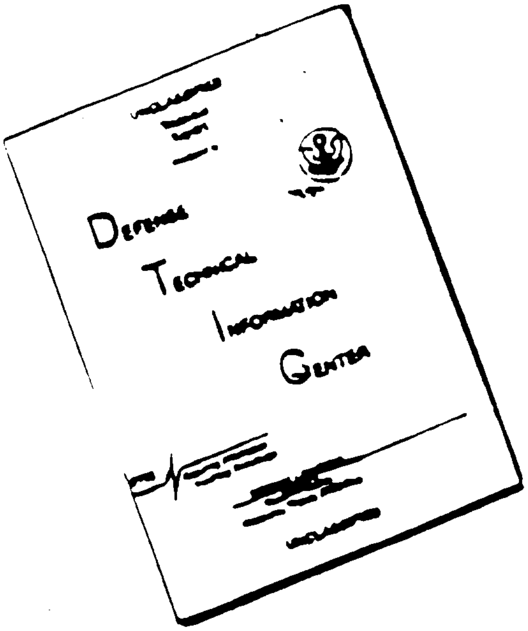
Hazardous Properties and Environmental Effects of Materials Used in Solar Heating and Cooling (SHAC) Technologies: Interim Handbook

December 1978

U.S. Department of Energy
Assistant Secretary for Environment
Division of Environmental Control Technology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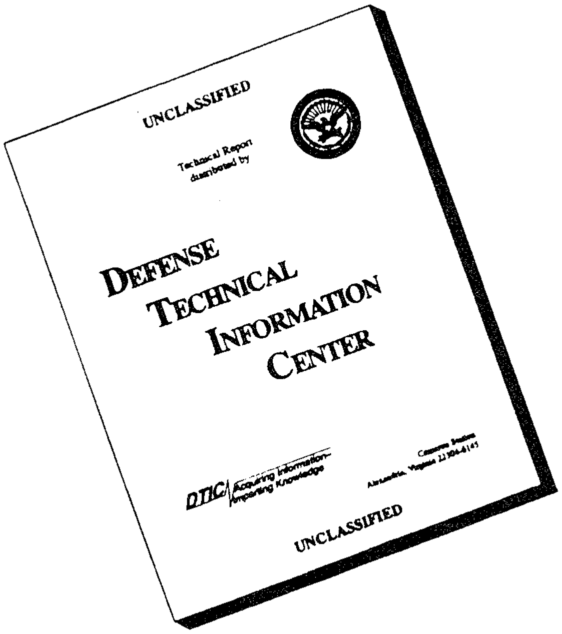

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PREFACE

This document has the term "interim handbook" in its title because it is not in final form, and much of it is not complete. It is published in this form chiefly as a vehicle to solicit comment and input from qualified spokesmen interested in the use of solar energy for heating and cooling.

In its final form, this handbook is expected to be widely distributed throughout the solar industry, and it is expected to be readily available to the general public. This edition is the framework upon which the final handbook will be built. The interim handbook is expected to be a living document that will expand as required to include new data, new concepts, and appropriate corrections. Revised draft editions of the interim handbook may be available at periodic intervals on request, and the final form of the handbook is scheduled for completion in February of 1980.

Qualified spokesmen wishing to influence the development of this handbook should contact the editor by letter. Contributions in the form of new data, new discussion topics, consultations, or expansions of those topics already included are solicited. Constructive comments designed to improve the format of this document are also welcome. The list of contributors will be expanded as needed to acknowledge significant new contributions or consultations.

Any reasonable disagreement with data, positions, projections, or issues in this handbook should be communicated by letter to the editor and should be carefully substantiated (documented if possible).

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I INTRODUCTION

The use of solar energy is often considered to be environmentally benign and to present few or no health hazards. However, all technologies impact the environment in which we live, and all technologies introduce situations that can lead to personal harm and property loss. Solar energy use is no exception, but the negative aspects appear to be far less hazardous than many other energy technologies if solar energy systems are carefully designed.

The critical time for affecting a technology is during its development. Past experience indicates that negative environmental impacts or safety hazards associated with a well entrenched technology are very expensive and difficult to correct. Furthermore, any well publicized incident involving personal injury, property loss, or environmental hazard generation can seriously retard public acceptance of a new technology. For these reasons, it is essential to consider methods for minimizing potential negative environmental impacts and include personal safety considerations as an integral part of the design process for any new technology. The use of solar energy is still in that early stage of development and public acceptance which allows for easy change; therefore, any health hazards and negative environmental effects can be minimized if they can be identified.

The widespread use of solar heating and cooling (SHAC) technologies in private residences is a goal being promoted by the federal, state, and local governments. As this goal is achieved, more and more homeowners and businessmen will come face to face with new technologies and materials that may be unfamiliar. It is desirable that a single reference source of hazardous material properties be available to these individuals.

A. Objectives of This Handbook

This handbook is intended to serve two primary functions. First, it is to complement and aid the development and use of SHAC technologies by providing a single reference source about hazardous properties and environmental effects. It is intended for use by homeowners, designers, architects, technologists, builders, and any other interested parties. The data and discussion in this handbook should help SHAC technologies develop along a path that minimizes environmental effects and hazards to health and property.

The second objective for this interim handbook is to identify data deficiencies. The needed data are pointed out for specific materials by their absence in this handbook and for specific issues by the text discussion. Some issues raised in this interim handbook are speculative, and some may prove to be of no real concern. Nevertheless, these issues need to be critically examined. Workers at various locations are currently collecting data relevant to many of the issues considered in this interim handbook, and the final edition of the handbook will report those results that help to resolve specific issues.

B. Limitations on the Data Presented

The data presented in this interim handbook result mostly from a survey of published literature and brochures provided by manufacturers of various materials. Hazardous properties data are limited to toxic properties and fire properties. Some chemical analysis of specific materials, and some determination of chemicals produced in a high-temperature environment, were performed specifically for this handbook.

In many respects existing hazardous properties data are inadequate. Most existing toxicity data are relevant to short-term effects. The fact that a material does not cause immediate toxic effects does not ensure the lack of long-term effects. Information on long-term toxic effects is expensive to generate and, therefore, is quite limited.

Fire properties are equally difficult to assess. Standard test methods do not gauge how a material behaves in all situations, and a list of test results is meaningful only for specific conditions.

Real data concerning environmental effects of careless disposal of liquids and solids are very limited, and only occasionally do they apply to SHAC materials. Consequently, the discussions concerning environmental effects are primarily extrapolations and speculations based on very sketchy data.

It is probable that some SHAC materials have hazardous properties that are not included in this handbook simply because the data are not available. A material cannot be considered free of hazardous properties simply because none are identified in this handbook.

The development of solar energy technology today is very dynamic, constantly changing, and very hard to characterize. The materials considered in this handbook were chosen because of their use in current technologies and their projected uses. Undoubtedly there are specific materials not included in this text which will be used in SHAC technologies.

Regardless of the care with which tables of data are assembled, errors do occur. Also, published work is not always accurate or correct. Comment from readers will undoubtedly point out more authoritative references and errors in this interim handbook. The final edition of the handbook will include all needed corrections and changes which have been discovered. Any data or claims in this interim handbook that appear to be out of context or incorrect for any reason should be checked in a cited reference (if applicable). If a discrepancy still exists, please notify the editor of this handbook by letter at the following address:

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C. The Concept of a Hazard versus a Hazardous Property

A hazardous property of a material is not a hazard; instead, it is any material property that can lead to personal harm if the material is used improperly. Hazards result when people use a material or an object in a manner that does not adequately protect against its potentially dangerous properties. In this report emphasis is placed on <u>properties</u> related to toxic hazards, fire dangers, and environmental effects. Specific hazards which appear to be easily overlooked are pointed out in the text. However, all potential hazards could not be addressed.

D. Guide to the Use of This Handbook

This handbook is not intended for use as a quick reference for those who are not already familiar with SHAC technologies. It is intended to be a source book, but a careful reading of the text is expected. General background information related to SHAC systems, how a particular material was chosen for this handbook, and codes and standards are given in Chapters II and III. Chapters IV through VIII contain the informational sections of the handbook. Each of these chapters is self-contained, and each is constructed similarly. Each informational chapter begins with a general discussion of the properties considered in that chapter, discusses the properties of specific categories of materials, and includes available data in tabular form with each discussion of a specific category. Materials are categorized according to their functional use in SHAC systems. These categories are explained in Chapter IV and can be listed as follows: (1) heat transfer fluids and fluid treatment chemicals, (2) insulation materials, (3) seals and sealant materials, (4) glazing materials, (5) collector materials, and (6) storage media.

The user of this handbook will find the Table of Contents and the List of Tables given at the beginning of the handbook as the chief aids in finding specific information. For example, a user interested in ethylene glycol (or any material containing ethylene glycol as the primary constituent) must first determine that ethylene glycol is a heat transfer fluid (if this is not obvious, then Chapter 4 should be carefully read for an explanation of the categories). Then, a quick reference to the Table of Contents would indicate that the following sections and tables contain the information on ethylene glycol:

Property	Section	Page	Table	Page
Physical Properties	IV-B-1.	32	IV-1	43
Chemical Characterization	V-C-1.-b	96	V-4	100
Toxicity Properties	VI-B.	118	VI-2	122
Fire Properties	VII-B	153	VII-1	155

All the important information relating to ethylene glycol (or glycols) cannot be presented in a table. There are no tabulated data for environmental effects for example. The user interested in any potential environmental effect of ethylene glycol would have to refer to the written text concerning environmental effects of heat transfer fluids.

II. SHAC SYSTEMS

Solar heating and cooling systems are usually classified as either active or passive. The general definition of a passive system is one for which no additional sources of energy (electrical blowers, pumps, etc.) are needed to transfer the thermal energy.[1] Active systems require auxiliary sources of power (usually electrical) to move the thermal energy. In general, active systems are more complicated than passive ones and require more expensive components. Active systems provide a greater degree of temperature control within a building.

A. Passive Systems

The simplest kind of passive system is the direct-gain type. It usually has a large expanse of window, usually double-glazed, facing south.[2] The building would be designed to have a considerable thermal mass, either in the floor (usually concrete) or in the walls of the structure, and an insulating layer on the outside of the structure. Adobe or masonry walls and concrete or brick floors are typical materials used in the construction of this type of building.

The heating of the building is controlled by overhangs so that in the winter, when the sun is low, the maximum amount of solar energy enters the building and in the summer, when the sun is high, a minimum amount enters.

A more sophisticated type of passive system uses a thermal storage wall immediately behind a large window facing south. The wall is usually painted black for maximum absorption. Materials used in the construction of the wall may be concrete, adobe, or water in containers. The Steven Baer[2] house is a variation of this type of passive system. It has a movable insulating door which can be raised and lowered to cover the south-facing window, and the thermal wall consists of 55 gallon drums containing water.

Another version of the thermal storage wall is the Trombe house[2] which has a large concrete wall behind a south-facing window. Ports are placed near the top and bottom of the wall so that natural convection helps circulate the heat. The summer heating is partially controlled by a roof overhang. Typical temperatures of the hot side of the wall range from 49 to 65° C (128 to 150° F).

Harold Hay's Skytherm concept[2] is yet another type of passive system. The thermal mass is supplied by a shallow pool located on the roof of the house; a black plastic open liner serves as the container. Direct contact of the water-filled liner with the metallic ceiling allows heat to be transferred to the inside. Insulating roof covers are placed over the pool to reduce heat losses at night. During the summer, the cover is used in daytime hours to reduce the heat flow, and at night it is opened to allow the building to cool.

Finally, there are passive systems which are similar to active systems, except that they use natural convective loops of the heat transfer fluid to move the energy. The Paul Davis[2] house in Corrales, New Mexico, is an example of this type of system.

B. Active Systems

All active systems have the following common features: collectors, heat transfer fluid circulated by a pump or fan, and an energy storage bin or tank. The collectors are usually mounted at such an angle to the horizon so that during the winter at noon, the sun's rays strike it at normal incidence. Several different types of heat transfer fluids can be used. They include water, water solutions, oils, and air. The energy storage bins are often located inside the building or underground just outside it. A variety of materials can be used to store the heat.

Active solar collectors are classified as concentrating or nonconcentrating. The concentrating type is often constructed of mirrors or lenses with a tubular collector placed at the focus. A heat transfer fluid is then circulated through the tube to transport the thermal energy to the point of utilization. The advantage of this type of collector over the nonconcentrating type is that the working temperature of the heat transfer fluid is much higher. A disadvantage is that, in most cases, this type of system requires a sun tracker to operate efficiently.

Commercially available nonconcentrating collectors are generally flatplate collectors consisting of a metallic sheet (steel, copper, or aluminum) with integral or thermally bonded tubing. The collector is insulated against heat losses from below with an insulating layer and from above by an air space formed by one or more transparent sheets sealed to a box around the metal surface of the collector. The transparent sheets are referred to as glazing, and they serve two purposes:

1. A dead airspace is created between the absorption plate and the glazing, thus reducing convection losses.
2. Visible or short wavelength radiation is allowed to pass through, but the infrared or long wavelength radiation emitted by the collector plate is not transmitted out of the collector box.

Typical operating temperatures for flat-plate collectors range from 38 to 121° C (100 to 250° F), but under conditions of stagnation (loss of heat transfer fluid flow) the temperature can easily reach 204° C (400° F) and higher.

C. Sources of Materials Lists

The lists of materials considered in this report were obtained from prototype systems, a survey of available literature, and by consultations with manufacturers. The intent was to make generically complete lists of materials currently considered for use in residential solar heating and cooling applications. The lists of specific materials are not complete because all manufacturers were not contacted and because manufacturers frequently change the materials they use.

Material lists for nine prototype, commercially available systems were provided for this study through the United States Department of Energy, Division of Solar Energy.[3] The Battelle Pacific Northwest Laboratory compiled the lists.[4] Two of the nine systems are designed to provide process heat and are not included in this handbook. Table II-1 lists the remaining seven systems with their generic materials lists.

TABLE II-I

Prototype Solar Heating Systems

Type of System	Absorber Material	Absorber Coating	Glazing Thickness mm (inches)	Insulation	Seals and Sealants	Energy Storage Medium	Energy Storage Insulation	Heat Transfer Fluid	Piping
Passive, heating, Trombe wall	Concrete	Black paint	Glass 3 (.125) double	Polyurethane walls, polystyrene foundation, Rockwool ceiling	Neoprene	Concrete wall 300 mm (12 inches) thick	-	-	-
Passive, heating, Trombe wall	Masonry	Black paint	Glass 3 (.125) double	Polyurethane walls, polystyrene foundation, Rockwool ceiling	Neoprene	Masonry wall 100 mm (4 inches) thick	-	-	-
Passive, heating Trombe wall	Steel water tank	Black paint	Glass 3 (.25) double	Polyurethane walls, polystyrene foundation, Rockwool ceiling	Neoprene	Water (steel tank)	-	-	-
Active, flat-plate, hot water	copper	Copper oxide	Tempered glass 3 (.125) double	Fiberglass	Neoprene Teflon tape, high temperature silicone sealant	Water (steel tank	Fiberglass	Glycol-water	Copper
Active, flat-plate, heating and hot water	Mild steel	Porcelain (formulation proprietary)	Tempered glass 3 (.125) double	Fiberglass, foam	Silicone rubber, butyl tape, EPDM rubber	Rock 1 1/2 to 3/4 inch diameter (wood bin)	Fiberglass R11	Air	Galvanized steel ducts, copper tubing
Active, flat-plate, heating	Mild steel	Porcelain (proprietary)	Tempered glass 3 (.125)	Fiberglass, foam	Silicone rubber, butyl tape	Rock 1 1/2 to 3/4 inch diameter (wood bin)	Fiberglass R11	Air	Galvanized steel ducts
Active, flat-plate, heating and cooling	Mild steel	Proprietary	Tempered glass 4 (.16) single	Rockwool, fiberglass	Neoprene, Teflon tape	Water (galvanized steel tank)	Fiberglass	Water-propylene glycol	Galvanized steel

III. CODES AND STANDARDS

Building codes and standards are designed to ensure that public safety and welfare are protected during the construction and occupancy of buildings and other structures. Building codes, zoning ordinances, fire codes, and health codes are laws which regulate land use, construction practices, and building use. Codes may be set by many governing bodies. Some states and most municipalities have building codes. Local governments enforce building codes through a system of permits and inspections which allow construction to proceed and permit occupancy when plans and construction practices meet prescribed standards for acceptability.

Standards are specific requirements placed on the design, manufacture, installation, or use of building components, systems, and materials. Standards are intended to ensure acceptable performance levels and safe operational procedures. A consensus standard is determined when interested parties agree to it. Standards are often incorporated into building codes, but a standard is not a legal requirement unless it has been incorporated into an applicable code.

The legal requirements detailed in codes are the occupant's chief protection against construction practices that could create hazards in homes using SHAC systems. It is important that the user of this handbook consult applicable building codes when designing a SHAC system. This handbook is not a replacement for building codes; it is intended to provide the information on hazardous properties of SHAC materials that can be used to supplement local codes.

A. Sources of Codes and Standards

There are many groups in the United States involved in code and standard development, but there is no readily available source of documentation on these efforts. Local building codes are available from local government offices, perhaps a Building and Inspection Division or a Code Enforcement Division. Libraries (public, industrial, and university) often have copies of local building codes.

Most local building codes are based on one of four model building codes, but local codes frequently deviate substantially from the model codes. The four model building codes and addresses where information on each code can be obtained are given as follows:

1. National Building Code

    American Insurance Association
    85 John Street
    New York, New York 10038

2. Uniform Building Code

    International Conference of Building Officials
    5360 South Workman Mill Road
    Whittier, California 90601

3. Basic Building Code

    Building Officials Conference of America
    1313 E. 60th Street
    Chicago, Illinois 60637

4. Southern Standard Building Code

    Southern Building Code Conference
    3617 8th Avenue South
    Birmingham, Alabama 35222

Standards are developed by various groups including, among many others, the American National Standards Institute (ANSI), the American Society for Testing and Materials (ASTM), the American Society of Mechanical Engineers (ASME), Underwriter's Laboratory, Inc. (UL), and the American Society for Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE). A complete set of all standards referenced by a local building code would fill a large number of volumes and be quite expensive to purchase. Copies of the standards are not readily available for public inspection. Potential sources of the few existing sets of standards are the offices of local government that enforce the standards, and certain libraries (public, industrial, and university).

The National Bureau of Standards maintains up-to-date information on standards and standardization activities in the United States. Lists of standards and names of organizations where copies can be obtained are provided as a service. Specific requests should be sent to

Standards Information Services
Room B162 Building 225
National Bureau of Standards
Washington, D.C. 20234.

The federal government requires that certain standards be met for those houses built with federal government assistance or loan insurance. The Federal Housing Administration (FHA) has determined Minimum Property Standards (MPS) that must be met for all homes financed by an FHA ensured loan. These standards are published in the following documents.

"HUD Minimum Property Standards, One- and Two-Family Dwellings," Document no. 4900.1

"HUD Minimum Property Standards, Multifamily Housing," Document no. 4910.1

"Care Type Housing," Document no. 4920.1

Specific requirements for houses using SHAC technologies have recently been published in

> "Intermediate Minimum Property Standards Supplement
> —Solar Heating and Domestic Hot Water Systems,"
> Document no. 4930.2.

Copies of these documents may be inspected by the public at local offices of the FHA and in many libraries. The documents may be purchased from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

The actual standards applicable to the various building trades are so numerous and the availability of copies of the standards so limited that a system of standard practices has evolved. These standard practices meet the local codes. The "Manual of Acceptable Practices, 1973," Document no. 4930.1, which details standard practices, has been published by HUD as a supplement to the Minimum Property Standards. This manual is also available from the U.S. Government Printing Office, and copies of it are usually found at the same locations as copies of the Minimum Property Standards.

Several organizations in the United States issue fire hazard standards, including the National Fire Protection Association (NFPA), UL, and ASTM. Many libraries have copies of model standards and handbooks published by these organizations. A very good reference on fire hazards is the Fire Protection Handbook published by the NFPA in Boston, Mass. This reference book is revised periodically, and the most recent edition, the 14th, was published in 1976.

B. Building Codes and Standards
Specifically Related to SHAC Systems

Codes, standards, and acceptable practices specifically related to SHAC systems are currently in an embryonic stage. Portions of existing codes cover aspects of SHAC systems, but there is a clear need for expanded codes to protect the homeowner from the potential hazard and unacceptable performance that could result from poorly designed or poorly installed SHAC systems. Substantial efforts are under way to develop standards that can be incorporated into codes,[5-7] and some standards are beginning to appear. The development of standards is a consensus process that takes time, and standards for SHAC systems must be flexible enough to accommodate the various SHAC technologies. For this reason, it may be several years before standards for SHAC systems are finalized. The following list gives standards, codes, and performance criteria relating to solar heating and cooling that had been published as of April of 1978.[8]

1. "Interim Performance Criteria for Solar Heating and Combined Heating/Cooling Systems and Dwellings," January 1, 1975, prepared for HUD by NBS. Available from GPO, order by SD Catalog No. C13.6/2:504, price $1.90.

2. "Interim Performance Criteria for Solar Heating and Cooling Systems in Commercial Buildings," prepared for ERDA by NBS, NBS Report NBSIR 76-1187, November 1976. Available from NTIS Order No. PB 262 114, price $5.50.

3. "Intermediate Minimum Property Standards Supplement - Solar Heating and Domestic Hot Water Systems," 1977 Edition, prepared for HUD by NBS. Available from GPO, order by SD Catalog No. 0-236-648, price $12.00.

4. "Heating and Air Conditioning Systems Installation Standards for One and Two Family Dwellings and Multifamily Housing Including Solar," Third Edition, February 1977.

Sheet Metal and Air Conditioning Contractors' National Association, Inc., 8224 Old Courthouse Road, Tysons Corner, Vienna Virginia 22180, price $10.00 - individuals $6.00 - A/E firms; educational institutions; public libraries; Federal, state, and local government agencies and departments.

5. ASHRAE Standard 93-77, "Methods for Testing the Thermal Performance of Solar Collectors," ASHRAE, 345 East 47th Street, New York, NY 10017, price $8.35.*

6. ASHRAE Standard 94-77, "Methods of Testing Thermal Storage Devices Based on Thermal Performance," ASHRAE, 345 East 47th Street, New York, NY 10017, price $6.35.*

7. "Florida Solar Energy Center Test Methods and Minimum Standards for Solar Collectors," June 1977, FSEC 77-5, Florida Solar Energy Center, 300 State Road 401, Cape Canaveral, FL 32920. No charge.

8. "Uniform Solar Energy Code," 1976 Edition, International Association of Plumbing and Mechanical Officials," 5032 Alhambra Avenue, Los Angeles, CA 90032, price $6.00.

9. ARI Standard 910-77, "Rating Standard for Solar Collectors," Air-Conditioning and Refrigeration Institute, 1815 North Fort Myer Drive, Arlington, VA 22209, price $3.50.

10. "Solar Energy - Criteria for Tax Exemption," October 1977, Virginia State Board of Housing, Richmond, VA 23219.

11. "Solar Energy Tax Credit - Revised Guidelines and Criteria," March 1978, Solar Office, Alternatives Division, State of California Energy Resoures Conservation and Development Commission, 1111 Howe Avenue, Sacramento, CA 95825.

12. "Performance Standards for Solar Energy Systems and Subsystems Applied to Energy Needs of Buildings (SBC 6101 through 6108)," October 1977, State of Minnesota Department of Administration, Building Code Division, 408 Metro Square Building, St. Paul, MN 55101.

*Both ASHRAE Standard 93-77 and 94-77 together are available at a price of $10.35.

IV. CLASSIFICATION SCHEME AND GENERAL PROPERTIES OF MATERIALS USED IN SHAC SYSTEMS

A. Classification of SHAC Materials

The various materials used in solar systems can be broken down into classes according to their function in the system. The classes are:

Heat transfer fluids

Insulations

Seals and sealants

Glazing

Collector materials

Storage media

There are other miscellaneous functions not specifically included in this listing, and not specifically addressed in this handbook. These functions are already represented in residential dwellings that do not have solar heating and cooling systems. Examples of components that would be in this miscellaneous class include pipes, electric motors, pumps, electrical wiring, and electrical control panels.

The selection of a specific material depends upon many factors; below are some of the more important factors which should be considered:

Physical and chemical properties

Toxicity

Environmental factors

Outgassing properties

Fire properties

Cost

Convenient and acceptable method of disposal of degraded
or obsolete materials

Compatibility with other materials

This chapter of the handbook discusses general physical properties. Emphasis is placed on those properties that affect the functionality of a material. Chemical properties, toxicity properties, environmental factors and disposal methods, and fire properties are each discussed in following chapters.

B. Heat Transfer Fluids

Heat transfer fluids, other than water, air, and the chemical salt-water mixtures used for cooling, can be classified under four broad headings: silicone oils, hydrocarbon oils, glycol-water solutions, and fluorocarbons. The fluorocarbons are generally used with solar cooling apparatus and are seldom used for heating. The other three types of fluids are used in heating.

Liquid heat transfer fluids often contain additives that are designed to prevent corrosion and degradation. Additives are treated as a category under heat transfer fluids in this report.

1. Glycol-Water Solutions

Water solutions of alcohols and glycols have been used for many years as an automotive heat transfer fluid. This use came about because automobiles are subjected to freezing temperatures, and water alone is not acceptable. The glycols were consequently labeled antifreezes, but water-glycol solutions are heat transfer fluids which have a greater range of operating temperature than water.

In the earlier years of the automobile industry, the most frequently used antifreezes were methyl alcohol (methanol), denatured ethyl alcohol (ethanol), and calcium chloride or other salt brines.[9,10] Occasionally petroleum-based fluids were used as coolants, but their flammability quickly eliminated them. Brine solutions were soon abandoned because of their corrosive action on many metals. Ethylene glycol was commercially introduced as an antifreeze in about 1925. Another fluid considered during this early period was glycerin-water solution. All of these antifreezes with the exception of ethylene glycol are considered low-boiling-point antifreezes.

During the early 1950's[9,10] the so-called permanent or high-boiling-point antifreezes (ethylene glycol) began to take large portions of the market and, by 1966, had over 99% of it. The advantage of ethylene glycol antifreeze over methanol, the nearest competitor, is that it has a higher boiling point. Vapors from a hot solution contain mostly water instead of ethylene glycol. This fact reduces evaporation losses and fire hazards caused by the vapors.

Diethylene and triethylene glycol have higher boiling points than ethylene glycol. Diethylene glycol is used in plasticizers, humectants, solvents, auto brake fluids, antifreezes, natural gas treatment, and softening agents.[9] Triethylene glycol is used as a desicant in air-dehumidification systems. When used in properly designed air sanitation systems, it also aids in the control of bacteria and virus content in the air.[9]

Propylene glycol is used as a heat transfer fluid in the food industry, as a food preservative, as an ingredient in cosmetics and oral hygiene products, and as a solvent for food colors and flavoring agents.[9] Dipropylene glycol is a coproduct in the manufacture of propylene glycol and has similar chemical properties.[9] It has, however, a higher boiling point than propylene glycol.

Glycerin is considered relatively non-toxic by the Food and Drug Administration.[9] It is used in the food industry as a heat transfer fluid and lubricant. It is also used in drugs and cosmetics, soaps, cleaning materials, and industrial skin protectives.

Methanol is a toxic and flammable liquid, and safety precautions for such materials should be followed.[5] In the past, as previously mentioned, it was used as an antifreeze, but that market has largely been taken over by ethylene glycol. Its primary uses today are as a solvent or a base material for the plastics industry.

2. Silicone Oils

The silicone oils are relatively new synthetic oils (introduced about 1950) and are used as heat transfer fluids in food processing, as foam preventives in other fluids, as mold release oils, in cosmetics, and in furniture polishes. They have a low toxicity, good thermal stability, and low combustibility. In general they are more expensive than the other heat transfer fluids.

3. Hydrocarbon Oils

The hydrocarbon oils can be classified as synthetic and natural. Synthetic oils are chemically synthesized from base materials and their compositions are reproducible. Their main uses are as aircraft lubricants, hydraulic fluids, heat transfer fluids, and automotive lubricants. The cost of these oils is usually higher than the natural hydrocarbon oils.

Natural hydrocarbon oils are derived from crude oil. The crude oil is distilled at a given temperature, and the distillation products that result constitute the base oil. Chemical additives are then put in to improve its performance. The chemical composition of natural hydrocarbon oils can vary depending upon the source of the crude. Many of the manufacturers of these oils use the crude from a particular field or fidlds (if blending is done) for a given product. When the field or fields run dry they change the name of their product. Even when the crude comes from particular fields there is no guarantee that the chemical composition of this oil is the same from year to year. However, most likely the major constituents are the same since the physical and chemical properties are held within tolerances, but the minor constitutents can vary.

Natural hydrocarbon oils are used as general lubricants, heat transfer fluids, plasticizers in plastics and rubbers, and automotive lubricants. They are relatively cheap.

Natural oils are chemically classified by generic names: aromatic, naphthenic, and paraffinic. Practically all natural oils are mixtures of these three classes of compounds. Oils which have 40% or greater aromatic or naphthenic content are classified as aromatic or naphthenic oils accordingly. Automobile crankcase oils are primarily paraffinic oils.

4. Fluorocarbon Gases

The fluorocarbon gases have been used for many years in home air conditioners, automotive air conditioners, as blowing agents for aerosol cans, and as blowing agents for insulating foams. They are chemically inert and do not readily biodegrade. Presently there is a controversy about their effect on the stratosphere.[11]

5. Fluid Treatment Chemicals

Almost all the commercial heat transfer fluids available have additives to improve their performance or add color. The exceptions are usually synthetic hydrocarbon oils and possibly the silicones. The additives for hydrocarbon oils are generally antioxidants, fungicides, and bactericides. The commercial water-soluble antifreezes almost always have one or more of the following: dye, anticorrosion, antifoaming, and antioxidant additives. In this report, all of these compounds are referred to as additives or fluid treatment chemicals. Since air can also be a heat transfer "fluid," any chemical that is used in the SHAC system because air is the heat transfer medium is included as a fluid treatment chemical.

Information on fluid treatment chemicals is often considered proprietary, and their compositions are difficult to determine. Furthermore, companies have no obligation to use the same treatment chemical in different batches of a product sold under a single brand name.

6. Important Physical Properties to Consider When Selecting Heat Transfer Fluids

There are several physical and chemical properties of heat transfer fluids that are important from a functional viewpoint:

coefficient of volume expansion

specific heat and thermal conductivity

temperature and viscosity characteristics

chemical stability (resistance to oxidation and thermal breakdown) boiling point and freezing point

The volume expansion of a fluid due to a temperature increase is given by the product of the expansion coefficient times the total volume times the increase in temperature. This quantity is important since in a closed system the fluid will be supplied to the system at about 25^{o} C (77^{o} F) but will typically operate at about 100^{o} C (212^{o} F) or greater. If an adequate expansion volume is not allowed, the pressures within the system can become very large and result in ruptured pipes.

The thermal capacity of a given weight of fluid is directly proportional to the specific heat. Equal weights of two fluids of different specific heat raised to the same temperature will contain different amounts of heat. Practically this means that in a system where heat is transferred from the solar collector to the place of utilization, the volume per second of fluid that must be circulated will be less for the higher specific heat fluid.

The thermal conductivity of the fluid is a measure of how fast heat can be transferred from one region of the fluid to another. This is important in a SHAC system since the fluid usually flows in tubes, and only the outer edge of the fluid volume is in contact with the hot or cold tube. In order that the fluid volume be heated or cooled uniformly in a short period of time, the thermal conductivity must be high. High specific heat and low viscosity are also important to good heat transfer.

The viscosity of a fluid is a measure of the resistance to flow caused by "friction." The higher the viscosity, the more effort (work) is required to move the fluid. In practical applications a solar system using a high viscosity fluid will require a larger pump motor consuming more power than one using a low viscosity fluid. If viscosity becomes too large, the amount of energy expended in moving the fluid can be greater than the amount of heat energy extracted from the solar collector. Most materials get less viscous as the temperature increases, so as a fluid increases in temperature, it requires less pumping energy.

The chemical stability of the fluid is an important economic and environmental consideration. Heat transfer fluids are subjected to a wide range of temperatures, and at the higher temperatures often oxidize (if exposed to air) or thermally degrade so periodic changing is required. Typical operating temperatures are 38 to 120° C (100 to 250° F) for flatplate collectors, but under conditions of stagnation (loss of flow of heat transfer fluid) the temperature can easily rise to 204° C (400° F) and higher, depending upon the construction of the collector. If the fluid does degrade and requires changing, the cost of operation increases.

Fluids that are no longer functional must be discarded or recycled. A fluid that is susceptible to degradation must be changed often, producing more waste than would a more stable fluid. Larger amounts of waste fluid imply a larger environmental impact. It is also possible that some degradation products are more environmentally hazardous than the original fluid.

Two other important properties of heat transfer fluids are the boiling and freezing points (or in the case of hydrocarbon fluids, the pour point). They are important because they limit the useful temperature range. Water, for instance, has heat transfer characteristics superior to any of the other fluids, but it freezes at 0° C (32° F) and boils at 100° C (212° F). If this is not considered in systems subjected to heating over the boiling point of the liquid, the pressure rating of the system may be exceeded, resulting in broken pipes. A typical pressure rating of commercial flatplate collectors is 1035 kilopascal (150 pounds per square inch) or less. (One kPa is equal to about 0.145 psi.)

Comparative rankings of heat transfer fluids can be given as follows:

I. Rank ordering of viscosity changes with temperature with water having the smallest.
   a. water
   b. glycol-water solutions
   c. silicone fluid
   d. hydrocarbon fluid

II. Rank ordering of specific heats and thermal conductivities with water having the largest.
   a. water
   b. glycol-water solutions
   c. hydrocarbon and silicone fluids (within 10% of being the same)

III. Rank ordering of volume expansion coefficient with water having the smallest.

a. water
b. glycol-water solutions
c. hydrocarbon oils
d. silicone fluids

7. Economic Considerations

The lifetime cost of a heat transfer fluid is one of the most important factors in determining its selection. Some relatively inexpensive fluids (such as the glycols) require periodic changing and, consequently, may have a greater lifetime cost than does a fluid of high initial cost, but which lasts as long as the equipment. Consideration has to be given to the possibility of leakage or boiloff of the fluid. New fluid may have to be added. All of these factors must be examined before selecting a heat transfer fluid.

8. Compatibility with Other Materials of the System

Heat transfer fluids may react with other materials in the system to change the functional characteristics of the system and generate byproducts that may be toxic. An example, to illustrate an impact on the functional characteristics, is the effect of silicone fluids on plastic materials. They have little effect on some of the available plastic materials, but will stiffen or harden polyvinyl chloride (PVC) materials.[12] It is probably inadvisable to use PVC pipe with a silicone heat transfer fluid. The metals used in the piping and construction can significantly alter the lifetimes and properties of heat transfer fluids. Copper can act as a catalyst to increase the degradation of some hydrocarbon oils. Glycol water solutions, if not properly inhibited, will eventually become acidic and corrode most metals. In selecting a heat transfer fluid, one should consult the manufacturer as to what materials are compatible with it.

9. Practical Problems

Practical problems associated with the use of heat transfer fluids include those of leakage through mechanical joints and seals. As the temperature rises, the viscosity drops, thus making ordinary threaded pipe fittings more susceptible to leakage. This problem can be overcome by welding or brazing the joints or by using special fitting compounds. The choice of materials for seals in pumps depends upon the operating temperature range and the particular fluid used. Manufacturers of heat transfer fluids generally recommend compatible materials for the different temperature ranges and should be consulted.

10. Typical System Using Liquid Heat Transfer Medium

A typical arrangement for a heat transfer system is shown in Fig. IV-1. An expansion tank serves as a reservoir for fluid and as the main venting point for the system. Usually an inert gas, such as nitrogen, is used in the expansion region, especially when the fluids used are susceptible to oxidation at high temperatures. A relief valve is installed to insure that damaging overpressures do not occur; a catch pot traps any fluid which may be vented.

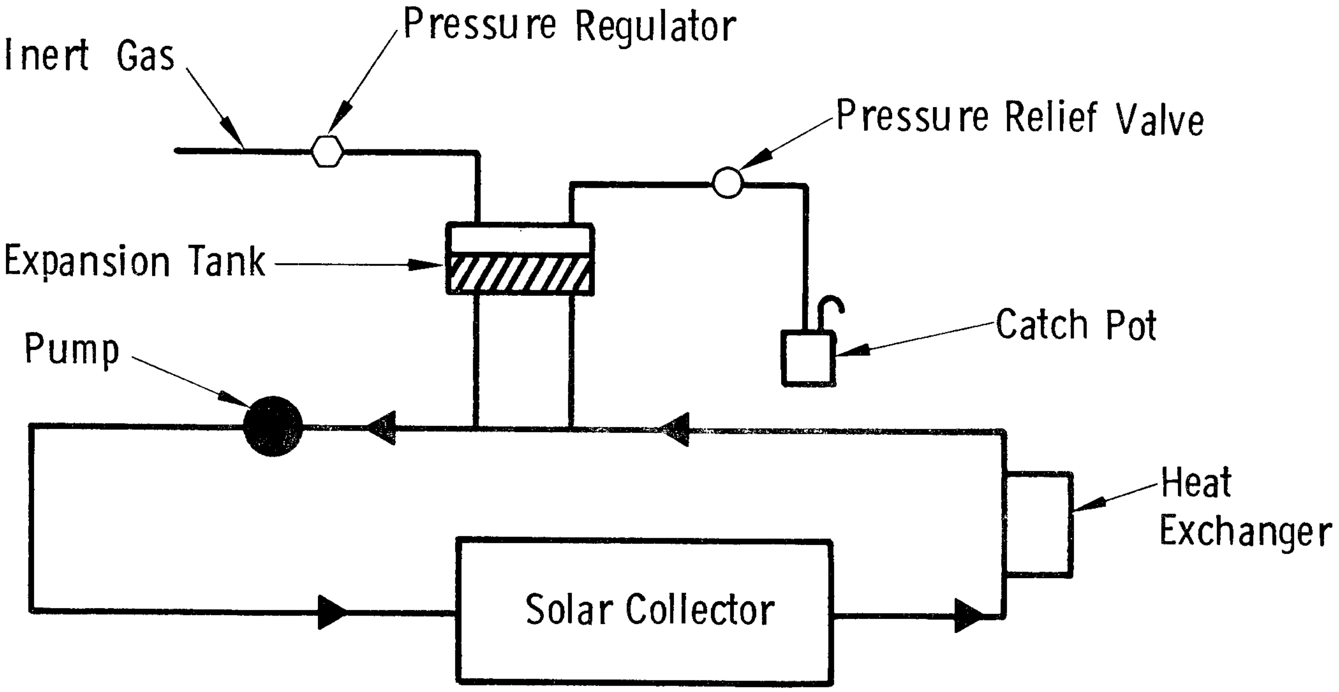

Figure IV-1. Typical Arrangements for a Solar Heat Transfer System

11. Physical Properties Data for Heat Transfer Fluids and Fluid Treatment Chemicals

Table IV-1 lists commercially available heat transfer fluids, their approximate costs and their important physical properties. Motor oil was included in this table for comparison sake, and not as a heat transfer fluid. Many of the physical properties are not given for motor oil but they are very similar to those given for other paraffinic oils. Most of the higher derivatives of ethylene glycol and propylene glycol are commercially sold as bulk chemicals; they are, however, also being considered as heat transfer fluids.

Table IV-1 also lists several additional heat transfer fluids examined for possible solar applications by Buchan et al of Colorado State University.[13] Table IV-2 lists heat transfer fluids primarily used for solar cooling.

Table IV-3 lists fluid treatment chemicals generically. For some generic classes, specific chemical compounds are given. The chromates are included for comparison, but are considered too toxic for use in present-day commercially available glycol heat transfer fluids.[14] Included in this table are fungicides and wood preservatives that might be used in air systems.

TABLE IV-1

Physical Properties of Heat Transfer Fluids Used for Heating

Commercial Name	Recommended Temp Range ^{o}C (^{o}F)	Viscosity Centistokes at temp in ^{o}C (^{o}F)	Thermal Conductivity w/m.^{o}K (BTU/hr ft^{o}F) at temp in ^{o}C (^{o}F)	Density g/cc at temp in ^{o}C (^{o}F)	Volume Expansion $^{o}C^{-1}$	Freeze Point or Pour Point ^{o}C (^{o}F)	Boiling Point or Boiling Range ^{o}C (^{o}F)	Specific Heat Kcal/kg ^{o}C at temp. in ^{o}C (^{o}F)	Manufacturer	Cost/gal (1977)
PARAFFINIC OILS										
Thermia C*	-9.5 to 289 (15 to 550)	7.5 at 99(210) 58 at 38(100)	.1229(.071)	.865 at 38 (100)	-	-12(10)	-	.56 at 300 (508)	Shell	$1.59/55 gal barrel
Exxon Caloria HT43	-9.5 to 311 (15 to 600)	5 at 99(210) 31 at 38 (100)	.1288(.0745)	.860	.001	-9.5 (15)	-	.56	Exxon	$.86 bulk
Mobiltherm 603	-7 to 316 (-15 to 400)	21.7 at 38 (100) 4.2 at 99 (210)	.1237(.0715)	.865 at 15 (59)	-	-7 (20)	10% 360(680) 90% 438(820)	.515 at 93 (200)	Mobil	$1.22 bulk
Mobiltherm Light	-26 to 204 (-15 to 400)	3.6 at 38 (100) - at 99 (210)	.1183(.0684)	.983 at 15 (59)	-	-29 (-20)	10% 260(500) 90% 354(678)	.482 at 93 (200)	Mobil	$1.19 bulk
Dowtherm HP	-9.5 to 288 (15 to 550)	.87 at 204 (400)	.1210(.070)	.749 at 204 (400)	-	-	-	.63 at 204 (100)	Dow	$1.57 bulk
Suntemp 1	-40 to 289 (-40 to 550)	3.0 at 93(200) 84 at 0 (32)	.1229	.9 at 22(72)	.00072	-40 (-40) freeze point	-	.56	Resource Technology Corporation	$3.50/55 gal barrel
20W Motor Oil	-	64 at 38 (100)	-	.88	-	-	-	-	-	-

*Formerly called Thermia 33.

TABLE IV-1 (continued)

Commercial Name	Recommended Temp Range ^oC (^oF)	Viscosity Centistokes at temp in ^oC (^oF)	Thermal Conductivity w/m·^oK (BTU/hr ft^oF) at temp in ^oC (^oF)	Density g/cc at temp in ^oC (^oF)	Volume Expansion $^oC^{-1}$	Freeze Point or Pour Point ^oC (^oF)	Boiling Point or Boiling Range ^oC (^oF)	Specific Heat Kcal/kg ^oC at temp. in ^oC (^oF)	Manufacturer	Cost/gal (1977)
AROMATIC, NAPTHENIC AND SYNTHETIC HYDROCARBON OILS										
DOWTHERM A	38 to 400 (100 to 750)	1 at 100 (212) 3.9 at 25 (75)	.1314 (.076)	1.056	approx. .00125 - 94 (194)	12 (53.6)	257.1 (494.8) boiling pt.	.500 at 204 (400)	Dow	$6.44 bulk
Dowtherm J	-73 to 302 (100 to 575)	.35 at 100 (212) 1.2 at 0 (32)	.1260 (.0729)	.867 at 25 (77)	approx. .00125 - 100 (212)	(-100) freeze point	181 (358) boiling pt.	.500 at 100 (212)	Dow	$4.28 bulk
Therminol 66	-27.8 to 289 (-18 to 550)	4.4 at 93 (200) 50000 at -18 (0)	.1022 (.0687) at 93 (200)	.150 at 93 (200)	.00070	-27.8 (-18)	10% 340(644) 90% 396(745)	.43 at 93 (200)	Monsanto	$6.95 bulk
Exxon Process Oil 0029	-	2.4 at 100 (212) 42.8 at 0 (32)	-	.879 at 15 (59)	.00040	-56 (-70)	-	-	Exxon	$.56 bulk
Thermia A*	-40 to 177 (-40 to 350)	2.3 at 100 (212) 10.3 at 38 (100)	(.077) at 38 (100)	.875 at 16 (60)	-	(-65)	-	.46 at 38 (100)	Shell	$1.59

* Formerly called Thermia 15

TABLE IV-1 (continued)

Commercial Name	Recommended Temp Range °C (°F)	Viscosity Centistokes at temp in °C (°F)	Thermal Conductivity w/m·°K (BTU/hr ft°F) at temp in °C (°F)	Density g/cc at temp in °C (°F)	Volume Expansion $^\circ C^{-1}$	Freeze Point or Pour Point °C (°F)	Boiling Point or Boiling Range °C (°F)	Specific Heat Kcal/kg °C at temp. in °C (°F)	Manufacturer	Cost/gal (1977)
SILICONE OILS										
SF 96(50)	260 (500) max	16 at 93 (200) 500 at -54 (065)	-	.963 at 25	.00092	-55 (-67)	-	.456	General Electric	$15.68/ 55 gal
Dow Corning 200	-	50 at 25 175 at -17.8	0.142 at 50	.960 at 25	.00104	-70 (-84)	-	.437	Dow	$15.92 bulk
ETHYLENE GLYCOLS										
Dowtherm SR-1 50% soln by wt	-34 to 107 (-29 to 224)	2.6 at 38 (100.4) 22 at -18 (0)	.4185 (.242) at 93 (200)	1.074 at (60)	.00063 - 55 (131)	-37.4 (-34) freeze point	110 (23) boiling pt.	.870 at 93 (200)	Dow	-
UCAR 17 50% by wt	-40 to 135 (-29 - 224)	.74 at 93 (200) 22 at -18 (0)	.4185 (.242) at 93 (200)	1.074 at (60)	.00063 - 55 (131)	-37.4 (-34) freeze point	110 (230) boiling pt.	.870 at 93 (200)	Union Carbide	-
Prestone II 50% by volume	-29 to 109 (-34 to 227)	.74 at 9 (200) 22 at -18 (0)	.4185 (.242) at 93 (200)	1.077 at (60)	.00063 - 55 (131)	-29 (-34) freeze point	109 (227) 50% soln in water	.870 at 93 (200)	Union Carbide	

TABLE IV-1 (continued)

Commercial Name	Recommended Temp Range °C (°F)	Viscosity Centistokes at temp in °C (°F)	Thermal Conductivity w/m·°K (BTU/hr ft°F) at temp in °C (°F)	Density g/cc at temp in °C (°F)	Volume Expansion °C-1	Freeze Point or Pour Point °C (°F)	Boiling Point or Boiling Range °C (°F)	Specific Heat Kcal/kg °C at temp. in °C (°F)	Manufacturer	Cost/gal (1977)
PROPYLENE GLYCOLS										
Dowfrost 50% soln by wt	-31 to 107 (-23 to 272)	3 at 38 (100) 70 at -18 (0)	.3891 (.225)	1.033 at 27 (80)	-	-31.5 (-4) freeze point	-	.850 at 27 (80)	Dow	-
UCAR 35 50% by wt	-31 to 107 (-23 to 222)	3 at 38 (100) 70 at 48 (0)	.3891 (.225)	1.048 at (60)	-	-31 (-23) freeze point	106 (222)	.850 at 27 (80)	Union Carbide	-
POLYGLYCOLS										
UCON 500	289 (550)	11.5 at 100 (212) 61 at 38 (100)	.1539 (.089)	.98 at 100 (212)	.00079	-37 (-35)	-	.52 at 100 (212)	Union Carbide	$2.40
Diethylene Glycol	-	32 at 20 (68)	-	1.1167 at 20 (68)	-	8.0 (17.6)	250 (482)	.551 at 0 (32)	-	-
Triethylene	-	42 at 20 (68)	-	1.124 at 20 (68)	-	-7.2 (19) freeze point	287 (548)	.525	-	-
Dipropylene Glycol	-	100 at 20 (68)	-	1.0252 at 20 (68)	.00073 at 20 (68)	-	233 (457)	-	-	-

TABLE IV-1 (continued)

Commercial Name	Recommended Temp Range °C (°F)	Viscosity Centistokes at temp in °C (°F)	Thermal Conductivity w/m·°K (BTU/hr ft°F) at temp in °C (°F)	Density g/cc at temp in °C (°F)	Volume Expansion °C -1	Freeze Point or Pour Point °C (°F)	Boiling Point or Boiling Range °C (°F)	Specific Heat Kcal/kg °C at temp. in °C (°F)	Manufacturer	Cost/gal (1977)
MISCELLANEOUS										
Glycerol 50%by wt	-	13 at 0 (32) .81 at 100 (212)	-	1.128 at 20	.000510 - 25 (77)	-23 (-9.4)	-	-	-	-
Water	0 to 100 unpressurized (0 to 212)	.30 at 93 1.8 at 0 (32)	-	1.000 at 4	.000207 - 20 (68)	0 (32) freeze point	100 (212)	1.00509 at 93 (200)		

TABLE IV-1 (continued)

Commercial Name	Recommended Temp Range ^{o}C (^{o}F)	Viscosity Centistokes at temp in ^{o}C (^{o}F)	Thermal Conductivity w/m·^{o}K (BTU/ hr ft^{o}F) at temp in ^{o}C (^{o}F)	Density g/cc at temp in ^{o}C (^{o}F)	Volume Expansion $^{o}C^{-1}$	Freeze Point or Pour Point ^{o}C (^{o}F)	Boiling Point or Boiling Range ^{o}C (^{o}F)	Specific Heat Kcal/kg ^{o}C at temp. in ^{o}C (^{o}F)	Cost/gal
Petrolatum	-	-	-	0.920	-	-	-	-	$1.11
Therminol 55	-	1610.0 at 0 30.1 at 100 5.0 at 200 2.1 at 300	-	0.8867	-	(-20)	(410)	-	-

TABLE IV-1 (continued)

Commercial Name	Recommended Temp Range °C (°F)	Viscosity Centistokes at temp in °C (°F)	Thermal Conductivity w/m·°K (BTU/hr ft°F) at temp in °C (°F)	Density g/cc at temp in °C (°F)	Volume Expansion $°C^{-1}$	Freeze Point or Pour Point °C (°F)	Boiling Point or Boiling Range °C (°F)	Specific Heat Kcal/kg °C at temp. in °C (°F)	Cost/gal (1977)
COLORADO STATE LIST OF POTENTIAL HEAT TRANSFER FLUIDS									
Acetyl tributyl citrate	-	42.7 at (77)	-	1.046	-	(-75)	(341)	-	$5.17
Benzyl chloride	-		-	1.1	-	(-45)	(354)	-	$2.94
Benzyl formate	-		-	1.085	-	(38)	(397)	-	$16.30
Butyl benzyl phthalate	-	65.2 at (68)	-	1.116	-	(-31)	(698)	-	$2.98
Metachloroaniline	-		-	1.223	-	(14)	(443)	-	$8.17
Creosote coal tar	-		-	1.07	-	-	(400)	-	$5.18
Cresyl diphenyl phosphate	-		-	1.208	-	(-36)	(734)	-	$6.91
Dibutyl phthalate	-	20.3 at (68)	-	1.0484	-	(-31)	(644)	-	$3.32
Orthodichlorobenzene	-		-	1.307	-	(-8)	(356)	-	$3.25
Diethyl O-phthalate	-	4.18 at (131)	-	1.120	-	(-41)	(568)	-	$3.45
O-dimethyl phthalate	-	16.7 at (68)	-	1.189	-	(32)	(540)	-	$3.61
Ethyl benzoate	-		-	1.043	-	(-27)	(415)	-	$10.45
Ethyl cinnamate	-		-	1.045	-	(54)	(520)	-	$31.40
Isobutyl salicylate	-		-	1.064	-	(43)	(498)	-	$11.11
Methyl benzoate	-		-	1.085	-	(10)	(389)	-	$5.68

TABLE IV-1 (continued)

Commercial Name	Recommended Temp Range °C (°F)	Viscosity Centistokes at temp in °C (°F)	Thermal Conductivity w/m·°K (BTU/hr ft°F) at temp in °C (°F)	Density g/cc at temp in °C (°F)	Volume Expansion °C-1	Freeze Point or Pour Point °C (°F)	Boiling Point or Boiling Range °C (°F)	Specific Heat Kcal/kg °C at temp. in °C (°F)	Cost/gal (1977)
Methyl phenylacetate	-	-	-	1.062	-	-	(424)	-	$9.82
Ortho nitrotoluene	-	-	-	1.163	-	(25)	(429)	-	$1.35
Perchloro-ethylene	-	-	-	1.625	-	(-8)	(250)	-	$2.24
Orth-phenetidine	-	-	-	1.065	-	(-4)	(442)	-	$8.05
Piperonyl butoxide	-	31.9 at 25	-	1.06	-	-	(356)	-	$39.81
Tributyl citrate	-	-	-	1.04	-	(-4)	(451)	-	$6.65
1,1,2-Tri-chloroethane	-	60 at 25 5 at 100	-	1.4432	-	(-31)	(237)	-	$3.27
Tri-O-cresyl phosphate	-	-	-	1.162	-	(-13)	(770)	-	$8.63
Allyl caproate	-	-	-	0.888	-	-	(367)	-	$22.01
Butyl oleate	-	-	-	0.873	-	(-16)	(343)	-	$1.89
Dibutyl sebacate	-	13.7 at (68)	-	0.936	-	(12)	(660)	-	$8.50
Di- (2 ethylhexyl adipate	-	-	-	0.9268	-	(-76)	(782)	-	$3.79
Di- (2 ethylhexyl sebacate	-	-	-	0.913	-	(-67)	(493)	-	$9.81
Divinyl benzene	-	1.09 at 68	-	0.929	-	(-88)	(383)	-	$6.81
Isobutyl isobutyrate	-	-	-	0.857	-	(-112)	(297)	-	$1.35
Methyl heptenone	-	-	-	0.860	-	(-87)	(343)	-	$34.81

TABLE IV-2

Heat Transfer Fluids Used for Cooling

Fluid	Chemical Formula
F11 (Freon 11)	CCl_3F
F12 (Freon 12)	CCl_2F_2
F22 (Freon 22)	$CHClF_2$
F113 (Freon 113)	$CCl_2F-CClF_2$
Lithium chloride-water	$LiCl-H_2O$
Lithium bromide-water	$LiBr-H_2O$
Ammonia	NH_3

TABLE IV-3

Fluid Treatment Chemicals

Generalized Catagories	Purpose	Metals Protected	Specific Compounds
Chromate salts	C	Iron, zinc, copper, brass	Lithium chromate, sodium chromate
Dichromate salts	C	Iron, zinc, copper, brass	Potassium dichromate
Nitrate salts	C	Iron, aluminium	Lithium nitrate, sodium nitrate
Sulfate salts	C	All metals	Sodium sulfate
Sulfite salts	C	All metals	Sodium sulfite
Borate salts	C	Iron and iron alloys	Sodium borate
Arsenate salts	C	Primarily aluminum	Potassium orthoarsenate
Phosphates salts	C	Iron, aluminium	Potassium hydrogen phosphate, sodium orthophosphate
Silicates salts	C	Copper, iron, aluminium	Sodium metasilicate
Triazoles	C	Primarily cuprous metals	Benzoltriazole
Benzoate salts	C	Iron	Sodium benzoate
-	P	-	Lithium hydroxide
-	W	-	2 ethylhexanol
Chlorine	B	-	Sodium hypochlorite
Chlorinated phenols	F, WP	-	O - phenylphenol, 2, 4, 5 - trichlorophenol (Dowicide 2), 2, 5, 6 - trichlorophenol (Dowicide 25), sodium 2, 4, 5 - trichlorophenol (Dowicide B), 2, 3, 4, 6 - tetrachlorophenol (Dowicide 6), pentachlarophenol (Dowicide G)
Quaternary Ammonium Compounds	F, B	-	Phenylmercuric triethanol - ammonium lactate

C - Corrosion inhibitor

W - Wetting agent for lithium bromide/water cooling system

B - Bactericide

F - Fungicide

P - Ph control for lithium bromide/water cooling system

WP - Wood preservative

C. Insulations

Insulating materials used in SHAC systems include glass and mineral wools, foamed plastics, and ceramic and refractory fibers.[15] Cellulose insulations are not generally used for solar applications and are not discussed here.

1. Glass Wool

Glass wool is composed of glass fibers which are noncombustible, inorganic, nonabsorbent, nonhygroscopic, and chemically stable. Glass wool is available in loose fiber form or with the fibers held together by a binder. The two common types of binders are starch and phenolic resins.[13] In most cases the fibers are bound for easier handling, but the binder becomes a problem for high-temperature applications because of binder decomposition. Since all flat-plate collectors will probably reach a high stagnation temperature at some time, loose glass wool may be the better insulation choice.

Fiberglass is sold mostly in the form of wool for insulating commercial and residential building, pipes, tanks, and refrigerators. Another important application of glass fiber is for reinforcing plastic and rubber products.

2. Mineral Wool

Mineral wool is a vitreous substance derived from molten slag, rock, or glass (or selected combinations of these ingredients).[10] Like glass wool, it is composed of fibers and is available in the form of blocks or boards bonded with asphalt or synthetic resins, or as a semirigid blanket. When strength is needed, blocks or boards are used. A common application is roof insulation. Mineral wool is also available as a granular material to be poured into place. It is often employed in the insulation of refrigerated trucks and railroad cars, refrigerators, and pipes.

3. Plastic Foams

Plastic foam insulations are, in general, lighter and superior in insulating properties to the glass and mineral wools. They have recently taken a larger share of the insulation market and are expected to continue to do so. The three most common foams used in the building industry which are also readily available for solar systems are polystyrene, urethane, and isocyanurate foams.

Polystyrene is the cheapest and poorest insulating foam of those mentioned above. It is made by molding prefoamed beads or by extrusion. The blowing agent used in these processes is most often pentane. Polystyrene foams have poor solvent resistance. Consequently, any adhesive used for installation should be carefully selected to ensure that it does not attack the foam.

Polystyrene foams are commonly used as insulation in residential and commercial buildings, and as meat trays, egg cartons, insulating cups, and marine flotation devices.

Polyurethane foam insulations are available as rigid slabs, as materials to be poured in place to form a rigid foam, and as flexible slabs. They are intermediate in cost and have good physical properties. They are manufactured by foaming with a blowing agent into large buns which are later sliced, or by foaming in place between two panels. They can also be sprayed or poured in place on exposed surfaces. Foams that are poured in place can generate 14 to 28 kPa (2 to 4 psi) pressures, even in open-top containers. Hence, appropriate precautions must be taken to withstand this pressure. The two blowing agents which are most frequently employed are trichlorofluoromethane (Freon 11) and carbon dioxide. If for some reason the blowing agent diffuses out and is replaced by air, the insulating ability of the foam will decrease. Metal barriers such as aluminum foil are often employed to minimize this effect.

Polyurethane foams are used in automobile seats, residential roof insulation, furniture, bedding, carpet underlays, insulation for heat storage tanks in industry, refrigerated freight cars and trucks, and as a marine flotation material.

Isocyanurate foams are the most expensive of the foams but offer the best temperature and fire properties. Almost all commercially available isocyanurate foams are in fact urethane-modified isocyanurate foams. The cost of these foams is inversely proportional to the amount of urethane in their composition, since the isocyanurates are the most expensive component. Inclusion of the urethane is necessary to reduce friability and brittleness.

The thermal stability of foams is often measured by thermogravimetric analysis (TGA). In this test, the weight loss is measured as a small sample is heated. A typical polyurethane foam will lose 30% of its weight at 300° C (572° F) while a urethane-modified isocyanurate loses only about 9%.

Applications for modified urethane-isocyanurate foams are similar to those for urethane foams. They are quite frequently used where good fire resistance is important.

Flame-retardant chemicals are often added to foam insulations to improve their fire resistance. Foam insulations can be sandwiched between aluminum foil or gypsum board (drywall) to increase their fire resistance.

4. Important Properties for Selecting Insulations

Physical properties that are included in this section are important from a purely functional viewpoint, and they include thermal conductivity, thermal expansion coefficient, and the upper temperature limit. Fire properties and toxicity properties are also important physical properties that are discussed in later chapters.

The thermal conductivity is a measure of the rate at which a material will conduct heat; the higher the value the poorer the insulating properties. This property is often expressed in terms of an R value which is related to the reciprocal of the thermal conductivity. Hence a high R value implies a good insulator. Values of R are additive so that, if the R value for 1 cm thick material is known, the R value for 2 cm is just twice that number. Some typical values of R for a 2.54 cm (1 inch) thickness of material are 3.2 for fiberglass insulation, 1.26 for white pine wood, 0.18 for glass, and 0.12 for concrete.

The thermal expansion coefficient is a measure of the fractional change along any linear dimension of a mass of a given material as the temperature changes by a single degree. If SHAC materials are used structurally in a system, allowances for expansion must be made.

The upper temperature limit is important for SHAC materials for several reasons. At temperatures above the recommended upper limit, materials do not function properly. They may boil, melt, give off noxious gases, soften, and/or rapidly degrade. The upper temperature limits of insulations and glazing materials used in collectors are especially important because of the possibility of stagnation conditions (loss of heat transfer fluid flow). Under such conditions, the temperature of the system can rise far above the normal operating temperature. Plastic glazing materials and many insulations cannot withstand the high stagnation temperatures for an extended time. All foam insulations and fiberglass using an organic binder are subject to this limitation, although one of the leading manufacturers of fiberglass insulation is developing a new binder material which will increase the upper temperature limit to 260° C (500° F).[16]

5. Data for Insulations

Table IV-4 lists some of the important physical properties of fiber insulating materials. Table IV-5 lists important physical and chemical properties of foam insulating materials. Table IV-6 gives a rating for the resistance to solvents of insulating materials.

TABLE IV-4

Physical Properties of Fiber Insulating Materials

Material	Density kg./m^3 (lb./ft^3)	Thermal Conductivity w/m^2 ·^{o}K (Btu - in/ft^2 -hr ·^{o}F)	R Value for 2.54 cm (1 in.) thickness	Upper Temperature Limit ^{o}C (^{o}F)	Approximate Cost per board ft. (1975)
Fiberglass with organic binder	24 (1.5)	0.045 (0.31)	3.2	177 (350)	0.12
Fiberglass, no binder	24 (1.5)	0.045	3.2	450 (850)	0.32
Mineral fiber blanket	160 (10.0)	0.045	3.2	649(1200)	0.12
Calcium silicate	208 (13.0)	0.055	2.6	649(1200)	0.60

TABLE IV-5

Physical Properties of Rigid Foam Insulations

Foam Type	Approximate cost per board ft (1977)	Density Kg/m (lbs/ft^3)	Max. Service Temperature °C (°F)	Thermal Conductivity w/m^2·°K (Btu in/ft^2 hr·°F)	R value 2.54cm(1 in) thickness	Thermal Coefficient of Expansion m/m-°C x 10^6 (°F)	Solvent Resistance	Resistance to Sunlight	Fungus Resistance	Comments
Polystyrene	$0.14	24.0-32.0 (1.5-2.0)	74.0-79.0 (165-175)	0.033-0.037 (0.23-0.26)	4.31-3.81	54-72.0 (30-40)	Poor	Poor	Excellent	Lowest Cost
Polyurethane	$0.30	32.0 (2.0)	93.0-121.0 (200-250)	0.017-0.025 (0.12-0.17)	8.3-5.9	72.0 (40.0)	Excellent	Poor	Excellent	Most versatile
Isocyanurate	$0.34	32.0 (2.0)	150 (300)	0.017-0.025 (0.12-0.17)	8.3-5.9	72.0 (40.0)	Excellent	Poor	Excellent	Best Temperature Resistance

TABLE IV-6

Solvent Resistance of Insulating Materials
at Different Temperatures

Solvent	Polystyrene 24°C (75°F)	Polystyrene 52°C (125°F)	Polyurethane 24°C (75°F)	Polyurethane 52°C (125°F)	Isocyanurate	Glass and Mineral Wool
Motor Oil	Good	Fair	Excellent	Excellent		Excellent
Gasoline	N.R.*	N.R.	Good	N.D.**		Excellent
Toluene	N.R.	N.R.	Excellent	N.D.		Excellent
Methylene Chloride	N.R.	N.R.	Fair	N.D.	Same or	Excellent
Methyl Alcohol	Fair	Poor	Good	Good	better than	Excellent
Acetone	N.R.	N.R.	Poor	N.D.	polyurethane	Excellent
Water	Excellent	Good	Excellent	Good		Excellent
Sulfuric Acid(10%)	Excellent	Good	Good	Good		Excellent
Sodium Hydroxide(10%)	Excellent	Fair	Good	Good		Excellent

*N.R..- Not recommended, very poor

**N.D. - No data available

D. Seals and Sealant Materials

Rubber seals and gaskets are used in solar collectors to seal the glazing to the collector frame and prevent leakage of heat transfer fluids from circulating pumps. Although there are relatively small amounts of these materials in a SHAC system, they are important to the overall efficiency and reliability. A poor rubber O-ring seal in a circulating pump could lead to leakage of the heat transfer fluid and could create a fire hazard if flammable heat transfer fluids were being used.

1. Types of Rubber Materials

Butyl, polysulfide, ethylene/propylene (EPDM), nitrile, silicone, fluorosilicone, fluorocarbon, and neoprene are the common generic types of rubbers or elastomers available for use in SHAC systems. There are many different formulations of each of these generic type rubbers.

Butyl rubbers of different formulations have been used for hose (steam, automotive), gaskets, conveyor belts, adhesives and sealants, tire curing bags, chemical tank liners, truck cab mounts, aircraft engine mounts, rail pads, bridge bearing pads, passenger car inner tubes, pharmaceutical stoppers, and appliance parts.[17] Properties which were important in deciding the above applications are: low gas permeability, thermal stability, ozone and weathering resistance, and chemical and moisture resistance.[17]

Resistance to solvents and chemicals is the outstanding characteristic of the polysulfide rubbers. Because of this property, polysulfide elastomers are used in the manufacture of paint rollers, hose liners, gas meter diaphragms, and adhesive cements. This type of rubber has about the same weathering and ozone resistance as butyl rubbers and is commonly used as a glazing sealant.

EPDM elastomers are not as resistant to solvents as the polysulfide rubbers, but their other properties are similar. They have an advantage over both butyl and polysulfide rubbers in that they can withstand higher temperatures. They have been used in the manufacture of automotive tires, wire and cable coverings, appliance hose, belting, gaskets, rolls, and footwear.[17]

Resistance to oil is an important property of nitrile rubbers and is the reason for their extensive use even though they cost more than other rubbers.[17] Nitrile rubbers are used as gaskets, hose, automobile window gaskets, and seals.

The most outstanding property of silicone and fluorosilicone elastomers is the very wide service temperature range: -73 to 260° C (-100 to 500° F). They can maintain elastomer properties at moderately elevated temperatures, 121 to 149° C (250 to 300° F), almost indefinitely. Silicone rubbers are used in the aerospace industry in the form of airframe seals, hot-air ducts, air and oxygen pressure-regulator diaphragms, O-rings, seals, gaskets for lubricating and hydraulic systems, and wire insulation.[17] They are used in the automotive industry as spark plug boots, ignition cable jacket, transmission seals, hose, and sealants. Other uses are oven-door and washer-dryer gaskets, construction sealant, pharmaceutical stoppers, medical tubing, and as insulation in steam irons, frying pans, and coffee makers.[17]

The fluoroelastomers (Viton and Fluorel) are generally more expensive than the other elastomers discussed here, but their superior chemical and heat resistance and low-temperature flexibility dictate their use in many cases. Viton and Fluorel are trade names applied to many different formulations. The major uses of these rubbers are for O-rings, gaskets, and seals.

Neoprene rubbers are made by the polymerization of chloroprene and probably enjoy wider application than any other type of synthetic rubber. Neoprene rubbers are used in industrial and automotive applications as garden hose, fire hose, air hose, automotive window and door gaskets, V belts, shock absorber covers, wire jackets, motor mounts, and adhesives.[17]

2. Selection of Sealant Materials

Besides cost, good high-temperature stability and compatibility with hot heat transfer fluids are the most important properties in selecting sealant materials. Two other important considerations are fire properties and outgassing at high temperatures.

The elastomers discussed above have different temperature characteristics, and care should be taken to ensure that the elastomer chosen does not experience a higher temperature than its maximum rating; otherwise, the elastomer may become ineffective.

Compatibility of the elastomer with heat transfer fluids can be important in the case of an O-ring seal in a circulating pump or a rubber gasket in the frame of the collector. A material which is degraded by the fluid could fail.

3. Data for Sealant Materials

Table IV-7 generically lists the common rubbers or elastomers and the fluorocarbon plastics which are commercially available. This table gives information about maximum continuous operating temperature, uses, and resistance to various agents that might be encountered in solar applications. The column labeled as "self-extinguishing" refers to a fire property. A "yes" under this column means that if a torch is applied to the material it will burn, but as soon as the torch is removed it will self-extinguish.

Table IV-8 lists commercially available rubbers, their costs, their continuous operating temperature maxima, and their uses.

TABLE IV-7[18-20]

Generic Materials for Seals and Sealants

					RESISTANCE TO:						
Generic Name	Useful Operating Temperature Min°C (°F) Max °C (°F)	Typical Continuous Service Max Temperature °C (°F)	Self-extinguishing	Uses	Atmospheric Agents	Heat	Flame	Mineral Oils	Aromatic Hydrocarbon Oils	Ethylene Glycol	Silicone Oils
Chloroprene (Neoprene)	-55 (-67) 149 (300)	93-107 (200-225)	yes	radiator hose, gaskets, seals, o-rings	E	G-E	G-E	G	P-F	G-E	G-E
Butyl	-40 (-40) 149 (300)	127 (260)	no*	gaskets, chemical tank liners	G-E	G-E	P	P	P	G-E	F-G
Polysulfide	-40 (-40) 121 (250	66-93 (150-200)	no	oil seals, glazing sealant	G-E	P-G	P	E	E	P	E
Ethylene/ Propylene (EPDM)	-54 (-65) 177 (350)	149 (300)	no*	seals, hose gaskets, auto window gaskets	E	G-E	P-E	P	P-F	E	E
Nitrile	-57 (-70) 149 (300)	121 (250)	no	components requiring oil resistance	F-G	G-E	P	E	F-G	G-E	G-E
Silicone	-73 (-100) 260 (500)	204 (400)	yes	gasket for high temperatures, glazing sealant	E	E	F-E	P-F	P-F	F-E	P-F
Fluoro Silicone	-73 (-100) 260 (500)	204-232 (400-450)	yes	gaskets, glazing sealant o-rings	E	E	F-E	F-E	F-E	F-E	G-E
Fluoro-elastomers (viton, fluorel)	-68 (-90) 310 (600)	204 (400)	yes	gaskets, o-rings	E	E	E	E	E	E	E
Fluorocarbon Plastic (Teflon)		204 (400)	yes	pipe thread seal	E	E	E	E	E	E	E

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*can be made flame retardant

E - excellent, G - good, F - fair, P - poor

TABLE IV-8

Specific Rubbers Commercially Available

Generic Name	Trade Name	Continuous Service Temp°C (°F)	Use	1977 Cost	Manufacturer	Comments
Chloroprene	Neoprene	93-107 (200-225)	Gaskets, seals, hose O-rings	-	DuPont makes base material	There are numerous companies which formulate neoprene rubber products
Silicone	RTV 108	204 (400)	Sealant	-	General Electric	
Fluoro Silicone	Silastic	204 (400)	Sealant	$9.10/lb in 40 lb lots	Dow Corning	This compound is recommended for systems where harsh hydrocarbon fluids or silicone fluids are used
Silicone	Silicone* rubber sealant	204 (400)	Sealant	$3.57/lb in 39 lb lots $4/cartridge	Dow Corning	
Fluoro Elastomer	Fluorel	204 (400)	Gaskets, O-rings, seals	-	3M makes base material	There are numerous companies which formulate Fluorel rubber products
Fluoro Elastomer	Viton	204 (400)	Gaskets, O-rings, seals	-	DuPont makes base material	There are numerous companies which formulate Viton rubber products
Butyl	Novacalk 420	82 (180)	Sealant	$0.49/lb $0.96/ centridge	Novagard	-
Polysulfide	Novacalk 600	93 (200)	Sealant	$1.26/lb $1.92/ centridge	Novagard	-
Polysulfide	GC-9	82 (180)	Sealant	$1.78/lb $2.39/ centridge	Peroria	-
EPDM	-	93 (300)	Gaskets	$0.51/lb $22/100 ft molded g sheet	Jasper	There are many companies which market EPDM rubbers with similar properties and costs
Butyl	Tremco 440	93 (200)	Sealant	-	Tremco	This particular product is in soft putty tape form
Fluorocarbon Plastic	Teflon	204 (400)	Pipe, thermal seal	-	DuPont	-

*Formerly marketed as Dow Corning 732, 781, and 8641.

E. Glazing Materials

1. Types of Glazing Materials

Glazing materials can be classified as either plastic or glass. The glass used for this purpose is usually a soda lime silicate glass which is tempered to increase its mechanical strength and to give a fine breaking pattern. Glass for solar use should be of low iron content so as to give maximum visible transmission. Significant amounts of iron in glass can be easily detected by observing the edges; the presence of iron will cause the glass to appear yellow to green when the glass is viewed from the edge. Some of the manufacturers call their low iron glass "clear" glass or "water white" glass.

Fully tempered glass cannot be further cut or ground; it must be prefabricated as required for its intended use before tempering.[21] Since there are already tempered glass panes on the market for other uses, it is economically advantageous to use already-available sizes whenever possible. Some manufacturers suggest patio-door panes for use in solar systems.

Tempered glass is presently used in patio doors, storm doors, commercial doors and windows, as a safety glass for automobiles, backstops for ballfields, and windows in ovens and dryers.[21] It is much stronger than ordinary glass.

There are several different types of plastic glazing materials on the market. The three trade name plastics which will be discussed here as representative are Teflon, Lucite, and Tedlar. Lucite is an acrylic material (the chemical name is polymethylmethacrylate, and the acronymn is PMMA) which is manufactured by several companies. Some of the manufacturers make a coated acrylic which has superior optical, abrasion-resistance and weathering properties compared to ordinary acrylic. However, the coated versions are about twice as costly. Recently, Lexan (a polycarbonate material) has been offered as a glazing material. Lexan is not now in wide use and is not discussed in this report.

Coated acrylics are used in commercial building glazing, in securing display cases and windows, around hockey rinks, for storm doors, urban areas of high vandalism, bullet resistant windows, and windows of commercial vehicles subject to vandalism.[22] Uncoated acrylics have been used in airplane canopies, helicopter glazing, dome skylights, window glazing in high breakage areas, lenses and windows for automotive tail lights and signal lights and dials on instrument panels.[10]

A comparison of glass with PMMA indicates that PMMA has greater resistance to breakage, is lighter in weight, and is more easily formed into different shapes. PMMA has been used in aircraft windows, but low abrasion resistance detracts from its use for automobile windshields. The newer coated versions, however, are approaching glass in resistance to abrasion. This material cannot be subjected to temperatures much above 90° C (194° F), so glass would be a better choice if higher temperatures were expected.

Teflon and Tedlar are fluorocarbon materials which are fabricated into thin films. The films are not as rigid as the glass and acrylic glazing materials and must be stretched. The fluorocarbon films are cheaper than glass or acrylic, but are subject to wrinkling with age.

Teflon sold for solar-glazing purposes is a copolymer of tetrafluoroethylene (TFE) and hexafluoropropylene (HFP). The more common variety of Teflon is a polymer consisting solely of TFE. Although these two materials are similar, their chemical and physical properties are not exactly the same. However, the toxicity of HFP and TFE have been shown to be similar[23] and relatively low at normal temperatures. At temperatures above the recommended operating temperature, toxic gases can be released from both materials.

Teflon materials have been used as chemical transfer tubes, fuel and hydraulic hoses, thread seal tapes, cookware coatings, insulation for electrical wiring, bearings, seals, gaskets, piston rings, and vessel linings. Teflon also has been used in artificial heart valves, hip joints, knee joints, arteries, bile ducts, wind pipes, and corneas.[23]

Tedlar is a polyvinylfluoride (PVF) polymer which is characterized by its resistance to weathering, outstanding toughness, and high dielectric strength and dielectric constant.[10] This material is strong, flexible, and fatigue-resistant. Its service temperature range is approximately -73 to 105° C with short-term peaking up to 205° C.

PVF films are used as finish coatings to decorate and protect a wide variety of subtrates. It is laminated to metals for interior and exterior wall surfaces. Its electrical properties make it attractive for use in capacitors, and for insulating electrical wires and cables.

2. Important Properties in the Selection of Glazing Materials

Properties which should be considered in selecting glazing material are:

Percent transmission of solar radiation

Weight

Coefficient of expansion

Maximum operating temperature

Lifetime and cost

Ease of sealing

Structural properties

The percentage of the incident radiation that is transmitted by a glazing material is important to the overall efficiency of a solar system. This percentage is given by multiplying the total incident radiation by the transmission coefficient. The radiation that is not transmitted is either reflected or absorbed by the glazing material. Different materials reflect and absorb different amounts of the incident radiation.

The weight of a particular glazing material can be important if the loading on the supporting structure is limited. Fluorocarbon films are much lighter than the thicker glass or acrylic glazings.

The coefficient of expansion is important in maintaining a seal. If the glazing material and the supporting structure are not matched in their expansion coefficients, a stress develops in the sealant material that may lead to failure of the seal.

Probably the most important property to be considered in selecting a glazing material is the maximum operating temperature. If this temperature is exceeded, the rigid materials may sag or deform, and the film materials can develop unwanted wrinkles. Toxic or combustible gases may be released from the plastic materials if this temperature is exceeded. Plastic glazing materials can catch fire at high temperatures if exposed to an ignition source.

The lifetime of glazing materials is an important economic consideration. Facts which should be examined in this regard are the weatherability and the probability of breakage from vandalism or accident. Although acrylics are more expensive than tempered glass, it may be economically advantageous to use them in an area of high vandalism. Plastics are slowly degraded by solar radiation, and glass may be the best choice if vandalism is not a problem.

Sealing of glazing materials can be important if periodic servicing is required. The rigid materials are in general more easily sealed and resealed than the plastic films.

A glazing material used as the external window for a solar collector must support positive and negative loads from wind, snow, rain, and hail. Local building codes usually dictate requirements that must be met for exterior building surfaces. In any case, a thin film may not be a good choice for the external window of a collector due to the various stresses it will be required to withstand.

3. Data for Glazing Materials

Table IV-9 lists the important physical properties and costs of the glazing materials most frequently used for solar applications. It should be noted that there are many manufacturers of glass and acrylic materials. The lifetime estimates given in this table may not consider degradation of the plastics caused by the sun's radiation.

TABLE IV-9

Data for Glazing Materials

Material Name (Manufacturer)	Percent Solar Transmission thickness cm (inches)	Weight kg/m^2 (lbs/sq ft)	Index of Refraction	Coefficient of Expansion x 10^5 /°C	Maximum Continuous Operating Temperature °C (°F)	Lifetime Years	Approximate cost per square ft (1977)
Teflon (Dupont)	96 [.0025 (.001)]	.047 (.01)	1.34	12.4	205 (400)	15 or greater	$0.17
Lucite (Dupont)	93 [.47 (.187)]	6.5 (1.4)	1.45	7	83 (180)	20*	$3.70***
Tedlar (Dupont)	92-94 [.01 (.004)]	.142 (.03)	1.46	5	107 (225) intermittent 255 (400)	5*	$0.27
Glass** (PPG)	85 [.32 (.125)]	10 (2.1)	1.5	.86	232-260 (450-500)	greater than 20	$2.32

*DuPont's data, Technical Bulletin E09700
**Standard clear PPG tempered glass patio pane.
***Uncoated acrylic approximately $2.00

F. Collector Materials

Most materials used in the construction of collectors (excluding insulation and glazing materials) are the metals and woods which are already common in residential construction. The prime concerns in selecting these materials are cost, plus compatibility with other materials in the system. Below is a brief description of the materials used in collectors.

1. Absorber Plate

Four metals—stainless steel, copper, aluminum and steel—and the plastic material polyvinylchloride have been used as absorbing plates for active systems. Toenjes[15] has discussed the corrosion properties of the metals when an aqueous solution is used as a heat transfer fluid.

Passive systems use masonry materials, adobe, and water in containers as absorbers; these same materials are also the heat storage medium.

2. Frame and Exterior Materials

The most common materials used for framing are galvanized steel, aluminum and wood. If the system is subjected to high temperatures, wood may be a poor choice, since it has been found that it deteriorates and that the autoignition temperature is reduced from 200 to 100° C (392 to 212° F).[24]

3. Absorber Plate Coatings

The most common types of absorber coatings are black paint and plated coatings. The plated coatings are usually nickel, copper, or chromium materials,[25,26] which have the desirable property of absorbing efficiently in the visible range of the solar spectrum and emitting poorly in the infrared. These coatings are generally applied at the factory. Some of the coatings available slowly degrade under normal environmental exposure to solar radiation, temperature, or moisture.

4. Collector Materials Physical Properties

The materials most often used in the absorber plate are stainless steel, copper, aluminum, and steel. Since these are common materials and their properties widely known, the properties will not be discussed here.

The absorber coatings are the most uncommon materials used in the construction of absorber plates. Table IV-10 lists a few which are available for solar purposes.

TABLE IV-10

Absorber Coatings[26]

Coating	Solar Absorptance (α)	Long Wave Emittance (ε)	α/ε	Approximate Cost (1975) $/sq ft
Black chrome (chromium oxide)	0.93	0 .06	15	-
Black nickel (nickel-zinc sulfur)	0.92	0.07	13	1.65
Black copper (copper oxide)	0.85	0.12	7	0.60
Black paint	0.97	0.97	1	0.35

G. Storage Media

1. Classes of Heat Storage Media

Since the sun only shines part of the time, solar systems require some type of heat storage medium. The two classes of heat storage media are those that store heat as sensible heat and those which store heat as heat-of-fusion. Sensible heat is the thermal energy contained by a material. The sensible heat of a material is reduced if its temperature decreases, and increased if its temperature increases. For example, to increase the temperature of water 1 degree requires more energy (sensible heat) than would be required to increase the temperature of an equal mass of steel one degree.

Energy is given up or taken in when a material melts or freezes; that quantity of energy is called the heat-of-fusion. Examples of this are the freezing and thawing of water or certain salt hydrate systems. The usual advantage of heat of fusion energy storage over ordinary sensible heat storage is that a greater quantity of energy can be stored in the same volume of material.

2. Important Properties for Selecting Heat Storage Media

Properties which are important in selecting a heat storage medium are:

Cost
Energy storage density
Stability
Toxicity
Fire properties

Cost is an important factor in choosing a heat-storage medium. The actual cost of the material is of prime importance, but there are other hidden costs which have to be considered. A material that stores energy at higher densities requires a smaller storage volume, and therefore requires less insulation material and less structural material for a heat storage bin or tank. The initial cost of the building itself may be lower if a smaller heat-storage volume can be used. The actual installation and removal of materials from heat-storage bins or tanks is probably cheaper and more convenient for liquids.

The stability of a heat storage medium is important from an economic as well as a practical point of view. A material which is stable and does not require changing during the lifetime of the system may be less costly than one which is cheaper but requires frequent changing.

Certain practical problems also influence the choice of a heat storage medium. A rock storage medium, for example, may require periodic treatment to prevent mold or fungi from building up. The actual handling of the material during installation and removal may be much easier for some materials than for others. Another very real practical problem which is often overlooked concerns the availability of an acceptable disposal method for waste materials when the useful life of the storage medium ends.

Some of the heat-of-fusion storage media melt unevenly and form layers of saturated solution and solid. Repeated cycling further separates the two-phase mixture which results in a decrease in heat-storage capacity. This problem can be partially overcome by using long, thin containers.[28]

3. Data on Heat Storage Media

Table IV-11 lists the three common sensible heat storage media and their pertinent physical properties.

Table IV-12 lists several phase-change heat-storage media which could be used for solar applications in the temperature range from 8 to 84^{o} C (46 to 183^{o} F). Glauber's salt has been used in the past for residential systems. All of these materials are still in the experimental stage and are not so widely used as the three sensible heat-storage media listed in Table IV-11.

TABLE IV-11

Sensible Heat Storage Media

Material	Specific Heat (cal/g·°C)	Density g/cm^3 (lb/ft^3)	Volume Heat Storage Capacity Cal/cm^3·°C (Btu/ft^3·°F)	Volume Ratio of Material to Water That Has Same Heat Storage	Approximate Cost (1977) \$/m^3 (\$/ft^3)
Water	1.00	1.00 (62.4)	1.00 (62.4)	1	0.11 (0.003)[a]
Rocks	0.20	2.60 (162)	0.52 (32)	3[b]	8.83 (0.25)
Concrete	0.20 to 0.24	2.3 to2.5 (145 to 156)	0.46 to 0.60 (28.7 to 37.4)	2	35.31 (1.00)[c]

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[a] City of Albuquerque price.

[b] Uniform sized rocks pack with a void fraction of about 0.42.

[c] Does not include any reinforcing bar.

TABLE IV-12

Phase Change Heat Storage Media[29]

Material	Heat of Fusion		Melting Point Temperature		Density		Volume Heat Storage Capacity	
	cal/g	(Btu/lb)	°C	(°F)	g/cm^3	(lb/ft^3)	cal/cm^3	(Btu/ft^3)
Propionamide	40.2	(72.3)	84	(183)	1.04	(64.9)	41.8	(4697)
Urea/NH Br	36.1	(64.9)	84	(183)				
Naphthalene	35.3	(63.5)	83	(181)	1.14	(71.1)	40.2	(4517)
Benzamide/Benzoic Acid	30.4	(54.7)	83	(181)				
$Ba(OH)_2\ 8H_2O$	63.5	(114.3)	82	(180)	2.18	(136.0)	138.4	(15552)
Biphenyl	28.5	(51.3)	71	(160)	0.99	(61.8)	28.0	(3146)
Stearic Acid	48.4	(87.2)	69	(156)	0.85	(53.0)	41.1	(4618)
Polyglycol E6000	45.4	(81.7)	66	(151)				
Palmitic Acid	44.3	(79.8)	64	(147)	0.85	(53.0)	27.6	(4225)
Paraffin Wax	41.5	(74.7)	64	(147)				
Myristic Acid	44.6	(80.3)	58	(136)	0.86	(53.7)	38.4	(4315)
Lauric Acid	42.4	(76.3)	49	(120)	0.87	(54.3)	36.9	(4146)
$Zn(NO_3)_2\ 6H_2O$	35.1	(64.1)	42	(108)	2.06	(128.5)	72.3	(8124)
$CaBr_2\ 6H_2O$	27.6	(49.7)	39	(102)				
$CaCl_2\ 6H_2O$	45.6	(82.1)	36	(97)	1.68	(104.8)	76.6	(8607)
Capric Acid	36.5	(65.7)	36	(97)	0.89	(55.5)	32.5	(3652)
$Na_2SO_4\ 10H_2O$	60.0	(108.0)	32	(90)	1.46	(91.1)	87.6	(9843)
Myristic/Capric Acid	35.3	(63.5)	27	(81)				
Polyglycol E600	30.4	(54.7)	22	(72)				
Caprylic Acid	35.5	(63.9)	21	(70)	0.91	(56.8)	32.3	(3629)
Polyglycol E400	23.8	(42.8)	08	(46)				

V. CHEMICAL COMPOSITION, THERMAL DEGRADATION PRODUCTS, AND THERMOXIDATIVE PRODUCTS OF SOME COMMERCIAL MATERIALS

Hazardous properties and undesirable environmental effects can result from small amounts of additives or impurities in a material, or from products of thermal degradation or partial oxidation, even though the major constituent of the material is innocuous. Chemical reactions during and after disposal can also produce materials with undesirable properties.

The chemical composition of a material is rarely revealed by manufacturers, and the additives used are almost never reported. The chemical composition of a material can vary from one manufacturer to another and from one batch to the next batch for the same manufacturer. Also, different additives may be used in different batches. Nevertheless, to assess the potential hazards and environmental effects, it is necessary to know both the initial chemical compositions of the various materials and the chemical compositions of the materials after normal and abnormal use conditions.

This section gives a compilation of chemical compositions and thermal degradation and thermoxidation products of various SHAC materials. The materials treated in this section are included in later sections on toxicology, fire properties, and environmental effects. Some of the data come from a literature survey, and some have been generated specifically for this handbook and are published with more background information elsewhere.[30] This compilation of data is not complete. There are so many materials under consideration for use in

SHAC systems, and each material has so many possible degradation modes and degradation products, that an all-inclusive data compilation is not feasible at this time.

Many of the data presented here have been obtained for specific brand-name products. While the analysis of such specific products was made in a careful and conscientious manner, it cannot be stated absolutely that this analysis realistically represents the product for the following reasons: (1) Commercial products vary in chemical composition, and (2) this analysis was not repeated a sufficient number of times to insure high accuracy.

The information given in this section is often in the form of chemical names. Users of this handbook may not be familiar with chemical nomenclature, but the information is important and cannot be readily conveyed in any other form. The reader who is unfamiliar with chemical nomenclature is warned that chemical names are precise. A change in spelling of a single letter (an o instead of an a , for example) signifies a different chemical composition that may have entirely different properties. In using this handbook, careful consideration of the spelling of chemical terms is advised to ensure that the information from the various sections of the handbook relates to the same chemical.

The data on degradation and thermoxidative products presented in this handbook are primarily related to the production of gaseous products. The data are most applicable to the two abnormal conditions of collector stagnation and fire. The products and the relative amounts of each are a strong function of temperature. For this reason, the data presented here can be taken as characteristic only of the temperature at which the data were obtained.

A. General Remarks Concerning Composition and Degradation of Polymeric Materials

Many materials used in SHAC systems are polymeric in nature. All plastics are polymeric. Many oils, most seals and sealants, and even woods are polymeric. SHAC materials which are not polymeric include metals, water, rocks, fluid treatment chemicals, and many heat transfer fluids.

1. Composition of Polymeric Materials

A polymeric material is a substance whose chemical composition can best be described as a long chain of repeating units. The units are a specific combination of atoms, and a unit is often referred to as a mer. Mers are connected to each other by chemical bonds, and a chain can be broken at the chemical bond between mer units. A chain can be terminated when a group that is not a mer is bonded to a mer. The ends of the chains in some polymeric materials attach to each other forming a cyclic structure. Tables in the following sections give the mer or unit for the various polymeric materials.

The number of units in a polymer can strongly affect the properties of a material. As an example, the monomer of polyethylene is ethylene, a gas with properties somewhat like natural gas. Polyethylene with four mers in the chain is a liquid with properties not unlike gasoline, while polyethylene with thousands of mer units is the common plastic used for many household items. As another example, most silicones have the same basic unit, but silicones can be light oils, heavy, viscous oils, or solids, depending on the number of units.

The above examples illustrate the large variety of material properties available to manufacturers from a single mer. Manufacturers rarely produce a polymeric material with a given number of mers; instead, they produce a product with desired physical properties. The material contains chains with a distribution of lengths.

2. Degradation of Polymeric Materials

Polymeric materials can degrade for a variety of reasons, and specific materials are more susceptible than others to one or more of the various causes of degradation. Stimuli that can promote degradation in polymers include air (oxygen), light (especially ultraviolet), heat, and mechanical damage. Burning can be considered a form of degradation. Chemicals produced by degradation may be gaseous, liquid, or solid.

Degradation and degradation products are important for a number of reasons. The physical characteristics of a material, and therefore its performance characteristics, are altered by degradation, but the chief reason for considering degradation products in this handbook is that such products may have different hazardous properties and environmental effects than the parent materials.

Two examples of potential hazards resulting from degradation can be given. Several insulating plastics give off toxic gases in appreciable amounts at temperatures easily reached by solar collectors. Wood degrades slowly at elevated temperatures, and its autoignition temperature decreases as it degrades, increasing the potential fire hazard. Major uncertainty exists concerning the effect of degradation on the toxicity of heat transfer fluids which are relatively nontoxic prior to degradation.

3. Pyrolysis of Polymeric Materials (Thermal Stability)

A standard method for measuring the thermal stability of polymeric materials consists of heating the material in the absence of oxygen (or any other reactive gas) and measuring the rate of weight loss. The gas that is evolved is often analyzed also. The process which is taking place is called pyrolysis, and the instrument used is called a thermogravimetric analyzer. This instrument actually measures the change in weight of a sample while it is being heated in an inert gas.

Each polymer has its own characteristic pyrolysis products. Identification of the gaseous products is usually sufficient to identify the polymer being degraded.[31]

Most polymers that are heated at a constant rate (in the absence of any reacting gas) show an onset of rapid gas evolution at a characteristic decomposition temperature. This characteristic temperature gives an indication of the short-term, high-temperature stability of the polymer. Below this temperature a polymer can still degrade and release volatile gases, but the rate of gas evolution decreases dramatically as the temperature decreases.

Some generalized statements can be made about the decomposition products of polymers within a general chemical type. Perhalogenated polymers such as polytetrafluoroethylene (Teflon) have a tendency to depolymerize when heated to their decomposition temperatures. Above 500^0 C, Teflon degrades rapidly to give tetrafluoroethylene, its mer. Polymers containing both hydrogen and halogen atoms have a tendency to release the hydrogen halide.[32] Hydrogen fluoride, for example, is a major gaseous pyrolysis product of polyvinyl fluoride.

Polyolefins, the repeating unit of which contains carbon and hydrogen, do not cleanly depolymerize but rather undergo random chain breakup when heated to give a variety of low-molecular-weight aliphatic (paraffinic) and aromatic hydrocarbons.[33,34] EPDM and butyl rubbers are SHAC sealants that belong to the class of polyolefins.

Nitrogen-containing polymers such as nylon, decompose to give hydrogen cyanide and ammonia in small quantities.[35-37] In the presence of air, there is also the possibility that (toxic) oxides of nitrogen will form in small quantities.[33]

Silicones degrade by a process in which the polymer attacks itself to give cyclic siloxanes having three to eight siloxane units in the ring.[38]

4. Thermoxidative Stability of a Polymer

If a sample is heated in a thermogravimetric analyzer with air (or oxygen) in contact with the sample instead of an inert gas, results that appear somewhat like those from the pyrolysis experiments are obtained. In this case, however, the thermoxidative stability of a sample is obtained instead of simply its thermal stability.

The composition of thermal degradation products when oxygen is present is very sensitive to conditions. If an ample supply of oxygen is available, the chief products will be carbon dioxide and water. In an oxygen-deficient environment, pyrolysis products will predominate. If elements other than carbon and hydrogen are present, other oxygenated products will be produced. For example, COF_2 is formed from polytetrafluoroethylene[39-42] and nitromethane is produced from nylon.[43]

B. Composition and Thermal Degradation Products of Plastic Materials

1. Composition of Plastic Materials

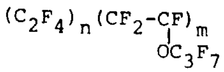
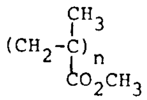
Table V-1 lists the composition of plastic materials (excluding insulating foams) used in solar applications. The formula for the mer unit is given in the third column, and the structure of the mer unit is given in the fourth column. The fifth through eleventh columns list the elemental composition of the plastic which is readily calculable from a knowledge of the formula of the mer unit. One plastic which is not completely defined by the structure of the mer unit is polyvinyl chloride (PVC); PVC contains proprietary additives that serve as stabilizers. Dehydrochlorination is prevented by these stabilizers.

2. Thermal Stability and Thermal Degradation Products of Plastics

Table V-2 lists the thermal degradation products of plastics considered for solar applications. The thermal stabilities of these solids were determined by dynamic thermogravimetric analysis (TGA). In dynamic TGA, sample weight change *vs* temperature is recorded as the sample is heated in a thermobalance at a given rate and in a specified environment. The environment used in this case was argon; the temperature rise rate was 10° C/min. Above a certain temperature, major fragmentation of the polymer backbone occurs, giving rise to volatile decomposition products which result in accelerated weight loss. This temperature is the polymer decomposition temperature and is an index of the inherent stability of the polymer. Since rather rapid heating rates

TABLE V-1

Composition of Plastic Solids Used in SHAC Systems

Trade Name And Suppliers	Chemical Name and Generic Class	Formula of Mer Unit	Structure of Mer Unit	Elemental Composition (Percent) C	H	N	O	S	F	Cl	References and Comments
Teflon, PTFE (DuPont)	Poly (Tetrafluoroethylene) Fluorocarbon polymer	C_2F_4	$(C_2F_4)_n$	24	-	-	-	-	76	-	Ref. 44
Teflon FEP (DuPont)	Copolymer of tetrafluoroethylene and hexafluoropropylene Fluorocarbon polymer	NA	$(C_2F_4)_n(C_3F_6)_m$	24	-	-	-	-	76	-	Ref, 45
Teflon, PFA (DuPont)	Copolymer of tetrafluoroethylene and perfluoropropyl perfluorovinyl ether	NA	 $(C_2F_4)_n(CF_2\text{-}\underset{OC_3F_7}{\underset{\vert}{C}}F)_m$	23	-	-	4	-	73	-	Ref, 46
Tedlar	Fluorocarbon polymer Poly (vinyl fluoride) A vinyl polymer	C_2H_3F	$(CHFCH_2)_n$	52.17	6.52	-	-	-	41.3	-	Ref. 44
Lucite (DuPont Plexiglas)(Rohm and Haas)	Poly (methylmethacrylate)	$C_5H_8O_2$	 $(CH_2\text{-}\overset{CH_3}{\overset{\vert}{\underset{CO_2CH_3}{\underset{\vert}{C}}}})_n$	60	8	-	32	-	-	-	Ref. 44
PVC, Geon. (B.F.Goodrich)	Poly (vinyl chloride) Vinyl polymer	C_2H_3Cl	$(CH_2CHCl)_n$	38.4	4.8	-	-	-	-	56.8	Proprietary stabilizers used in small quantities Typical stabilizers are organo-tin compounds or inorganic lead compounds. Ref. 44
Nylon, HT-4 (NASA)	Poly (1.4-phenylene-terephthalamide)	$C_{14}H_{10}O_2N_2$	$(OCC_6H_4CONHC_6H_4NH)_n$	70.5	4.2	11.76	13.44	-	-	-	Ref. 47
Nylon, 6,6 (DuPont)	Poly (hexamethylene diamide) Polyamide	$C_{12}H_{22}O_3N_2$	$(HNOC[CH_2]_4CONH[CH_2]_6)_n$	63.72	9.73	12.39	14.16	-	-	-	Ref. 44

NA Not Available

TABLE V-2

Thermal Stability and Thermal Degradation Products of Plastic Solids Used in SHAC Systems

Material (Supplier)	Sandia TGA Data			Literature Data	
	Temperature at 3% Wt. Loss °C	Polymer[+] Decomposition Temperature PDT °C	Temperature of Maximum Rate of Wt. Loss °C	Decomposition Temperature °C	Thermal Degradation Products Reported in Literatures
Teflon, PTFE (DuPont)	510	525	585	540[46]	Tetrafluoroethylene (95%) carbon tetrafluoride (1.5%) hexafluoroethylene[32]
Teflon, FEP (DuPont)	460	468	570	460[46]	Tetrafluoroethylene (75-84%) hexafluoropropylene (16-25%)[51,17]
Teflon, PFA (DuPont)	--	--	--	450[46]	NA
Tedlar (DuPont)	250	247	268	250[48]	Hydrogen fluoride, butadiene, allyl fluoride, benzene, toluene, naphthalene, vinyl fluoride, others[52,53]
Lucite (DuPont) Plexiglas (Rohm & Haas)	230	242	358	310[49]	Major: Methyl methacrylate; Trace: Benzene, water[54,55,56]
PVC, Geon, Halon (B.F. Goodrich, Allidd Chemical & many others)	230	238	308	220[49]	HCl, vinyl chloride, benzene toluene, numerous saturated and unsaturated aliphatic and aromatic compounds[50,43]
Nylon, HT-4 (NASA)	--	--	--	420[43]	CO, CO_2, H_2O, HCN, benzonitrile, benzene, methane and numerous other products in small quantities[43,57]
Nylon, 6,6 (DuPont)	360	398	470	380[50]	Major: carbon dioxide, water Minor: ammonia, hydrogen cyanide, organic nitriles, cyclic ketones, esters, and hydrocarbons[35,36,37]

[+] Criterion used was the extrapolated onset of the decomposition; i.e., the intersection of the tangent of the steepest part of the curve of the first major weight loss step with the tangent of the weight loss curve prior to the onset of the first major weight loss step.

NA - Not Available

are usually used in dynamic TGA, the data relate to the short-term stability of a material.

In order to determine the short-term stability from the TGA data, three criteria were used: (1) the temperature at which the polymer suffered a 3 percent weight loss, (2) the temperature at decomposition onset (beginning of significant weight loss), and (3) the temperature where the weight loss reached a maximum. It should be noted that slow decomposition can occur at temperatures lower than those indicated by these criteria.

Table V-2 gives a temperature range of 230° to 510° C for the temperatures at which the plastics used in SHAC systems have lost 3% of their weight.

If stagnation in a solar collector should occur, a reasonable temperature that could be expected for most flatplate collectors is about 205° C (400° F). The cover plates would probably be at an undetermined temperature somewhat less than this, and PVC, Lucite, and Tedlar could be expected to slowly decompose. The actual rate of decomposition would have to be determined by experiment. The two experimental techniques often used to measure decomposition rate are isothermal evolved gas analysis (EGA) and isodhermal TGA. The composition of the thermal degradation products is temperature-dependent.[58] In the case of PVC, hydrochloric acid, and, in the case of Tedlar, hydrofluoric acid is the first products to form during degradation.[53,57] It is expected that both of these products would evolve at temperatures near 205° C (400° F). At this temperature, the degradation of the other plastics listed in Table V-2 is less likely, but might occur slowly. Although the products listed in the last column of Table V-2 were reported to be formed at higher temperatures, it is anticipated that at least some of these products would also appear at that temperature.

If temperatures of 500° C or higher are attained, all of the plastics would decompose and evolve the products in Table V-2 unless ample oxygen were available. Table V-3 lists the combustion products of the plastics materials formed when an excess of oxygen is available.

Table V-3 also lists data taken by TGA using air instead of argon as the gas surrounding the heated sample. These data are presented under the sections labeled "TGA Data" (thermoxidative stability).

Higher decomposition temperatures of these materials were found for thermoxidation than for pyrolysis in the absence of oxygen. These data are contrary to intuitition and previous findings with other types of polymers.[63] Probably the weight loss incurred in the early stages of degradation is counterbalanced by the uptake and incorporation of oxygen.

TABLE V-3

Thermoxidative Stability and Combustion Products of Plastic Solids Used in SHAC Systems

Material (Supplier)	Sandia TGA Data			Literature Data	Combustion Products
	Temperature at 3% Wt. Loss °C	Polymer+ Decomposition Temperature (PDT) °C	Temperature of Maximum Rate of Wt. Loss °C	Decomposition Temperature °C	
Teflon, PTFE (DuPont)	525	535	588	550[51]	CO_2, CO, COF_2, tetrafluoroethylene, SiF_4 formed via reaction with glass[39–42]
Teflon, FEP (DuPont)	470	490	540	480[51]	NA; probably CO_2CO, SiF_4, COF_2 thermal degradation products; see Table V-2
Teflon, PFA (DuPont)	-	-	-	450[51]	NA; probably CO_2CO, SiF_4, COF_2 plus low molecular wt. fluorocarbons
Teflon (DuPont)	270	275	295	-	CO_2, benzene, HF, Fluorobenzene xylene, vinyl fluoride, others[54]
Lucite (DuPont), Plexiglas (Rohm & Haas)	262	270	330	-	Methylmethacrylate monomer, CO_2, CO, C_2H_4, H_2
PVC, Geon (Halon, B.F. Goodrich, Allied Chemical and many others)	267	281	345	-	HCl, CO_2, CP, vinyl chloride, benzene, toluene, methane, ethane, methyl, chloride[60–62]
Nylon, HT-4 (NASA)	260	440	520	480	CO_2, CO, H_2O, nitromethane HCN, acetone, benzonitrile[53,43]
Nylon 6,6 (DuPont)	360	422	490	-	CO_2, CO, CH_4, HCN, NH_3, ethylene and acetylene[62]

+Criterion used was the extrapolated onset of the decomposition; i.e., the intersection of the tangent of the steepest part of the curve of the first major weight loss step with the tangent of the weight loss curve prior to the onset of the first major weight loss step.

NA Not Available

C. Composition and Thermal Degradation of Heat Transfer Fluids

1. Chemical Composition of Heat Transfer Fluids

Data on the composition of 13 heat transfer fluids were obtained from manufacturers and from analysis of the commercial products. Data sheets for each of these materials are given as Appendix A. These data indicate the fluids can be grouped into four major categories:

1. Polydimethyl siloxanes
   - Sample 4 - SF 96 (50 CS)
   - Sample 5 - DC 200 (100 CS)
2. Glycols and Polyglycols
   - Sample 8 - UCON 50-HB-280X
   - Sample 9 - Dowtherm SR-1
   - Sample 10 - Dowfrost
3. Low molecular weight, high aromatic content fluids (synthetic fluids)
   - Sample 6 - Dowtherm A
   - Sample 7 - Therminol 66
4. Petroleum distillates fractions (natural fluids)
   - Sample 1 - Exxon 3029
   - Sample 2 - Exxon Caloria HT43
   - Sample 3 - Suntemp 1
   - Sample 11 - Thermia 33
   - Sample 12 - Mobiltherm 603
   - Sample 13 - Mobiltherm light

a. Polydimethylsiloxanes

The polydimethylsiloxanes (samples 4 and 5) differ in that sample 4 had a 50 centistoke viscosity while sample 5 had a 100 centistoke viscosity. This difference in viscosity directly reflects differences in the average molecular weights of the samples. Sample 5 had a higher molecular weight than did sample 4 as determined by gel permeation chromatography (GPC).

The infrared (IR) analysis confirmed the dimethylsiloxane structure for these samples.

Elemental analysis indicated only a few parts per million of metals present in both samples 4 and 5, and no sulfur, nitrogen, or halogens were detected.

b. Glycols and Polyglycols

Dowfrost (sample 10) is an inhibited propylene glycol. The inhibitor was experimentally confirmed to be potassium monohydrogen phosphate (K_2HPO_4) by x-ray spectroscopy. This inhibitor is present in low concentrations (less than 5 wt%). UCAR 35 was not analyzed, but the data from the manufacturer (Union Carbide) indicate it is a propylene glycol with the same inhibitor.

Dowtherm SR-1 (sample 9) is an inhibited ethylene glycol. The inhibitor is also potassium monohydrogen phosphate (K_2HPO_4). This sample also contains a red dye (less than 1% concentration).

The data sheets for samples 9 and 10 include elemental analyses by emission spectroscopy of the ashed residues.

Sample 8 is a polyglycol which also contains an additive (less than 1%). The polymeric nature and the polyalkylene composition of the sample was verified by GPC and IR. Gas chromatographic/mass spectral (GC/MS) data suggest that the additive could be a phenyl-naphthalamine. This class of compounds was, until recently, in common use as antioxidants. The elemental analysis indicated the presence of nitrogen, which is consistent with an amine compound.

c. Low Molecular Weight, High Aromatic Content Fluids

Dowtherm A (sample 6) is a mixture of biphenyl (26%) and diphenyl oxide (74%). No metals, sulfur, nitrogen, or halogens were detected.

Therminol 66 (sample 7) is a mixture of terphenyls hydrogenated to various extents.* No sulfur, nitrogen, halogen, or metals were detected.

d. Petroleum Distillate Fractions (Natural Oils)

Samples 1, 2, 3, 11, 12, and 13 are difficult to uniquely identify and characterize because they represent products obtained by fractional distillation of crude oil. As such, they have graded properties which are caused by the fact that they are mixtures with a wide molecular weight distribution, and they have varying proportions of aromatics. Sample 1 has a wide molecular weight distribution with a high average molecular weight material and a high aromatic content. The

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*Manufacturer's data

manufacturer indicates an aromatic content of 24%; the data taken in this study (GPC, GC/MS, and IR) suggest a value of less than 10%. Sulfur, nitrogen, halogens, and metals were not detected.

Sample 12 appears to be very similar to sample 1 except that its molecular weight distribution is higher and the very small amount of residue obtained from ashing the sample contained calcium and silicon.

Sample 11 is similar to sample 12 except it has about twice the aromatic content. The small ashed residue also contained calcium and silicon.

Sample 13 had the highest aromatic content of all the petroleum distillate fractions; it also had the lowest molecular weight distribution. The small ashed residue contained silicon as the major component.

Sample 2 is classified as a paraffinic oil of low aromatic content. The manufacturer indicates an aromatic content of 14%, but the data taken here indicate a lower figure. No sulfur, nitrogen, halogen, or metals were detected.

Sample 3 is very similar to sample 2 except that it had a higher aromatic content. Also a red dye was added to the fluid (less than 1%).

2. Thermal Stability, Thermal Degradation, and Thermoxidative Stability of Heat Transfer Fluids

Some data relative to thermal stability and degradation products have been generated for liquid heat transfer fluids[30] at a temperature somewhat higher than the 205°C (400°F) previously referred to as a reasonable stagnation temperature. This was done by sealing a sample of the particular fluid in a glass ampule, heating it for seven days at

232° C (450°F), allowing it to cool, and analyzing the gas above the liquid. No attempt was made to analyze the liquid products.

The data in Table V-4 indicate that all the heat transfer fluids are relatively stable at 232° C (450°F) from a functional viewpoint. None of the fluids yielded outgassing products exceeding 1 wt% when heated for seven days at that temperature.

The gases that are produced as the major products from all the fluids (hydrogen and methane) are quite flammable and potentially explosive. It cannot be determined from these data whether the amount of decomposition that can occur at normal operating temperatures or under stagnation conditions creates a hazardous situation due to the presence of hydrogen and methane. Experiments specifically designed to determine the potential hazard are needed.

The thermoxidative stability of heat transfer fluids is an important consideration for systems that have air in contact with the fluids. Air may be present due to leaks, or the original design may not have required the inert gas as shown on Figure IV-1, page 42. Oxidation of the liquids during stagnation conditions is a possible problem in such systems. Quantitative data for thermoxidative stability were not generated for this handbook and none are presented.

TABLE V-4

Percent Composition of Outgassing Products From
SHAC Heat Transfer Liquids After Aging at 232°C(450°F) for 7 Days

Decomposition Products	Silicone SF-96 50 (General Electric)	Uncon 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

D. Thermoxidative Stability and Outgassing Products of Selected Insulating Materials

The thermoxidative stability and outgassing products of selected insulating materials are considered in this section. The compositions and thermal stabilities of foam insulation materials are given in earlier sections of this chapter that discuss plastics.

The thermoxidative stability of selected insulating materials was determined using dynamic and isothermal TGA with an air atmosphere over the samples. The dynamic measurements were made from room temperature to 600° C at a constant heating rate of 10° C/min. The data from the dynamic measurements given in Table V-5 show the observed percentage weight loss at three temperatures for each of five selected materials.

In isothermal TGA, a sample of material is rapidly heated to some specified temperature on the thermobalance, and its weight is monitored as a function of time. For this work, the specified temperature was 200° C, and Table V-5 gives the percentage weight loss observed with this test for the five materials.

The outgassing products were determined for the five selected materials by heating samples in high vacuum at 200° C and using a mass spectrometer to analyze the resulting products. The identified products are listed in Table V-5 for each material. This list should be used with caution since the quantities of the gases produced were not determined, and the tests were made in high vacuum. For three of the samples, trichlorofluoromethane (used as a blowing agent during manufacture) is the major outgassing product. The outgassing products labeled "degradation products" are unidentified species.

TABLE V-5

Dynamic and Isothermal Thermogravimetric and Outgassing Analysis of Selected Insulating Materials

Material	Dynamic TGA[a] in Air Percent Weight Loss			Isothermal TGA in Air at 200°C Percent Weight Loss		Outgassing Products[b] at 200°C in High Vacuum
	200°C	400°C	600°C	15 MIN	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, TF-600,[c] 2.0 lb/ft^3	1.2	27.7	86.6	3.3	3.3	H_2O, CO_2, HCl, Trichlorofluoromethane, and other degradation products
Rigid Polyurethane Foam, Suprathane[d] 2.0 lb/ft	13.2	56.2	94.6	9.9	11.1	H_2O, CO_2, HCl Trichlorofluoromethane, Chloro ethyl phosphate, and other degradation products
Rigid Polyurethane Foam, Olin A602C5[e] 2.0 lb/ft	4.2	33.7	63.3	6.2	7.5	H_2O, 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_2O, CO_2

NOTES:
- 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 Corp.

E. Composition and Thermal Degradation Products of Seal and Sealant Materials

1. Composition of Seals and Sealants

Table V-6 lists some commercially available sealant and seal materials and their composition. Teflon tape used to seal pipe threads was not listed because that material was already included in earlier tables.

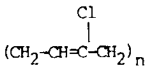
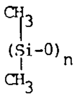
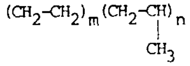
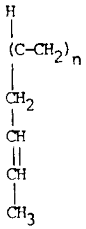
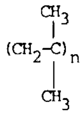
The types of additives commonly used in these materials are listed at the bottom of this table, but no attempt was made to identify all additives for each material for two reasons: first, information about additives is considered proprietary, and, second, the analytical effort required would be beyond the scope of the present study.

2. Volatile Products Present in Seal and Sealant Materials

Attempts were made to identify the volatile additives that were present in the seal and sealant materials. The volatiles experimentally detected for a few commercial materials are listed in Table V-6. The Neoprene and EPDM gasket materials do not contain significant amounts of volatile products. Dow Corning 781 silicone rubber caulking had the least amount of outgassing of all the materials tested. Small quantities of water and low molecular weight siloxanes (silicones) were detected by GC/MS in the vapors from the silicone rubbers. Phthalate esters outgassed in moderate quantities from both polysulfide rubbers. It is guessed that phthalates are used as plastisizers in the polysulfides to enhance physical softness. The largest amount of outgassing occurred with the butyl rubber products, Novacaulk 420 and

TABLE V-6

Composition of Sealants Used in SHAC Systems

Trade Name and Suppliers	Chemical Name and Generic Class	Formula of Mer Unit	Structure of Mer Unit	Elemental Composition C	H	N	O	S	F	Cl	Comments
Neoprene (DuPont and others)	*Poly(2-Chloro-1,3-butadiene) *Halocarbon addition polymer	C_4H_5Cl	 $(CH_2-CH=C(Cl)-CH_2)_n$	54.24	5.65	-	-	-	-	-	Neoprene is formulated with numerous additives; types used are listed below. Specific additives used are proprietary. Elemental composition is for the base resin only.
DC781 Silicone Building Sealant (Dow Corning)	*Poly(dimethylsilcxane)	C_2H_6SiO	 $(Si(CH_3)_2-O)_n$	32.43	8.11	-	2.62	-	-	-	Si content is 37.84%. Moisture cured vulcanizate. Acetic acid <u>not</u> evolved. Small amounts of silicone monomers and dimers evolved at 200°C; water was also detected among the outgassing products.
EPDM Rubber (Parker Seal, Ball Rubber, and Jasper)	*Copolymer of ethylene propylene and a diene, such as 1, 4-hexadiene		 $(CH_2-CH_2)_m(CH_2-CH(CH_3))_n$	85.71	14.28	-	-	-	-	-	EPDM, is formulated with numerous additives; types used are listed below.* Specific additives used are proprietary. Elemental composition is for the base resin only. Ref. 45
	*Polyolefin copolymer		 $(CH(CH_2-CH=CH-CH_3)-CH_2)_n$	-	-	-	-	-	-	-	
Polysulfides (Novacalk 600, GC-9 from Novagard and Pecora, respectively)	*Copolymer of ethylene tetrasulfide and disulfide with the tetrasulfide and disulfide of bis (2-chloroethyl) ether		$(CH_2CH_2S_4)_n$ $(CH_2CH_2S_2)_m$ $(CH_2CH_2OCH_2CH_2S_2)_0$ $(CH_2CH_2OCH_2VH_2S_2)_p$	-	-	-	-	-	-	-	Outgassing of Novacalk 600 and GC-9 indicated presence of a phthalate structure; phthalates are generally used as plasticizers. Ref. 45
	*Polysulfide			-	-	-	-	-	-	-	
Butyl Rubber Novacalk 420, (Novagard)	*Poly(Isobutene) *Polyolefin	C_4H_8	 $(CH_2-C(CH_3)_2)_n$	85.71	14.2	-	-	-	-	-	Saturated alkanes outgassed at 200°C. Ref, 45

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*Additive types: Processing aids antioxidants, metallic oxides, curing agent and/or accelerator, filler or reinforcing agent, physical softeners.

EPDM = Ethylene/propylene/diene terpolymer

Tremco 440; in these, the outgassing products consisted primarily of low-molecular-weight aliphatic (paraffinic) hydrocarbons. These materials may have been present in the butyl rubbers before vulcanization or may have been added to make them softer.

3. Thermal Stability and Thermal Degradation Products of Seal and Sealant Materials

Table V-7 lists the thermal degradation products found in the literature for seal and sealant materials. Thermal stabilities of the sealants are generally lower than for the plastics in earlier sections. The polysulfides caulking materials, i.e., Novacaulk 600 and GC-9, were the least stable of all the solar materials tested. Significant decomposition occurred below the temperature of 205° C (400° F), a moderate stagnation temperature for the collector surface. The seals and sealants would probably be at an undetermined temperature somewhat lower than the collector surface; however, except for the silicone rubber caulking compound, all the seal and sealant materials listed would slowly decompose and evolve the products listed in Table V-7 if a temperature of 205° C were reached.

Higher decomposition temperatures for sealant materials were found for thermoxidation than for pyrolysis in the absence of oxygen (see Table V-8). These data are analogous to those for other plastics discussed on page 93.

TABLE V-7

Thermal Stability and Thermal Degradation Products of Sealants used in SHAC Systems

	Sandia TGA Data			Literature Data	
Material(Supplier)	Temperature at 3% Wt. Loss °C	Polymer+ Decomposition Temperature °C	Temperature of Maximum Rate of Wt. Loss °C	Decomposition Temperature °C	Thermal Degradation Products Reported in the Literature (References)
Neoprene (DuPont and others)	235	297	315	265[59]	Major: Hydrogen chloride, 1,3 butadiene, benzene toluene[59,69,70]
D. C.781 Silicone building sealant, (Dow Corning)	420	462	550	450[64]	Cyclic polysiloxanes $[(CH_3)_2SiO]_n$ where n=3 to 8[38]
EPDM Rubber (Parker Seal)	340	427	467	410[65]	Ethylene, propylene (major) plus longer chain hydorcarbons; also methane and hydrogen[33,34]
EPDM Rubber (Ball Rubber Co.)	240	428	465	410[65]	as above[33,34]
EPDM Rubber (Jasper Rubber Co.)	235	438	470	410[65]	as above[33,34]
Polysulfide, Novacalk 600 (Novagard Co.)	184	230	300	220-260[66]	Diethyl disulfide, ethyl mercaptan, Ethylthieoethylmercaptan, ethylene, hydrogen sulfide (trace)[66]
Polysulfide, GC-9 (Pecora Co.)	185	220	300	220-260[66]	as above[66]
Butyl Rubber, Novacalk 420, (Novagard Co.)	170	360	412	336[67]	Isobutene, isobutane, pentenes, neopentane and methane[68]

+ Criterion used was the extrapolated onset of the decomposition; i.e., the intersection of the tangent of the steepest part of the curve of the first major weight loss step with the tangent of the weight loss curve prior to the onset of the first major weight loss step.

TABLE V-8

Thermoxidative Stability and Combustion Products of Sealants Used in SHAC Systems

	Sandia TGA Data			Literature Data	
Material (Supplier)	Temperature at 3% Wt. Loss °C	Polymer+ Decomposition Temperature (PDT) °C	Temperature of Maximum Rate of Wt. Loss °C	Decomposition Temperature °C	Combustion Products
Neoprene (DuPont and others)	235	314	335	-	CO_2, CO, H_2O, H_2, CH_4, C_2H_6 ethylene, Cl, 1,2-butadiene, benzene, toluene[71]
D.C.781 Silicone, building sealant (Dow Corning)	370	500	555	-	Formaldehyde, formic acid, CO, CO_2, cyclic polysiloxanes $[(CH_3)_2SiO]_n$ with n=3 to 8.[72,58]
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	180-220[73]	CO_2, CO, sulfoxides, H_2O, C_2H_5SCHO, HCHS, C_2H_5OH thioformaldehyde[73]
Polysulfide, GC-9 (Pecora Co.)	225	240	360	180-220[73]	as above[73]
Butyl Rubber, Novacalk 420 (Novafard Co.)	270	360	411	-	N.A., probable products are CO_2, CO, H_2O, H_2, isobutene, pentenes and acetylene

+Criterion used was the extrapolated onset of the decomposition; i.e., the intersection of the steepest part of the curve of the first major weight loss step with the tangent of the weight loss curve prior to the onset of the first major weight loss step.

F. Composition and Thermal Degradation of Thermal Storage Media

1. Composition of Phase Change Thermal Storage Media

Table V-9 gives phase-change thermal storage materials, their chemical formulae, and a few physical properties. The fact that some of the numbers given on this table differ slightly from some of the numbers given in Table IV-13 for the same physical property illustrates that differences exist in the literature from source to source.

2. Thermal Degradation of Phase-Change Thermal Storage Media

The thermal storage materials in most applications will not be subjected to temperatures higher than the normal operating temperatures of a flatplate collector (50-90° C). In order to determine the long-term (years) stability of these materials, accelerated aging experiments would have to be performed. The short-term (months) stability of these materials in the temperature range of 50 to 90° C should be very good. Generally, organic compounds do not thermally degrade until temperatures of about 200° C are reached.[74] The most stable organic compound listed in Table V-9 is biphenyl; this is one of the most stable organic compounds in existence. Diphenyl oxide and naphthalene also have very high thermal stability.

TABLE V-9

Composition and Properties of Thermal Storage Media for SHAC Systems

Material	Structure	Specific Gravity[45]	Boiling Point °C[45]	Melting Point °C[45]
Propionamide	$C_2H_5CONH_2$	0.93	213	81
Urea/NH_4Br	NH_2CONH_2/NH_4Br	--	--	--
Diphenyl oxide	$(C_6H_5)_2O$	1.1	259	27
Naphthalene	$C_{10}H_8$	1.1	218	80
Lauric acid	$CH_3(CH_2)_{10}CO_2H$	0.87	131	44
Benzamide	$C_6H_5CONH_2$	1.08	290	128
Benzoic acid	$C_6H_5CO_2H$	1.27	250	122
$Ba(OH)_2 \cdot 8H_2O$	--	2.18	798	78
Biphenyl	$C_6H_5C_6H_5$	1.98[74]	254	70
Stearic acid	$CH_3(CH_2)_{16}CO_2H$	0.8	386	69
Palmitic acid	$CH_3(CH_2)_{13}CO_2H$	0.5	390	62
Paraffin Wax	$CH_3(CH_2)_nCH_3$+ branched alkanes	0.8	>371	47-65
Myristic acid	$CH_3(CH_2)_{11}CO_3H$	0.84	250	57
$Zn(NO_3)_2 \cdot 6H_2O$	--	2.07	$-6H_2O$ 105-131	36
$CaBr_2 \cdot 6H_2O$	--	2.30	--	38
$CaCl_2 \cdot 6H_2O$	--	1.71	$-6H_2O$ 200	30
Capric acid	$CH_3(CH_2)_8CO_2H$	0.89	270	32
Polyglycol E600	--	--	>300	Below 25°C
E400	--	--		
E6000	--	--		
Caprylic acid	$CH_3(CH_2)_6CO_2H$	0.91	239	17
$Na_2SO_4 \cdot 10H_2O$	--	1.46	--	32

VI. TOXIC PROPERTIES AND OTHER POTENTIAL HEALTH EFFECTS OF SHAC MATERIALS

Most potential health effects caused by SHAC materials are toxic effects. However, there are several unusual situations that can lead to health effects caused by fungi or other microbiological agents. These few cases are discussed in this chapter in those subsections dedicated to specific classes of materials. Accidental injury, such as burns, or any other physical injury are not considered in this handbook.

Toxicity may be defined as the degree to which a nonliving material is able to produce injury or illness once it reaches a susceptible site in or on an organism. While the toxicity of most SHAC materials has not been completely characterized, there are enough data to allow an initial estimation of the potential hazards likely to be associated with the use of most of the materials.

In using the toxicity data presented in this handbook, it is important to recognize the distinction between toxicity and a toxicity hazard. 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. A very toxic material may pose very 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.

Before a chemical can produce injury to the body, the body must be exposed to it. The most likely routes of exposure associated with SHAC materials are:

1. absorption through lungs after inhalation
2. absorption through the skin
3. ingestion

The injury produced by a chemical after exposure is influenced by the magnitude of the exposure, or dose, and the length of exposure. As a general rule, the injury produced increases with increasing dose. It is essential to recognize that no compound is completely nontoxic (safe). For example, both table salt and water can cause illness if enough is consumed over a short period of time. Thus, the concept of the rate at which a dose is received becomes very important. Chronic (long-term) exposure to small amounts of some materials may be relatively safe, while a short exposure to large amounts may produce injury or death. Other compounds may produce injury either from exposures to large amounts in a short time period or when the exposure is to small amounts over longer periods of time (i.e., days to years). For certain materials (e.g., many carcinogens) repeated exposures to small amounts may be more dangerous than larger exposures in a single event.

The type of exposure is also very important. Accidental contact of irritants with the skin and eyes may produce local injury (e.g., inflammation). Other compounds may have to be absorbed into the body before toxic effects may occur. Following absorption, the material can produce any number of toxic effects, depending on its properties. For some compounds, the toxic effects following exposure may be evident immediately, while for others the effects may occur only after a period of days, months, or years (a latent period). The latter is particularly true in the case of chronic exposure to small amounts of material over long time periods. The disease produced by a toxic material may last for a short period (i.e., days to weeks), after which recovery is complete. On the other hand, the toxic material may cause illness for long time periods, and recovery may never be complete even if the exposure is terminated (e.g., brain damage).

Some difficulties and uncertainties arise when attempting to estimate the hazard to man of a large number of compounds. Factors to be considered include:

1. 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.
2. The chance of exposure may be greater for persons constructing or servicing the system.
3. The longevity and subsequent hazards associated with disposal of components of the system must be considered.
4. The hazard or even toxicity of a material may also 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. A fire may release very toxic combustion products which, when inhaled, may result in death or serious injury. (Many of the deaths that result from certain types of airplane crashes are from highly toxic combustion gases

produced by fire, not from the crash itself.)

5. Some persons may be much more sensitive to the toxic effects of a compound than others (hypersensitivity).

6. Some compounds may alter (increase or decrease) the toxicity of other compounds present. Thus, an exposure to two or more compounds at the same time or in sequence may be more dangerous than an exposure to a single compound. This is frequently of concern when a person is taking medication.

7. Most of the available data, including those presented in subsequent tables, are derived from studies on laboratory animals, and humans may not respond to toxic materials exactly as animals do.

A commonly used measure of toxicity in animal studies is the dose estimated to cause an effect in 50% of the test animals. When the effect measured is death after exposure to a chemical, the dosage determined is the median lethal dose or LD_{50}. When toxic symptoms or injury is measured, the dosage calculated is the median toxic dose or TD_{50}. LD_{50}'s and TD_{50}'s are commonly expressed in terms of milligrams or grams of compound per kilogram of body weight (average weight for man is about 70 kg). For some materials data are given as LD_{Lo}. In this handbook, LD_{Lo} is the lowest recorded dose known to have caused death in humans.

In considering these data, it is important to recognize that, for some materials, the principal toxic manifestations may be cancer or birth defects in unborn offspring. The dose required to produce cancer or birth defects is not necessarily related to the dose required to produce deaths. Materials that are known carcinogens are marked on the tables with footnotes.

A. Toxicity Rating Systems

We have adopted and slightly revised two separate toxicity rating systems, one described by Durham[75], and one by Gosselin,[76]*et al.* Durham's system rates toxicity for four types of exposures. These exposure types can be defined as follows:

Acute Local - Material contact in a localized area of skin or mucous membrane lasting seconds, minutes, or hours.

Acute Systemic - Introduction of a material into the body through inhalation, ingestion, or skin permeation over a time period of seconds, minutes, or hours.

Chronic Local - Repeated material contact in a localized area of skin or mucous membrane over time periods of days, months, or years.

Chronic Systemic - Repeated introduction of a material into the body through inhalation, ingestion, or skin permeation over a time period of days, months, or years.

Durham assigns numerical ratings to the toxic manifestations of a material as follows.

U = Unknown; i.e., insufficient toxicity data are available. Until the hazard potential of the chemical is characterized it should be handled with care.

0 = Generally recognized as nontoxic under conditions of normal use or toxic only under unusually large exposures.

1 = Slight toxicity.

In general, those substances classified as having "slight toxicity" for a particular exposure type produce changes in the human body which are readily reversible and which will disappear following termination of exposure.

2 = Moderate toxicity.

Those substances classified as having "moderate toxicity" may produce irreversible as well as reversible changes in the human body. Usually, these changes are not of such severity as to threaten life or produce serious physical impairment.

3 = Severe toxicity.

Those substances which are classified as having "severe toxicity" produce irreversible, life-threatening changes in the human body.

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.

The numerical toxicity rating system of Gosselin, et al, is based on the acute toxicity of a single dose taken orally. The system is presented in Table VI-1. Although the Gosselin system uses the phrase "probable oral lethal dose (human)," assignment of a rating to a particular material is usually based on data obtained in laboratory animals.

TABLE VI-1

Gosselin's Rating System[76]

Toxicity Rating or Class	Probable Oral LETHAL Dose (Human)	
	Dose	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 nontoxic	Above 15 gm/kg	More than 1 quart (2.2 lb.)

B. Heat Transfer Fluids

The toxicity of heat transfer fluids, especially liquids, is very important in the safe use of SHAC technologies for several reasons. The person who installs SHAC systems will be exposed to the fluids on a regular basis. Thus, safety for installation personnel is dependent on the toxicity of the materials. The safe containment of spills and storage of fluid containers (both full and empty) clearly requires an assessment of the fluid toxicity. Liquids that are very toxic could conceivably contaminate shallow wells and streams to a dangerous level if spilled or disposed of in a manner that allowed the contamination of ground water.

A major concern of the solar industry involves liquid heat transfer fluids used in solar hot-water heaters. In such systems, a heat exchanger is often immersed in potable water. Leakage of toxic fluids into the hot water reservoir could have undesirable consequences. Systems using toxic liquids and having a heat exchanger in a potable water reservoir should use special precautions. One possibility is using a heat exchanger with two walls separated by a void. Since double-wall wall heat exchangers of this kind are more expensive and less efficient than single-wall heat exchangers, toxicity is a subject of considerable significance to SHAC technologies. An alternative to the double-wall heat exchanger that might be acceptable would be to require that some indicator such as a strong dye or foul tasting substance be added to the heat transfer fluids in such systems. This approach would require careful definition of the toxicity of allowed materials and the level of leak that must be announced by the indicator. This suggestion has not been carefully considered, and current standards require double-wall heat exchangers. The resident of a home using such a system would have to be well informed about the indicator and would have to accept the responsibility for prompt maintenance when leakage is indicated.

The toxicity level of liquid heat transfer fluids which are toxic enough to require special precautions in a solar hot-water heater has not been defined by standards groups at this time, but a solar standards committee of the American Society of Mechanical Engineers is currently considering the problem.

Heat transfer fluids can be very toxic, even though the major constituent is relatively nontoxic. Fluid treatment chemicals are often toxic, and these additives are rarely identified by manufacturers. Technical-grade liquids are often used in industrial applications, and they are not very pure. Such fluids can contain toxic residuals from the manufacturing process. Distributors of heat transfer fluids may not be aware of the additives or the grade of material, and may, in good faith, report in their literature that a toxic material is nontoxic.

The possibility must also be recognized that nontoxic fluids may become toxic because of use conditions. There has been no systematic study of this phenomenon, but it is known that water can pick up toxic amounts of metals from a metallic container after standing for a long period in a closed system. Also, prolonged exposure to other materials and elevated temperatures can cause chemical reactions and fluid degradation that could give rise to toxic substances.

Indirect health effects may arise with some types of heat transfer fluid used. An example of this occurs when air is used as a heat transfer "fluid." It has been reported[77] that air systems in humid climates using rock as a thermal storage medium can develop fungi. The dispersal of fungi into the air can lead to allergic reactions, primarily in the respiratory tract and on the skin. Aspergillus and Monilia are two common kinds of fungi that cause this type of illness.[77] In order to control the growth of fungi, the use of fungicides which may also be toxic to man, may be necessary.

Leakage of heat transfer fluids from the collector could result in toxic vapors. For roof-top liquid collector systems, the exposure to the user would probably be minimal, but for the service personnel this may not be true.

Toxicity data for heat transfer fluids is given in Table VI-2, and toxicity data for fluid treatment chemicals is given in Table VI-3. In these tables, the generic name of the material is given first, and then, where applicable, a typical product is given that has that chemical substance as its main constituent. This is followed by LD_{50} levels and a rating using Gosselin's system. The right-hand side of the table gives a toxicity rating according to the Durham system.

It should be emphasized that the toxicity ratings on these tables are for pure chemical substances and not necessarily the product. If a named product contains other substances (such as dyes, residuals from manufacturing, degradation products, or fluid treatment chemicals), the toxicity of the product may be greater than the toxicity indicated on these tables.

Table VI-4 gives data for the toxicity of outgassing products from heat transfer fluids. The first column gives the chemical that outgasses from the product listed in the second column. These outgassing products are reported in Section V.C.1 of this handbook.

TABLE VI-2

Toxicity of Heat Transfer Fluids

CHEMICAL SUBSTANCE (GENERIC)	COMMERCIAL PRODUCT	ACUTE TOXICITY (INGESTION)	TOXICITY RATING[a] GOSSELIN[76]	TOXIC HAZARD RATING[a] DURHAM[75]				
					Acute		Chronic	
					Local	Systemic	Local	Systemic
Ammonia, anhydrous NH_3	-	-	-	Irritant	3	U	1	U
				Ingestion	3	U		U
				Inhalation	3	U		U
				Skin absorption		U		U
Bromides	-	-	-	Irritant	1		1	
				Ingestion	2	2		2
				Inhalation	2			2
Chlorodifluoromethane Syn: Freon 22 $ClHCF_2$	Freon 22	-	-	-				
Dichlorodifluoromethane Syn: Freon 12 CCl_2F_2	Freon 12	-	-	Irritant	0		U	
				Ingestion	0		U	
				Inhalation	0	1	U	1
				Skin absorption	0		U	
Dichlorotetrafluoroethane Syn: Freon 114 $F_2ClCCClF_2$	Freon 114	-	-	Irritant	1		U	U
				Ingestion			U	U
				Inhalation	1	1	U	U
				Skin absorption			U	U
Diethylene glycol[b] Syn: diglycol $CH_2OHCH_2OCH_2CH_2OH$	-	Oral-human LD_{Lo}=1000 mg/kg[78]	3	Irritant	1		1	U
				Ingestion		2		U
				Inhalation		2		U
				Skin absorption				U
Dipropylene glycol Syn: 2,2-dihydroxy-isopropyl ether $(CH_3CHOHCH_2)_2O$	-	Oral-rat LD_{50}=15 gm/kg[78]	1	Irritant	U		U	
				Ingestion	U	2	U	2
				Inhalation	U		U	1
				Skin absorption	U		U	
Ethylene glycol Syn: 1,2-ethanediol; glycol; ethylene alcohol; glycol alcohol CH_2OHCH_2OH	Dowtherm SR-1; UCAR-thermofluid 17	Oral-human LD_{Lo}=1500 mg/kg[78]		Irritant	low		1	
				Ingestion	low	3		2
		Oral-rat LD_{50}=5840 mg/kg[78]		Inhalation	low			
			2	Skin absorption	low			

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

[b] Suspected carcinogen of bladder

TABLE VI-2 (continued)

CHEMICAL SUBSTANCE (GENERIC)	COMMERCIAL PRODUCT	ACUTE TOXICITY (INGESTION)	TOXICITY RATING[a] GOSSELIN[76]	TOXIC HAZARD RATING[a] DURHAM[75]	Acute		Chronic	
					Local	Systemic	Local	Systemic
Ethylene oxide[c] Syn: 1,2-epoxy-ethane oxirane $(CH_2)_2O$	UCON 30	Oral-rat[78] LD_{50}=330 mg/kg	4	Irritant	3		2	U
				Ingestion				U
				Inhalation		2		U
				Skin absorption				U
Fluorotrichloro-methane Syn: trichloro-fluoromethane $FCCl_3$	Freon 11	-	-	Irritant	1		1	
				Ingestion		1		1
				Inhalation		2		2
				Skin absorption		1		1
Glycerine Syn: 1,2,3-propane-triol; glycerol $CH_2OHCHOHCH_2OH$	-	Oral-guinea pig[78] LD_{50}=7750 mg/kg	2	Irritant	1			
				Ingestion		1		
Lithium bromide LiBr	-	-	-	See bromides and lithium compounds				
Lithium chloride $LiCl \cdot H_2O$	-	Oral-rat LD_{50}=757 mg/kg[78]	3	See lithium compounds				
Lithium compounds	-	-	-	Irritant	2		U	
				Ingestion		3	U	2
				Inhalation		2	U	2
				Skin absorption			U	
Methanol Syn: methyl alcohol CH_3OH	-	-	-	Irritant	1		1	
				Ingestion		3		2
				Inhalation	1	2	1	2
				Skin absorption		2		2
Phenyl ether-diphenyl mixture	Dowtherm A	Oral-rat LD_{Lo}=4380 mg/kg[78]	3	Not highly toxic but mild irritant				

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

[c] Carcinogen

TABLE VI-2 (continued)

CHEMICAL SUBSTANCE (GENERIC	COMMERCIAL PRODUCT	ACUTE TOXICITY (INGESTION)	TOXICITY RATING[a] GOSSELIN[76]	TOXIC HAZARD RATING[a] DURHAM[75]	Acute Local	Acute Systemic	Chronic Local	Chronic Systemic
Polyethylene glycol	UCON 50-HB-280-X	Oral-rat LD$_{50}$=6130 mg/kg[78]	2	-				
	E400		2					
	E600		2					
	E6000		1					
Propylene glycol Syn: 1,2-propanediol; 1,2-dihydroxypropane $CH_2OHCHOHCH_3$	Dowfrost; UCAR Food Freeze 35	Oral-rat LD$_{50}$=21 gm/kg[78]	1	Irritant	1		1	
		Oral-mouse LD$_{50}$=24 gm/kg[78]	-	Ingestion		1		1
				Inhalation				
				Skin absorption				
Propylene oxide[c] Syn: 1,2-epoxypropane; propene oxide; methyl oxirane OCH_2CHCH_3	UCON L20	Oral-rat LD$_{50}$=930 mg/kg[78]	-	Irritant	2		1	U
		Oral-guinea pig LD$_{50}$=690 mg/kg[78]	3	Ingestion		2		U
				Inhalation		2		U
				Skin absorption				U
Silicone Oil Syn: Dimethyl polysiloxane	Dow Corning 200	No unequivocal toxic effects are recognized	-	-				
m-Terphenyl Syn: m-phenylbiphenyl; benzene-1, 3-diphenyl $(C_6H_5)_2C_6H_4$	Therminol 66		-	Irritant	U		U	
				Ingestion	U	2	U	2
				Inhalation	U	2	U	
				Skin absorption	U		U	
Triethylene glycol Syn: 2,2'-ethylene dioxydiethanol; glycol; bis(hydroethyl) ether $(CH_2OCH_2CH_2OH)_2$	-	Oral-mouse LD$_{50}$=18500 mg/kg[78]	1	-				
Trifluorotrichloroethane Syn: Freon 113 CCl_3CF_3	Freon 113	-	-	Irritant	U		U	U
				Ingestion	U		U	U
				Inhalation	U	2	U	U
				Skin absorption	U		U	U

---

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

[c] Carcinogen

TABLE VI-3

Toxicity of Fluid Treatment Chemicals

CHEMICAL SUBSTANCE (GENERIC)	COMMERCIAL PRODUCT	ACUTE TOXICITY (INGESTION)	TOXICITY RATING[a] GOSSELIN[76]	TOXIC HAZARD RATING[a] DURHAM[75]	Acute		Chronic	
					Local	Systemic	Local	Systemic
Arsenic compounds[b]	-	-	-	Irritant	2		2	
				Ingestion	3	3		3
				Inhalation		3		3
Benzotriazole	-	Oral-rat LD_{Lo}=500 mg/kg[78]	3	-				
Boron compounds	-	-	-	Irritant		U	0	
				Ingestion	2	U	0	2
				Inhalation	2	U	0	2
				Skin absorption		U	0	2
Chlorinated phenols	-	-	-	Irritant	3		U	
				Ingestion	3	3	U	3
				Inhalation	3	3	U	3
				Skin absorption		3	U	3
Chromium compounds[c]	-	-	-	Irritant	3	U	3	
				Ingestion	3	U	3	3
				Inhalation	3	U	3	3
				Skin absorption		U		
2-ethylhexanol Syn: 2-ethylhexyl alcohol	-	Oral-rat LD_{50}=3200 mg/kg[78]	-	-				
		Oral-mouse LD_{50}=3200 mg/kg[78]	-					
Hypochlorites	-	-	-	Irritant	2		U	U
				Ingestion		2	U	U
				Inhalation		2	U	U
				Skin absorption			U	U
Lithium chromate $Li_2CrO_4 \cdot 2H_2O$	-	-	-	see chromium compounds				

---

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

[b] Suspected carcinogen of bladder

[c] Carcinogen

TABLE VI-3 (continued)

CHEMICAL SUBSTANCE (GENERIC)	COMMERCIAL PRODUCT	ACUTE TOXICITY (INGESTION)	TOXICITY RATING[a] GOSSELIN[76]		TOXICITY HAZARD RATING[a] DURHAM[75]			
					Acute		Chronic	
					Local	Systemic	Local	Systemic
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	U	2
				Inhalation	U	2	U	2
				Skin absorption	U		U	
Nitrites	-	-	-	Irritant	U		U	
				Ingestion	U	3	U	3
				Inhalation	U	3	U	3
				Skin absorption	U		U	

---

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

TABLE VI-3 (continued)

CHEMICAL SUBSTANCE (GENERIC)	COMMERCIAL PRODUCT	ACUTE TOXICITY (INGESTION)	TOXICITY RATING[a] GOSSELIN[76]	TOXIC HAZARD RATING[a] DURHAM[75]	Acute Local	Acute Systemic	Chronic Local	Chronic Systemic
Parathion Syn.: O,O-diethyl O-P-nitrophenyl thiophosphate; "Alkron"; compound 3422; DNTP; DPP; E-605 genithion; niran; paradust; paraflow; paraspray; parawet; penphos; phos-kil thiopos; vapophor; and many others $C_{10}H_{14}NO_5PS$		Oral-human LD_{Lo}=240 mg/kg[78] Oral-rat LD_{50}=2 mg/kg[78]	6	Irritant	U		U	
				Ingestion	U	3	U	3
				Inhalation	U	3	U	3
				Skin absorption	U	3	U	3
Pentachlorophenol Cl_5C_6OH	Dowicide G	Oral-human LD_{Lo}=29 mg/kg[78] Oral-rat LD_{50}=50 mg/kg[78]	4	Irritant	3		2	
				Ingestion		3		2
				Inhalation		3		2
				Skin absorption		3		2
Phenylmercuric triethanol ammonium lactate		Oral-rat LD_{50}=30 mg/kg[78]	5	See mercury compounds, organic				
o-Phenylphenol	Dowicide 1	Oral-rat LD_{50}=2700 mg/kg[78]	3	Irritant	1		1	
				Ingestion		2		2
Phosphates, organic				See parathion				
Potassium arsenate[d] Syn: potassium dihydrogen arsenate; Macquer's salt KH_2AsO_4				See arsenic compounds				
Potassium dichromate[d] Syn.: potassium bichromate; red potassium chromate $K_2Cr_2O_7$		Oral-human child LD_{Lo}=50 mg/kg[78]	5	See chromium compounds				

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

[d] Recognized carcinogen

TABLE VI-3 (continued)

CHEMICAL SUBSTANCE (GENERIC)	COMMERCIAL PRODUCT	ACUTE TOXICITY (INGESTION)	TOXICITY RATING[a] GOSSELIN[76]	TOXIC HAZARD RATING[a] DURHAM[75]				
					Acute		Chronic	
					Local	Systemic	Local	Systemic
Potassium hydrogen Phosphate Syn.: potassium phosphate, dibasic K_2HPO_4				Toxic hazard rating: U				
Sodium benzoate Syn.: Benzoate of soda $NaC_7H_5O_2$		Oral-rat LD_{50}=4100 mg/kg[78] Oral-rabbit LD_{Lo}=2000 mg/kg[78]	3	Irritant	0		0	0
				Ingestion	0	1	0	0
				Inhalation	0		0	0
				Skin absorption	0		0	0
Sodium borate Syn.: Sodium tetraborate $Na_2B_4O_7$				See boron compounds				
Sodium chromate[d] Na_2CrO_4				See chromium compounds				
Sodium hydroxide Syn.: Caustic soda; Sodium hydrate; lye; white caustic NaOH	Drano (drain opener)	Oral-rabbit LD_{Lo}=500 mg/kg[78]	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[78]	3					
Sodium nitrate Syn.: Soda niter; nitratine $NaNO_3$		Oral-rat LD_{Lo}=200 mg/kg[78]	4	See nitrates				
Sodium-o-phosphate Syn.: trisodium phosphate $Na_3PO_4 \cdot 12\ H_2O$				Irritant	2		2	U
				Ingestion		2		U
				Skin absorption				U
Sodium sulfate (Sol. Sulfate Salts of Sodium)		Amount of sulfate anion usually absorbed has no toxicological significance.						

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

[d] Recognized carcinogen

TABLE VI-3 (continued)

CHEMICAL SUBSTANCE (GENERIC)	COMMERCIAL PRODUCT	ACUTE TOXICITY (INGESTION)	TOXICITY RATING[a] GOSSELIN[76]	TOXIC HAZARD RATING[a] DURHAM[75] Acute Local	Acute Systemic	Chronic Local	Chronic Systemic
Sodium 2,4,5-trichlorophenol	Dowicide B	Oral-rat LD_{50}=1620 mg/kg[78]	3	See chlorinated phenols			
2,3,4,6-trichlorophenol	Dowicide 6	Oral-rat LD_{50}=140 mg/kg[78] Oral-guinea pig LD_{50}=250 mg/kg[78]	4 -	See chlorinated phenols			
2,4,5-trichlorophenol	Dowicide 2	Oral-rat LD_{50}=820 mg/kg[78]	3	See chlorinated phenols			
2,4,6-trichlorophenol[d]	Dowicide 2s	Oral-rat LD_{50}=820 mg/kg[78]	3	See chlorinated phenols			

---

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

[d] Recognized carcinogen

TABLE VI-4

Toxicity of Outgassing Products from Heat Transfer Liquids

OUTGASSING SUBSTANCE (GENERIC)	FROM COMMERCIAL PRODUCT	TOXIC HAZARD RATING[a] DURHAM[75]				
			Acute		Chronic	
			Local	Systemic	Local	Systemic
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_2H_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_2H_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
Hydrogen H_2	SF 96, silicone; Exxon Process Oil 3029; Exxon Caloria HT043; Therminol 66; Mobiltherm 603; Mobiltherm Light	Irritant	0		0	0
		Ingestion	0		0	0
		Inhalation	0	1	0	0
		Skin absorption	0		0	0

---

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

TABLE VI-4 (continued)

OUTGASSING SUBSTANCE (GENERIC)	FROM COMMERCIAL PRODUCT	TOXIC HAZARD RATING[a] DURHAM[75]				
			Acute		Chronic	
			Local	Systemic	Local	Systemic
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	0		0	
		Ingestion	0		0	
		Inhalation	0	1	0	
		Skin absorption	0		0	
Nitrogen N_2	SF96, 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.

C. Insulation Materials

The insulation materials used in SHAC systems are already in common use throughout the building industry. Any toxicity hazard resulting from the normal use of insulation to the resident of an insulated building is minimal, unless the material overheats or burns. There is some evidence that fibers or small particles of some insulation materials are carcinogens[79], but it is unlikely that residents of insulated houses are exposed to particulates or fibers of these materials. This is not necessarily the case for manufacturers and installers of insulations.

Insulation materials that overheat or burn can be a serious toxicity hazard because of their degradation products. All plastic foams and fiberglass material with binders evolve toxic gases when overheated. The plastic foams have a relatively low maximum operating temperature (see Table IV-5) and should not be used in direct contact with collectors, heat transfer system components such as pipes or air ducts, or heat storage units. Even if the normal operating temperature is below the maximum working temperature for the plastic foam, abnormal conditions can lead to higher temperatures, resulting in a hazardous situation.

Definitive data are not available to determine the gases evolved or the rates of gas evolution from the various insulations at various temperatures (above or below the maximum operating temperature).

D. Seals and Sealant Materials

The rubber-like materials that are used for seals in SHAC systems present a minimal toxicity hazard when considering ingestion of the materials themselves. Exposure to temperatures well above the maximum working temperature (see Table IV-4) will cause many of these materials to release toxic gases. The quantity of sealant material is so small in a SHAC system that the real toxicity hazard associated with gases from overheated seals is small.

There is a hypothetical condition involving sealant material that could lead to a toxicity hazard: Sealant materials are directly exposed to the heat transfer fluids at elevated temperatures for long periods of time. Additives and degradation products from the sealant materials could collect in the heat transfer fluid and make an otherwise slightly toxic fluid quite toxic. This situation might be accelerated by collector stagnation. There are no data to support this hypothesis.

E. Glazing Materials

There are no data available to indicate that glazing materials present any toxicity hazard in normal use. The glazing materials are glass and plastics. Glass plates present no toxicity hazard and do not produce any outgassing products when overheated. Plastics give off gases at the temperatures normally encountered in collectors. These gases have not been well characterized, but it is probable that some are toxic.

Most glazing materials are exposed to the outside atmosphere, and human exposure to any outgassing products is not likely to be significant. Some designs may exist that allow gases from the glazing material to pass directly into living areas. Such designs should not use plastic glazing materials since chronic exposure to the outgassing products could possibly lead to health problems.

F. Collector Materials

Collector surfaces are usually metals such as copper, steel, or aluminum, with special coatings. The metals and the special coatings can be toxic if ingested in chemically active forms (ionic species, rather than metallic). Ingestion of chemically active forms of metals used in collectors is extremely unlikely.

Application of the special coatings to collector surfaces can present toxicity hazards to manufacturing personnel if sprays or dusts are produced.

G. Heat Storage Media

Many materials suggested for heat storage media are quite toxic. Some of these materials are unfamiliar to most people. Routine exposure to these substances will be limited to manufacturer's personnel, installers, and maintenance personnel. One-time, accidental exposure may be a problem with small children.

Certain problems may occur when rocks are used as a storage medium with a forced-air system. In dry weather, some rocks produce dust, while in humid weather, some rocks absorb water. Wet rocks can serve as a medium for fungi and bacteria growth. If dusting occurs, or if fungi or bacteria are present, the flowing air can transport these undesirable materials into living areas, and respiratory problems may result.

Toxicity data for heat storage media are given in Table VI-5.

TABLE VI-5

Toxicity of Thermal Storage Media

CHEMICAL SUBSTANCE (GENERIC)	ACUTE TOXICITY (INGESTION)	TOXICITY RATING[a] GOSSELIN[76]	TOXIC HAZARD RATING[a] DURHAM[75]	Acute		Chronic	
				Local	Systemic	Local	Systemic
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 $Ba(OH)_2 \cdot 8H_2O$	-	-	see barium compounds				
Benzamide	Oral-mouse LD_{50}=1160 mg/kg[78]	3	-				
Benzoic acid Syn: phenylformic acid C_6H_5COOH	Oral-rat LD_{50}=3040 mg/kg'[78]	3	Irritant	1		0	
			Ingestion	1	1	0	1
	Oral-mouse LD_{50}=2370 mg/kg[78]	-	Inhalation	1		0	
			Skin absorption			0	
Biphenyl Syn: Diphenyl $C_6H_5C_6H_5$	Oral-rat LD_{50}=3280 mg/kg[78]	3	Irritant	U		U	
			Ingestion	U	2	U	2
	Oral-rabbit LD_{50}=24 0 mg/kg[78]	-	Inhalation	U	2	U	2
			Skin absorption	U		U	
Bromides	-	-	Irritant	1		1	
			Ingestion	2	2		2
			Inhalation	2			2
Calcium bromide $CaBr_2 \cdot 6H_2O$	-	-	see bromides				
Calcium chloride $CaCl_2$	Oral-rat LD_{50}=1000 mg/kg[78]	3	see calcium compounds				
	Oral-rabbit LD_{Lo}=1384 mg/kg[78]	-					
Calcium compounds	-	-	Irritant	1	U	1	U
			Ingestion	1	U		U
			Inhalation	1	U		U
			Skin absorption		U		U

---

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

TABLE VI-5 (continued)

CHEMICAL SUBSTANCE (GENERIC)	ACUTE TOXICITY (INGESTION)	TOXICITY RATING[a] GOSSELIN [76]	TOXIC HAZARD RATING[a] DURHAM [75]				
				Acute		Chronic	
				Local	Systemic	Local	Systemic
Caprylic acid Syn: octanoic acid $CH_{33}(CH_2)_6COOH$	-	-	Experimental data suggest low toxicity				
Diphenyl oxide $(CH_5)_2O$	Oral-rat LD_{50}=3370 mg/kg [78]	3	-				
Glaubers salt $NaSO_4 \cdot 10H_2O$	see Sodium sulfate	-	-				
Lauric acid Syn: dodecanoic acid $CH_3(CH_2)_{10}COOH$	-	-	-				
Myristic acid Syn: tetradecanoic acid	nontoxic by oral administration	-	-				
Naphthalene Syn: moth flakes; white tar; tar campher. $C_{10}H_8$	Oral-rat LD_{50}-1780 mg/kg[78] LD_{Lo}=100 mg/kg [78]	3 4	Irritant	2		1	
			Ingestion		2		2
			Inhalation		2		1
			Skin absorption		2		2
Nitrates	-	-	Irritant	U		U	
			Ingestion	U	2	U	2
			Inhalation	U	2	U	2
			Skin absorption	U		U	
Paraffin wax[b]	-	-	Irritant	0	0		
			Ingestion	0	0		
			Inhalation	0	0		
			Skin absorption	0	0		
Polyethylene glycol 400 $HOCH_2(CH_2OCH_2)_nCH_2OH$ (n varies from 8-10)	-	2	Toxic Hazard Rating: U				
Polyethylene glycol 600	-	2	-				
Polyethylene glycol 6000	Oral-rat LD_{Lo}=50 gms/kg [78]	1	Toxicity: U				

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

[b] Suspected carcinogen of bladder

TABLE VI-5 (continued)

CHEMICAL SUBSTANCE (GENERIC)	ACUTE TOXICITY (INGESTION)	TOXICITY RATING[a] GOSSELIN[76]	TOXIC HAZARD RATING[a] DURHAM[75]			
			Acute		Chronic	
			Local	Systemic	Local	Systemic
Sodium sulfate	Amount of sulfate anion usually absorbed has no toxicological significance					
Stearic acid Syn: octadecanoic acid $CH_3(CH_2)_{16}COOH$			Toxicity: slight			
Zinc nitrate $Zn(NO_3)_2 \cdot 6H_2O$	Oral-rat Ld_{50}=1190 mg/kg[78]	3	see nitrates			

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

H. Combustion Products,
Outgassing Products, and Degradation Products

Abnormal situations, such as collector stagnation and fires, cause degradation of SHAC materials to produce many new gases. The tables in this section give toxicity data for those gases identified in Chapter V as substances produced in abnormal situations.

The gases listed are representative of only one specific experiment. Different temperatures and the close proximity of other materials might give other gases. There are no definitive data that allow a prediction of the quantities of gases produced or the relative amounts of different gases.

Table VI-6 gives toxicity data for outgassing products, Table VI-7 gives toxicity data for thermal degradation products, and Table VI-8 gives toxicity data for combustion products. In these tables, the chemical substance given in the first column is a gaseous product from the commercial product listed in the second column.

TABLE VI-6

Toxicity of Outgassing Products from Solids

CHEMICAL SUBSTANCE (GENERIC)	FROM COMMERCIAL PRODUCT		TOXIC HAZARD RATING[a] DURHAM[75]			
			Acute		Chronic	
			Local	Systemic	Local	Systemic
Argon A	Novacalk 420; butyl rubber; Novacalk 600, polysulfide	Irritant	0		U	U
		Ingestion	0		U	U
		Inhalation	0	1	U	U
		Skin absorption	0		U	U
Carbon dioxide CO_2	Novacalk 420; butyl rubber; Novacalk 600, polysulfide; polyisocyanurate foam with a urethane modidier; tan polyurethane foam; suprathane; pink fiberglass insulation with phenolic binder	Irritant	0		0	
		Ingestion	0		0	
		Inhalation	0	1	0	1
		Skin absorption	0		0	
Carbon monoxide CO	Novacalk 420, butyl rubber; Novacalk 600, polysulfide	Irritant	0		0	
		Ingestion	0		0	
		Inhalation	0	3	0	1
		Skin absorption	0		0	
Fluorotrichloromethane Syn: trichlorofluoromethane $FCCl_3$	Freon 11; polyphenylisocyanurate foam with a urethane modifier; tan, polyurethane foam; Suprathane	Irritant	1		1	
		Ingestion		1		1
		Inhalation		2		2
		Skin absorption				
Hydrogen H_2	Novacalk 600, polysulfide	Irritant	0		0	0
		Ingestion	0		0	0
		Inhalation	0	1	0	0
		Skin absorption	0		0	0
Hydrochloric acid Syn: muriatic acid HCl	polyphenylisocyanurate foam with a urethane modifier; tan polyurethane; Suprathane	Irritant	3		2	
		Ingestion		3		U
		Inhalation		3		U
		Skin absorption				U

---

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

TABLE VI-6 (continued)

CHEMICAL SUBSTANCE (GENERIC)	FROM COMMERCIAL PRODUCT		TOXICITY HAZARD RATING[a] DURHAM[75]			
			Acute		Chronic	
			Local	Systemic	Local	Systemic
Methane Syn: marsh gas; methyl hydride	Novacalk 420, butyl rubber; Novacalk 600, polysulfide	Irritant	0		0	
		Ingestion	0		0	
		Inhalation	0	1	0	1
		Skin absorption	0		0	
Methyl styrene C_9H_{10}	common white styrofoam	Irritant	2		U	U
		Ingestion		3	U	U
		Inhalation		2	U	U
		Skin absorption			U	U
Nitrogen N_2	Novacalk 420, butyl rubber; Novacalk 600, polysulfide	Toxicity: none				
Phenylethylene Syn: vinylbenzene, stryene (monomer), cinnamene $C_6H_5CHCH_2$	common white styrofoam	Irritant	2		U	
		Ingestion		2	U	2
		Inhalation		2	U	2
		Skin absorption			U	

---

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

TABLE VI-7

Toxicity of Thermal Degradation Gases From Solids

CHEMICAL SUBSTANCE (GENERIC)	FROM COMMERCIAL PRODUCT		TOXIC HAZARD RATING[a] DURHAM[75] Acute Local	Acute Systemic	Chronic Local	Chronic Systemic
Ammonia, anhydrous Syn: ammonia gas NH_3	Nylon 6,6	Irritant	3	U	1	U
		Ingestion	3	U		U
		Inhalation	3	U		U
		Skin absorption		U		U
Benzene[b] Syn: coal naphtha C_6H_6	Geon; Halon; Plexiglass; Lucite; PVC; Neoprene; Nylon HT-4	Irritant	2		0	
		Ingestion	1	2	0	3
		Inhalation	1	2	0	3
		Skin absorption		2	0	3
1,3 Butadiene Syn: erythrene $CH_2CHCHCH_2$	Neoprene	Irritant	2		1	U
		Ingestion	2			U
		Inhalation	2	2		U
		Skin absorption				U
Carbon dioxide Syn: carbonic acid; carbonic anhydride CO_2	Nylon 6,6; Nylon HT-4	Irritant	0		0	
		Ingestion	0		0	
		Inhalation	0	1	0	1
Carbon tetrafluoride Syn: tetrafluoromethane CF_4	Teflon, PTFE	Irritant			U	U
		Ingestion			U	U
		Inhalation	2	2	U	U
		Skin absorption			U	U
Ethylene Syn: ethene CH_2CH_2	Novacalk 600; EPDM rubber	Irritant	0		0	0
		Ingestion	0		0	0
		Inhalation	0	2	0	0
		Skin absorption	0		0	0
Ethyl mercaptan Syn: ethanethiol; ethyl hydrosulfide; ethyl thioalcohol ethyl sulfhydrate C_2H_5SH	Novacalk 600	Irritant	2		U	U
		Ingestion		2	U	U
		Inhalation		2	U	U
		Skin absorption			U	U
Hexafluoropropylene Syn: perfluoropropene $CF\ CF{:}CF_2$	Teflon, FEP PTFE	Toxic hazard Ratings: U Toxicity: Animal experiments suggest moderate toxicity				
Hydrochloric acid Syn: muriatic acid hydrogen chloride HCl	Tedlar; PVC; Neoprene; Geon; Halon	Irritant	3		2	U
		Ingestion		3		U
		Inhalation		3		U
		Skin absorption				U
Hydrocyanic acid Syn: hydrogen cyanide; prussic acid HCN	Nylon 6,6; Nylon HT-4	Irritant	2		U	U
		Ingestion		3	U	U
		Inhalation		3	U	U
		Skin absorption		3	U	U
Hydrofluoric acid Syn: hydrogen fluoride HF	Tedlar	Irritant	3		2	
		Ingestion		3		3
		Inhalation		3		3
		Skin absorption				

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

[b] Suspected carcinogen of bladder.

TABLE VI-7 (continued)

CHEMICAL SUBSTANCE (GENERIC)	FROM COMMERCIAL PRODUCT		TOXIC HAZARD RATING[a] DURHAM[75]			
			Acute		Chronic	
			Local	Systemic	Local	Systemic
Hydrogen H_2	EDPM rubber	Irritant	0		0	0
		Ingestion	0		0	0
		Inhalation	0	1	0	0
		Skin absorption	0		0	0
Hydrogen sulfide H_2S	Novacalk 600	Irritant	3		U	
		Ingestion			U	
		Inhalation		3	U	3
		Skin absorption				
Isobutane Syn.: 2-methyl propane C_4H_{10}	Novacalk 420	Irritant	0		0	U
		Ingestion	0		0	U
		Inhalation	0	1	0	U
		Skin absorption	0		0	U
Methane Syn.: marsh gas CH_4	Dow Corning 781; Novacalk 420; EPDM rubber; Nylon HT-4	Irritant	0		0	
		Ingestion	0		0	
		Inhalation	0	1	0	1
		Skin absorption	0		0	
Methyl methacrylate (monomer) $CH_2C(CH_3)COOCH_3$	Plexiglass; Lucite	Irritant	1		U	
		Ingestion		2	U	1
		Inhalation		1	U	1
		Skin absorption			U	
Propylene Syn.: propene C_3H_6	EPDM rubber	Irritant	0		0	0
		Ingestion	0		0	0
		Inhalation	0	2	0	0
		Skin absorption	0		0	0
Silica Syn.: silicon dioxide; cristobalite SiO_2	Dow Corning 781	Irritant		0		
		Ingestion	0			
		Inhalation	2	0	3	1
		Skin absorption		0		
Toluene Syn.: methylbenzene; phenylmethane; toluol $C_6H_5CH_3$	Geon; Halon; PVC; Neoprene	Irritant	1		1	
		Ingestion		2		2
		Inhalation		2		2
		Skin absorption		1		2
Vinyl chloride Syn.: chloroethylene; chloroethene CH_2CHCl	PVC; Geon; Halon	Irritant	2		2	
		Ingestion				
		Inhalation		2		3
		Skin absorption				

---

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

TABLE VI-8

Toxicity of Combustion Gases from Solids

CHEMICAL SUBSTANCE (GENERIC)	FROM COMMERCIAL PRODUCT		TOXIC HAZARD RATING[a] DURHAM[75] Acute Local	Acute Systemic	Chronic Local	Chronic Systemic
Acetone Syn.: dimethyl ketone; 2-propanone CH_3COCH_3	Nylon HT-4	Irritant	1		1	
		Ingestion	2	2		1
		Inhalation	2	2		1
		Skin absorption		2		1
Acetylene Syn.: ethyne C_2H_2	Butyl rubber Novacalk 420; Nylon 6,6	Inhalation	0	2	0	1
Ammonia Syn.: ammonia gas NH_3	Nylon 6,6	Irritant	3	U	1	U
		Ingestion	3	U		U
		Inhalation	3	U		U
Benzene[b] Syn.: coal naphtha C_6H_6	Neoprene; PVC; Geon; Halon	Irritant	2		0	
		Ingestion	1	2	0	3
		Inhalation	1	2	0	3
		Skin absorption		2	0	3
Butadiene-1,3 (uninhibited) Syn: erythrene $CH_2CHCHCH_2$	Neoprene	Irritant	2		1	U
		Ingestion	2			U
		Inhalation	2	2		U
Carbon dioxide CO_2	Neoprene Dow Corning 781; Novacalk 600; Polysulfide, C9; butyl rubber, Novacalk 420; Teflon, PTFE; Teflon, FEP; Teflon, PFA; Tedlar; Lucite; Plexiglass; PVC; Geon; Halon; Nylon HT-4; Nylon 6,6	Inhalation	0	1	0	1
Carbon monoxide	Neoprene; Dow Corning 781; polysulfide, Novacalk 600; polysulfide, C9; butyl rubber, Novacalk 420; Teflon, PTFE; Teflon, FEP; Teflon, PFA; Lucite; Plexiglass; PVC; Geon; Halon; Nylon HT-4; Nylon 6,6	Inhalation	0	3	0	1
Carbonyl fluoride Syn.: fluoroformyl fluoride COF_2	Teflon, PTFE	Irritant	3	U	U	U
		Inhalation	3	U	U	U

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

[b] Recognized carcinogen of the blood-forming tissues.

TABLE VI-8 (continued)

CHEMICAL SUBSTANCE (GENERIC)	FROM COMMERCIAL PRODUCT		TOXIC HAZARD RATING[a] DURHAM[75] Acute Local	Acute Systemic	Chronic Local	Chronic Systemic
Ethane C_2H_6	Neoprene PVC; Geon; Halon	Inhalation	0	2	0	1
Ethyl alcohol Syn.: ethanol; CH_3CH_2Oh	Polysulfide; Novacalk 600; Polysulfide, C9	Irritant	1		1	
		Ingestion		2		1
		Inhalation		2		1
		Skin absorption				
Ethylene Syn.: ethene; CH_2CH_2	Neoprene; Nylon 6,6	Inhalation	0	2	0	0
Fluorides		Irritant	3		1	
		Ingestion		3		3
		Inhalation		3		3
Formaldehyde[c] Syn.: methanal; methyl aldehyde; formalin HCHO	Dow Corning 781	Irritant	3			U
		Allergen	1		1	U
		Ingestion		3		U
		Inhalation		3		U
Formic acid Syn.: methanoic acid; hydrogen carboxylic acid HCOOH	Dow Corning 781	Irritant	2		2	
		Ingestion		3		1
		Inhalation		2		
Hydrochloric acid Syn.: muriatic acid; hydrogen chloride HCl	Neoprene; PVC; Geon; Halon	Irritant	3		2	U
		Ingestion		3		U
		Inhalation		3		U
Hydrocyanic acid Syn.: hydrogen cyanide; prussic acid HCN	Nylon HT-4; Nylon 6,6	Irritant	2		U	U
		Ingestion		3	U	U
		Inhalation		3	U	U
		Skin absorption		3	U	U
Hydrofluoric acid Syn.: hydrogen fluoride HF	Tedlar	Irritant	3		2	
		Ingestion		3		3
		Inhalation		3		3
Hydrogen H_2	Neoprene; butyl rubber, Novacalk 420; Lucite; Plexiglass	Inhalation	0	1	0	0

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

[c] A suspected carcinogen of the lung.

TABLE VI-8 (continued)

CHEMICAL SUBSTANCE (GENERIC)	FROM COMMERCIAL PRODUCT		TOXIC HAZARD RATING[a] DURHAM[75] Acute Local	Acute Systemic	Chronic Local	Chronic Systemic
Methane Syn.: marsh gas CH_4	Neoprene; PVC Geon; Halon;	Inhalation	0	1	0	1
Methyl chloride Syn.: chloromethane CH_3Cl	PVC; Geon; Halon	Irritant	1		U	
		Inhalation	1	3	U	2
Methyl methacrylate (monomer) $CH_2C(CH_3)COOCH_3$	Lucite; Plexiglass	Irritant	1		U	
		Ingestion		2	U	1
		Inhalation		1	U	1
Nitromethane CH_3NO_2	Nylon HT-4	Irritant	2		U	U
		Ingestion		3	U	U
		Inhalation		3	U	U
Silicon tetrafluoride Syn.: tetrafluorosilane SiF_4	Teflon, PTFE; Teflon, FEP; Teflon, PFA	See fluorides				
Toluene Syn.: methylbenzene phenylmethane; toluol $C_6H_5CH_3$	PVC; Geon; Halon; Neoprene	Irritant	1		1	
		Ingestion		2		2
		Inhalation		2		2
		Skin absorption		1		2
Vinyl chloride[d] Syn.: chloroethylene; chloroethene CH_2CHCl	PVC; Geon; Halon	Irritant	2		2	
		Inhalation		2		3
Vinyl fluoride Syn.: fluoroethylene $CH_2{:}CHF$	Tedlar	See fluorides				
Xylene $C_6H_4(CH_3)_2$	Tedlar	Irritant	1		1	
		Inhalation		2		2
		Skin absorption		2		2

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

[d] A recognized carcinogen of the liver.

VII. FIRE HAZARD PROPERTIES OF SHAC MATERIALS

Tests for fire hazard properties of materials have been developed to assess the hazard of a material as installed or in its end use configuration. Numerous standards, regulations, and tests have also been developed which apply to manufacturing, storing, and shipping large quantities of materials. Most available data are quite specialized and difficult for an untrained person to interpret. Nevertheless, fire hazard properties are extremely important when substantial quantities of new materials are introduced into the building industry, and the data that exist must be made available to users and designers of SHAC technologies. Current work at the National Bureau of Standards will develop tests and define properties that are directly related to residential fire hazards of heat transfer fluids, but those results are not yet available.

This chapter contains discussions that aid in data interpretation and tabulated data. Detailed descriptions of the tests and hazard identification system for which data are presented may be found in appendices B and C. A very useful supplementary reference to this chapter is the Fire Protection Handbook, published periodically by the National Fire Protection Association. This reference is available at most libraries. The most recent edition, the 14th, was published in 1976.

A. Interpretation of Fire Hazard Properties Data

Interpretation of the tables in the following sections may be difficult for the casual user of this handbook. To aid in understanding the tables, a description and some discussion of the data are given below. Fire hazard properties data are normally used in conjunction with criteria and standards. Some of these standards are found in documents referenced in Chapter III. Without a specific standard, the value of the numbers in a particular category are not necessarily meaningful. For example, cellular plastics may have an E84 flame spread classification much less than red oak flooring, but when each is installed as interior finish material, the plastic may be much more hazardous. For this example, building codes have separate requirements for cellular plastics because the standard test method fails to gauge the hazard.

The fire hazard indicated by the data is relative. There is no way to absolutely equate fire hazard to the data that can be taken in tests. Each column in the tables that follow gives an indication of relative fire hazards, but caution is advised in interpretation. The numbers in a given column are truly representative of relative hazards only if all other parameters are equal. Consequently, all data must be considered if a assessment of the relative fire hazards of the different materials is to be meaningful.

1. Data for Solids

Ease of Ignition Data

The column labeled ASTM D1929 gives the minimum air temperature for the ignition (from a pilot flame) of a solid sample when air at the stated temperature flows past the sample. Consider the data for Teflon (Table VII-4). The number 986 in the second column indicates that the sample must be at a temperature of 986° F to ignite from a pilot flame.[80,81]

Surface Flame Spread

The data under the first two columns for surface flame spread are given in relative numbers. Red oak has a value of 100 in both columns (see Table VII-2), while rigid urethane foam (polyester) has a value of 1000. This suggests that flame moves along the same size surface of this foam ten times faster than it does on red oak.

Heat Release

The Ohio State University test[82] is a measure of the heat released from a surface that is exposed to radiant energy, and the values under the column labeled ASTM E83 are measures of the heat release from a burning sample. The values under ASTM E83 are relative with red oak having a value of 100. Larger numbers mean a greater heat release (200 would mean twice as much heat released as from an identical-size sample of red oak), and smaller numbers mean less heat is released. The column for total heat of combustion involves only the total amount of heat released for a given weight of material, regardless of the time involved.

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. Large numbers on the NBS chamber test indicate large amounts of smoke. The NBS chamber test is done for a flaming sample and for a smoldering sample.[83]

2. Data for Fluids

Flash Point - The flash point of a liquid is that 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, and a lower temperature indicates easier ignition.

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.

In SHAC systems, the flash and fire points are most indicative of the fire hazards encountered when there is a system failure allowing large leaks.

Ignition Temperature - The third column on the tables for fluids gives the temperature at which a fluid in a nearly closed vessel will spontaneously ignite. In a SHAC 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.

Flammable Limits (% by volume) - The flammable limits give the range of vapor (or gas) concentration in air that will support flame propagation. 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 flammable limit range. A material with a lower low-limit may be considered a greater fire hazard than a material with a higher low-limit.

Vapor Density - This number gives the ratio of the vapor (or gas) density divided by the density of air. A number greater than 1 indicates that the gas may collect along the floor (or other low areas) and present a treacherous fire hazard.

Boiling Point - A flammable material with a lower boiling point generates more vapors at a lower temperature and is a greater fire hazard in abnormal situations than is a flammable material with a higher boiling point.

Specific Heat - A material with a higher specific heat does not increase temperature as rapidly (when abnormal heat sources are present) and, therefore, does not produce vapors as rapidly as does a material with a lower specific heat. The material with a lower specific heat is a greater fire hazard if all other factors are equal.

Heat of Combustion - A material with a higher heat of combustion gives off more heat when burning than one with a lower heat of combustion, and the material with a higher heat of combustion is more likely to sustain a fire if all other parameters are equal.

B. Fire Hazard Properties

1. Heat Transfer Fluids

The fire hazard properties of heat transfer fluids are important both from a personal safety viewpoint and from an economic viewpoint. Accidents can occur that endanger life and property, and the insurability of systems using combustible liquids is a nonaccident economic consideration. Some criteria for acceptable fire properties for heat transfer fluids are contained in the NBSIR 77-1187 and the HUD interim performance criteria. Both documents are referenced in Chapter III.

There are several potential fire hazards involving heat transfer fluids. Welding or soldering pipes containing combustible liquids and/or vapors could cause fires and explosions unless proper precautions are used. Leaks of fluids (especially hot fluids) near pilot flames, heaters, or other heat sources could result in a fire. Rupture of a heat transfer fluid line or storage tank during a fire could make a small fire larger and more damaging. Toxic gases given off by burning fluids are also a potential hazard.

One possible fire hazard that may not have been previously noted is the potential flammability of the gases in the heat transfer system due to degradation of the heat transfer fluid. Table V-4 in this handbook indicates that hydrogen and methane are the chief gases formed above many heat transfer fluids as they degrade. Venting these gases near an ignition source or applying heat to pipes that contain these gases (as in soldering or torch cutting) could be disastrous.

Data for fire hazard properties of heat transfer fluids are given in Table VII-1. Most of the information in this table was acquired directly from manufacturers. Since fluid treatment chemicals are a very minor constituent in heat transfer fluids, no separate data for the fire properties of fluid treatment chemicals are given.

TABLE VII-1

Fire Hazard Properties of Heat Transfer Fluids Used in SHAC Systems

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 603	380[85]	-	-	-	-	-	-	0.51[85] (@300°F)	-	-	-
Mobiltherm Light	250[85]	-	-	-	-	-	> 400	0.43[85] (@300°F)	-	-	-
Dowtherm A $(C_6H_5)_2O(C_6H_5)_2$ and diphenyl	241[86]	275[86]	1150[86]	0.5 - 6.2 (@500°F)	13.8[86] (@60°F)	> 1[86]	494.8[86]	0.50[85] (@400°F)	15,500	-	polimerizes slowly
Dowtherm HP Paraffinic Oil	379[86]	460[86]	-	-	very low[86]	> 1[86]	660-890[86]	0.63[86]	-	-	stable
Dowtherm J Alkylated aromatics	132[86]	155[86]	806[86]	-	17[86]	> 1[86]	358[86]	-	-	-	stable
Dowtherm SR-1 CH_2OHCH_2OH based	240[86]	250[86]	-	-	infinite[86]	> 1[86]	325[86]	0.74[86] (@300°F)	-	-	stable
Dowfrost $CH_2CHOHCH_2OH$	214[86]	220[86]	-	2.6 - 12.5[86]	infinite[86]	2.62[86]	370[86]	-	-	-	stable
Dow Corning 200 Dimethyl siloxane polymer	*	-	-	-	-	-	-	-	Methyl-siloxanes 11,517 (theoretical)[133]	-	-
SF-96 (50) - Dimethyl siloxane polymer	> 535[86]	-	-	-	< 10[87]	-	305[86]	0.36[86]	Methyl-siloxanes 11,517 (theoretical)[133]	-	-
Exxon Process Oil 3029 Naphthenic	300[88]	-	-	-	-	-	-	-	-	-	-
Exxon Caloria HT 43	420[88]	-	-	-	-	-	-	0.50[88] (@212°F)	-	-	-
Suntemp 1	380[89]	-	824[89]	-	-	-	671[89]	0.56[89]	-	-	-
Therminol 66 Modified terphenyl	355[90]	382[90]	705[90]	-	negligible	-	644[90]	0.38[90] (@100°F)	-	-	stable
Thermia 33	455[91]	-	-	-	-	-	-	0.56[91] (@300°F)	-	-	-
Ucar Thermofluid 17 Ethylene glycol based	260[92]	-	-	(see ethylene glycol)	-	-	356[92]	0.56[92]	-	1 (ethylene glycol)	0 (ethylene glycol)

TABLE VII-1 (continued)

Material	Flash Point ($^{\circ}$F)	Fire Point ($^{\circ}$F)	Ignition Temp ($^{\circ}$F)	Flammable Limits (% by vol)	Solubility in Water (ppm)	Vapor Density Air = 1	Boiling Point ($^{\circ}$F)	Sp. Heat Btu/lb ($^{\circ}$F)	Heat of Comb. Btu/lb	Suggested Hazard Identification**	
										Flammability	Reactivity
Ucar Food Freeze 35 Propylene glycol based	-	-	-	(see propylene glycol)	-	-	222[92] (50% water)	-	-	1 (propylene glycol)	0 (propylene glycol)
Ucon 30	-	-	-		-	-	-	-	-	-	-
Ucon L20	> 500[92]	-	-	-	-	-	-	-	-	-	-
Ucon 50-HB-280-X	471[92]	600[92]	779[92]	-	yes[92]	-	-	0.51[92] (@200°F)	-	-	-
Methanol CH_3OH	52	-	725	6.7 - 36	infinite	1.11	147	0.60 (@58°F)	9600	3	0
NH_3-NaSCN	-	-	-	-	139.3[95] (NaSCN)	-	-	-	-	-	-
Fluorocarbons: F-11 CCl_3F	-	-	-	nonflammable[95]	0.11[94] (@77°F)	4.70[96]	74.9[98]	0.208[94] (@77°F)	-	0	-
F-12 CCl_2F_2	-	-	-	nonflammable[96]	0.028[94] (@77°F)	3.24[95]	-21.6[98]	0.232[94] (@77°F)	-	0	-
F-22 $CHClF_2$	-	-	1170	practically nonflammable[96]	0.30 (@77°F)[94]	3.55[95]	48[131]	0.300 (@77°F)[94]	-	0	-
F-113 CCl_2F-$CClF_2$	-	-	1258	practically nonflammable[95]	0.017 (@77°F)[94]	6.43[95]	117.6[100]	0.218[94] (@77°F)	-	0	-
F-114 $CClF_2$-$CClF_2$	-	-	-	practically nonflammable[95]	0.013 (@77°F)[94]	5.89[95]	38.8	0.243[94] (@77°F)	-	0	-
F-114B2 $CBrF_2$-$CBrF_2$	-	-	-	nonflammable[94]	-	-	117.6[95]	0.166[94] (@77°F)	-	0	-
LiCl	-	-	-	nonflammable	63.7 (@59°F)[95]	-	2147-2480[95]	-	-	-	-
LiBr	-	-	-	nonflammable	145 (@59°F)[95]	-	2309[95]	-	-	-	-
NH_3	gas	gas	1204	15 - 28	90 (@59°F)	0.6	-28	0.50 (@100°F)	-	0 (gas) 1 (liq)	1 (gas) 1 (liq)
Ethylene Glycol CH_2OHCH_2OH	232 (CC)	-	752	3.2 -	infinite	2.14[99]	387	0.573 (@67.8°F)	-	1	0
Propylene Glycol $CH_3CHOHCH_2OH$	210 (CC)	-	700	2.6 - 12.5	infinite	2.62[99]	370	-	-	1	0
Triethylene Glycol $HOCH_2(CH_2\ OCH_2)_2$-CH_2OH	350 (CC)		700	0.9 - 9.2	infinite	5.17[99]	550	-	-	1	0
Glycerine $HOCH_2CHOH$-CH_2OH	320 (CC)	-	698	-	infinite	3.17[99]	554	0.576 (@59-122°F)	7770	1	0

TABLE VII-1 (continued

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
Water H_2O	-	-	-	nonflammable	infinite	0.62	212	0.999 (@68°F)	-	0	0
Air	-	-	-	nonflammable	0.0024 (@68°F)[97]	1.0	-	0.25 (@100°F)[97]	-	0	0

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*Dow Corning 200 0

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

** see Appendix C

2. Insulating Materials

Many insulating materials will burn, and some will burn quite vigorously. Plastic foam insulations, cellulose fiber insulation, and even fiberglass with an organic binder can burn. Insulations that do not normally burn include mineral fibers and fiberglass with no binder.

The polymeric (or plastic) foam insulations and the cellulose fiber insulations are so flammable that they are usually treated with flame-retardant chemicals. The plastic foams are often sandwiched between layers of some other material that serves as a fire barrier. Most polymeric foam insulations also give off toxic gases when burning.

An unusual fire threat associated with some insulations can arise when organic heat transfer fluids are used.[100] If the liquid leaks into the voids of an insulating material, a slow reaction with the air in the voids can occur when the system temperature reaches about 260° C (500° F). This reaction is enhanced if calcium silicate is present since it is a catalyst. The slow oxidation process is not well understood, but it appears to occur most frequently with closed-cell insulations. An insulation material saturated with fluid would offer a large fuel surface under poor dissipation conditions, and an accidental external spark or the slow oxidation process could cause ignition.

Data for fire hazard properties of flammable insulation materials are given in Table VII-2.

TABLE VII-2

Fire Hazard Properties of Insulation Materials Used in SHAC Systems

Material	Ease of Ignition*	Surface Flame Spread*			Heat Release*		Heat of* Combustion Btu/lb	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.	Ohio State Univ. Test Btu/ft^2-min.	ASTM E84 Tunnel Test		NBS Chamber Test Flaming Dm	NBS Chamber Test Nonflaming Dm	ASTM E84 Tunnel Test		
Red Oak (for comparison)	-	100^{101}	99^{102}	-	-	100	8835^{103} (wood)	$76\text{-}1/4^{102}$	$395\text{-}1/4^{102}$	100^{101}	-	Moderate
INSULATIONS												
Flexible urethane foams:	-	-	-	-	-	-	-	20^{102}	156^{102}	-	-	-
Polyester, FR	-	-	1000^{102}	-	-	-	-	$110\text{-}770^{101}$ 10	161^{105}	-	-	-
Polyether	-	-	1490^{102}	-	-	-	-	319^{105}	515^{105}	-	-	-
Polyether, FR	-	-	10^{102}	-	-	-	-	$159\text{-}202^{101}$ 285	290^{105}	-	-	-
Rigid urethane Foams:	-	-	-	-	210^{106} (F.R.) (@2.5 Btu/sec-ft^2	-	12000^{103} (gen. urethanes) 16000 (gen. urethanes)	-	-	-	180-190	Moderate
Polyester, FR	-	-	1440^{102}	-	-	-	-	525^{105}	454^{105}	-	-	-
Polyether	590^{102}	-	2220^{102}	-	-	-	-	-	-	-	-	-
Polyether, FR	-	-	880^{102}	-	-	-	-	196^{105}	119^{105}	-	-	-
Isocyanurate foam	-	-	-	-	-	-	-	-	-	-	284	-
Isocyanurate foam, FR	-	-	-	-	-	-	17870	225^{105}	300^{105}	-	-	-
Polystyrene foam, rigid	655	-	114^{111}	$0.5\text{-}2.5^{102}$	melts on^{106} vertical; liq. burns	-	17420^{108}	390^{109}	25^{109}	-	150-170	Moderate
Polystyrene foam, rigid, FR	-	-	13^{102}	-	-	-	-	260^{102}	10^{102}	-	-	-
TF-600 Board (Celotex Corp.)	850^{110}	25^{110}	-	-	-	5-10	-	-	-	$75\text{-}145^{110}$	-	-
Fiberglass (bonded)	-	20-40 (vinyl coated)^{101}	-	-	-	10-25 (vinyl coated)	$30\text{-}40^{108}$	25^{109}	25^{109}	$25\text{-}75^{101}$ (vinyl coated)	-	-
Fiberglass (unbonded)	-	-	-	-	-	10-25	-	-	-	0	-	-

* see Appendix B

3. Seals and Sealants

Seals are used in such small quantities in SHAC systems that the sealant materials are relatively unimportant as sources of fire hazards. Toxic gases are released when the materials burn, but, in any fire involving a SHAC system, the toxic gas contribution from seals would be insignificant when compared with other sources (insulations, for example).

Data on the fire hazard properties of sealant materials are given in Table VII-3.

TABLE VII-3

Fire Hazard Properties for Sealant Materials Used in SHAC Systems

Material	Ease of Ignition*	Surface Flame Spread*			Heat Release*		Heat of Combustion Btu/lb	Smoke Production*			Maximum* Continuous Service Temp. °F	Relative Flammability
								NBS Chamber Test				
	ASTM D1929 Flash Ignition Temp. °F	ASTM E84 Tunnel Test	ASTM E162 Radiant Panel Test	Burning Rate (Horizontal) in./min.	Ohio State Univ. Test Btu/ft^2-min.	ASTM E84 Tunnel Test		Flaming Dm	Nonflaming Dm	ASTM E84 Tunnel Test		
Neoprene rubber	-	-	3[111]	-	-	-	-	> 660[105] (F.R.)	> 660[105] (F.R.)	-	-	-
Silicone rubber	-	-	-	-	-	-	-	385[105]	240[105]	-	-	-
Polysulfides:	-	-	-	-	-	-	-	-	-	-	-	-
GC9 (Pocora Corp.)	-	-	-	-	-	-	-	-	-	-	-	-
Novacalk 415 (Novagard Corp.)	-	-	-	-	-	-	-	-	-	-	-	-

* see Appendix B

4. Glazing Materials

Glass glazing materials do not burn, but plastic glazing materials do. Fire hazards associated with plastic glazing materials include the toxic gases produced and their potential contribution to a roof surface fire. They are easier to ignite than normal roofing materials, and provide additional fuel.

Data for the fire hazard properties of plastic glazing materials, as well as several other common plastics, are given in Table VII-4.

TABLE VII-4

Fire Hazard Properties of Plastic Glazing Materials and Some Other Common Plastic Materials Used in SHAC Systems

Material	Ease of Ignition*	Surface Flame Spread*			Heat Release*			Smoke Production*			Maximum Continuous Service Temp. °F	Relative Flammability
								NBS Chamber Test				
	ASTM D1929 Flash Ignition Temp. °F	ASTM E84 Tunnel Test	ASTM E162 Radiant Panel Test	Burning Rate (Horizontal) in./min.	Ohio State Univ. Test Btu/ft^2-min.	ASTM E84 Tunnel Test	Heat of Combustion Btu/lb	Flaming Dm	Nonflaming Dm	ASTM E84 Tunnel Test		
Tedlar	-	-	4^{111}	-	-	-	-	0.9^{104} 4^{115}	1^{112}	-	220-250^{99}	Low^{99}
Plexiglass	536-572^{102}	-	118-360^{111}	0.6-1.6^{102}	-	-	-	59^{104}	328^{112}	-	140-200^{99}	Moderate^{99}
Plexiglass, FR	-	-	376^{105}	-	-	-	-	283^{104}	-	-	-	Very Low^{99}
Teflon	986^{102}(self ign.)	-		nonigniting^{102}	-	-	-	55^{103} 53^{105}	0^{107,105}	-	550^{99}	Low^{99}
Nylon	790^{102}	-	-	self extinguishing 44^{107} (glass-reinforced)	-	-	13,000^{114} (nylon-6)	95^{105}	300^{105}	-	175-250^{99}	-
Nylon, FR	-	-	-	-	-	-	-	-	-	-	-	-
PVC, rigid	735^{102}	0-25	9.6^{102}	self extinguishing^{102}	200 (@2.5 Btu/sec-ft^2)	-	7720^{103}	525-660^{102} 525-535^{105}	270-470^{105} 300-490^{102}	-	120-160^{99}	Low^{99}
PVC, rigid, FR	-	-	3.2^{102}	-	-	-	9290^{108}	-	-	-	-	-
ABS (acrylonitrile-butadiene-styrene)	-	-	37-312^{111}	1.0-2.0^{102} 0.9-1.4^{107}	-	-	-	660^{102} 450^{109}	71^{102} 220^{113}	-	140-230^{99}	Moderate^{99}
Polycarbonate (Lexan)	-	-	18^{111}	self extinguishing^{107}	-	-	13,330^{105}	324^{102} 174^{102} 100-248	21^{105} 12^{102}	-	250^{99}	Low^{99}
Fiberglass, reinforced	655-750^{111} (?%)	50-85^{101} (?%)	-	-	-	0-25 (?%)	-	395^{102} (?%)	350^{102} (?%)	> 200 (?%)	300-350^{99}	Low^{99}
Polyester, 21% reinforced	-	-	30-56^{102}	-	-	-	-	-	-	-	-	-
Polyester, 27% reinforced	-	-	239^{102}	-	-	-	-	152^{104}	-	-	-	-
Polyester, 27% reinforced	-	-	154^{102}	-	-	-	-	-	-	-	-	-

* see Appendix B

5. Collector Materials

Most materials used in collectors (with the exception of insulations, wood, and glazing materials) are nonflammable and do not present any fire hazards; therefore, no tabulated data are presented. Glazing materials and insulations are covered in earlier sections.

Several potential fire hazards are possible with collectors. If wood is used as a structural material in a collector, it should be well insulated from the hot components. Wood slowly degrades when exposed to higher temperatures, and its flash-ignition temperature drops as it degrades. Flash-ignition temperatures as low as 100° C have been observed for thermally aged wood in some experiments.[24]

Plastic foam insulations have fairly low continuous service temperatures, and above their maximum service temperatures they degrade rapidly to give more flammable materials. Since there is the possibility of stagnation in collectors, plastic foam insulations should not be used in direct contact with collector surfaces or heat transfer pipes.

6. Thermal Storage Media

When thermal storage media are used with an active SHAC system, they are usually well insulated and isolated from any ignition source. For this reason, there does not appear to be a significant probability that they could accidentally ignite. In a fire situation, however, thermal storage media could add considerable fuel to make a small fire much larger and more damaging, and toxic gases produced by the burning media could be hazardous.

Data for the fire hazard properties of potential thermal storage materials are given in Table VII-5. Most thermal storage media that are flammable 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 tabulating their fire hazard properties.

TABLE VII-5

Fire Hazard Properties of Thermal Storage Materials Used in SHAC Systems

Material	Flash Point ($^{\circ}$F)	Fire Point ($^{\circ}$F)	Ignition Temp ($^{\circ}$F)	Flammable Limits (% by vol)	Solubility in Water (ppm)	Vapor Density Air = 1	Boiling Point ($^{\circ}$F)	Sp. Heat Btu/lb ($^{\circ}$F)	Heat of Comb. Btu/lb	Suggested Hazard* Identification	
										Flammability	Reactivity
Propionamide $C_2H_5CONH_2$	-	-	-	-	yes[96]	-	-	-	-	-	-
Urea/NH_4Br	-	-	-	-	yes	-	-	-	-	-	-
Diphenyl oxide $(C_6H_5)_2O$	239	-	1148	0.8 - 1.5	no slight[105]	5.86[99]	498	-	-	1	0
Napthalene $C_{10}H_8$	174 (CC)	-	979	0.9 - 5.9	no[103] slight[103]	4.4	424 (sublimes)	-	-	2	0
Lauric acid $CH_3(CH_2)_{10}COOH$	-	-	-	slightly flammable[110]	no[95]	-	268[95]	-	-	1	1
Benzamide $C_6H_5CONH_2$	-	-	-	-	slight[95]	-	554[95]	-	-	-	-
Benzoic acid $C_6H_5CONH_2$	250	-	1058	-	slight[95]	4.21	482[95]	-	-	1	-
Barium hydroxide Octo-Hydrate $Ba(OH)_2$-$8H_2O$	-	-	-	nonflammable	5.6[95] (@59°F)	-	1436[95]	-	-	0	-
Biphenyl $C_6H_5C_6H_5$	235[103]	-	1004	0.6 - 5.8 (@232°F) -(@322°F)	no	5.31[99]	489	-	-	1[103]	0
Stearic acid $CH_3(CH_2)_{16}COOH$	385[103]	-	743	-	no[105]	9.8[99]	721[99]	-	-	1[103]	0
Palmitic acid $C_{15}H_{27}COOH$	-	-	-	-	no[110]	-	332[110]	-	-	-	-
Paraffin wax	390[119]	-	473[119]	-	no[95]	-	> 734[119]	-	-	1	0
Myristic acid $C_{13}H_{27}COOH$	-	-	-	-	no[95]	-	301[131]	0.539[97] (@212°F)	-	0	-
Zinc nitrate hexa-hydrate $Zn(NO_3)_2 6H_2O$	-	-	-	nonflammable	184[95] (@59°F)	-	221-268[131]	-	-	0	-

TABLE VII-5 (continued)

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
Calcium bromide Hexa-hydrate $CaBr_2$-6H_2O	-	-	-	nonflammable	594 (@59°F)[95]	-	300[131]	-	-	-	0
Calcium chloride Hexa-hydrate CaC_2-6H_2O	-	-	-	nonflammable	279 (@59°F)[95]	-	392[131]	-	-	-	0
Capric acid $CH_3(CH_2)_8COOH$	-	-	-	-	no[95]	-	518[131]	-	-	-	-
Myristic/capric acid	-	-	-	-	-	-	-	-	-	-	-
Polyglycol E600	-	480 (OC)	-	-	-	-	-	-	-	-	-
Polyglycol E400	-	460 (OC)	-	-	-	-	-	-	-	-	2
Polyglycol E6000	-	495 (OC)	-	-	-	-	-	-	-	-	1
Caprylic acid $CH_3(CH_2)_6COOH$	-	-	-	-	slight[95]	-	230[131]	-	-	-	-
Glauber's salt Na_2SO_4-10 H_2O	-	-	-	nonflammable	11 (@59°F)[95]	-	212[131]	-	-	-	0
Rock	-	-	-	nonflammable (usually)	-	-	-	-	-	-	0

* see Appendix C

VIII. ENVIRONMENTAL EFFECTS OF AND DISPOSAL METHODS FOR SHAC MATERIALS

All technologies impact the natural environment, and the challenge facing all technologies is to minimize the negative aspects of this impact. In this handbook, environmental effects discussed are limited to physical, biological, and ecological effects. Socioeconomic issues are not treated (see references 1 and 123 for discussions of these issues), and most issues relating to personal safety and health effects are treated in Chapters V and VI on toxicity and fire properties.

Technologies used in SHAC systems have been carefully considered for the overall environmental impact in several reports,[119-121] and many of the issues addressed in this handbook were first identified in one of these earlier reports.

Some environmental effects arise from a particular technology during its normal functioning, and some effects result from the procurement and disposal of materials. Thermal pollution of a river by a coal-burning power plant would be an environmental effect that results from the normal operation of that technology. The ecological damage caused by the strip mining of coal and the air pollution caused by disposing of the ash and gases through smoke stacks are examples of environmental effects that result from the procurement and disposal of materials. A third class of environmental effects results from abnormal conditions such as an industrial fire.

Solar heating and cooling technologies do not appear to have any major negative impacts on the environment that result from normal functioning. There are some minor, localized effects that may occur, especially in poorly designed or poorly assembled systems. Spills and leaks of heat transfer liquids or storage media and spray from cooling units can damage lawns, flowers, shrubs, and trees. Small amounts of air pollution result from the venting of gases from heat transfer systems and from the outgassing of plastic glazing materials. These effects appear to be of significance only in a very localized environment.

Most effects caused by abnormal situations in a residence using SHAC technologies are relevant to individual safety. Environmental effects caused by an abnormal situation in a single SHAC residence would be localized, with the possible exception of some air pollution resulting from a fire.

Any major environmental impact caused by SHAC technologies will probably result from the procurement and disposal of materials. As SHAC technologies gain wide use, obtaining the needed materials will have an increasing impact on air and water quality due to mining and manufacturing activities. These effects have been projected and compared with pollution caused by energy production using standard power plants.[119] The negative environmental impacts resulting from procurement of SHAC materials have been estimated to be less than those resulting from conventional power plants for an equal amount of useful energy delivered to the consumer.[119] Consequently, the use of SHAC technologies should result in improved water and air quality if there is no significant pollution caused by disposal of SHAC materials.

Environmental pollution caused by procurement of SHAC materials is not discussed in detail in this handbook since it is more the concern of mining and manufacturing than of designers and consumers.

Most of the potential environmental hazards discussed in detail in this handbook result from improper disposal of SHAC materials. Designers and consumers of SHAC systems have control over most of these risks through their choice of materials and disposal methods. The user of a SHAC system should always insure that an acceptable disposal method will be available for SHAC materials when the materials are no longer useful.

There are very few existing data that can be used to quantitatively determine the environmental impact of various SHAC materials, and there are at present no accurate projections of the materials or the quantities of materials that will be used. Consequently, the potential environmental effects addressed in this chapter are somewhat speculative. Work is currently underway at various laboratories to address these problems, and a later edition of this handbook will incorporate new results.

A. Heat Transfer Fluids

Localized environmental effects can result from improper disposal, leaks and spills of liquids, and from venting of gases. These effects may include local vegetation damage and local groundwater contamination. Most potential environmental hazards resulting from the use of heat transfer fluids result during or after disposal.

Waste fluids may be toxic, they may constitute a fire hazard, and they may be harmful to vegetation. Recycling of some of the heat transfer fluids may become feasible when the quantities become large, but currently, at the beginning of the solar industry, this is not economically attractive.

For disposal purposes, the heat transfer fluids can be classified as glycols, silicones, hydrocarbons, and gases. The gases are the freons used primarily in cooling systems.

1. Glycols

The liquid heat transfer fluids most commonly used in SHAC systems are glycols (ethylene and propylene glycol). These materials are routinely discarded into sewer systems. Ethylene glycol and propylene glycol are biodegradable,[127] and sewer disposal is apparently 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 it into the sewer. Another five parts of water should be poured into the drain after the diluted mixture.

If many SHAC systems using glycol are located in one area, disposal through the sewer system may not be acceptable. The effect of appreciable glycol concentrations on the sanitary sewage systems has not been studied. Any glycol not biodegraded in the sanitary systems will be exposed to chlorine. Chlorine and glycols could react to form much more dangerous chemicals that would be released into rivers. Glycol-water solutions also contain fluid treatment chemicals which may not be biodegradable. Appreciable concentrations of these chemicals in rivers and groundwater systems could be dangerous. Many questions remain to be answered concerning large-scale-disposal of glycol heat transfer fluids through the sewer system, and alternate methods are not presently available.

2. Silicones

If silicone fluids are widely used in SHAC systems, recycling will become an important means of disposal. However, if their use is limited, it may not be economically advantageous to recycle them, and alternate methods would be needed. Presently, manufacturers of these fluids dispose of their waste by carefully controlled incineration.[129] This is an acceptable means of disposal, but it requires special equipment to control the particulate emissions. Since the special equipment is expensive, some central collection procedure would have to be developed if incineration of waste silicone oils from systems is to be used as a disposal technique. Recycling is probably a more viable alternative.

Landfill appears to be an acceptable solution to the disposing of small quantities of waste silicone oils. The silicone oils are low in toxicity to animals and fish,[130] but long-term environmental consequences are not known. There is some evidence that soil plays an important role in degrading the silicone fluid molecule,[131] but the mechanism for degradation of the silicone oils is not known. Much more work should be done before landfill is used for large amounts of silicone oil.

A possible alternative would be to use an existing system to collect the waste silicone oils until the quantities become large enough for recycling. A system that is readily available is waste oil collection by local automobile service stations and transport to reprocessors of waste automotive oil. The effect of small quantities of silicone oils in hydrocarbon oil reprocessing is not known. Two refinery personnel were contacted on this point, but they were not sure they could refine the waste crankcase oils contaminated with silicone oils.[126,132]

3. Hydrocarbon Oils

Hydrocarbon oils have not been widely used in SHAC systems, but their disposal is not a new problem. In 1974 it was estimated that the United States generated 2.5 billion gallons of all types of waste oils.[122] About 625 million gallons of the total were automotive lubricating oil, and about 394 million gallons were generated by industry. Hence, the disposal of waste oils has been studied in detail. Since the physical and chemical properties of the automotive and industrial oils are very similar to many of the natural hydrocarbon heat transfer fluids, this earlier experience is directly applicable. Methods which are presently being used to dispose of waste hydrocarbon oils include recycling, incineration, and road surfacing for dust control. The recycling of industrial waste oils, especially for large users, is economically advantageous. These waste oils generally have few contaminants and are easily and readily reprocessed. Waste motor oils, on the other hand, are contaminated with brake fluid, transmission fluid, kerosene, water, antifreeze, other solvents, additives, metal particles produced by engine wear, and lead and lead compounds from gasoline. The amount of lead contaminant can be as great as 1 wt%.[122] In spite of all the additives and contaminants, crankcase oils can be economically reprocessed for lubricating purposes. Some reprocessed waste oils are used as feedstocks for petrochemical production, and some are used as plasticizers for rubber products.[122]

Waste oils have been successfully burned as a fuel for power plants.[123,124] A blend of 20% waste automobile oil and 80% No. 2 fuel oil did not violate EPA or the State of Maryland Air Quality Control Limits (1975) when burned in a power plant. Sulfur compounds and particulate emissions were appreciably higher for the blend than for fuel oil alone.

Waste hydrocarbon oils are occasionally used as thinning agents for asphalt, form release oils for concrete construction, and road surfacing materials.[122] The use of oil on the surface of dirt roads for dust control is decreasing. It was found[125] that only about 1 wt% of the oil applied to a test road remained on the road for an acceptable time period. Apparently, most of the oil was removed from the road (along with soil particles) by wind during dry months and by rain water. A more effective means of road surfacing is to work thick sludge from settling ponds into the road surface.[126]

Part of all crankcase waste oils discarded ends up in landfills with the oil filters. It has been estimated that 8 to 10% of the total crankcase oils are discarded in this manner.[122]

The most desirable disposal techniques for waste oils, recycling and burning as a fuel, affect the environment. Recycling of waste lubricating oils generates an acid sludge,[122] which is usually buried in landfill. Burning waste oils, especially crankcase oils, gives rise to particulate emissions.

Many hydrocarbon oils that are useful for SHAC systems are chemically similar to industrial and automotive oils. If they are widely used, waste oils will be widely dispersed, and a means of collecting them into large quantities will be desirable. For these oils, local service stations could serve as collection facilities for later disposal. It is not clear if the more exotic synthetic hydrocarbon fluids can be discarded in this manner without causing detrimental effects at the refineries. There are no data at this time relative to the reprocessing of a mixture containing the synthetic hydrocarbon fluids, and it is difficult to predict the behavior of such mixtures at the refineries. One refinery consultant estimated[125] that they could contend with them if the synthetic oil mixture was kept below 10%.

The burning of waste oils in home heating units by individuals is inadvisable until more data are obtained on how it affects the residential unit. If it must be burned, the percentage of waste oil in No. 2 fuel oil should be less than 10% by volume. Burning by power plants appears to be a satisfactory means of disposal.

In conclusion, it does not appear that SHAC technologies will generate large quantities of hydrocarbon oil wastes. Those wastes that will be generated can be discarded at local service stations. If at some future date hydrocarbon heat transfer fluids become widely used in SHAC systems, a more sophisticated disposal technique may have to be developed.

4. Gases

Disposal of the gaseous heat transfer fluids (freons) by venting into the atmosphere is not uncommon in existing systems, but it is not clear that it is acceptable due to the potential effect of freon on the atmospheric ozone. It would not be difficult for maintenance personnel to be equipped with small pumps and storage tanks to collect waste freon. This waste material could then be recycled or properly disposed of by manufacturers.

B. Solid Wastes

A survey of materials currently used in active systems indicates that most of the solid wastes are glazings, insulations, and metals. Solid wastes from passive systems consist largely of glazings, insulations, and storage media (examples are adobe, concrete, bricks, and metal tanks for liquid storage). Most of the solid wastes from SHAC systems are already present in homes.

The disposal of solid materials should utilize the methods currently used for common solid urban refuse, namely: sanitary landfill, pulverization/sanitary landfill, direct incineration of combustible materials, and recycling of metals. Newer methods which are now being evaluated are pyrolysis, high-density bailing, recycling glass as glass wool insulation, and recycling plastics. Disposal by sanitary landfill is presently the most common and cheapest method[133] for solid materials. Since SHAC systems contain large quantities of metal, recycling should be favored.

1. Insulation Materials

Small amounts of air pollution are possible if certain insulation materials are exposed to high temperatures. Foams blown with freon can degrade at elevated temperatures, reducing the insulating properties and releasing freon into the atmosphere. (Carbon dioxide-blown foams are available, but they have slightly less insulating ability). Organic binders used with fiberglass and mineral wall can also give off small amounts of toxic gases if exposed to high temperatures.

Burning insulating materials (especially the plastic foams), give off copious quantities of toxic gases and particulates unless controlled conditions are used.

Disposal of insulating materials by those methods already in common use is apparently acceptable.

2. Seals and Sealants

The quantity of sealant material used in SHAC systems is so small that any environmental effects will be minimal.

3. Glazing Materials

Glazing materials made from glass do not present any negative environmental effects during use and disposal (with the possible exception of glare and personal injury due to sharp edges). Normal landfill disposal is acceptable.

Plastic glazing materials outgas at normal operating temperatures and add small amounts of air pollution. Disposal of plastic glazing materials by incineration can also add substantially to air pollution unless the incineration is very carefully controlled. Disposal by landfill is adequate and environmentally sound.

4. Collector Materials

Most collector materials are normal building materials and common metals. Landfill disposal and recycling of the metals appear to be adequate. Many materials used in absorber coatings are toxic, and some contain heavy metals. The coatings could possibly degrade or oxidize in landfills to release water-soluble toxic substances. If this happened, many units in the same landfill would be required to significantly impact the environment; therefore, landfill disposal is acceptable for limited numbers of units.

No other significant environmental effect is foreseen.

5. Storage Media

Environmental effects caused by materials most commonly used as storage media (water, rocks, masonry, etc.) are insignificant, and disposal is easily handled by landfill methods. Those materials that store energy using a phase change have not been widely used, and, at the present time, it does not appear that they will be used in quantities great enough to cause significant environmental hazards or disposal problems.

APPENDIX A. Data Sheets for Certain Heat Transfer Fluids

The following data were obtained for thirteen samples of liquid heat transfer fluids. The data were obtained for specific samples, and may not be representative of all other samples of a specific brand named material since manufacturers often change ingredients in a product. No information is available that allows the tracing of these samples back to the date or place of manufacture.

SAMPLE 1

1. Material - Process Oil 3029

2. Manufacturer - Exxon

3. Generic Class - Naphthenic Mineral Oil*

4. Composition -

   A. General - A petroleum distillate fraction of wide molecular weight distribution composed of high molecular weight material of low aromatic content and low molecular weight material of high aromatic content. Total aromatic content 24%.*

   B.

Component	Percent
Oil	>95%

   C. Elemental Analysis - C = 87.2%, H = 13.4%

   D. Heavy Metals - None Detected

   E. Halogen, Sulfur, Phosphorous, Nitrogen - Nil

5. Tests Performed - Gel Permeation Chromatography (GPC), Gas Chromatography/Mass Spectroscopy (GS/MS), Infrared (IR) Analysis Emission Spectroscopy.

6. Comments - IR and GPC data do not support the manufacturer's value of 24% aromatic content. An aromatic content of 10% is consistent with our data.

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*Manufacturer's Data

SAMPLE 2

1. Material - Caloria HT 43

2. Manufacturer - Exxon

3. Generic Class - Paraffinic oil of low aromatic content (14%)*

4. Composition -

   A. General - A petroleum distillate fraction of moderate molecular weight distribution and low aromatic content.
   B.

Component	Percent
Oil	>95%

   C. Elemental Analysis - C = 85.9%, H = 13.8%
   D. Heavy Metals - None detected
   E. Halogen, Sulfur, Nitrogen - Nil

5. Tests Performed - See Sample 1

6. Comments - Again our data suggest aromatics present but not at the level given by manufacturer. See Sample 1 comments.

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*Manufacturer's Data

SAMPLE 3

1. Material - Sun Temp

2. Manufacturer - Resource Technology Corporation

3. Generic Class - Paraffinic oil of low aromatic content.

4. Composition -

   A. General - Appears to be like Exxon's Caloria HT 43, i.e., a petroleum distillate fraction of moderate molecular weight distribution and low aromatic content.

   B.

Component	Percent
Oil	>95%

   A red dye has been added to this oil but at very low concentration (1%)

   C. Elemental Analysis - C = 86.3%, H = 12.9%

   D. Heavy Metals - None detected

   E. Halogen, Sulfur, Nitrogen - Nil

5. Tests Performed - See Sample 1

6. Comments - Material is very similar to Caloria HT 43 but with a red dye added.

SAMPLE 4

1. Material - SF 96 (50 CS)
2. Manufacturer - General Electric
3. Generic Class - Polydimethylsiloxane
4. Composition -
    - A. General - A polydimethylsiloxane of 50 centistoke viscosity.*
    - B.

Component	Percent
Oil	99%

    - C. Elemental Analysis - C = 31.3%, H = 8.4%
    - D. Heavy Metal(ppm) - Fe = 4, Na = 13, Cu = 10, K = 4
    - E. Halogen, Sulfur, Nitrogen - Nil
5. Tests Performed - See Sample 1
6. Comments - None

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*Manufacturer's Data

SAMPLE 5

1. Material - DC-200 (100 CS)

2. Manufacturer - Dow Corning

3. Generic Class - Polydimethylsiloxane

4. Composition -

   A. General - A polydimethylsiloxane of 100 centistoke viscosity.*

   B.

Component	Percent
Oil	>99%

   C. Elemental Analysis - C = 31.2%, H = 8.3%

   D. Heavy Metal (PPM) - Fe = 6 ppm, Na = 13, Cu = 6, K = 3, Ca = 4

   E. Halogen, Sulfur, Nitrogen - Nil

5. Tests Performed - see Sample 1

6. Comments - None

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*Manufacturer's Data

SAMPLE 6

1. Material - Dowtherm A

2. Manufacturer - Dow Corning

3. Generic Class - Aromatic

4. Composition -

   A. General - A mixture of diphenyl and diphenyl oxide

   B.

Component	Percent
Diphenyl	26%
Diphenyl oxide	74%*

   C. Elemental Analysis - C = 87.0%, H = 6.2%

   D. Heavy Metal - None Detected

   E. Halogen, Sulfur, Nitrogen - Nil

5. Tests Performed - See Sample 1

6. Comments - Our data is consistent with manufacturer's data.

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*Manufacturer's Data

SAMPLE 7

1. Materials - Therminol 66

2. Manufacturer - Monsanto Corporation

3. Generic Class - Mixture of Terphenyls*

4. Composition -

   A. General - Mixture of terphenyls

   B.

Component	Percent
Major Peak	>95%
Minor Peak	5%

   C. Elemental Analysis - C = 90.4%, H = 9.2 %

   D. Heavy Metal - None detected

   E. Halogen, Sulfur, Nitrogen - Nil

5. Tests Performed - See Sample 1

6. Comments - A mixture of terphenyls hydrogenated to various extents.

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*Manufacturer's Data

SAMPLE 8

1. Material - UCON Heat Transfer Fluid

2. Manufacturer - Union Carbide

3. Generic Class - Polyglycol

4. Composition -

   A. General - A polyglycol with an additive
   B.

Component	Percent
Polyglycol - Main Peak	>90%
Additive	10%

   C. Elemental Analysis - C = 59.1%, H = 9.8%
   D. Heavy Metal - None detected
   E. Halogen, Sulfur, Nitrogen = 0.2%, others Nil

5. Tests Performed - See Sample 1

6. Comments - The GC/MS data suggest that the additive may be a phenyl naphthalamine.

SAMPLE 9

1. Material - Dowtherm SR-1

2. Manufacturer - Dow

3. Generic Class - Inhibited ethylene glycol

4. Composition -

   A. General - Ethylene Glycol with inhibitor and red dye

   B.

Component	Percent
Ethylene glycol	>95%
Inhibitor - K_2HPO_4 (white solid)	5%
Red dye	1%

   C. Elemental Analysis - C = 37.2%, H = 9.8%
   Elements Present (PPM) in Ashed Residue (1.6% Residue).

Na	32,000
Li	6
Rb	40
Ca	250
Al	80
Cu	100
Fl	300
Mg	300
Mn	50
Si	500
P	100,000
K	Major Component

   D. Halogen, Sulfur, Nitrogen - Absent

5. Tests Performed - Gel Permeation Chromatography (GPC), Infrared (IR) Analysis, Gas Chromatography/Mass Spectroscopy (GC/MS), Emission Spectroscopy, X-ray Spectroscopy

6. Comments - It was possible to separate the inhibitor from the ethylene glycol, and this white solid was analyzed as K_2HPO_4.

SAMPLE 10

1. Material - Dowfrost

2. Manufacturer - Dow Chemical Corporation

3. Generic Class - Propylene Glycol and Inhibitor

4. Composition -

   A. General - Propylene glycol with inhibitor

   B.

Component	Percent
Propylene glycol	>95%
Inhibitor - K_2HPO_4	5%

   C. Elemental Analysis - C = 43.5%, H = 10.6%

   D. Elements Present (PPM) in Ashed Residue (2.5% Residue)

Na	10,000
Li	4
Rb	50
Ca	130
Al	250
Cu	60
Fe	400
Mg	200
Mn	60
Si	150
P	100,000
K	Major Component

   E. Halogen, Sulfur, Nitrogen - Absent

5. Tests Performed - See Sample 9

6. Comments - It was possible to separate the inhibitor from the propylene glycol and this white solid was analyzed as K_2HPO_4.

SAMPLE 11

1. Material - Thermia 33*

2. Manufacturer - Shell Oil Company

3. Generic Class - Petroleum distillate fraction

4. Composition -

   A. General - A petroleum distillate fraction similar to Exxon's Process Oil (see Sample 10) but of higher molecular weight.
   B.

Component	Percent
Oil	>95%

   C. Elemental Analysis - C = 86.4%, H = 13.4%
   D. Heavy Metals - Ca and Si = Major Component
      Al and Fe= Minor Component
   E. Halogen, Sulfur, Nitrogen - Nil

5. Tests Performed - See Sample 9

6. Comments - The aromatic content of Thermia 33 is higher than that of Exxon Process Oil (Sample 10).

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*Now called Thermia C

SAMPLE 12

1. Material - Mobiltherm 603

2. Manufacturer - Mobil Oil

3. Generic Class - Petroleum distillate fraction

4. Composition -

   A. General - A petroleum distillate fraction similar to Exxon's Process Oil (Sample 1) but of higher molecular weight.
   B.

Component	Percent
Oil	>95%

   C. Elemental Analysis - C = 86.2%, H = 13.7%
   D. Heavy Metals - Ca and Si = Major Components
      Al and Fe= Minor Components
   E. Halogen, Sulfur, and Nitrogen - Nil

5. Tests Performed - See Sample 9

6. Comments - This material is like Exxon's Process Oil but of higher molecular weight.

SAMPLE 13

1. Material - Mobiltherm Light

2. Manufacturer - Mobil Oil

3. Generic Class - Petroleum distillate fraction

4. Composition -

   A. General - A low molecular weight petroleum distillate fraction of very high aromatic content

   B.

Component	Percent
Oil	>95%

   C. Elemental Analysis - C = 88.9%, H = 9.57%

   D. Heavy Metal - Si = Major Component
   Fe and Al = Minor Components

   E. Halogen, Sulfur, Nitrogen - Nil

5. Tests Performed - See Sample 9

6. Comments - None

Appendix B. Fire Hazard Properties Tests

Fire hazard properties data are obtained under controlled test conditions. Caution must be used when extrapolating small-scale test results to full-scale, uncontrolled situations for the following two reasons: (1) the physical phenomena occuring in controlled test conditions are often different than those in uncontrolled situations; and, (2) materials may perform differently under varied test conditions, and they may react differently when tested alone than they do when tested in conjunction with other materials.

Many so-called fire hazard properties of materials are not truly material properties but measures of material behavior in a standardized environment. Changes in environment may have greater effect on the resultant behavior of materials than do changes in material properties.

Most of the testing methods and standards are determined by one of three groups, the National Fire Protection Association (NFPA), the American Society for Testing and Materials (ASTM), and Underwriters Laboratories, Inc. (UL). Tests are routinely referred to by an acronymn and a number, such as ASTM D2863 (oxygen index test), and they are performed according to strict specifications.

The testing methods and parameters chosen for presentation in this handbook are given in sections 1. and 2. below, and they are separated into methods applicable to solids and fluids. There are numerous other fire tests and parameters that are not given in this handbook.

1. Tests Used for Solid Materials

The fire tests for solid materials for which data are given in this handbook are related to ignition, flame spread, heat release, and smoke production.

a. Test for Ease of Ignition

Ease of ignition may be 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 characteristic 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.[80,81]

(1) ASTM D1929

This test uses a vertical furnace tube 254 mm (10 in.) long with a 102 mm (4 in.) inside diameter. It is heated by electrical current passing through a nichrome wire wound around the tube. An inner refractory tube 254 mm (10 in.) long, with a 76 mm (3 in.) inside diameter, contains the specimen. Air is admitted at a controlled rate, and its temperature is measured by means of thermocouples.

In the ASTM D1929 test, a 3-gram specimen is exposed to air at successively higher temperatures until ignition is observed. Flash-ignition temperature is defined as the lowest initial temperature of air passing around the specimen at which an amount of combustible gas sufficient to be ignited by a small external pilot flame is evolved. Self-ignition temperature is defined as the lowest initial temperature of air passing around the specimen at which, in the absence of an ignition source, self-sustained heating of the sample is indicated by an explosion, flame, or sustained glow. This test is also known as the Setchkin ignition test.

b. Tests for Surface Flame Spread

Tests for surface flame spread provide a relative measure of the hazard associated with the transmission of flame along the surface of a given material. Numbers used to classify the flame spread of materials are generally relative indices and may not necessarily be related to the flame spread rate under all conditions. The numerical values obtained for a material from a given test method do not necessarily compare with values obtained from other tests.

(1) ASTM E84, 7.62 m (25 ft) Tunnel Test

The Tunnel Test is perhaps t most widely accepted test for characterizing surface flame spread. A material specimen 7.32 m (24 ft) long and 0.514 m (20.25 in) wide is mounted face down to form the ceiling of the horizontal test chamber which is 7.62 m (25 ft) long, 0.488 m (14.75 in.), wide and 0.305 m (12 in.) high. A fire source consisting of two gas burners is mounted 0.305 m (12 in.) from one end of the test chamber and 0.19 m (7.5 in.) below the surface of the sample. The test begins with the ignition of the fire source. During the test, the flame spread distance and time are recorded. A flame spread number is determined using the data. The number determined for a material can be compared with asbestos-cement board, rated as 0, and select grade red oak flooring, which is rated at 100.

(2) ASTM E162 Radiant Panel Test

The test employs a radiant heat source consisting of a 305 mm (12 in.) by 457 mm (18 in.) vertically mounted, porous refractory panel maintained at 670 ± 4 C (1238 ± 7 F). A specimen measuring 457 mm (18 in.) by 152 mm (6 in.) is supported in front of the panel, with the longer dimension inclined 30 degrees from vertical. A pilot burner ignites the top of the specimen so that the flame front progresses downward along the underside, which is exposed to the radiant panel. The rate of flame spread, the measured temperature rise, and the rate of heat release from the specimen (determined in separate tests) are used to determine a numerical rating on a relative scale. The relative scale is similar to that used for the tunnel test, with select red oak assigned a value of 99 and asbestos board a value of 0.

c. Tests for Heat Release

Tests for heat release rate provide a measure of the rate at which heat is produced during burning of a 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.

(1) Ohio State University Heat Release Test[82]

The heat release rate apparatus employs a chamber 0.89 m (35 in.) high, 0.41 m (16 in.) wide, and 0.20 m (8 in.) deep, with a pyramidal top section 0.395 m (15.5 in.) high connecting to an outlet. The chamber contains electrically heated "globar" silicone carbide rods. The usual specimen has an exposed square surface that is 0.254 m (10 in.) on each side and is positioned 0.076 m (3 in.) from the radiant panel, although the distance from the panel can be varied from zero to .018 m (7 in.). The specimen usually is exposed to a constant radiant energy flux. The values of heat release rate are calculated in terms of watts per unit surface area exposed.

(2) ASTM E84, 7.62 m (25 ft) Tunnel Test

Although this test (described on previous pages) is essentially for surface flammability, it also provides a relative measure of heat contribution to a fire that is determined by the temperature of the gases at the tunnel exit.

d. Tests for Smoke Production

Smoke is measured by light attenuation. The amount of light obscuration depends on the number, shape, and size of smoke particles, as well as the wavelength and path length of the light. Smoke is affected by the ventilation, aging or coagulation, and air movement.

(1) National Bureau of Standards Smoke Density Chamber Test[83]

The test chamber is a closed cabinet, 0.91 m (3 ft) wide, 0.91 m (3 ft) high, and 0.61 m (2 ft) deep. A specimen 0.076 m (3 in.) square is supported vertically in a frame and is exposed to heat under either flaming or nonflaming (smoldering) conditions. Specimen thickness can be varied, but the exposed surface area is defined by a standardized holder. The heat source for the nonflaming test is an electric furnace, adjusted to give a heat flux of 25,000 W/square meter (2.2 Btu/sec/square foot) at the specimen surface. For the flaming test, a small pilot flame is used to ignite the sample surface. A vertical optical path through the chamber is used for measuring light absorption. This minimizes measurement differences due to smoke stratification and provides an overall average for the entire chamber.

Smoke measurements are expressed in terms of specific optical density, which can be defined mathematically as

$$D_s = V/AL \log_{10}(I_o/I)$$

where D_s = specific optical density

I_o = optical signal without smoke

I = optical signal with smoke

L = light path

A = sample surface area

V = smoke chamber volume.

The maximum value of D_s during a test (corrected for window smoke deposit) is reported. Since smoke production is affected by the specimen thickness, values of D_s are usually corrected to unit thickness. The symbol D_S is used to represent the maximum specific optical density corrected to unit thickness.

Variations of this test include different levels of heat flux (as high as 100,000 W/square meter), specimen weight monitoring, and different degrees of ventilation.

(2) ASTM E84, 7.62m (25 ft) Tunnel Test

The test is primarily for surface flame spread, but it also provides a measure of smoke evolution when light absorption is determined during the course of the test.

2. Tests and Parameters Used for Fluids

Liquids and gases behave very differently from solids, and the parameters that are important for fire hazard assessment are very different. Tests and parameters for fluids are defined in this section.

a. Flash Point

The flash point of a liquid is the minimum temperature at which it gives off enough vapor to form an ignitable mixture with air near the surface of the liquid (open cup) or within a vessel (closed cup).* An ignitable mixture is one within the flammable range (between the upper and lower limits, see subsection VII.A.2.d) that is capable of propagating the flame away from an ignition source. Some evaporation takes place below the flash points but not in sufficient quantities to form an ignitable mixture.

Flash point data may represent either closed-cup tests* or open-cup tests.* Data that are designated CC and OC are known to represent closed-cup and open-cup, respectively. Much of the data are from manufacturers' literature and probably represent open-cup data since that is the more frequently used method.

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*There are several types of apparatus for determining flash point by test. The Tag Closed Tester (ASTM D56) is intended for testing liquids having a viscosity less than 45 CS at 100 F and a flash point below 175° F. The Pensky-Martens Closed Tester (ASTM D93) is considered accurate for testing liquids having a viscosity of 45 CS or more at 100° F or a flash point of 175° F or higher. The Cleveland Open Tester (ASTM D92) is sometimes used for high flash point liquids. The Tag Open Tester (ASTM D1310) is frequently used for low flash liquids, where it is desired to have tests more representative of conditions in open tanks of flammable liquids or for labeling and transportation purposes. For most liquids, the numerical value in degrees Fahrenheit of the closed cup flash point is some 10 to 20% lower than that of the open cup flash point for the same liquid, but there are some cases where the difference is greater or smaller.

A material with a lower flash point may be considered more fire hazardous than a material with higher flash point if all the other parameters are similar.

b. Fire Point

Fire point is defined as the lowest temperature of a liquid in an open container at which vapors are evolved fast enough to support continuous combustion. The fire point is usually a few degrees above the flash point. The Cleveland Open Cup Tester (ASTM D92) is normally used to measure the fire points. A material with lower fire point may be considered more fire hazardous if other properties are equal.

c. Ignition Temperature (Autoignition Temperature, or Autogenous Ignition Temperature)

The ignition temperature that is usually reported for a flammable liquid is the temperature to which a nearly closed vessel must be heated in order to cause spontaneous combustion if the liquid is quickly introduced into the container. Time intervals of a minute or more between introduction of the liquid into the container and combustion are not uncommon. ASTM D2155, Autoignition Temperature of Liquid Petroleum Products, gives the standard test procedure.

In general, ignition temperatures may be changed substantially by a change of test conditions. For this reason, ignition temperatures should be considered approximations. Some of the variables known to affect ignition temperatures are percentage of the vapor in air, shape and size of the volume where ignition occurs, rate and duration of heating, nature of the ignition source, and catalytic effects.

d. 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 boundary-line mixtures of vapor or gas in air which will just propagate flame are known as "lower and upper flammable limits" and are usually expressed in terms of percentage by volume of gas or vapor in air. In popular terms, a mixture below the lower flammable limit is too "lean to burn" and a mixture above the upper flammable limit too "rich to burn."

The concentration range defined by the upper and lower flammable limits is known as the "flammable range."

Flammable limit data are determined at ambient temperatures and atmospheric pressures, unless otherwise indicated. In general, an increase in temperature or pressure decreases the lower limit and increases the upper limit.

e. Vapor Pressure

If a sufficient quantity of a volatile material is placed in a closed container, it will evaporate until the gas pressure of the material reaches a value at which condensation exactly equals evaporation. This value of pressure, commonly referred to as "vapor pressure", is correctly referred to as the equilibrium vapor pressure or the saturated vapor pressure. Measured values of vapor pressure are very temperature dependent, and a flammable substance with a higher vapor pressure has a greater tendency to form a combustible mixture with air.

f. Vapor Density

Vapor density (the technically correct term is "specific 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 of ignition and flash back (if the vapor is flammable).

g. Boiling Point

Boiling point is the temperature at which the saturated vapor pressure of a liquid equals atmospheric pressure.

h. Specific Heat

The specific heat of a material is defined as the quantity of heat absorbed (or given off) when one unit of mass increases (or decreases) one degree of temperature. For the same mass of materials, it takes more heat for a substance with higher specific heat to reach the same temperature than it does for a substance with a lower specific heat.

i. Heat of Combustion

The total heat of combustion is the amount of heat released by one unit weight of a material during complete combustion.

j. Thermal Conductivity

Thermal conductivity is a material property that can be used to calculate the rate of heat flow through a material. For the same values of temperature gradient and cross-sectional area, a substance with higher thermal conductivity will transfer heat faster than a material with lower thermal conductivity.

Appendix C. Suggested Fire Hazard Identification for Industry

A suggested hazard identification system has been developed by the NFPA and revised in 1969. This warning system 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, and its chief purpose is to warn firefighters of the dangerous conditions. Nevertheless, the rating system is of interest when considering SHAC materials.

The system identifies the hazards of a material in three categories: "health," "flammability," and "reactivity." The order of severity in each of these categories is indicated by five divisions, ranging from 4, which warns of a severe hazard, to zero, which suggests no special hazard.

1. Health Hazard Identification for Firefighters

In general, the health hazard identification warns firefighters of toxic risks due to single exposure, which may vary from a few seconds up to an hour. The explanations of the hazard levels refer to protective equipment normally used by firefighters. The risk indices are defined as follows:

4 Materials that are so dangerous to health that firefighters must not be exposed to them. A few whiffs of the vapor could cause death, or the vapor or liquid could be fatal on penetrating the firefighter's normal full protective clothing. The normal full protective clothing and breathing apparatus available to the average fire department will not provide adequate protection against inhalation or skin contact with these materials.

3 These materials are extremely hazardous to health, but areas containing the material may be entered with extreme care. Full protective clothing,

including self-contained breathing apparatus, coat, pants, gloves, boots, and bands around legs, arms, and waist should be used. No skin surface should be exposed.

2 These materials are hazardous to health, but areas containing them may be entered freely with a self-contained breathing apparatus which has a full-faced mask to provide eye protection.

1 These materials are only slightly hazardous to health. It may be desirable to wear self-contained breathing apparatus when entering areas containing the material.

0 These materials, under fire conditions, would offer no hazard beyond that of ordinary combustible material.

2. Flammability Hazard Identification for Firefighters

Susceptibility to burning is the basis for assigning risk indices within this category. 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 Materials that will not burn are in this catagory.

3. Reactivity (Stability) Hazard Identification for Firefighters

The assignment of hazard levels in the reactivity category is based upon the ability of materials to release energy either by themselves or in combination with water. The risk indices are given 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 are normally 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 are normally 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 are normally stable even under fire exposure conditions and are not reactive with water. Normal fire fighting procedures may be used.

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16. Abstract

The use of solar energy for home heating and cooling- is often considered to be environmentally benign and to present few or no health hazards. However, all technologies impact the environment, and all can introduce situations that lead to personal harm and property loss. Environmental impact and hazardous situations can be minimized if the needed information is identified and communicated to users and designers during the early development stages of a technology.

The goal of this program is to provide a single reference source of hazardous properties and environmental effects of materials used in solar heating and cooling for heat transfer fluids, insulations, seals and sealant materials, glazing material, collector material, and storage material. Hazardous properties that are emphasized are those related to toxicity (using Durham and Gasselin rating schemes) and fires (using rating schemes for Health Hazard Identified for Firefighters, Flammability Hazard Identified for Firefighters, and Reactivity/Stability Hazard Identified for Firefighters). Chemical characterizations of some materials are presented and environmental effects are surveyed.

This interim handbook is the first of several editions. Comments and suggestions for improvement are solicited from qualified spokespersons. New data and expanded treatments will follow in later editions.

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