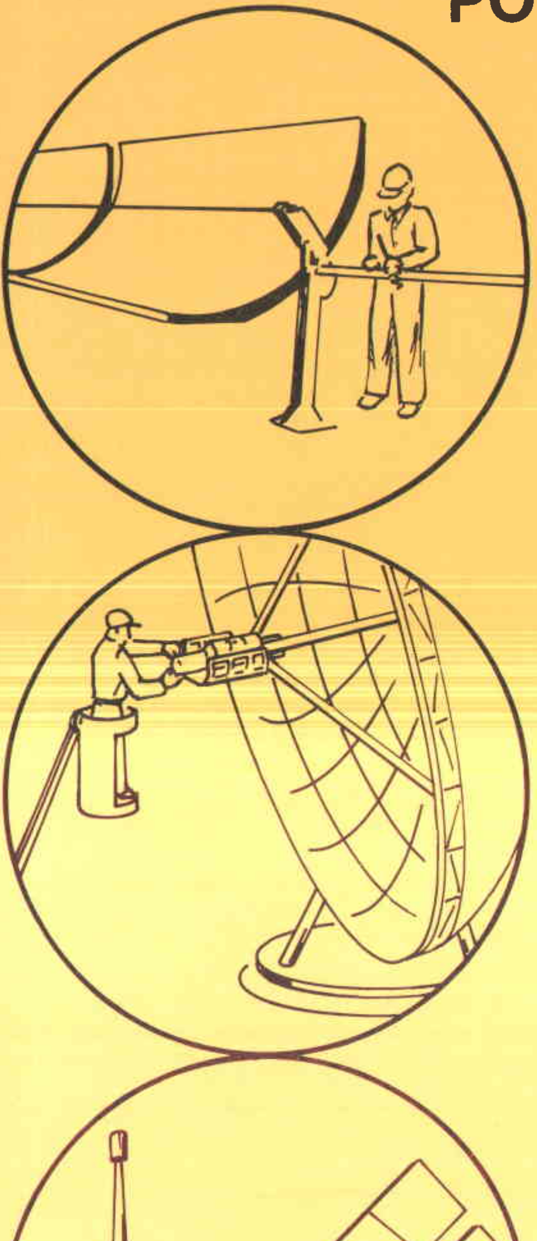
STMPO-546

WORKER HEALTH and SAFETY in SOLAR THERMAL POWER SYSTEMS



VI. Solar Ponds

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WORKER HEALTH AND SAFETY IN SOLAR THERMAL POWER SYSTEMS

VI. Solar Ponds

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Credits

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Abstract

The design of solar pond electric power generation systems is reviewed to delineate factors which may affect worker health and safety. Materials handling problems are identified, including brine production and circulation hazards. Toxicity of microorganisms and of pond additives is considered, as well as salt intrusion and dispersal. Each appears to have a potential negative health effect. An effect of the water supply quality on worker health may arise from impurities in the water and from waste disposal. This is of major importance if agricultural runoff waters are used. Other hazards identified include fire and reduced visibility hazards.

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1. Introduction

In the past several years various systems have been designed or constructed for generating electricity from solar energy through a thermal conversion process. These devices, referred to under the generic description of solar thermal power systems (STPS), have utilized several means of achieving this conversion of solar to electric energy. In the main, reflecting or refracting elements are used to focus incident sunlight onto a receiver in which a working fluid is heated. This heated fluid may then be used directly to generate electricity, for example by turning a turbine-generator set if the fluid is high pressure steam. Alternatively, the heated fluid may operate through an intermediate heat transfer system, and then some secondary fluid provides the means for electric power generation. For example, the receiver might be cooled with a liquid such as oil, molten salt, or sodium, and steam generated in one or more coolant-to-water steam heat exchangers. The diversity of such designs is quite large, as will be the operating conditions encountered. Generally, however, there is considerable effort expended towards achieving relatively high temperatures in the receiver and generation fluids, since in that way high thermodynamic efficiencies of solar-to-electric power may be achieved. The impetus for high efficiencies may seem misdirected at first, for one presumes that sunlight is "free". However, the economics of the focusing elements dictates that one must be about as parsimonious with sunlight as with fossil fuels. In distinction to solar heating and cooling applications, which are based generally on flat plate, non-focusing collectors, and operate at low temperatures, STPS systems are generally envisioned as being high technology, sophisticated, and modestly complex in design. In fact, there may well be more impetus in STPS plants than in fossil fuel plants to achieve extremely high temperatures and thermodynamic efficiencies, again because of the economics of the focusing of sunlight. As a reflection of this, several designs for Brayton cycle STPS plants, operating at about 800°C (~1500°F), have been developed. Such a system would represent a radical departure for fossil fueled plants, where at most such gas turbines are being considered for near-term application in combined cycle power plants.

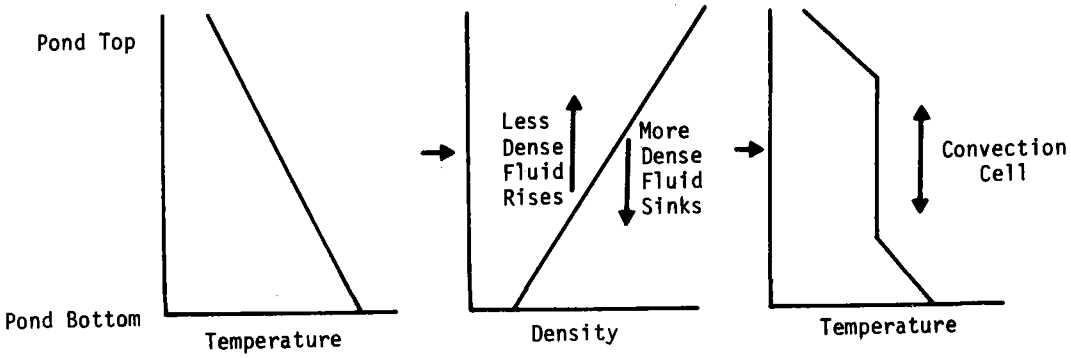
In the company of these various designs for STPS plants based on focusing of sunlight, a singular exception to this pattern has been proposed. That is the idea of the solar pond. A solar pond in its most unencumbered form is simply a shallow lake of water. The water, being exposed to the sun is heated, much as water might be for solar space heating applications. In such a circumstance, the water towards the bottom of the pond will tend to be hotter than the water above it, since there will be thermal losses at the pond's surface.

The object in the design of a solar pond is to obtain sufficiently hot water from the pond to make this hot water an economic heat source for electric power generation. For example, the hot water might be fed to a subatmospheric flash drum, and the steam thus generated used to drive a turbine. A second option would be to use the hot water to vaporize some secondary fluid, such as isobutane, and then in turn use this fluid to drive a turbine. In some sense these modes of operation resemble those for ocean thermal energy conversion (OTEC) devices, with the solar pond replacing the hot surface waters utilized in OTEC devices as a heat source, or for hot water geothermal power plants.

The temperature gradient in a solar pond will, unless compensated, lead to a density profile in which the hotter and less dense fluid will be towards the bottom of the pond. This will lead to natural convection vertically through the pond, which in turn will tend to equalize temperatures throughout the vertical profile of the pond. This is an undesirable event for the generation of electricity by the system described above. To prevent this, a salt is added to the waters of the solar pond, and a concentration profile superimposed such that deeper waters will have higher salt concentrations. Higher concentrations of salt lead to higher densities for the salt/water brine. The intention then is to establish a sufficiently large concentration gradient that the temperature effect on density will be reversed. This is shown schematically in Figure 1. In this manner natural convection can be suppressed.

Water is a relatively poor conductor of heat in the absence of convection, so a convection-free solar pond can achieve peak temperatures approaching the boiling point of the brine. In conventional fossil fuel plants, such a temperature would be unacceptably low for efficient and economic electric power generation. Similarly, the focusing STPS designs described above must achieve much higher temperatures. However, the economic constraints of the high cost of solar focusing devices will not apply to solar ponds. In support of solar ponds, one might speculate that the lower cost of a water-filled pond than an equal area of heliostats or other focusing devices might make solar ponds attractive even if the thermodynamic conversion efficiency were low. Drawing again the analogy to OTEC systems, utilizing low temperature energy sources, such as warm water, may be economic so long as gathering the source does not cost too much. A secondary *modus vivendi* may be operating in the utilization of solar ponds, in that some natural or already established man-made lakes, such as the Salton Sea, have high salt concentrations. It may then be necessary to stabilize the water flows to the lake, and to provide for water quality improvements. A solar pond may provide adequate justification

a) Without salt concentration profile



b) With salt concentration profile

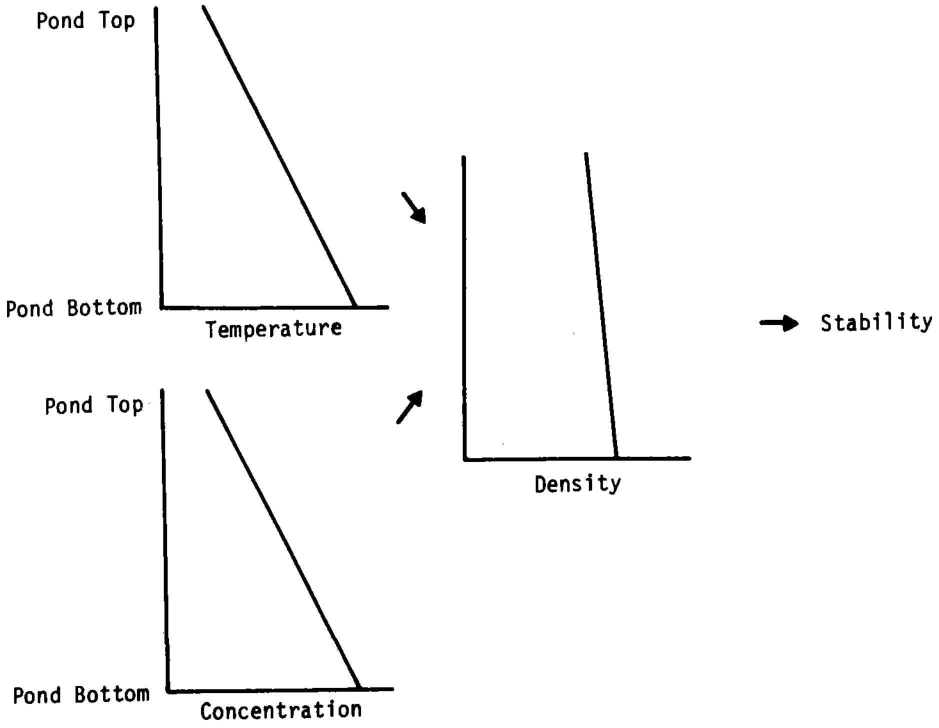


Figure 1

Temperature, Concentration, and Density Profiles in Solar Ponds and economic incentive to support these objectives, just as hydroelectric power projects have a synergistic relationship to flood control systems.

The following sections describe technologies applicable to solar ponds, and provide an overview of potential unique hazards associated with this type of STPS. Worker health and safety is addressed in operating areas where the designs extant are sufficiently explicit to allow reasonable conclusions to be drawn.

2. Normal Operation of Solar Ponds

The procedures by which solar ponds may be used for power production have been studied and compared [1-4] for the several types of solar pond power systems developed. The basic operating procedures are described in the following sections.

2.1 Collector Subsystem Design and Operation

The collector function common to all STPS is fulfilled by the pond water and bottom. In the sense of component function, the pond might also be classified as the receiver, but that may be merely a semantic distinction. The solar insolation will, in part, be adsorbed by the pond waters and bottom. Typical sunlight penetration is shown in Figure 2 [4]. As can be seen from that figure, most of the sunlight will be adsorbed in the first one to two meters of water.

A pilot solar pond is typically 2 m (6 ft) deep. A design is shown in Figure 3. It may be lined to enhance adsorption and to prevent salt water seepage into the ground. Materials such as Shelter-Rite XR-5, hypalon, and chlorinated polyethylene are possible liners. Inlet and outlet pipes are needed at several depths in the pond for movement of stratified layers of water.

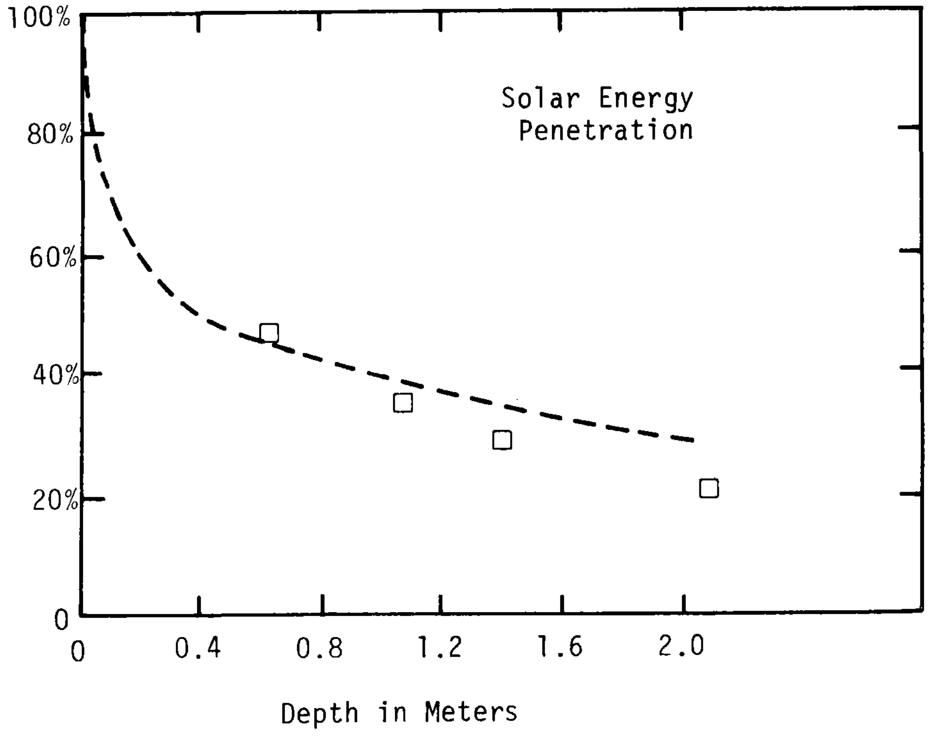


Figure 2

Solar Energy Penetration in a Solar Pond

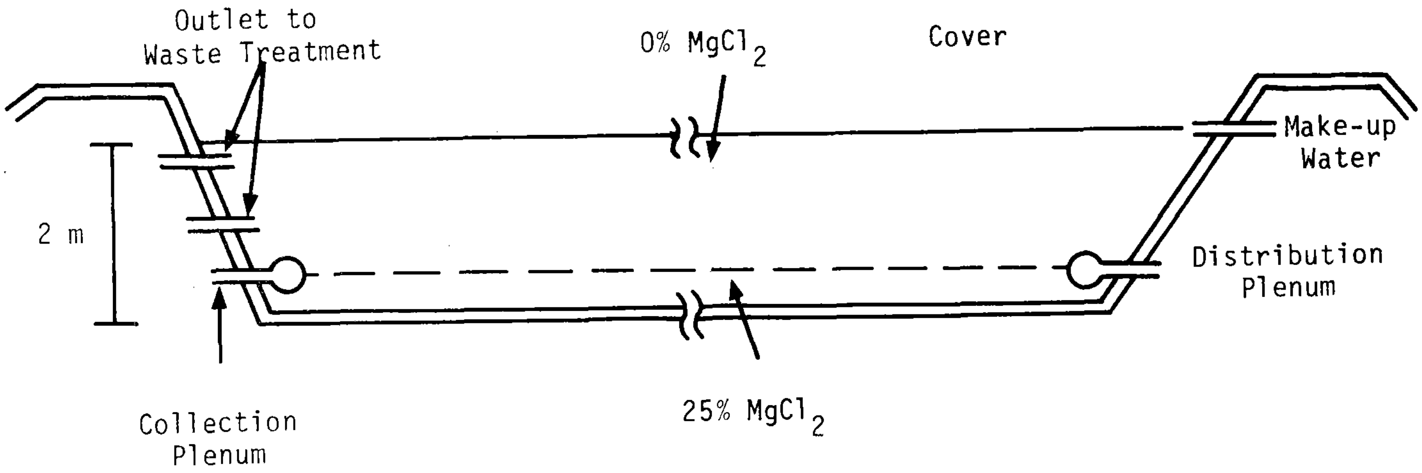


Figure 3

A Proposed Solar Pond Design

A cover might be advantageous to stop surface waves, and to keep out debris. Such covers have both positive and negative effects on heating of pond waters. The covers, generally suggested to be made of Tedlar® or simlar material, will adsorb some solar insolation. However, evaporative losses will be reduced. Evaporative losses may be the primary energy loss from a pond, as well as increasing the water consumption markedly. If a cover is used, appropriate supporting structures may have to be used.

Hydrodynamic stability in the pond is essential for efficient power production. As noted above, the principal design feature of a solar pond which allows its use as an STPS is the brine concentration-induced stabilization of hot fluid at the bottom of the pond. Any factor which could disrupt this gradient, and result in convection and a partial loss of stratification, will lead to a reduction in the temperature gradient across the pond. In turn the pond efficiency will be reduced. The pond will not spontaneously recover its stratification if this were to occur, since many such Rayleigh-Taylor hydrodynamic instabilities are self-perpetuating. Small disruptions can be suppressed by the injection of brine of a specific concentration in the region in which the convection cell has developed. Figure 4 shows the result of such cell stabilization procedure. Apparatus is needed, therefore, to create an entire range of brine concentrations and to inject or extract at any desired depth. The frequency of occurrence of this destabilization in a solar pond is unknown due to the lack of operating experience.

The upward diffusion of salt will in time destabilize the density profile in a solar pond. This upward flux of material can be suppressed by superimposing a downward flow of the brine. For example, one may simultaneously take brine from the bottom of the pond and replace fresh water at the top of the pond. This creates a falling pond effect, in which the downward movement of

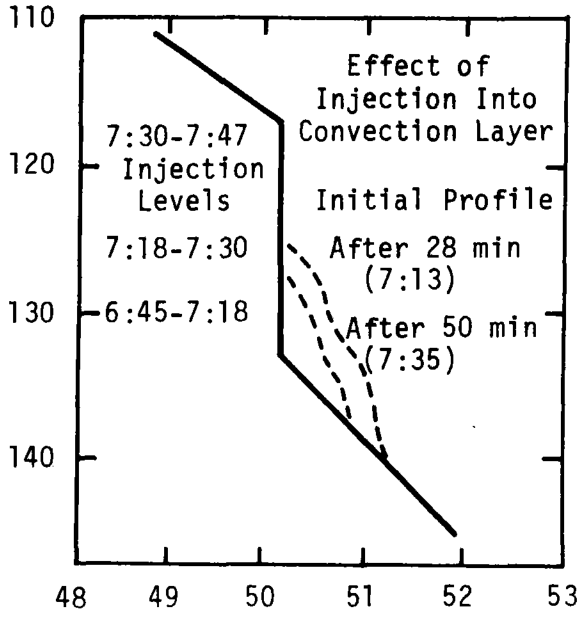


Figure 4

Effect of Brine Injection on a Convection Cell water will then balance the upward movement of salt. Salt must be replaced at the bottom in order to maintain the density gradient.

2.2 Power Generation Subsystem Design and Operation

The hot brine used for power production is extracted through a series of pipes located towards the bottom of the pond. The hot brine is then used directly or indirectly for electric power production. The two choices involve the use of a binary or a flash steam cycle. In the former, the brine is used to boil a second fluid. It is this second fluid which drives a turbine for electric power generation. In the latter choice, the brine is sent to a subatmospheric flash drum, from which steam and concentrated brine exit. The steam is used directly in a subatmospheric turbine system. These two systems will be described in greater detail in the following sections.

2.2.1 Binary cycle power generation

A binary cycle power generation subsystem will use hot brine from the solar pond to boil a generating fluid in one or more heat exchangers. A schematic of a proposed subsystem is shown in Figure 5.

Possible working fluids are the Freons®, ammonia, or isobutane. Ammonia is 40% more efficient than isobutane, but it is also more potentially hazardous. Operating conditions cited will be based on the assumption that isobutane is the working fluid. The heated working fluid is used to drive a turbine generator.

The hot brine to the heat exchangers will be from 70 to 90°C in an operating solar pond [1-4]. Table 1 presents some predicted operating conditions for a solar pond producing 9.9 MWe gross and 6.1 to 7.6 MWe net from brine at these temperatures. Such a solar pond would have an area of about 1 km^2 = 250 ac. Note that the cycle efficiencies cited in Table 1, 4.6 to 7.6%, are far lower

actual
PREDICTED
5 MWe gross
3.8 net.

and are still high by 2x

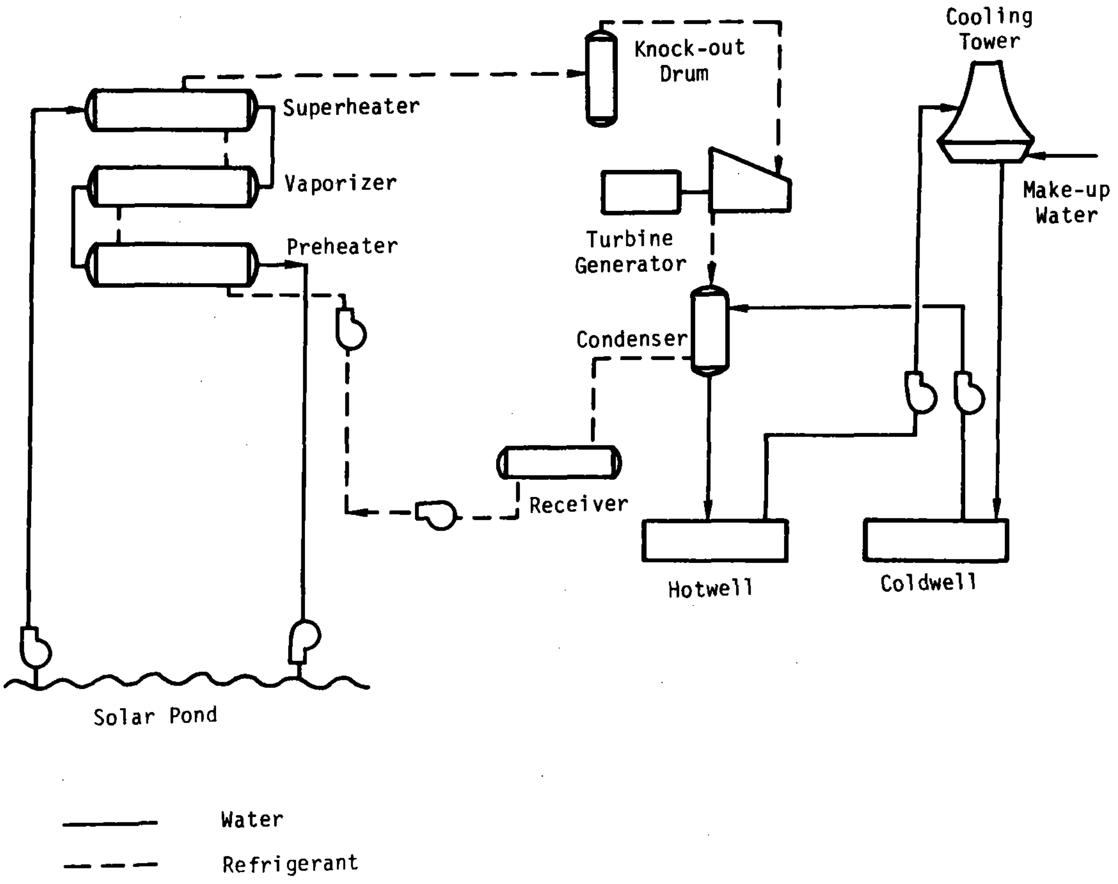


Figure 5

Binary Fluid Cycle Power Generation Subsystem

Table 1

Operating Conditions for the Binary System Solar Pond at 70°C and 90°C.
Gross Power Output = 9.9 MWe

Initial System Conditions		
Operation Temperature (°C)	90	70
Overall turbine efficiency	~73%	~73%
Turbine exhaust pressure (kPa)	476	476
Pressure drop in heat exchangers (kPa)	69	69
Operating Conditions		
Pond water flow rate (ton(metric)/sec)	2.97	6.34
Working fluid flow rate (ton/sec)	0.35	0.61
Cooling water flow rate (ton/sec)	2.05	3.55
Make up water for cooling tower (ton/sec)	0.040	0.071
Net power output (MWe)	7.6	6.1
Power Plant		
Cooling water temperature (°C)	19	19
Change in pond water temperature (°C)	11	8
Condensing temperature (°C)	36	36
Parasitic power losses:		
Cooling water (MWe)	1.0	1.7
Working fluid (MWe)	0.5	0.5
Pond water (MWe)	0.8	1.6
Actual Rankine cycle efficiency (%)	7.6	4.6

than those for conventional, nuclear, and STPS generating plants, which are typically 30 to 40% in current and near-term designs. For an efficiency η, the cooling load in a power plant per unit power output goes as (1-η)/η (i.e. as the ratio of reject heat to work). Thus the solar ponds described in Table 1 will have cooling loads 5 to 15 times as large per unit capacity as the other types of power plants cited.

$\frac{.95}{.05} = 19$

$\frac{.66}{.33} = 2$

~9.5x

2.2.2 Flash steam power generation

The second alternative cycle in the solar pond power plant is a flash steam cycle. In this system, pond water is pumped into a subatmospheric flash vessel. There, a pressure and temperature drop occurs, and flashes some of the brine to steam. The steam is used directly to run the turbine generator system. Figure 6 shows a system schematic.

Unlike the binary cycle, the flash steam cycle provides fresh water and concentrated brine for reinjection into the pond without added equipment. The disadvantage is that turbines that could handle this system are not commercially produced, and may be so expensive and so inefficient as to negate any benefits. In principle, the absence of a heat exchanger and its temperature drop might make a flash steam cycle more efficient than a binary cycle. The same choice of options and advantages exists in OTEC designs, and it appears that binary cycles are proving more practical and cost-effective in spite of lower cycle efficiencies. However, the conditions and economics in OTEC and solar ponds are far from identical. It would be unwarranted to conclude that the same preferential ordering of attenuators will prevail in the two cases.

2.2.3 Diurnal and meteorological cycles in power generation

The plants described above would be approximately 1 km^2 in area and 2 m deep. The total thermal mass would be

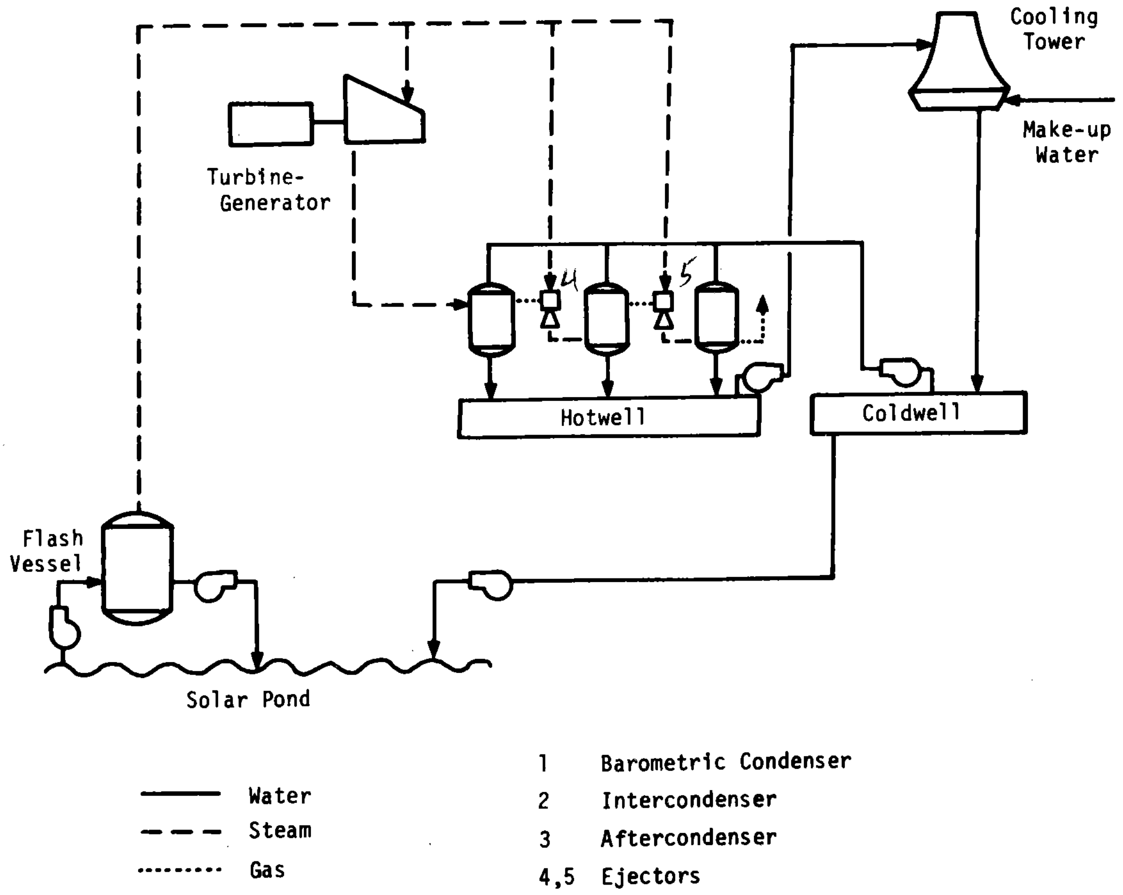


Figure 6

Flash Steam Cycle Power Generation Subsystem

$$1\ \text{km}^2 \times 2\ \text{m} \times \sim 4.2\ \frac{\text{kJ}}{\text{kg K}} \times \sim 10^3\ \frac{\text{kg}}{\text{m}^3} = \sim 10^7\ \frac{\text{MJ}}{\text{K}}$$

The power outputs of ∿10 MWe gross would require, depending on efficiency, a thermal power input of $\overset{200-1000}{\sim\cancel{100}}$ MW. Thus, the characteristic rate of change of the average pond temperature in the absence of solar input is

$$\frac{100\ \text{MW}}{10^7\ \text{MJ/K}} = 10^{-\overset{6}{\cancel{5}}}\ \frac{\text{K}}{\text{s}} \approx 10\ \frac{\text{K}}{\text{day}} \qquad \frac{2-10\,°\text{K}}{\text{day}}$$

This is not a completely descriptive analysis, for it is not the average, but the peak pond temperature on which cycle efficiency depends, and the region of highest temperature in the pond will be depleted more quickly. However, this calculation demonstrates that the thermal inertia of a solar pond is quite large. The pond certainly should be able to produce power at night with only modest loss in cycle efficiency. It is quite likely that operation during several days of cloudiness should be possible. This is particularly true in view of the non-focusing nature of solar ponds. Unlike other STPS, the diffuse insolation available with cloudcover is utilized as well as direct insolation. Consequently, substantial usable insolation is available to a solar pond under conditions in which it is not for other STPS.

3. Potential Hazards to Workers in Solar Pond STPS

3.1 Problem Scope

The use of solar ponds is a relatively less well defined endeavor than the other types of STPS reviewed in this report series [5-9]. Where possible these reports have tried to identify potential hazards to workers in a definitive and quantitative manner. The lack of reference designs or similar design documents for solar ponds precludes, the authors believe, a similarly concrete approach. Instead, the range of areas of potential worker hazards will be identified. Specific areas in which lack of knowledge or lack of design development preclude appropriate consideration will be noted.

As in the assessment of routine hazards [8], a standard system size of 100 MWe is assumed. This may be partitioned into independent or proximate modules as necessary. Where results are dependent on this partitioning, this will be noted. In rough terms, 100 MWe of solar ponds will have an area of about 25 km^2, and a minimum volume of 5.0×10^7 m^3.

3.2 Construction of Solar Ponds

The procedure for constructing a solar pond will be quite different for artificial ponds than for natural lakes. The pond depth, configuration, and materials will be determined by the conditions of the plant site prior to pond construction. For example, requirements for grading, drainage, access, and materials assembly will be substantially simpler for a natural saline lake converted to a solar pond than for an artificial pond.

The establishment of a solar pond requires the placement of a liner on the ground only if the soil is sufficiently porous that significant salt water intrusion might occur. As a rule of thumb, soils with a 20% clay pan will not need liners.

The terrain must be level to some small fraction of the 2 m pond depth. This may present a substantial earthmoving task except in carefully selected sites. There will in general have to be an earth berm erected around the site. This is done both to contain the liner if one is used, and to provide for brine containment during rains.

The most commonly suggested salt for a solar pond is magnesium chloride, $MgCl_2$. The saturation concentration of this salt is about 25 wt.%. The concentration of $MgCl_2$ brine will decrease approximately linearly from this value towards zero as the depth in the pond decreases, giving an average concentration of about 12.5 wt.%. A concentration of 12.5 wt.% $MgCl_2$ at 40°C has a density of 1100 kg/m^3 [10]. A 100 MWe solar pond system having 25 km^2 of area nd 2 m depth will thus have about

$$25\ \text{km}^2 \times 2\ \text{m} \times 1.1\text{x}10^3\ \frac{\text{kg}}{\text{m}^3} \times 0.125\ \frac{\text{kg MgCl}_2}{\text{kg}} \cong 7\text{x}10^6\ \text{tons MgCl}_2$$

This will have to be brought to the site or sites used. A typical unit train has 100 boxcars holding ∿100 tons each. This amount of salt would thus require ∿700 unit trains.

The salt will have to be dissolved to form brines of progressively lower concentrations as the layers of brine are successively placed in the pond. During this time convection must be suppressed in the presumed absence of pond operation. The heat of solution of $MgCl_2$ is 150 kJ/mol [10] at infinite dilution and starting from anhydrous salt. As a conservative approximation, one could estimate the maximum temperature rise of the brine during dissolution by using this heat release. In 25 wt.% $MgCl_2$, there are 15.9 mols H_2O per mol $MgCl_2$. The heat capacities of $MgCl_2$ and H_2O are 77.0 and 75.3 J/mol K [10], so assuming additivity, the maximum temperature rise would be

$$\frac{150\ \text{kJ/mol}}{[77.0+(15.9)(75.3)]\ \frac{\text{J}}{\text{mol (MgCl}_2\text{) K}}} = 118\ \text{K}$$

actually, this would be helpful in starting up the pond!

In reality, a substantially smaller temperature rise would occur, since the use of the heat of solution at infinite dilution is an overestimate of the value at finite dilution. Further, a hydrated, rather than anhydrous salt, would have been used, and the heat of solution would again be reduced. However, a salt such as the octohydrate, $MgCl_2 \cdot 8\ \overset{H}{M}_2O$, would require shipping about 2.5 times as much salt to the site. (If the solution processes were performed in sequence, such as anhydrous to octohydrate salt, then octohydrate salt to brine, the same total heat would be released. This might exacerbate, rather than reduce, the thermal release problems.)

The heat release could cause some potential safety hazards such as dispersal of hot brine. It may also require that procedures for temperature adjustment be included in the brine making process.

3.3 Water Supplies for Solar Ponds

A typical 100 MWe coal-fired power plant uses approximately 250 ha-m (1 ha (hectare) = 10^4 m^2) (2,000 acre-ft) of water per year for cooling. Due to the lower efficiency of a solar pond, it was estimated in Section 2.2.1 that 5 to 15 times as much cooling water would be required, or 1,250 to 3,750 ha-m/yr (10,000 to 30,000 acre-ft/yr). The pond will also consume water due to evaporation. Depending on location, evaporation may amount to 1.5 to 3.0 m/yr (5 to 10 ft/yr) [12] in areas in the arid southwest well-suited to solar pond development. Since the 100 MWe pond will have an area of about 25 km^2 (2500 ha; 6200 acres; 9.7 mi^2), evaporation will amount to 3750 to 7500 ha-m/yr (30,000 to 60,000 acre-ft/yr). Total water consumption is thus 5,000 to 11,250 ha-m/hr (40,000 to 90,000 acre-ft/yr). This is 20 to 45 times as much water as would be consumed by an equivalent coal-fired plant. The use of a cover on the pond could decrease water consumption by 2/3 to 3/4.

The joint problems of salt and water supplies can be quite substantially modified in some natural pond sites. For example, if the solar pond were built in an area where at least some proportion of the salt were already present, the handling problems described can be reduced. One such solar pond site is the Salton Sea, located in the Imperial Valley in California; 15-18% or 150 km^2 of the sea would be used for a 600 MWe solar pond [11]. In 1972 the salinity of the Salton Sea was 38,000 ppm (3.8 wt.%) and increasing at a rate of 550 ppm per year [12]. The projected salinity level would be 42,000 ppm (4.2 wt.%) by 1979. The water in the Salton Sea is supplied from agricultural runoff from surrounding farmlands. The salinity of the runoff water averages 3000 ppm and brings in $12x10^6$ kg/yr of nitrogen compounds and $0.5x10^6$ kg/yr of phosphates. Some fraction of the 2000 tons of insecticides dumped annually over local farmlands also ends up in the runoff entering the Salton Sea.

Under these circumstances, the water and part of the salt may be available without extraordinary diversion of materials to the solar pond. A schematic diagram of such a natural solar pond is shown in Figure 7. The principle additional features required are a means of handling wastes in the inflow water. This will likely require an evaporation pond about 10% as large as the solar pond, as shown in Figure 7. This will potentially expose the plant workers to a series of hazardous materials, including pesticides and chemicals in the inflow water and the necessary treatment chemicals.

3.4 Salt Deposition and Dispersal

Salt deposition and dispersal is a problem identified in many cooling tower applications. For example, the Palo Verde Nuclear Generating Station Environmental Statement [13] reports that the maximum instantaneous particulate concentration at the cooling tower mouth is 1860 $\mu g/m^3$. During the 40 year lifespan of the plant, greater than 5600 kg/ha (5,000 lb/acre) of salt will be deposited on up to 2300 offsite hectares (5600 acres) and more than 1100 kg/ha (1000 lb/acre) will be deposited on up to 8900 ha (22,000 acres). Most will remain in upper soil regions, resulting in lower rates of water penetration and increased erosion. Local vegetation will suffer mainly because of the increased osmotic potential, making it difficult for the plant root to withdraw water from the soil. Also, specific ions may inhibit plant nutrition or be toxic. Seed germination may occur less frequently and eventually cease. Non-halophytes will decline and then cease, leaving the halophytes to take over. In the California desert this means the saltbush would thrive whereas creosote and burrobush would die off. Local agriculture may

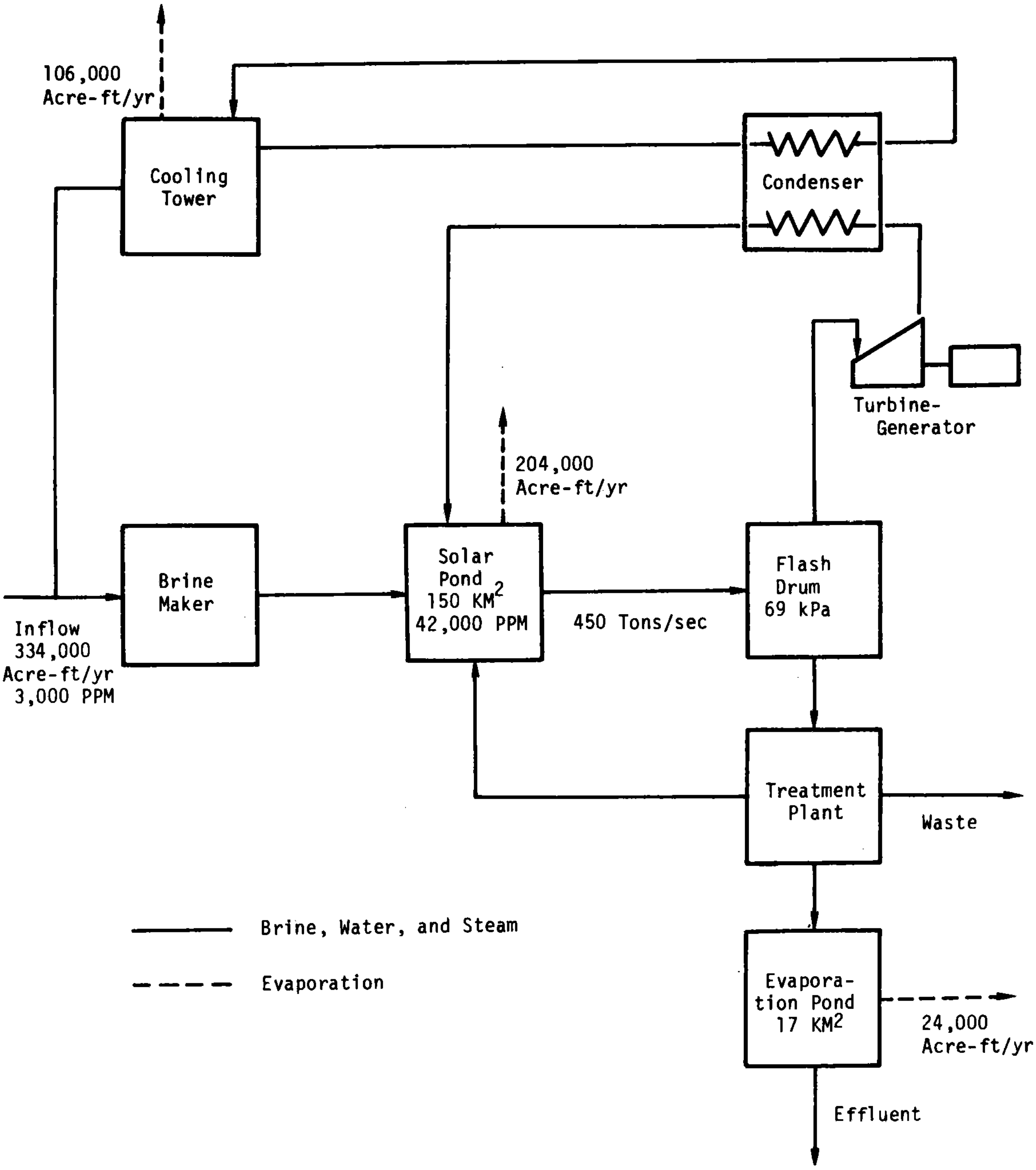


Figure 7

Salton Sea System

survive the salt because of large volumes of irrigation water that discourage salt buildup. To prevent detrimental effects on productivity, flushing may have to be increased.

3.5 Microorganisms

Bacterial growth in solar ponds is a complex problem, since salt and nutrient concentrations, and temperatures, will vary in the different layers. There are extreme halophilic bacteria that can exist even at salt concentrations of 25-30%. If any strains are pathogenic, this may pose a serious health problem to plant workers. In a site such as the Salton Sea, where the rest of the sea is used for recreation and substantial populations are nearby, the potential problem is more serious. Even if the bacteria are not pathogenic, their presence reduces the transparency and thus the efficiency of the pond. Addition of antibacterial agents, on the other hand, may also create a health hazard.

3.6 Microscale Meteorological Effects

Due to the large amounts of water used and evaporated, fog formation in the area of a solar pond is a possible problem. The San Joaquin Nuclear Project [14] reports very little fog, less than 17 hrs/yr fog from the cooling towers. Meteorological conditions in the area will be the determining factor as to whether formation is extensive. If fog formation is extensive, the reduced visibility may create various worker hazards.

3.7 Operations and Maintenance

Solar pond operations and maintenance (O&M) can be partitioned into two principal areas, the power generating equipment and the pond itself. The power generating equipment will be considered in view of the extensive work done in geothermal power systems, particularly those based on hot water use.

The operation~~s~~ and maintenance of the pond is more speculative, since it is a unique feature of a solar pond STPS, and will be considered separately.

3.7.1 Power generating equipment O&M

Much of the necessary analysis of the power generating equipment can be inferred from geothermal plants operating on a binary fluid cycle. The geothermal plants operate at somewhat higher temperatures and slightly lower flow rates and salinity. Within the diversity possible in power plants, however, they are a reasonably good comparison to projected solar pond operations.

Table 2 lists various types of equipment expected in geothermal or solar STPS plants, along with reliability and maintainability factors. Failure modes for power plant equipment are also noted. Substantial worker time will be spent in routine inspection and repair or replacement of worn parts. Many factors are closely related to accident and injury sources in the electric power industry [6]. A higher rate from injury may come from electrical equipment, fire hazards from turbine working fluids, and contact with hot brine. The effects of chronic exposure to working fluids such as ammonia may have to be considered.

3.7.2 Pond O&M

Pond O&M hazards are more speculative, because there are few existing systems even remotely similar to proposed solar ponds. Many special problems and hazards may arise due to the large scale operation. These problems include debris and microorganisms, materials handling, and waste disposal.

Debris or microorganisms in the pond will be detrimental to plant operations for two reasons. First, as discussed above, reduced clarity lowers the thermal stratification of the pond by reducing the amount of light reaching

Table 2

Solar Pond STPS Generating Equipment Failure Modes
(Adapted in part from Ref. 15)

Equipment	Failure Mode	Adverse Safety Effect
Pumps	Component wear (blades, seals, impellers)	
Vapor/liquid separator	Corrosion or erosion	May affect turbine operation if separation is ineffective
Brine/working fluid heat exchanger	Corrision	
	Leaks or occlusion	Overpressurization. Turbine damage
Turbine	Component wear, fatigue, erosion	Missile generation
Alternator/generator	Short or open circuit	Fire hazards (H_2 coolant)
Condensor	Leaks	
Working fluid	Leaks	Fire hazard (e.g. isobutane)

the bottom. This will lower peak temperatures and plant efficiency. Secondly, larger debris as well as algae growth may plug brine transport pipes located in the pond. This will inhibit the uniform flow of hot brine in and out of the pond. However it occurs, there must either be access to the pipes in order to correct the problem or some external means of treating the pond. For example, a person could be sent out in a boat to manually or mechanically clear the pipes, or chemicals would be used to coagulate and precipitate algae. Each suggested means has some technical problems for pond operating, as well as some associated worker hazards. For example, a person in a boat or on a platform over the pond may disturb the pond's hydrodynamic stability with any equipment put in the water. There is also some possibility of falling into the pond. Since the pond waters are up to 90°C, falling in would lead to serious burns. The buoyancy due to the high concentration of salt in the water might float a person provided that person was not wearing heavy tools or clothing. Ingestion of pond waters during such an accident could lead to serious injury.

Materials handling presents some significant potential hazards. Both in establishing the pond and in normal plant operations, large volumes of salt must be made into brine of varying concentrations and processed through a pumping network in the solar pond. If a convection cell is developed, additional brine must be made and injected at specific depths in the pond. All of these operations involve chemical and mechanical hazards for plant workers. The magnitude of these hazards is undetermined due to the unique scale and nature of operations.

Waste disposal may present a series of potential worker hazards. In the solar pond proposed for the Salton Sea, agricultural runoff is the primary source of water for pond and generating plant operation. The nutrients in the agricultural runoff will accumulate in the pond. At some time this increase may interfere with the salt gradient and with other plant operations. Therefore, waste disposal must be included in the plant.

The most likely method of stabilizing impurity concentrations in the pond will be by evaporation of a portion of the pond effluent. This will reduce handling problems and conserve water, but require the disposal of concentrated solutions of potentially hazardous or toxic materials. Problems associated with sanitary waste disposal may be shared by solar pond operations, including toxicity of chemicals used in waste concentration and treatment.

4. Conclusions

The design of solar pond STPS is still quite speculative, but several technically feasible systems do exist. Several types of hazards to workers in solar pond STPS have been identified. While some effect of the design on these hazards is noted, in general no clear delineation and ordering can yet be developed for alternative solar ponds.

Material handling problems, uncluding mechanical hazards and chemical hazard and toxicity, are potentially significant adverse contributors to worker health and safety. Brine handling problems are present in several aspects of plant construction, operation, and maintenance. Toxicity of additives to control microorganisms, or of the microorganisms themselves is an area of potential concern both for workers and other exposed population. Salt intrusion and dispersal may be of concern.

Depending on the water supply used, toxic or hazardous materials may be present. This may lead to additional hazards to workers, including hazards from waste disposal processes needed to stabilize pond concentration of these materials.

Other hazards identified include fire hazards from flammable turbine working fluids such as isobutane, and micrometeorological effects leading to reduced visibility.

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