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BATES SOLAR-INDUSTRIAL PROCESS-STEAM APPLICATION

DRAFT SAFETY REPORT

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BATES SOLAR INDUSTRIAL PROCESS
HEAT APPLICATION SAFETY ANALYSIS

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BATES SOLAR INDUSTRIAL PROCESS HEAT APPLICATION SAFETY ANALYSIS

A. Introduction

The Department of Energy from the San Francisco Operations office has awarded Bates Container, Inc. and its prime subcontractor, The BDM Corporation, a contract to design a Solar Industrial Process Heat System. Bates, a corrugated box manufacturer, proposes to install approximately 35,000 square feet of linear parabolic trough solar collectors on the roof of its new corrugator plant. The parabolic collectors will collect the thermal energy required to generate 5500 lbs/hr of steam to drive the corrugator. The solar energy system will satisfy the average daily demand of the corrugator and will operate in parallel with the fossil fuel boiler which will supply supplemental steam when necessary. A schematic of the system is presented in figure 1.

Phase One, Design and Analyses, of the Bates Solar Industrial Process Heat Project requires a Preliminary Safety Analysis to be done on the solar energy system and an assessment of its effect on the employees. Potential hazards of the system are to be addressed, including corrective measures.

A description of each of the subsystems is contained in the following sections. For each subsystem the possible safety hazards are identified and recommendations are made to either eliminate or control the hazards at an acceptable level. Table 1 summarizes the subsystems, their safety analysis, and resolution. Safety procedures will be written as part of the O&M plan, and all hazards will be clearly marked with warning signs.

B. System Description

BDM has designed a cost-effective roof-mounted solar array for the Bates Solar application project. This was accomplished by integrating the collector mounting system with the structural support. The resulting

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Figure 1. Schematic of Solar Industrial Process Steam System

TABLE 1. BATES SUBSYSTEM ANALYSIS

<u>SUBSYSTEM</u>	<u>SAFETY ANALYSIS</u>	<u>RESOLUTION</u>
MOUNTING STRUCTURE	MAINTENANCE WALKWAY LIGHTING ROOF ACCESS	HANDRAILS, SLIP-RESISTANT TREADS, LIFELINES FLOODLIGHTS, FLASHLIGHTS HANDRAILS, INTERLOCK
COLLECTOR	FOCAL POINT OF COLLECTOR HIGH TEMP OF RECIVER TUBE	WARNING WARNING
HEAT TRANSFER FLUID	TOXICITY OUTGASSING PRODUCTS LEAKS FIRE	PRECAUTIONS WHEN HANDLING SMALL AMOUNTS GUTTERS, LEAK DETECTORS, TEST PRESSURIZING, SENSORS, VALVES, AIT
INSULATION	WICKING	GAPS IN INSULATION WITH DRAIN HOLES
PUMP/FILTRATION UNIT	HOT SURFACES	WARNING SIGN
HEAT EXCHANGER ROOM	POSSIBLE VAPOR EXPLOSION	VENTS, FIREWALL FOAM SPRINKLER
PROTECTION, INDIVIDUAL	HIGH TEMP, ELEVATION, HOT FLUIDS	PROTECTIVE CLOTHING, LIFELINE, FIRST AID STATIONS, SHOWER, EYEWASH
LIGHTNING PROTECTION		LIGHTNING PROTECTION SYSTEM
FIRE PROTECTION	SPARKS OIL VAPOR	CONDUIT, CLOSED SWITCHES FOAM, STEEL ROOF, LEAK-PROOF, WELDED CONNECTIONS, SPECIAL INSULATING PROCEDURES, HIGH AIT FLUID (850° F), TEMP- ERATURE DETECTORS, WATER- FOAM FIRE SYSTEM

structure, shown in figure 2, consists of a sloped frame of steel open-web joists supported by steel I-beams on reinforced concrete piers. Collector joists support the collector vertically along each collector row and provide attachment points for the collector bearing blocks. These vertical joists, lying flat, support the collector drag loads and provide a maintenance walkway. The frame/column system is designed to withstand winds up to 100 mph.

The solar collector and integral roof structure have been designed to endure the extremes of weather in the Fort Worth area and to comply with the Dallas-Fort Worth Building Code. The following design criteria were used:

- (1) 40 mph wind (operational condition with collector in any attitude)
- (2) 25 psf wind load (100 mph, survival condition from building code with collector stowed)
- (3) Structure weight loads (collector system plus support structure)
- (4) 0 to 100° F temperature conditions

The large horizontal joists incorporated between collector rows as part of the support structure will double as maintenance walkways for the collector system. The width of these girders allows room for a repair person to maintain the system. To prevent slipping on these beams, slip-resistant treads will cover the walkways. Collapsing handrails on the walkway will be featured to comply with OSHA standard 1910.23 and to minimize shading effects. See figure 3.

Most of the maintenance work will be conducted at night so as not to interrupt the solar energy collection. Floodlights mounted on the roof will illuminate the array when repairs are being made on the system. Explosion-proof lights will also be available to the workers.

Access to the roof-mounted solar array will be via fixed stairway located on the Bates facility. Handrails and non-skid runners on the stairway will be provided as required by OSHA standard 1910.24. A lockable opening atop the stairway will be the entrance to the roof. To comply with OSHA standard 1910.23, the opening will have a hinged cover

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Figure 2. Design Concept for Solar Collector Support Structure for Bates Installation

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Figure 3. Collector Gutter System

of standard strength and construction and removable standard railings on all exposed sides, except at the entrance to the stairway. The stairway will continue on the roof up to the maintenance walkway, which is approximately two feet above the roof. Locks will be installed prior to the stairway to minimize unauthorized access.

An interlock between the door to the roof and the solar energy system will be in effect so that when the door opens, the solar energy system shuts down. This reduces the possibility of encountering hazardous situations on the roof, such as pressurized hot heat transfer fluid.

C. Master Control System (MCS) and Data Acquisition System (DAS)

The key to the safe operation of the Bates facility is the MCS. The control room will be separate from the corrugator which will reduce the noise and help prevent contamination to the instrumentation. The control room will house the data acquisition hardware which includes a Hewlett-Packard 9825 series programmable calculator, signal conditioner, cassette tape storage, and I/O display. Also in the room will be a Hewlett-Packard 9815 programmable calculator which will be used as the system controller.

Since the main computer is both programmable and able to initiate control functions, the sensor inputs are compared to acceptable and alarm levels. Corrective actions, such as valve adjustments and closures, can be signaled and initiated if needed.

Collector stow can be initiated by a signal indicating low insolation, under pressure, or over temperature. Low pressure detectors and Resistance Temperature Devices (RTD's) will be located on each row for flow control. These signals are input to the MCS which interprets them. If they are beyond alarm thresholds, collector stow and flow stoppage can be automatically initiated for each row or systemwide. Additionally, four valves make up the CS temperature control and safety controls. The first and last are used for positive shut-off of the row outlet since the flow control valve is not designed for the function. The second is located at the inlet and is an automatic on/off valve that can be closed

from MCS signals arising through a no-flow low pressure condition. It also can be manually operated. Its function is to stop flow into the collector in case of a break. The third valve senses the row output temperature and fixes flow to meet the required temperature. In the event of a break this valve can be closed, thus isolating the collector row.

The heat transfer fluid loop, pump flow, and safety circuit consist of pump speed controls, a series of automatic shut-off valves to isolate sections of the heat transfer loop, and flow meters to detect leaks in the circuit. The flow meters are located on either side of the pump and ensure that intergrate fluid flows are equal.

Safety controls regulating the solar and fossil steam generator liquid levels, pressure relief valves, and makeup water levels will also be installed.

For visual observation of the system operating conditions, Bailey meters will be mounted for flow measurements of both the heat transfer fluid and steam. Pressure meters will be installed to gauge fluid and steam conditions at the appropriate locations.

D. The Collector

The collector used for the baseline design was the equivalent of the Solar Kinetics (SKI) linear parabolic trough with a 7-foot aperture, designated the T-700. The current Solar Kinetics troughs have been evaluated by Sandia Laboratories as one of the best systems available today.

The T-700 is manufactured in 20-foot long sections and constructed with aluminum components using a monocoque design with an aircraft grade aluminum skin. The reflector surface is an acrylic film made by 3M, FEK-244. Weather testing has shown less than 4-percent specular loss over 3 years and no other satisfactory degradation.

The collector structure is extremely resistant to deflection and damage because of its monocoque design and high grade aluminum skin.

Natural hailstones up to three-fourth-inch diameter have not caused damage to the aluminum skin in the Solar Kinetics test stand in Dallas. Extrapolation of wind tunnel test shows the T-700 able to withstand 90 mph winds in the stowed position and steady 40 mph winds at any focal position.

Since maintenance on the array will be conducted mostly at night after the system has cooled, the collectors will present no danger. However, if workers are on the roof while the system is hot, sensible precautions need to be taken, such as keeping limbs away from the focal point of the parabolic collector and being aware of the high temperature of the receiver tube.

E. Heat Transfer System

The heat transfer fluid selected for the Bates project is Therminol-60 manufactured by The Monsanto Chemical Company. Therminol-60 is an inexpensive, synthetic hydrocarbon mixture with excellent chemical properties and temperature range which make it ideal for this kind of operation.

Monsanto has conducted laboratory experiments to determine the toxicity levels of Therminol-60. Humans and rabbits were subjected to dermal applications of T-60, and rats were exposed to inhalation and ingestion tests. The Manager of the Environmental Assessment & Toxicology Department has concluded that Therminol-60 is considered nontoxic by ingestion in single doses and by single dermal applications. Prolonged contact with the fluid can cause eye irritation and skin irritation; therefore, immediate removal of T-60 is necessary. This can be achieved by flushing eyes or skin with plenty of water. Standard industrial precautions should be exercised when handling T-60 to minimize contact.

Due to its low vapor pressure, T-60 does not present an inhalation hazard at ambient temperatures. Vapor emitted by T-60 heated to elevated temperatures may be mildly irritating and cause discomfort on prolonged exposure. However, in the heat transfer installation, the fluid will be

used in a closed system with the expansion tank vent trapped so as to condense any vapor. Consequently, there should be little or no opportunity for workers to come in contact with the vapor.

Minimal maintenance and, therefore, minimal employee exposure to the heat transfer fluid is expected since the system incorporates a continuous filtration unit and make-up system. The filtration system eliminates the sludge, or oxidation and thermal degradation precipitates, from the heat transfer fluid. The anticipated life expectancy of T-60 is thirty years, which should negate the need for periodic oil changes.

Measures are being taken to prevent any leaks of the heat transfer fluid in the solar energy system. Leaks constitute a fire hazard, an environmental problem, and a safety risk. As the temperature of the heat transfer fluid rises, the viscosity drops, thus making ordinary threaded pipe fittings more susceptible to leakage. Either butt or socketed joint welds will be used on valving, pipe joints, reducers, and any other connections. Certified welders guarantee their work which will minimize the possibility of leaks. A leak test using compressed nitrogen and leak detector will be performed prior to the installation of insulation.

The heat exchanger, the pump, and filtration unit will be tested, similarly, to ensure the absence of leaks. Pressure testing of the heat transfer subsystem will be done according to paragraph 137.2 of ANSI B31.1.

The flex hose connected to the collector is usually silver-brazed, but has been a source for possible leaking. To prevent any problems from occurring, this connection will be welded according to the specifications of the other pipe connections in the system. Gutters around the perimeter of the roof and troughs located under any overhanging fluid transport pipe will keep any large spills from dripping off the roof and harming either persons or the environment below. Oil leaks should not penetrate the galvanized steel roof. Tools accidentally dropped by maintenance workers will also be collected by this containment system. No oil is expected to leak through the Bates roof since the fluid will have a tendency to flow down the sloped roof to its lowest point of potential energy, thus the gutters.

Therminol-60 as well as other heat transfer fluids will eventually oxidize and degrade when exposed to the atmosphere; therefore, the overflow tank will be pressurized with commercial-grade nitrogen to act as a blanket to the fluid, preventing outside air from contacting it. Nitrogen was selected because it is inert, inexpensive, readily available, and nontoxic. The pressurized tank will be secured to prevent any accidental dislodging. The pressure will be regulated at both the nitrogen supply and also on the tank as a gas bleed-off when the fluid is expanding. Pressure for the incoming nitrogen will be kept at 1-2 psi above ambient pressure to ensure a positive pressure when the system is thermally at a minimum. A pressure relief valve will be used to vent the gas as the fluid expands. The suggested arrangement is in parallel with the main piping system to prevent pumping losses and to ensure maintenance without affecting the main supply.

At the end of the working day the heat transfer system can be checked for leaks by pressurizing the system with nitrogen to 100 psi, the daily operating pressure. If a drop in pressure over and above temperature effects has occurred by the following morning, a leak is probable and a visual search of the system must be conducted. The leak can be isolated by closing off select collector rows and pressurizing the system.

The ullage system will be sized to accommodate the expansion of the heat transfer fluid when it is heated to high temperatures to prevent overflowing and over-pressure. Thus, the tank will be one-fourth full at ambient temperature and three-fourths full at operating temperature.

The ullage system is also functional in removing contaminants from the fluid through condensation. Noncondensable vapors, the outgassing products of T-60, will be automatically vented and condensed in a cold trap each day as the fluid is heated and expanded.

The remainder of the heat transfer system includes the piping, insulation, pump, and filtration unit. Mild steel was selected for the piping system because of its cost, weldability, availability, and adaptability to valving and couplers. Welded joints increase reliability by minimizing possible leaks.

The piping system will be insulated with a standard high temperature insulation, aluminum-silicon fibers. To prevent the transfer of leaking oil, there will be gaps in the insulation, especially in areas of potential leaks such as T-joints, valves, and instrumentation. This can be seen in figure 4.

Valves have been located to permit control and isolation of individual collectors and sectors of the main header for repair. These valves will also be insulated. Adjusting the flow will be done with the use of gloves. Valve stems will be placed horizontally to prevent any fluid leakage from entering the insulation.

The insulation will be jacketed with aluminum to protect against deterioration and weather effects. This aluminum jacket is expected to reach maximum temperature of 95° F and, therefore, will not be hazardous to persons working on the solar array.

Leak detection will be provided via leak detectors located under all valves shown in figure 4. Holes will be located in insulation gaps near areas for potential leaks. These holes minimize the amount of insulation contamination by allowing the fluid to drain out and be detected. Windows will also be incorporated into the aluminum jacket to detect insulation contamination by the fluids.

A high temperature, variable speed pump will be installed at the mixing tank discharge and sized to provide 200 gal/min at 100 psia of head. The pump will be insulated except for its motor which would overheat if insulated. A sign will be posted to warn the employees about the hot surfaces of the motor.

The pump will be located on the pumping pad at the base of the Bates building on the west side. The pumping pad will be enclosed by a 6-foot high chain link fence topped with barbed wire for security reasons. A floodlight will illuminate the pad for maintenance and for discouraging vandals.

Also, located on the pumping pad is the filtration unit. This unit will be insulated and covered to prevent heat loss as well as protecting the employees from the hot machinery. A hoist may be required for the removal of the filter cartridges once a year. These cartridges are expected to weigh 75 pounds each.

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Figure 4. Typical Valve Insulation

F. Fire

Many precautions were incorporated in the design of the heat transfer system to prevent the possibility of fire stemming from the solar array. To prevent oil leaks the system will be built with low carbon steel pipe and will have all tees, couplers, valves, and reducers socket welded. After the heat transfer system is assembled and welded, a leak check using compressed nitrogen and soapy water will be performed on all welded joints, valves, and fittings. This will ensure a leak tight system. Then the only possible place for future leaks to occur will be around the compression type fittings and valve seals. The valves will be installed with the stem pointing down so that if a leak does occur the oil will not saturate the insulation.

The insulation chosen for the solar array is an alumina-silica blanket. It has excellent thermal conductivity properties and will not burn. It will be used to wrap both the pipe and valves. Non-wicking insulations such as foamglass and calcium silicate were considered for wrapping the valves and fittings only; however, further research into these products proved they had no benefit over the alumina-silica blanket. Foamglass requires a buffer insulation between it and the valve for temperatures above 450° F. The manufacturers recommend alumina-silica for the buffer insulation. This negates the use of the more costly and more thermally conductive foamglass. Though calcium silicate is non-wicking, it was not selected because it will absorb oil. This poses a fire hazard as explained in the literature from Monsanto, the manufacturers of the heat transfer fluid. The exothermal oxidation reaction between the oil and calcium silicate could cause spontaneous combustion when exposed to the air.

Since the chosen insulation, alumina-silica, wicks somewhat and could transmit leaking oil along the piping, the following procedure will be followed to address this effect. Around every joint, valve, and fitting there will be a 2-inch break between the insulation surrounding the fitting and the insulation surrounding the pipes. A 1/2-inch diameter drain hole will be drilled at the bottom of this gap in the aluminum

jacket covering the insulation. This will ensure that any oil leak will be contained to a very local area. The drain hole will also serve for visual location of leaks by their dripping.

In the event of repair to the system which requires removal of the aluminum jacket, in order to prevent accidental exposure of oil-saturated insulation to the air, inspection holes will be cut in the aluminum jacket and covered with transparent plates. These plates will be installed at all valve and compression fittings and periodically along the piping. A visual examination will warn the repairperson if a leak has occurred.

The selection of the heat transfer fluid Therminol 60 was made due to the high autoignition temperature of any component designed to produce 500° F temperatures of the system. This fluid will pour at -90° F and has a maximum operating temperature of 600° F.

In the case of a major line break in the collectors, automatic opening and closing valves will be installed to isolate the break. These valves will actuate whenever there is a sudden loss of line pressure. Any oil spilled will be contained by a network of gutters which will isolate the oil from any combustionable material and drain the oil to a safe area. The only combustionable material that could be near the oil will be coated with gypsum to flameproof it.

The solar array will be wired with a continuous, low-melting point, conductive tape which, when exposed to flame, will create an open circuit. This device will then trip an alarm inside the Bates building to warn the employees to evacuate and will notify the firm alarm service which in turn will contact the local fire department. The neighborhood fire department is located within two-tenths of a mile from the Bates facility.

In the event a fire does break out on the roof, a fire protection system will transport foam to the pitch of the roof and to the trough along both sides of the building. The normally dry transport piping will be activated when the sensing tape is open-circuited. A chemical housed inside the building will automatically mix with water under pressure to produce foam which will be transported through piping to nozzles located

on the roof. Any oil fire will then be suffocated by the foam and washed off the roof.

Since the steam generator is inside the plant building, special precautions will be implemented for safety. The room will be located along the perimeter of the building and have explosion vents in its exterior wall. Also a fire barrier wall will be installed on each interior side. High volume air vents will be installed in the room to evacuate any oil vapors, in case of a leak. Foam nozzles will also be installed to flood the room in case of fire.

No smoking will be permitted anywhere near the solar energy system.

G. Individual Protection

When maintaining the solar array, employees will be protected from the hot surfaces by the use of protective clothing and sensible procedures. Employees will be expected to wear high temperature resistant coveralls, gloves, and hard hat with face shield. Safety belts or harnesses may be required.

Abiding by the rules of the company and heeding warning signs will be expected of the employees. No one should be permitted to work on the collector or heat transfer system while they are operating or when they are hot. When working on the solar array during daytime hours, sunglasses will be provided to protect employees' eyes from concentrated sunlight.

First aid kits and supplies will be easily accessible to the maintenance workers. A safety shower and eyewash fountain will also be available.

H. Lightning Protection

Several methods for protecting the Bates facility against lightning have been considered. These include the passive or standard lightning rod, radioactive lightning rods, and towers or poles which are an extended form of a lightning rod. Another lightning protection device

being considered is the Dissipation Array System (DAS) developed by the president of Lightning Elimination Assoc., Inc. This system is going to be installed on the new BDM/TAC facility in Albuquerque, New Mexico, to protect the photovoltaic array mounted on its roof. The DAS is a proven success from results of the other users of the system and was chosen for the Bates facility.

The DAS includes a dissipator, a ground current collector (GCC), and service wires. The ground current collector wire is buried 10 inches below the ground surface around the facility it is going to protect. Rods about a yard long will be connected to the GCC wire and buried at 30-foot intervals. The service wire connects the GCC to the dissipator--a type of antenna dependent on the structure it is protecting. For a more detailed discussion of the DAS and its theory of operation consult "Lightning Strike Elimination, The Story of Dissipating Array Systems," Roy B. Carpenter, Jr., Sept. 1979, Rpt. No. LEA-79-1, Lightning Elimination Associates, 12516 Lakeland Rd., Santa Fe Springs, California 90670.

Transient suppressers will also be installed in the Bates system between the DC wiring on the roof and the power supply or instrumentation below. This suppressor will reduce the voltage surges in the wiring when lightning strikes.

The pump and filter located outside on the pumping pad will need to be grounded. The heat transfer fluid piping that connects to these two units will ground these units, but the use of a buried copper pipe connected to the two units will ensure that they are grounded.