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FOSTER WHEELER SOLAR DEVELOPMENT CORPORATION

MODULAR INDUSTRIAL SOLAR RETROFIT (MISR) INTERFACE DESIGN FOR DAVIS & GECK DE PUERTO RICO

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Section 1

INTRODUCTION

An interface design has been prepared for the installation of a Modular Industrial Solar Retrofit (MISR) System at Davis & Geck's Manati, P.R. facility. This MISR system has been tailored to the needs of Davis & Geck: It differs from the existing MISR system in that the collector field has been rearranged and all provisions for freeze protection have been eliminated. Based upon this design, a price estimate has been prepared for a MISR field installation.

Section 2

OPERATING STRATEGY

Davis & Geck's Manati, P.R. facility currently uses 125 lb/in^{2}g steam produced by two steam generators: the kerosene fired braid wash steam boiler and an unfired steam generator. The latter utilizes hot oil, heated in a kerosene fired furnace, as the source of heat for steam; this oil enters the steam generator at 560°F and returns at 550°F. The actual demand on the unfired steam generator is 3,100 lb steam/hr, that on the braid wash steam boiler is 643 lb. steam/hr. The braid wash steam boiler is utilized largely in the daytime and can start up rapidly.

To make the most efficient use of a MISR system, we propose the following operating strategy:

- Substitute MISR generated steam for that produced by the braid wash steam boiler whenever the MISR system is operating.
- Introduce any additional steam from the MISR system into the steam line from the unfired steam generator downstream of the flow control valve in that line.

The rationale for this operating strategy is as follows:

- Both the braid wash steam boiler and the unfired steam generator can rapidly be brought on line--the former because of its low thermal inertia, the latter because its hot oil heat source also serves other functions.
- The braid wash steam boiler is used intermittently.
- Steam from the braid wash boiler is used at lower pressures than that from the unfired steam generator.

o The hot oil return temperature exceeds the temperatures available at any place in a MISR system. Accordingly, it makes no sense to utilize the MISR system to keep the oil hot. Rather steam from the MISR system will simply be introduced to the steam line from the steam generator downstream of the steam generator's flow control loop. The balance of steam required in this line will then be provided by the unfired steam generator.

This operating strategy requires some manual operation, in particular the starting up and shutting down of the braid wash steam boiler. At this time, however, we have not proposed a more sophisticated automatic control system because of the possible introduction of absorption chillers that would increase demand for steam and closely match the ability of the MISR system to supply this. Should the supply of steam from the MISR system exceed plant requirements with the braid wash steam boiler shut down and with no steam being produced by the unfired steam generator, steam could then be vented or collectors could be stowed individually.

Should however the occasional manual operation of the MISR system be judged undesireable, the following control system could be introduced:

- A pressure transmitter would be placed in the steam line from the MISR system.
- As the pressure rises above the 125 lb/in^2g set point, six of the collectors (i.e. one row of three ΔT loops) would be stowed. Should the pressure rise further, additional collectors would stow.
- As the pressure falls below 125 lb/in^2g, the collectors would unstow and start tracking the sun.

Section 3

DESCRIPTION OF DESIGN

System Description

The proposed design is comprised of a parabolic trough collector field with a steam generator, expansion tank/accumulator, and pumps and piping connect the MISR system with the existing plant. It is described in the series of drawings listed in Table 1. When insolation is sufficient, water is circulated through the collector field to an unfired boiler in which saturated steam is generated. At peak insolation, water will leave the collector at 460°F if 125 lb/in^{2}g steam is being generated; if insolation or the required steam pressure is lower, this exit temperature will be lower. The water flow through the field is fixed--no attempt is made to control the water temperature other than by heat transfer (i.e., the generation of steam) in the boiler. As no attempt is made to maintain a constant exit temperature from the collector field, overheating following sudden increases in insolation is avoided.

The skid-mounted equipment includes a kettle-type steam generator, a nitrogen-blanketed expansion tank/accumulator, a circulation pump, and a feedwater boost pump. The expansion tank has a nitrogen blanket to avoid corrosion in the tank and stop the dissolution of oxygen in the water throughout the field and distribution piping. The partial pressure exerted by the nitrogen also serves two other important roles: it prevents the water from draining back into the low-lying expansion tank/accumulator when the system

Table 1

LIST OF DRAWINGS

Drawing No.	Description
1-01-1	Plot Plan
1-50-1	Stm. Gener. & Solar Collector P&ID
1-50-2	MISR System Sect. B Solar Collector P&ID
1-51-1	Stm. Gen. & Solar Collect. Equip. Plot Plan & Solar Collector
1-51-2	Stm. Gen. & Solar Collect. Equip. Piping Plans & Sects.
1-51-3	Stm. Gen. & Solar Collect. Equip. Piping Sections
2-52-1	Piping Isometric
2-52-2	Piping Isometric
2-52-3	Piping Isometric
1-73-1	Power and Grounding Plan
1-73-3	Elec. - One Line & Elementary Diagram
1-73-4	Interconnecting Wiring Diagram
1-43-001A	Pier Arrangement
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1-46-2A	Structural Steel Skid Base Details
1-51-4	Stm. Gen. & Solar Misc. Piping Details
1-73-2	Elec. Plan & Details

is cool, and it ensures that the total pressure in the heat-transfer loop precludes boiling in the receiver tubes. The water used as the heat-transfer fluid is equal in quality to the boiler feedwater. The skid lies on the north side of the field; it will not shade the collectors. Boiler feedwater is supplied under level control to the steam generator at 200 lb/in^2g and 85°F; a booster pump is mounted on the skid for this purpose and for drawing water from existing plant water lines. A provision is made for blowdown so that an acceptable dissolved solids content in the boiler is maintained.

The collectors selected are line-focusing parabolic trough collectors with tracking receivers and reflectors manufactured by Suntec Systems, Inc. Each of 12 ΔT loops comprises two 120 ft. long collectors with an aperture of 10 ft. The collectors/receivers are connected to the heat-transfer fluid distribution piping by flexible metal hoses. The collector axis-to-axis separation is set at 20 ft., thus conveniently allowing easy vehicular access to the collectors for maintenance, while minimizing the delivered cost of solar thermal energy —in general, increased collector spacing reduces shading while increasing costs and heat losses.

The control system selected for the collector field is a Honeywell Flux-Line Suntracker System. It is a highly distributed system, allowing nearly autonomous operation of the collectors. The control system consists of local controllers mounted on each collector and, for a single MISR system, a combined field and master controller.

The local controller provides self-protection and sun-tracking features for the collector. These features allow the collector to:

- Lock onto the sun upon receipt of a command to track, by initiating an automatic search sequence.
- Rotate to maintain accurate collector-sun positioning when direct normal insolation (DNI) is adequate.
- Maintain a relatively stable attitude should insolation fall or winds become gusty at speeds less than stow wind speed.
- Stow when the system is not authorized to operate
- Monitor the receiver temperature so that the collector is stowed when the temperature is too high
- Provide for manual control of the collector
- Stop collector rotation should the collector exceed normal travel limits
- Maintain an accurate position during brief periods (1 to 15 min) of insufficient DNI and reinitiate search sequence should the sun be obscured for longer periods
- Drive full speed over its entire range of travel

The field/master controller performs morning start-up and evening shutdown of the collectors and protects them against high winds by stowing them. It can also interface with other collectors. Its functions are to:

- Send track authorization and stow commands to the local controllers
- Send and receive commands to open or close valves and to switch pumps on or off
- Receive environmental data (direct normal insolation, wind speed, etc.) and act upon these data as required

- Monitor and act upon discrete signals (e.g., shutdown requests caused by abnormal temperatures, flow rates, power loss, and steam demand)
- Accommodate start-and-stop software timers (with delays) relating to DNI, wind speed, power loss, etc.
- Provide a manual control to synchronously position the entire collector field to any desired position without impairing system safety, thus facilitating the rain washing of the collectors.

The field/master controller will have a 24-Vdc backup system.

The collector is positioned by a dc motor. Bidirectional control of the motor is provided by a transistor drive circuit mounted in the local controller. The solid-state drive circuit offers improved reliability over a more conventional relay control, especially for an application such as this, which requires numerous start-stop cycles.

Power to the dc motor is provided by 24-V battery packs. Six collectors are powered from one battery pack; the batteries are continuously trickle-charged. This power distribution method offers several advantages. The power to the field is low and essentially constant (115-V load required for battery charging), thus minimizing field power wiring requirements. More important, the batteries provide an emergency power source to drive the collectors to "stow" in case of a power failure; power failures are particularly likely to occur during adverse weather that could damage collectors left in an unstowed condition. To enhance system safety, the battery packs are placed at two field locations rather than all being mounted on the skid.

System Operation and Control

The operating procedures devised for this MISR system are the simplest possible that are compatible with the safe, reliable, and efficient operation of the system. The control system is correspondingly simple.

A solar intensity detector starts the system after sunrise, when the intensity of radiation reaches 50 Btu/h•ft^2. If the wind speed is below 25 mi/h, the demand switch (HS-33) is on, and minimum steam pressure is exceeded in the header (PSL-32 not on), pump P-101 starts to circulate water through the field, kettle boiler, and accumulator and pump P-102, the feed-water pump, commences to supply water to the kettle boiler.

Flow Switch FSL-7 detects flow and sends signals to Controller UC-100, which, in turn, sends tracking signals to the local controllers mounted on each collector. These signals cause the collectors to rotate upward. As the reflected image from the collectors crosses the indirect image flux sensors located at the receiver, feedback signals are sent to the local controllers. The collectors then begin tracking the sun, focusing its reflection upon the receiver and thereby warming the water circulating through the tubes.

Steam generation occurs when the pressure in the kettle boiler (SG-101) slightly exceeds the pressure in the plant steam header into which steam from the MISR system is delivered.

The flow through the collector field is maintained constant so that the water exit temperature under conditions of peak insolation is 460°F. Should insolation be lower, the temperature of the water leaving the collector field will be lower. With this mode of operation, tank, line, and receiver heat losses are lower than if an attempt were made to maintain a constant exit temperature irrespective of insolation level. Water continues to be heated until the insolation falls below 50 Btu/h•ft^2 for more than 15 minutes. At this point the collectors are stowed and the pumps stop. The collectors remain stowed and the pump is stopped overnight unless freeze protection is required. The set point for collector stowing should be regarded as provisional in this preliminary design phase. It will be finally determined in the course of detailed design.

At all times, boiler feedwater of adequate quality is fed to the kettle boiler at a rate determined by the level controller (LIC-11). Control is exerted by a cascaded loop, with the feedwater flow control (FIC-8) reset by the level control; this method eliminates rapid fluctuations in the flow of water. To maintain the dissolved solids concentration in the water within the kettle boiler at an acceptable level, water will be periodically blown down from the boiler using a manual blowdown valve.

The water level within the expansion tank/accumulator (TK-101) rises and falls to accommodate thermal expansion and contraction in the collector and distribution piping. A nitrogen blanket is held over the liquid; the nitrogen has a partial pressure of 291 lb/in^{2}g at 200°F.

The control valve in this system is pneumatically actuated utilizing instrument air from the existing facility.

Boiling in the collector receiver tubes and downstream of the collector tubes is prevented by maintaining a pressure in the water heat-transfer loop and expansion tank/accumulator (TK-101) that exceeds the vapor pressure of water as it emerges from the collector field. This pressure originates in the expansion tank/accumulator (TK-101) and is determined by the partial pressures of nitrogen and water in the vapor space of the accumulator. As water continually circulates through TK-101, the expansion tank/accumulator should essentially remain at the temperature of the water emerging from the steam generator (SG-101) and have a corresponding vapor pressure. The partial pressure of nitrogen is determined by its initial pressure in the cold system and by the changes in temperature and volume of the vapor space that occur as the water warmed and its level in the tank rises. The nitrogen pressure and water level in the cold system are such that these values lie within safe limits when the system operates. At all times the partial pressure of nitrogen is sufficient to prevent the water in the heat-transfer loop from draining back into the expansion tank/accumulator.

Subcooled boiling can occur if the receiver tubewall temperature exceeds the boiling point of the water. This boiling results in the formation of bubbles that will collapse in the main flow of fluid, resulting in an additional pressure drop and possible pitting of the receiver tubes should concentration of chemicals occur as a result of boiling.

Our calculations indicate that the water flows through the receiver tubes at a mean velocity of 2.13 ft/s. This translates into a Reynold's number of 1.9×10^5, a waterside heat-transfer coefficient of 948 Btu/h·ft·°F, and a water skin temperature of ≃465°F at the collector exit. Because the pressure at the collector exit is expected to exceed 520 lb/in^2g, subcooled boiling is not anticipated. Should it occur because of the highly turbulent flow, we anticipate that there will be no accumulation of chemicals in the boundary layer and that the bubbles will collapse once they emerge from the thin boundary layer. It will, however, be important to avoid fouling of the receiver tubes. Should solids levels in the water be too high, a porous scale will form. Water will permeate this scale and boil, possibly causing corrosion.

More extensive, subcooled boiling and possible corrosion may also be caused by the gross maldistribution of flow through the tubes. However, such maldistribution will be manifested through abnormal receiver temperatures that can be detected.

System Performance

The performance of a MISR system located in San Juan, P.R. was simulated for both east-west and north-south orientations. Steam production was limited to 3743 lb/hr - no account was taken of future expansions or the possible installation of absorption chillers. The results of these simulations are presented in Table 2 and Figure 1. As would be expected for such a low latitude, MISR system performance with north-south oriented collectors is superior despite the limit placed upon steam production.

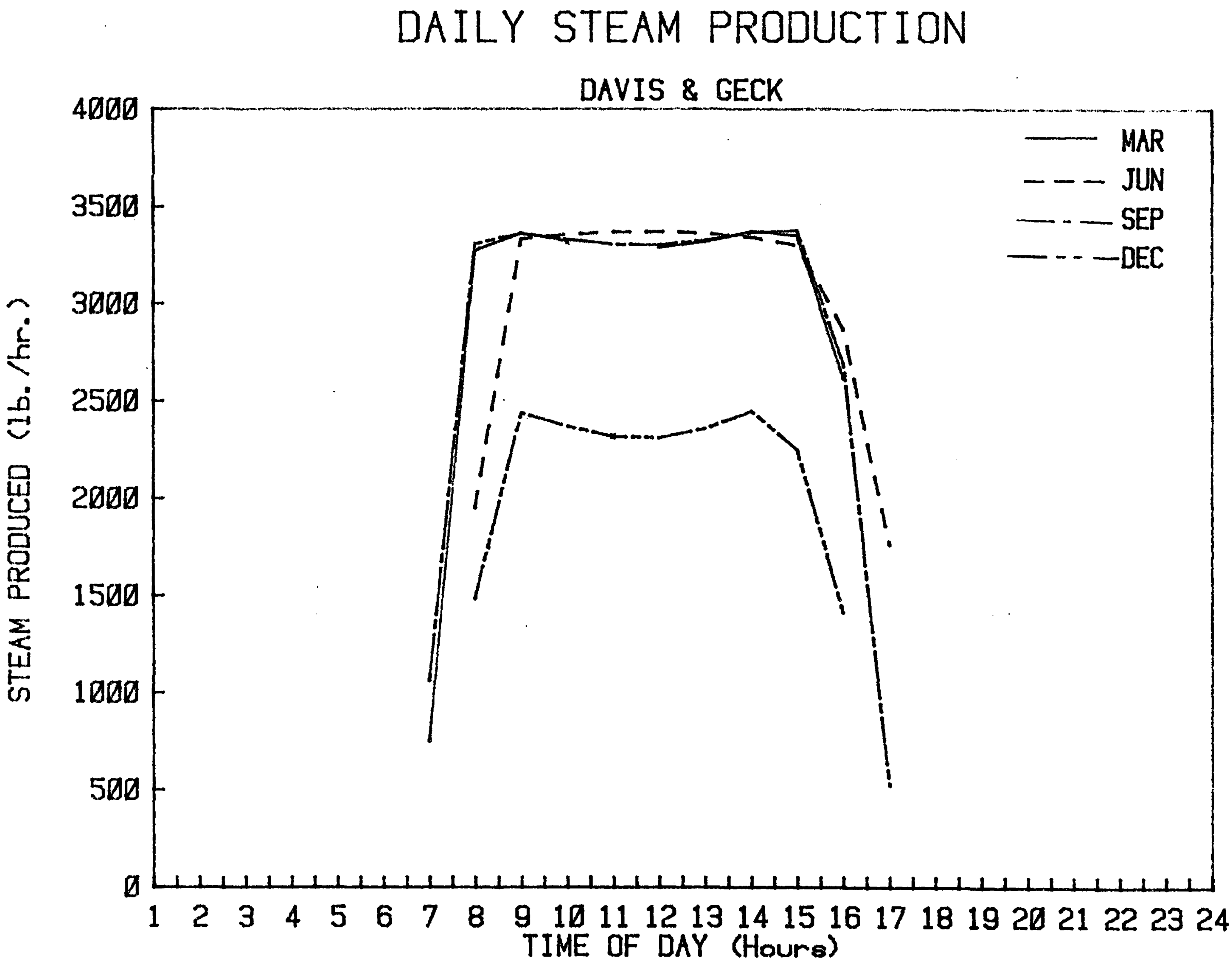
Table 2

MISR SYSTEM PERFORMANCE

Month	Energy Delivered by MISR System * (10^6Btu as 125 lb/in^2g steam) N-S Collector Orientation	E-W Collector Orientation
January	485.9	517.1
February	508.0	436.0
March	711.5	492.7
April	736.8	445.6
May	614.5	392.4
June	712.1	487.1
July	828.7	549.4
August	687.1	416.4
September	611.2	390.5
October	587.1	468.6
November	468.7	469.4
December	491.4	558.6
Total/yr	7443.0	5623.8

* (Mass of steam delivered)x(enthalpy steam - enthalpy boiler feedwater).

FIGURE 1


DAILY STEAM PRODUCTION
DAVIS & GECK
MAR
JUN
SEP
DEC
STEAM PRODUCED (lb./hr.)
4000
3500
3000
2500
2000
1500
1000
500
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
TIME OF DAY (Hours)

Section 4

COST ESTIMATES

An estimate for the cost of installing a MISR system at Davis & Geck's Manati, Puerto Rico facility is presented in Table 3. In addition to the items included in the table, a final price might also include a negotiable fee and a sum to cover contingencies. It should be emphasized that the installation cost for a MISR system will fall appreciably should mass production of collectors and the sale of multiple systems be achieved: should 20 systems of the same design be installed in a year, the cost of an individual system will probably be 20% less than the sum presented here.

Should Davis & Geck decide to install a MISR system, they may make use of U.S. Investment and Energy Investment Tax Credits. Puerto Rico's tax incentives for solar energy are essentially limited to residential hot water systems and expire on January 1, 1983. A MISR system has a depreciable life of 5 years.

Table 3

MISR COST ACCOUNTING FORM

(Cost Accounting Categories for Production and Installation of a MISR System at Davis & Geck, Manati, Puerto Rico)

Cost Item	Cost ($)
1. Site	148,200
2. Collector System	784,300
3. Equipment Skid	232,000
4. Manifolds	245,500
5. Special Equipment/Facilities	25,800
6. Engineering Services	223,800
7. Other	15,600
8. Contingency	150,000
9. Fee	Negotiable
Total	$1,825,200

Table 3 MISR Cost Accounting Form (Cost Accounting Categories for Production and Installation of MISR System at Davis & Geck, Manati, Puerto Rico)

Cost Item	Equipment or Material Purchase ($)	Delivery of Equipment or Material to Site ($)	On-Site Assembly, Installation, or Fabrication ($)	Checkout and Start-Up ($)	Total Cost ($)
1. Site					
• Site preparation (clearing, grading, fine-grading, etc.)	---	---	21,910	---	21,910
• Foundations:					
- Collectors and manifold	44,000	---	66,000	---	110,000
- Skid	6,500	---	9,750	---	16,250
Subtotal					148,160
2. Collector System					
• Collector pylons and drive	168,152	650	2,738	---	171,540
• Collector structure	178,560 }				
• Reflector system	175,462 }	10,400	5,380	---	369,802
• Receiver system	133,996	600	3,765	---	138,361
• Tracking/control	99,087	250	3,621	732	104,590
Subtotal					784,293
3. Equipment Skid					
(Single subcontract)	170,750	---	---	---	170,750
• Pump	27,700	---	---	---	27,700
• Instrumentation	33,511	---	---	---	33,511
Subtotal					231,961
4. Manifolds					
• Instrumentation	7,995	---		---	
• Electrical:					
- Grounding	1,800	---		---	
- Conduit/cable/fittings	5,020	---		---	
- Miscellaneous equipment	18,960	---		---	
• Piping:			55,000		
- Insulated pipe	120,272			---	
- Valves and pipe specialty items	8,000			---	
- Flex hoses and receiver connections	12,000	5,000		---	245,483
• Bracing/supports:					
- Structure	11,436				
Subtotal					
5. Special Equipment/Facilities					
• Lifts, cranes, special tools	25,000	---	---	---	25,000
• Collector cleaning/washing equipment	787	---	---	---	787
Subtotal					25,787

Table 3 MISR Cost Accounting Form (Cost Accounting Categories for Production and Installation of MISR System at Davis & Geck, Manati, Puerto Rico) (Cont)

Cost Item	Equipment or Material Purchase ($)	Delivery of Equipment or Material to Site ($)	On-Site Assembly, Installation, or Fabrication ($)	Checkout and Start-Up ($)	Total Cost ($)
6. Engineering Services					
• Project management	67,000	---	---	---	67,000
• System design/analysis	2,400	---	---	---	2,400
• A/E services	51,300	---	---	---	51,300
• Field indirect costs	75,350	---	---	12,750	88,100
• Instrumentation and electrical service contract	15,000	---	---	---	15,000
Subtotal					223,800
7. Other					
• Spares:					
- Valves and instrumentation (5% of initial cost)	2,500	---	---	---	2,500
- 20-ft receivers (2)	1,763	70	---	---	1,833
- Local control circuit boards (2)	3,500	40	---	---	3,540
- Glass reflectors	7,575	150	---	---	7,725
Subtotal					15,598
8. Contingency and Fee					
• Contingency	---	---	---	---	150,000
• Fee	---	---	---	---	Negotiable
TOTAL					1,825,082

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