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Report No. 78.1455.JMC-373
Contract No. ET-78-C-03-2197

CONCEPTUAL DESIGN REPORT
SOLAR PRODUCTION OF INDUSTRIAL
PROCESS STEAM
AT

ORE-IDA FROZEN-FRIED-POTATO PLANT

Record File # DE-AC03-78CS 32197.8-1

PREPARED BY

J. M. Cherne, G. H. Gelb, J. D. Pinkerton
and S. F. Paige

With Assistance from Nathan Little of CH2M Hill

PREPARED FOR

Department of Energy
Solar Industrial Process Heat Branch
Conservation and Solar
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One Space Park • Redondo Beach • California 90278

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1. INTRODUCTION AND SUMMARY

TRW, under contract ET-78-C-03-2197 from the Department of Energy, is designing a system for the demonstration of the Solar Production of Industrial Process Steam. This report presents the Conceptual Design of this system as defined in Task 2 of the Statement of Work. Also included in this Conceptual Design Report is an Environmental Impact Assessment, as required by Task 3, and a System Safety Analysis report, as required by Task 4. These latter two tasks will be revised as the Detailed Design (Task 5) is accomplished in the latter part of this Phase I activity. It was intended that a preliminary economic analysis (Task 1) would be presented with the Conceptual Design; however, since the Department of Energy requested that we hold off on an economic analysis until they recommend a uniform procedure, none of this work was accomplished.

The system as proposed and conceptualized consists of an array of 9,520 square feet of parabolic trough concentrating solar energy collectors manufactured by the Hexcel Corporation which generate pressurized hot water. The pressurized water is allowed to flash to steam at 300 psi (417°F) and fed directly into the high pressure steam lines of the Ore-Ida Foods, Inc., processing plant in Ontario, Oregon. Steam is normally generated in the factory by fossil-fired boilers and is used by means of a steam-to-oil heat exchanger for the process of frying potatoes in their frozen food processing line. The high pressure steam is also cascaded down to 125 psi for use in other food processing operations.

This solar system will generate 2×10^6 Btu/hr during peak periods of insolation. Steam requirements in the plant for frying potatoes are: 43×10^6 Btu/hr at 300 psi and 52×10^6 Btu/hr at the lower temperatures and pressures. The Ontario plant operates on a 24 hr/day schedule six days a week during the potato processing campaigns and five days a week for the remainder of the year. The seventh day and sixth day, respectively, use steam for cleanup operations. An analysis of the steam generated, based on available annual insolation data and energy utilized in the plant, is contained in Section 5 of this report.

During the Conceptual Design, we examined several system concepts in order to produce a configuration which minimized solar system cost and maximized the potential for application of this system to other industrial processes using steam, both in and outside the food processing field.

2. ORE-IDA STEAM REQUIREMENTS

At the Ontario, Oregon plant of Ore-Ida, two dual-fueled boilers (gas or oil) each produce 300 psi steam at the rate of 50,000 lbs per hour. Forty-five percent of this steam is used at 417°F for all of the potato frying operations. The remainder is used for other processes in the plant at lower temperatures.

The plant operates three-eight hour shifts per day, six days a week from August through December; and five days per week, three shifts per day, from January through July. During the day shifts of the seventh and sixth days, steam is used for cleanup operations in the plant. Depending on production requirements, a planned shutdown is scheduled for one week in the spring, a month in July, and a week at Christmas to provide vacations and to accomplish equipment maintenance.

An analysis of a 13-month segment of operation between September 1977 and September 1978 is presented in Figure 1. This graphical presentation shows all of the planned holidays and vacations, plus shutdowns for unscheduled maintenance. All of the solar-produced steam would be used on those days and parts of the days presented with shading. During the cold months (November through March) when exterior temperatures drop below freezing, the solar heat will be used to help prevent freezing of the blanching and washing tanks when the plant is shut down.

The frying operations at Ore-Ida are accomplished with three separate and independent frying lines, two of which (Prime Fryers Nos. 1 and 2) are alike. We plan to interface our solar steam system to one of the heat exchangers of Prime Fryer No. 2 as shown in Figure 2. Frying is performed in stages with a separate heat exchanger supplying the heated oil for each stage. The stage for our demonstration has a consumption of 8.6×10^6 Btu per hour. Therefore, at peak solar energy collection, we will be supplying 23% of the steam for this stage of the process.

STEAM UTILIZED AT ORE-IDA ONTARIO, OREGON, PLANT

Figure 1

Figure 2. Ore-Ida Plant Layout

Annual requirements for fryer line steam and projected solar produced steam are tabulated below.

Table 1. Annual Energy Projections

Total annual steam required for frying	2.5×10^{11} Btu
Annual steam required for one stage of fryer line No. 2	4.8×10^{10} Btu
Annual steam supplied by solar system	3.5×10^9 Btu
Parasitic electrical energy consumed in pumping (direct thermal equivalent)	1.0×10^8 Btu
Net energy generated	3.4×10^9 Btu
Natural gas displaced	5.0×10^6 cu ft

The potential for expanding this system to the total needs of the Ontario, Oregon plant exists. Ore-Ida has three other plants producing the same products. A tabulation of their steam requirements is included below.

Table 2. Ore-Ida Foods Inc. Steam Requirements

	<u><300°F Steam Btu/year</u>	<u>>350°F Steam Btu/year</u>
Ontario, Oregon	3.0×10^{11}	2.5×10^{11}
Burley, Idaho	2.9×10^{11}	2.4×10^{11}
Greenville, Michigan	1.3×10^{11}	1.1×10^{11}
Plover, Wisconsin	3.0×10^{11}	2.5×10^{11}

In addition to Ore-Ida, there are 115 other food processors in the Snake River and Columbia River basins, all faced with the same energy problems and anxious to find alternate sources.

3. SYSTEM DESIGN

3.1 SYSTEM CONCEPT

The system proposed by TRW will consist of an array of parabolic trough concentrating collectors installed on the roof of the Ore-Ida packaging building in close proximity to the heat exchanger of Prime Fryer Number 2. The design of the heat transfer loop through the collectors and the method of generating steam were major concerns in the trade-offs of the system concept.

Three of the conceptual approaches for the SPIPS were thoroughly analyzed and evaluated. (A fourth concept involving boiling in the Solar receiver was rejected due to lack of experimental data upon which to base design calculations.) The three systems are referred to as:

- Heat Transfer Fluid/Steam System
- Pressurized Water/Flash System
- Pressurized Water/Steam System.

A brief discussion of each of these concepts follows:

3.1.1 Heat Transfer Fluid/Steam System (HTFSS)

In the HTFSS concept, the collector field coolant is a low vapor pressure, non-aqueous heat transfer fluid which delivers heat to an unfired steam generator. The latter device produces the steam needed for heating cooking oil in the fryer as well as lower pressure steam used in downstream potato processing steps.

A number of potential heat transfer fluids were identified. These included Caloria HT-43, Therminol 66, Dowtherms A and G, and silicone oil. The first four were rejected (see Appendix) due to their known toxicity, carcinogenic potential and degree of flammability. The remaining fluid is a silicon compound having attractive properties as a heat transfer fluid. One such fluid, Syltherm 800, manufactured by Dow Corning has the following properties:

Table 3. Syltherm 800 Properties

Freezing point	-50 ⁰ F
Vapor pressure	<1 atmosphere at 670 ⁰ F
Flash point	310 ⁰ F
Fire point	380 ⁰ F

Silicone fluids similar to Syltherm are used for cosmetics and medical applications. Syltherm is rated for up to 700⁰F service; however the fluid tends to decompose at a rate related to its operating temperature into lower, gaseous fractions which must be vented off. Fresh fluid makeup is therefore needed. Syltherm is also an oxygen and water getter and must be protected from air and water. The material tends to polymerize in contact with these substances, increasing its viscosity.

A process flow diagram for an HTFSS is shown in Figure 3; major system components are listed in Table 4. Presuming the use of a silicone fluid such as Syltherm 800, hot fluid would leave the collector field from the outlet manifold connecting the 14 receiver tubes (see Section 3.3) at 680⁰F and flow to unfired steam generator Number 1. After giving up its heat, the heat transfer fluid would return to an expansion tank at about 470⁰F. The expansion tank would also function as the interface for system pressurization through a nitrogen blanket. Products of Syltherm decomposition could be drawn off and vented from the tank. Syltherm then completes the heat transfer loop by being pumped back to the collector field inlet manifold. The collector outlet temperature of the fluid is shown being controlled by bypassing a portion of the fluid around the circulating pump; throttling of the circulating fluid is also a possible control means.

Although silicones are used in medicines, Syltherm 800 has not yet received Food and Drug Administration clearance as a food additive. Because of the potential for Syltherm penetration into the plant's steam line and its subsequent direct contact with the potatoes, an intermediate steam heat transfer loop would be required.

Figure 3. Heat Transfer Fluid/Steam System Process Flow Diagram

Table 4. Components of HTFSS

AV-01	Automatic Air Vent
E-01	Blowdown Heat Exchanger
P-01	Syltherm Circulation Pump 100 gpm 10 hp
P-02	#1 Feed Water Pump 5 gpm 1/3 hp
P-03	Feed Water Pump
PR-01	Overflow Pressure Regulator
PR-02	N ₂ Gas Blanket Pressure Regulator
PR-09	125 psi Pressure REgulation Valve
S-01	Water Trap
S-02	Deaerator
SG-01	Sight Glass
SG-02	Sight Glass
SG-03	Sight Glass Steam Generator #2
SG-04	Sight Glass, Hot Well
T-01	Syltherm Condensate Catch Tank
T-02	Syltherm Expansion Tank
T-03	N ₂ Tank
T-04	Hot Well Tank
U-01	Existing #2 Fryer
U-02	Deionizer
V-01	Syltherm Flow Control Valve
V-02	Automatic Recirculating Valve
V-03	Bottom Blowdown Valve
V-04	Level Control Valve
V-06	Drain Valve
V-07	Level Control Valve
V-08	Feed Water Isolation Valve
V-10	Check Valve 300 psi line
V-11	Steam Valve to Deaerator Tank
V-12	Feed Water Isolation Valve

Table 5. HTFSS Process Parameters

Description		Pressure (psia)	Temp (°F)	Flow Rate (lb/hr)
1	Hot Syltherm From Collector	45	620	33,330
2	Cooled Syltherm From Steam Genrator No. 1	35	470	33,330
3	Outlet of Expansion Tank	35	470	33,330
4	Bypass Loop	35	470	0-33,330
5	Inlet to Collector Field	100	470	0-33,330
6	Circulation Pump Output	100	470	0-33,330
7	Expansion Tank Vent	45	—	Vent Buildup of Syltherm Decomposition Products
8	Steam From Generator No. 1	400	450	2,000
9	Feed Water to Generator No. 1	400	450	2,000
10	Condensate From Generator No. 2	400	450(-)	2,000
11	Steam From Generator No. 2	300	417	1,932
12	Steam Delivered to 300 Psia Heater	300	417	1,657
13	Steam to Throttle Valve	300	417	1,932 max
14	Steam to 125 Psia Header	125	365	1,932 max
15	Treated Water From Existing Boiler Feed Pump	300-350	75	1,951
16	Steam to Deaerator	125	365	275
17	Makeup Water From Deionizer	30	60	1,676
18	Output of Deaerator	14.7	210	1,951
19	Output of Deaerator Feed Water Pump	300-350	210	1,951
20	Feedwater Input to Steam Generator No. 2	300-350	75 or 210	1,951
21	Steam Generator No. 2 Blowdown	300	417	19

In the unfired steam generator Number 1, heat from the Syltherm is transferred to water producing steam at 450°F (425 psia). This steam then flows to unfired steam generator Number 2, in which it condenses, giving up its heat of vaporization to produce steam at 417°F (300 psia) for delivery to the plant steam header at Fryer Number 2.

Condensate from steam generator Number 2 is returned to generator Number 1 through a recirculation pump. The feed for generator Number 2 is treated city water, which may be supplied from either a deionizer and deaerator dedicated to the SPIPS, or from the main water treatment system employed in the plant's boilers.

Major process parameters and values are summarized in Table 5. The system is sized for a peak energy delivered to the heat transfer fluid of 2.0×10^6 Btu/hr. The heat transfer fluid circulating pump requirements were based upon data gathered at tests of the Hexcel collector and receiver at Sandia in November 1977 using a receiver tube with an insert plug and Therminol 66.^{1,2} Corrections to that data for Syltherm 800 were based upon a Blasius equation form of pressure drop correlation.

3.1.2 Pressurized Water/Flash Steam System (PWFSS)

In the PWFSS concept, the collector receiver tubes are cooled by circulating pressurized water. The hot water then undergoes a homoenthalpic expansion down to the desired process steam pressure. As it expands, it flashes into low quality steam; the steam is separated and delivered to the Fryer steam main.

Figure 4 shows the PWFSS process flow; Table 6 lists the major components of the system. Hot water at 477°F, 600 psia flows from the collector field to a flash tank where it is throttled to 300 psia,

¹V. Dudley and R. Workhoven, "Performance Testing of the Hexcel Parabolic Trough Solar Collector", Sandia Laboratories Report SAND78-0381, March 1978.

²Private Communication, S. Farley (Hexcel) to G. Gelb, November 6, 1978.

Figure 4. Pressurized Water Flash Steam System Process Flow Diagram

Table 6. Components of PWFSS

AV-01	Automatic Air Vent
BPR-01	Bach Press Regulator Hot Well
BPR-02	Bach Pressure Regulator, Flash Tank Water Side
BPR-03	Bach Pressure Rgulator, Flash Tank Steam Side
E-01	Blowdown Heat Exchanger
P-01	Collector Field Feed Pump
P-02	Collector Field Circulation Pump (freeze protection)
P-03	Optional Feed Water Pump
S-01	Deaerator (optional)
T-01	Flash Tank
T-02	Hot Well
U-01	Number 2 Fryer
U-02	Deionizer
U-03	Feed Water Treatment
U-04	Feed Pump Drive
V-01	Pressurized Water Flow Control Valve
V-02	Automatic Recirculating Valve
V-03	Hot Well Level Control Valve
V-04	Flash Tank Level Control Valve
V-05	Bottom Blowdown Valve (intermittent)
V-06	Surface Blowdown Valve (continuous)
V-07	Steam Cutoff Valve to Feed Pump Drive
V-08	Flow Control Valve to Feed Pump Drive
V-09	Steam Cutoff Valve to 125 psi line
V-10	Pressure Reducing Valve
V-11	Check Valve 300 psi line
V-12	Check Valve Feed Water Line
V-13	Cutoff Valve Feed Water Line
V-14	Cutoff Valve Option Feed Water Treatment
V-15	Steam Cutoff to Deaerator Tank
V-16	Level Control Valve Deaerator Tank

Table 7. PWFSS Process Parameters

Description		Pressure (psia)	Temp (°F)	Flow Rate (lb/hr)
1	Pressurized Water From Collector Field	600	477	23,850
2	Condensate From Flash Tank	300	417	21,920
3	Pressurized Water to Collector Field	610	399	23,850
4	Circulation Pump Outlet	620	410	23,850
5	Bypass Loop	300	410	TBD
6	Freeze Protection Pump Loop	600	410	770
20	Steam From Flash Tank	300	417	1,930
21	Steam to Plant 300 Psi Line	300	417	1,200
22	Steam to Feed Water Pump	300	417	730
23	Bypass Steam to 125 Psi Line	300	417	1,200
24	Steam to 125 Psi Plant Steam	125	350	1,930
25	Steam to Deaerator	125	350	275
26	Makeup Water to Deionizer	ATM	60	1,675
27	Makeup Feed Water to Deaerator	ATM	60	1,950
28	Makeup Feed Water From Deaerator	ATM	200	1,950
29	Makeup Feed Water From Plant Feed Water Pump	35	200	1,950
30	Blowdown From Flash Tank	300	417	19-100
31	Feed Water to Hotwell	350	260	1,930

Figure 5. Pump Work Required in PWFSS

producing about 8 percent quality steam at 417⁰F. The hot water portion, or "drips", is combined with makeup water from either a stand-alone dedicated feed water treatment system, or the feed water treatment system of the main plant and then returned to the collector field through a feed water pump. Continuous or periodic blow-down of the flash tank is required to prevent solids buildup.

Major process flow states and parameter values for the PWFS are to be found in Table 7. The system feed water pump is relatively large due to the high pressure differential and mass flow rate it must pump. Collector field pressure losses were calculated using a form of turbulent flow pressure drop correlation for round tubes.

The collector outlet fluid pressure and temperature were selected through a trade-off analysis of outlet conditions against a pump performance requirement, in which the product of pump differential pressure and circulating water per pound of steam produced was calculated (as shown in Figure 5). Although the chosen values do not minimize that parameter, they are sufficiently close to the minimum while giving adequate control margin for the pressure control valves.

3.1.3 Pressurized Water/Steam System (PWSS)

The PWSS contains elements from both HTFS and PWSS concepts as seen in Figure 6. Major components of the system are listed in Table 8. Pressurized water at 600 psia and 477⁰F gives up sensible heat in an unfired steam generator producing the required 417⁰F (300 psia) saturated steam for the fryer. Cooled pressurized water returns to a nitrogen-blanketed expansion tank volume from which it is pumped back to the collector field. As in the HTFSS, makeup treated water is added to the inlet of the steam generator through a liquid level controller.

Major PWSS process flow states and parameter values can be found in Table 9. Note that although the PWSS collector field pressure is the same as in the PWFSS, the circulating pump of the former system is much smaller since it only has to work against the pressure drop of the field piping and not the flash pressure drop of the PWFSS.

Figure 6. Pressurized Water Steam System Process Flow Diagram

Table 8. Components of PWSS

AV-01	Hydroscopic Air Vent and Check Valve
E-01	Unfired Steam Generator
E-02	Blowdown Heat Exchanger
P-01	Collector Field Circulating Pump
P-02	Collector Field Circulating Pump (Freeze Protection)
P-03	Optional Feed Water Pump
S-01	Deaerator
T-01	Drain-Down Tank 800 Gallon, 600 Psig
U-01	Number 2 Fryer
U-02	Deionizer
U-03	Feed Water Chemical Treatment
V-01	Pressurized Water Flow Control Valve
V-02	Automatic Recirculating Valve
V-03	Check Valve Freeze Protection Recirculating Pump
V-04	N ₂ Drain-Down Valve
V-06	N ₂ Pressure Regulator, 600 Psig
V-09	Makeup Feed Water Valve
V-11	Check Valve Steam Generator, 300 Psi Line
V-12	Check Valve Plant Header, 300 Psi
V-13	Bypass Valve, 300 Psi Line
V-14	Cutoff Valve, 125 Psi Line
V-15	Pressure Reducing Valve, 125 Psi Line
V-16	Steam Cutoff to Deaerator Tank
V-17	Deaerator Level Control Valve
V-18	Automatic Recirculating Valve
V-19	Cutoff Valve, Optional Feed Water Treatment
V-20	Cutoff Valve Feed Water Line
V-21	Bottom Blowdown Valve
V-22	Level Control Valve Steam Generator

Table 9. PWSS Process Parameters

Description		Pressure (psia)	Temp (°F)	Flow Rate (lb/hr)
1	Hot Water From Collector Field	600	477	44,640
2	Hot Water From Steam Generator	600	437	44,640
3	Makeup Water	20	60	2,400
4	Hot Water From Expansion Tank	600	437	44,640
5	Hot Water Recirculation to Prevent Freezing	650	100-437	770 max
6	Bypass to Control Mass Flow Thru Collector Field	650	437	44,640 max
7	Hot Water to Collector Field	650	437	44,640
8	Drain-Down for Freeze Protection	20	40	770
9	N ₂ Pressurization	600	437	3 cfm
20	Steam From Generator	300	417	1,932
21	Steam to 300 Psi Header	300	417	1,932
22	Steam to 125 PR Valve	300	417	1,932 max
23	Steam to 125 Header	125	365	1,932 max
24	Feed Water From Gas Boiler Feed Water Pump	350	175	1,951
25	Steam to Deaerator	125	350-365	275
26	Makeup Water From Deionizer	30	60	1,676
27	Makeup Water From Feed Pump	14.7	210	1,951
28	Feed Water From Feed Pump	300-350	210	1,951
29	Feed Water to Blowdown Heat Exchanger	300-350	75-210	1,951
30	Blowdown to Remove Solids From Steam Generator	300	417	19
31	Feed Water to Steam Generator	350	235	1,951

3.2 SYSTEM ANALYSIS

The system schematics and parameters given in Section 3.1 were the basis for preliminary equipment and piping sizing. Where there was a question about appropriate equipment or piping size, several sizes were analyzed. This preliminary selection of equipment allowed the systems' mechanical parameters to be defined (Table 10), and a preliminary cost estimate to be prepared (Table 11).

In general, the results of this estimate indicate that the difference in the cost for the piping, valves, insulation, and pumping costs, for the three systems considered is small, relative to the total cost of these items. The unfired boilers are the most expensive single item, excluding the collectors, of the systems considered. Therefore the pressurized water/flash steam system has a lower initial cost since it does not require such a boiler. This system, however, has the highest operating cost in terms of the electrical requirements for pumping. The flash system has slight lower heat losses due to reduced piping and lower peak temperatures.

Maintaining the correct water quality in these systems is important to their proper operation. Therefore, before final design of one of these systems is completed it will be necessary to perform a chemical analysis of the water available on the site. In general, where the high pressure collector loop is closed, there is probably no need to chemically treat the water in this loop on a continuous basis.

The steam side of either the unfired boiler or the flash tank is an open system, therefore, the water will have to be treated. If the feedwater is obtained from city water, it will be necessary to pass it through a water softener and a deaerator. It appears possible to obtain the feedwater from the feedwater supply available in the existing boiler room. This water is already softened and deaerated. Either feedwater supply system will require that chemicals be added to the steam generating subsystem through a tank and metering pump system.

To obtain feedwater from the boiler room, a pipe would have to be run from the boiler room to the vicinity of the No. 2 Fryer Line where the process steam generator will be located. As shown in Figure 7, this distance is approximately 500 feet. The pipeline would cost approximately

TABLE 10 SYSTEM PARAMETERS

	Pressurized Water/Steam	Pressurized Water/ Steam	Heat Transfer Fluid/Steam
System Volume, Ft ³	105	84	47
Pressure Loss at Design Flow Through Collector System Pipe, PSID	23	300	59
Recirculation Pump Hp (70 Percent Efficiency)	2.1	16.6	4.5
Heat Loss From Collector Piping, Btu/Hr.	96,500	80,600	108,600

TABLE 11. MECHANICAL EQUIPMENT COSTS⁽¹⁾

	<u>PRESSURIZED WATER/STEAM</u>	<u>PRESSURIZED WATER/ FLASH STEAM</u>	<u>HEAT TRANSFER FLUID/STEAM</u>
PIPING, FITTINGS & VALVES	\$50,500	48,100	50,200
INSULATION	27,000	25,200	27,000
MAJOR EQUIPMENT			
Unfired Boiler	31,000		61,200
Expansion Tank	14,700		6,300
Flash Tank		12,600	
Field Circulation Pump	7,800	22,500	7,800
Recirculation Pump	2,400	2,400	
Feedwater Pump	1,800	1,800	1,800
Makeup Pump	2,400		
Boiler Circulation Pump			1,800
Water Softener	600	600	600
Deaerator	9,000	9,000	9,000
Blowdown HX	1,000		1,000
Steam Separator	2,000	2,000	2,000
Chemical Feed Equipment	1,500	1,500	1,500
ELECTRICAL PUMPING COSTS ⁽²⁾	<u>1,200</u>	<u>8,600</u>	<u>2,400</u>
TOTAL	\$152,900	\$134,300	\$172,600

(1) Costs include installation but do not include OH and profit.

(2) Present worth for a 20 year period assuming a 9 percent fuel inflation rate and a 9 percent discount rate.

PLAN
1" = 20'-0"

KEY

NOTES:
1. FEEDWATER PIPING SHALL PARALLEL THE EXISTING STEAM AND CONDENSATE PIPING BETWEEN THE BOILER ROOM AND PRIME LINE NO. 2. THE PIPING SHALL SLOPE TOWARDS THE BOILER ROOM TO ALLOW DRAINING. DRAIN PLUGS SHALL BE PROVIDED AT ALL LOW POINTS IN THE FEEDWATER PIPING

Figure 7.
Layout of Feedwater Piping
from Boiler Room to SPIPS
Steam Generator

PRELIMINARY

\$5,500, if it is uninsulated, or \$11,000 if the pipeline is insulated. In lieu of installing a pipeline, a separate water softener and deaerator system could be installed at a cost of approximately \$12,000. In addition, the latter system would require continual maintenance, and would use valuable additional floor space in the plant.

Blowdown, both continuous and intermittent, will be required to control the solids in the water. The rate of blowdown will depend upon the type of steam generator tank finally selected, and the quality of the feedwater. This will be determined as soon as final design of the system begins. The continuous blowdown will be passed through a heat recovery system which will preheat the feedwater, and reduce the temperature of the blowdown to levels safe for the sanitary sewer system. Intermittent blowdown will be discharged through a steam and water separator to allow steam to flash safely, and the water to be discharged to the sanitary sewer.

A preliminary layout drawing (Figure 8) has been completed for the Pressurized Water Steam System locating the unfired boiler in the Crib Storage Room. At this time, Ore-Ida plant personnel are considering two additional locations; in the equipment room immediately north of the Crib Storage Room, and along the east wall next to the No. 2 Fryer Line. The space available in the latter two locations is severely limited by existing equipment. Although the Crib Storage Room is relatively large, this space is more or less full depending upon the plant production patterns. In any of these locations it will be difficult to locate more than one steam generator. The expansion tank or flash tank can be elevated at any one of these locations. There will be enough room to locate the field circulation pumps.

3.2.1 Summary of Conceptual Design Analyses

The preceding discussion presented the considerations and evaluations which were carried out during the Conceptual Design. The activities are summarized below along with the major conclusions. Table 12 highlights these conclusions.

Figure 8.
Preliminary Layout of PWSS
in Crib Storage Room

Table 12. Summary of Conceptual Design Trade-off Analyses

<u>Concept</u>	<u>Installed Cost</u>	<u>Present Value of Pumping Costs</u>	<u>Technology Unknowns</u>	<u>Safety</u>	<u>Use of Plant Space</u>	<u>Solar Energy Utilization Btu/ft²/Year Heat Rate</u>	<u>Reliability and Maintenance</u>
Heat Transfer Fluid/Steam System (HTFSS)	\$170,200	\$2,400	<2 years operating experience with silicone fluids	Low field pressure; slight fire hazard	Two steam generators and pumps	2.71×10^5	Most complex system; control of heat transfer fluid thermal degradation
Pressurized Water/Steam System (PWSS)	151,700	1,200	Limited experience with high pressure, high temperature receivers	High field working pressure; no fire hazard	Single steam generator and pump	2.90×10^5	Control of water quality in field loop to prevent corrosion
Pressurized Water/Flash System (PWFS)	129,700	8,600	Limited experience with high pressure, high temperature receivers	High field working pressure; no fire hazard	Flash tank and pump	2.93×10^5	Control of water quality in field loop to prevent corrosion; severe service for circulating pump

In the proposal, TRW identified a number of potential collector fluids broadly grouped as aqueous and non-aqueous. We believed there was a potential cost advantage in using a low vapor pressure, non-aqueous heat transfer fluid in terms of reduced piping costs. We identified silicone fluids, particularly Syltherm 800 as the most promising in terms of low toxicity, flammability and pumping losses, and good thermal stability, with good low temperature operation.

Since Syltherm has not been approved as a food additive, we were forced to incorporate a secondary heat transfer loop between the collector fluid loop and the fryer steam. As shown in Table 12, this additional loop increased the concept's cost, and increased heat transfer losses through additional pipe lengths and fittings, and higher working temperatures differential to drive the heat transfer. The additional equipment also causes a space problem within the plant's available space.

Of the two concepts employing water as the collector fluid, the PWFSS was shown to have 17 percent lower initial and 12 percent lower life cycle costs (excluding collector costs). The differential capital costs of the flash system's larger pump over that of the pressurized water/steam system did not offset the differential cost of the latter's unfired steam generator. Over the life of the installation, the PWFSS additional cost burdens of electricity was not enough to offset the initial investment differential. Furthermore, the PWFSS appears to have lower parasitic heat losses and is more readily fit within the allocated space for the SPIPS steam generating equipment.

On these bases, we have selected the Pressurized Water/Flash Steam System as our preferred choice to carry into Detail Design.

3.3 COLLECTOR ARRAY

3.3.1 Collector Configuration

The southern portion of the roof of Packaging Building No. 527 was analyzed as the site for the solar collector field. The roof has plan dimensions of 300 x 210 feet and a small slope to the east and west from a north-to-south running peak. The roof surface is composed of tar felt over a layer of mineral wool insulation. The roof structure is composed of precast concrete single and double tee beams.

Several collector configurations were laid out on the roof area and were analyzed in terms of the following constraints and guidelines:

- minimum interference with existing roof penetrations and roof-mounted equipment
- a maximum collector aperture of 10,000 square feet
- minimum piping requirements
- maximum conservation of rooftop space
- maximizing the distance from potential sources of collector surface contamination

Based upon these considerations, the configuration shown in Figure 9 was selected. The configuration consists of fourteen 80-foot long parabolic trough collectors in the south and west portion of the roof arranged in a north-south axis orientation. This arrangement results in a collector aperture of 9,520 square feet. The collector modules are placed in such a way that:

- a minimum 6-foot passage exists between rows when the collectors are pointed straight up
- adequate passage area lies between any collector and edge of the roof and high equipment mounted on the roof
- a visitor observation area is provided
- location is most remote from effluents of food processing exhausts just in case these should prove to be detrimental to collector performance.

Cool collector fluid flows to an inlet manifold of each collector bank; heated fluid is collected in a central manifold between the two

SOLAR COLLECTOR LAYOUT AND PIPING PLAN

SCALE - 1 IN. = 10 FT.

REVISED 12-18-78

DRAWING NO.	
TITLE	
SOLAR PRODUCTION OF INDUSTRIAL PROCESS STEAM	
SOLAR LAYOUT - COLLECTORS AND PIPING	
ORE-IDA FACTORY	
DESIGNED BY	APPROVED BY
NAME	DATE
DATE	12-18-78
TRW ENERGY SYSTEMS COMPANY	
Energy Systems Management Division	

Figure 9.
SPIPS Collector Array
Configuration

banks and returns to the northeast quadrant of the roof area and then to the steam generation area.

A 15-foot collector-to-collector axis spacing was chosen on the basis of computer analyses furnished by Hexcel. In the analyses the amount of daily energy collected by a field was determined as a function of collector spacing. The calculations showed that on a yearly basis increasing the collector spacing from 15 feet to 20 feet, an increase of 33% in required roof area, only increased the collected energy by 4%.

Eighty-foot long modules were chosen over shorter lengths in order to minimize installation and piping cost through reduction in the number of flexible hoses, fittings and risers. Calculations of receiver tube pressure drop and temperature rise, as indicated in Section 3.1, showed no unfavorable effect due to using an 80-foot receiver tube.

3.3.2 Freeze Protection

The Ontario, Oregon area has experienced temperatures as low as -25°F. Cloudy daytime and nighttime freeze protection of the collector field must be considered.

If a silicone fluid were to be used in the collector field, it could remain in the piping without causing damage; however, start-up and circulating power requirements would increase. For example, Syltherm's viscosity increases by 400% as it drops from room temperature to -25°F, increasing the pressure drop per unit length by about 40%. One strategy which might be used in a HTFSS would be to not circulate heat transfer fluid until the receiver tubes were sufficiently heated by the sun to raise the fluid's temperature above some lower level. In addition to the warm fluid in the receivers, the circulation pump, reservoir, and unfired steam generator would also contain warm fluid which would reduce pumping power requirements during start-up.

Water as the coolant presents a potential for piping system freeze-up and rupture. Antifreeze compounds cannot be used because of the potential for food contamination, and thermal degradation at normal receiver operating temperatures.

During cold periods, water could be routinely drained and the piping backfilled with an inert gas, such as nitrogen. The approach introduces control logic and component complexity, increased costs for nitrogen, and the need for larger tankage to store the drainoff.

As an alternative, the possibility of circulating a small amount of warm water through the field was examined. In a simplified analysis, it was assumed that a 20 mph/-25°F wind was blowing normal to the receiver tube. Under these conditions, the heat lost at the outer face of the receiver's Pyrex shield would be about $\frac{3.1 \text{ Btu}}{\text{hr-ft-}^\circ\text{F}}$. However, the controlling heat transfer rate is the natural convection in the air gap between the receiver and the glass. The heat transfer coefficient is estimated to be:

$$h \approx 0.2 \frac{\text{Btu}}{\text{hr-ft-}^\circ\text{F}} \quad \text{for a receiver tube temperature of } 500^\circ\text{F}$$

$$h \approx 0.1 \frac{\text{Btu}}{\text{hr-ft-}^\circ\text{F}} \quad \text{for a receiver tube temperature of } 40^\circ\text{F}$$

Using these values, a strategy was developed in which the circulation pump is turned on only when the water in the receiver falls below about 40°F and stays on only long enough to replace the chilled water with hot water from the surge tank. The chilled water mixes with the surge tank water, dropping the bulk temperature of the surge tank water. As the surge tank temperature drops, the rate at which heat is lost from the receiver also drops. A sample case, shown in Figure 10, indicates a 300 gallon tank of water initially at 475°F could keep the field from freezing for over 70 hours. Past that point, a small (approximately 3 kw) electric immersion heater should be able to maintain the tank and field water at around 40°F indefinitely.

Figure 10. Freeze Protection By Controlled Admission of Surge Tank Hot Water

3.4 CONTROLS AND INSTRUMENTATION

The SPIPS control system is designed to control the flow of coolant through the collector field so as to maximize the collection of solar energy and its delivery to the frying process as steam. The control system controls the solar system to account for three different combinations of insolation and thermal load. These are: 1) generation and delivery of all solar steam to 300 psi or 125 psi plant steam lines, 2) generation and delivery of part of the solar steam to plant whenever demand is less than solar capacity, and 3) collection of solar energy whenever insolation is too small to generate steam but solar heat can be applied to preheat the SPIPS. The control system also detects abnormal and emergency situations, and acts to correct the problem(s) while protecting equipment and personnel.

As part and adjunct to the SPIPS controls and instrumentation, the SPIPS will have data acquisition and monitoring systems. The data acquisition system measures, reduces, records and displays data to permit evaluation of system performance, in terms of figures of merit such as collector field collection efficiency or the percentage of steam supplied to the No. 2 fryer from the SPIPS.

The SPIPS monitoring system consists of various gauges, recorders and visual displays which assist the operating personnel in determining the status and performance of the solar system.

System operation is divided into four modes:

- System start-up
- Sunny day operation
- System shutdown/nighttime operation including protection from freezing
- Emergency operation

The first three modes are considered as part of normal system operation. Emergency control system operation refers to procedures instituted to protect the system, plant and personnel. For the solar steam production system, problems can result from such failures as:

- Circulating pump failure
- Piping rupture
- Wind damage
- Low steam generator water level

In each case, abnormal conditions are indicated by out of tolerance parameter values and corrective action is initiated. Such conditions might include:

- Loss of electric power
- Excessive collector outlet temperature
- Excessive steam generator pressure
- Excessive wind speed
- Low water level signal
- Loss of coolant flow signal
- Excessive coolant pump pressure or pump motor temperature

In the following sections, the operation of the control system is detailed together with a list of components and estimated system costs.

3.4.1 Normal Operation

The daily operation of the SPIPS begins with start-up in which the master control system rotates the collectors from their nighttime stowed (inverted) position. Start-up is initiated in the morning when sufficient energy is received by the field total solar radiation pyrliometer. The collector modules are commanded to go to a vertical position (straight up) after which sun seeking trackers on each module (shadow band sensors) take over to acquire and track the sun. If cloud cover reduces solar intensity, the total radiation pyrliometer - after an adjustable (15 seconds to 5 minutes) waiting period - issues a collector-stow command. Override stow commands may also be issued by the collector control system on the basis of a high limit signal from the wind sensor.

Each of the fourteen collector modules contain a high limit temperature sensor in the form of a thermal sensor in contact with the individual receiver surfaces. If a surface temperature exceeds an adjustable, pre-selected value that module is commanded to stow. A latching relay prevents subsequent sun tracking when the receiver cools off, i.e., manual unlatch is required.

There are also no/low flow, and low coolant pressure sensors contained in the heat transfer loop control system. In the event of individual module stowage, a status signal is provided to the operator's control panel.

The fourteen collector module drive motors, as well as their controllers are DC powered. Lead acid batteries are provided in case of line power outage. In the event of AC power loss, the batteries' trickle charger shuts off, the batteries take up the power load, and a field-stow command is issued. The slewing rate for the modules is 90° rotation in one minute, i.e., it takes three minutes to rotate from a west-facing position to an inverted position for stow. Defocusing requires about ten degrees of collector rotation position; it occurs in about six seconds. The temperature rise of a fully illuminated empty receiver tube is estimated to be $0.5^{\circ}\text{F}/\text{second}$ at solar noon and thus the maximum possible receiver tube overheat temperature is very small.

When the sun is acquired, the heat transfer loop controller shown in Figure 11 acts as follows: the collector modules controller sends a signal (Sci) to the heat transfer loop controller that the collectors are tracking; the heat transfer loop controller scans the temperatures of the receiver tubes (TC01 , TC02 through TC014) and compares them with the steam temperature, TS0 ; if any of the receiver temperatures exceed the steam temperature by 40°F or more, and the pump inlet pressure, PC_g is greater than 600 psi, the circulation pump P-01 is turned on by motor controller, EA-6.

The loop controller modulates control valve VC1 to control the coolant flow so that the coolant outlet temperature is adjusted to T_{set} . The proposed controller is capable of employing three modes of temperature feed back control; proportional, integral, and rate.

Once the circulation pump is turned on, a latch, t_L , prevents it from turning off again for a preset, adjustable waiting period. This strategy should prevent excessive pump cycling during intermittent cloud passage.

The above control loop would be appropriate to either the HTFSS or the PWFSS. In the PWFSS, it will be necessary to provide control of not only coolant outlet temperature but also outlet pressure so that the proper expansion pressure ratio is maintained. In the PWFSS a back pressure regulator would be used to establish outlet pressure. Outlet temperature control would be through a bypass from the pump's outlet directly to the

Figure 11. Schematic of Collector Coolant Heat Transfer Control Loop

sensing point of the back pressure regulator. The loop controller would modulate VCl to maintain coolant outlet temperature at T_{set} .

The loop controller also provides a means for orderly shutdown in the evening. As solar insolation decreases, VCl will adjust the coolant flow rate downward to maintain outlet temperature. At a preset minimum flow rate, the circulation pump will be shut off. For the PWFSS the back-pressure regulator valve will then close off further flow to the flash tank. Once the total pyrheliometer shows the sun has set, a module stow command would be issued.

3.4.2 Freeze Protection

The control system protects the collector field from freezing when the insolation is insufficient by circulating warm water through the field. Calculations presented in Section 3.3.2 estimate that the thermal energy in the system is sufficient to last 70 hours. If the conditions for freeze-up persist longer than this, the system can be drained under a N_2 purge to exclude oxygen.

Note that system drain is in lieu of the alternative suggested in Section 3.3.2, the installation of a small electric immersion heater in the surge tank to keep the water warm. Further statistical analyses of the weather patterns in the Ontario area are needed before a final decision as to drain or electric heat can be made.

If it is necessary to drain the field, the following action occurs when temperature TSU is below $90^{\circ}F$ and freezing conditions exist. The draindown valve opens permitting N_2 gas to flow into the inlet coolant line. The collectors are unstowed and rotated to the vertically up position to allow the receiver tubes to drain. The water coolant drains down into the expansion tank displacing the N_2 purge gas into the field piping.

To refill the system, the following action occurs. With the collectors tracking, and the receiver tubes above $40^{\circ}F$, the draindown valve is closed and the coolant flow control valve is opened. The circulating pump is turned on, and it pumps the water out of the expansion tank

into the field. The collectors are then rotated to the receiver-up position and the solenoid-controlled vent valves open allowing N_2 to vent through the automatic vent valves.

3.4.3 Control of Solar Steam Supply

With reference to Figure 11, SPIPS steam is fed to a Tee connection in the 300 psi steam header from the main boilers. The Tee connects to the existing control valve VSL for the Number Two Fryer. The control valve is actuated by the temperature of the frying oil and modulates the flow of steam to the Fryer. Steam flows through check valves V-11; V-12 to the control valve preferentially from the SPIPS solar while the balance of the steam demand is delivered through V-12.

The balancing of load between the SPIPS and plant boilers occurs as follows. As energy collected in the solar field increases, the amount of solar steam produced increases proportionately causing the pressure in the steam generator to increase. As long as the back pressure controller on the SPIPS steam line is set slightly above that of the main line, SPIPS will flow into the fryer heat exchanger. Since the SPIPS supply is only a small percentage of the total boiler output, we do not anticipate any major control system instabilities between the two steam sources.

Under most conditions the Number Two Fryer will use all of the solar steam available. When the Fryer is down and, during clean-up on weekends, solar steam may be diverted to the 125 psi steam header via cutoff valve V-14 and pressure-reducing valve V-15. Steam is also diverted into this line to keep the washing and blanching tanks from freezing on non-production days during the months of October through April when freezing weather may occur. The flow to this line is self-regulating in the same manner as previously discussed.

When the steam demand for the Number Two Fryer and/or the 125 psi steam header is less than the available SPIPS steam rate, the collector field tracking may be modulated. Control occurs in the following manner. The steam pressure P_{so} (for a given heat flux from the solar field) will rise as the steam demand is reduced. When the pressure increases above a maximum set pressure of 350 psi, the module controller causes the

collector to defocus slightly. The reduced insolation on the receivers will reduce the heat input to the SPIPS. By alternate focussing and defocussing of the field the amount of solar energy collected during periods of reduced demand may be controlled.

3.5 DATA COLLECTION AND ANALYSIS

The data collection and analysis activity is designed to provide information which may be used to assess the economic viability and commercialization potential of the SPIPS.

The instrumentation and data acquisition system has been designed to provide major data required to evaluate the performance of the Ore-Ida installation while avoiding an unnecessarily elaborate data analysis system. The hardware and software tools which will be used to evaluate the solar system performance during the 12 months of operation in Phase III are outlined below.

3.5.1 System Data Collection

The data to be gathered to support the evaluation process include measurements describing the operation of the system on daily, weekly, monthly and annual bases. System operation is characterized by the solar energy collected, transported and lost, and the system pumping and control energy required, as well as the steam generated and fossil fuel displaced.

A preliminary list of the operating parameters which will be monitored and typical instrumentation are shown in Table 12A. Approximately 30 channels of data will be recorded using a multiple channel data logger with cassette tape storage such as a Datel Model DL2-C. Units of this type provide on-site conversion of sensor outputs for storage as digitally formatted measurements ready for direct data processing. These units also record time and date, as well as providing transducer calibration signals. Stored data will be forwarded to TRW regularly, together with a copy of the operator's log.

Data will also be presented in real time for operator use. These data, along with a display control board showing system piping, valving, collector position and status will afford the operator a means for manual system control.

3.5.2 Data Analysis

The data resulting from operation of this solar steam system will be reduced, evaluated and presented in a format which will permit its use

Table 12A SPIPS Measured Parameters and Instrumentation

Symbol	Parameter	Type of Sensor*	Range	Fluid	Press psi	Temp F	Accuracy (+/-%)
TC0	Hot coolant outlet temp.	T/C	30-600°F	H ₂ O	600		1/2
TC5	Coolant inlet temp.	T/C	30-600°F	H ₂ O	600		1/2
WC	Coolant flow rate	OP, Turb.	0-100 gpm	H ₂ O	600	417	1/2
PC	Coolant outlet press	PT	0-600 psi	H ₂ O	600	417	1/2
ΔPC	Collector pressure drop	PSID	0-50 psid	H ₂ O	600	Amb	1/2
Pso	Solar steam pressure	PT	0-450 psig	Steam	300	417	1/2
TSO	Solar steam temperature	T/C	30-450°F	Steam	300	417	1/2
Qs	Solar steam quality	Cal	350°F	Steam	300	350	1
WS	Solar steam flow	OP	0-3×10 ³ #/hr	Steam	300	417	1/2
WF	Feed water supply flow rate	OP, TURB	0-100 gpm	Water	350	200	1/2
TFI	Feed water temperature	T/C	30-250°F	Water	350	200	1/2

*Legend

CAL = Calorimeter

PT = Pressure transducer

Turb. = Turbine meter

OP = orifice plate

T/C = Thermo. couple

Table 12A (Cont'd)

Symbol	Parameter	Type of Sensor	Range	Fluid	Press psi	Temp ° F	Accuracy (+%)
W_{FS}	Fossil steam flow to #2 fryer	OP	3×10^4 #/hr	Steam	300	417	$\frac{1}{2}$
Q_F	Fossil steam quality	Cal	350° F	Steam	300	350	1
T_S	Fossil steam temp	T/C	0-450° F	Steam	300	417	$\frac{1}{2}$
P_S	Fossil steam pressure	PT	0-350	Steam	300	417	$\frac{1}{2}$
T_{amb}	Ambient temperature	Resistant thermometer	-30,+120° F	Air	atm	amb	
M_{W2}	Wind speed	Anemometer	0-100 mph	Air	atm	amb	
M_{W3}	Wind direction	Wind vane	0-360	Air	atm	amb	
M_{W4}	Direct solar insolation	Pyrheliometer	0-2800 watts/m ²	Air	atm	amb	$\frac{1}{2}$
M_{W5}	Total solar insolation	Pyranometer	0-2800 watts/m ²	Air	atm	amb	$\frac{1}{2}$
EA3	SPIPS electric energy consumed	Watt meter	TBD	Electricity	atm	amb	1
EA4	Electric power demand	Watt meter	TBD	Electricity	atm	amb	1
EA6	CWC pump energy	Watt meter	TBD	Electricity	atm	amb	1
EA7	SPIPS power equipment operating time	Clock	8000 hrs.	-	atm	amb	-

(Table 12A (Cont'd)

Reliability and Maintainability Data

A1	Component unscheduled down time	Operator's log
A2	Failure effects on operations	Operator's log
A3	Cause of failure	Operator's log
A4	Repair action required	Operator's log
A5	Number of maintenance events	Operator's log
A6	Time to maintain each component	Operator's log
A7	Material costs for each maintenance event	Operator's log

in assessing the appropriateness of this type of solar steam system for other industrial process steam applications. Direct comparison will be made between identical fryers operating with and without solar steam. The total fossil energy displaced and steam produced by the solar steam for each month of the year will be presented in tabular and graphic form. Solar system efficiency will also be presented for each month showing the relationship between performance of this system and the available insolation.

Operation of parallel fossil and solar-assisted fryers will also permit direct assessment of operation and maintenance support costs. Estimates of the mean times between failure and mean times to repair for both the solar and fossil-fueled system components will provide the operating experience necessary to demonstrate the credibility of solar systems. These analyses will also highlight the solar component or system improvements needed to make solar produced industrial process steam more cost effective.

The results of the performance analysis will provide other potential industrial users of solar systems with the data needed to assess the system and evaluate its suitability in their application.

4. INSOLATION DATA

For this design the amount of solar insolation received at Ontario was taken as equal to that measured at Boise State University. These data are shown in Table 13. It was the original intention to correct these data for climatological differences between Boise and Ontario by comparing three months of simultaneous data at both locations. To do this a pyr-heliometer was to be installed at Ontario in October. The pyr-heliometer was not received at TRW until December 23; therefore, this correlation could not be made in time for this report.

TABLE 13. MONTHLY DIRECT SOLAR
INSOLATION MEASURED AT BOISE STATE
UNIVERSITY

<u>Month</u>	<u>Total Direct Insolation Btu/ft²</u>
January	8,597
February	35,241
March	37,287
April	72,082
May	49,842
June	81,714
July	93,244
August	62,190
September	64,603
October	57,111
November	23,806
December	<u>14,272</u>
TOTAL	599,989

A second correlation using data from the National Climatic Center (NCC) was undertaken when it became obvious that the direct comparison data would not be available in time. This correlation involves a computer regression analysis of historical opaque cloud cover data. This analysis, based on a method developed by NCC using the SOLMET data base, is in progress.

In this analysis the clear sky hourly solar radiation is calculated as a function of the solar zenith angle by the equation:

$$I_{cs} = a_0 + a_1 \cos \alpha + a_2 \cos^2 \alpha + a_3 \cos^3 \alpha \quad (1)$$

where:

I_{cs} = Clear sky solar radiation (kJ/m^2)

α = Zenith angle

a_i = Regression coefficients

The second equation gives the actual solar radiation received on a horizontal surface as a function of the opaque cloud cover factor (commonly recorded at weather stations throughout the United States.)

This equation is:

$$I_h = I_{cs} [C_0 + C_2 OPQ^2 + C_3 OPQ^2 + C_4 OPQ^3 + C_5 P] \quad (2)$$

where:

I_h = Insolation on a horizontal surface (kJ/m^2)

OPQ = Opaque cloud cover (dimensionless)

P = Precipitation index (= 1 if precipitation, = 0 if no precipitation)

C_i = Regression coefficients

The proper regression coefficients were derived for 22 climatic regions by NCC. Ely, Nevada is the SOLMET Station in Boise's climatic region. The regression coefficients are given in Table 14, below.

TABLE 14.
REGRESSION COEFFICIENTS FOR ELY, NEVADA

a_0	for clear sky	-68, -57, -42, -46,
	morning, Jan-Dec	-86, -146, -184, -184,
		-133, -94, -94, -80

TABLE 14 (CONTINUED)

a_0	for clear sky, afternoon, Jan-Dec	-69, -36, -32, -23, -56, -122, -137, -178, -123, -82, -96, -75
a_1, a_2, a_3	morning afternoon	3260, 2430, -1560 3180, 2530, -1590
$c_0 - c_2$		1.000, 0., -0.192
$c_3 - c_5$		0.247, -0.602, -0.210

To extrapolate the results of the regression equations to all stations in the climatic region, a correction factor is used. Since the stations within one region were assumed to be climatically similar, the same effects of precipitable water, turbidity and albedo were assumed. The latitude correction factor is accounted for in equation 1 since the zenith angle α is a function of latitude. The only remaining correction factor is for a difference in station altitude. This correction is shown in equation 3, below.

$$G(p) = G(p_s) + \left(\frac{p_s - p}{p_s} \right) [G(p_0) - G(p_s)] \quad (3)$$

where:

$G(p)$ = global solar radiation at the station in question whose mean monthly station pressure (proportional to altitude) is p .

$G(p_s)$ = global solar radiation at the SOLMET, or reference station, whose mean monthly station pressure is p_s .

$G(p_0)$ = global solar radiation at the top of the atmosphere — extraterrestrial radiation (ETR) — where the pressure $p_0 = 0$.

TRW has received the hourly TDF-14 data from the NCC in North Carolina. This data for Ontario Airport, Oregon is available in tape format for 1948 to 1954. The SOLMET modeling technique described above is applicable to Ontario. Insolation in Ontario will be predicted as a function of opaque cloud cover using the above technique. This analysis will provide an estimate that is based on local climatic patterns.

5. ANALYSIS OF THERMAL ENERGY GENERATED

In the previous section the available data on solar insolation were discussed. The amount of insolation which could go to generate steam has been calculated as discussed in this section. The calculation was based on a combination of theoretical models and actual experimental measurements of the Hexcel collector efficiency. The energy collected was calculated at one hour intervals throughout the year, then summed to obtain daily, monthly, and annual energy collection values.

5.1 MODEL DESCRIPTION

The TRW Focusing Parabolic Collector model which was used to calculate the energy collected is a computer program based on the SOLSYS subroutine FOCMWE developed by Sandia Laboratories and modified by TRW. The program is coded in Fortran and is operable on the TRW timesharing computer system. An hour by hour analysis of collector performance under various temperature, orientation, and insolation conditions produces graphical and printed output of collected energy and collection efficiency.

The model has three stages of operation: data input and correction, collector performance analysis, and output processing. The data input and correction stage is used for all meteorological and program control inputs. The insolation data is corrected for tilt angle of the collector if the data is for a horizontal surface. The collector performance is then simulated for each hour of the year using actual collector efficiencies and calculated sun angles. The output is both graphical representations of insolation and collector efficiency.

Hourly weather data inputs are provided from the NCC TDF-14 data base for Boise. The input parameters are hour, day, month, wind speed, and ambient temperature. The insolation is provided by measurements made at Boise State University.

The geometry relating the sun's position to the orientation of the collector is based upon the geometric routines in SOLSYS. They allow either east-west oriented or north-south oriented collectors at any desired tilt angle from horizontal. Combinations of east-west and north-south are also available. The entire year or any subset

of the year and/or day can be simulated.

The collector efficiency portion of the program is based on an empirical approach using experimental data. The data were from a series of tests¹ performed at Sandia Laboratories in New Mexico on the Hexcel collector.

The efficiency of the collector is shown in Figure 12. The efficiency is the fraction of the direct normal insolation falling on the collector aperture which the receiver fluid absorbs. Efficiency is plotted against the parameter $(\bar{T} - T_{amb})/I$ where $\bar{T}$ is the average fluid temperature, T_{amb} is the ambient temperature and I is the insolation.

The conversion of insolation to heat transferred to a working fluid by the collector is given by

$$Q = \eta_1 \eta_2 I_d$$

where:

Q = Heat transferred to working fluid (Btu/hr-ft²)

I_d = Direct insolation (Btu/hr-ft²)

$\eta_1 \eta_2$ = Efficiency factors.

The first efficiency factor is the collector efficiency which was previously discussed. The second efficiency factor, shown in Figure 13 corrects for performance of the collector under non-normal angles of solar incidence. This occurs since a fraction of the insolation which strikes the receiver at non-normal incidence angles is reflected off of the tube and is not collected. This correction is based on measurements made by Hexcel.

1 Dudley, Vernon E. and Workhoven, Robert M. "Performance Testing of the Hexcel Parabolic Trough Solar Collector" SAND78-0381, March 1978, available from NTIS.

Figure 12. Efficiency of Hexcel Collector

Figure 13. Effect of the Angle of Incidence on Collector Efficiency

5.2 CALCULATION RESULTS

The results of the calculations using the model previously discussed are summarized in Table 15. Here the monthly collected energy, in BTU's/ft²-mo. are shown for the three different system concepts for both east-west (E-W) and north-south (N-S) orientations.

The PWFSS with the north-south orientation collects the most energy. It collects about eight percent more than the HTFSS and about one percent more than the pressurized water system. (This difference is attributable to the different temperatures of collector.) In all cases the N-S collects about thirty percent more than the E-W orientation. This difference dictates the use of N-S collector field orientation. No attempt was made to correlate the collected energy with the operable days of the plant. The weather data did not cover a long enough historical period to justify a statistical correlation of this type. However, even excluding the months of July and August when most plant non production periods occur the N-S orientation still provides twenty three percent more collected energy than E-W.

Figures 14 and 15 show the collected energy for the PWFSS system with a N-S orientation plotted on monthly and daily bases. It is interesting to note in Figure 15 how the insolation and collected energy vary on a day to day basis. Periods of extended low levels of insolation are clearly visible in January and May while April, for example, appeared to be mostly clear.

Table 15. Summary of Collected Energy
(Btu/ft²-mo)

Month	Insolation	Heat Transfer Fluid Steam System		Pressurized Water Flash Steam System		Pressurized Water Steam System	
		N-S	E-W	N-S	E-W	N-S	E-W
Jan	8597.0	1835.4	2208.6	2164.8	2586.8	2129.0	2546.2
Feb	35241.0	13253.4	11669.3	14524.1	12684.8	14392.4	12579.2
Mar	37287.0	15060.3	12013.8	16494.3	13000.5	16343.2	12898.5
Apr	72082.0	34117.1	24353.6	36865.3	26065.2	36581.9	25889.1
May	49842.0	22076.1	15334.1	24171.6	16702.0	23951.3	16558.3
June	81714.0	40271.2	29117.7	43228.7	31161.4	42923.3	30950.4
July	93244.0	47709.2	33115.6	50928.3	35209.7	50598.3	34994.8
Aug	62150.0	29324.8	19759.3	31788.9	21285.1	31532.8	21126.9
Sept	64603.0	31285.1	21868.3	33457.2	23234.7	33234.5	23094.6
Oct	57111.0	23996.0	20939.9	25965.6	22472.9	25761.3	22315.7
Nov	23806.0	7985.7	8940.5	8739.6	9713.7	8660.6	9632.5
Dec	14272.0	3952.3	5199.5	4383.3	5697.5	4337.1	5645.1
Totals	599989.0	270866.7	204520.1	292711.7	219814.4	290445.8	218231.5

Figure 14. Monthly Insolation and Collected Energy
for PWFSS, N-S Collector Orientation

477

417

NS

Figure 15. Daily Insolation and Collected Energy for PWFSS, N-S Collector Orientation

6. ENVIRONMENTAL IMPACT ASSESSMENT

This section of the report presents a generalized assessment of environmental impacts associated with the proposed SPIPS project. The purpose of the assessment is to provide early identification of potential environmental impacts associated with the project so that necessary mitigating measures may be incorporated into the project design.

For the purpose of this discussion, the "environment" is defined as the physical and natural surroundings in the project area but specifically excludes direct effects on man. The potential for elements of the project to affect man will be discussed in the Health and Safety Analysis, Section 7.

6.1 DESCRIPTION OF EXISTING ENVIRONMENT

The site of the proposed SPIPS project is Ore-Ida's potato processing facility in Ontario, Oregon. With its estimated 1975 population of 7,775 people, Ontario is the largest and fastest growing city in Malheur County.¹ The county has 60 by 170-mile rectangular shape and is situated along the border between Oregon and Idaho. As shown in Figure 16, Ontario is located in the northeastern section of the county with Nyssa and Vale as neighboring communities. This general area accounts for 85% of the county's population. Ontario lies upon the flood plain in an area south of the confluence of the Malheur and Snake Rivers. The Ore-Ida facility covers an area of over 200 acres adjacent to the Snake River. The terrain of the area around Ontario consists of nearly level river valley plains and plateaus adjacent to dissected and rolling bench lands and uplands. Elevations range from 2100 at the Snake River to 3700 feet attained by one of the buttes in the area.

¹CH2M Hill, Title unknown, proposal for establishing a geothermal production well for the Ore-Ida Foods, Inc., Ontario, Oregon.

Figure 16. Location of Proposed SPIPS Project

The climate is generally semiarid with hot, dry summers and cold, snowy winters. Average annual precipitation ranges from 9 to 11 inches, 60% of which falls from October through March. Snowfall accounts for 45% of the precipitation during this period. Insolation data for the Ontario region has been provided elsewhere in this report.

Predominant winds in the area are from the north and west. Most of the precipitation however, is associated with winds from the southwest.

The major air pollution sources in the area are nearby agricultural operations, windblown dust (particularly during summer months), and smoke from forest fires which also occur most frequently during the summer. The pollutant of prime concern from these sources would be particulate matter. There are no air quality monitoring stations established for the Ontario area, so data on representative ambient levels of air pollutants is unavailable. Partial atmospheric inversions occur once every 30 to 40 days, but their effects are minor and often go unnoticed.

Ontario is located within the Malheur River hydrologic basin. With respective mean annual (calendar year, 1974) discharge rates of 270 and 24,850 cubic feet per second (cfs), the Malheur and Snake Rivers are the only major perennial surface water sources in the area. Flow along the Malheur is regulated by 1) irrigation reservoirs located on tributaries and 2) irrigation diversions along the length of the river. There are also interbasin transfers of irrigation water. The combined effects of widespread irrigation, and natural surface and base flow characteristics results in widely varying water quality throughout the year.

Wastewater produced within the plant (e.g., potato washing water and floor drainage) is piped to an on-site treatment plant which provides primary and secondary treatment. The secondary effluent is discharged to the Snake River.

6.2 POTENTIAL ENVIRONMENTAL IMPACTS

The following is a listing of the general types of impacts often considered in environmental impact assessments:

- impact on ambient air quality
- impact on ambient water quality and associated aquatic biota
- impact of use of water as a resource
- impact on landforms and the biota associated with affected land resources
- noise impacts
- energy impacts

With respect to the proposed SPIPS project, the above categories are either not applicable or inconsequential in terms of the magnitude of potential adverse impacts. In some cases, the expected impacts are beneficial; while in other cases, adverse impacts can be easily mitigated with proper engineering controls. Each of the above categories will be briefly discussed in context of its association with the proposed project.

The direct impacts of the SPIPS project on ambient air quality is expected to be beneficial to the extent that solar energy displaces the burning of fossil fuel for heat energy. The combustion of fossil fuels can give rise to a variety of air pollutants, including NO_x , SO_x and particulates. Because Ore-Ida currently uses a gas-fired boiler to produce process steam, one would expect that only a low level of air pollutants would be produced. Thus, the magnitude of the beneficial air quality impacts associated with displacing natural gas combustion with solar energy would be small. However, Ore-Ida's gas supply is interruptible and it is likely that the replacement fuel will not be as clean as natural gas. Under these circumstances, the air quality benefits associated with SPIPS will be increased.

The collector heat transfer loop uses pressurized hot water, is self-contained and, under normal operating conditions, no discharges will be made to the water environment. The only possible exceptions to this would be: 1) minor leaks that may occur at pump seals and other connections, and 2) accidental spills resulting from a major break in the heat transfer circuit. Any minor leaks that may be present are expected to be small and insignificant in magnitude. The system should be engineered to eliminate this type of loss to the best extent possible. A major break in the heat transfer circuit could result in the loss of the total inventory of about 600 gallons of hot pressurized water. Much of the water will flash to steam, but any which remains as a liquid will leave the site by one of two drainage pathways depending on where the break occurred. If the break occurred at some location outside of the buildings, (e.g., within the roof-based collector system or external piping) the flow would eventually go to storm drainage which discharges directly to the Snake River. If the break occurred inside one of the buildings, liquids would pass to floor drainage systems to the on-site wastewater treatment plant as a component of the wastewater normally received by this plant. The ultimate impact of either of these discharges on the water environment and its associated biota will depend primarily on corrosion inhibitors which may be constituents of the pressurized water system. Attention will have to be directed towards materials used as corrosion inhibitors and their potential effects on water quality, associated biota and wastewater treatment processes. However, it should be noted that the overall impact associated with the inadvertent discharge of the entire heat transfer fluid inventory to the Snake River would be minimized by the following factors:

- for economic and safety reasons, accidental ruptures of the type that would cause such a spill should occur rarely,
- even if the entire 600-gallon inventory reached the Snake River without prior treatment in the treatment plant, the total volume of the discharge would be small compared to the river's discharge rate of thousands of cubic feet per second

- the adverse effects of a large-scale spill could be further mitigated by construction of a drainage sump which would allow the spilled heat transfer fluid to be collected in one place and disposed of properly

The collector field fluid circuit will be self-contained and periodic commitments of water resources to the system will be needed only to make up for water loss via small leaks, or whenever the entire inventory requires replacement. It is expected that the total allocation of water resources for the proposed SPIPS project will be small compared to other uses of water around the plant.

No new natural land resources would have to be allocated for the projected SPIPS project. The collector field will be placed upon an existing roof and other elements of the system will be situated adjacent to or on existing structures. Currently there is substantial paving of the grounds in the general vicinity of the proposed installation site. Therefore, one would expect that no natural land resources will be disturbed or allocated as a result of the proposed project.

For the proposed project, human beings would be the primary receptor for adverse noise impacts. In accordance with statements made earlier in this section, issues associated with noise impacts will be discussed in the Health and Safety portion of this report.

The energy impacts of the proposed SPIPS project are obviously beneficial. The project allows for the use of an energy resource that would otherwise be wasted, while conserving fossil fuels which are in short supply.

6.3 COORDINATION WITH FEDERAL, STATE, REGIONAL AND LOCAL PLANS

In light of the current nationwide energy situation, it is unlikely that existing federal, state, regional or local plans would hinder development of the proposed project. The SPIPS project would be in line with national plans and goals to demonstrate the applicability of solar energy for useful purposes, while also achieving conservation of fossil fuel energy resources. Furthermore, the Malheur County Comprehensive Plan²

²Comprehensive Planning Staff, Malheur County, "Comprehensive Planning Program, Background Reports, Volume IV: Land Capabilities and Natural Resources," August 1977.

notes the favorable insolation characteristics of the area and has recommended that action be taken to make use of solar energy within the county.

It may be necessary for Ore-Ida officials to check with local and state environmental officials to determine: 1) whether the plant's wastewater discharge permits will have to be altered due to possible intermittent accidental discharges of the fluid inventory, and 2) whether the constituents of the heat transfer fluid are deemed dangerous enough to establish spill prevention and contingency cleanup plans. It seems unlikely that either permit alteration or contingency plans will be required but the ultimate decision will depend on the nature of additives that may be necessary for the heat transfer fluid and policies set by concerned environmental officials.

6.4 DESCRIPTION OF ALTERNATIVES

Major alternatives to the proposed action are listed below:

- do not use the SPIPS but continue to use the existing gas-fired system, i.e., a "no action" alternative
- use the SPIPS but with another heat transfer fluid
- use another fossil fuel to provide the necessary heat
- use electrically-heated boilers
- use geothermal energy

In relation to the above alternatives, the proposed project seems to be the best approach. The "no action" alternative would result in increased use of fossil fuels. Furthermore, Ore-Ida's supply of natural gas is interruptible; therefore, use of another dirtier fuel would result in additional pollutant outputs.

A variety of other heat transfer fluids were considered in the early stages of this project. (A discussion of heat transfer fluid selection is presented in the Appendix.) For toxicity and flammability reasons, the pressurized water system was chosen as the best alternative.

Electrically-heated boilers would not involve the on-site generation of combustion products, but there will likely be air pollution, water pollution and solid wastes associated with the initial generation of the electricity. Moreover, depending on the method of electricity generation, there may be large energy inefficiencies associated with the use of an electrically-heated boiler.

The use of geothermal energy resources is currently being examined by Ore-Ida personnel. However, the geothermal energy is not hot enough to supply the requirements for frying potatoes.

7. HEALTH AND SAFETY ANALYSIS

This section of the report presents a preliminary Health and Safety analysis of the proposed SPIPS project. The purpose of the analysis is to provide an early identification of hazards that may be associated with the project. The results of this analysis can then be used to prescribe the appropriate corrective and mitigative measures which will permit the proposed system to operate in a manner which gives adequate consideration to overall safety and health.

7.1 SCOPE

The major objective of the safety analysis for the proposed Ore-Ida SPIPS system is to show how this system can be operated in a manner which will protect the health and ensure the safety of the following subpopulations:

- the general public
- visitors to the facility
- Ore-Ida personnel not associated with the operation of the solar powered system
- construction, testing and other personnel involved in the maintenance and operation of the system.

In light of the fact that Ore-Ida's food products are widely marketed, the term "general public" listed above would have to include the people who buy and consume Ore-Ida's products. Therefore, the safety analysis will have to consider the extent to which the proposed solar powered unit may adversely affect the quality and marketability of Ore-Ida's food products.

7.2 REGULATIONS, GUIDELINES AND REQUIREMENTS PERTAINING TO THE SPIPS PROJECT

While there is no set of safety standards that apply specifically to solar powered process steam production units, regulations and guidelines do exist for some of the components and elements which comprise the system. For the most part, the regulations and guidelines refer to construction, operating and maintenance procedures normally considered good operating

practices for pieces of equipment or processes commonly found within industrial settings. In other cases, the guidelines concern general aspects of solar energy applications. Some of the regulations and guidelines that may apply to the SPIPS project are listed in Table 16.

7.3 POTENTIAL HAZARDOUS CONDITIONS

Because each system has different characteristics, strict adherence to the specific guidelines contained in Table 16 will not guarantee freedom from hazardous conditions within the project. This is especially true for a solar energy project which is expected to include a number of processes and pieces of equipment which are not commonly found within usual industrial installations. Some of the potential hazardous conditions that may be associated with the proposed Ore-Ida SPIPS project will be discussed in the following paragraphs. The potential safety problems will be discussed with respect to three major system components: 1) the collector/receiver system, 2) the heat transfer fluid element and 3) the machinery and other equipment required for the operation of the SPIPS system. Techniques of mitigating or eliminating specified hazards will also be provided.

7.3.1 The Collector/Receiver System

The main safety problems associated with the collector/receiver system are the solar reflectance hazards. If the skin or eyes of personnel is brought near the focal point of the parabolic collector during periods of sunshine, severe burns could result. The effect on the eyes could be temporary or permanent blindness depending on eye orientation to the light rays and length of exposure. For the skin, the result would be a concentrated sunburn. Burns could also result from contact with exposed portions of the heat transfer circuit (piping, ends of receiver tubes, etc.). A glare hazard may also exist for persons located in or near the collector field, but this is not considered to be a major problem.

Location of the collectors on a rooftop limits access and therefore forms a natural barrier. Nevertheless, a hazard may still exist for personnel whose activities require that they be on the rooftop. Populations which are most at risk include: personnel involved in the construction, testing operation and maintenance of the SPIPS system; other Ore-Ida

Table 16. Standards, Codes and Regulations
Establishing Safety Guidelines
which May Be Applicable to the
Ore-Ida SPIPS Project

- Occupational Safety and Health Administration Regulations
- Food and Drug Administration Regulations
- Department of Energy publication on environmental factors of solar energy system
- Environmental Protection Agency publication concerning accidents and unscheduled events associated with non-nuclear energy resources
- American Society of Mechanical Engineers Boiler and Pressure Vessel Codes
- National Fire Protection Association Fire Protection Handbook and National Fire Codes
- American National Standards Institute Standards for piping, minimum design loads and safety color codes for marking physical hazards
- H-1 Code for Hydraulic Pumps
- National Board of Fire Underwriters' Codes for Building and Equipment
- National Electric Manufacturers Association Standards for Electrical Equipment and Controls
- Safety rules for the installation and maintenance of electric supply and communication lines
- Steel Boiler Institute Code for boilers
- Tubular Exchanger Manufacturers Association's Standards for heat exchangers
- Underwriters' Laboratory Standards
- Uniform Building Code
- Standards of American Institute of Steel Construction and American Concrete Institute
- Interstate Commerce Commission Shipping Standards and Regulations
- National Safety Council's Accident Prevention Manual for Industrial Operations

personnel whose duties require that they spend time on the roof of the building in question; and visitors to the facility--authorized or unauthorized.

Thus the most serious of the hazards presented by the collector/receiver field are associated with exposure to the solar reflectance at or near the focal length (less than two feet). Techniques which may be used to eliminate, reduce the frequency of or mitigate the severity of this set of potential hazards are: establishing controls to strictly limit access to the roof so that only authorized personnel can gain entry (one may also want to use fencing to even further limit access); providing authorized personnel with proper instruction on methods of avoiding the hazards posed by the collection field; requiring that the proper protective equipment is worn; properly designing and insulating the supports at the end of the receiver tube and the heat transfer piping circuit to minimize the chance of contact burns; and using safety warning devices and signs.

Glare hazards at a distance will not be a problem since the reflection is no greater than that from glass buildings or a large area of water.

7.3.2 Heat Transfer Fluid

The heat transfer fluid element of the proposed system has the potential of creating a variety of health and safety problems. Depending on choice of fluid, these problems could include; fires, burns due to contact with spilled hot fluid or hot piping and other components of the heat transfer circuit, toxic effects resulting when personnel are exposed to the fluid following a major spill or normal leakage, and potential toxicity effects associated with food contamination.

Some of these problems were serious enough to preclude the use of certain kinds of heat transfer fluids. The major criteria used in this selection process were flammability and toxicity. Ore-Ida's insurance restrictions were such that the use of a flammable heat transfer fluid was essentially ruled out. In addition, because steam produced by the SPIPS unit is for food processing, it is important that the heat transfer fluid (which could, under a failure, leak through the coils of a steam generator) be nontoxic and accepted by the Food and Drug Administration (FDA) for

food contact. This latter point is especially crucial at Ore-Ida's Ontario facility because process steam lines are interconnected and widely distributed throughout the plant. A discussion of details considered in the heat transfer fluid selection process is presented in the Appendix.

The use of water as the heat transfer fluid still presents burn hazards. Methods which can be used to reduce the frequency or severity of such hazards include: properly insulating exposed piping and other hot components; decreasing the risk of rupture by following the good practice guidelines and standards referred to in Section 7.2; and instructing plant personnel in proper methods of handling the situation resulting from a major rupture in the heat transfer fluid circuit. If a major rupture occurred within a component on the roof, it will be necessary that adequate drainage be provided so that the hot fluids are quickly routed to the ground level by preferred pathways.

7.3.3 Machinery and Other Components

This element of the SPIPS system includes boilers, pumps, electrical components and piping. The types of potential hazards associated with these elements include: injury to personnel caused by moving parts of machinery; fatigue and hearing impairment due to vibration and noise from equipment; injury due to electrical shock, injury due to contact with hot pipes; hazards caused by the instability of supporting structure under normal and stressed modes; fire hazards due to lightning, electrical connections, or other causes; and injury or damage resulting from sabotage, vandalism or other similar events.

It is anticipated that the kinds of hazards listed above will not present a significant hazard if the guidelines and regulations referred to in Section 7.2 are followed. Controls will have to be implemented to protect against sabotage and vandalism, and emergency procedures should be developed for plausible major accidents. A matrix of applicable standards and codes for the kinds of equipment most likely to be used in the SPIPS project are presented in another TRW document¹.

¹TRW Energy Systems Group, Conceptual Design: Solar Total Energy Large Scale Experiment Number 1, Final Report, October 21, 1977, pp. 80-83.

With regards to the equipment and design chosen for the SPIPS, three additional points need to be made. First, the piping used to convey the heat transfer fluid from the collectors to the steam generator has to be so constructed that it will be capable of withstanding the thermal shock that may result if the pipe is sprayed during fire fighting activities. Secondly, consideration should be given to the potential hazards that may result if a freeze up of the heat transfer fluid occurs during the evening and night. Finally, many of the hazards associated with the SPIPS system are the result of a failure of identifiable system elements. Therefore, a detailed failure mode analysis should be performed during final design phases of the project.

8. COST ESTIMATE

Cost estimates of the construction cost of both the pressurized water/steam system and the pressurized water flash steam system are tabulated below. These figures include subcontractors overhead and profit.

<u>Component</u>	<u>PWSS</u>	<u>PWFSS</u>
Hexcel Collectors (9,520 sq.ft.) including tracking control	\$ 185,640	\$ 185,640
Installation of collectors on roof and shipping	10,000	10,000
Piping, fittings, and valves	60,100	60,100
Insulation	31,500	31,500
Major Equipment		
Unfired boiler	38,700	-
Flash tank	-	15,800
Expansion tank	18,400	-
Field Circulation Pump	9,800	15,000
Recirculation Pump	3,000	3,000
Makeup pump	3,000	-
Blowdown heat exchanger	1,300	1,300
Steam separator	2,500	2,500
Chemical feed equipment	1,900	2,100
Electrical Equipment		
Starters	600	600
Circuit breakers	700	500
Contactors	500	500
Conduit	1,500	1,500
Structural		
Cutting Roof	600	600
Patch Roof	15,700	15,700
Wood curb collection base	5,000	5,000
Anchor bolts	3,100	3,100
System controls, instrumentation	<u>40,000</u>	<u>40,000</u>
Subtotal	\$ 433,540	\$ 394,440
Contingency--20% on all except collectors	<u>49,580</u>	<u>41,760</u>
Total	<u>\$ 483,120</u>	<u>\$ 436,200</u>

9. DETAIL DESIGN

Starting with the conceptual design defined in this report the process of Detailed Design will be continued. Detailed Design includes the refinement of materials selection, component sizing, thermal, fluid, and structural analyses; all of which result in drawings and specifications in sufficient detail such that the hardware may be fabricated and assembled into a system which will function as required.

In the process of defining the details of the system, costs of elements and the total system will be continually assessed in order to maintain the most cost effective system on a life cycle basis.

In order to control the design and construction of the system and its components, system specifications and detail component specifications will be developed in the Detail Design task. An outline of these specifications follows. Those characteristics presently defined are specified; those which are labeled TBD, are to be determined in the Detail Design.

9.1 OUTLINE OF SYSTEM SPECIFICATIONS

SPIPS SYSTEM SPECIFICATION

1. PURPOSE

This specification is intended to provide an outline for the detailed design of a Solar Energy Pressurized Water/Steam System to be installed at the Ontario, Oregon plant of Ore-Ida Foods Inc. The designer will be expected to design the system in full accordance with all applicable rules, regulations, requirements, codes and standards.

2. CODES AND STANDARDS

The following documents are applicable to the extent specified herein:

- 2.1 American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section VIII.
- 2.2 American National Standards Institute, ANSI B31.1.

- 2.3 American Society for Testing and Materials, Annual Book of ASTM Standards.
- 2.4 National Electrical Manufacturers Association (NEMA) Standards.
- 2.5 American Institute of Steel Construction 7th Edition.
- 2.6 American Welding Society.
- 2.7 Uniform Building Code.
- 2.8 Uniform Plumbing Code.
- 2.9 Oregon Boiler and Pressure Vessel Law.
- 2.10 National Electrical Code.
- 2.11 Ontario, Oregon Building and Safety Code.
- 2.12 Title 29, Code of Federal Regulation, OSHA.
- 2.13 Environmental regulations.

3. SYSTEM REQUIREMENTS

3.1 ENERGY SUPPLIED

Based on a maximum of 10,000 square feet of single axis tracking, concentrating collectors and the insolation defined for Boise, Idaho in Table 2-2 of the TRW SPIPS proposal, the system shall deliver not less than 3.5×10^9 Btu/year of 417°F, 300 psi steam to the Ore-Ida steam system.

3.2 SYSTEM OPERATING CONDITIONS

3.2.1 Operating

(a) The system shall be capable of operating 365 days per year during the daylight hours from sunrise to sunset. Storage capability will not be included.

(b) The system shall be fully operable under the following conditions:

- Wind - less than 30 MPH
- Snow and Ice (TBD)

- Sand and Dust (TBD)
- Temperatures (TBD)
- Other (TBD)

(c) Operation of the system will be fully automatic. That is, no personnel actions will be involved in the various system operations. Manual overrides and/or bypasses will be provided to permit operation or shutdown of the system at the discretion of operating personnel or in the event of automatic equipment failures.

3.2.2 Stowage

(a) The system shall be capable of sensing the following:

- Solar incidence
- Conditions in excess of those shown in 3.1.1(b).

Under these conditions, the system will, within TBD seconds, automatically proceed to a stowed position wherein:

- The collectors are pointed down and locked
- All the pumps are deactivated
- The system is physically isolated from the process plant boiler system and potato processing operations.

In this stowed condition, the system shall, without damage, withstand the following conditions:

- Wind to 100 MPH
- Rain (TBD)
- Snow and Ice (TBD)
- Sand and Dust (TBD)
- Temperatures (TBD)
- Other (TBD)

Upon the return of the environmental condition specified in Paragraph 3.2.1(b) above, the system shall automatically return to normal operation within TBD seconds.

3.3 RELIABILITY

The overall system MTBF shall be equal to or greater than TBD hours.

3.4 SAFETY

3.4.1 The system shall be designed so that any system or equipment failures will result in safe system conditions, and to minimize hazards to equipment, facilities, personnel, and the plant products and processes.

(a) The system shall be designed so that no single failure will cause any fluid other than water or steam to come into contact with the product or plant processes.

(b) All working fluids and heat transfer fluids will be selected to meet the following standards or regulations.

- Flammability (TBD)
- Toxicity (TBD)
- TBD
- TBD

(c) All fluids shall be compatible with, and prevent damages to, the structures and materials with which they come into contact.

(d) The system shall be designed to sense leakage of working fluids and heat transfer fluids by detecting pressure variations of TBD psi off-nominal and temperatures of TBD off-nominal, and shall, within TBD seconds, place the system in the stowed condition.

(e) Provisions shall be made (1) to contain all spilled fluids and (2) for safety and clean-up devices and procedures to minimize hazards to personnel, product, facilities, equipment, and product processes.

3.5 ENVIRONMENTAL PROTECTION

The system shall be designed to comply with TBD documents.

3.6 MAINTENANCE

3.6.1 The system shall be designed for maintenance by the process plant maintenance personnel without special training other than familiarization with the SPIPS system.

3.6.2 The system shall be designed for maintenance using standard tools and test equipment.

3.6.3 The system shall be designed to preclude scheduled and preventive maintenance, except as specifically noted in this specification.

3.7 SYSTEM EVALUATION

The system shall be designed to incorporate those system sensors and instrumentation necessary to assess performance of the system and provide the data necessary to perform economic analysis of the solar system and comparison to the normal operation which it supplants.

4. SUBSYSTEM REQUIREMENTS

4.1 PHYSICAL CONFIGURATION

The collector field will be configured so that:

- The orientation maximizes collected energy
- The length of the collector rows will optimize the heat transfer fluid temperature rise.
- Piping costs are minimized.

4.1.2 Operating Conditions and Limits

(a) The collector shall produce a temperature rise of 1° to 2°F/foot at the coolant flow rates between 4 and 7 gallons/minute and collector outlet temperatures between 400°F and 500°F .

(b) The nominal working fluid outlet temperature shall be 450° .

4.1.3 Collector Control System

(a) The collector sensing and control system shall be designed to accomplish the following:

- Provide a pointing accuracy of $\text{TBD} \pm 0^{\circ}$.
- Sense the environmental condition specified in Paragraph 3.2.1 above.
- Place the collector system in the stowed position as defined in Paragraph 3.2.2 above within TBD seconds.

- Sense the return of environmental conditions to the satisfactory range and return the collector system to operating conditions within TBD seconds.

4.1.4 Subsystem Efficiency

The collector collection efficiency shall be not less than 60 percent.

4.2 PIPING

4.2.1 General

The system shall be configured to minimize piping runs and costs, i.e., the distance between the collector field and the unfired boiler shall be as short as possible consistent with safety, operating and physical interface constraints.

4.2.2 Piping System

The piping system shall be designed to, and be compatible with water at temperatures of TBD⁰F and flow rates of TBD gallons/minute at nominal pressures of TBD psia.

The piping system shall be designed to withstand the following minimum and maximum conditions:

- TBD⁰F
- TBD⁰psia
- (TBD) Other

4.2.3 Heat Transfer

Heat transfer losses in the piping system shall not exceed (TBD).

4.3 UNFIRED BOILER

4.3.1 The boiler shall be built to conform to ASME codes.

4.3.2 Design requirements are as follows:

- Steam output--2220 lb/hr at 300 psia, 417⁰F
- Condensate return 353⁰+ (TBD)⁰F
- Fluid inlet temperature 482⁰+ (TBD)⁰F
- Fluid outlet temperature 430⁰+(TBD)⁰F
- Fluid Flow rate 53,000+ (TBD) lbs/hr
131+ (TBD) gallon/minute

- Heat Exchanger LMTD $38.3^{\circ}\pm$ (TBD) $^{\circ}\text{F}$
- Heat Exchanger UA $50,900\pm$ (TBD) BTU/hr - $^{\circ}\text{F}$

4.4 HEAT TRANSFER FLUID PUMP

The pump must be capable of moving $7\pm$ (TBD) gallons/minute of heat transfer fluid through a nominal 1200 feet of absorber tube and must be capable of operating for (TBD) hours with the specified fluid and the specified operating conditions without preventive maintenance. The MTBF of the pump shall be (TBD) hours.

4.5 CONTROL SYSTEM

4.5.1 The control system must perform the following functions automatically:

- Supply additional heat from the collector system when the collector fluid outlet temperature reaches or exceeds 480°F , and simultaneously reduce the amount of steam provided by the plant fossil fuel boilers.
- Sense when the fluid temperature decreases to less than 480°F , and simultaneously increase the heat supplied by the plant fossil fuel boiler.
- Receive a stow signal from the collector system and simultaneously provide for shutting off the steam flow path SPIPS to the plant process being served;
- Simultaneously, shut off the fluid supply pump.
- Reverse the process when the collector system returns to the operating condition.

Table 5.1 below summarizes the control action requirement and responses (Table 5.1 is TBD).

- The control system shall be designed to place the system in a safe condition in the event of failures or emergency situations and shall be designed to sense and take appropriate action in the following cases:
 - loss of electric power
 - collector outlet temperatures $\geq$ (TBD) $^{\circ}\text{F}$
 - boiler pressures $\geq$ (TBD) psia
 - low water level signal (TBD)
 - loss of coolant fluid (TBD)
 - coolant pump pressure $\geq$ (TBD)psia
 - pump motor temperature $\geq$ (TBD) $^{\circ}\text{F}$.

4.6 DATA COLLECTION SYSTEM

The data collection system shall provide the input data necessary to evaluate the performance of this system and provide the basis for evaluating the applicability of this type of system to other industrial processes.

4.6.1 Data Automatic Collection Requirements

The data automatic collection system shall provide the data necessary to determine the following:

- Total hourly direct solar insolation
- Active collector field area as a function of time
- Collector field inlet and outlet temperature as a function of time
- Steam pressure and temperature from the boiler
- Volume of steam produced
- Indication of solar system outage as a function of time, including outage of a single collector string
- Indication of reason for automatic stop
- HTF flow rate as a function of time
- Solar system electrical power as a function of time.

4.6.2 Manually Entered Data

The data collection system shall provide for the following data to be supplied manually:

- Time, duration, cost and reason for maintenance actions
- Natural gas and/or fuel oil usage
- Description of unusual occurrences or malfunctions of the solar system
- Identification of solar system shutdowns resulting from process plant operations.

4.6.3 Data Collection Format

Automatically collected data shall be recorded on magnetic tape compatible with TRW's data processing capabilities. All recorded data shall be relatable to calendar data and time.

9.2 COMPONENT SPECIFICATION

All components shall conform to the requirements and standards called for in the system specification.

9.2.1 Mechanical Components

9.2.1.1 Piping System

- a. Piping shall be carbon steel, seamless, or electric resistance welded, ASTM A53, Grade B, ASTM A135, Grade B or ASTM A106, Grade B. All piping shall be Schedule 40 except that Schedule 80 pipe shall be used where screwed fittings are used. Piping 2 inches and larger shall be butt welded or flanged. Piping less than 2 inches may be threaded.
- b. Fittings shall be carbon steel, butt welded type to match pipe wall thickness, ASTM A234, conforming to ANSI B16.9 standards. All ells shall be long radius, unless otherwise designated. Reducers shall be concentric type, unless otherwise designated.
- c. Flanges shall be forged steel ASTM A181, Grade I or II with weld neck, faced and drilled, 1/16-inch raised face, ANSI B16.5 standard.
- d. Taps required for gages, thermometer wells, and instrumentation shall be made from forged steel Weldolets, Threadolets, or Sockolets of the appropriate pressure class to match the piping, and as specified on the plans.

9.2.1.2 Valves

- a. Gate valves shall be OS&Y flanged end, cast steel, with 11 1/2-13 CR stainless trim, discs, and seat rings. The valves shall be Stockham 15-OF, or approved equal.
- b. Check valves shall be flanged end, cast steel, clear-way swing check valves. The discs and seat rings shall be hardened 11 1/2-13 CR stainless. Valves shall be Stockham 30-SF, or approved equal.

- c. Control valves shall be flanged, cast steel body, stainless steel trim, with TFE lined bushing and TFE packing. Valve actuators and positioners shall be sized to match the application.

9.2.1.3 Insulation

- a. All process piping and fittings, inside and outside the buildings, shall be insulated with Owens-Corning Kaylo 10 Asbestos Free pipe insulation, or approved equal. Insulation located inside the buildings shall be provided with a cloth jacket. All other piping shall be provided with a weatherproof aluminum jacket.

9.2.1.4 Flash Steam Generator

Steam generator shall be capable of generating TBD lb/hr or saturated steam at 300 psia and 417⁰F from TBD lbs/hr of pressurized water at TBD⁰F, and TBD psia.

The generator shall be a complete factory assembled package consisting of the following components:

- a. Generator constructed and stamped in accordance with the ASME Code with Insurance Company certification. The shell shall be flange grade steel, SA515 Grade 70 steel. Shell shall be fully x-rayed and stress-relieved according to Section VIII-UW-2(c) of ASME Code and ASME stamped for a design pressure of 350 psig at 450⁰F.
- b. Steel lifting lugs.
- c. Steam-moisture separator.
- d. Full length steel skid foundation to support the generator 18 inches above the floor.
- e. Steam pressure gauge 6-inch dial with shutoff cock and syphon. Trerice 500X or equal.
- f. Air operated, fully modulating, steam pressure control with air pressure indicator. Fisher 416R or equal.
- g. Air filter and pressure control.

- h. Air operated control valve with stainless steel trim.
300# ANSI RF cast steel. Fisher 667ES or equal.
- i. Shellside, ASME Section I steam safety valve.
- j. Combination water column and pump controller, Magnetrol 600 or equal.
- k. ASME reflex gauge glass and trycocks. Jerguson.
- l. Two (2) thermometers, bi-metal, adjustable dial type with separable #304 stainless steel wells installed in HT43 inlet and outlet nozzles.
- m. Independent steam pressure safety system to automatically shut off high temperature water flow at steam pressure exceeding 325 psig.
- n. Two (2) ASME tandem blowoff valves. Yarway 1-1/4 inches.
- o. Fibre-type high density insulation 3-inch thick with heavy gauge anodized zinc coated steel jacket.

9.2.1.5 Pumps

- a. Field circulation pump shall be a single stage, end suction, overhung impeller, process pump with vertically split casing. It shall be suitable for continuous operation at 450°F, pumping water at 90 gpm at 60°F, and 600 feet of head. It shall have a casing rated for 600 psia. The pumps shall be an Ingersoll-Rand Model TBD or equal.
- b. Makeup water pump and recirculation pump shall be plunger-type pumps with the following pumping characteristics:

	<u>Operating Flow Temperature Head</u>		
Makeup Pump	5 gpm	60°F	810 feet
Recirc. Pump	2 gpm	90°F	120 feet

Both pumps shall have a casing design pressure of 600 psia. Pumps shall be Hills-McCanna Model P/D II, or equal.

9.2.1.6 Blowdown Equipment

- a. Continuous blowdown system shall operate at TBD gpm at TBD⁰F. The system shall be a Sentry Package Blowdown System or equal.
- b. Intermittent blowdown steam and water separator shall be sized to match an operating pressure of 300 psia. Use Cleaver-Brooks steam and water separator, or equal.

9.2.1.7 Chemical Feed System

The chemical feed system shall be a steel tank packaged unit, sized to meet water quality requirements with one refill per day.

The system shall come complete with:

- a. Steel tank and hinged lid
- b. Metering pump and motor
- c. Agitator
- d. Gauge glass and valves
- e. Strainer
- f. Relief valve.

9.2.2 Electrical

9.2.2.1 Services Required

- a. Power at 120 volts, single phase will be provided for collector motors, makeup pump, and recirculation pump.
- b. Power at 460-volts 3-phase will be provided for the field circulation pumps.
- c. Power as required, will be provided for all instrumentation and controls.

9.2.2.2 Conduit and Tubing

- a. Rigid steel conduit, including couplings, elbows, nipples, and other fittings shall be galvanized by hot-dipping, electroplating, sheradizing, or metalizing process, and shall meet the requirements of ANSI C80.1 and ANSI C80.4, NEMA FB-1, UL, and the NEC. Do not use setscrew-type couplings.

- b. Rigid polyvinyl chloride (PVC) conduit shall be Schedule 40 UL listed for concrete encased, direct burial underground, and exposed use. Rigid PVC conduit, including couplings, elbows, nipples, and other fittings shall conform to the requirements of the latest edition of NEMA 1C-2 and NEMA 1C-3, UL, NEC, Federal Specification WC-1094, and shall meet applicable ASTM test requirements for the intended use. PVC conduit shall be rated 90°C.
- c. Flexible conduit shall be moistureproof flexible steel, polyvinyl chloride jacketed type, UL approved, with continuous copper ground path in the flexible steel tube, and shall be Anaconda Sealtite conduit, Electritlex, or equal. Flexible conduit used in dry, concealed areas for lighting fixtures may be nonmoistureproof, flexible steel conduit, Anaconda Type CN, Triangle Tristeeel, or equal.

9.2.2.3 Motor Control

Starters shall be full voltage, magnetic type, 120-volt control circuit with control power transformer, overloads in all ungrounded legs, and in NEMA 1 enclosure.

APPENDIX

Selection of a Heat Transfer Fluid

Major criteria to be used in the selection of the heat transfer fluid for the SPIPS project include the following:

- low or non-flammability
- low toxicity and acceptability to the Food and Drug Administration (FDA)
- high operating temperature limit
- low viscosity and pumpability after reaching overnight low temperatures
- long operating life
- low cost

A list of the heat transfer fluids considered is presented below. Relevant characteristics for each of these fluids are compiled in Table A-1.

1. Caloria HT-43	(Exxon)
2. Dowtherm G	(Dow Chemical)
3. Therminol 66	(Monsanto)
4. Syltherm 800	(Dow Corning)
5. SWS-101	(Stauffer)
6. L-45	(Union Carbide)
7. SF-1153 and 1154	(General Electric)
8. UCAR 35	(Union Carbide)
9. Water, Pressurized	

The listing can be categorized into four general groups: 1) organic fluids, 2) silicone fluids, 3) propylene glycol based fluids, and 4) aqueous fluids. Numbers 1 through 3 in the above listing are organic fluids; 4 through 7 are silicone fluids, and number 8 is a propylene glycol derived fluid. The organic fluids present a higher fire risk than do the other fluids and are also more toxic. There are additional technical problems associated with the organic fluids such as their lower operating temperatures (as compared with Syltherm 800) and the tendency that organic fluids have of forming solid residues during high temperature degradation.

TABLE A-1. Flammability and Toxicity Data for
Candidate Heat Transfer Fluids

Fluid (Manufacturer)	Flammability Parameters ⁽¹⁾	Toxicity Parameters ⁽²⁾	Types of Fluid-- ⁽³⁾ Notes
1. Caloria HT-43 (Exxon)	Flash point--425°F	TLV (inhalation of the oil mist) = 5mg/m ³ (assumed to be the same as that for regular mineral oil mist). Has general low order of toxicity.	Organic; petroleum derived oil; similar to mineral oil
2. Dowtherm G (Dow Chemical)	Flash point--305°F	Slightly irritating to skin and eyes; 4gm/kg dose sur- vived by all test animals; odor serves as warning when the material is present at low levels.	Organic; mixture of di- and tri-aryl esters
3. Therminol 66 (Monsanto)	Flash point--335°F	TLV (inhalation of oil mist) = 5mg/m ³ rat LD ₅₀ = 10.2gm/kg (oral) rat LD ₅₀ = 6.8gm/kg (skin)	Organic; mixture of hydro- genated terphenyls
4. Syltherm 800 or Silicone 3 (Dow Corning)	Flash point--310°F tends to self-exting- uish via formation of SiO ₂ on the burning surface	Not toxic, no deaths reported at doses of more than 27gm/kg	Silicone fluid; dimethyl polysiloxanes of varying molecular weights and resultant viscosities

TABLE A-1. (Continued)

<u>Fluid (Manufacturer)</u>	<u>Flammability (1) Parameters</u>	<u>Toxicity Parameters (2)</u>	<u>Types of Fluids--(3) Notes</u>
5. SWS-101 (SWS Silicores Corporation-- Stauffer)	Flash point varies with viscosity; for 50 centistcke material f.p. = 535°F	Non-toxic; non-irritating	Silicone fluid; dimethyl polysiloxanes of varying molecular weights and resultant viscosities
6. SF-1153 & 1154 (General Electric)	Flash point--435°F	Very low in toxicity, impos- sible to determine an LD ₅₀ slight temporary eye irrita- tion following eye contact	Silicone fluid; polydimethyl siloxane fluid with better high temperature stability than GE's normal polydimethyl siloxanes (SF 96)
88 7. L-45 (Union Carbide)	Flash point-->535°F	Low order of toxicity; maximum possible oral doses produced no deaths in test animals	Silicone fluid, dimethyl poly- siloxanes of varying molecular weights and viscosities
8. UCAR 35 (Union Carbide)	No flammability data available, but is stated to have a low flammability hazard; ultimate fire hazard depends on extent to which material is mixed with water	Low toxicity	Phosphate inhibited propylene glycol

TABLE A-1. (Continued)

<u>Fluid (Manufacturer)</u>	<u>Flammability Parameters</u> ⁽¹⁾	<u>Toxicity Parameters</u> ⁽²⁾	<u>Types of Fluid--</u> ⁽³⁾ <u>Notes</u>
9. Water	Absolutely not flammable	Not toxic, but the corrosion inhibitors may impart some level of toxicity	Aqueous with additives to provide corrosion pro- tection

(1) All flash point data is Cleveland open cup.

(2) TLV is threshold limit value. Recommended standards established by the American Conference of Governmental Industrial Hygienist. The stated level is believed to be safe for an average of 8 hrs/day, 40 hrs/week exposures. Rat LD₅₀ is the calculated dose which will kill 50% of the experimental rats exposed to the test material by either oral or skin routes of entry. Values are expressed in terms of grams of test material per kilogram of test animal body weight.

(3) Polydimethyl Siloxane $\equiv$ dimethyl polysiloxane

The maximum operating temperature for the propylene glycol fluid is 275°F. This one fact makes this fluid unacceptable for the SPIPS project.

Of the silicone fluids, Dow Corning seems to have made a major advance in improving thermal stability with their Syltherm 800 (previously called Silicone B). When used in closed systems under inert atmospheres, Syltherm 800 demonstrates good thermal stability at temperatures greater than 700°F. While it is known that dimethyl polysiloxanes will burn, they tend to be self-extinguishing due to the formation of a SiO₂ layer on the burning surface.

The overall toxicity of the silicone materials is quite low, and certain viscosity categories are acceptable by FDA as indirect food additives for a variety of specified operations. However, the type of indirect food contact that would result from a leak of a silicone heat transfer fluid into the process steam line is not covered by existing FDA regulations. Discussions with FDA officials indicate that they may be able to rule on the acceptability of a silicone heat transfer fluid on the basis of a letter describing the intended use. However, no guarantees were given and it was not indicated how long this process would take, nor how official the resulting decision would be, considering the informal nature of the request. A formal petition to obtain FDA's approval for a food additive could take months and cost thousands of dollars. The limited use of silicone heat transfer fluids in the food processing industry would probably not warrant such an expenditure.

If there were a leak of silicone fluid from the heat transfer circuit into the process steam lines, the interconnected nature of the steam lines throughout the plant could cause widespread distribution of the silicone and the possible contamination of food products at the affected locations. If the contaminating material is not FDA approved, the products may be deemed adulterated and could not be sold to the public.

The remaining choice was the aqueous system. The exact nature and amounts of corrosion inhibitors that may be needed are not currently known. The determination of which corrosion inhibitors should be used should consider both the physical and toxicological properties of the

resultant mixture. A major guideline will be to utilize those substances presently used by Ore-Ida in their fossil-fired steam boilers.