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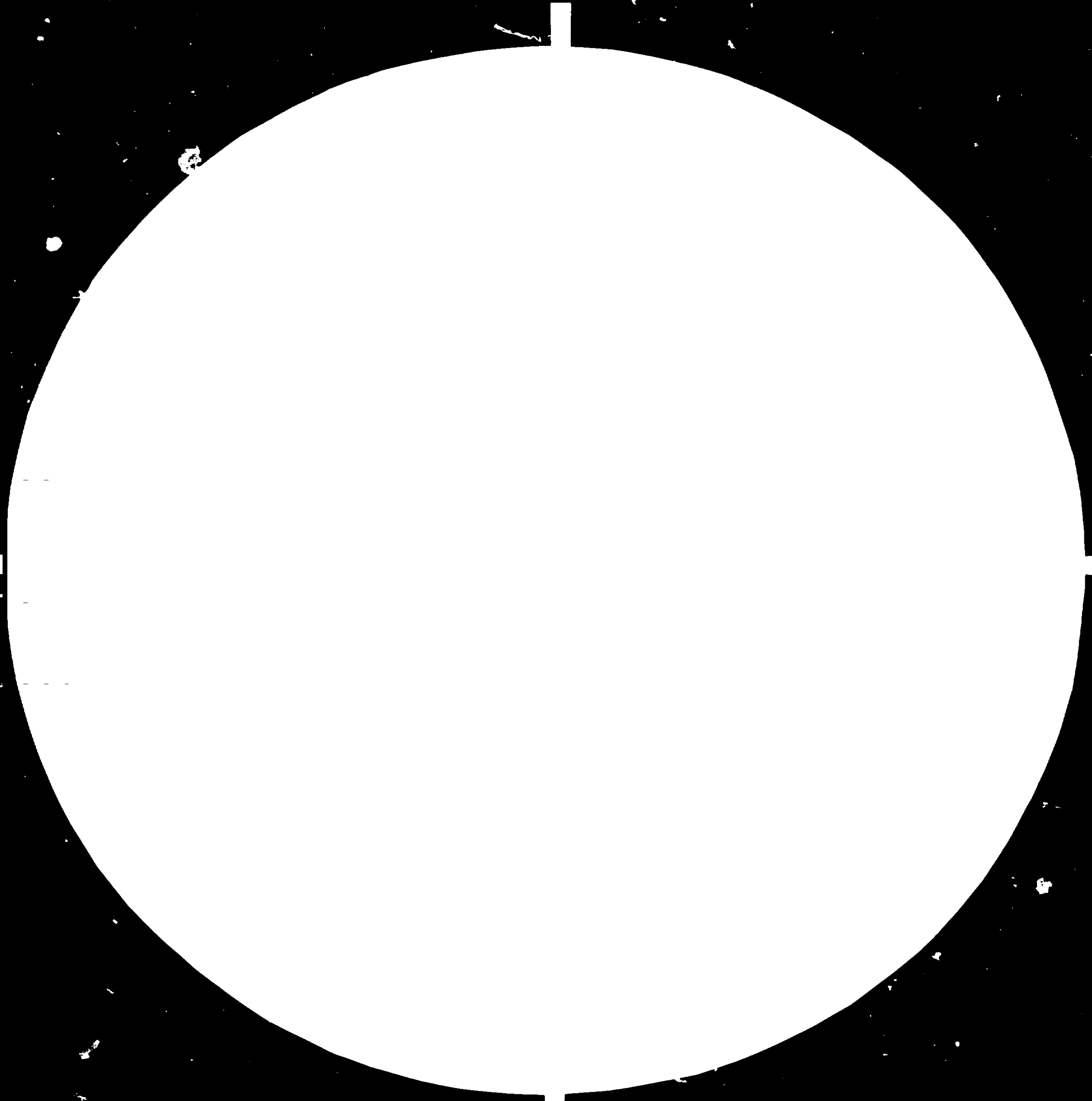

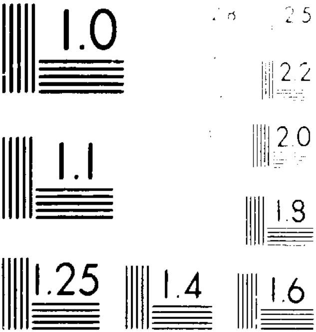
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A PRELIMINARY ENERGY ASSESSMENT FOR THE LAKE NATRON SODA ASH PROJECT WITH EMPHASIS ON USE OF ALTERNATIVE ENERGY SOURCES

Submitted to: STATE MINING CORPORATION,
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Date: 26TH NOVEMBER, 1982

A PRELIMINARY ENERGY ASSESSMENT FOR THE LAKE NATRON SODA ASH PROJECT WITH EMPHASIS ON USE OF ALTERNATIVE ENERGY SOURCES

ABSTRACT

This report defines and discusses a soda ash processing plant energy requirements and characterizes both types and quality. Because of the plant's remote site and national cash flow problems, emphasis has been placed on the possible use of alternative energy sources if found to be cost-effective. Several different methodologies for using solar and geothermal energy are compared. Expected performance is given for each method. Solar energy can be used effectively for half the thermal requirements. The plant will be located in the Great Rift Valley, an area known to have geothermal activity, but this geothermal resource has yet to be evaluated for its possible energy contribution.

INTRODUCTION

Lake Natron, located in the Great Rift Valley of East Africa, is a natural resource rich in two forms of sodium carbonate. The sodium carbonate (soda ash) is a basic ingredient for many industrial applications, including glass manufacture, concrete manufacturing, as a feedstock for chemical manufacturing, water purification, and many other uses. The Government of the United Republic of Tanzania, through its parastatal organization the State Mining Corporation (STAMICO), has surveyed present and anticipated demand for soda ash within the country and found the demand to be

1981 about 11,000 tonnes (actual)
1985 about 26,000 tonnes (projected).

STAMICO has determined that the proposed soda ash processing plant should be designed to produce 27,000 tonnes per year (about 90 tonnes per day), using a simplified process similar to the process used at Lake Magadi in Kenya. That process and its daily utilities requirements are shown in Figure 1, utilizing the lake's crust material as feedstock (includes heat losses) and conversion.

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STAMICO has also determined that the soda ash processing plant should be located at Lake Natron. There will, of course, need to be developed a supporting infrastructure as none currently exists. However, problems of the infrastructure are outside the scope of this report.

The sodium carbonate resource has been described by Mushi (ref.1) and by the Japanese Team (ref 2 and 3) and these descriptions were the bases on which the energy study was made. The Japanese study also touches on the issue of fresh process water, but presented no definitive data. Thus, water remains an unresolved issue. The Japanese presented long-term temperature, humidity, rainfall and evaporation data from Lake Magadi (after Hargrave, ref.4) which appear to be appropriate for use with the Lake Natron plant Insolation data covering ten years at Nairobi is available (references 5 and 6) and is summarized in Table I. Conversations with persons having knowledge of microclimatology of Lake Natron indicate that its insolation may be better than that at Nairobi.

DISCUSSION

Solar energy is a diverse field and can be used in many ways. One of the simplest and most cost-effective uses is to make hot water in the temperature range of 60°C to 80°C; higher temperature water or other liquids require increasingly complex and costly systems to achieve the higher temperatures.

The process energy requirements have been examined not only for quantity of energy but also for quality (temperature) of the energy. The result is a process which is modified slightly from that used at Magadi (figure 1). This modified process, shown in figure 2, is different mainly in that drying the washed crust and removing the water of hydration from the $Na_2CO_3 \cdot H_2O$ can easily be done with low-grade heat using solar energy. As figure 2 shows, more than half of the entire thermal energy requirement can be met using low-grade heat. Solar energy provides a very attractive life-cycle cost for this application. Using a shallow solar pond, described in Appendix A, the 220 gigajoules of thermal energy required for first stage drying can be provided at an installed cost of about $1.2 million US.

Photovoltaic generation of electricity can be attractive under certain conditions, usually in application remote from any source of electricity and when the electric power requirement is modest. Certainly, the Lake Natron plant is remote from all sources of electricity, but the power requirement is probably large enough so that other methods of generating electricity are more attractive. Very simply, the energy problem can be stated as three unrelated problems:

- Provide 220 gigajoules per day in the form of water whose temperature is at least 70°C (for first stage drying);
- Provide 214 gigajoules per day in the form of 600 psig saturated steam (250°C) (for second stage calcining);
- Provide 6,500 kWhr per day (270 kW average load) as dc electricity to run various pumps and motors.

Solar and geothermal technologies which might be considered as candidates to supply the required process energy are evaluated in Table II. Although Table II is predicated on a solar fraction of 80 percent (amount of energy supplied by solar divided by total energy required), it may be attractive to cease operations whenever energy from solar is insufficient. The only real problem with this approach is that idle time cannot be scheduled.

CONCLUSIONS AND RECOMMENDATIONS

The geothermal resource MUST be defined, for, if adequate, it can be used effectively to meet all energy needs, or portions of the energy needs. If the resource quantity will not supply all needs, electricity should receive first consideration, then first stage drying, then third stage calcining.

Solar energy can be used cost-effectively to supply process heat for first stage drying. The shallow solar pond appears to be the best choice, although a flat-plate collector made very much like a SSP but using a Sol-a-Roll absorber with trickle flow should be considered. The Sol-a-Roll absorber is made of a tough EPDM material (ethylene propylene diene monomer) and could possibly offer improved economics.

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Electricity can best be provided from geothermal resources provided the existence of an adequate resource can be established. If the geothermal resource is inadequate the SSP + Rankine-cycle expander/generator is recommended (see Appendix B for Rankine-cycle discussion). This technology received a rating of 8, being down-graded because of the complexity of a SSP and a vapor expander working together.

Photovoltaics are expensive for this application and are not recommended for that reason only. The technology is simpler and reliability is greater than for the first two choices, but these advantages do not overcome the cost disadvantage.

Solar energy is not appropriate for second stage calcining.

The solar resource should be more fully examined to see if data exists for a closer geographic location. If no other data exists (and long-term representative data is what is needed), perhaps weather satellite pictures could be studied to determine the relation ship between insolation levels at Lake Natron and at Nairobi. This technique has been developed at the University of Miami (Florida) by Dr. Homer Heiser.

If geothermal energy cannot be used to make electricity with which to make steam for second stage calcining, a fossil fuel-fired boiler should be employed.

ACKNOWLEDGEMENTS

The writer especially wishes to thank Mr. H.H. Kihwelo, STAMICO Project Manager, and Mr. J.D. Adhia, UN Salt and Soda Ash Expert for their assistance, counsel and many courtesies.. Mr. Haji Ali's skillful driving to convey us to Lake Natron is very much appreciated. Many others, too numerous to mention, also contributed to the success of this mission, and to them I say, "Thank you".

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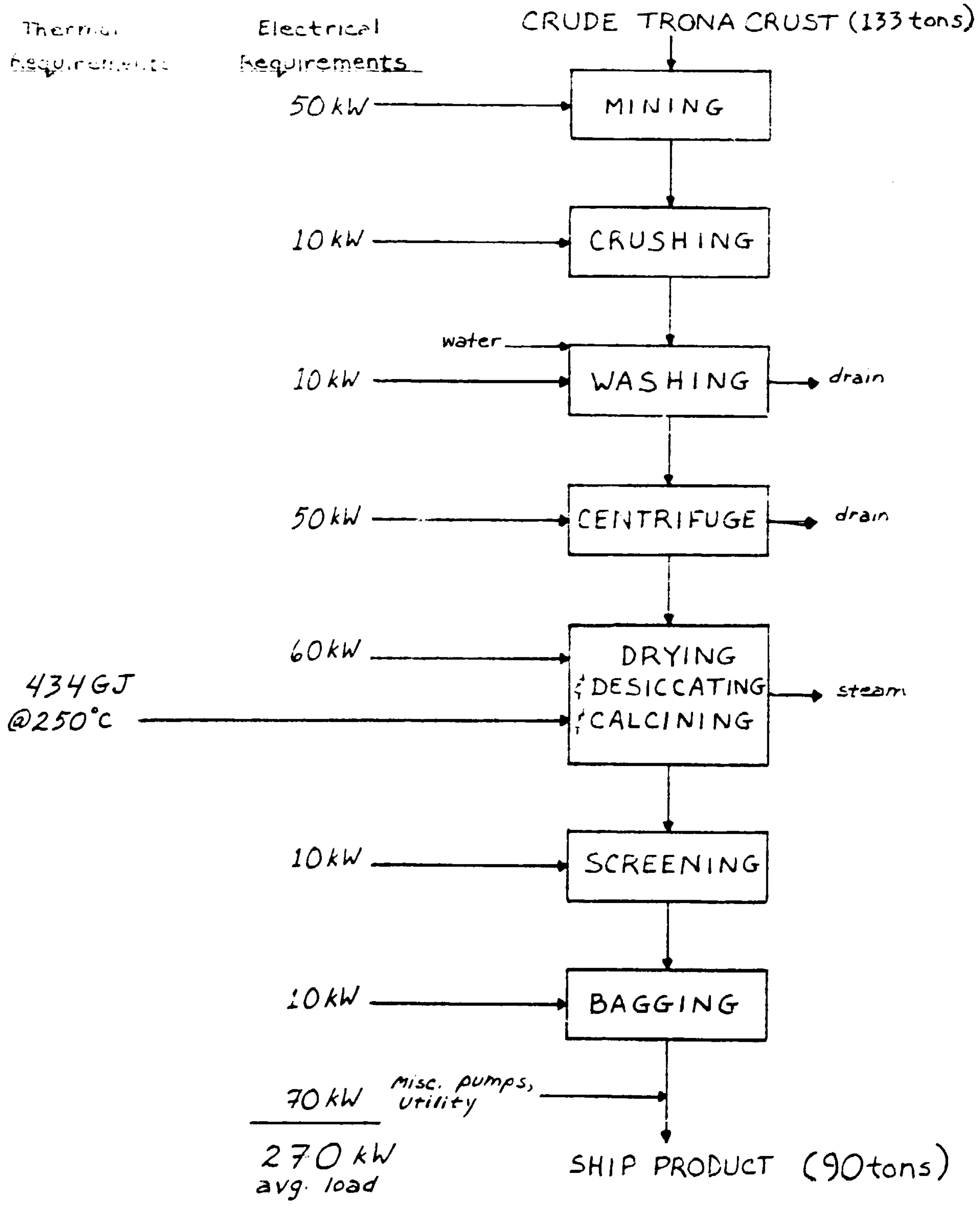

Figure 1 - Soda Ash Process Used at Lake Magadi, Kenya

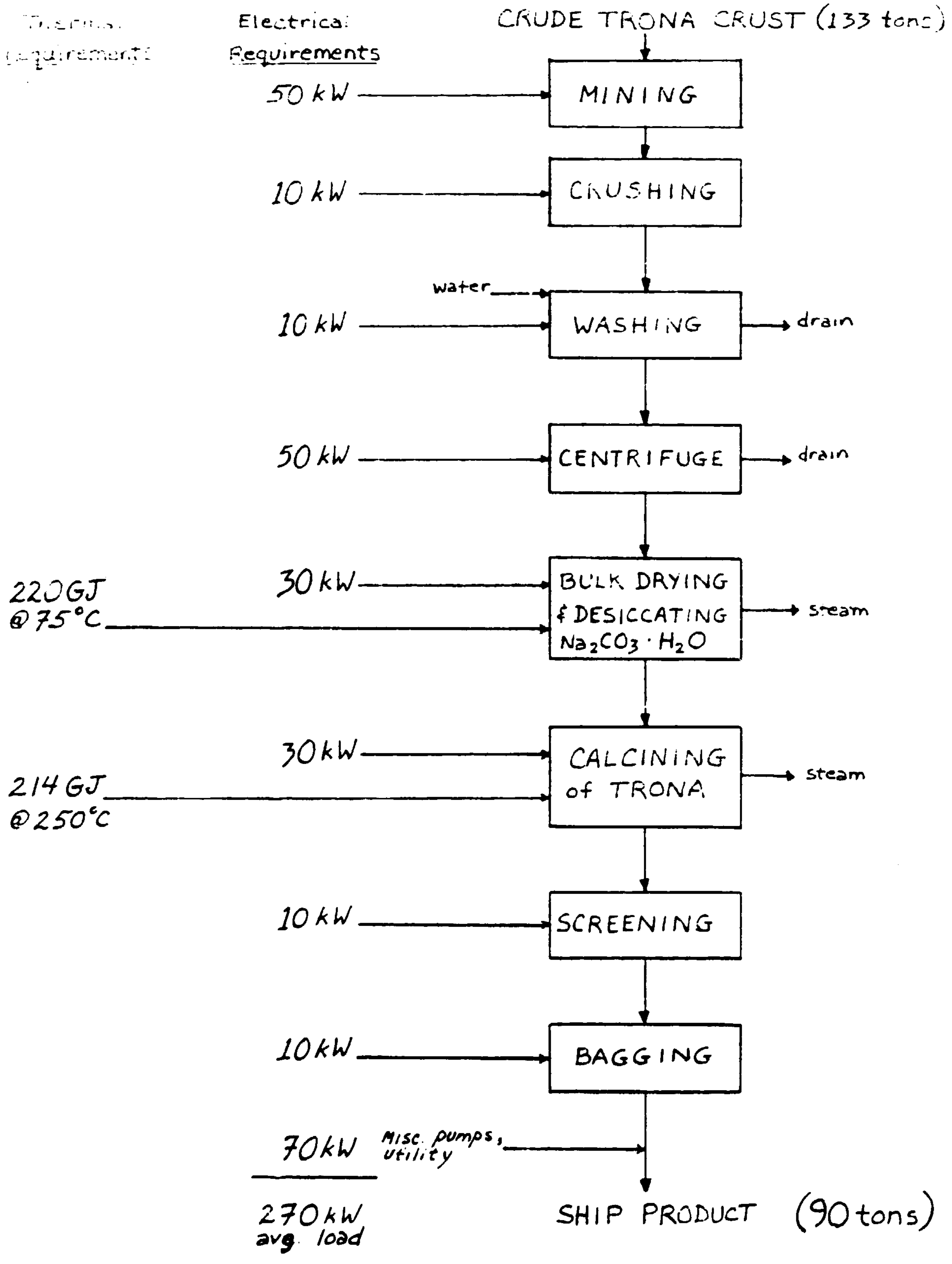

Figure 2 - Soda Ash Process And Energy Requirements For Proposed Lake Natron Project

TABLE I

AVERAGE DAILY TOTAL HORIZONTAL INSOLATION FOR NAIROBI TEN YEARS ENDING 31ST DECEMBER, 1973

MJ/$\underset{m}{\cancel{M}}^{2}$-day

Jan	Feb.	March	April	May	June	July	Aug.	Sept.	October.	Nove.	Dec.
23.0	24.2	23.5	20.4	17.2	16.5	13.5	14.1	19.7	20.9	20.2	22.3

TABLE II

COMPARATIVE DATA FOR CANDIDATE SOLAR TECHNOLOGIES - LAKE NATRON PROJECT

	Daily Requirement	Land Area Req'd Hec.	Status of Technology Development	Rating (Note 1	Installed Cost 1982 $US x 10^6	EXPECTED ANNUAL					Remarks
						Energy Harvest (Note 2)	Cost Savings $US x 10^6 (Note 3)	Supplement Energy cost $US x 10^6 (Note 3)	Operating Cost $US x 10^3 (Note 3)	Maintenance cost $US x 10^3	
1ST STAGE DRYING											
-Shallow solar pond (SSP)	220GJ	.2	Excellent	10	1.2	53×10^3GJ	0.8	0.2	1	30	Best choice
-Salt Gradient Pond	220GJ	2	Currently being developed.			Not appropriate at this time					
-Flat Plate Collectors	220GJ	1-2	Excellent	8	2	53×10^3GJ	0.8	0.2	1	40	Cost is main problem
-Geothermal	220GJ	$\frac{1}{4}$	Excellent	10	0.2	66×10^3GJ	1.0	None	None	2	Presence of suitable geothermal resource has not been verified. Site exploratory work is required
2ND STAGE CALCINING											
-Solar thermal	All strictly solar-thermal methods are inappropriate because technology is not well developed										
-SSP + Rankine-cycle generator	214GJ	20	Poor on this size	3	10-15	51×10^3GJ					Prohibitive cost
-Geothermal Rankine-cycle generator	215GJ	$\frac{3}{4}$	Good	10	5	64×10^3GJ	1.0	None	None	20	Resource unproven
ELECTRIC UTILITY											Note that a diesel generator required to supplement solar.
-SSP + Rankine-cycle generator	6.5MWhr	$2\frac{1}{2}$	Good	8	2	1560MWhr	.22	.05	1.5	50	
-Photovoltaic (PV)	6.5MWhr	$2\frac{1}{2}$	Exceleent	8	13	1560MWhr	.22	.05	None	100	Cost is high but easy maintenance
-Geothermal + Rankine-cycle generator	6.5MWhr	$\frac{3}{4}$	Satisfactory	10	0.8	1950MWhr	.28	None	None	20	Resource unproven

NOTES
1. Rating is a judgement of appropriateness of a method and uses a scale of 1 to 10, where 1 is clearly not appropriate and 10 is recommended without reservation
2. Expected annual energy harvest is the amount of energy of the required quality expected to be provided by solar and assumes a solar fraction of 60% (reasonable)
3. Assumes oil at the site cost $US446 per metric ton ($US 0.38 per litre) and is converted to useful heat at 65% overall efficiency (50% for electricity generation)

APPENDIX A

SHALLOW SOLAR PONDS

DESCRIPTION

The shallow solar pond (SSP) is a solar energy collector that is intended to supply large amounts of heat to industrial applications at a cost that is competitive with fossil fuel. The shallow solar pond concept is not new, having been examined several times for applications in electric generation and desalination. It has been rejected in the past because low fuel costs and materials problems have made it uneconomical. Today, rising fuel costs and improvements in inexpensive plastics make the shallow solar pond look very promising. The Lake Natron area appears to be ideally suited for shallow solar pond use for the first stage drying in the soda ash production process.

A typical shallow solar pond facility consists of several modules (ponds) covering an area of more than one hectare. A typical shallow solar pond module consists of a 5m x ~~100~~ 60m plastic bag filled with water to a depth of 60 to 80mm. The bag rests on a layer of insulation and is covered with a fiberglass greenhouse glazing (covering) as shown in Figure A1. In addition to the modules (ponds) the installation at Lake Natron will require 2,200m^3 of hot water storage to operate the first stage dryers 24 hours per day.

Because the normal output of the shallow solar pond is water between 40°C and 85°C, the most ideal application for shallow solar pond are those that can use the hot water directly and are in competition with very high fuel costs, or scarce fuel. Other applications might use only the heat obtained from the shallow solar pond through a heat exchanger. This heat, in turn, can be used to drive a vapor turbine to obtain shaft power. Both applications are possible for the Lake Natron Soda Ash plant, the latter being used to provide the plant's electricity requirement of 6,480kWhr per day. A sketch of a typical shallow solar pond is shown schematically in Figure A2.

LIMITATIONS

Like all solar thermal energy systems, the shallow solar pond has considerations that must be kept in mind. The most important consideration is area. Since the shallow solar pond concept requires a fairly large area, it is usually emplaced on the ground. Where land costs are high or the terrain is improper, ~~are~~ the shallow solar pond may not be appropriate.

The site of the shallow solar pond must be relatively free of shadows from trees, buildings, mountains, smoke plumes, etc. It is particularly important that chemicals from a nearby processing plant, or other, not deposit chemicals on the modules To do so can greatly reduce their effectiveness. MOST FAILURES of SOLAR INDUSTRIAL PROCESS HEAT systems can be attributed to such deposits.

Land area is not a problem at Lake Natron. However, chemical deposits CAN be a problem. The potential chemical deposits can be reduced to a safe level by appropriate treatment in the discharge stack. Such treatment is considered to be imperative.

Another potential problem at Lake Natron are the animals, particularly the baboons, and termites. Their possible effects on solar systems must be carefully evaluated. They are not considered to be a problem with a vapor expander/generator as it is made of more durable materials.

ENERGY CALCULATIONS

The thermal energy required daily by the first stage dryer is 220GJ for 90 tonnes/day of operation. The electric load is 270kW (average) or 6,500kWhr per day. If a Rankine-cycle vapor expander is used, the thermal energy required to operate it turns out to be the same quantity as for the first stage drying, 220GJ per day. Thus, the sizing and designs can be similar. Sizing calculations for the first stage drying requirements are shown in Table A1.

OPERATION OF THE SHALLOW SOLAR POND

The shallow solar pond can be operated in either the batch mode or flow-through mode. Calculations and judgement will determine the preferred mode during the design phase. In a batch mode, the ponds are filled in the morning through a common manifold from the spent water storage tank. When all the ponds are filled pump P1 is shut down and the ponds are valved closed. In the late afternoon, when the temperature in the ponds has just peaked, the water is pumped by pump P2 from the bags into an insulated hot storage tank for use. The main advantages of this mode of energy collection are the simplicity of the control system and the smaller amount of piping required.

In the flow through mode, spent water enters one end of the pond, is passed through the pond, and is withdrawn at the other end and sent to hot storage. Water depth in the plastic bag is controlled by flow rate and weirs in the pond (bag). The control system for this mode of operation is more complex as it must not only turn pumps on and off appropriately, but it must also change velve position to regulate flow rates through the ponds (bags). This mode probably does not offer any advantage to the Lake Natron Project so long as a typical bag is used.

Two water reservoirs are required, both insulated. Hot water from the ponds will be stored in late afternoon in the hot storage tank so that 24 hours per day operation is possible. Hot water will be drawn from the hot storage tank, passed through the first stage dryer heat exchanger, and return to spent water storage. It is necessary to use two storage tanks in order not to compromise the quality of the process hot water, which would happen if spent water were returned to the hot storage tank.

MAINTENANCE

Because of their simple design, shallow solar pond systems should require minimum maintenance. The insulation, curbing and bed are expected to last at least 30 years, provided the ground they are set on is stable. For a system to be located in the Great Rift Valley, some caution may need to be exercised in design. Pumps and valves will require normal maintenance. Reservoirs may not require much maintenance unless the insulation is stripped off by animals. The bags are the only items that will require an on-going service program. The bag is protected by the glazing and curbing and has no specific periodic maintenance program. Small leaks can be repaired in place by maintenance personnel using a patch and adhesive supplied by the bag manufacturer. Appropriate choice of bag material to withstand ultra-voilet radiotion and high temperatures will minimize problems due to bag deterioration.

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Fly ash from the calcining process may be hazardous to the long-term performance of the shallow solar pond by depositing on the glazing and preventing the sunlight from getting into the pond to heat the water. For this ~~s~~reason, it is necessary to restrict the evolution of fly ash at the source. It might seem that sand and dust in a semi-desert area could present a similar problem. However, the experience of the solar community is that sand and dust on collector glazings do not prevent sunlight from passing through the glazing, so sand and dust are not seen as a potential problem.

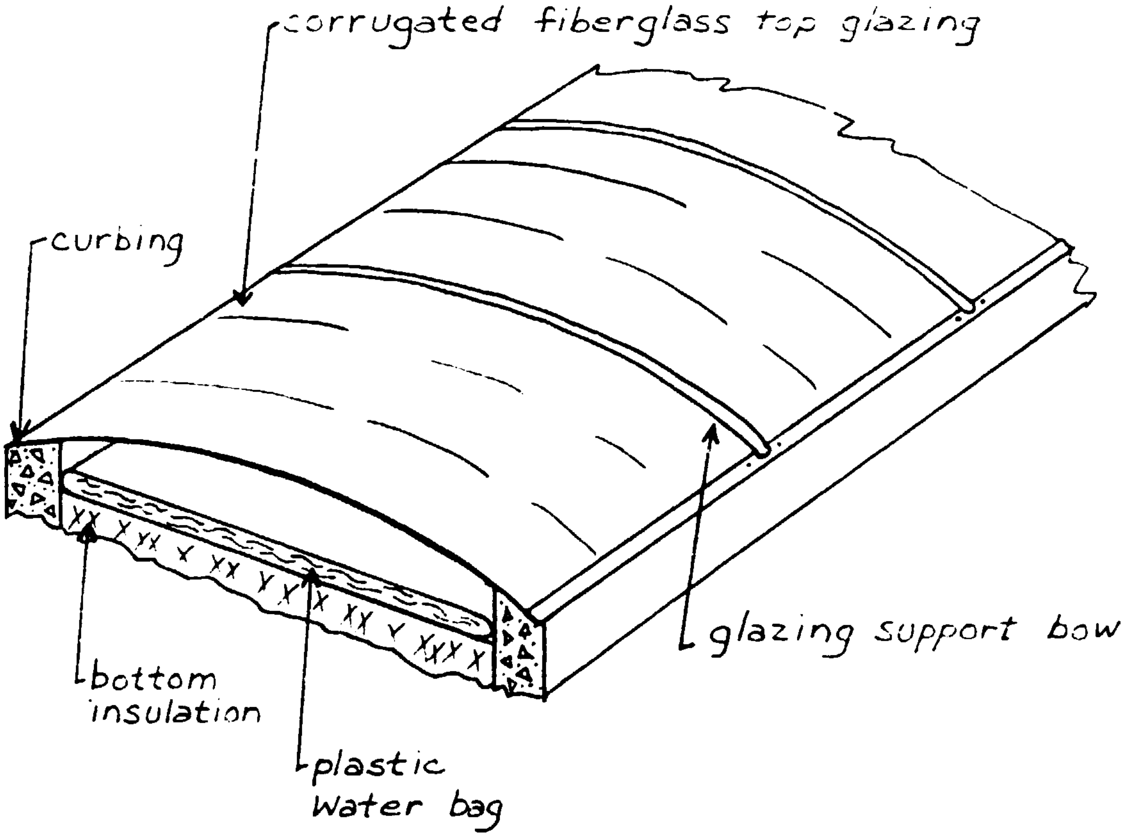

Figure A-1 Typical Section of Shallow Solar Pond showing Elements of Construction

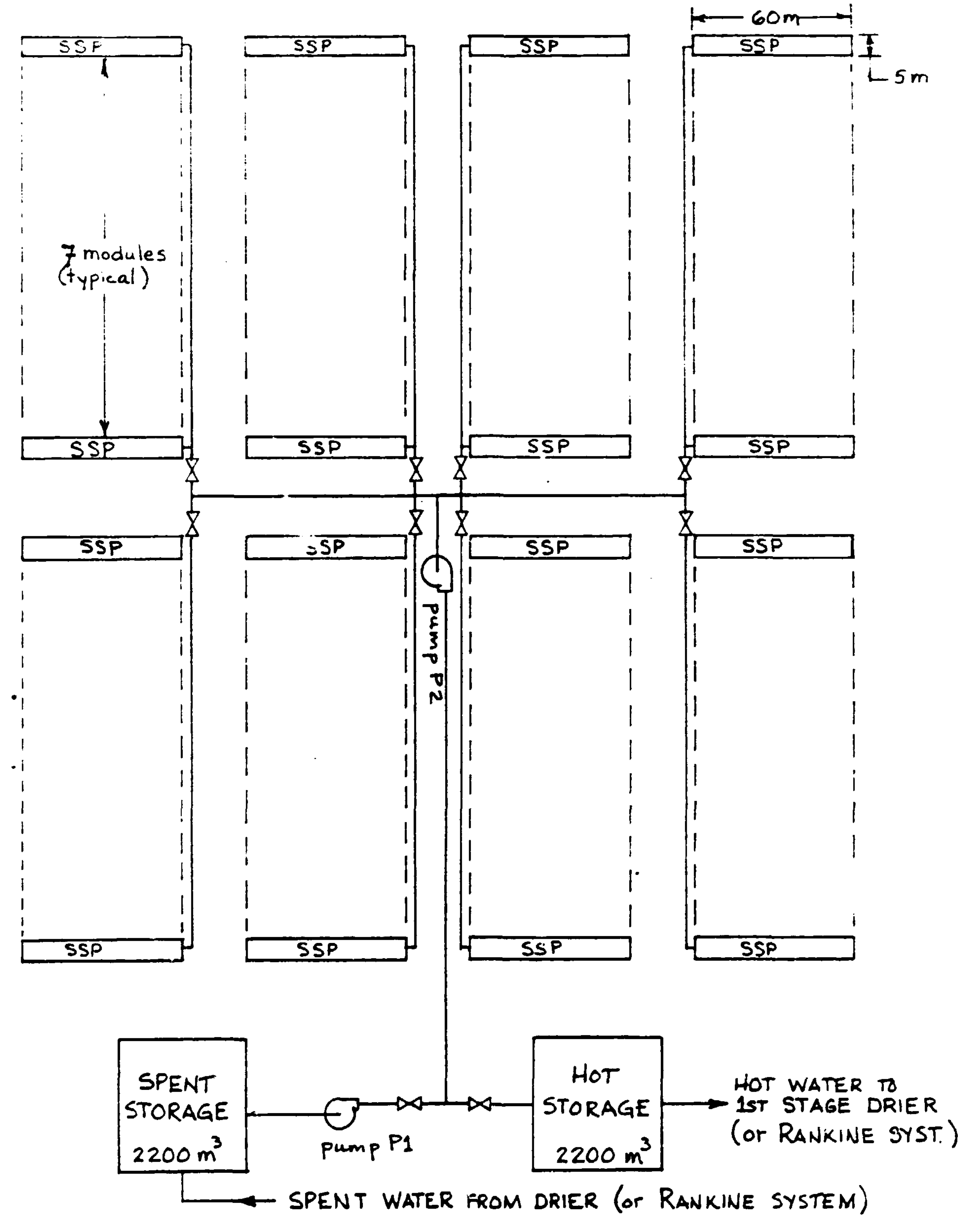

FIGURE A2 - SHALLOW SOLAR POND for COLLECTING 220 GJ/DAY FROM SOLAR ENERGY

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep	Oct	Nov.	Dec.		Annual
Total Horizontal Insolation, MJ/m²	23.0	24.2	23.5	20.4	17.2	16.5	13.5	14.1	19.7	20.9	20.2	22.3		
Total Thermal Energy from Solar, GJ/day	351	370	359	313	264	253	206	216	301	320	309	341		
80% Solar Fraction, GJ/day	281	296	287	250	211	202	165	173	241	256	247	273		
less losses, GJ/day	42	44	43	37	32	30	25	26	36	38	37	41		
AVAILABLE ENERGY from Solar, GJ/day	239	252	244	213	179	172	140	147	205	218	210	232		
USEABLE ENERGY, GJ/mo.	6820	6160	6820	6390					6150	6758	6300	6820		52,218GJ
QUESTIONABLE ①					3410	3300	3410	3410						13,530GJ
Hot Storage Temp., °C	80	81	81	80	78	75	72	72	74	76	78	81		
Spent Storage Temp., °C	67	67	68	68	68	66	64	64	63	64	66	68		

Note ① - Energy amounts shown as "QUESTIONABLE" can probably be utilized by operating one-half load of the first stage drier while performing maintenance on the other half-section during the months of May, June, July & August

TABLE AI - PRELIMINARY CALCULATIONS of ENERGY AVAILABLE from a 15,600m² SSP

APPENDIX B

THE RANKINE-CYCLE
VAPOR EXPANDER/GENERATOR

The Rankine-cycle vapor expander/generator is a device which employs a working fluid which changes phase from liquid to gas and back to liquid. During the process, high pressure gas is allowed to expand to a lower pressure gas through a vapor-expander (a gas turbine is one example), causing a shaft to rotate, enabling it to do work. Organic materials (refrigerants) are commonly used as working fluids, although water, propane, ammonia and others could be used, depending on the application.

The Rankine-cycle system requires an external source of heat and an external sink. The heat source represents the greatest potential long-term cost, and that is why it is necessary to explore the possibility of using geothermal energy. Performance of a Rankine-cycle system is directly related to the quality (temperature) of the source and sink. A well designed system can achieve 70 to 80 percent of Carnot efficiency. Thus, one can express a Rankine-cycle system's overall efficiency as

$$\text{Efficiency} = 0.70 \times \frac{\text{Tsource} - \text{Tsink}}{\text{Tsource}}$$

where the temperature are thermodynamic values. Thus, for a source temperature of 85°C and a sink temperature of 25°C,

$$\text{Efficiency} = 0.7 \times \frac{(85 + 273)-(25 + 273)}{(85 + 273)} = 11.7 \text{ percent}$$

The Rankine-cycle system is described schematically in Figure B1.

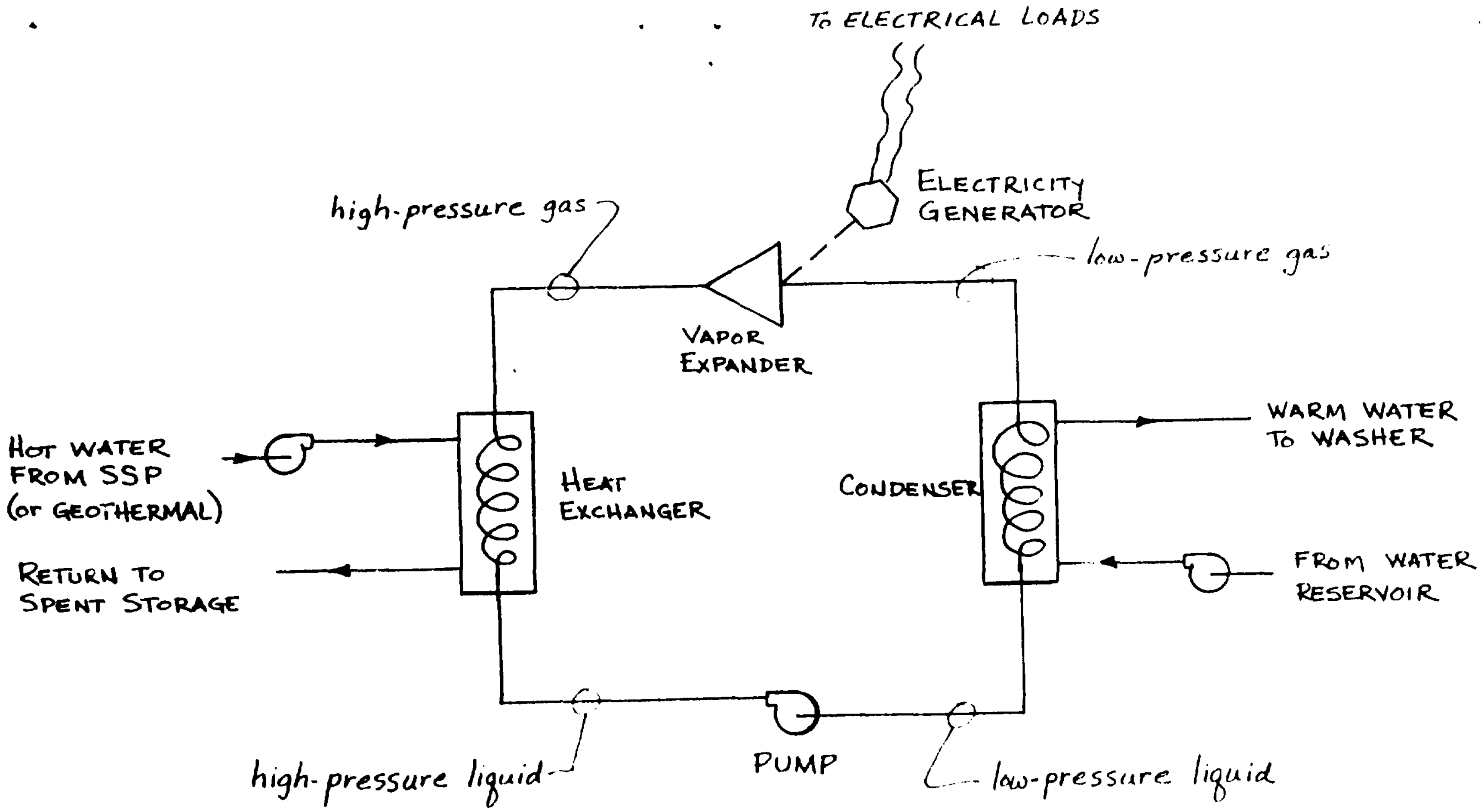

FIGURE B1 - SCHEMATIC DIAGRAM - ELECTRICITY PRODUCTION VIA RANKINE-CYCLE SYSTEM