

## WHITE CLIFFS - OPERATING EXPERIENCE

Stephen Kaneff

Department of Engineering Physics  
Research School of Physical Sciences  
The Australian National University  
Canberra. A.C.T. Australia

### ABSTRACT

Developmental work for the fourteen dish White Cliffs Solar Power Station commenced in July 1979; engineering design started in August 1980; and construction was completed in December 1981. Experimental running of the full system commenced in March 1982, design specifications were met by June 1982 and robust reliable operation was established by June 1983. The system now supplies the small township on a stand alone basis (with diesel back-up) and runs automatically and largely unattended; handling being by local personnel.

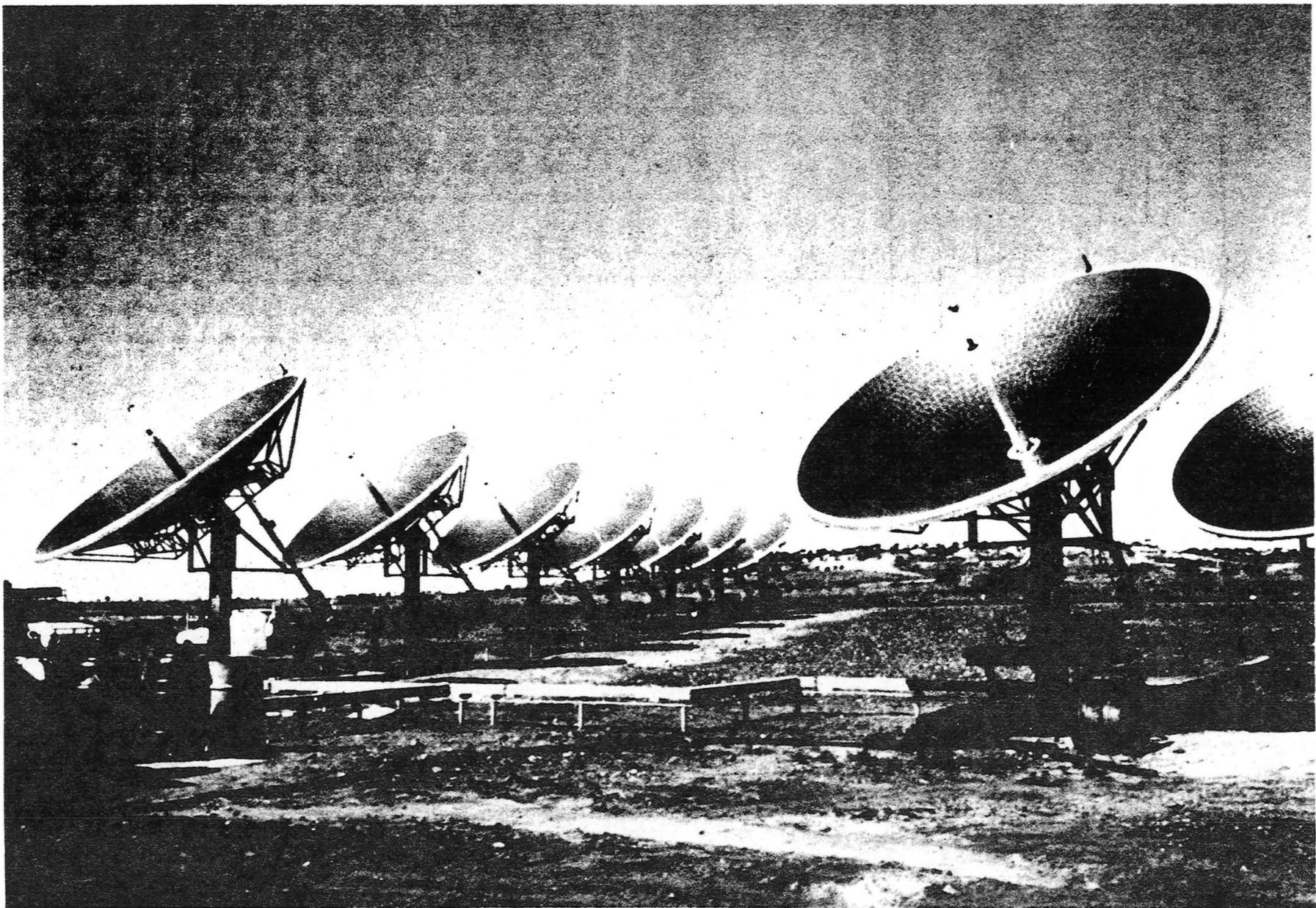
The area is remote and subject to extreme environmental conditions, solution of the associated problems required careful and thoughtful attention and the application of resources. Notwithstanding the wide range and harshness of conditions, the difficulties caused by remoteness and the lack of a technological base and the need for relatively rapid demonstration of success, the project has had a very positive outcome. Qualitative and quantitative information and lessons are now available to enable considerable simplifications to be made for a new system, reducing both hardware and operation and maintenance costs.

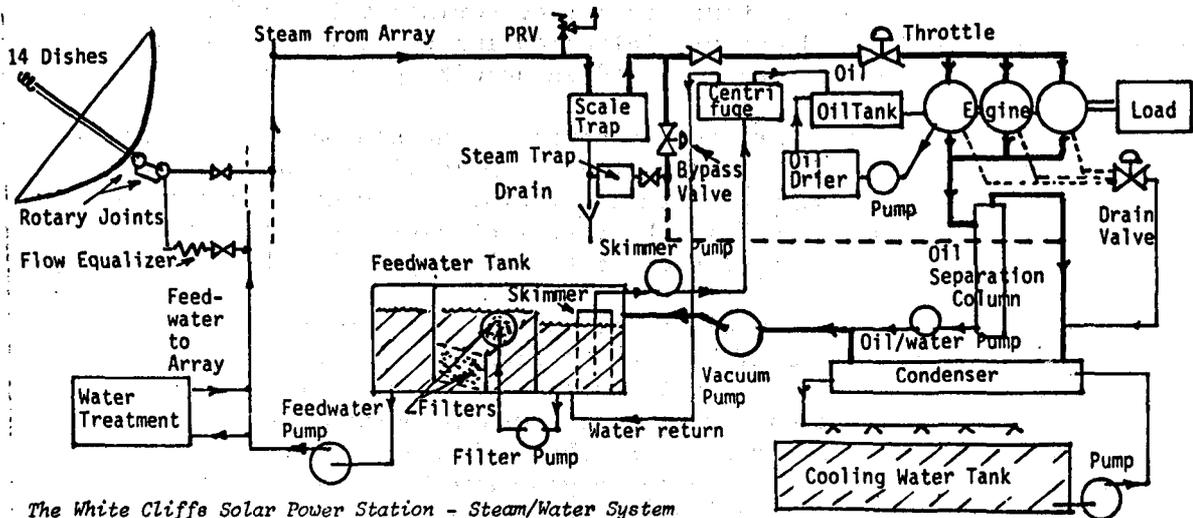
Experience and lessons from the project are presented, particularly in relation to: system performance in various environmental conditions; design philosophies for collectors, the array, control systems, engine and plant; operation and maintenance strategies and cost reducing possibilities. Experience so far gives encouragement for the future of such paraboloidal dish systems in appropriate areas.

### 1. INTRODUCTION

Description and performance information for the White Cliffs Solar Power Station has already appeared elsewhere (for example, Kaneff 1983a, 1983b, 1983c, 1983d); the following details therefore serve as a brief reminder of station details:

The White Cliffs project is intended primarily to help ascertain viability of paraboloidal dish systems in providing energy and water for Australia's inland and remote areas. The small opal mining town of White Cliffs (1100 km west of Sydney) was chosen because it had no existing power supply and is sufficiently remote to provide an authentic environment. Experimental and theoretical investigations commenced in July 1979, engineering design in August 1980 and construction was completed by December 1981; output specifications were met by June 1982 and continuous reliable operation was established by June 1983. The station now supplies the township on a continuous round-the-clock basis





The White Cliffs Solar Power Station - Steam/Water System  
Figure 1.

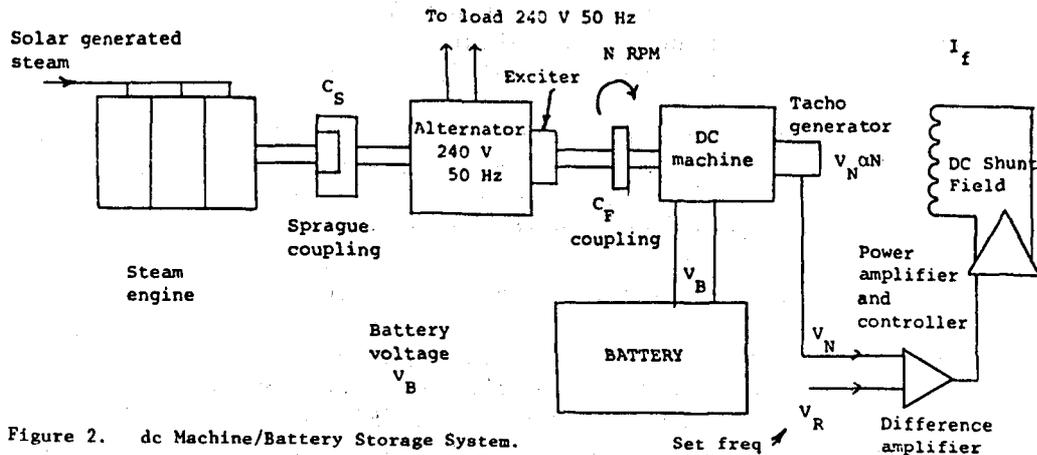


Figure 2. dc Machine/Battery Storage System.

that is, stand alone (with diesel back-up).

### 1.1 System Description

Figures 1 and 2 portray the installation which produces 25 kWe and over 100kW low quality heat at an insolation level of 1 kW/m<sup>2</sup> and comprises 14 modular semi-autonomous paraboloidal tracking collectors, each 5 m diameter with fibreglass substrate and plane mirror tile reflecting surfaces (2300 tiles per collector), moving in azimuth and elevation driven by printed circuit motors through actuators and controlled by dish-mounted sun sensor. Each collector carries its own battery supply, charged from the central plant.

A central controller intrudes on the modular units only to give instructions for starting, offsteering (in case of steam or energy flow balance failure), stopping and parking (normal or strong wind mode). In the event of central control failure, each collector can continue operation, close down, park and offsteer (in response to absorber overheat). The collector array operates at wind velocities of up to 80 km/h, above which it parks automatically, vertically

facing. Normally the collectors are parked horizontally facing south east, to reduce dust collection and dew precipitation and to obviate excessive movement when parking at the end of each day and in acquiring the sun in the morning.

Steam at up to 550°C and 7 MPa is generated in the semi-cavity absorber of each collector, conveyed through horizontal and vertical axis rotary joints, thence in insulated pipes to a high performance reciprocating uniflow steam engine which converts the available solar heat to mechanical work at heat-to-mechanical work conversion efficiencies of up to 22%, (typically 17-20%).

The automatic cycle begins on clock command some 10-25 minutes after sunrise; feedwater flow is then established in the array over an allocated 10 minutes; the array acquires the sun within the next 3 minutes; steam lines warm up and steam quality rises. At an engine room steam temperature of 180°C, the bypass valve closes. When steam pressure reaches 2.5 MPa, the throttle opens and the electric starter engages, so ensuring engine start in the correct direction; the drain valve closes and the engine accelerates as it warms up. On a sunny day engine start occurs some 12-6 minutes after the array is first tracking; within a further 20-6 minutes, the engine is delivering useful power to the load (that is, generating 3+ kWe to supply auxiliaries and some load). Useful power is generated within about 45-25 minutes from initiation of the 'start' signal, depending on time of start and on insolation.

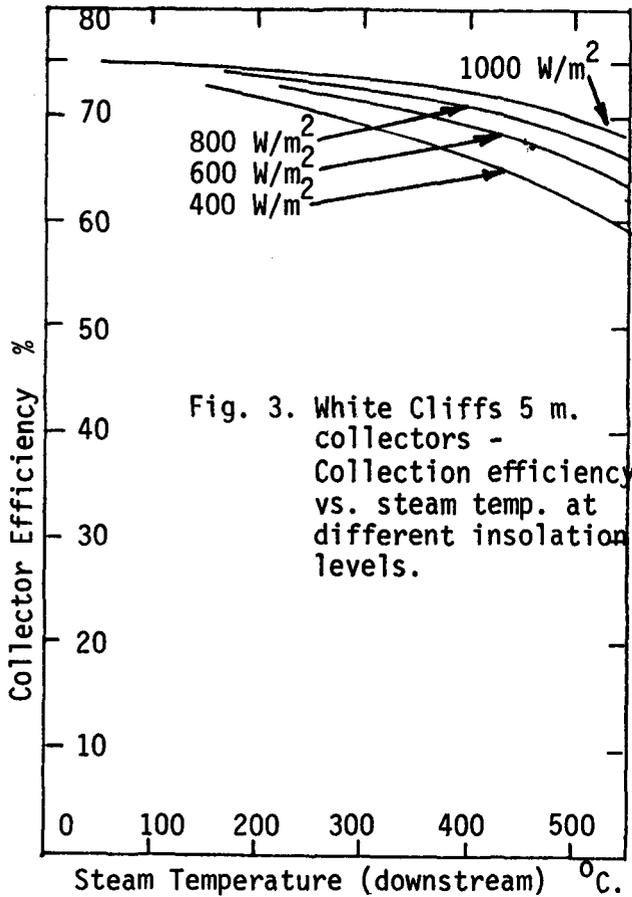
A clock signal 30-40 minutes before sunset (approximately the limit of useful nett power output) causes the array to park horizontally facing south east. During intermittent cloud, the engine stops and starts automatically in accordance with available steam quality; during cloud, the tracking system provides timed pulses for following the sun which can then be acquired within seconds of emerging. For obvious continuous cloud, the system can be manually locked out.

Figure 2 depicts the engine/load combination designed to maintain energy flow balance. Excess engine output beyond that required to supply the ac load at any moment, is stored, via a dc machine, in a 760 ah lead acid heavy duty traction-type battery, while in times of inadequate insolation, energy is drawn from the battery to drive or help drive the alternator and supply the town. In the absence of sunlight, the battery/dc machine alone drive the alternator, the steam engine being stationary, a situation facilitated by a free-wheel (ratchet) type coupling between engine and alternator. Storage available is intended to cope with overnight requirements but if the battery is discharged before further solar energy is collected, a back-up diesel unit starts automatically to supply the load. A flash boiler permits engine testing and acts as an emergency supply if the diesel set is out of service.

## 1.2 Performance

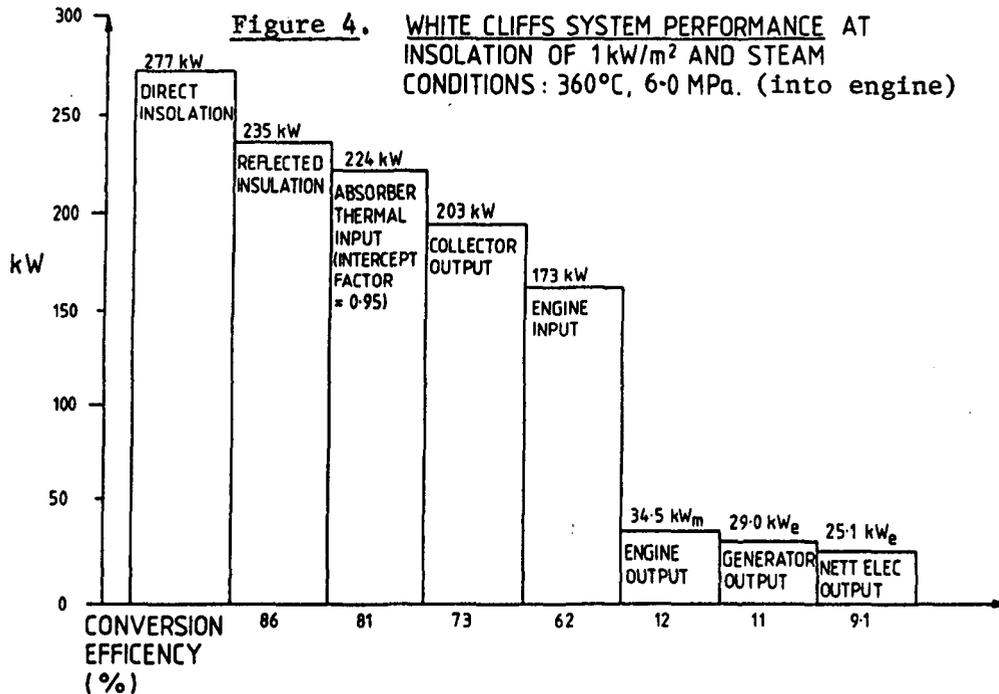
Robust economical hardware was sought, construction being based on agricultural and automotive practices. Dish manufacturing tolerances were relaxed by permitting a 'fuzzy' focus which nevertheless allows 95% of reflected energy to be intercepted by the semi-cavity absorber 160 mm diameter and 160 mm long, which is accordingly subject to relatively low heat stresses.

Figure 3 shows collector performance as a function of insolation level and steam temperature. Figure 4 is the cascade diagram at stated sun and engine-room conditions; while higher steam quality can be achieved in the engine-room,



system output is not necessarily higher and may be lower, due to enhanced losses. Figure 5 shows the generated electrical power profile for operation when peak insolation was  $874 W/m^2$ . Useful nett electrical output flows from 50 minutes after sunrise until 30 minutes before sunset in this case and depends on feedwater flow as well as on insolation. (Distortion at the start of the curve for insolation is caused by a small hill). Figure 6 shows the steady state relationship between insolation and gross electrical output.

It may be noted from Figure 6 that at insolation levels below about  $400 W/m^2$ , there is inadequate output generated to make up the power taken by auxiliaries (that is, a little over  $3 kW_e$ ). Generally the array collection efficiency increases as insolation increases (at given steam operating temperature).



## 2. ENVIRONMENTAL EXPERIENCES

White Cliffs' climate is typical of much of that of inland Australia, with an irregular rainfall whose average is well below 25 cm (10 inches) per annum. Much of this precipitation appears as thunderstorms which cause sporadic flooding at times. During good years (1983 for example), the whole countryside is carpeted with greenery; animal and bird life abound and insolation is more uncertain than normal. At other times (most of the time) conditions become extremely dry and dusty, with much sunshine.

### 2.1 Insolation and Cloud

Figure 7 depicts the hourly and seasonal variations in direct insolation for White Cliffs according to a well known formula. But our records over the past 4 years have frequently recorded higher values than these, especially following rain (suggesting that atmospheric dust plays an important part in the process). It is not uncommon during the period October to March for peak insolation to exceed 1 kW/m<sup>2</sup> (even reaching 1.07 kW/m<sup>2</sup> on rare occasions.

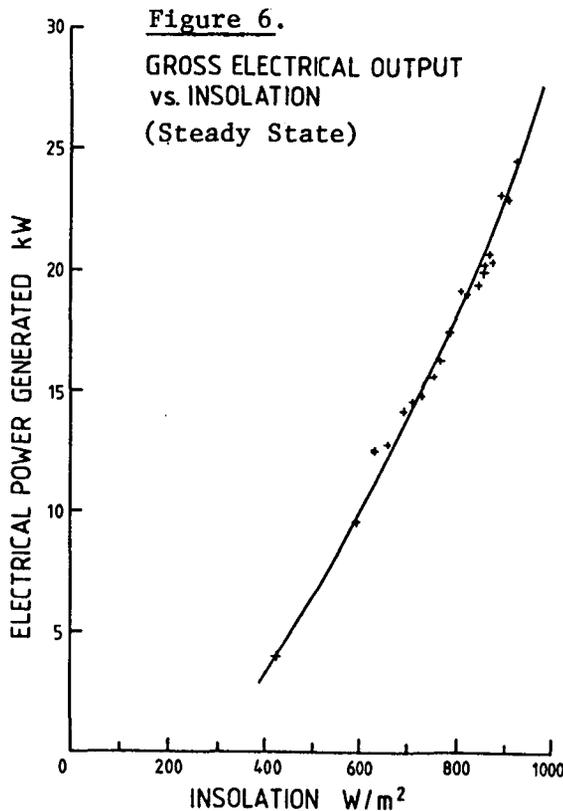
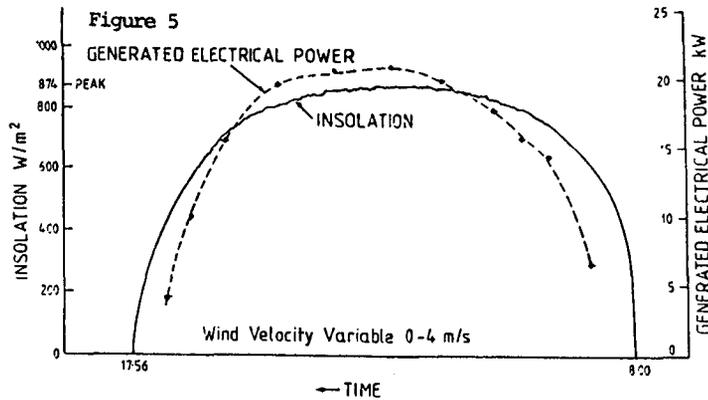
Meteorological records for the White Cliffs region show approximately 3000 hours of sunshine per year and an incident energy of around 2100 kWh/m<sup>2</sup> per annum. Our records for 1980 show some 2400 kWh/m<sup>2</sup> per annum, a figure which should be compared with the values of Table I which shows an ideal situation for mean energy/day/m<sup>2</sup> and mean peak insolation for each month on the basis of 100% sunny days - total annual incident energy would then be 3390 kWh/m<sup>2</sup>.

TABLE I. Mean Energy per Day and Peak Insolation Level at White Cliffs for Ideal Conditions

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Mean energy/ kWh/day/m <sup>2</sup>	11.1	10.5	9.44	8.25	7.25	7.0	7.2	8.95	9.41	10.45	11.1	11.25
Mean Peak Insolation W/m <sup>2</sup>	947	944	938	920	890	885	890	920	938	944	947	948

But the above figures for incident energy per year disguise the form and content of the available useful insolation. While, as may be expected for areas which are reputedly very sunny, many days over the year are completely sunny, and very few are completely cloudy. But a surprisingly large number of days are only partly sunny: these may be considered in three categories, days in which:

- (1) a continuous band of sunshine is followed by a continuous band of cloud or vice versa (such as occurs when a cloud front arrives or existing continuous cloud clears). The system operation in such circumstances is straightforward.
- (2) intermittent cloud is present - a surprisingly frequent phenomenon which can occur at any time of year but particularly in summer. What is often involved is the local formation of a matrix of very slow-moving clouds in the early afternoon lasting until late afternoon. Mechanisms involved



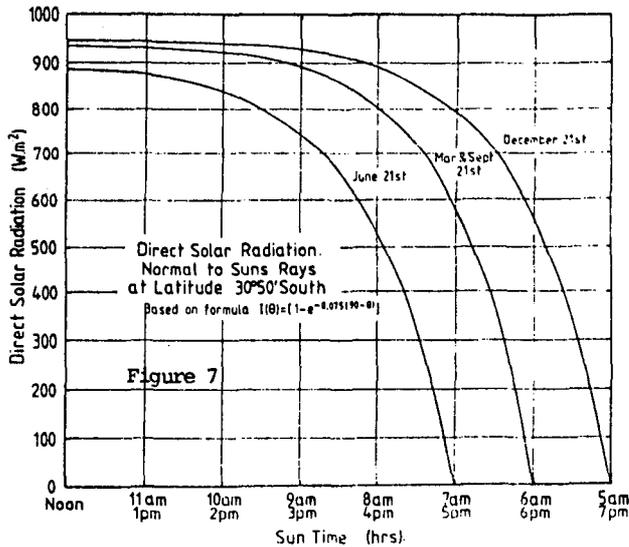
appear to be the formation of 'chimneys' of hot air rising from the ground in a relatively stable pattern accompanied by the formation of a corresponding stable pattern of cloud which moves but slowly, causing insolation at any given point to vary from full sunshine to shadow. The periods of sun and shade vary typically in the range of a few minutes to 20-30 minutes - sometimes the clear periods are longer, and sometimes they are the shorter.

In such circumstances the solar steam system operates in accordance with the steam quality available, running and stopping in turn. While the station auxiliaries (especially the feedwater pump, the water and oil circulating and treatment pumps and the cooling water pump) are running continuously, some 3 kWe energy is expended. If there is no steam energy, this quantity has to come from the batteries. It can happen, therefore, depending on the mark-space ratio of the sun/shade, that there may be a nett overall loss of energy while running in this mode, or at least the nett useful energy over the operating period may not be worth the trouble to run.

Even relatively short spikes of shade can cause momentary loss of superheat from which the system takes time to recover. This kind of operation requires special attention.

- (3) haze due to sparse cloud, water vapour and/or high level dust is present, lowering the mean insolation level usually with a characteristic 'spikey' profile, with the insolation varying by a significant amount in relation to the total insolation - the spikes are frequent (every minute or so, sometimes less frequent). Apart from lowering steam quality and station output, neither the steam system nor the engine can reach temperature equilibrium and overall efficiency is lowered as is output.

Coping with the above situation presents problems of operating strategy which need intelligent decisions. A heat store of some tens of minutes' capacity would go some way to improve performance in these conditions (as the current amount of heat stored in the steam system is small, involving only heat capacity of steam lines and insulation) but the cost effectiveness of this has yet



to be resolved and there are grounds for expecting better returns from an automatic fossil fuel burner inserted just before the engine to maintain good superheat.

In the meantime, the station operations manager relies on judgement and prediction of insolation conditions when situations (2) and (3) above arise, as to whether or not to run or continue to run the solar steam system (adding superheat from a fossil fuel in this case is quite efficient, more so than running the diesel back-up system).

Were a new multidish central plant system to be designed, a viable

option might be to run all dishes except a small number near the plant at lower temperatures, even wet steam, then to add the superheat from the dishes near the plant; a fossil fuel burner could then be added close to the engine to cope with the abovementioned problems.

## 2.2 Wind

White Cliffs is located on a relatively flat plain with occasional small hills some tens of metres high. Available meteorological information is sparse and does not provide an adequate or true picture of wind conditions. The area is obviously very windy and local observers report harrowing tales of past storms. Our records over 4 years at the solar site (anemometers at 7 m and 30 m above ground) and on a nearby hill (25 m higher than the site) show that whereas the wind normally dies down at night at the 7 m level, at 30 m above ground and on the hill, the wind almost never stops, with an average velocity of about  $7 \text{ ms}^{-1}$  (making this an excellent site for wind generators).

The wind can be described as being very strong and gusty during the day quite frequently, strongly buffetting the collectors. Although generally strong, winds are not unduly so and the 80 km/h speed for which the array is designed to park vertically upwards has been exceeded only once on our records at a time when the dishes were already parked vertically; but speeds have approached the park value many times. Although extremely strong winds are uncommon, during its daily operation the array experiences very severe buffetting from the wind especially from late spring to early autumn and steep velocity fronts cause sudden mechanical shocks. Apart from unpleasant effects on people, the wind influences on the solar system include:

(1) perturbation of array tracking - because of general structural resilience (enhanced by the relaxation of rigidity and backlash criteria in order to reduce costs), the presence of strong buffetting winds (particularly from certain directions in relation to collector orientation) can readily cause perpetual hunting of the altitude/azimuth drives, unless appropriate precautions are taken. The designed solution was to permit only intermittent drive, not

continuous - sun sensor signals which denote tracking errors, are allowed to correct the collector orientation to produce zero error but the drive circuits are then inhibited for 10-15 s before further operation is allowed. This strategy has proved extremely satisfactory under all experienced operating conditions and produces a tracking which is more than adequate for the purpose (better than  $\pm 0.15^\circ$  pointing error).

(2) the raising of dust clouds and the blowing and depositing of dust onto the collectors - but fine dust particles which settle can also readily be blown off by strong winds, tending to reduce the effect.

(3) the convecting away of heat from the semi-cavity absorbers. This is the most substantial problem from wind and tends to counter the benefits of simplicity of design. In strong winds each absorber can lose more than 1 kW thermal energy above a no-wind condition. This loss is avoidable so that new protected absorbers, closer to a true cavity, are being installed to reduce this substantial loss.

(4) the depositing of large quantities of dust in plant rooms as a result of wind blowing from a particular direction and sometimes by dustladen whirlwinds which more often than seems reasonable, choose a path to the plant.

(5) sudden mechanical shocks on all components arising from wind changes (in some cases wind velocity fronts starting from almost still air to  $30 \text{ ms}^{-1}$  within one minute or so).

### 2.3 Precipitation

The effect of rain is only slight because of its infrequent occurrence. Most clouds moving over White Cliffs, although reducing solar energy, seem reluctant to part with their moisture. When rain does fall, it is useful in partly washing the dishes but the action is incomplete - some residual dirt remains. Dew, which is frequent in spring and autumn, and results in several litres of condensate on each dish, acts to consolidate part of the deposited dust on the mirrors.

### 2.4 Dust

Both coarse low level dust blown up by strong winds and high level fine dust occur in abundance in the inland. The former is not a problem since it rarely deposits or remains on the mirrors. The latter often reduces insolation directly and also produces a frequent deposit of fine dust on the dishes and on all other components.

Dust of one kind or another has to be accepted as a fact of life and equipment designed accordingly, either dustproof or dust tolerant. With this in mind, all components have been produced successfully to live with the problem of dust. However the mirrors are regularly affected and, unless cleaned, can suffer an energy loss of up to 20% after a few weeks - this loss removes valuable superheat and is a serious effect.

Cleaning of dishes is therefore considered desirable and is carried out with a frequency of 10-30 days, depending on the state of the mirrors. Because of the absence of grime and due to the fact that the consolidated particles are

very small, cleaning is carried out by manually rubbing with a large lambswool pad mounted on a long flexible tube- this cleans and polishes the mirrors in a time typically 5-10 minutes per dish, depending on its state. To remove tedium, however, we are experimenting with automatic cleaning devices.

## 2.5 Extremes of Temperature

Temperatures from just below freezing in winter to well above 40°C (up to 47°C) in summer are a feature of the White Cliffs' climate. Humidity in summer can also be a problem. Equipment is not difficult to make tolerant of these conditions and no anti-freeze protection is used in the steam system which is always, to some extent, charged with water when the system is not running.

In summary, although the environment is harsh and inhospitable on occasions, by applying appropriate design and operating strategies, any problems can be coped with reasonably readily.

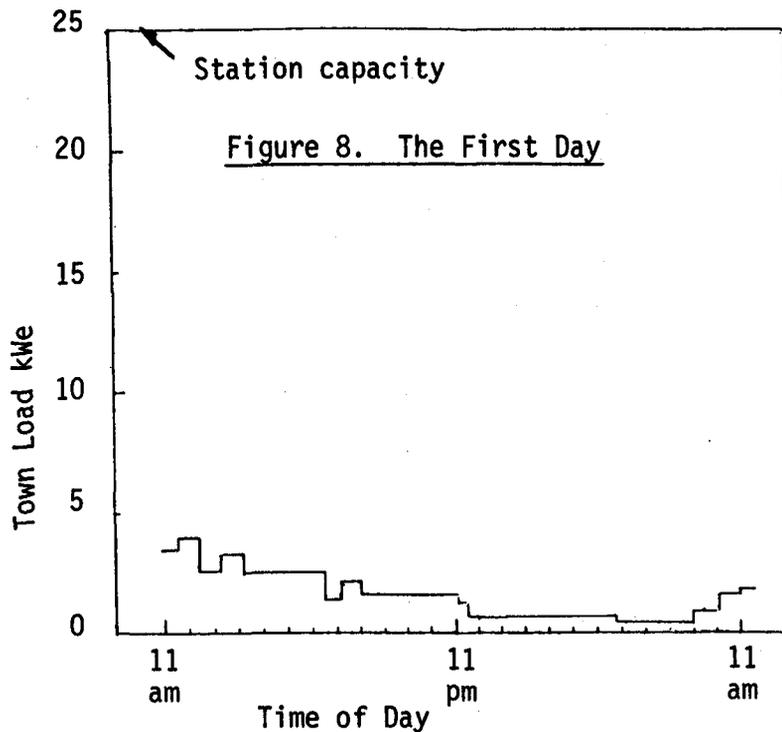
## 3. HARDWARE EXPERIENCE

The solar array has presented extremely few problems. During the early phase of collector development, several options were considered and eventually fibre-glass substrates were selected in stead of the initially preferred pressed metal shells due to a perceived inadequate time to perfect the various processes involved. In operation over the past two years no technological changes have been necessary to the array (but we are currently improving the absorbers to improve output by reducing wind convection losses). Tracking performance has been equal to all encountered conditions.

All control, electrical and electronic systems worked from the start and have continued to operate trouble-free. A particularly valuable feature during the commissioning phase has been the facility for manual or automatic operation.

The engine and steam system, on the other hand, required by far the major part of time and resources to develop. In the absence of commercial units of adequately high efficiency, an experimental high performance uniflow reciprocating steam engine was selected on the basis of steam car experience - realised by converting a 3 cylinder Lister diesel engine to steam operation. This was achieved relatively simply and cheaply by retaining engine block, crankshaft and bearings, oil pump and filter, electric starter, flywheel and connecting rods and bearings, but using General Motors' pistons, rings and liners, suitably machined.. Three new cylinder shells were made, each with valve plates, guides and steam chamber and heat shields and three impulse pins were fitted to the tops of each piston. The problem of spare parts was consequently not taxing. Such a converted engine, if produced in relatively small numbers, would cost less than a diesel engine of the same output.

The original conversion, while conceptually sound, required much attention before it emerged as a robust, reliable unit of good performance in everyday operation. Development work was carried out over 18 months on the valve mechanism, the system for extracting oil form the exhaust steam/condensate and on feedwater treatment, all this work being carried out largely on site (1100 km from our laboratory). We consider the steam /engine system is now very satisfactory and applicable in other situations, for example for using crop and other wastes for raising steam and generating electricity.



### 3.1 Commissioning

Because of the remoteness of the site and the consequent difficulty of carrying out complex maintenance, the New South Wales Government, owners of the station, considered that commercial standard reliability should be established before connecting the supply to the township and leaving it in charge of local people. This phase of the project was completed in June 1983 and the Energy Authority of New South Wales then carried out extensive tests in July and August. Over the approximately 18 months during which the system was operated

on 'dummy' load, all manner of operating conditions were successfully coped with. Without change, the system was connected two months later to the town in November.

### 3.2 Supplying White Cliffs

The conventional wisdom in power supply circles suggested that 25 kWe to supply a community of 40-50 people (10 houses, hospital, school, hall and post office as well as street lights) was hardly adequate. The system itself was not sized to power White Cliffs but was determined by other factors; the site was not chosen until some time after other parameters were set.

It was therefore not without some interest that local citizens, Energy Authority and Australian National University personnel gathered at the station site at 11.00 am on November 3 1983. The switch was thrown and the subsequent loads drawn over the next 24 hours were as indicated in Figure 8. When noting the frugal nature of all things in White Cliffs the magnitude of the load is not so surprising. To date the load has not risen above 10 kWe.

Attendance at the station by the operations manager, 7 hours on the first day, has progressively reduced to less than 2 hours per day and should reach less than the 1 hour per day targeted in the first few months of continuous operation. Make-up requirements are up to 10 litres distilled water per day for the steam system and up to 1000 litres of cooling water on a very hot sunny day.

### 3.3 Practicability

Remoteness of the site has carried with it various logistic problems; but it

did not prove too difficult to establish a field station with adequate resources to handle maintenance and a fair amount of development on site. The level of technology was deliberately chosen to be agricultural/automotive in character so that it would suitably be operated and maintained by local personnel - this philosophy has been vindicated in practice. No problems have arisen over the past 2 years that could not be handled on the spot, except those for which it was decided to change configuration or components and which required machining sophistication. The top end of the engine can be dismantled, adjusted and put together again by one person in less than 4 hours; in 7 hours the engine can be stripped and re-assembled by a person with automotive engine experience.

Confidence has been established that this kind of system is technologically viable for providing continuous electric power on a stand alone basis with diesel back up in areas such as White Cliffs.

### 3.4 Costs

Overall project costs were approximately \$A11/4 million, mainly salaries for research and development. Hardware costs for the system as currently on site were \$12,500/kWe (\$A, Dec. 1981 values). After a period of continuous supply to White Cliffs it is hoped to be able to ascertain the true generation costs.

### 4. POTENTIAL

White Cliffs has proved robust, reliable and manageable. It has provided valuable experience in two areas of interest which motivated us to carry out the project:

- (a) As a means for gaining information towards designing very large paraboloidal arrays for gathering, converting, transporting, storing and utilizing solar energy through the use of thermochemical systems and large central plant with high energy collection efficiency and a range of energy rich products;
- (b) to realise a family of modular paraboloidal units suitable as stand-alone systems for remote area supply and for connecting to an electric grid. Our choice of steam Rankine cycle engine was dictated by two factors - no alternative engine was available to us; the engine used was deemed the most likely to be completely maintainable by those living in remote areas.

A new White Cliffs could, by pushing the technology as far as it can go, (better absorbers, better energy transport, shorter lines, more efficient engine, less auxiliary power) might just double its overall efficiency to 18%; so 7 dishes of 5 m diameter would be required, the overall system cost with overnight storage and diesel back-up being about \$A6700 (Aug. 1983).

Based on White Cliffs type technology but employing 11 m dishes, and a production run of 15-20 dishes, 30 kWe systems might be produced at around \$5000/kWe. An order of magnitude reduction of costs on the current White Cliffs system seems potentially possible through use of the emerging Stirling and Brayton engine technologies when these become available.

In the meantime and in the near future, an 11 m dish with azimuth axis mounted steam Rankine cycle engine could have cost and application advantages in the remote areas of Australia.

## ACKNOWLEDGEMENTS

The assistance of the New South Wales Government in funding the White Cliffs project, the Australian National University for providing resources and facilities and the contributions of the many staff members on the project, are all gratefully acknowledged.

## REFERENCES

- Kaneff, S. (1983a), "The White Cliffs Solar Power Station", Proceedings Fourth Parabolic Dish Solar Thermal Program Review, Nov. 30-Dec.2, 1982 Pasadena California, Sponsored by U.S. Dept. of Energy, conducted by JPL. DOE/JPL-1060-58, pp. 299-317.
- Kaneff, S. (1983b), "The White Cliffs Solar Power Station", Paper 359-3.4.2-D, International Solar Energy Society World Congress, Perth, 14-19 August 1983, 5pp. (To be published).
- Kaneff, S. (1983c), "On the Practical and Potential Viability of Paraboloidal Dish Solar Thermal Electric Power Systems", Paper 360-3.6-B, International Solar Energy Society World Congress, Perth, 14-19 August 1983, 5pp. (To be published).
- Kaneff, S. (1983d), "The Development of Viable Paraboloidal Collectors for High Quality Heat Production". Paper 361-2.8.1-C, International Solar Energy Society World Congress, Perth, 14-19 August, 1983, 5pp. (To be published).