DEMONSTRATION AND PERFORMANCE TESTING OF A PARABOLIC DISH COLLECTOR

PROGRESS REPORT

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PRINCIPAL PARTICIPANTS IN THE PROJECT

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ACKNOWLEDGMENTS

The continued support of the head of the Department of Engineering Physics Professor Kaneff and the director of the Research School of Physical Sciences Professor Carver is gratefully acknowledged and appreciated.

The financial support of Anutech Pty Ltd is also gratefully acknowledged. The availability of non-standard large sheets of aluminium and acrylic was made possible only because of bulk ordering as a result of Anutech's anticipated requirements. This circumstance greatly alleviated the sheet jointing problems.

1. DESCRIPTION OF PROJECT

1.1 Objectives

The objective of the project, as defined in Schedule A of the contract, is as follows:

> 'to construct and operate a pilot parabolic dish collector based on the press-formed metal parabolic system and so gain data on the thermal performance of such a collector.
>
> A single sun-tracking prototype unit complete with focal absorbers is to be built and installed on campus. This is to be coupled to a thermal test loop to enable the system's performance to be measured.'

The NERDDC support for this project through 1979/80 is $82,900.

1.2 Allied Projects: Practical Interpretation of Objectives

Several other projects, funded from sources other than NERDDC, have arisen in anticipation of success of this project.

They require pairs of collectors generally as described in the publication ref 4.3 (Carden, P O, 'A proposal for construction of a solar pilot plant based on high temperature (500 C) shell mirror collectors', July 1978). The present NERDDC project and the previous one entitled 'Solar Power for Remote Areas - Fluid Heating to 200 C and Above' are also based on the concepts described in ref 4.3.

Since the allied projects are complete installations embodying numbers of the proposed collector pairs it was expedient for us to identify the prototype for these installations with the NERDDC project. A consequence of this policy is that the NERDDC collector installation comprises two mirror collectors mounted on a common frame instead of the single collector implied by the title of the project. It also includes several other features which Council may consider to be more sophisticated than was intended since the requirements of the installation now go beyond the collection of thermal data to include the practical necessities for operating reliably and efficiently on a day-to-day basis. These requirements are particularly reflected in the collector control system and the ability to stow by 'clamming'.

Council may take the view that the allied projects are premature and that inclusion in the NERDDC project of features additional to those detailed in Schedule A are therefore unwarranted. Expediency was one of the reasons why the writer

(Dr Carden) chose the path he did. But there were other more complex reasons which have been made apparent in the body of this report.

1.3 Collector Concept

As described in ref 4.3, paraboloids 3.66 m diam and 0.9 m deep are press-formed from discs of sheet aluminium 1.2 mm thick. The aluminium was produced in Sydney and is being fabricated into discs at the Commonwealth Aircraft Corporation, Melbourne. Three sheets are edge welded together on an automatic TIG welding machine and the composite then cut to a diameter of 4.5 m to form a disc. The discs are then trucked to Canberra for press forming. The resulting paraboloid is stiffened at the rim by means of a ring rolled from 35 mm OD tubing. This ring is glued to the paraboloid with epoxy resin.

Eventually it is hoped to apply a mirror surface directly to the aluminium paraboloid. But for this generation of collectors silvered or aluminised acrylic liners are to be used. These liners are manufactured in Canberra. Each is made by gluing three sheets of clear acrylic together edge-to-edge. The sheets are 1 mm thick, 4 m long and 1.4 m wide and come from Japan. After gluing, the composite is cut into a circle 4 m diameter. A circle is placed into a blow moulding machine where it is heated and formed into a paraboloidal shape. Some of the clear liners may be back silvered using chemical deposition techniques. This work will be performed by expert contractors working in Canberra or Melbourne. Other liners will be trucked to Siding Springs Observatory where they will be back or front aluminised. This work will be performed primarily by members of the Anglo-Australian Observatory.

Reflective surfaces will receive an appropriate protective coating.

Each liner is to be attached to the concave side of an aluminium paraboloid by means of a flexible hermetic seal at the rim. The assembly constitutes a mirror collector, two of which are mounted on each frame.

The frames are being made under contract in Canberra. Each comprises a steel base in the form of a cross, a central vertical column which carries the azimuth bearings, a rotating tube which fits over the column, a horizontal elevation axis attached to the top of the tube, a rectangular elevation frame hinged to the horizontal axis and finally two collector frames hinged either side of the elevation frame each of which carries a mirror collector. The azimuth actuator is mounted on a horizontal radial arm fixed to the base of the rotating tube previously referred to. This actuator drives a small polyurethane tyred wheel which bears on a rolled ring attached to the base cross.

The elevation actuator drives a screw mechanism for varying the distance between two pivots. The pivot points are attached to the elevation frame and to a second arm welded to the rotating tube.

Drawings show the design of the components referred to above.

As described above two mirror collectors per frame are mounted on frames which are hinged either side of the elevation frame. This arrangement enables the mirror collectors to close together face-to-face so as to provide protection of the sensitive mirror surfaces from wind blown grit, dust and rain at times when the environment is hazardous.

In this 'clammed' position the collectors may also act like a wind vane thus ensuring that a minimum section area is presented to the wind and the aerodynamic forces accordingly reduced to safe values even in the strongest winds anticipated.

The occurrence of wind-vaning in strong winds is assured by virtue of the azimuth friction drive which will slip if the azimuthal torque exceeds a certain threshold value. However, it is preferable to drive the mirrors to the wind vaning position by an automatic procedure and this will be done whenever the wind velocity exceeds a predetermined level.

Whereas the elevation and azimuth actuators are based on dc printed motors, the clam actuators are hydraulic rams fed in parallel from a central controlling unit.

As previously reported all the major features of collector design and manufacture have been tested on one sixth scale models. A model vacuum press has been built and operated. The resulting model aluminium paraboloids have been subjected to wind tests. Similarly a model blow moulder has been built and the liners so produced subjected to several mechanical tests as well as application of the two candidate reflective surfaces.

1.4 Mirror Manufacture Concept

The full scale manufacturing methods follow closely the methods developed on the one sixth scale vacuum press and blow moulder.

The vacuum press concept has been described elsewhere (ref 4.3). A brief description follows.

A concave paraboloidal die stands with rim horizontal and apex downwards.

It is completely filled with water and then a circle of sheet aluminium is clamped to its rim thus completely enclosing the water. The water is then pumped out of the die causing the sheet aluminium to be drawn to the shape of the die. The rim clamp is controlled so as to allow a limited amount of draw feed from the edge.

A major undertaking was the machining of the paraboloidal die which could only have been done in-house because the ANU possesses a large vertical axis boring mill. The mill was modified so that the cutting tool moved in a parabolic path. This was achieved by making use of the principle that the sum of the distances from a point on the parabola to the focus and directrix is constant. In accordance with this principle fixed length chains were used to constrain the motion of the tool post. A further problem was to design a mechanism which maintained the face of the cutting wheel tangential to the parabola in order to achieve a consistent and acceptable finish. The eventual solution to this problem was satisfingly simple and effective.

In our previous progress report two options for blow moulding the acrylic liners were described. A major difficulty in this process results from the fact that acrylic sheets of the size ideally required, viz approximately 4 m diameter, are not available. Therefore either several standard size sheets must be edge-glued together before blow moulding or the blow moulding process must be adapted to producing curved segments which may then be edge-glued together to form the required paraboloid. The first option was finally selected.

The 1.5 mm thick sheets of acrylic purchased were ordered sufficiently long to minimise glueing. In fact three of these sheets glued with two parallel seams are sufficient for each liner. The seam is a double lap joint using a strip either side of the joint. The strips are cut from 1.5 mm acrylic sheet and are nominally 20 mm wide.

After three sheets have been edge glued, the composite is cut into a circle approximately 3.8 m diameter. A light coating of grease is applied to the upper surface so as to retain the polished finish when the acrylic is forced against the disc surface.

The blow moulding machine comprises the following components: air plenum, die, heater cage, rim clamps, blower and controls. The air plenum is essentially a circular brick wall about 300 mm high lined internally with thermal insulation and provided with electric air heaters. Fitted in a groove at the top of the wall is an inflatable sealing ring.

An acrylic circle is lowered onto the sealing ring. The circle receives additional support from vertical props located within the air plenum. The die is them lowered over the acrylic circle. The die consists of a tubular rim ring attached to which is the paraboloidal die. This will in fact be an aluminium sheet pressing from the vacuum press. The apex of the die is uppermost so that in the moulding process the centre of the acrylic circle is forced upwards into the die.

After the die is in place it is fixed by means of clamping bars attached to the floor. The inflatable seall is expanded thus clamping the rim of the acrylic circle between the inflatable seal and the rim ring of the die.

The heater cage is lowered over the die. The heater cage is a light paraboloidal frame to which is attached electric heating wire and thermal insulation.

Once the equipment is assembled the moulding process begins by heating the die and the air in the air plenum. The heated air also brings the acrylic sheet up to the operating temperature of about 150 C. Then the blower forces additional hot air (heated in an auxilliary heater) into the plenum thus causing moulding to occur. Air within the die space is allowed to escape through a few small holes.

When moulding is complete, the whole is quickly cooled by blowing ambient air and by removing the heating cage. Then the seal is deflated, the die unclamped and removed and finally the paraboloidal liner is extracted.

It is intended that the blow-moulded acrylic liners receive a variety of reflective coatings. The most favoured is a vacuum deposited layer of aluminium on the back surface (convex side). Arrangements have been made to do this at the Anglo-Australian Observatory, Siding Springs, NSW.

A variation of this technique which should be tried is front surface aluminising. The extra reflectance may outweigh the reduced life time although transparent coatings which should prolong the life are known to be available.

Back silvering using techniques similar to those used for glass mirror manufacture are also being developed on our behalf by Varga Bros, Melbourne.

Unfortunately, the costs of each of these methods are expensive for this first generation of collectors being about $500 per mirror.

1.5 Collector Control

The objectives of the collector control system are as follows:

- face the collectors accurately towards the sun when the sun is shining;
- maintain control in non-sun conditions eg. during

intermittent cloudy conditions;

- offsteer ie. to direct the collectors a small angle away from directly pointing at the sun in order to reduce and control the solar input under certain conditions. This is an important facility for development of the power station should an energy storage facility not be incorporated immediately. In this case a means is required for matching the solar energy input to the consumer power demand;
- stow in an emergency ie. reduce elevation to zero, close the clam, and steer in azimuth to the wind-vaning position.

The control system is specified in accordance with the above objectives. As can be seen by referring to the schematic diagram Figure 1 two modes of operation are possible called 'pointing' and 'tracking'.

For the pointing mode the sun's co-ordinates are computed for a given time-of-day and the control system directs the collector to point in the prescribed direction. The computation for each collector pair is corrected for non-verticality of the azimuth axis: an east-west lean requires an adjustment to local time; a north-south lean requires an adjustment to local latitude. The time and latitude corrections are known as the collectors local parameters. Other parameters may be required describing the non-orthogonality of the elevation and azimuth axis and the azimuth actuator drive ratio. The latter possibility arises from the use of a friction drive embodying a polyurethane tyred wheel. This method of drive is much less expensive than a corresponding gear train, is free from back-lash and allows wind-vaing to occur automatically in extreme winds.

Offsets may of course be easily accommodated in the pointing mode by simple addition in the computation.

In the tracking mode, effective when the sun is unambiguously visible, an offset detector is employed to measure the position of the sun relative to the focal axis of the collectors. The offset detector comprises a metal square which throws a shadow on a matrix of photo transistors. Both the metal square and the matrix are fixed to the collectors and aligned with their focal axis. Thus the position of the shadow as detected by the matrix measures the direction and amount of offset. It is therefore possible by a single servo connection to automatically track the sun with a given offset.

Even in the pointing mode the offset detector gives a measure of offset when the sun is shining so that the error, if any, in the pointing computation may be monitored.

The same error in the pointing computation is monitored in the tracking mode because the pointing co-ordinates are computed whether they are to be used in control or not.

Thus daily records of the monitored computation error will be available and these will be used in a sort of slow response servo loop to trim the local parameters in order to ultimately render the computational error zero. The system will therefore automatically accommodate slow drifts in local parameters as would be caused for example by foundation settling or wear in the azimuth friction wheel.

Finally it is possible and indeed advantageous to have both modes operating simultaneously. In this case the pointing co-ordinates are computed and, as can be seen in Figure 1, the time integral of the offset error (as determined by the offset detector and knowledge of the required offset) is added to the computed co-ordinates. The actuators point in accordance with these computed co-ordinates. Clearly the time integral will cease to grow when the offset error is zero ie. the system stabilises when the collectors are pointing precisely where required. Since no signal comes from the offset error detector when insolation is below a certain threshold, the correction represented by the time integral will be preserved when a cloud occludes the sun. But the sun's co-ordinates continue to be computed so that when the cloud passes, the collectors will still be on target.

The dual mode appears to be very versatile and should be suitable for all power generating situations. Otherwise, when the collectors have to be directed away from the sun, the pointing mode is appropriate.

1.6 Test Loop

The collectors will be coupled to a hot oil test loop with the objective of measuring the performance of the collectors under a variety of naturally occurring insolation conditions and at a variety of absorber temperatures. The test loop will be designed so that absorber temperature is an independently controlled parameter. This will be achieved by mans of a variable speed fixed displacement pump in the delivery line to the absorbers. The speed of the pump will be automatically controlled so as to maintain a constant measured temperature of the oil exiting the absorbers. Figure 2 illustrates the test loop concept and shows the major components.

1.7 Location

Considerable care has been given to the choice of a suitable site for the demonstration collectors. Primary requirements are: adequate sunshine, proximity to laboratory, acceptable cost. Unfortunately the area near the laboratory is fairly congested and sites at ground level suffer from considerable shading. Two ground level sites and three roof-top sites were initially considered. The choices soon narrowed to one ground location and one roof-top location on the basis of cost. Finally a decision was made favouring the roof-top location on the existing solar platform above the laboratory. This entails removing the equipment already on the platform until finance is obtained for a second platform to be located adjacent to the existing one.

2. ACHIEVEMENT TO DATE

The achievement of the Energy Conversion Group up to the date of this report must be measured against the original programme described in our 1979/80 progress report. This programme anticipated funding from the Energy Authority of NSW (EANSW) as well as from NERDDC and ANU. Our subsequent application to NERDDC was based on this programme. NERDDC was unable to meet the full amount of this application and although the final work programme proposed by NERDDC was pared down to the limit it was acknowledged that even this could not be achieved without additional funds from elsewhere. Since it had already been announced that EANSW was to fund the White Cliffs power station, there was no difficulty in anyone's mind at that time in identifying EANSW as the source of additional funds.

The original work programme, required work force and cash flow appeared as Figures 8a, b and c in the 1979/80 progress report of the project entitled 'Solar Power for Remote Locations

- Fluid Heating 200 C and Above'. These are reproduced here as Figures 3a,b and c. Actual dates have been included in the time scales commencing four weeks after receipt of the first $200,000 from the EANSW. It will be seen that the programme allowed for building sufficient collectors for the White Cliffs power station and for a process heat installation at the Uncle Ben's of Australia factory at Bathurst.

A particular feature of the work force requirement, Figure 3b, was the large number of people anticipated as being necessary to get us through the development phase in a reasonable time by pursuing parallel paths. In the event a smaller work force was achieved, growing at a slower rate but continuing for a longer period in comparison to the schedule. Consequently, much of the development was forced to be serial rather than parallel.

2.1 Status of Programme

The status at the date of this report is shown by the shading in Figure 3a. Despite the shortcomings referred to above it will be seen that the programme is not seriously behind schedule. (However according to the ANUTECH project manager the programme is seriously behind schedule since it is desired that the entire White Cliffs power station be operational by the end of 1980)

The following is a status report for each major task identified in Figure 3a.

Control and Monitoring: Behind schedule with collector control. Test loop and test loop control and monitoring at early design stage. The collector control system has been assigned for some time to contractors, NR Pty Ltd of Canberra. This company has suffered from pressure of other work and difficulty in obtaining and retaining suitable staff. In addition, the requirements of the White Cliffs project necessitated a further degree of sophistication to be introduced particularly with regard to the offset facility described earlier.

However a fairly comprehensive specification has been drafted and NR Pty Ltd have succeeded in producing a nicely designed actuator motor control unit. Plans are well advanced for incorporating the purchased microprocessor into the unit and for writing the control and communication software. The completed unit, called the Mirror Control Unit (MCU) will also include interfacing for several thermocouples and for the offset detector.

For control of the MCU and the test loop, a Commodore PET computer has been purchased.

Actuators: The design of these units is complete and all components have been purchased or built.

Mounts: (Frame including absorber.) Design is complete, manufacture is complete. Approval has been granted for locating the collectors on the roof of the laboratory. The ANU is presently seeking tenders for the supply of footings and fixing of the frame in its final roof-top location.

The absorber is constructed simply of a coil of stainless steel tubing.

A prototype has been built and tested in the laboratory. It was heated electrically to 550 C and produced superheated steam at 1000 psi.

Lifting Tackle: This heading covers a number of devices anticipated as being necessary for handling and turning over the formed and unformed sheets of aluminium and acrylic. It properly also includes unconventional work tables and special equipment required for transporting the acrylic liners to the Anglo-Australian Observatory and for subsequent handling during the aluminising process.

Although handling equipment appears adequate at this stage, certainly for the production of the two collectors required by NERDDC, much is done by hand and is probably inadequate for the quantities to be manufactured for the allied projects.

Transport and handling equipment for the aluminising process is built.

Vacuum Press: All tasks preceeding 'test press, produce shells' have been completed. The full contingency time allowance for machining the die was required. The quality of the die is generally good although there are a few steps in the parabolic profile towards the rim of the die. The effect of these steps is yet to be discovered. The slope accuracy of the die appears to be about 10 mrads according to a hastily executed laser scan. (Because of the continual urging to meet the ANUTECH schedule it has been difficult to carry out a more comprehensive assessment of the die.)

The vacuum press operates very satisfactorily although no fully formed paraboloids have been produced to date This is because at about 80% of full draw the sheets split at the weld. An intensive programme is presently underway both at the ANU and at the Commonwealth Aircraft Corporation (CAC) to overcome this problem.

At the ANU the primary sheet metal testing device is a bulge tester. Circular samples 250 mm diameter are clamped to a flat plate by a ring. They are then hydraulically inflated until they burst. In this way biaxial stresses are imposed upon the sample thus closely paralleling those induced in vacuum forming. The bulge test elongation should also have a meaningful relationship to that produced in the press.

Bulge tests carried out on alloy samples prior to ordering the aluminium for the paraboloids indicated that elongation would be adequate even when welded, although the weld reduced elongation at failure and failure generally always occurred at the weld. Apparently the conclusions drawn from the bulge tests were invalidated by the step upwards in scale and by the differences in nature between bulge testing and vacuum press forming. Model tests with welded sheet had not been carried out because of the great difficulty in welding the 0.2 mm sheet required by the model press. The solution tried so far is to anneal the sheet prior to forming. An oven has been constructed for this purpose. However, the sheet as supplied is already annealed and futher annealing has only resulted in an obvious increase in grain growth and a slight shift in the position of the failure.

Following a meeting with materials engineers from CAC two further possible solutions were identified: (1) annealing after 50% draw; (2) grind and plenish the weld. The CAC engineers tested samples of the sheet purchased and confirmed that it was 'dead soft' and had adequate elongation for the job. They also stated that they could find no fault in the automatic welding procedure carried out by CAC.

Subsequent tests by ANU seem to rule out solution (1) above. This procedure seems only to cause a poor finish due to grain growth which becomes apparent during the second part of the draw.

A further candidate solution has been added to the investigation viz begin the press forming with a shallow cone instead of a disc. The possibility of producing cones is being actively investigated by CAC.

Aluminium Sheet: Following extensive investigation and tests the alloy chosen was 1200 temper O.

The widest sheets available in Australia were 1.5 m. Thus it was necessary to join a minimum of three sheets edge-to-edge to obtain sufficient width for the circles required for forming into paraboloids.

Because of the quantities required for the allied projects it was possible to order sheets 4.5 m long without having to pay a significant premium. Thus, with these long sheets the welds required were reduced to two. CAC agreed to weld the sheets together using an automatic TIG welding machine.

All the sheets for the allied projects (sufficient for about 44 paraboloids) have been delivered to CAC. In an attempt to keep to schedle on the White Cliffs some 80% have already been welded although this process has now been suspended pending a solution to the press forming problem.

Blow Moulder: Due to inadequate space at the ANU this machine has been located at the ANUTECH factory, Fyshwick. Except for the die, which is intended to be one of the sheet aluminium paraboloids, the blow moulder is complete. Initial tests are in progress without a die. The object of these tests is to produce spherical forms approximating the required paraboloids and so expose any faults in the process as early as possible.

There was an initial problem with the inflatable sealing and clamping ring. It failed to hold the rim of the acrylic discs during blow moulding. This problem was overcome by inflating the ring to the full design pressure of 15 psi. However the joint in the sealing ring subsequently sprang a leak and efforts are now underway, with cooperation from the manufacturer of the ring, to repair it.

However, despite this problem, blow moulding to 50% of final draw has been achieved at which point one of the glued joints failed over a short distance. Evidently there is still a problem with quality control of the glued joint or perhaps strength. Fortunately, strength can easily be improved by increasing the glued overlap The main problem with quality control seems to be related to maintaining sufficient pressure to effect the bond with the pressure sensitive cyanoacrylate glue. The cold winter temperatures also appear to be a factor.

Steps are being taken to improve the process in these areas.

Acrylic Discs: Extra long sheets (4m) of 1.5 mm clear acrylic sheet were ordered sufficient for approximtely 36 parboloids. Standard sheets 2.4 m long could have been used but this option would require more glued joints. This option however remains should the supply of long ones be insufficient.

The width of all sheets is just over 1.3 m. Thus three long sheets glued edge-to-edge are required for each disc.

All the long sheets ordered have arrived as well as a small quantity of standard sheets.

Following extensive experimental work the edge-to-edge glueing system has been selected. It consists of glueing a single lapping strip 20 mm wide to one side of the butted sheets using cyanoacrylate glue.

A large circular glueing table is completed and on site.

Silvering (Aluminising) Process: The primary options still remain: aluminising at the Angle-Australian Observatory or silvering at Canberra or Melbourne by Varga Bros Pty Ltd.

With regard to the silvering process Varga Bros have performed many experiments and have a workable method although one of unknown life.

Negotiations have advanced to the stage where a notional price of $500 per paraboloid for silvering in Canberra has been put forward.

Some additional equipment would be required such as a large tray and containers for distilled water.

With regard to aluminising, two ANU parties have visited the observatory and have agreed to the methodology, manning and costing of the process.

A standard 2.4 m sheet has been aluminised to ensure that nothing in the acrylic will damage the vacuum equipment of the aluminising plant.

The logistics involved in the process have been worked out and all necessary auxilliary equipment such as crates and special lifting gear have been manufactured. The method of transport involving a low trailer has been determined.

2.2 Staffing and Labour Force

Because the NERDDC project is intimately related to the allied projects the allocation of the total labour force to individual projects is not clear-cut. However, for the purposes of this report it is instructive to adopt the ANUTECH policy that all costs related to achieving the NERDDC objective should be chargeable to NERDDC. Following this policy we define the NERDDC project as those activities which lead to the NERDDC objectives. Additional work required to achieve the objectives of an allied project are allocated to that project.

In accordance with this definition five members of the Energy Conversion Group are presently engaged full time on the NERDDC project. Two are funded by the ANU, three by NERDDC.

From the beginning of this year, two additional technical officers, paid by ANUTECH (EANSW) have been attached to the group. These have spent between them approximately 12 man-months on the NERDDC project and are now engaged almost exclusively on the White Cliffs project.

In addition ANUTECH retains a part-time (2 days per week) project manager and part-time project supervisor drawn from the building industry. Whether these have provided a net benefit to the NERDDC project is debated in Section 5.

The project manager, for example, necessarily consumes many man-hours of staff time gathering data in order to keep himself informed and for inclusion in reports to the ANUTECH Board and others. It is also questionable whether his experience has led him to appreciated the nature of research and development. Certainly it can be argued that there was inadequate provision for additional R and D staff from ANUTECH sources. In fact, only 25% of the additional staff effort shown in Figure 3b was obtained: 1 man year instead of 4.

Of the remaining labour force shown in Figure 3b : 4 contract professionls, 4 ANU workshop staff, 3 contract tradesmen; these have been substantially provided and for the periods designated. This accounts for our good progress during the tool building phase of the project. According to ANU records the ANU workshop has provided a total of 2924 man hours during the period January 1 to July 18, 1980.

The contract professionals include CAC personnel engaged in welding (2 man days per disc) and metallurgical investigations; Varga Bros engaged in developing silvering techniques; Anglo-Australian Observatory personnel, NR Pty Ltd on the control system.

No contract tradesmen had to be engaged as all necessary in-house work was able to be performed by ANU workshop staff.

Many items were designed in-house and put out to tender (only the designer is counted as part of the labour force in this intance). These included the frame, actuators, some of the lifting gear, and the castings for the press die.

3. RELATED PROJECTS

Projects related to the NERDDC funded project are: (a) high temperature process heat, a project planned to be carried out at the Bathurst factory of Uncle Ben's of Australia Pty Ltd; (b) the 25 kWe solar power sation, to be constructed at White Cliffs, NSW.

Both of these related projects were presented as part of an integrated R and D programme in our 1978/79 Application to NERDDC. The integrated programme was summarised in the diagram reproduced here as Figure 4.

3.1 High Temperature Process Heat

The application in this case is for food drying at the Uncle Ben's pet food factory. Solar heat is to augment heat presently supplied by steam from an oil fired high pressure boiler. The manufacturing cost of the solar collectors is to be met by Uncle Ben's of Australia and that company has already provided $24,000 towards research and development through the Energy Research Foundation.

The objective of the project is to demonstrate the effectiveness of the ANU paraboloidal mirror collectors for providing high temperature process heat for this and similar applications.

Two pairs of collectors are to be installed in the first instance with provision for expansion to one hundred pairs. A final choice for the heat transfer fluid is yet to be made, the candidates being, oil, pressurised water and steam.

Significant energy storage is not contemplated at this stage.

3.2 The 25 KWe Solar Power Station

The application of the collectors in this instance is to provide superheated steam for a reciprocating steam engine coupled to an alternator. Funding is by EANSW who will also provide the reticulation network to consumers and a back-up diesel generator.

The objectives of this project have been greatly influenced by the objectives of Premier Wran who negotiated initially on a person-to-person basis with Professor Kaneff independently of the EANSW and ANU.

Evidently Premier Wran strongly supports the development of alternative energy systems. He sees great advantage in a public demonstration of the White Cliffs power station as early as possible there being a very strong preference for a date before the end of this year.

The initial negotiations culminated in the ANU accepting a committment to construct a solar power station by mid-1981 at the latest for the sum of $800,000. Although some members of the Energy Conversion Group were asked to provide technical material for the submission, no member was invited to participate in negotiating this committment either before or after the press announcement.

The salient features of the specification for the solar power station were as follows: - net power output 25 kWe for direct insolation of 800 w/m ; - liquid fuel back-up boiler for the steam engine; - steam conditions to engine 500 C, 1000 psi; - fourteen pairs of collectors (10 m aperture per collector); - energy storage not essential at this stage but preferred if possible.

3.3 Effect of Related Projects on NERDDC Project

The importance placed by Premier Wran on a 1980 completion date together with the size of the contract caused the ANU to treat the White Cliffs project with unprecedented concern resulting in intervention at ANU Council level. The NERDDC and Uncle Ben's of Australia projects became relatively incidental.

On occasions the three projects were in danger of loosing a common identity. Modifications to the NERDDC collectors were openly mooted and even different types of collectors eg. spun dishes. The writer strongly opposed these moves for the reasons given on page 40, most importantly because the NERDDC project needed the financial assistance that presumably was available from the White Cliffs project. Separate development could therefore lead to the demise of the Energy Conversion Group which surely was not the intention of Premier Wran since the work of the Group must have had some positive influence on his decision to finance the White Cliffs project.

However, preservation of commonality between the NERDDC and White Cliffs projects resulted in a serious difficulty in maintaining an acceptable degree of autonomy for the Energy Conversion Group as viewed by the head of that Group. This resulted from the untried approach adopted by the ANU to deal with the project: the incorporation of Anutech Pty Ltd the powerful bureacracy created to administer the project; the method and personnel chosen for management of the project including the development of the collectors. All these factors have not helped the NERDDC project to the extent that such a golden opportunity could and should have helped.

4. WHITE CLIFFS

4.1 Origin

Proposals for a 25 kWe solar power station using Energy Conversion Group developed mirror collectors and a Pritchard steam engine were developed by the writer as early as August 1977. These early proposals involved the first negotiations with Pritchard Steam Power regarding the use of a Pritchard engine for this purpose.

Proposals were made to SERIWA and Lend Lease Corporation. A solar power station was also mentioned as a possible development at Maryborough, Victoria.

The same proposal was stated in our 1978/79 application to NERDDC as a near term goal and was also described in a paper presented at Perth in August 1978 Ref 3.13.

Professor Kaneff presented essentially the same proposal to Premier Wran through private channels available to him.

4.2 Project Organisation - ANUTECH Pty Ltd

Whatever the objectives of the ANU with regard to the White Cliffs project they were thought to be achievable by channelling all project activities through a limited liability private company. Thus ANUTECH Pty Ltd was created. In the event, the EANSW has insisted that the contractual obligation resides with the University and not ANUTECH.

The board of directors of ANUTECH comprise selected members of ANU Council, the deputy Vice Chancellor and the director of the Research School of Physical Sciences. The organisation of ANUTECH is illustrated in Figure 5.

The proposed method of operating ANUTECH in conjunction with the ANU work is embodied in a Modus Operandi which is said to have been based on the premise that what was involved in the White Cliffs project was technology transfer ie. it supposed that the research and development had already been achieved and it only remained to apply standard practice to the remainder of system engineering design, to manufacture and to installation. Accordingly, the initiative was to come from within ANUTECH and any residual research and development that ANUTECH found still necessary to be done was to be let out to contract. The Energy Conversion Group was to have first preference for such contractual research and development.

In the event difficulties have arisen in following the modus operandi due to the above premise being false: at the commencement of the project the bulk of the research and development was yet to be achieved. This theme is enlarged upon in Section 5.

4.3 Contract

At the date of this report, and as far as the writer is aware, a contract between EANSW and ANU has not yet been signed although agreement has been virtually reached as to the form of the contract.

The present draft recognises that the project is developmental but there is still a clear obligation to build a working power station by mid 1981 at the latest. Moreover ANUTECH feels a very strong obligation to meet the earlier date of December 1980.

5. NON-TECHNICAL DIFFICULTIES

5.1 Maintenance of Common Identification of the Three Projects

The three projects involved have been fairly clearly defined in the documentation. The process heating project (Uncle Ben's of Australia) is defined in the publication (ref 4.3). The method of manufacture of the collectors is by press forming metal dishes and blow-moulding acrylic liners. Mounting dishes in pairs with the ability to clam is a stated feature.

The NERDDC project is defined in Schedule A. It is based broadly on work already done under a previous NERDDC contract. Press forming is an essential feature.

At the beginning it seemed possible that the 25 kWe power station might take off on a different tack.

Although the writer understood before leaving for the USA in April 1979 that he would be 'handling' the White Cliffs project it was clear upon his return that Professor Kaneff was to be directly responsible. There were also indications that Professor Kaneff had taken new initiatives in design and indeed this had been forshadowed in reports appearing in the national press at the time of the grant.

There was also a strong feeling expressed by one or two members of the Energy Conversion Group that the White Cliffs project should be independent on the grounds that it was under different management and had different objectives. The Energy Conversion Group should pursue its objectives carefully and relatively unhurried and, it was argued, this was incompatible with the expediency required by the White Cliffs project.

On the other hand, the two-year projections for the White Cliffs project which emanated from the Energy Conversion Group were all based on the assumption that the NERDDC project would be pushed through and continue with gathering momentum into the White Cliffs project.

In the event a great deal of momentum was lost. A new organisation had to be created, information had to be transferred to new people. There was much going over of old ground: spun dishes versus press forming, the relative merits of different forms of reflective surface, hydraulic versus electronic actuators, control philosophy, stowing strategy.

Perhaps it speaks well of the NEPDDC project that it has so far been accepted as the White Cliffs prototype. But the arguments put forward in favour of maintaining common identity were related to other factors besides merit:

1. We had already looked at a large number of alternatives and each one required some research and development. In other words there didn't seem to be a sure way to achieve the White Cliffs power station.
2. Maintaining more than one research and development project would be counter productive. The Energy Conversion Group would not survive if a second R and D group was created with such substantial funding.
3. the NERDDC project could not proceed independently since insufficient funds had been made available from NERDDC. (This had been made clear during negotiations and was apparent from the application and subsequent correspondence.)

The writer tried to ensure that there would be a common identity of the three projects by making strong bids for the position of supervisor of the ANUTECH project as well as the NERDDC project. These bids were also motivated by a conviction that such an appointment would give the White Cliffs project the best chance of success and also the certain knowledge that, like-it-or-not, failure of the White Cliffs project would reflect detrimentally on the future of the ECG. The bids failed.

5.2 Management

Problems in management have arisen from the extremely influential position of the ANUTECH Project Manager who reports directly to the Head of Department and members of the Board of ANUTECH, comprising the Deputy Vice Chancellor, members of the ANU Council and the Director of the Research School of Physical Sciences. Under the circumstances the ANUTECH Project Manager has little option other than to exert a parallel management role on the Energy Conversion Group and this invariably causes some confusion and a breakdown in established procedures. In many instances normal checks and approval routines have been abolished, an example being the placing of orders by staff against the ANUTECH account which does not require the approval of the group head.

The impact of the White Cliffs project has been such that at times it has not been possible for the head of the group to maintain responsibility for the output of the group. This is because the project manager is not responsible to the head of the group and in fact prepares work schedules without consulting him.

Instructions to individual members are issued indirectly through distributed work schedules and action requests.

Quite likely his intention is simply to expedite a course already set by the group head. But such single-mindedness does not allow for the need to anticipate problems and search for possible solutions at an early date. The likelihood of problems occurring has been underestimated as can be seen by the history of estimated completion dates shown in Figure 6.

Although this style of management may be successful in the building industry it is questionable whether it is appropriate for research and development.

However it must be acknowledged that the effects of Anutech management have been softened (and disguised) by the congenial personalities of both manager and supervisor.

5.3 Morale

In the early days of the project there was within the Energy Conversion Group a feeling of being bypassed by a new well funded organisation. Undoubtedly, this had a detrimental effect on the morale of some members.

Later, after common identity had virtually been achieved staff began to feel an inexorable pressure to meet deadlines. One felt compelled to set aside those tasks of a review nature which are essential in a properly conducted research and development project. For example, the parabolic profile of the vacuum press die has not been measured over the whole of its area to obtain its slope error characteristics. Although no-one complained it was apparent that the imposed conditions were taking their toll. One member reacted by taking a period of eight weeks leave.

The morale of the writer, as head of the Energy Conversion Group, suffered to an unprecedented extent. He felt placed in an almost impossible position, responsible to NERDDC for a project that was controlled by Anutech PL and sensing that his work, carefully nurtured since 1973, was now put at great risk without his consent.

6. TECHNICAL DIFFICULTIES AND MAJOR HOLD-UPS

6.1 Past and Present

Machining the die for the vacuum press presented a problem which has not been fully solved. The accuracy of the parabolic profile near the rim has probably suffered as a result. The method of confining the cutter to follow a parabola was by means of a chain using the principle that the sun of the distances from a point on the parabola to the focus and a line parallel to the directrix is constant. The set-up is illustrated in Figure 7a. In practice the chain was used to carry the weight of the machining head and this caused stick-slip action near the rim due to the horizontal component of chain force. The stick-sip action occurred even when the cutter was moved down the profile.

Two hydraulic rams were installed parallel to the sections of chain as shown in Figure 7b in an effort to overcome this difficulty. The action of the rams was supposed to cancel the chain forces on the cutter and at the same time impose a fixed tension on the chains. The weight of the machining head was counter balanced. In addition the sliding action of the tool post was carefully adjusted and lubricated.

Three modifications considerably improved performance but did not entirely remove the stick-slip action. The result is that the profile of a small section near the rim of the die displays a number of small steps of the order of .15 mm.

A second area of difficulty has been the control system which over a year ago was made the responsibility of NR Pty Ltd and a mature student who was also associated with NR Pty Ltd. Because of the student's thesis requirements the control system was not specified in detail. This has proved to be an error although in retrospect many new features imposed by the requirements of the power station could not have been anticipated a year ago. To add to the difficulties NR Pty Ltd has experienced severe staffing problems. Often pressure of other work curtailed effort on our system. At one time the entire job was reallocated to another person who subsequently left after several months.

The result of these difficulties is that the control system is considerably behind schedule.

6.2 Forseeable Problem Areas

Perhaps the major forseeable difficulty is that there is a great deal of work yet to be done and a shortage of resources to do it. Although most of the work has been mapped out in theory one can be sure that in some cases the theory will not work and we will have to try another approach. Quality control a materials handling, especially with respect to the acrylic liners, are danger areas.

One component that has not been designed yet is the rim seal and attachment between acrylic liner and aluminium paraboloid. It is felt that it would not be profitable to design this until we have produced a liner for examination and testing.

7. FINANCIAL

7.1 NERDDC Grant

According to the accounts of the Research School of Physical Sciences the present NERDDC grant is fully expended. The project is however continuing to be supported by ANUTECH and the School. ANUTECH will probably continue support as long as it is identified by ANUTECH as White Cliffs prototype development. Additional School support is expected to be limited to a total of about 10% of the NERDDC grant.

The School is faced with the problem of allocating running costs, ie. the cost of School services, workshop, etc, to the various projects. These allocations tend to be uncorrelated with the NERDDC budget and therefore only loosely controllable by the grantee. A solution is to avoid the use of School services altogether except in cases where the School has submitted a successful tender for the work. However, the development of the vacuum press had to be carried out in-house so there was no other option than to use the School workshop and accept the charges.

It is possible that an application will be made for a supplementary grant from NERDDC should costs continue to escalate. It is also possible that the project will be halted until a supplementary grant is applied for and received.

7.2 Collector Costs

At this point it is possible to present estimates of the cost of manufactured collectors based on orders placed, quotations received and best present estimtes for the work still to be done.

This information, prepared by the ANUTECH Project Manager, is presented in Table I.

.ABLE I

BREAKDOWN OF COLLECTOR MANUFACTURING COSTS-

DOLLARS PER SQUARE METER OF APERTURE

(prepared by figures supplied by ANUTECH Pty Ltd. Estimates are ex-factory uncrated and are less expenditure for factory rental, management, administration and contingency.)

Collector frame	129.65
Actuators	106.20
Reflective liners	44.25
Collector control unit	37.50
Factory labour	35.00
Sheet aluminium paraboloids	34.60
Pipe insulation on frame	30.35
Piping on frame	22.50
Paraboloidal rim support rings	20.75
Frame wiring	15.00
Absorbers	10.00
Anti-hail protection	10.00
Flexible connectors	6.00
TOTAL	502

8. RECOMMENDATIONS

The non-technical difficulties encountered in this project have been reported here frankly in the hope that similar problems may be avoided in the future.

It is suggested that two methods of avoiding the difficulties are as follows:

1. Where a project depends on financial assistance from a grantor additional to NERDDC, make the NERDDC grant on condition that the project has a single supervisor responsible to all grantors.

2. Wherever possible ensure that NERDDC supported projects are independent of additional assistance.

9. REFERENCES

3.13 Carden, P O, 'Solar power for remote areas', paper presented at the ISES Symposium, Perth, August 1978.

4.3 Carden, P O, 'A proposal for the construction of a solar pilot plant based on high temperature (500C) shell mirror collectors' July 1978. Research submission.

Figure 1, explanatory notes.

Beginning at the top r.h.s. of Fig 1, table 1 contains precomputed values of ELS(I),sun's elevation, vs. time TD(I) (where I is a variable index). For a given real time TD the MCU computes from table 1 a value ELS for the sun's elevation. This is transformed into a target elevation ELN by addition of required offset and a correction ELA.

Because the actuator is a linear device and causes rotation about the elevation axis by virtue of a change in the length of a side of a triangle containing the actuator, the relation between the length of this side EN and elevation angle requires solving a triangle. The precomputed solution for this is contained in table 2. Factor K (positive and fairly constant) relates a decrease in EN below a reference length ENR to an increase in EL above a reference angle ELR. It is derived from the table upon entering a value of EN.

Hence, continuing the circuit descripttion, we arrive at the point where a target actuator length ENN is derived. The motor is switched on at prescribed instants and switched off when EN equals or exceeds ENN.

A further transformation involving K converts EN back to angular co-ordinates in order that the error in the computed sun-path (ELD) may be monitored.

The offset detector (mid right hand side) measures the actual offset (the deviation from direct sun-facing) whenever the sun is shining. This measurement ELX is compared with the required offset OF(1) and the difference is effectively integrated with respect to time to give the correction ELA. This circuit branch is disconnected if only the "pointing" mode is required e.g. for stowing or maintenance.

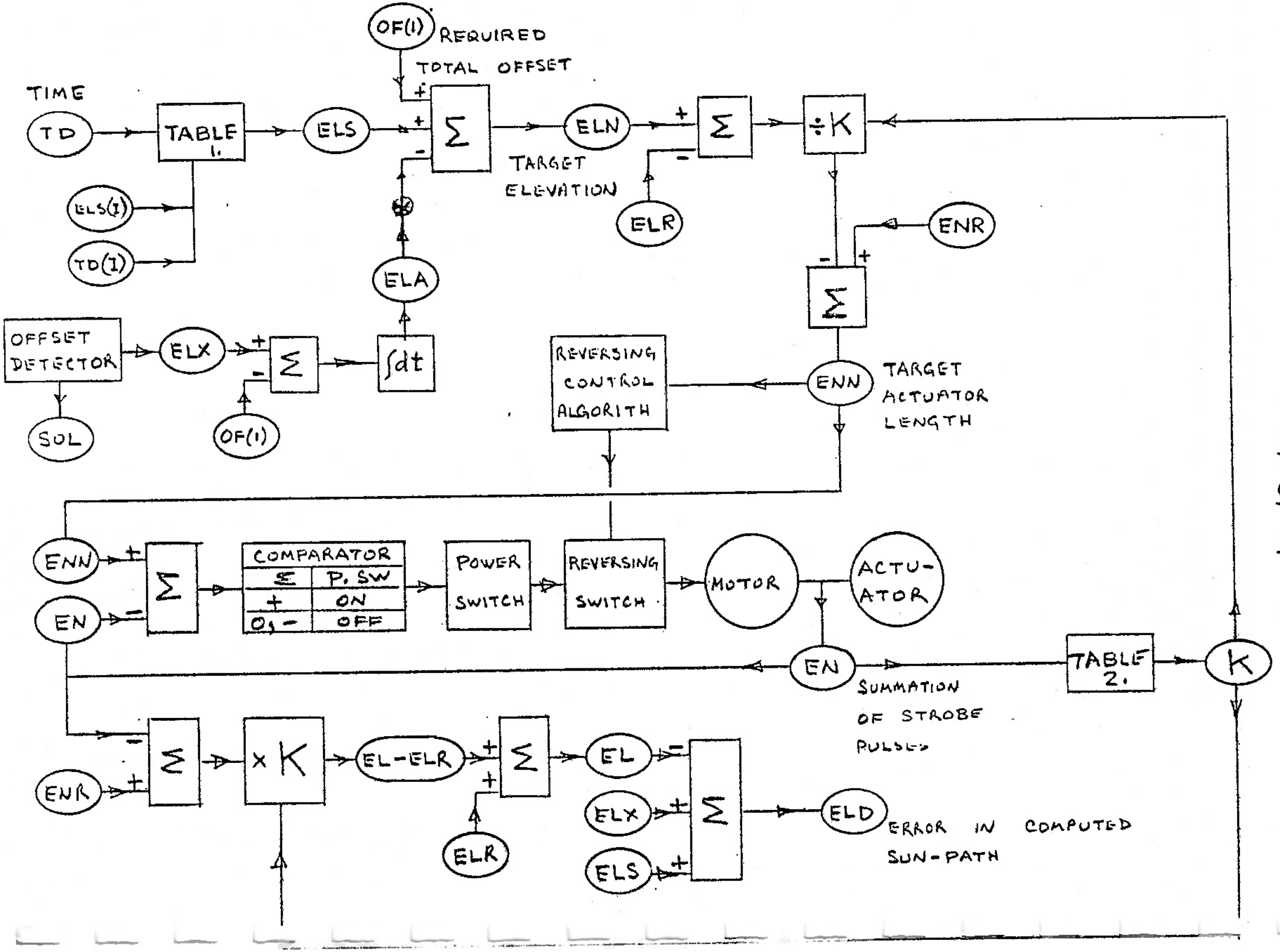


FIG 1

CONTROL SYSTEM

M.C.U. ELEVATION

DUAL MODE

⊛ BREAK FOR "POINTING"

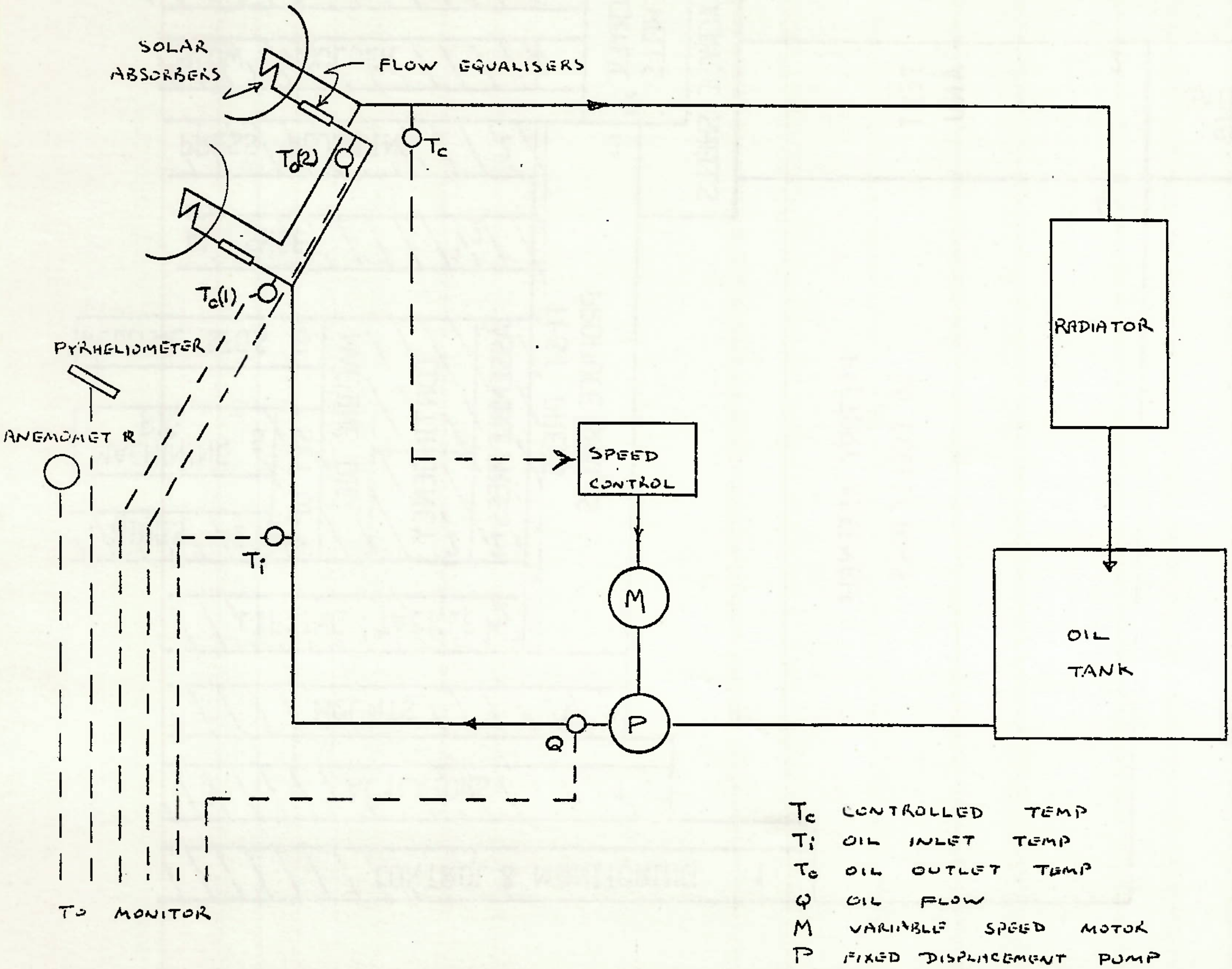
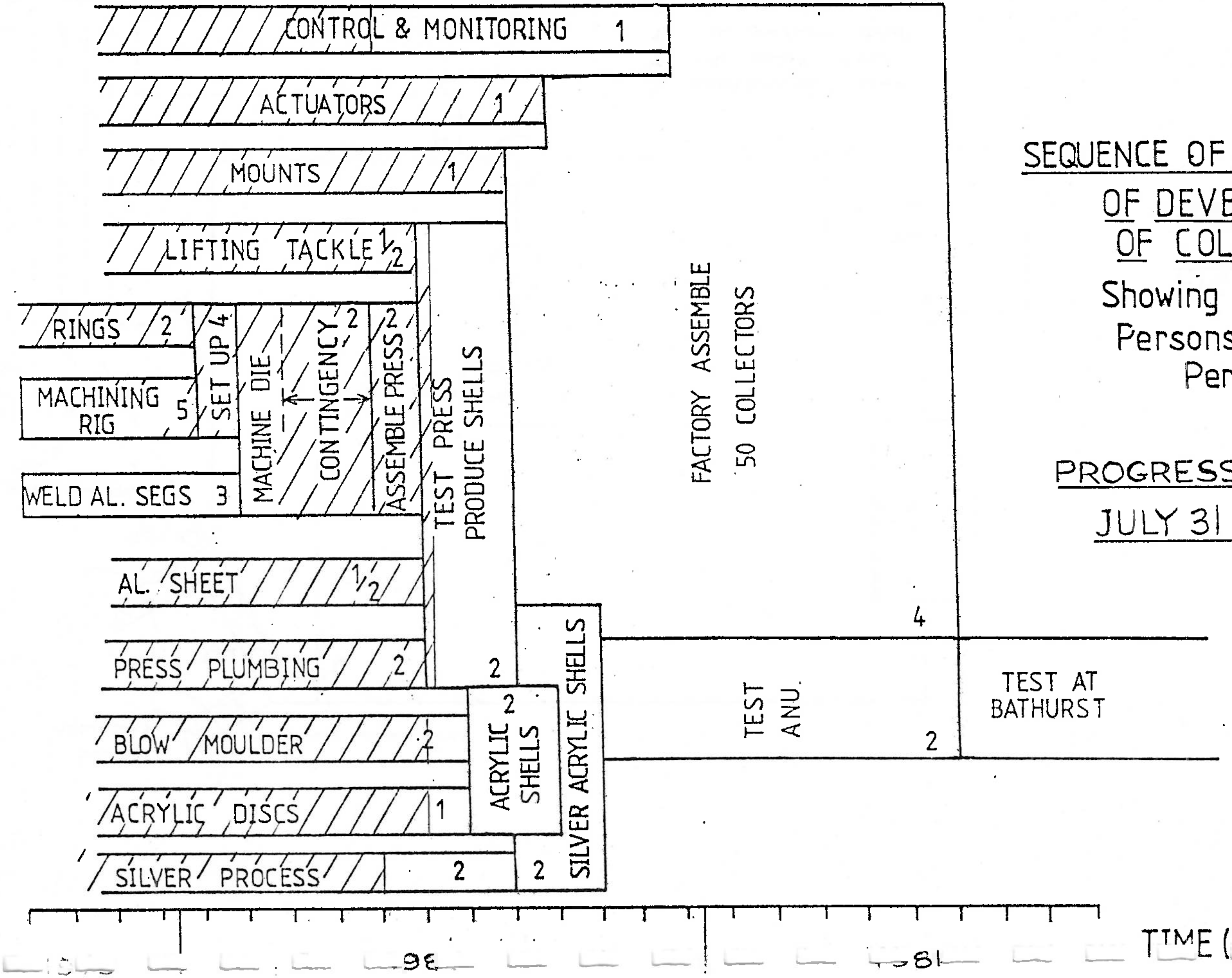


FIG 2

TEST LOOP



SEQUENCE OF MAJOR STAGE OF DEVELOPMENT OF COLLECTORS

Showing Number of Persons Required Per Stage

PROGRESS TO JULY 31 1980

Fig 3a

ORIGIN & FUNDING OF WORK FORCE

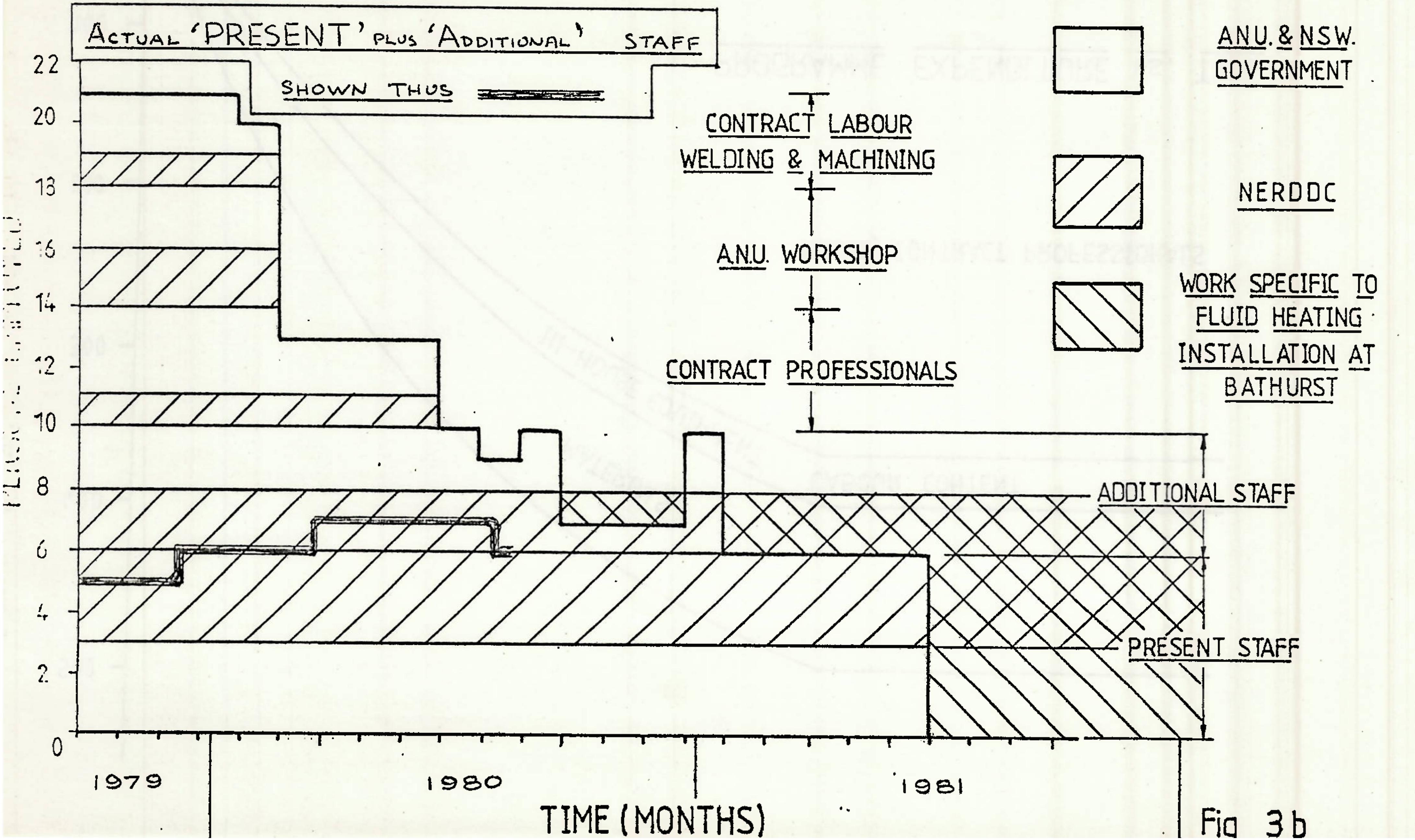
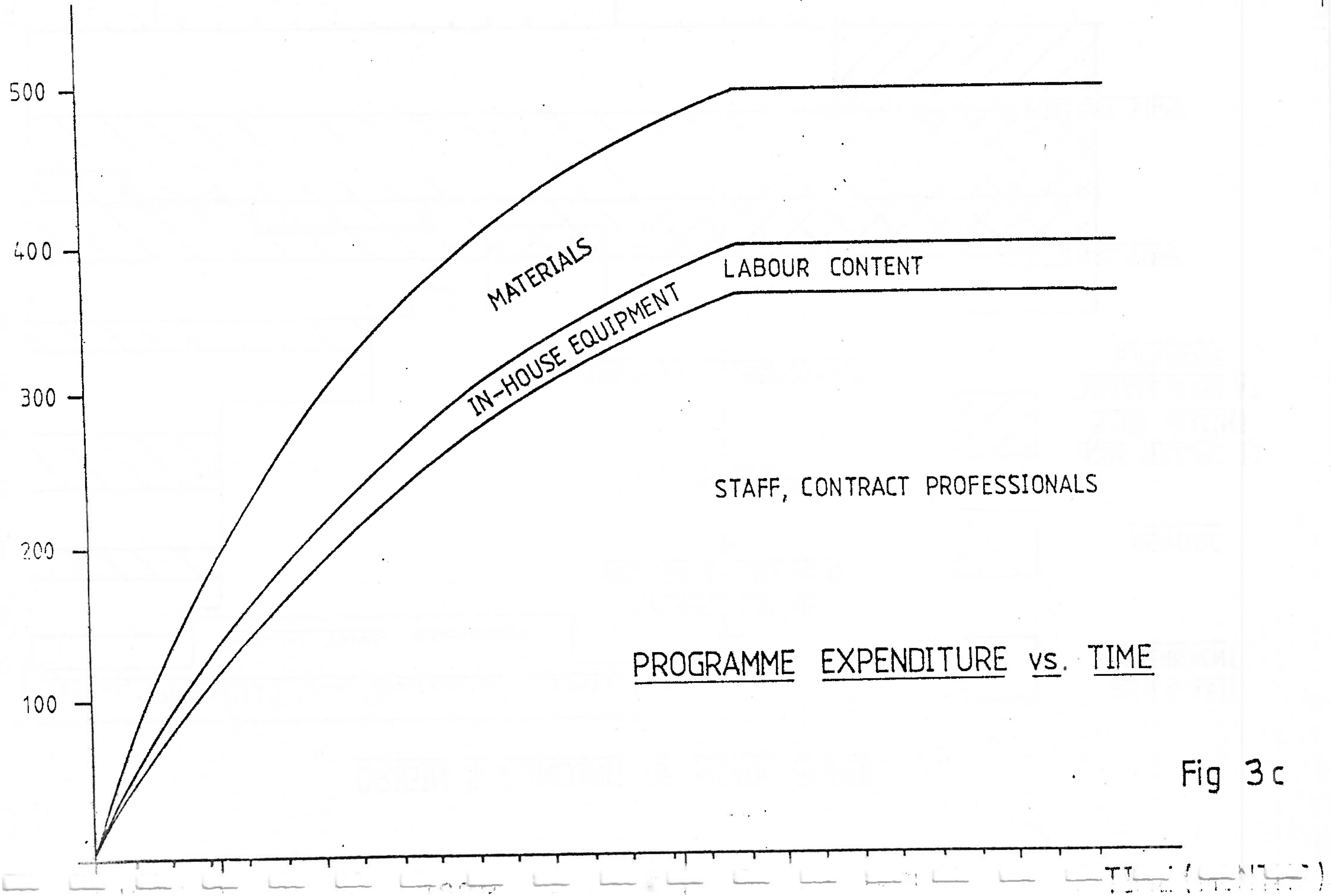


Fig 3b

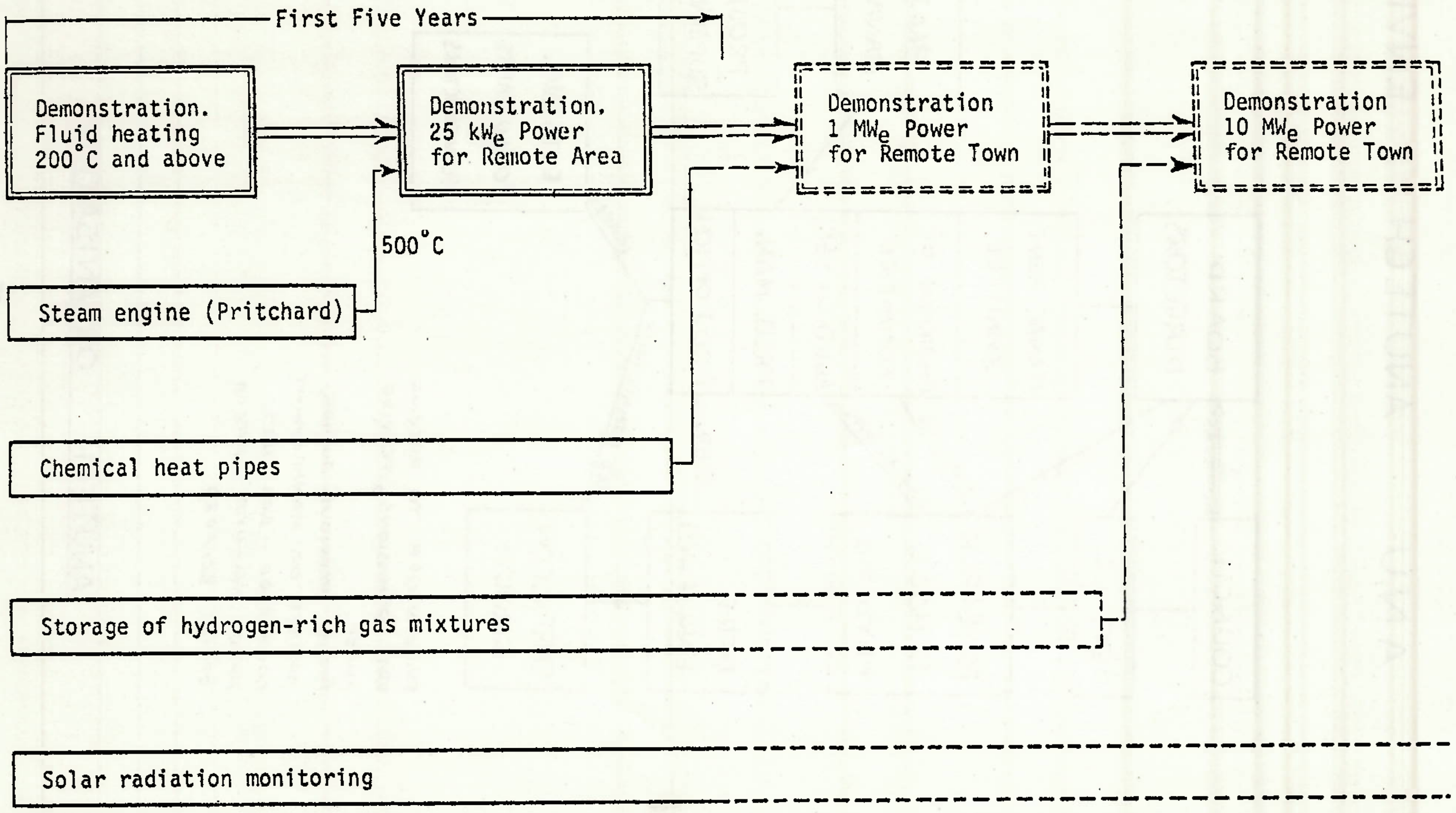


PROGRAMME EXPENDITURE vs. TIME

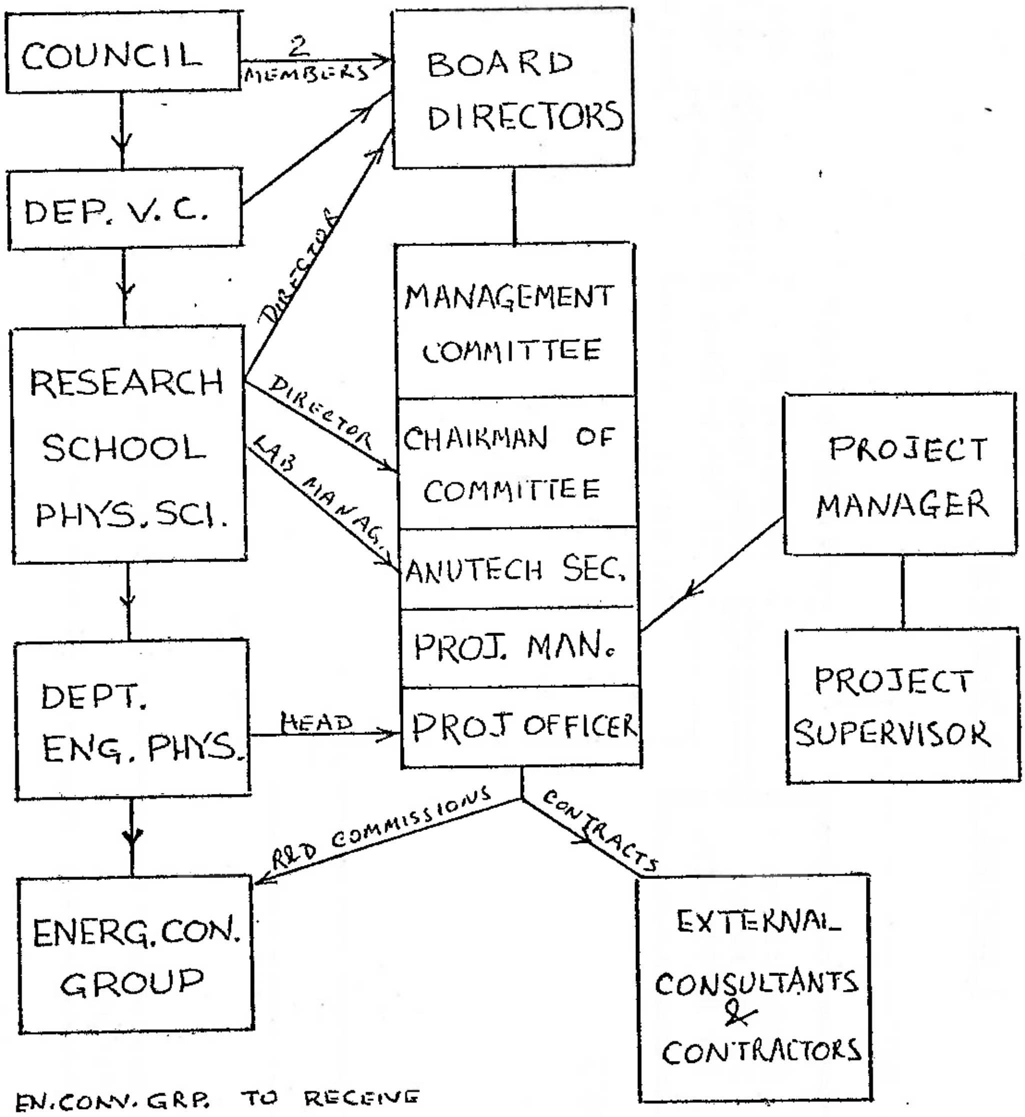
Fig 3c

FIGURE 4

Integrated R,D&D Programme



A.N.U. ANUTECH ENVIRON



EN. CONV. GRP. TO RECEIVE R&D COMMISSIONS, PROVIDE ADVICE.
(HEAD PREVIOUS JUNIOR MEMBER OF MANAGEMENT COMMITTEE – RESIGNED. NEVER APPOINTED ANUTECH OFFICE BEARER)

ANUTECH ORGANISATION

FIG 5

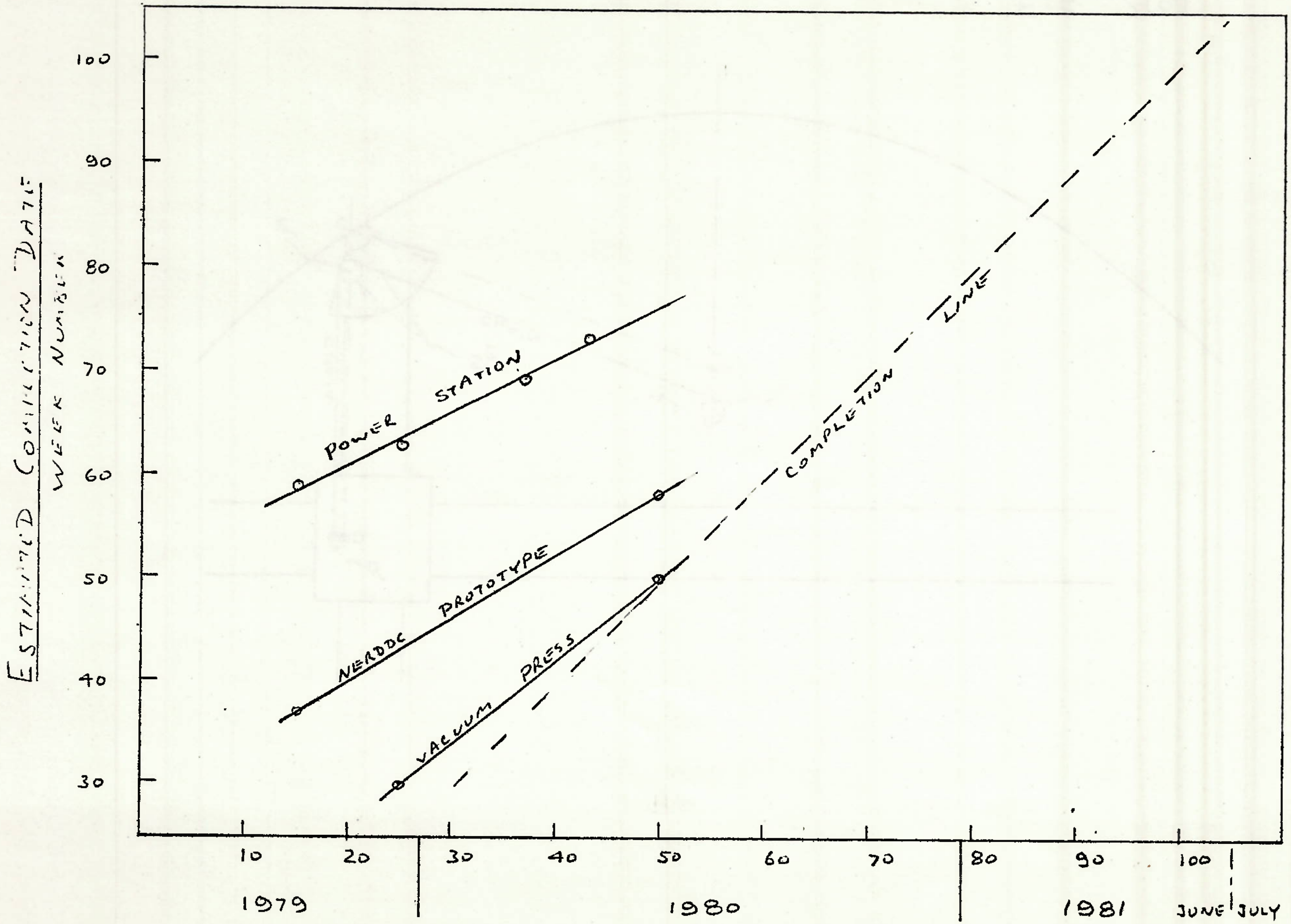

ESTIMATED COMPLETION DATE
WEEK NUMBER
100
90
80
70
60
50
40
30
POWER STATION
NERDDC PROTOTYPE
VACUUM PRESS
COMPLETION LINE
10
20
30
40
50
60
70
80
90
100
1979
1980
1981
JUNE
JULY

FIG 6

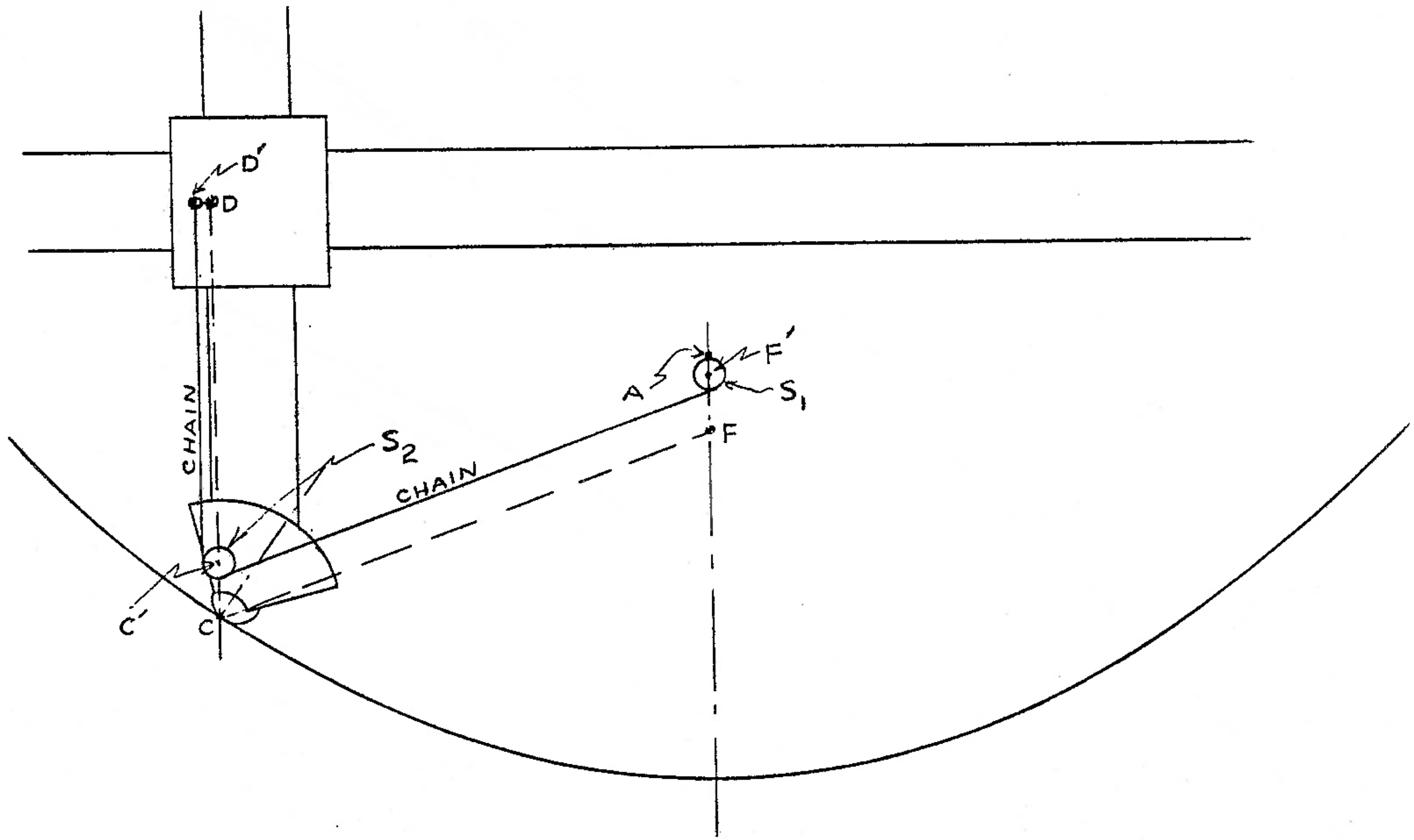


FIG 7(a)

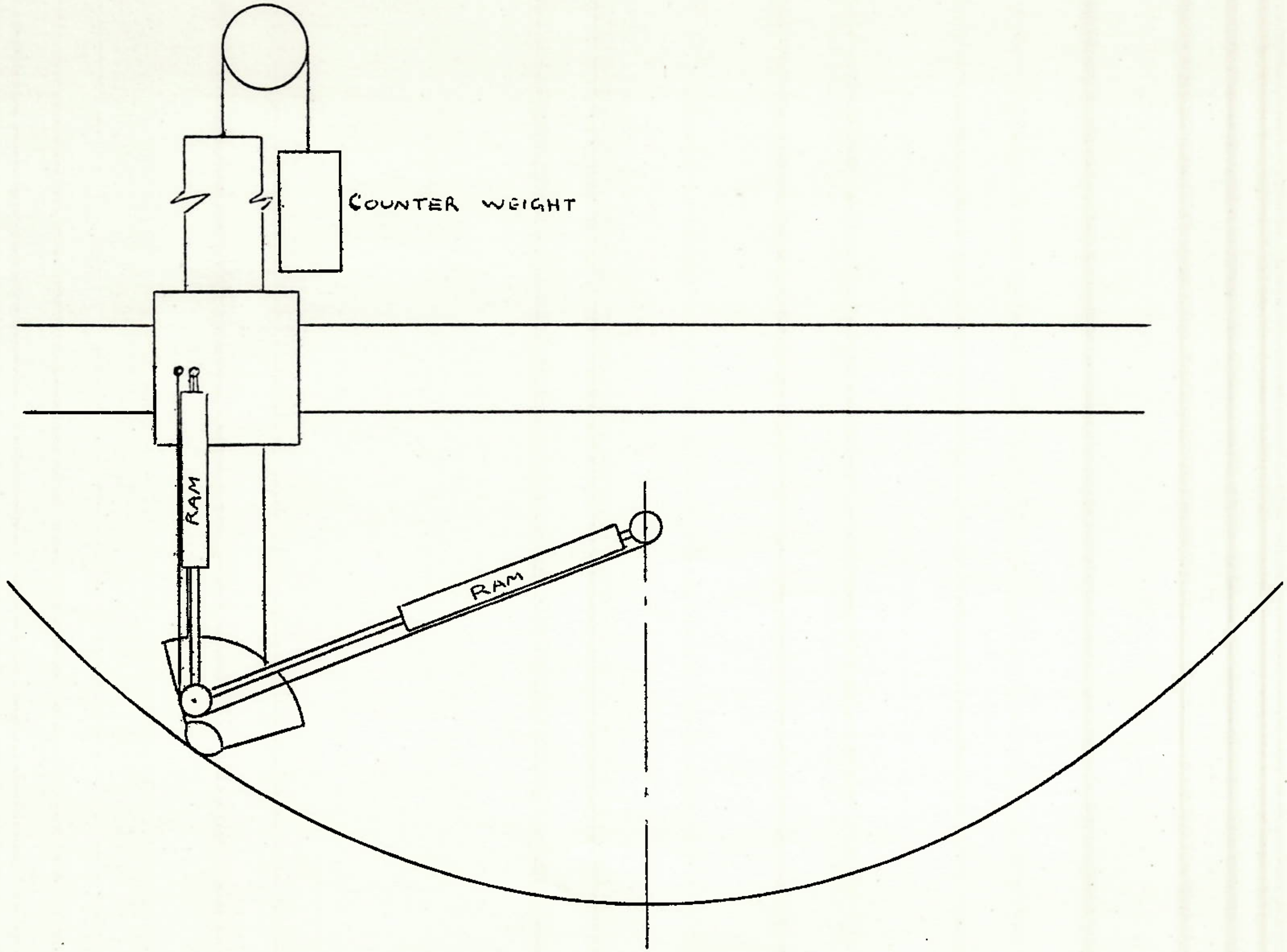


FIG 7(b)