M+2 FILE OF 10756 28 3/30/80

DOE/SF/10756-T1

Bechtel National, Inc.

Engineers — Constructors

Fifty Beale Street
San Francisco, California

Mail Address: P. O. Box 3965, San Francisco, CA 94119

March 14, 1980

Job 13535

MASTER

U.S. Department of Energy
San Francisco Operations Office
1333 Broadway
Oakland, California 94612

Attention: Dr. S. Douglass Elliott, Jr.
Solar Energy Division

Subject: Heat Pipe Test Plan Transmittal
(Contract DE-AC03-79SF10756)

AC03-79SF10756

Dear Doug:

In the enclosure we are transmitting for your review and approval the subject test plan submitted by Dynatherm. Bechtel review is in progress at this time and we are expecting to forward our approval recommendations to you by March 21, 1980. We are transmitting the plan in advance of our recommendation, however, to afford as much time as possible for your parallel review. In this manner we hope to shorten the approval cycle and initiate the actual test work as soon as possible.

By copy of this letter we are requesting Bill Moore of Sandia to initiate a parallel review as well.

If you have any questions or comments, please call me on (415) 768-6672.

Very truly yours,

J. H. Westsik

J. H. Westsik
Project Engineer
Research and Engineering

JHW:fed
Enclosure

cc: Mr. C. W. Moore - Sandia, w/att.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Rev 3/31/10

REVISIONS				
LTR	PAGE	DESCRIPTION	DATE	APPROVED

Need to describe "mounting
ings" in figs 332-338.

CONTRACT NO.

13535-TSA-1

W. B. Bienert

2/9/80

PREPARED BY

DATE

REVIEWED/APPROVED

DATE

APPROVED

DATE

APPROVED

DATE

dynatherm

CORPORATION

COCKEYSVILLE,

MARYLAND

21030

TITLE

HEAT PIPE TESTING PROGRAM
TEST PLAN

SIZE

A

CODE IDENT. NO.

34881

DRAWING NO.

0168-1010

SCALE:

SHEET 1 OF 36

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

FORM D-0103 REV.B

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

TABLE OF CONTENTS

	Page
1. INTRODUCTION	3
2. HEAT PIPE PERFORMANCE REQUIREMENTS	4
3. TEST FIXTURE DESIGN	8
3.1 Life Test Fixtures	12
3.2 Component Test Fixtures	19
4. HEAT PIPE DESIGN	23
5. LIFE TEST PLAN	28
6. COMPONENT TEST PLAN	34
6.1 Sodium Heat Pipe	34
6.2 Potassium Heat Pipe	35
REFERENCES	36

1. INTRODUCTION

950 1125

Cockeysville, MD

Under a subcontract to Bechtel National, Inc., Dynatherm Corporation is currently conducting a Preliminary Heat Pipe Receiver Test Program. The objective of this program is twofold:

- (1) to perform life testing on several typical solar receiver heat pipes under conditions which simulate the requirements of the receiver, and
- (2) to conduct additional performance tests with selected heat pipes in order to further map their performance, in particular, with regard to their transient behavior.

This Test Plan provides a detailed description of the tests which will be conducted, of the hardware to be used, of the test fixtures, and of the rationale for selecting the particular test program. Originally it was intended to generate separate plans for the life tests and the performance tests. However, because of the commonality of many of the issues, the format of a single plan for all tests was chosen.

The Test Plan is organized in four major sections. Section 2 (which follows this Introduction) discusses the performance requirements as they are currently defined by the latest receiver studies. Section 3 describes in detail the test fixtures which have been designed for this program. Their capabilities for simulating receiver conditions as well as their limitations are discussed. The heat pipes themselves, which were largely developed during a previous program (Ref. 1), are the topic of Section 4. Finally, detailed test plans for both the life test program and the component testing are presented in Sections 5 and 6.

2. HEAT PIPE PERFORMANCE REQUIREMENTS

The performance requirements of the heat pipes in a central solar receiver have been evaluated in three separate, but related, studies (Ref. 1, 2, 3). Figure 2.1 gives the maximum axial heat transport requirement as a function of vapor temperature as derived from the latest study (Ref. 3). Two separate curves are given. The higher heat loads are representative of the current study results which correspond to a peak receiver flux of 1.34 MW/m^2 . The curve with the lower heat loads corresponds to a peak receiver flux of 1.1 MW/m^2 . This reduction was felt necessary by Foster Wheeler (Ref. 3) in order to reduce the thermal stresses on the heat pipe's end cap to an acceptable value. Reducing the peak receiver flux does not necessarily entail a proportional across-the-board scaling down of all receiver fluxes. But, in lieu of better information, a simple proportional scaling of the heat pipe loads was adopted for the lower curve. The curves in Figure 2.1 give the limiting requirements for all the heat pipes in the receiver. It turns out that the most severe requirements are imposed on the heat pipes in Panel 8 of the current receiver designs. The curves for pipes in other panels would fall below these limiting curves.

The maximum evaporator heat fluxes which the heat pipes will experience are at least as important as the axial heat transport requirements. These heat fluxes are also shown in Figure 2.1. The maximum evaporator fluxes were derived from the computer model developed in Reference 1. This model predicts the maximum heat flux impinging on the cylindrical surface of the heat pipe as a fraction of the solar flux normal to the receiver wall. This fraction was found to be 0.291. Assuming that the same fraction holds for all heat pipes in the receiver (only approximately correct), the right-hand scale in Figure 2.1 was developed.

The heat fluxes to which the endcaps of the heat pipes will be exposed depend on their geometry. "Flat" endcaps would be exposed to the full normal receiver flux. The present design utilizes conical endcaps with the cone angle selected such that the peak endcap flux equals the peak flux on the cylindrical surface. Thus, the heat fluxes given in Figure 2.1 are representative of the peak fluxes to which any part of the heat pipes will be exposed.

FIGURE 2.1
AXIAL HEAT TRANSPORT AND EVAPORATOR FLUX
REQUIREMENTS FOR SOLAR RECEIVER HEAT PIPES

The third important parameter of heat pipe performance is the ramp rate to which they will be exposed. The flux ramping requirements were taken from Reference 4 and are listed in Table 2.1 together with the corresponding power ramping rates. Only the worst case conditions are given and these will apply to a few heat pipes in the west cavity during the equinox. Again, two sets of numbers are shown--the higher ones corresponding to a peak receiver flux of 1.34 MW/m^2 ; the lower ones (in parenthesis) to a peak flux of 1.1 MW/m^2 . As proven by many tests, heat pipes can tolerate instantaneous removal of the heat input. Thus, the controlling transient will be the ramp rate during normal start-up focusing. According to Table 2.1, this rate is 17.5 (14.3) Watts/sec.

The goal for the lifetime of a solar receiver and its components is 30 years. Since there will be at least one daily start-up and shutdown, the number of cycles the heat pipes will experience will be at least 11,000.

Based on the current receiver concepts, the heat pipes will be oriented either horizontally or with a slight tilt ($<15^\circ$) such that the evaporator is below the condenser. Such a tilt is favorable for the heat pipe's performance since gravity will aid the capillary forces which affect the circulation of the working fluid. As a rule of thumb, the capillary forces are augmented by about a factor of 2 in a typical 1 meter long heat pipe which is tilted by 10 degrees. The life test fixtures to be described in the next section permit testing only in the horizontal orientation. Thus, the performance requirements imposed during life testing will actually be more stringent than during actual service.

PARAMETER	Peak Receiver Heat Flux Change	Peak Heat Pipe Load Change
	$\text{kW/m}^2\text{-sec}$	Watts/sec
Diurnal Solar Variation	± 0.18 (0.15)	± 1.68 (1.38)
Normal Start-Up/Shutdown Focusing/Defocusing	± 1.88 (1.54)	± 17.5 (14.3)
Unanticipated Cloud Passage	- 67.0 (55.0)	- 624 (512)

TABLE 2.1
RECEIVER FLUX AND HEAT PIPE POWER RAMP RATES

3. TEST FIXTURE DESIGN

The common feature of the test fixtures for the life tests and for the component tests is the mode of heating the heat pipes. In both cases, an array of radiant quartz lamps will be used to simulate the solar flux. Previous development testing used induction heating almost exclusively. While the latter is convenient for laboratory testing, it is not economical for multiple long duration tests. Furthermore, induction heating couples electromagnetic fields into the heat pipe envelope and, to a very small extent, also into the liquid metal working fluid. The resulting forces could conceivably interfere with the capillary pumping. Radiation heating, on the other hand, simulates closely the solar input.

A cross section of the geometry of the test fixtures is shown schematically in Figure 3.1. The evaporator of the heat pipe is surrounded by 12 tubular quartz lamps (GE Type T3). Each lamp is located in the "focal line" of a semicircular reflector. The reflector consists of a water cooled aluminum tube whose interior surface is covered with a highly reflective aluminum foil. The projected performance of this radiant heating is summarized in Table 1. A range of values is shown in Table 1 for the geometrical efficiency and the heat radiation heat losses from the evaporator. The uncertainty in the geometrical efficiency results from different assumptions on the self-absorption by the quartz lamps. The spread in the predicted thermal losses is due to the difficulty of accurately calculating the effective absorptance of the specular reflectors.

Because of the temperature dependence of the radiation losses, the achievable net input to the heat pipe is a function of temperature. The average predicted heat input capability along with the uncertainty band is shown in Figure 3.2. On the right-hand scale of this figure is shown the predicted maximum evaporator heat flux. Since this type of test fixture will provide a uniform heat distribution, the flux is simply the net heat input divided by the evaporator area.

Up to this point, the description of the test fixture applies equally to the life tests and the component tests. Specifics pertaining to each type of test individually are covered in the following subsections.

FIGURE 3.1
SCHEMATIC CROSS-SECTION OF RADIANT TEST FIXTURE

Number of Heat Lamps	12
Maximum Electrical Input per Heat Pipe (kW)	21.3
Radiant Efficiency of Lamps (%)	86
Geometrical Efficiency of Fixture (%)	49 to 58
Heat Pipe Absorptance	0.9
Absorbed Radiant Heat (kW)	8.1 to 9.5
Radiation Heat Loss from Evaporator at 900°C (kW)	1.4 to 2.9
Net Input to Heat Pipe at 900°C (kW)	5.2 to 8.1

TABLE 1
PROJECTED PERFORMANCE OF RADIANT HEAT PIPE TEST FIXTURE

FIGURE 3.2
CAPABILITY OF LIFE TEST FIXTURE -
NET HEAT INPUT TO HEAT PIPE, EVAPORATOR FLUX,
AND HEAT REJECTION CAPABILITY

3.1 Life Test Fixtures

Life tests will be performed simultaneously on six individual heat pipes. Three identical fixtures will be used, each holding two heat pipes. The mechanical design of these fixtures is shown in Figure 3.3. The heat pipes are located on a common axis with the evaporator ends facing each other. The evaporators are surrounded by the quartz heating lamps as previously described. Each of the evaporators is 12 inches long and the active length of the lamps is 25 inches. (The data given in Table 1 apply to one-half of a fixture.) The reflectors, the reflecting end plates, and the tubular support structure are water cooled. The heat pipes are supported by two mounting rings and the whole assembly is supported by a long aluminum channel which, in turn, is mounted against the cinder block wall. The condenser sections of the heat pipes are allowed to dissipate the heat by radiation and natural convection to the environment. The calculated dissipation capability for various condenser lengths is shown in the previously introduced Figure 3.2. The heat rejection capability can be adjusted by insulating a fraction of the heat pipe's condenser. Referring to Figure 3.2, a two foot long exposed condenser will allow a maximum heat throughput of 7.4 kW at 750°C (the intersection of the net radiant heat input and the heat rejection curve). If only a one foot condenser length is exposed, the maximum achievable temperature is 915°C with a corresponding heat load of 6.5 kW. The exact condenser lengths to be used in the three different test fixtures will be discussed in Section 5.

The ramping capability of the test fixture is shown in Figure 3.4. The start-up curve in this figure is based on applying full power instantaneously to the radiant heat lamps. The temperature rise of the heat pipe is then determined by the sensible heat of the heat pipe and the heat rejection from the condenser. The shutdown curve is based on turning the power off instantaneously and letting the temperature decay. Both the start-up and the shutdown ramping capability exceed the requirements of the receiver and probably the capability of the heat pipes.

Each of the six heat pipes on life test will be instrumented with five Type K thermocouples as shown in Figure 3.5. Two T/C's will monitor the evaporator temperature, one the vapor temperature and one the condenser temperature. The vapor thermocouple will be located on a short (4 inches) insulated section of the heat pipe.

FIGURE 3.3
LIFE TEST FIXTURE

FIGURE 3.4
MAXIMUM RAMPING CAPABILITY OF
LIFE AND COMPONENT TEST FIXTURE

FIGURE 3.5
INSTRUMENTATION DIAGRAM

The fifth thermocouple (also located on the insulated section) will be used to control the heat pipe temperature via a programmed L&N Electromax III Controller. The four indicating thermocouples will be continuously displayed on a 24 point L&N Speed-omax Recorder.

Figure 3.6 shows the electrical control schematic of the three test fixtures. The main power will be supplied by a three phase, 480 V, 55 A bus. The input to each bank of quartz lamps (connected in a delta) will be controlled by an SCR driver which, in turn, is controlled by the Electromax temperature controller. The setpoint of the controller will be programmed by an L&N Process Programmer. Two such programmers will be used for the three fixture installation. Each of the programmers has two output channels which can be independently programmed. Three of the available channels will program the cycling of the three test fixtures; the fourth one will be used as a master control for the entire test installation. The total available power of about 45 kW imposes some limitations on the cycling sequence. It will be recalled that the required electrical input of a single fixture at full power is 42.6 kW. Thus, the cycles must be phased such that the sum of the input powers does not exceed 45 kW.

Figure 3.7 shows a schematic of the heat rejection and safety circuit. The thermal power transported by the heat pipes will be dissipated by radiation and natural convection to the environment and does not require auxiliary cooling. However, 50 to 70% of the input power will be dissipated in the reflectors and the rest of the fixtures and must be removed by water cooling. As shown in Figure 3.7, separate cooling circuits will be used for each fixture. Flow switches will deactivate the SCR drivers in case of pump failure or major water leaks. The cooling water will be recirculated through a cooling tower. In order to protect the test fixtures from a power failure, automatic switch-over to city water cooling is provided. Although the lamps will shut down in case of a power failure, the sensible heat of the pipes would damage the reflectors if continuous cooling were not provided.

FIGURE 3.6

LIFE TEST CONTROL AND DATA ACQUISITION SYSTEM

FIGURE 3.7
SCHEMATIC OF COOLING SYSTEM

3.2 Component Test Fixture

The component test fixture which is shown in Figure 3.8 is basically one-half of a life test fixture. A water cooled reflector is substituted for the second heat pipe. The quartz lamps have a heated length of 10 inches as compared to 25 inches for the life test fixtures. The shorter lamps are rated for 2000 Watts at a voltage of 240 V. Thus, at the rated input, the available power from 12 lamps will be 24 kW (as compared to 21.3 kW per heat pipe in the life test fixtures). Since the lamps can tolerate considerable overvoltage (although at the expense of life time) and since a supply voltage of 480 V is available, it is estimated that at least twice as much power can be applied to a heat pipe in the component test fixture as in the life test fixtures. Assuming the same efficiency of the test fixture, the available net input power to the heat pipe will be as follows:

@ 750°C : 15 kW (temperature at which highest
power is required)

@ 920°C : 13 kW (peak temperature)

The corresponding evaporator heat fluxes for a 12-inch long evaporator are as follows:

@ 750°C : 0.30 MW/m²

@ 920°C : 0.26 MW/m²

These fluxes can be increased further by shortening the evaporator length. Thus, the capability of the component test fixture (in terms of maximum total Q and heat flux) will exceed the predicted requirements of the receiver and probably also the capability of the heat pipes.

In some of the component tests, the heat will be rejected to a water cooled gas gap calorimeter. This will permit the pipe temperature and the throughput to be controlled independently. Also, the rejected heat can then be measured directly and does not have to be calculated as is the case with heat rejection by radiation and convection. The calorimeter will be employed for the steady-state performance tests. It will not be used during the ramping tests because its thermal mass would constitute an unnatural load on the heat pipes.

FIGURE 3.8
COMPONENT TEST FIXTURE

Power to the lamps will be controlled by the same type of SCR driver as in the life test fixtures. But the control will be manual in order to allow for testing over a wide range of conditions. The instrumentation will also be similar to that of the life tests; i.e., thermocouples attached at various locations of the heat pipe.

A schematic of the instrumentation and control diagram of the component test fixture is shown in Figure 3.9.

Unlike the life test fixtures which have to be operated horizontally, the component test fixture can be tilted. The reason that the life test fixtures must operate horizontally is simply the fact that two heat pipes are installed with the evaporators opposing each other. The amount of tilt available in the component test fixture will depend on how much the lamps can be tilted without affecting their lifetime. The manufacturer specifies horizontal operation but typical receiver tilts of 5 to 15 degrees can probably be tolerated.

FIGURE 3.9
INSTRUMENTATION AND CONTROL DIAGRAM OF COMPONENT TEST FIXTURE

4. HEAT PIPE DESIGN

The heat pipes for the solar receiver use a liquid metal working fluid. Potassium is the fluid in those pipes which operate below 500°C and sodium is used in the higher temperature pipes. The structural material of all heat pipes is Incoloy 800 H.

The design of the heat pipe envelope is shown in Figure 4.1. The outside diameter of 60.3 mm (2.375 inches) and the wall thickness of 3.9 mm (0.154 inch) is common to all pipes. The evaporator length of 300 mm (12 inches) and a short insulated (adiabatic) section of 100 mm (4 inches) length are also common. The purpose of the adiabatic section is to provide a zone where the vapor temperature can be measured without interference of heat transfer into or out of the pipe. The condenser length of the potassium pipes is 900 mm (36 inches) and that of the sodium pipes is 600 mm (24 inches). The potassium pipes need to be longer in order to reject the required amount of heat at their lower operating temperature. In the actual receiver, the condenser lengths will vary from 500 mm (20 inches) to 700 mm (28 inches) (Ref. 2). Since the length of the condenser is not critical to the heat pipe performance, the selected lengths simulate the actual conditions reasonably well.

The evaporator end of the heat pipe is equipped with a conical endcap. The included angle of the cone is 30° and its tip has a radius of 10 mm (0.4 inch). The angle was selected such that the peak heat flux on the endcap equals approximately the peak flux on the cylindrical section of the pipe. The endcap at the condenser end, which also includes the fill tube, is of the same design as in Dynatherm's commercial liquid metal heat pipes.

0.343"
in Fig 4.1

The stainless steel wick structure is shown in Figure 4.2. The exact dimensions of the axial flow channels have not yet been selected and will be slightly different for the sodium and potassium heat pipes. The approximate size of the wide channels is 3 x 3 mm (1/8 x 1/8 inch) and that of the smaller channels is 1.5 x 3 mm (1/16 x 1/8 inch). Experimental performance data from a previous heat pipe of almost identical wick and envelope design are shown in Figure 4.3. The data are superimposed on the transport requirements given in Figure 2.1. The circles are results obtained with sodium as the fluid. Solid circles symbolize performance limits of the pipe while

Sodium Heat Pipes : L = 40 inches
Potassium Heat Pipes : L = 52 inches
Material : Incoloy 800 H

FIGURE 4.1
HEAT PIPE ENVELOPE

FIGURE 4.2
HEAT PIPE WICK DESIGN

FIGURE 4.3
 PREVIOUS EXPERIMENTAL RESULTS WITH
 SODIUM AND POTASSIUM HEAT PIPE

open circles indicate limitations of the previously used test fixture. The sharp drop-off of the sodium performance below 550°C is due to the fundamental vapor limit. Potassium (triangles) has a higher vapor limit as shown by the better performance of potassium at low temperatures. However, at higher temperatures, potassium has poorer performance than sodium. It is for this reason that potassium heat pipes will be used in the low temperature zones of the receiver (below 550°C) and sodium heat pipes in the higher temperature zones.

The ramping capability of these types of heat pipes has not yet been sufficiently studied. Most previous tests were performed at a slight tilt ($5-15^{\circ}$) where permissible start-up rates of 17 to 30 Watts/sec were measured. In the horizontal orientation, the permissible start-up rate was found to be between 2 and 6 Watts/sec. No limit was observed for the shutdown rates. The previously measured start-up rates are compatible with the diurnal solar variation but not with start-up focusing. One objective of the component tests will be to better characterize the ramping capability. Also, the present test fixtures simulate the solar input more closely than RF heating. Thus, the previous ramping data may not be valid.

5. LIFE TEST PLAN

Three identical life test fixtures will be operated in a preselected cycling pattern. Each of the fixtures holds two identical heat pipes. The fixtures are designated LTF 1, LTF 2, and LTF 3.

The heat pipes in LTF 1 will be ramped to a maximum temperature of 915°C . This corresponds to the maximum receiver temperature plus 10% (expressed in degrees F) as specified in the Statement of Work. The overall length of these heat pipes will be 1000 mm (40 inches) and the active condenser length 300 mm (12 inches). The working fluid will be sodium.

The heat pipes in LTF 2 will be ramped to a maximum temperature of 750°C . At this temperature, the heat pipes in the receiver will experience the highest transport requirement. The overall length of the heat pipes in this fixture will be 1000 mm (40 inches) and the active condenser length 600 mm (24 inches). The working fluid of these heat pipes will be sodium.

LTF 3 will have two potassium heat pipes with an overall length of 1300 mm (52 inches). The active condenser will be 900 mm (36 inches) long. These pipes will be ramped to 500°C which will simulate the performance requirements of the low temperature potassium pipes in the receiver. The above test conditions are summarized in Table 5.1.

The cycling pattern for the three fixtures has been designed to maximize the number of cycles per day while at the same time maintaining the maximum electric power demand at less than 45 kW. Two options for the cycling pattern have been developed which are shown in Figures 5.1 and 5.2. Both patterns assume a linear power-versus-time relationship. The linear ramps neglect the change in slope of the heat rejection versus temperature curves (see Figure 3.2). They also neglect the heat capacity of the system because of which very little input will be required during the downward ramp.

Option 1 (Figure 5.1) has a cycle time of 1.5 hours and a start-up and shutdown time of 1.0 hour each. Option 2 (Figure 5.2) has a cycle time of 2.5 hours, a start-up

PARAMETER	LTF 1	LTF 2	LTF 3
Objective	Test for Maximum Temperature	Test for Maximum Power	Test Low Temperature Range
Type of Heat Pipe	Sodium	Sodium	Potassium
Condenser Length	1 Foot	2 Feet	3 Feet
Max. Temperature	915°C	750°C	500°C
Max. Power*	6.5 kW	7.5 kW	4.0 kW
Max. Electric Input Required**	11.5 kW	21.3 kW	21.3 kW

*Based on average of projected fixture efficiency.

**Electrical input per heat pipe; input to fixture is twice that amount.

TABLE 5.1
TEST PARAMETERS

FIGURE 5.1

LIFE TEST CYCLING PATTERN - OPTION 1

FIGURE 5.2
LIFE TEST CYCLING PATTERN - OPTION 2

period of 2.0 hours, and a shutdown time of 1.5 hours. Details of the two cycling patterns are given in Table 5.2. The main difference between the two patterns is the start-up ramping rate of the heat pipes. It is twice as high in Option 1 as in Option 2. The total number of cycles in Option 1 is ~~75%~~ ^{DATA STFT} larger than in Option 2.

Obviously, Option 1 is the preferred one and will be implemented first. Option 2 will be used only if the ramp rates in Option 1 are incompatible with the current heat pipe design.

A calibration will be performed of the heat input capability of the radiant heat test fixture and of the heat rejection capability of the condensers. The heat losses from the adiabatic section of the pipe will also be evaluated. For this test a calorimeter will be attached to one of the two heat pipes in a test fixture. The gas gap mixture will be adjusted such that both pipes operate at the same temperature. Calibration tests will then be conducted over the full range of steady-state temperatures and powers.

CYCLING OPTIONS	OPTION 1	OPTION 2
Heat Pipe Start-Up Rate (W/sec) LTF 1/ LTF 2/ LTF 3	3.6/4.1/2.2	1.8/2.1/1.1
Heat Pipe Shutdown Rate (W/sec) LTF 1/ LTF 2/ LTF 3	3.6/4.1/2.2	3.6/4.1/2.2
Equivalent Receiver Flux Start-Up Rate ($\text{MW/m}^2\text{-sec}$)	0.44×10^{-3}	0.22×10^{-3}
Equivalent Receiver Flux Shutdown Rate ($\text{MW/m}^2\text{-sec}$)	0.44×10^{-3}	0.44×10^{-3}
Duration of Complete Cycle (hours)	1.5	2.5
Start-Up/Shutdown (hours)	1.0/1.0	2.0/1.5
Number of Cycles/Day-Fixture (11 hours)	7	4
Number of Heat Pipe Cycles/Day	42	24
Number of Heat Pipe Cycles in Five Months (80% Utilization Factor)	3629	2074

TABLE 5.2
SUMMARY OF CYCLING OPTIONS

6. COMPONENT TEST PLAN

Two heat pipes will be fabricated for this phase of the project -- one sodium and one potassium pipe. They will have the same wick structure and geometry as the ones used in the life tests. The test plan for these pipes is outlined below.

6.1 Sodium Heat Pipe

1. Operate under steady-state conditions over the full required performance curve (Figure 2.1). It is recognized that the sodium pipe will fall short of the requirements at very low temperatures because of the fundamental vapor limit. For this and the following test, a calorimeter will be used for heat rejection. Also, the lamp voltage may have to be increased above the nominal 240 V in order to apply the necessary input power.
2. Determine the maximum steady-state transport capability of the heat pipe as a function of temperature. The purpose of this test is to establish the design margin and to verify previous test results obtained with RF heating (see Figure 4.3).
3. Perform start-up ramping. This series of tests will be done without the calorimeter and with natural radiation and convection cooling. The following ramp tests will be conducted:
 - a. From cold condition to point of maximum power
 - b. From cold condition to maximum temperature
 - c. Preheat condenser to 400°C, then ramp to point of maximum power
 - d. Preheat condenser then ramp to maximum temperature

The ramp rate for the above tests will be the equivalent of a receiver flux rate of 1.88×10^{-3} MW/m²-sec. If this ramp rate is incompatible with the heat pipe, the maximum allowable rate will be determined.

4. Induce an intentional failure of the heat pipe. This will be done by using an excessive ramp rate. The induced failure will not be associated with a high pressure in the heat pipe. Applying excess heat flux would be another cause for failure but probably cannot be achieved with the present test fixture. Loss of cooling would result in excessive heat pipe temperature and pressure and probably cause considerable damage to the test fixture. The intentional failure test will be performed after testing the potassium heat pipe.

6.2 Potassium Heat Pipe

- 1. Operate under steady-state condition over the required performance curve but with an upper limit of 600°C.**
- 2. Determine maximum steady-state transport capability up to 600°C.**
- 3. Perform start-up ramping without calorimeter as follows:**
 - a. From cold condition to 600°C**
 - b. Preheat condenser to 400°C and then ramp to 600°C**

As with the sodium heat pipe, the ramp rate will correspond to a receiver flux rate of 1.88×10^{-3} MW/m²-sec. If this rate is too high, the maximum permissible rate will be established.

REFERENCES

1. "Heat Pipe Central Solar Receiver", Final Technical Report, Volume 1, Dynatherm Corporation Report No. DTM-79-6, April 1979
2. "Combined Cycle Solar Hybrid Power System Study Project", Second Interim Project Review, June 14-15, 1979. Prepared by Bechtel National Inc.
3. "Preliminary Heat Pipe Receiver Testing Program", FWDC Technical Progress Report No. 9-41-3137
4. Draft of System Requirements *Specification* Study, prepared by Bechtel National Inc., November 1979