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THERMACORE, INC.

LANCASTER, PENNSYLVANIA

FINAL REPORT

SPACE STATION RADIATOR HEAT PIPES

REPORT OF LIFE TEST RESULTS

NOVEMBER 21, 1990

PREPARED FOR:

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GEORGE C. MARSHALL SPACE FLIGHT CENTER
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16. Abstract Thermacore, Incorporated developed two prototype 15 meter long Space Station radiator heat pipes under NASA MSFC contract number NAS8-37261. At the conclusion of that contract, Thermacore agreed to life test those heat pipes for one year under NASA purchase order number H-010950. This report documents the results of this testing.

The test evaluated the compatibility of the materials used in construction of these heat pipes with anhydrous ammonia. Both heat pipes had aluminum pressure boundaries with an internal capillary wick material of sintered aluminum powder. Test results indicated that non-condensible gas was being generated in both pipes at a rate sufficient to blanket two foot of condenser length per month. The gas is suspected to be generated by a reaction between the ammonia and the by-products of a fluxing agent used during wick fabrication. This fluxing agent is used to remove the aluminum oxide from the aluminum powder to permit powder bonding during sintering.

As an alternative to flux sintering, Thermacore devloped under IR & D funding a new technique to fabricate the aluminum powder wick structure. This new technique bonds the aluminum powder together using plastic eliminating the need for flux. We are currently life testing this wick structure with anhydrous ammonia. After 5300 hours of testing, there are no signs of incompatibility.

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1.0 INTRODUCTION

Under a 1986 Phase II SBIR, Thermacore, Incorporated successfully developed for the National Aeronautics and Space Administration Marshall Space Flight Center (contract No. NAS8-37261) a high performance 15 meter long prototype Space Station radiator heat pipe. The heat pipe pressure envelope was aluminum and the internal capillary wick material was sintered aluminum powder and ammonia was the working fluid. The work performed under that contract first established the heat pipe design requirements; developed the necessary technology to fabricate this heat pipe; and concluded with the design, fabrication and test of two prototype radiator heat pipes.

The prototype heat pipe transported 3200 watts with an evaporator to radiator surface temperature drop of less than three degrees Celsius. This power level exceeded the 1430 watt contract goal by more than 120%. The power-length product, a measure of heat pipe performance, exceeded 1,800,000 watt-inches, which is believed to be a record.

The high heat transfer rate was made possible by the sintered aluminum powder metal wick structure that provides capillary pumping to return condensate to the evaporator. The high performance wick makes the heat pipe less sensitive to gravitational effects than previous devices of this kind. For example, it transported 1430 watts with the evaporator elevated 15 centimeters above the condenser. This unprecedented performance now makes it possible to assure proper zero-g operation with 1-g testing of heat pipes of this size.

At the completion of the two year contract, Thermacore agreed to life test the two prototype heat pipes for one year at their expense. This report documents the results of the life testing.

2.0 CONCLUSIONS AND RECOMMENDATIONS

Test results indicated that non-condensible gas (NCG) was being generated in both pipes. The rate of gas generation was sufficient to blanket two foot of condenser length per month. The gas in these heat pipes is suspected to be caused by a reaction between ammonia and residue of the flux used during sintering of the aluminum powder wick structure. Thermacore recommends the following action to solve this compatibility problem.

1. Thermacore has developed a new aluminum powder wick structure as a replacement for the flux sintered wick. It uses the same aluminum powder only it is bonded together using plastic. Thermacore has been conducting compatibility testing of this new wick structure with ammonia using small (8"long) reflux type heat pipes. There is no sign of gas generation or any other incompatibility after 5300 hours of testing.

   To further vertify the compatibility of the new plastic bonded wick structure, we recommend that a radiator heat pipe containing a significant portion of wick be fabricated and life tested. A 15 meter radiator heat pipe uses approximately 25 pounds of aluminum powder. The small reflux type life test pipes contain approximately 2 ounces of aluminum powder. If there is any incompatibility, it is expected to be more pronounced in a heat pipe that has a significant amount of powder in contact with the ammonia.

2. We recommend conducting analysis to identify the cause of the NCG generation in the flux sintered wick. If it is due to the residue of the sintering flux, a solvent could possibly be found to eliminate the reactive flux residue before heat pipe processing. This would allow the use of flux sintered powder without the problem of gas generation.

3.0 RADIATOR HEAT PIPE DESIGN, TEST SETUP AND RESULTS

This section of the report documents the results of the life testing. Two prototype radiator heat pipes were tested. A brief description of the design of the prototype radiator is found in Section 3.1. The test facility used during life testing is described in Section 3.2 and the test results are documented in Section 3.3.

3.1 RADIATOR HEAT PIPE DESIGN

The overall design of the radiator heat pipe is shown in Figure 1. The evaporator section employs the Thermacore developed external artery design. There are three evaporator legs arranged in parallel and manifolded to the condenser leg. The condenser section is cylindrical in design and is 13.7 meters long. A more detailed heat pipe design description can be found in the final report for contract NAS8-37261.

3.2 TEST SETUP

A schematic of the test setup is shown in Figure 2. Both heat pipes were mounted side-by-side on a 16 meter long by 30 centimeter wide wooden table. The heat pipes were supported by fifteen individually adjustable wooden leveling blocks. Heat input during life testing was achieved using Minco Thermofoil heaters pasted to the heat pipe evaporator. Both heat pipes were cooled by tap water circulated through 1/4" diameter copper tubes connected in parallel and clamped to the top and bottom of each condenser section.

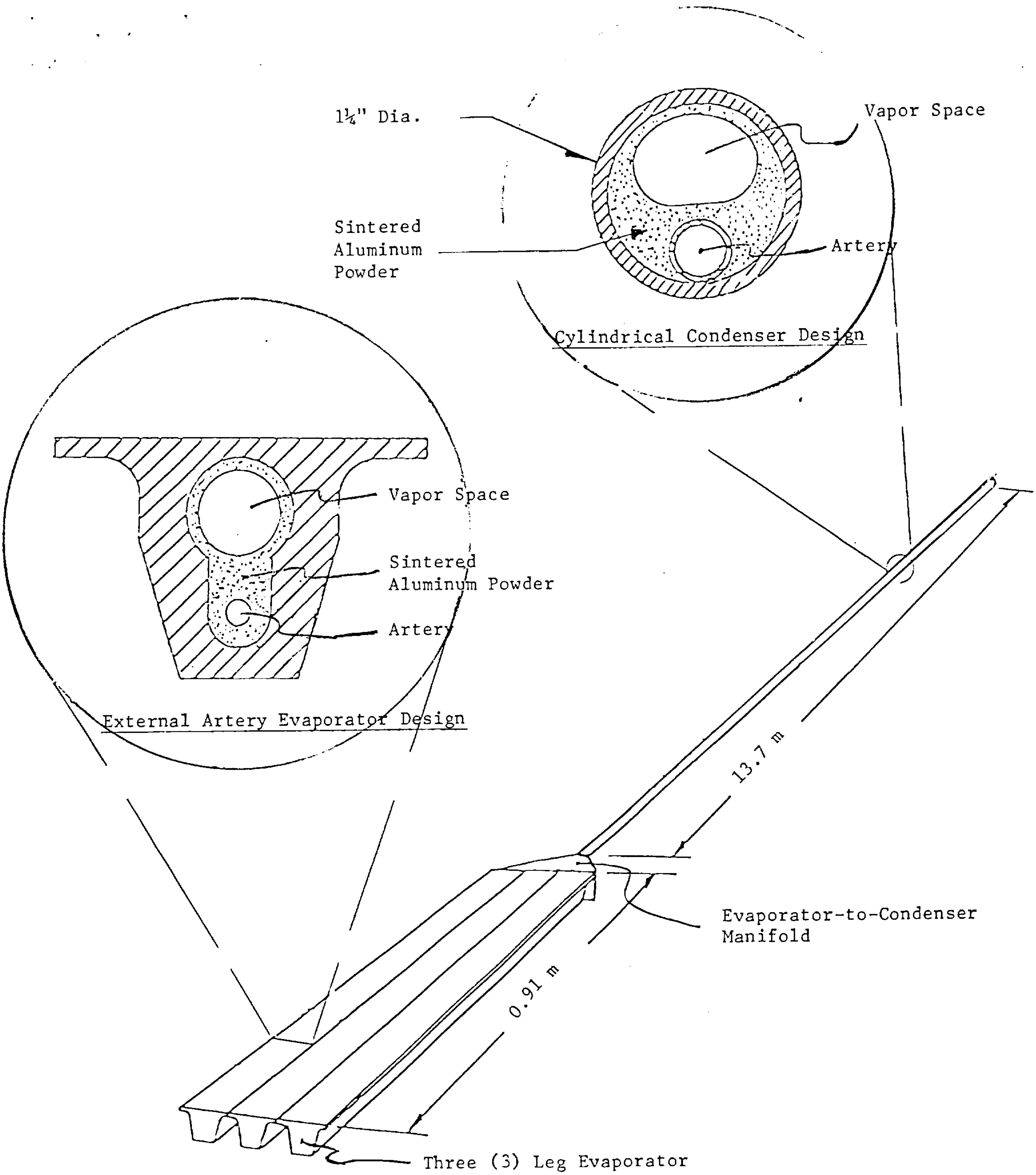

Figure 1. Prototype Radiator Heat Pipe

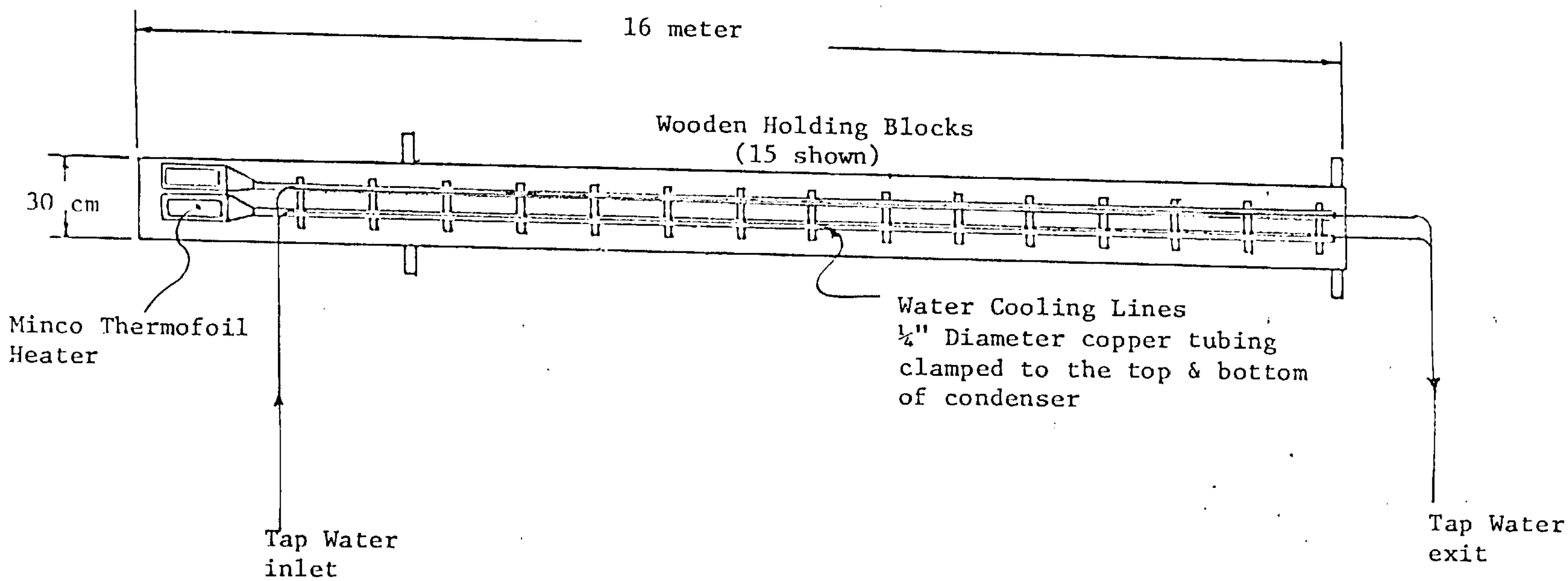

Figure 2 . Schematic of life test set-up

During life testing, the temperature profile for each heat pipe was monitored using twenty-five type J thermocouples: Nine were mounted in the wall of the evaporator and sixteen were attached evenly down the length of the condenser.

Input power was set at approximately 400 watts per pipe. Evaporator temperature was maintained between 19 to 30°C. These pipes were operated continuously, while the thermocouple temperatures were recorded every 100-200 hrs.

3.3 TEST RESULTS

Test results indicate that Non-Condensible Gas (NCG) was being generated in both pipes. Non-condensible gas that was generated collected in the condenser section of the heat pipe. Gas was being generated at a rate sufficient to blanket two foot of condenser length per month. The gas in these heat pipes is suspected to be caused by a reaction between ammonia and residue of the sintering flux compounds.

Aluminum powder is difficult to sinter because of its tenacious, stable oxide that readily forms on the surface of the aluminum particles. In order to permit sintering aluminum particles together, this oxide barrier must be removed. This is accomplished using a proprietary fluxing agent. The flux is combined with the aluminum powder and this flux/aluminum powder mixture is introduced to the heat pipe. The flux removes the oxide during sintering and permits the aluminum powder to bond together and bond to the heat pipe wall. It is the flux residue left behind that is suspected to react with ammonia to generate gas.

Thermacore over the past two years under an IR & D effort has developed a new technique to fabricate this aluminum powder wick structure that eliminates the need for flux.

This technique involves bonding the aluminum powder together using plastic. Table 1 is a comparison of the wick physical properties of the plastic bonded powder and the flux sintered powder. Note that the permeability of the plastic bonded powder is actually better than sintered powder resulting in the capability for increased heat pipe thermal performance.

Thermacore has been conducting compatibility testing of this new wick structure with ammonia using reflux type heat pipes shown in Figure 3. There is no sign of gas generation after 5300 hours of testing. To further evaluate the compatibility of the new plastic bonded wick structure, we recommend that a radiator heat pipe be fabricated and life tested. A 15 meter radiator pipe uses approximately 25 pounds of aluminum powder. The small reflux type life test pipes contain approximately 2 ounces. If there is any incompatibility it is expected to be more pronounced in the radiator heat pipe which has significantly more powder in contact with ammonia.

TABLE 1. Aluminum Powder Metal Wick Structure Comparison

WICK PROPERTIES	FLUX SINTERED WICK	PLASTIC BONDED WICK
CAPILLARY RADIUS	3.5 X 10^{-3}cm	3.5 X 10^{-3}cm
PERMEABILITY	2.5 X 10^{-7}cm2	1.1 X 10^{-6}cm^2*
THERMAL CONDUCTIVITY	23 W/m°C	23 W/m°C
POROSITY	0.48	0.56

***Factor Of 4 Increase In Permeability**

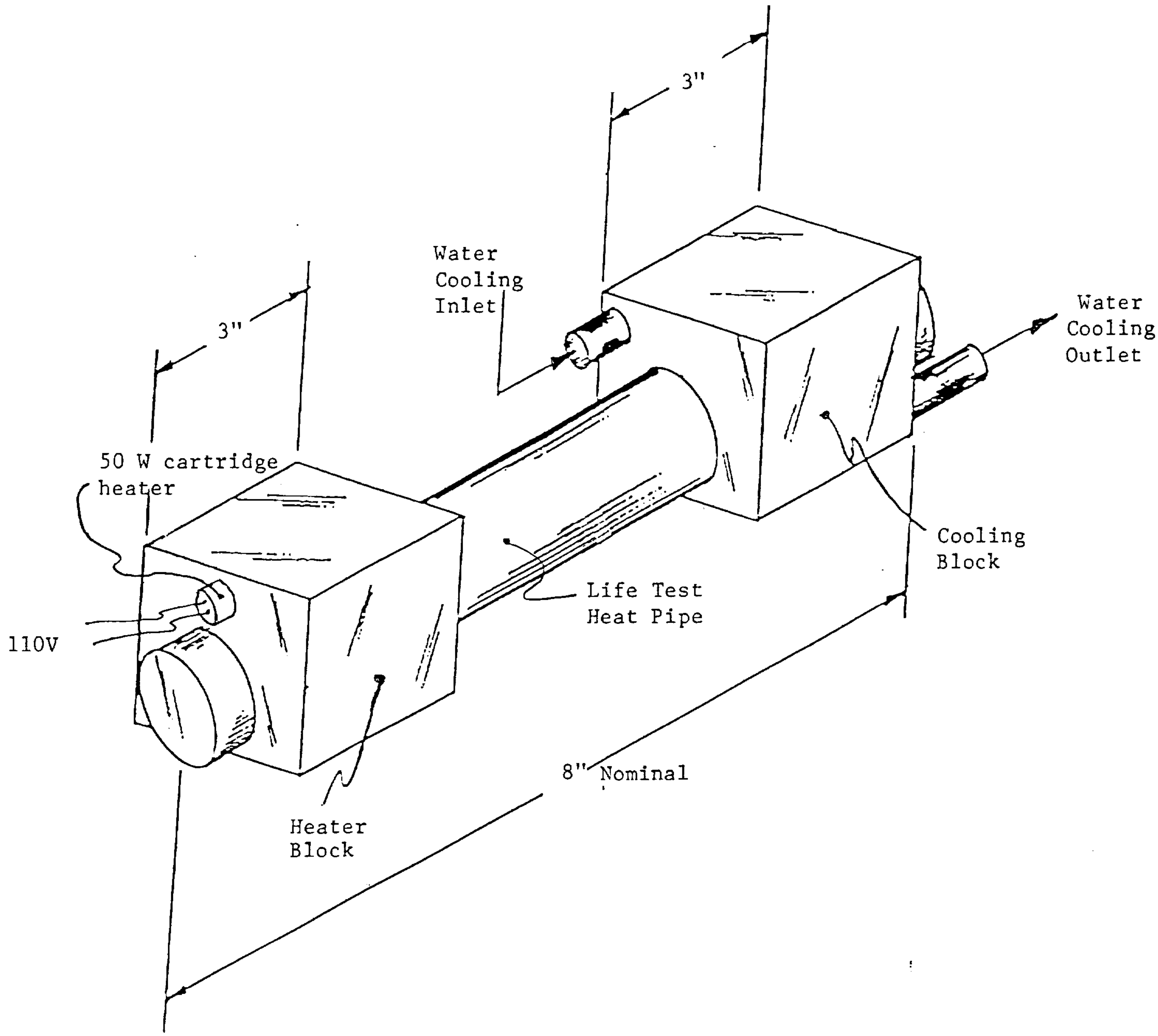

Figure 3. Typical Life Test Heat Pipe