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THE HEAT PI?E EXPERIMENT

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THE HEAT PIPE EXPERIMENT

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SPACE SCIENCES LABORATORY

INTRODUCTION

The purpose of the heat pipe experiment is to demonstrate the feasibility of maintaining a large enclosure at a uniform and constant temperature despite heat addition and removal at several localized regions on or in the enclosure. The isothermal characteristics of a conventional heat pipe have been demonstrated under zero gravity conditions.* The constancy of temperature of a collection of matter undergoing a change of state while absorbing or rejecting heat is a common laboratory phenomenon. By tying the heat pipe concept intimately to the concept of a heat reservoir (or sink) based on the heat of fusion, it should be possible to maintain a volume, large enough to be operationally interesting to space experimentalists, at a constant and uniform temperature corresponding to the melting point of the fusible solid in the heat reservoir. This volume would be most welcome to experimentalists with difficult mounting problems imposed by heat removal requirements or to experimentalists who cannot tolerate temperature changes or temperature gradients. While it is recognized that one cannot achieve perfect uniformity and constancy of temperature with the arrangement to be proposed, one can approach the ideal arrangement as closely as desired for the practical purposes of experimentalists.

Precision optical equipment, such as telescopes and star trackers, accurate frequency standards or clocks, electronic data processing

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*Deverall, J. E., et al.: Orbital Heat Pipe Experiment, Los Alamos Scientific Laboratory Report LA-3714, Los Alamos, N. M., June 5, 1967.

equipment, etc., are often sensitive to thermal gradients and temperature drifts. The proposed experiment should pave the way for the elimination of such problems in space and should save a tremendous amount of design and engineering money devoted to the solution of such problems by present methods. Any scientific experiment which is temperature sensitive must be carefully calibrated in a controlled environment, and this temperature dependence must be reflected in housekeeping measurements and data-processing programs. Accurate temperature control achieved by modest and reliable means could result in huge cost savings in the area of space experimentation and improve the scientific data by reducing calibration problems.

The testing of a large heat pipe cannot be done on the ground because gravity will strongly and adversely affect the working fluid distribution. It should be pointed out in the beginning that several very effective systems for space use may not be operationally tested on the ground in final configuration. Such systems would include nuclear rockets, nuclear power supplies, and large heat pipes.

DISCUSSION OF THE BASIC PRINCIPLES

Suppose that it is desired to maintain the volume shown in Figure 1 at a uniform and constant temperature. The volume can have any shape or size, and may receive heat from the sun or from the dissipation of electrical power and lose heat by radiation into space. Control problems will be diminished if the inputs balance the outputs over a reasonable period of time, but there is a problem with non-uniform heating and cooling and with variations in temperature as heat is added or subtracted.

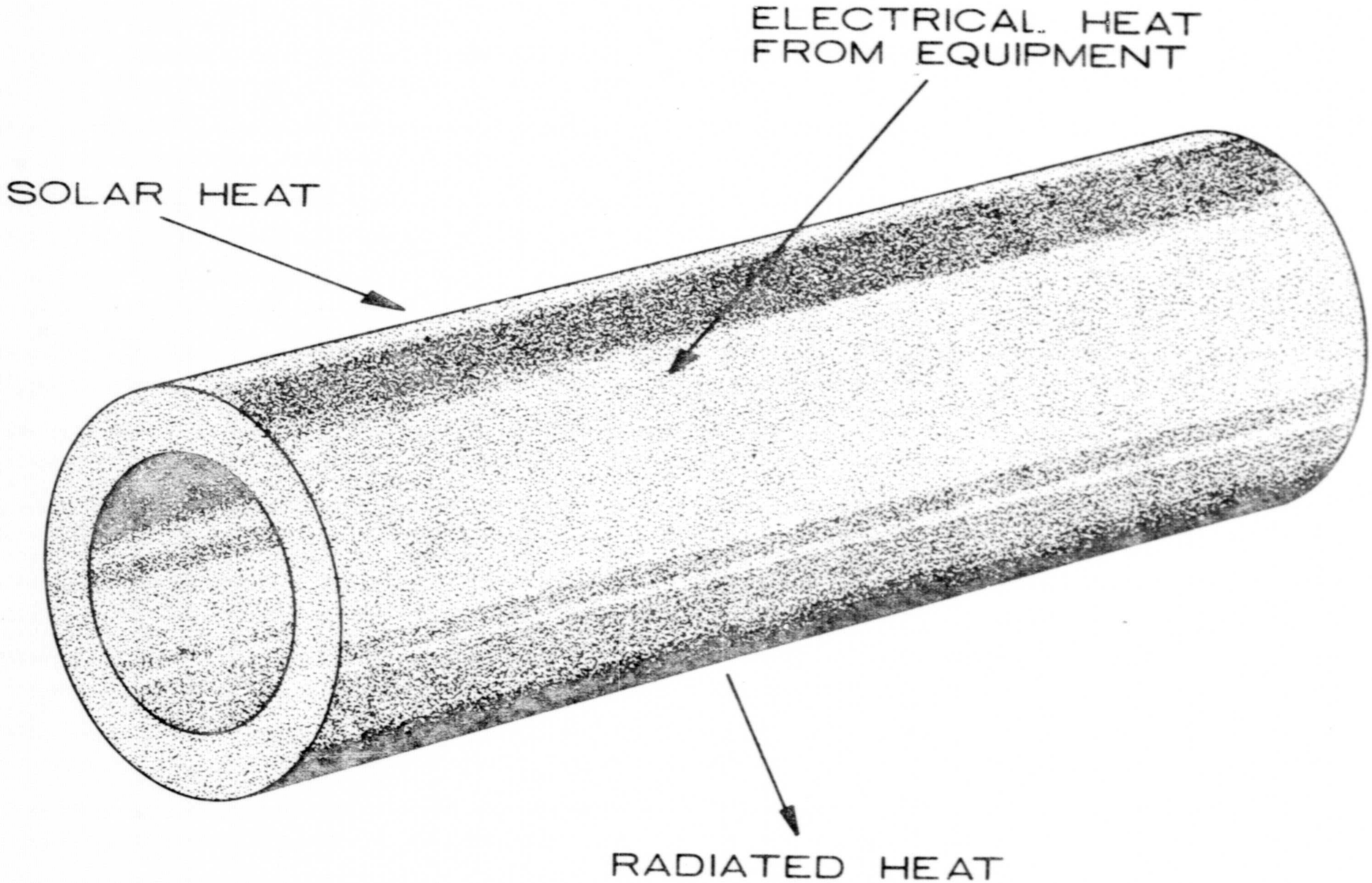
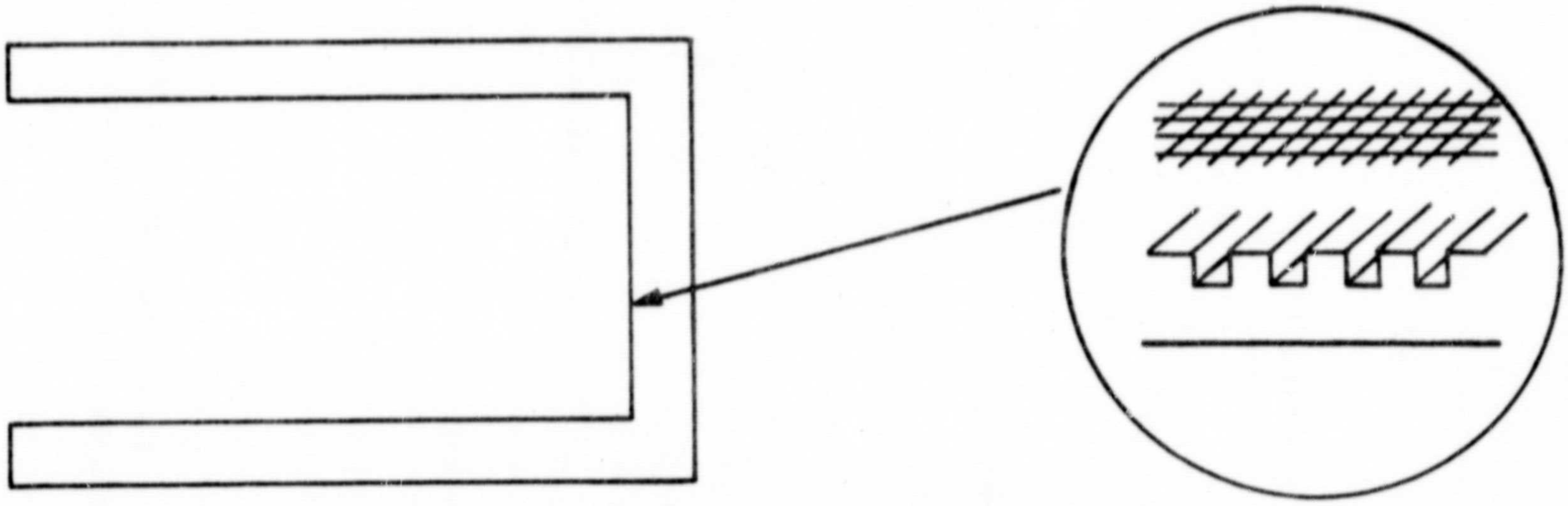


FIG. 1. Problem Area: To Maintain a Volume at a Uniform and Constant Temperature

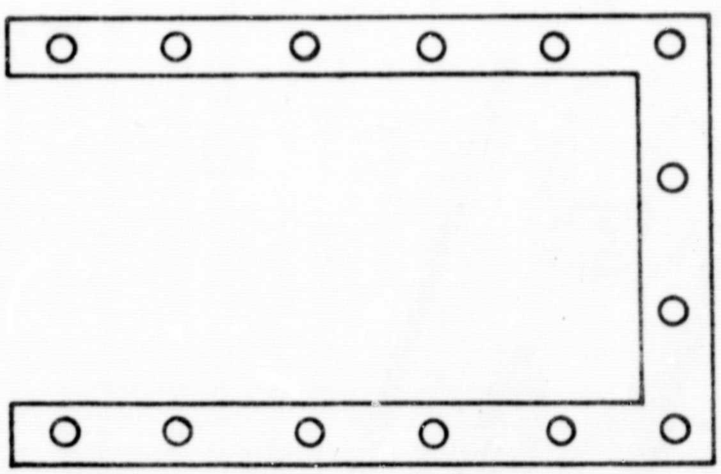
To maintain a uniform temperature, it is proposed that the structure of Figure 1 be made into one large heat pipe with a cross section such as shown in Figure 2. The interconnecting collant passages contain a small amount of fluid which, by capillary action in a zero gravity field, distributes itself over the surfaces of the passages. The volume of liquid and vapor in equilibrium guarantees a uniform temperature as long as surface tension forces can restore the flow of liquid to surfaces being heated. Because of the large heat of vaporization of many liquids, there is no problem here. For example, it appears possible to transfer a kilowatt of power with the liquid flow available from a surface 3 inches wide, with a distance of 1 foot between source and sink. In most satellite applications, a concept such as that shown in Figure 2 could easily be overdesigned by a factor of a thousand without any special effort or unusual cost.

The temperature of a device such as Figure 2 may remain uniform over the volume, but it will fluctuate as heat is added or subtracted. Temperature changes have associated with them the mismatch of materials with unequal expansion coefficients and the change of pressure in the coolant passages. This change of pressure could result in unwelcome stresses and bulges.

To alleviate the problem, a heat reservoir of a fusible material is connected to the volume to be controlled by a heat pipe, which may have any desirable size or shape. This connection is shown simply in Figure 3, but it should not be assumed that the thermal reservoir and the controlled volume must be so obviously separated. For example, a configuration such as shown in Figure 4 could be used, with the



Capillaries can be mono-directional or bidirectional (90°).



A HEAT PIPE STRUCTURE

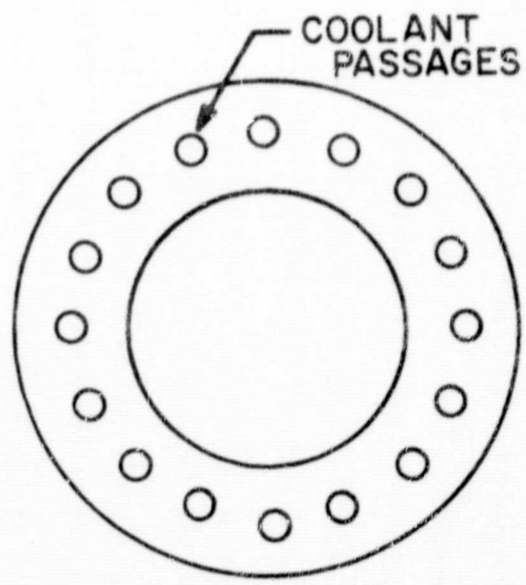


FIG. 2. A Heat Pipe Structure. A uniform temperature is guaranteed by making the entire structure into a heat pipe. One concept would be obtained by packing screen wire into the passages to help distribute the liquid from one cylindrical surface to the other.

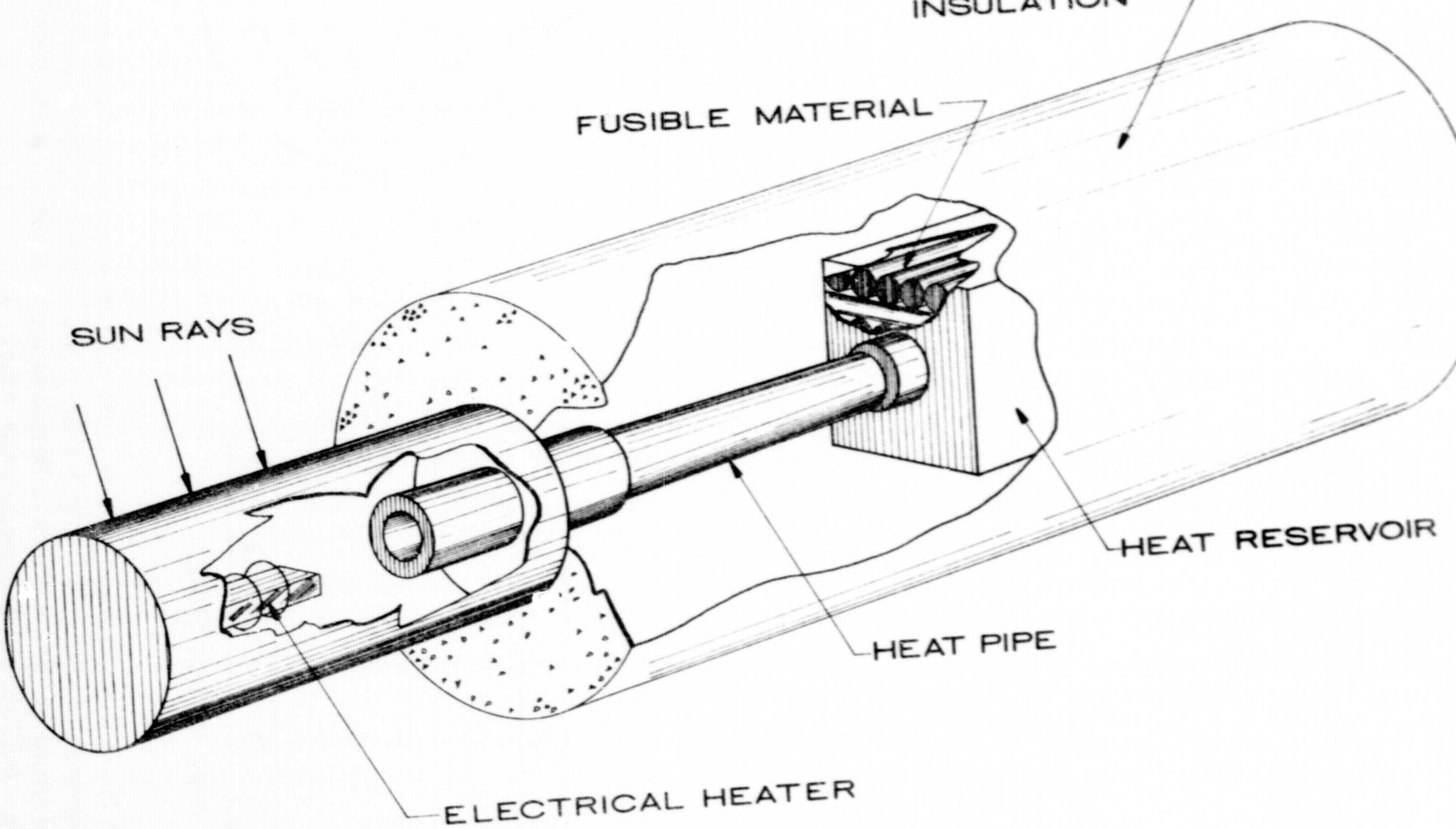


FIG. 3. An Isothermal Constant Temperature System. This schematic drawing is not to scale. In general, the volume containing the fusible material would be much smaller than the controlled volume.

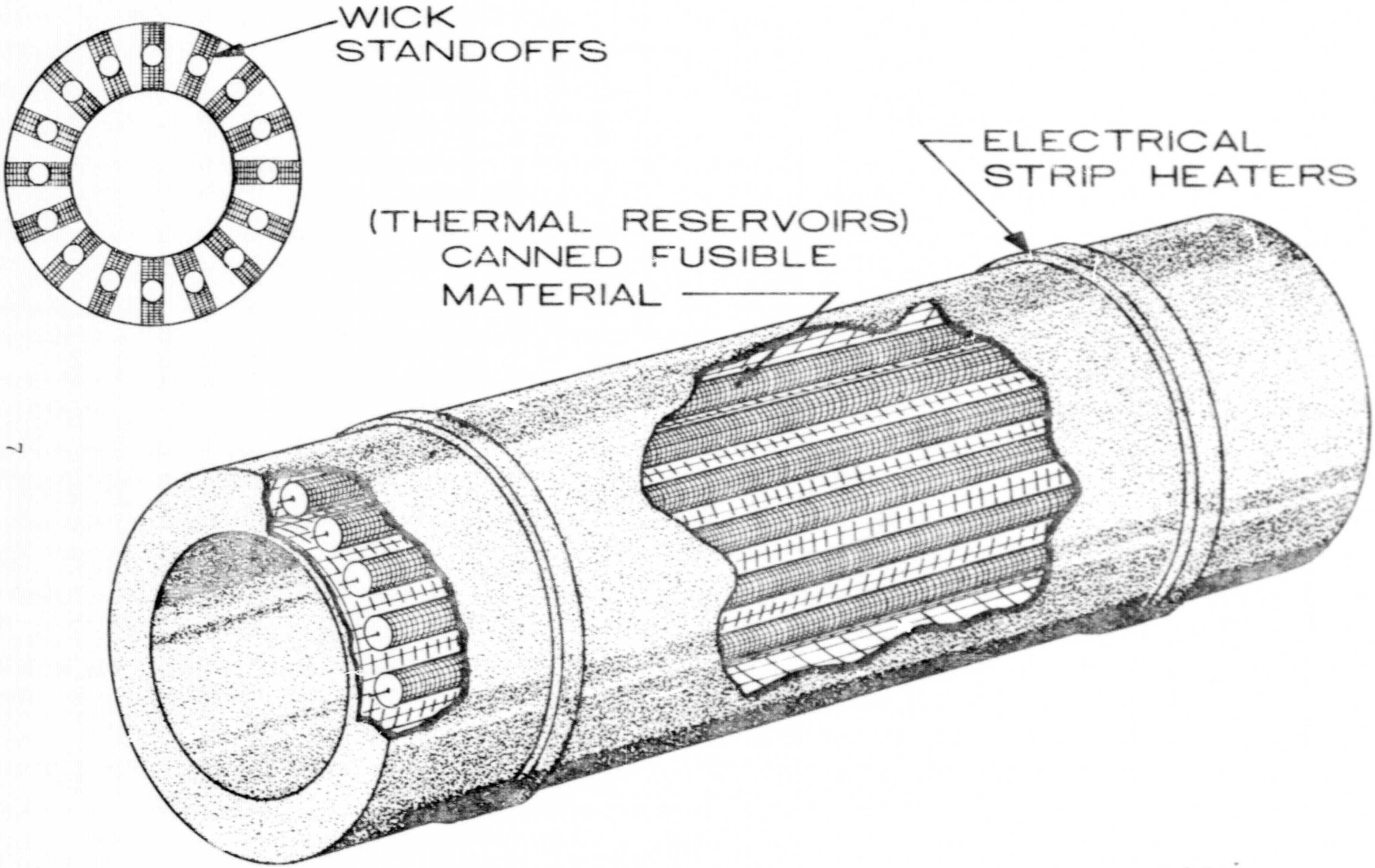


FIG. 4. A Schematic Drawing Showing the Introduction of Fusible Material Into a Heat Pipe Configuration. The drawing is for illustration only, and is not drawn to scale.

fusible material enclosed adjacent to the controlled volume and connected intimately with the volume by the heat pipe principle. The container of fusible solid is actually a heat pipe with a matrix of fusible material. This arrangement will reduce the problem of temperature variations associated with temperature gradients across the fusible material as it melts or solidifies at the heat exchange surface.

SPECIAL FEATURES OF THE SYSTEM

A heat pipe system designed to operate in space could be of any shape, size, or configuration, with part of the system exposed to the space environment and part shielded or insulated. The system should be designed to achieve passively an average operating temperature slightly below that of the fusion temperature of the thermal reservoir, so that a slight addition of electrical power could achieve positive control at the desired temperature.

The fusible solid should be distributed in convenient sized cans stacked in a suitable volume, with the space between the cans packed with wicking material and acting as a heat pipe, as shown in Figure 5. This will insure that only small temperature differences develop during heating and cooling cycles and will solve the problem of heat distribution to the fusible material. Temperature differences between the controlled volume and the thermal reservoir should be measured during flight, and the absolute temperature should be measured as accurately as possible. If possible, the system should be permitted to cool below the fusion temperature and then heated steadily to obtain curves such as shown in Figures 6 and 7. If possible, an attempt at total temperature control should be made by turning the heater on and off as the supply of solid in the thermal reservoir increases or decreases. The amount of solid could be measured by sound propagation or by strains

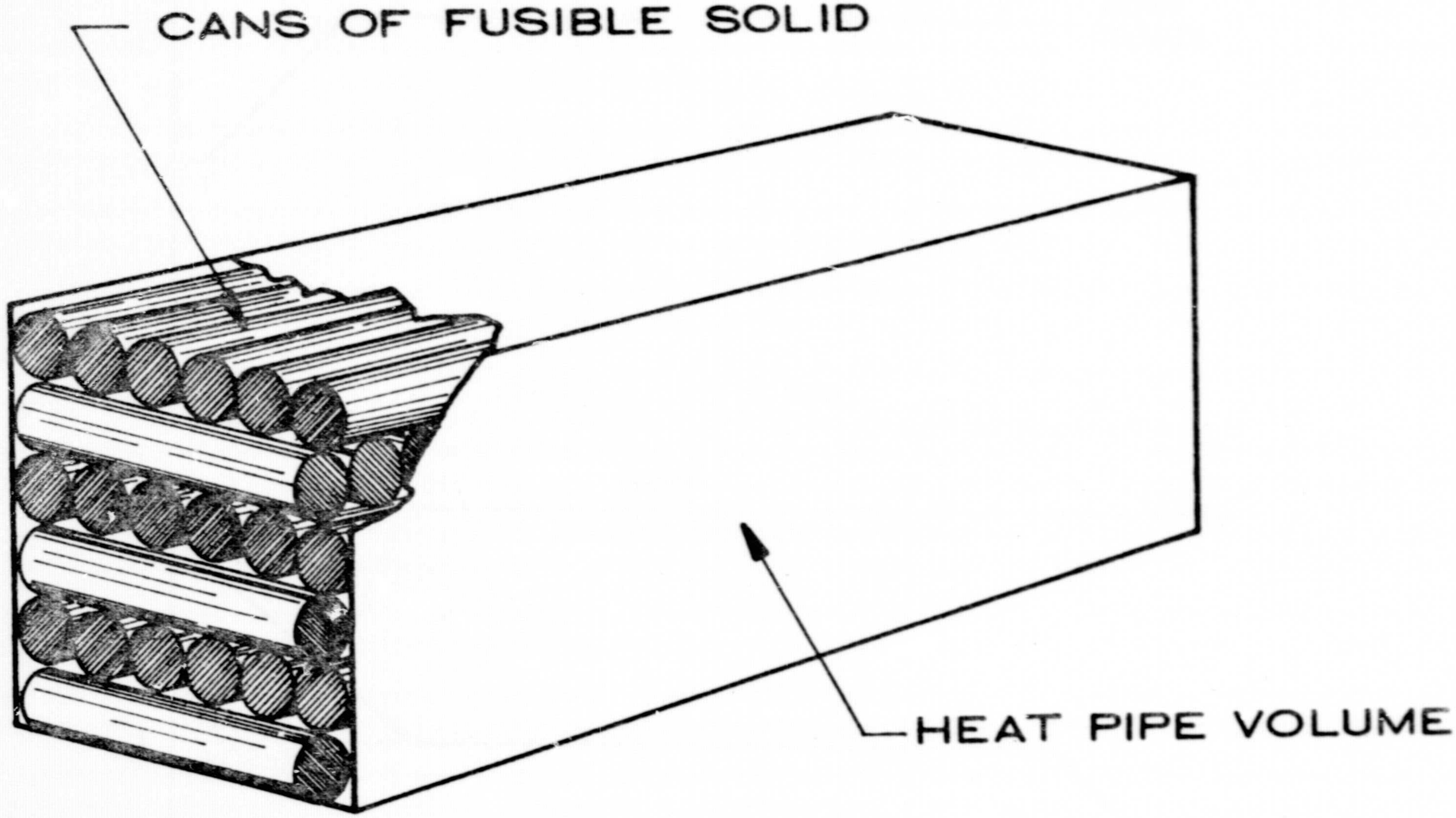


FIG. 5. Disposition of Fusible Solid

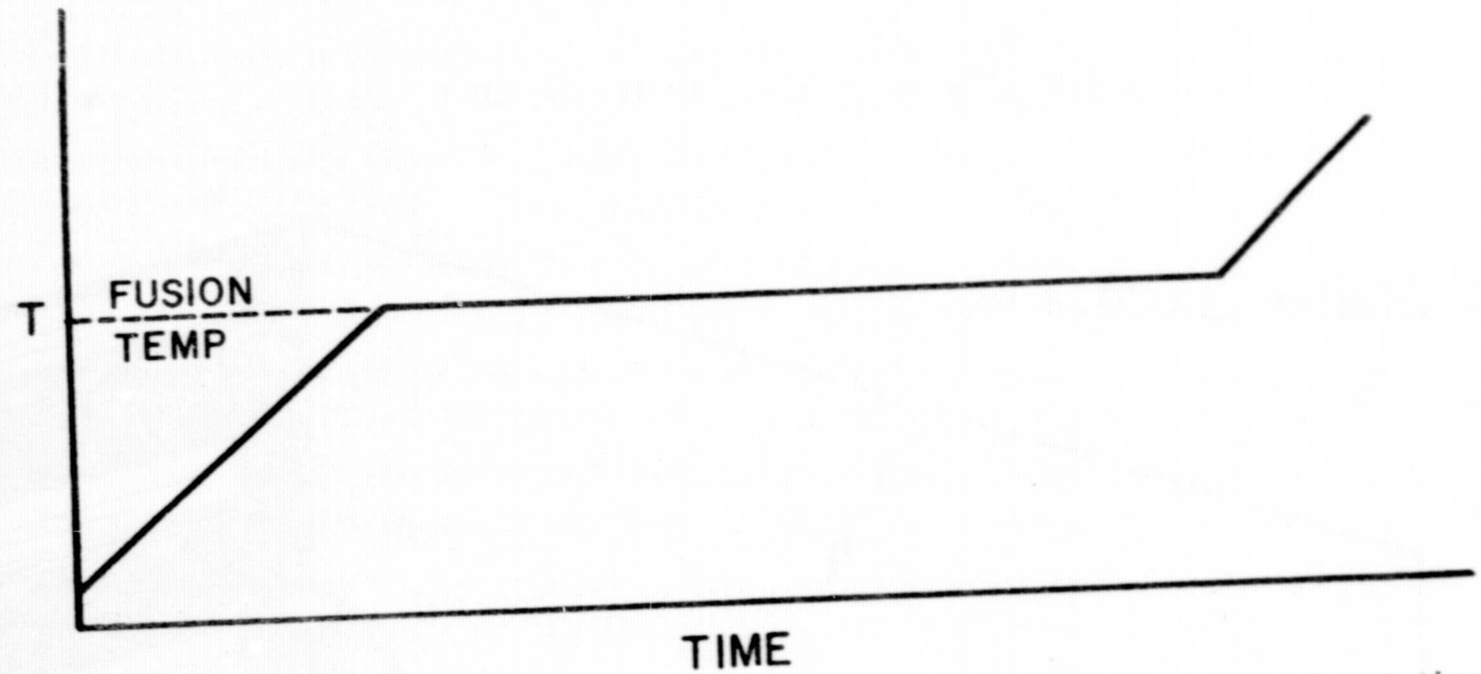


FIG. 6. The Time Behavior of a Heat Pipe-Fusible Solid Configuration with Heat Added at a Constant Rate

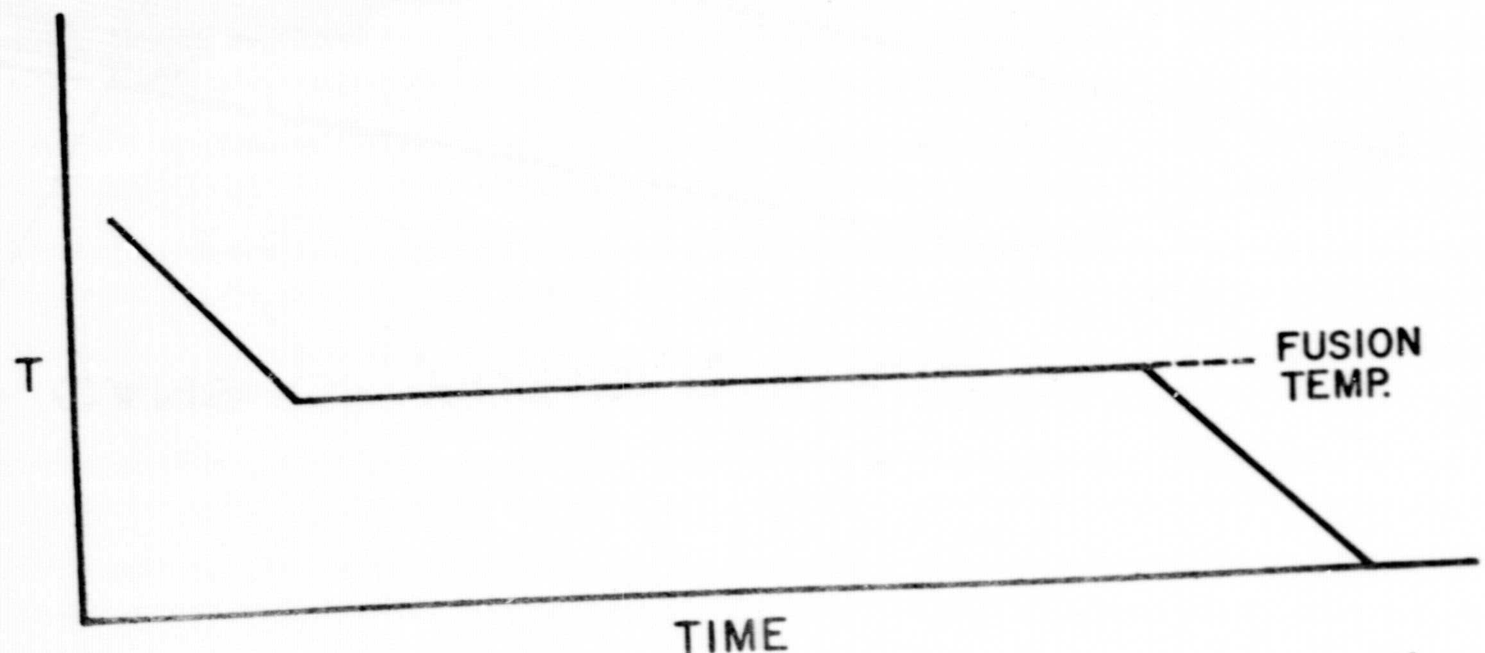


FIG. 7. The Time Behavior of a Heat Pipe-Fusible Solid Configuration as Heat is Removed at a Constant Rate

associated with the volume changes.

SUMMARY

A system capable of achieveing a constant and uniform temperature over a sizable volume has been described. It is relatively immune to problems of localized heat additions and subtractions and possesses remarkable simplicity, low cost, and reliability properties, and is susceptible to simple and direct operational checks under space conditions.