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TITLE: DEVELOPMENT OF AN INTEGRATED HEAT PIPE-THERMAL STORAGE SYSTEM FOR A SOLAR RECEIVER

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DEVELOPMENT OF AN INTEGRATED HEAT PIPE-THERMAL STORAGE SYSTEM FOR A SOLAR RECEIVER

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The Organic Rankine Cycle (ORC) Solar Dynamic Power System (SDPS) is one of the candidates for Space Station prime power application. In the low earth orbit of the Space Station approximately 34 minutes of the 94-minute orbital period is spend in eclipse with no solar energy input to the power system. For this period the SDPS will use thermal energy storage (TES) material to provide a constant power output. Sundstrand Corporation is developing a ORC-SDPS candidate for the Space Station that uses toluene as the organic fluid and LiOH as the TES material.[1] An integrated heat-pipe thermal storage receiver system is being developed as part of the ORC-SDPS solar receiver.[2,3] This system incorporates potassium heat pipe elements to absorb and transfer the solar energy within the receiver cavity (Fig. 1). The heat pipes contain the TES canisters within the potassium vapor space with the toluene heater tube used as the condenser region of the heat pipe. During the insolation period of the earth orbit, solar energy is delivered to the heat pipe in the

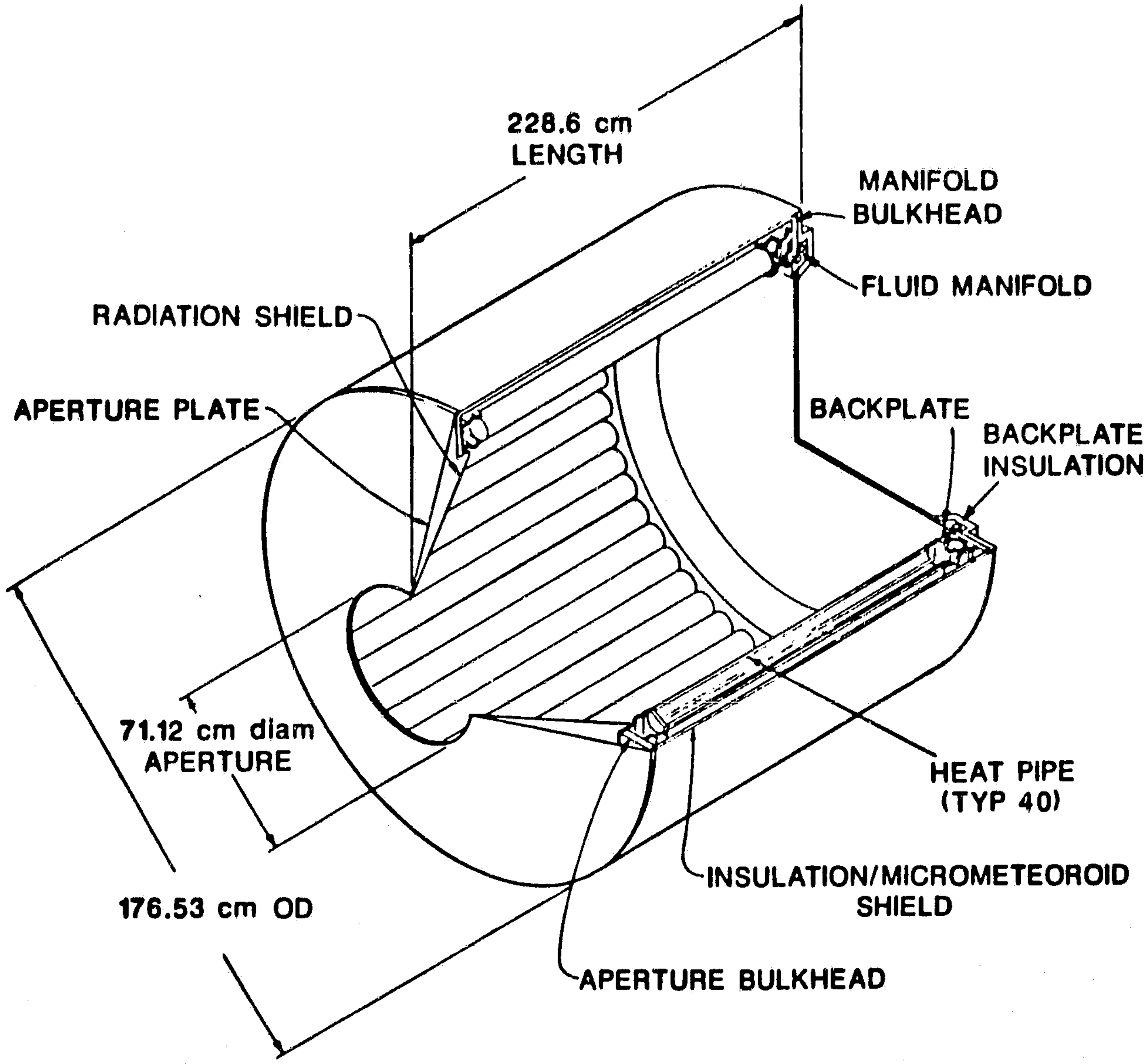

Fig. 1. Rankine cycle receiver.

ORC-SDPS receiver cavity. The heat pipe transforms the non-uniform solar flux incident in the heat pipe surface within the receiver cavity to an essentially uniform flux at the potassium vapor condensation interface in the heat pipe. During solar insolation, part of the thermal energy is delivered to the heater tube and the balance is stored in the TES units. During the eclipse period of the orbit, the balance stored in the TES units is transferred by the potassium vapor to the toluene heater tube.

The solar receiver heat pipes are similar to conventional alkali metal heat pipes but they are unique in operational characteristics. The solar radial flux is delivered to a semicylindrical surface section of the heat pipe, and it varies in power density from end to end with a peak flux of about 7.5 w/cm^2 approximately 50 cm from one end. The operational temperature is limited to 775 K in the potassium vapor space under the maximum heat input to each pipe of 5.7 kW. During eclipse the heat pipe is required to continue to function in a transfer mode, using the latent heat of the LiOH as the heat source to provide the necessary heat to the toluene heater. The resulting heat pipe design, shown in Fig. 2, has been developed to meet these requirements.

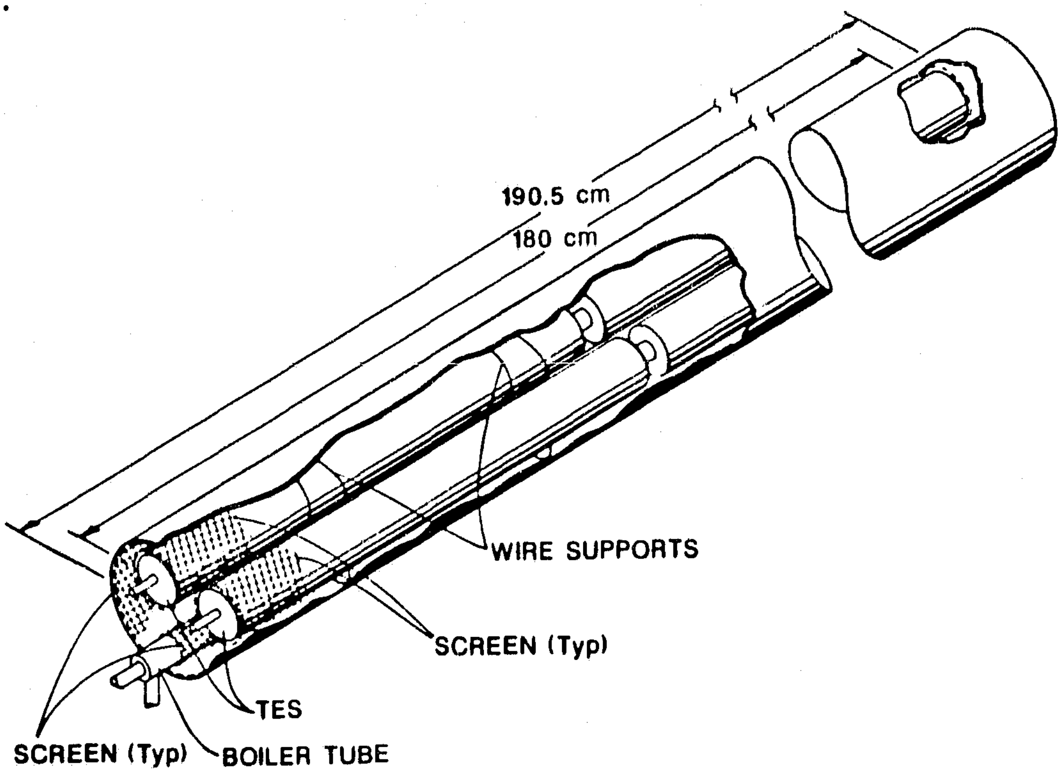

Fig. 2. Axial heat pipe with thermal storage units.

A developmental performance verification heat pipe was constructed from stainless steel tubing 190 cm in length with an outside diameter of 12.7 cm. The wick structure designed to provide liquid return for the varied heat transfer performance requirement consisted of three layers of 100 mesh screen placed against the inner wall for circumferential distribution of the potassium fluid. Similar layers of screen were placed around the TES units and heater tube to provide a fluid path for the condensate during operation. Axial fluid distribution was provided by six arteries, two between each of the TES units and two between the heater tube and the circumferential distribution wick. Potassium was vacuum-distilled into the heat pipe and the heat pipe wet-in at 775 K to fill the screen wick and arteries. The heat pipe was tested in a vacuum chamber, Fig. 3, with simulated solar heat input being provided by a variable zoned rf induction coil (Fig. 4). This coil was separated into four distinct zones, each providing a different semi-cylindrical radial heat input flux into the heat pipe. Heat loss on the back half of the pipe was kept to minimum with radiation shielding. Thermocouples were used to monitor the temperature profile circumferentially and axially (Fig. 5).

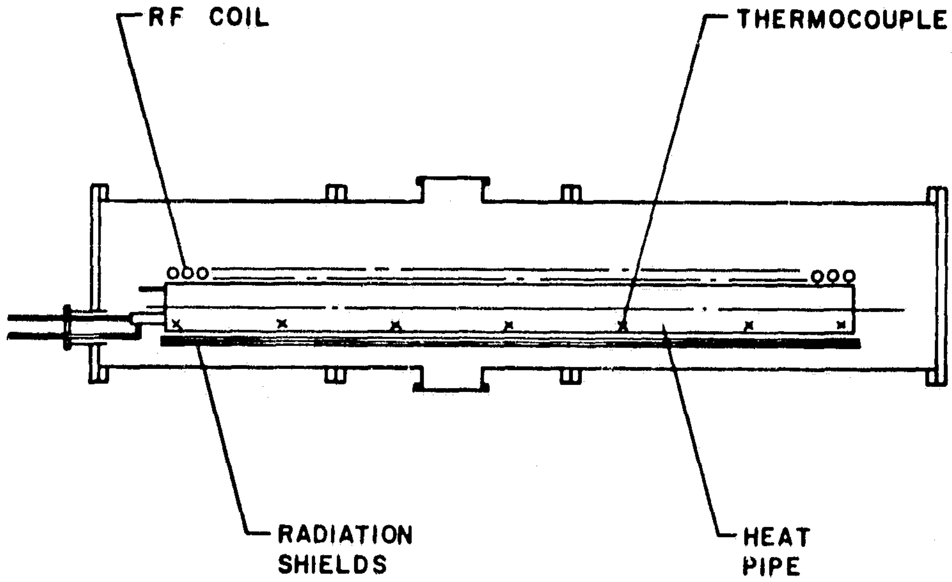

Fig. 3. Heat pipe element test setup.

Tests were conducted to satisfy the conditions of 4.8 kW throughput for normal operation and 5.7 kW heat throughput for an upper limit. Heat throughputs were measured using a calorimetric flow system that simulated the toluene flow system, as shown in Fig. 6. Thermal charge and discharge of the internal thermal storage canisters was conducted to simulate an earth orbit cycle. The heat pipe was operated with a constant input orbit cycle. The heat pipe was operated with a constant input of 5.2 kW during the simulated insolation period. At 753 K, a power level of 3 kW was removed through the heater tube and the balance of the input power was stored in the TES canisters. When the temperature of the heat pipe reached 775 K the eclipse cycle was started. The average

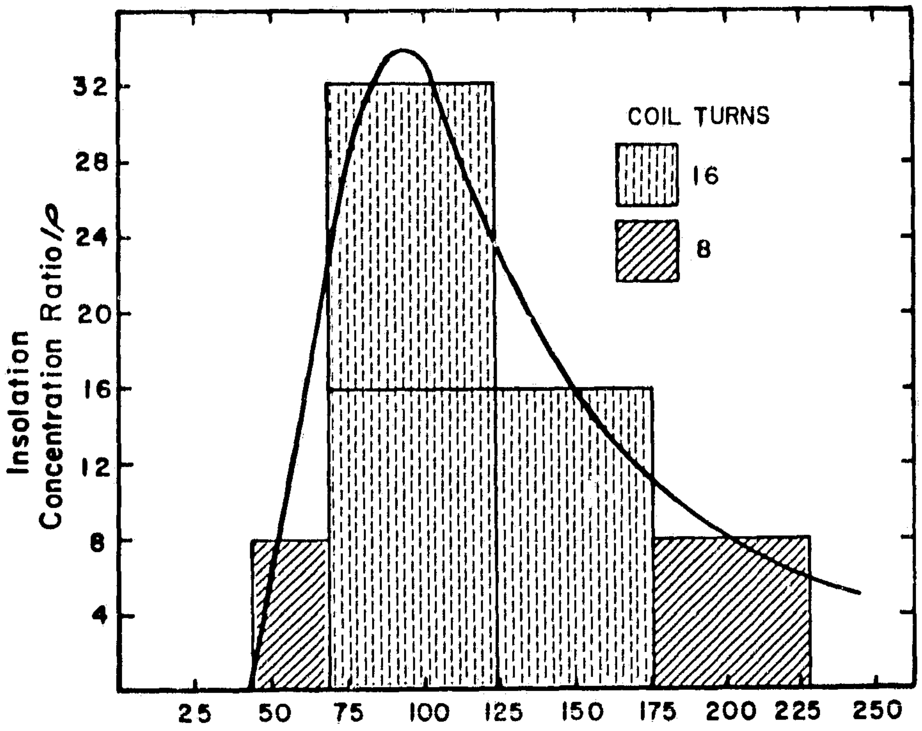

Fig. 4. Insolation concentration versus cavity depth.

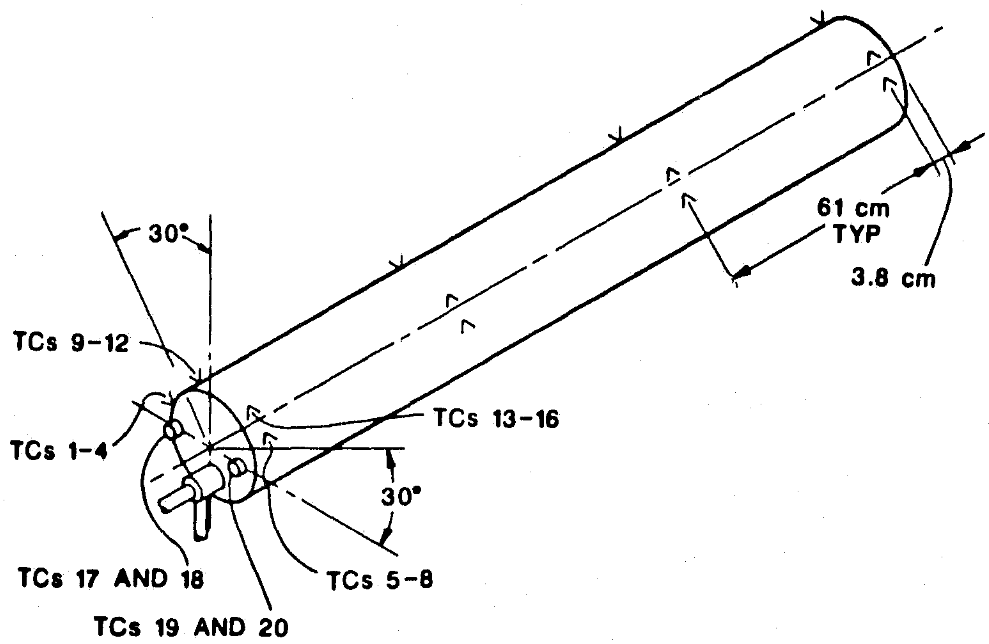

Fig. 5. Thermocouple locations.

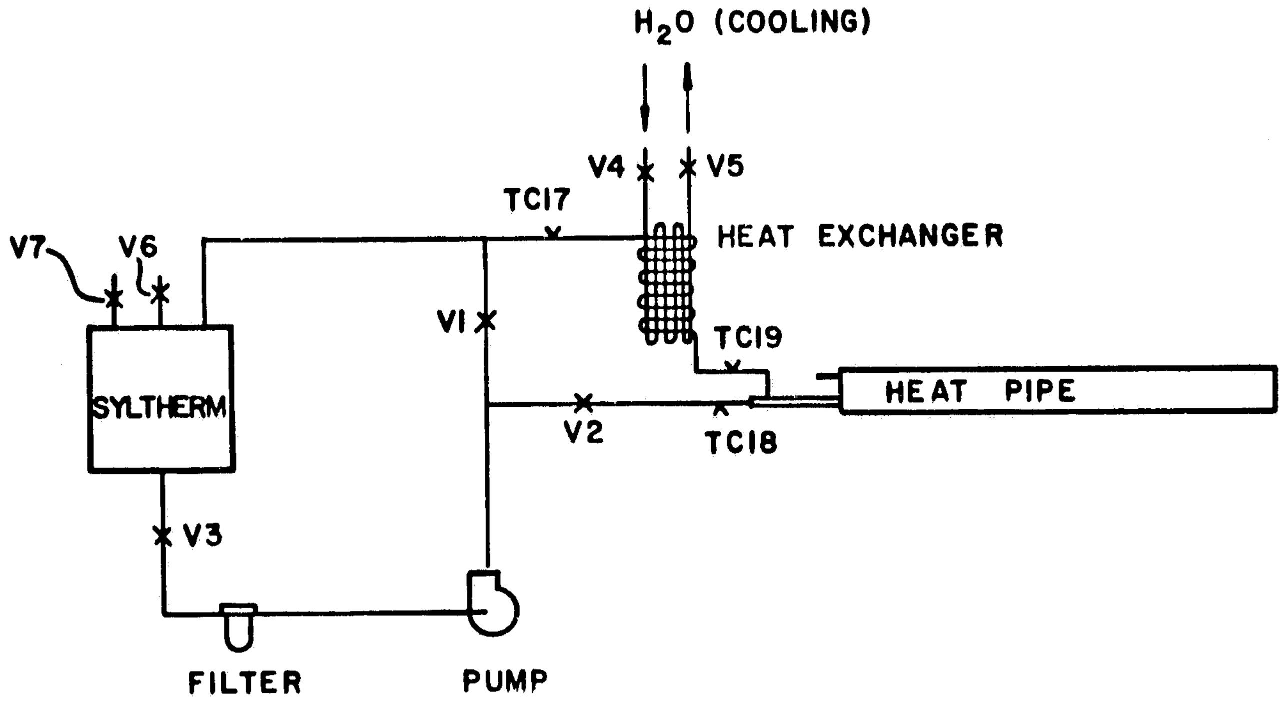

Fig. 6. Calorimetry setup.

power throughput remained approximately 3.0 kW during the test cycles (Fig, 7). The temperature swing was ± 25 K.

A test was conducted with the input flux varied axially to demonstrate the design-peak-heat flux capability of 15 watts/cm^2. An rf coil was fabricated to provide greater than 5 kW heat input to the heat pipe over the area that received 15 watts/cm^2 or more in normal operation. The heat pipe was isothermal within 5 K at a temperature of 733 K with no hot spots or other abnormalities.

Heat pipe transient performance tests were conducted to determine the operating characteristics and power input limits of the heat pipe/thermal storage elements under conditions corresponding to reacquisition of the sun during emergence from the eclipse conditions and to initial start-up of the solar dynamic power system. During start-up of the system from the frozen state, the working fluid in the heat pipe must be melted and must be made available to the internal phase change cycle at a rate higher than that at which vapor from the evaporator is lost to the frozen regions of the heat pipe. Determination of the start-up limits was established by a series of tests conducted with decreasing times to full input power level for the heat pipe. The most rapid start-up time was 10 seconds. These tests were completed without any evidence of malfunction of the heat pipe assembly. The temperature distribution through the heat pipe was symmetric and uniform through the start-up, even in the minimum time start (Fig. 8).

An integrated heat pipe/thermal storage element has been designed and developed that meets the functional requirements of (1) absorbing the solar energy in the receiver, (2) transporting the energy to the organic Rankine heater, (3) providing thermal storage for the eclipse phase, (4) allowing uniform discharge from the thermal storage to the heater. The heat pipe assembly has been operated at design input powers of 4.8 kW and 5.7 kW. Thermal cycle tests to simulate the insulation and eclipse periods have demonstrated the successful charge and discharge of the TES canisters. Axial flux levels to 15 watts/cm^2 have been demonstrated and transient tests have demonstrated that the heat pipe will successfully startup from the frozen condition with full power at the onset.

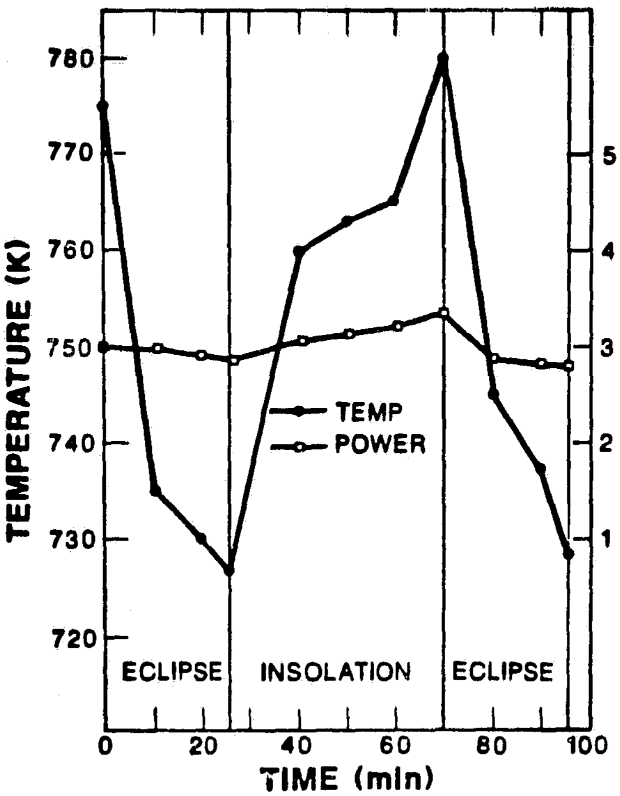

Fig. 7. TES canister fully charged at start of exlipse.

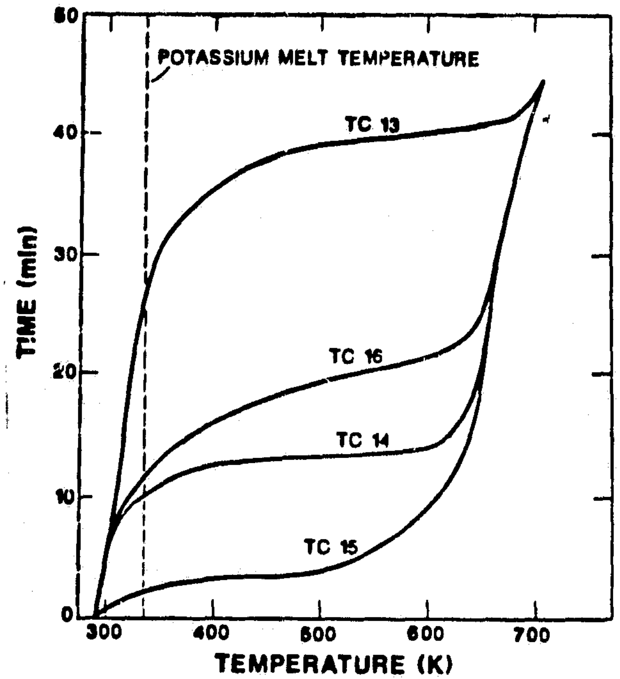

Fig. 8. Temperature versus time of one axial set of thermocouples during solid phase startup to peak input power.

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