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LARGE SCALE SUPERFLUID PRACTICE

S. Caspi, C. Taylor, W.S. Gilbert,
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July 1982

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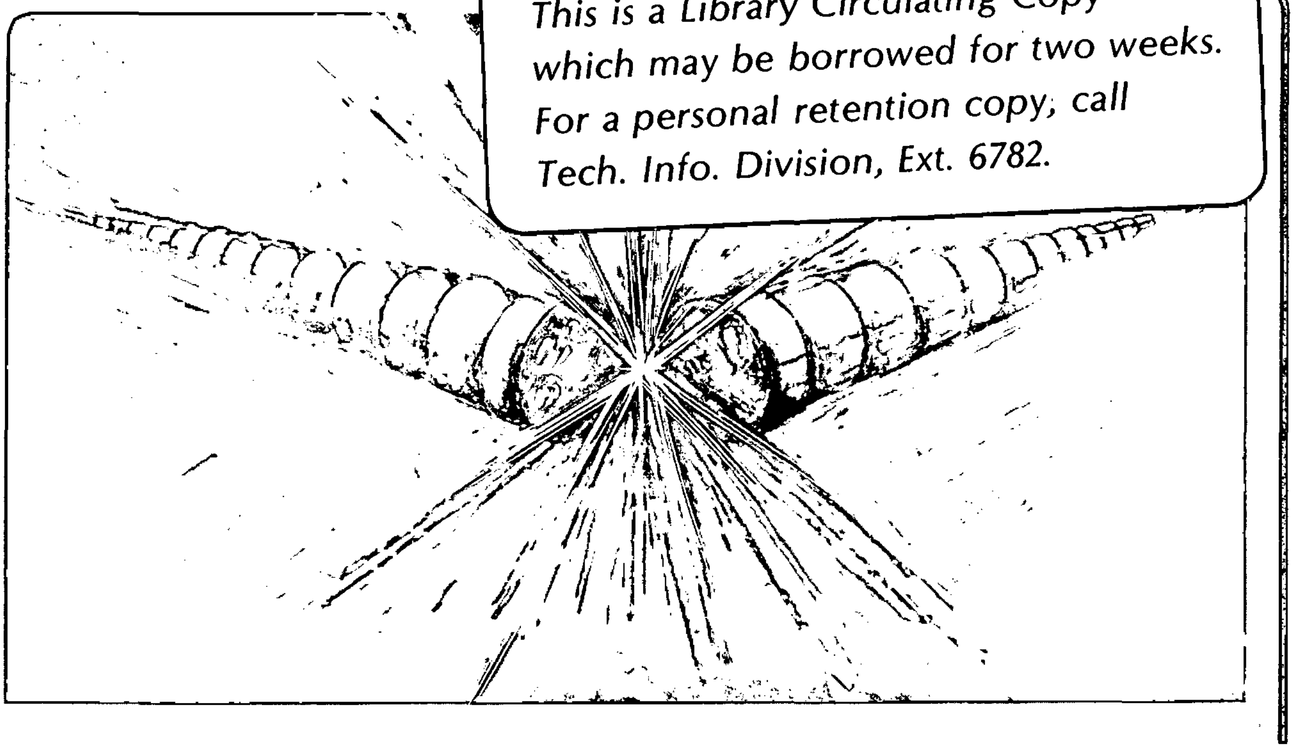

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INTRODUCTION

Since 1979 Lawrence Berkeley Laboratory has been testing superconducting magnets in He II. The 1 atm pressure, 1.8 K, He II, test facility, is an integral part of the LBL Research and Development program on high field superconducting dipole magnets for particle accelerators [1]. Some of the experience gained in this facility and the details of its operation are reported here.

EXPERIMENTAL TEST FACILITY

The dewar is based on the principle of the Claudet bath [2] and provides He II at 1.8 K and 1 atm on a continuous basis. We report here on the dewar in the vertical configuration [3], Fig. 1. The facility was modified recently to accommodate horizontal magnets and a He II volume of up to 400 liters [4].

The vertical dewar consisted of a 28-ℓ He I chamber, a 142-ℓ He II chamber, and a He II refrigeration system. The He I chamber is a heat intercept for the magnet current leads and instrumentation wires, a liquid supply

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for 1.8 K refrigeration, and an atmospheric pressure intercept for the lower He II reservoir. The tube connecting the two chambers permits mass flow to maintain atmospheric pressure in the lower vessel. During steady state operation, He I at 4.4 K and 1 atm is precooled to about 2.6 K in a counter flow heat exchanger. It then expands through a regulated Joule Thompson valve, and exits at a vapor pressure corresponding to about 1.75 K. Downstream, it exchanges heat with the 1.8 K He II reservoir, then precools the counterflow heat exchanger, and finally exits to a pump.

Seven carbon glass thermometers were placed inside the dewar. In the upper vessel, T2 and T1 were 1 and 10 mm from the bottom respectively. In the lower, He II, reservoir, the sensors were mounted as follows (distances are below the top flange): T3 - 5 mm, T4 - 30 mm, T5 - 365 mm, T6 - 835 mm, and T7 - 1225 mm at the bottom of the dewar. The temperature was measured with an accuracy better than 5 mK below T_λ using an H.P. 9845 data acquisition system.

COOLDOWN AND PRODUCTION OF He II

During a typical cooldown the liquid in the region of the heat exchanger reached T_λ (see Fig. 2) approximately three hours after the JT valve was set into operation. During this period, the liquid below the heat exchanger showed good mixing resulting in a temperature difference T7 - T5 < 100 mK. Above the heat exchanger, the liquid was stagnant and the temperature remained near 4.2 K. Temperature sensor T5 was the first to reach T_λ and remained at T_λ until the rest of the liquid in the lower reservoir was cooled to T_λ. The expansion of this "lambda liquid" is gravitationally free and is caused by the heat transfer process at the He I - He II boundary. Helium II expands upwards and downwards but at different rates because of the different bath temperatures in the two directions. Experimentally when the transition boundary passes a sensor location the measured temperature drops to T_λ and remains constant. The boundary is sharp, sensor T3 does not see the cold boundary approaching until the temperature at T4, which is only 25 mm away, has been at T_λ for some time. We estimate T3 remains around 4 K until the boundary is within 1 mm of the sensor. The boundary is thought to be even sharper than the 3 mm thickness of the sensors. The boundary velocity between sensors T6 and T7 which start at $T_\infty = 2.2$ K is 2 mm/sec and between sensors T3 and T4 which start at $T_\infty = 4$ K, is 0.1 mm/sec. These values are typical but depend on the refrigeration power. An estimate on the thickness of the He II - He I boundary layer is reported in Ref. 5.

JOULE THOMSON (JT) EXPANSION VALVE

The temperature across the JT valve during cooldown is shown in Fig. 3. The upstream temperature depends on the heat exchange between the incoming He I liquid and the return cold vapor through the counterflow heat exchanger. The downstream temperature usually reflects the equilibrium between temperature and pressure according to the saturation curve. During the initial cooldown period however, for a pressure less than 40 Torr, the downstream temperature remains at ~2.2 K regardless of the pressure. This behavior changes when the lower reservoir drops below 2.6 K. At this time the downstream temperature falls abruptly to its equilibrium value of 1.8 K and any change in pressure is immediately reflected in a change in the saturation temperature. Simultaneously the upstream temperature levels off about 2.6 K and, as long as this value is maintained, the overall operation is stable. When the temperature difference across the lower heat exchanger is small (e.g. less than ~100 mK) the counterflow heat exchanger cools further and the temperature upstream of the JT drops abruptly to ~2 K. At this temperature the liquid behaves as superfluid and it flows unimpeded through the JT valve. The uncontrolled rush of liquid floods the lower heat exchanger, reduces the cooling efficiency and as a result the system develops a thermal instability. When this happens the JT valve must be shut off so that the heat exchanger dries out and the upstream liquid warms up to He I temperature before cooling can resume.

An undesirable thermal condition can develop under similar circumstances where there is excess refrigeration. When the temperature of the lower reservoir is too low (<1.7 K) or the temperature difference across the heat exchanger is below ~100 mK, the heat flux through the channel connecting the lower and upper vessels is reduced. Accordingly the temperature gradient across the channel is reduced by increasing the effective length from the He II/He I interface to the main He II bath. As result the interface moves up through the tube until it crosses the channel entrance at the bottom of the He I reservoir. A stable layer of cold helium with a temperature $T_\lambda - \varepsilon$ is establshed that draws heat from He I by conduction only (Fig. 2).

SUPERLEAK

One of the design goals of the He II test facility was to have a simple procedure for magnet installation before and after each test. This was accomplished by using a breakable seal between all flanges. The application of an epoxy resin seal (50-50 mix of Shell Epon 828 and Versamid 140) was found to be leaktight even though superleaks can develop in He II. This procedure has been used about 30 times and found to be reliable. The only time a superleak was observed was when the membrane of a pressure transducer developed a superleak. The recorded superleak is shown in Fig. 4 and described below.

The cooldown from 4.4 K proceeded at first with no indication that any leak was present, as indicated by cooldown rate and vacuum. After superfluid was created and propagated throughout the dewar the He II/He I interface finally reached the top of the He II vessel and entered the connecting tube. At this time the superfluid also reached the superleak in the pressure transducer located on the upper flange. The superleak spoiled the vacuum and the gas in the vacuum space cooled the He I vessel and warmed up the lower dewar by convection. This heat leak raised the temperature in the vicinity of the superleak above the lambda temperature and the flow of helium into the vacuum stopped. Slowly the vacuum was pumped to its original value and cooldown resumed at a temperature just above T_λ and continued until superfluid again reached the superleak area. This cycle was recorded for over 3 hours with the lower reservoir temperature oscillating around T_λ. In the time sequence the behavior indicated where the superleak might be and when the pressure transducer was removed the superleak went away. To find such a superleak at room temperature is quite difficult if not impossible and this string of events led to its elimination.

CALORIMETRY

The isothermal behavior of superfluid He II and the absence of vapor when it is used at 1 atmosphere provide the means for calorimetry using a straightforward energy balance. The rate of change of temperature during magnet cycling is plotted in Fig. 5 and temperature jumps due to energy dumps during magnet quenches are shown in Fig. 6. The absence of stratification is clearly visible although some of the temperature sensors are located as far apart as 1.5 m.

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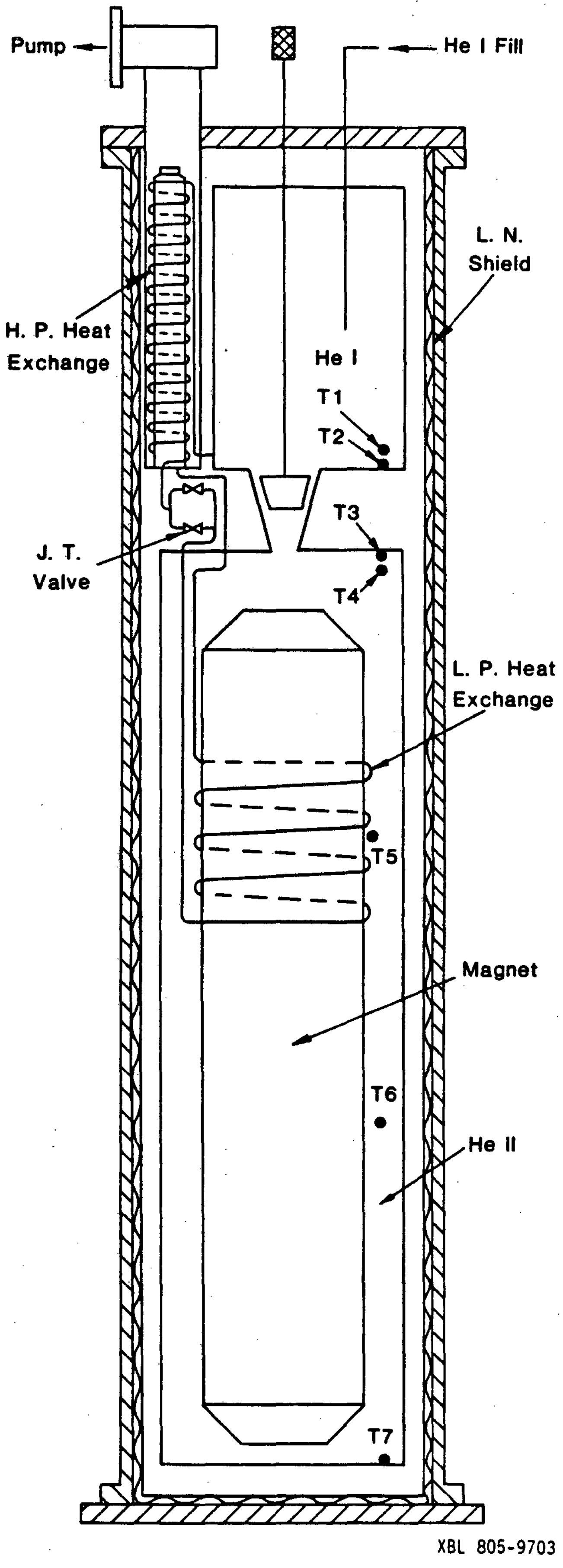

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Fig. 1 Helium II refrigeration system for testing Superconducting Magnets.

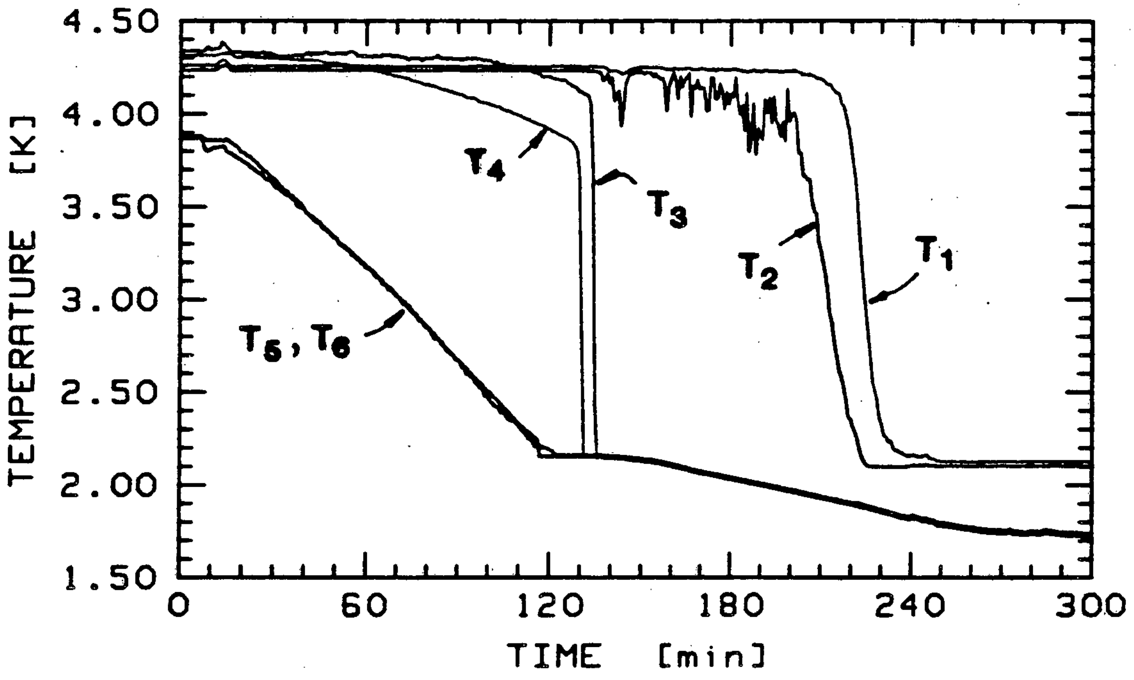

Fig. 2 Temperature at various locations in the cryostat during cooldown.

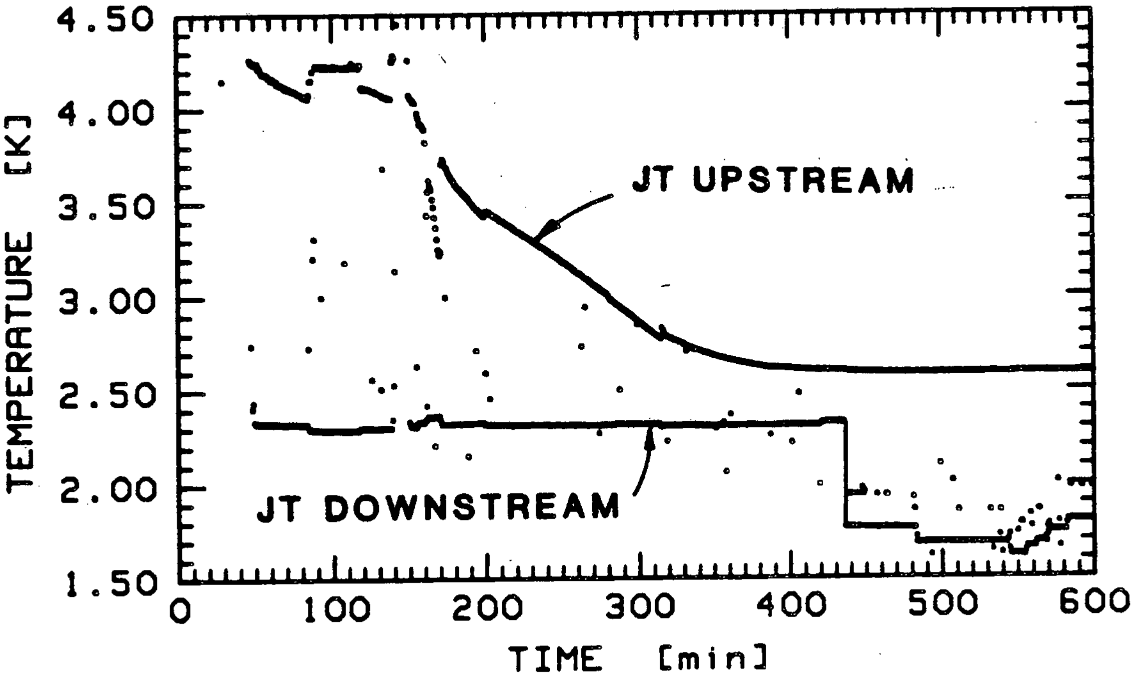

Fig. 3 Temperatures at the JT valve during cooldown.

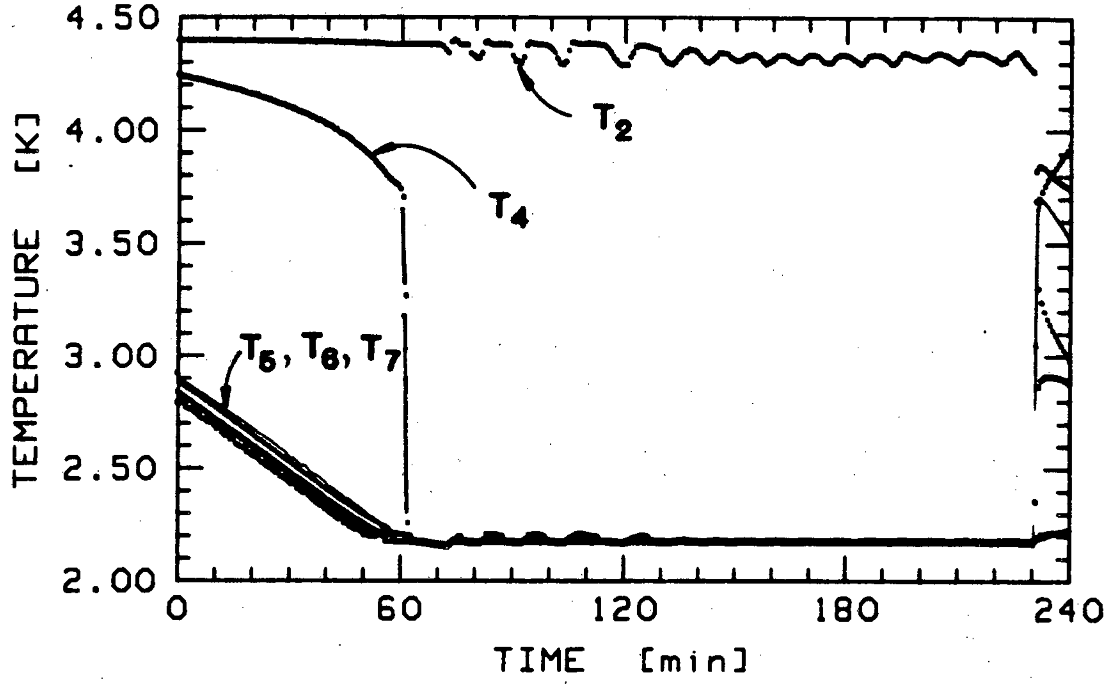

Fig. 4 A superleak inhibits cryostat cooldown below T_λ.

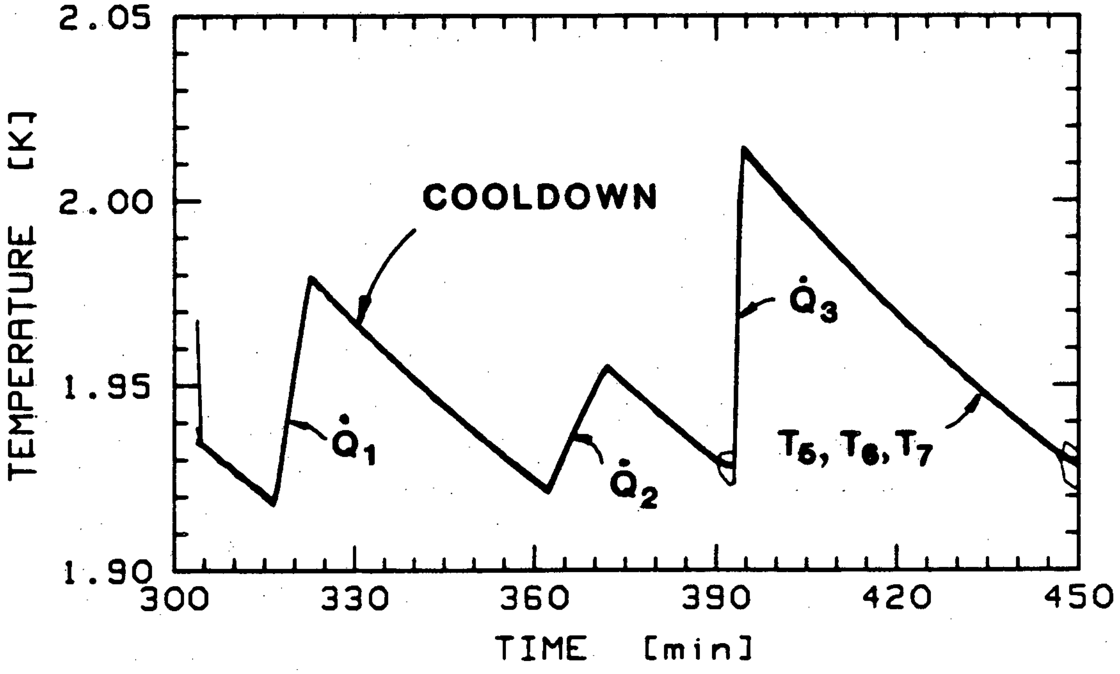

Fig. 5 Superfluid temperature response to various heat inputs.

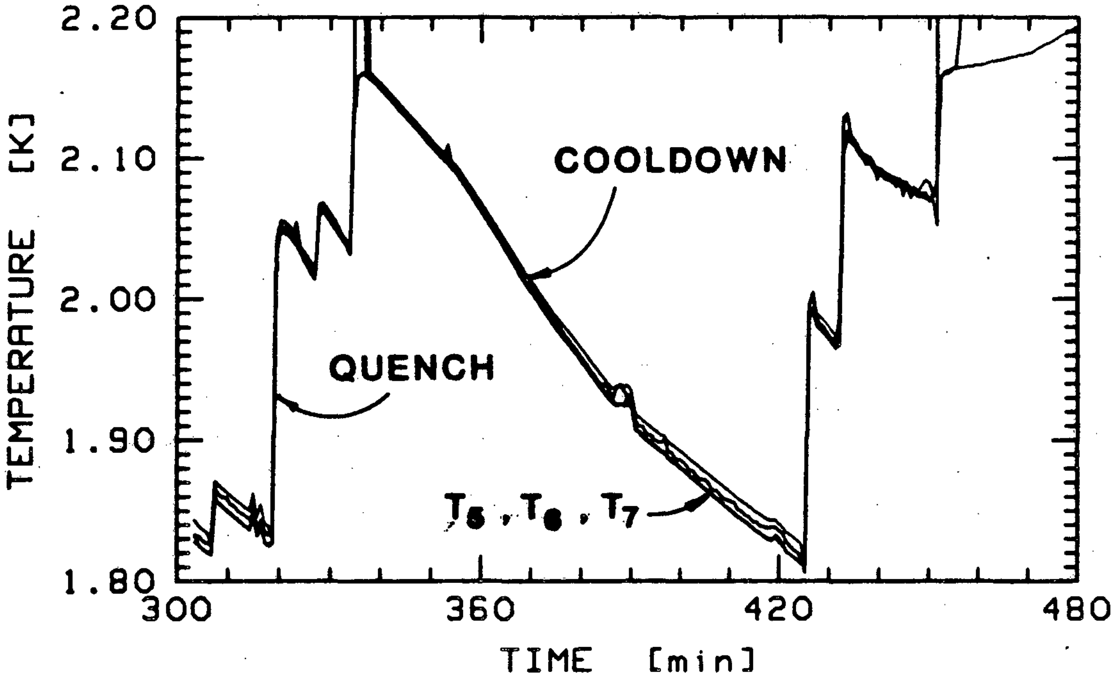

Fig. 6 Cryostat temperature variations for several quenches with some cooling in between.

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