

PROGRESS REPORT ON THE DESIGN OF A VARYING TEMPERATURE IRRADIATION EXPERIMENT FOR OPERATION IN HFIR

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OBJECTIVE

The purpose of this experiment is to determine effects of temperature variation during irradiation on *microstructure and mechanical properties of potential fusion reactor structural materials.*

SUMMARY

A varying temperature irradiation experiment is being performed under the framework of the Japan-USA Program of Irradiation Tests for fusion Research (JUPITER) to study the effects of temperature variation on the microstructure and mechanical properties of candidate fusion reactor structural materials. An irradiation capsule has been designed for operation in the High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory (ORNL) that will allow four sets of metallurgical test specimens to be irradiated to exposure levels ranging from 5 to 10 dpa. Two sets of specimens will be irradiated at constant temperatures of 500°C and 350°C. Matching specimen sets will be irradiated to similar exposure levels, with 10% of the exposure to occur at reduced temperatures of 300°C and 200°C. A listing of the specimens included in the experiment is given in Table 1.

Table 1. Specimen Listing for the Varying Temperature Experiment

Specimen Type	Material	Number (350/200)	Number (500/300)
JP-TEM	Ferritic	200	200
	Vanadium	320	320
	Molybdenum	90	90
	Tungsten	50	50
	Austenitic	130	150
	Copper	80	80
	Nickel	120	120
	Others	50	50
JP-CVN-F1	Ferritic	48	48
JP-TN-1	Ferritic	110	110
	Vanadium	170	120
	Austenitic	70	50
Bar-7	Molybdenum	40	40
	Tungsten	40	40

The specimens are sealed in a static helium environment inside holes drilled into four axially displaced cylindrical specimen holders, as shown in Figures 1 and 2. The low temperature holders are aluminum, and the high temperature holders are beryllium. Aluminum and beryllium sleeves surround the specimens and ensure adequate thermal contact between the specimens and the holders. Holder temperatures, and therefore the specimen temperatures, are controlled by regulating the heat from cartridge type heaters within each holder. Independently controlled temperature control gas mixtures of helium and neon (or argon if required) flow between the holders and the capsule housing tube. The relative amount of the gases in the mixtures is adjusted to control the thermal conductivity of the mixture so that the heater output required to maintain the desired operating temperatures can be minimized.

Specimen temperatures are controlled whenever the reactor power is greater than a low power limit tentatively set at 8.5 MW in order to reduce the exposure levels at improper low temperatures to below 10^{-4} dpa. Specimens in the variable temperature holders will be maintained at 200°C and 300°C for approximately the first 55 hours of each 23-day (average) reactor cycle. Their temperature will then be increased to equal that of the specimens in the corresponding constant temperature zone for the duration of the cycle. The capsule is scheduled for 10 cycles of operation in an europium shielded RB☆ position beginning in early 1998.

PROGRESS

The design of the varying temperature experiment is approaching completion having moved from the conceptual design phase to the final design stage during this reporting period. Work has focused on 1) the development of a robust heater design, 2) testing of the proposed control gas mixture separation scheme, and 3) development of heat transfer models required to set final holder dimensions. A test facility has been constructed and is being used to operate a prototype holder in order to test the heater and gas seal designs used in this experiment, to measure the time response and extent of temperature variations due to control gas mixture adjustments and to benchmark the thermal calculations used in the design of the experiment.

Gas Flow Tests

Electric heaters are used to control specimen temperatures. The required heater output is reduced by flowing less thermally conductive gas mixtures through the temperature control gas gaps during periods of reduced reactor power operation. The thermal conductivity of the gas mixture must be reduced before the reactor can be operated at full power. In order to minimize the delays associated with changing the gas mixture, the capsule is designed to allow the neon or argon to mix with helium inside the capsule at the entrance of the temperature control gas gaps. This is accomplished by utilizing the arrangement shown in Figure 3.

Helium is supplied to the inner region of all four specimen holders at a constant flow rate in order to increase the heat transfer between the heaters and holders. The helium exits the inner region of the capsule by flowing through small holes in the wall of the zone separation piece attached to the base of each specimen holder. Neon or argon (or helium if required) is supplied to this region and mixes with the helium to form the gas mixture. The mixture flows up through the gap and out of the capsule through an effluent tube. To return the control gas to pure helium, the flow of neon is terminated. Pure helium quickly sweeps the residual neon out of all four gas gaps because it is supplied to them in parallel.

The inner radius of the capsule housing tube is used as the outer edge of the four temperature control gas gaps. The outer radius of the holders defines the inner edge of the gas gaps. The four gas gap regions are separated by a grafoil seal held by the upper and lower separation pieces of adjacent specimen holders. An overhanging portion of the seal is compressed between the housing wall and the lower edge of the upper separation piece. The seals mitigate the mixing of gas mixtures from adjacent zones, however some mixing is tolerable and can be compensated for by adding either extra neon or helium to the gas mixtures of upper zones as required.

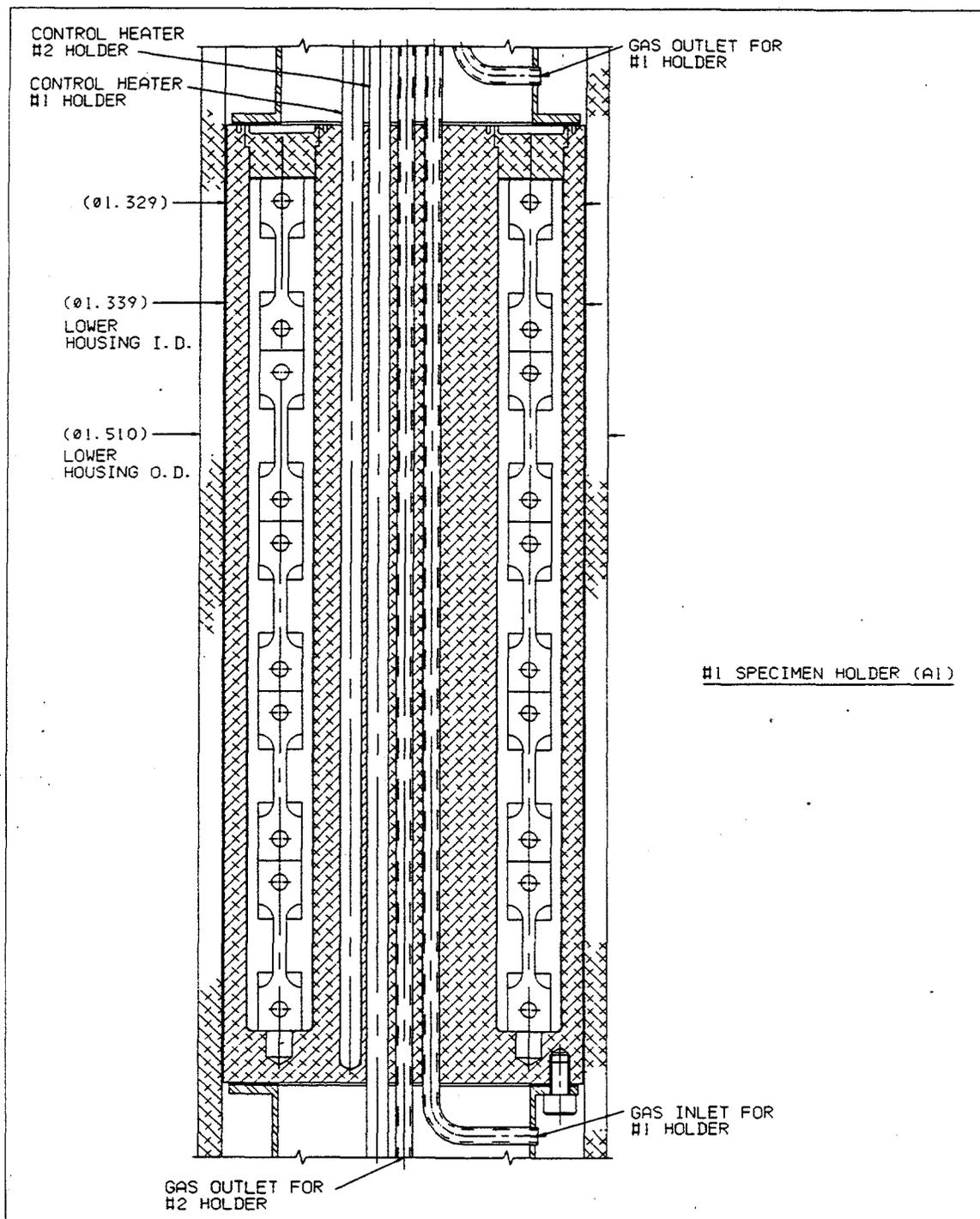


Figure 1.A specimen holder. The specimens are encased in sleeves, which are inserted into holes drilled into the face of the holder. Caps are welded at the end of the holes to seal the specimens in a static helium atmosphere. The inner radius of the housing tube and the outer radius of the holder defines the temperature control gas gap for the holder.

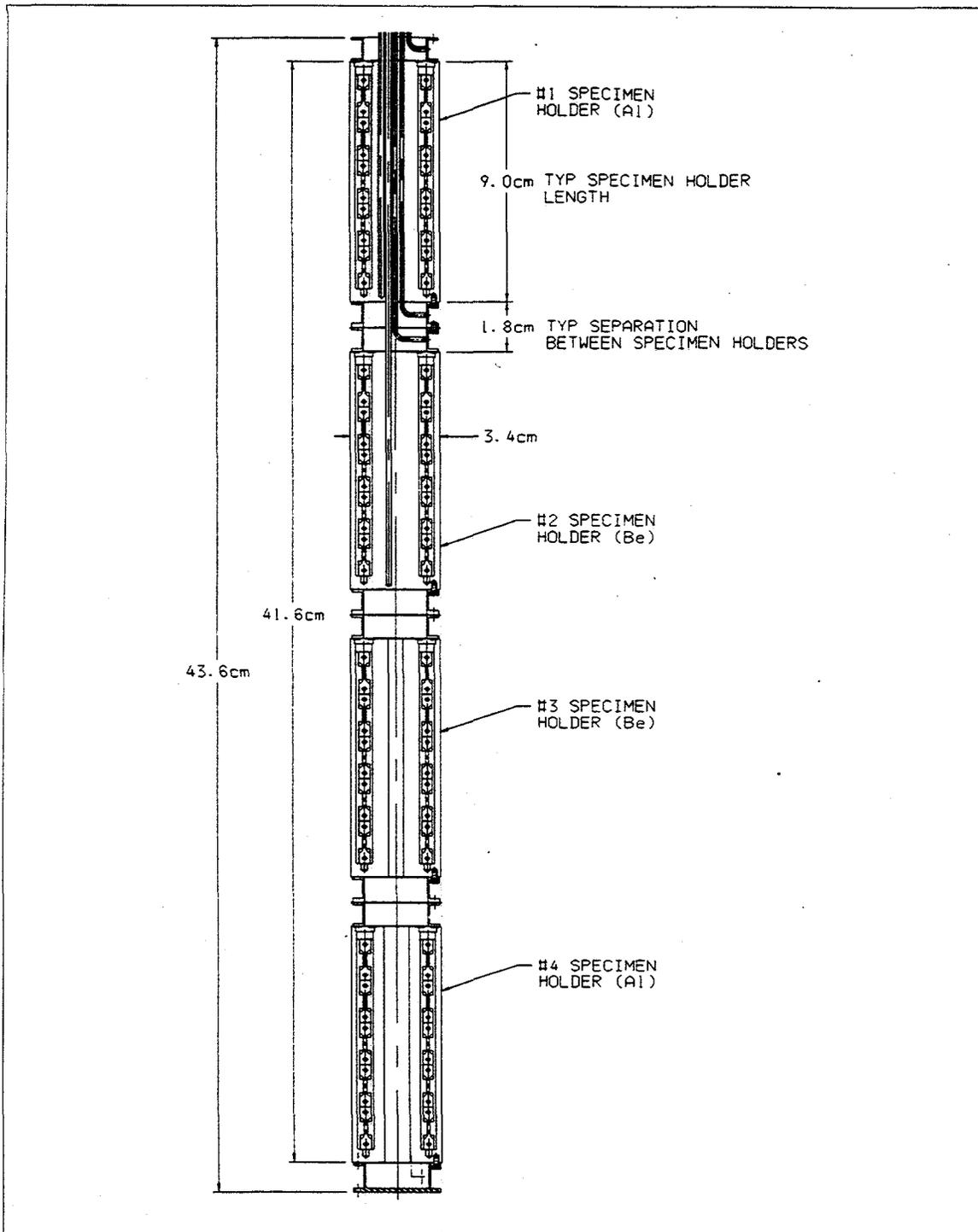


Figure 2. The arrangement of four specimen holders in the Varying Temperature Experiment. The lower two holders are varying temperature holders and the upper holders are their constant temperature counterparts. The two central, high temperature, holders are beryllium and the end, low temperature holders are aluminum.

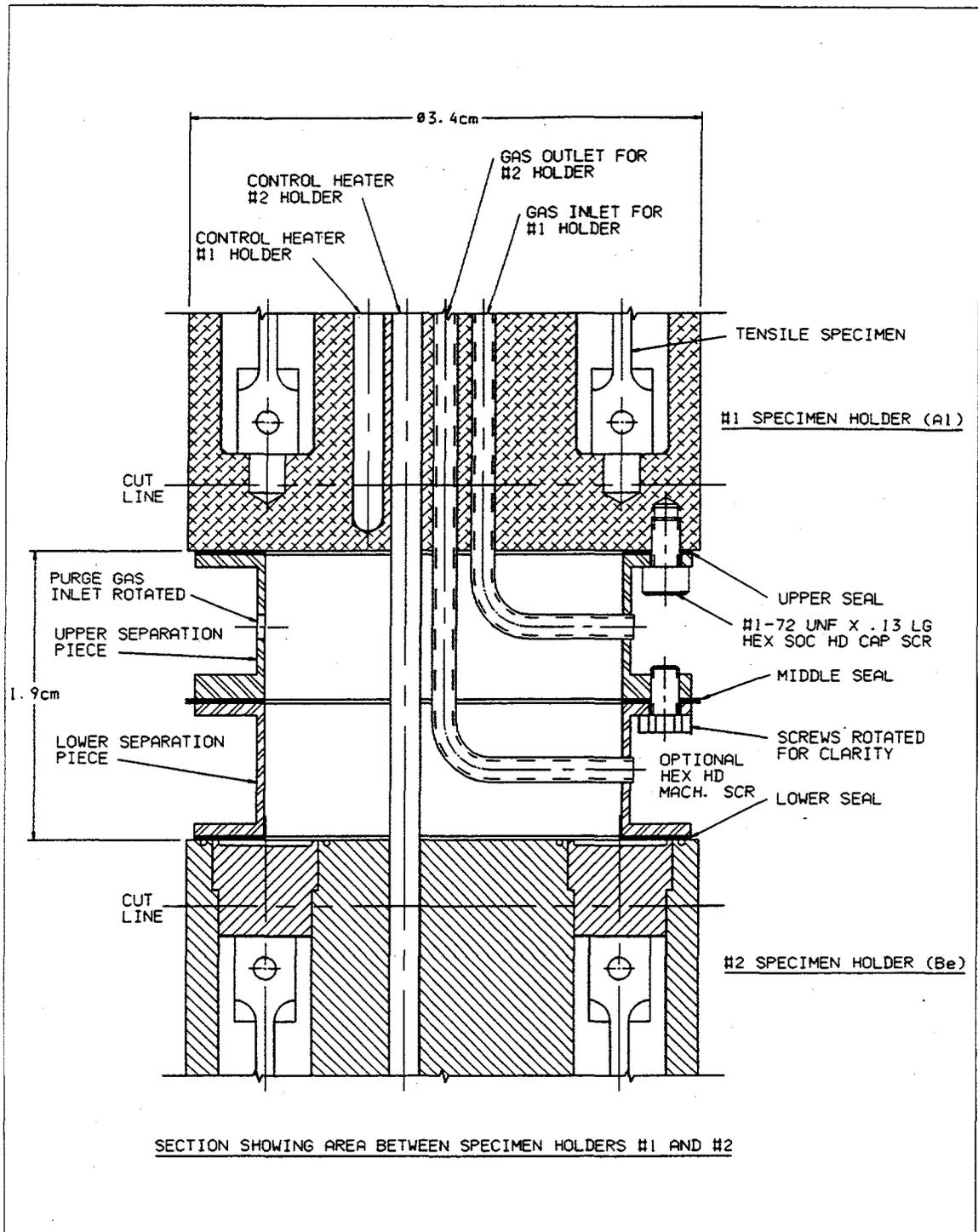


Figure 3. Arrangement of the region between two holders. The heaters and gas tubes for lower holders passes through holes in the upper holders. Stainless steel separation pieces physically and thermally separate the holders. The seal between the separation piece separates the control gas mixtures and centers the holders in the capsule housing tube.

The gas gap separation seals also center the holders within the capsule housing tube, helping to establish a symmetric gas gap, and provide insulation against heat loss from the end of the holders. The maximum range of temperature control through gas mixture adjustment is permitted when all of the heat generated within the holder is lost across the gas gap. The thin-walled, stainless steel separation pieces are designed to minimize parasitic end losses.

Time response tests have been conducted in which the temperature of a prototype holder was increased using a combination of heat input and gas mixture adjustment. The results from a typical experiment are shown in Figure 4. The temperature began to drop almost immediately after the flow of argon was terminated and was essentially eliminated within a minute of terminating the flow.

Heater Development

Two heater designs are used in this experiment. Both designs incorporate two axially displaced, nichrome elements housed in a 2.23-mm O.D. stainless steel sheath. The elements can be controlled independently, together, or with elements from other heaters to form heating zones. The heaters are inserted into axial holes in the inner region of the holders. One type of heater is used to control holder temperature. The other is used to add heat to the holder when the reactor is operating at reduced power.

The heater elements in the control heaters are slightly overlapped and together span the length of a holder. By operating either the upper or lower element, heat can be added selectively to the top or bottom of a specimen holder. This allows the heaters to compensate for the temperature gradients encountered during the operation of the experiment. There are three control heaters for each specimen holder.

The common heaters (named because they add heat to more than one holder) are similar to the control heaters except that their elements are longer (each element spans the length of a specimen holder) and the elements are displaced so that they add heat to adjacent holders. The common heaters are used in conjunction with the control gas mixtures primarily to reduce the required power output of the control heaters. They can be also used as the control heaters if necessary.

Several control heaters have been built and tested to failure in the testing facility. The greatest potential for failure occurs due to overheating in the region between the holder into which a heater is supplying heat and the holder directly above it. This is due to the nickel extension leads in this region, which produce an appreciable amount of heat when the heaters are operated at high current. A nickel transition is required between the nichrome heater element and the copper extension leads because the high temperatures expected within the elements at full power would melt copper extension leads if they were connected directly to the nichrome.

The exposed region of the heaters is a fusible link in the event of a simultaneous heater controller and fuse failure. If the controller were to inadvertently expose the heaters to the maximum voltage potential of 110 VAC and the fuse for that heater (10 amps) did not blow, the nickel wire will overheat and melt, opening the control circuit. It is possible that the current could short through the sheath to the grounded structure of the capsule, however the heat input into the capsule would be terminated. Testing has shown that heater failure can be avoided by limiting the sheath temperature in the region between holders to less than 1000°C. In the capsule, thermocouples monitor heater sheath temperatures in the exposed region between the two high temperature holders.

Three control heaters have been cycled dozens of times beyond the peak demand expected during the experiment. The current through both elements has (to date) been rapidly increased from 0 to 9 amps (a total of power output of approximately 160 watts per element) and allowed to operate at this power until temperature equilibrium was attained. Both elements in the heaters have been operated at 9 amps for extended periods to simulate reactor start-up with long delays at low power. Also, individual elements have been operated at

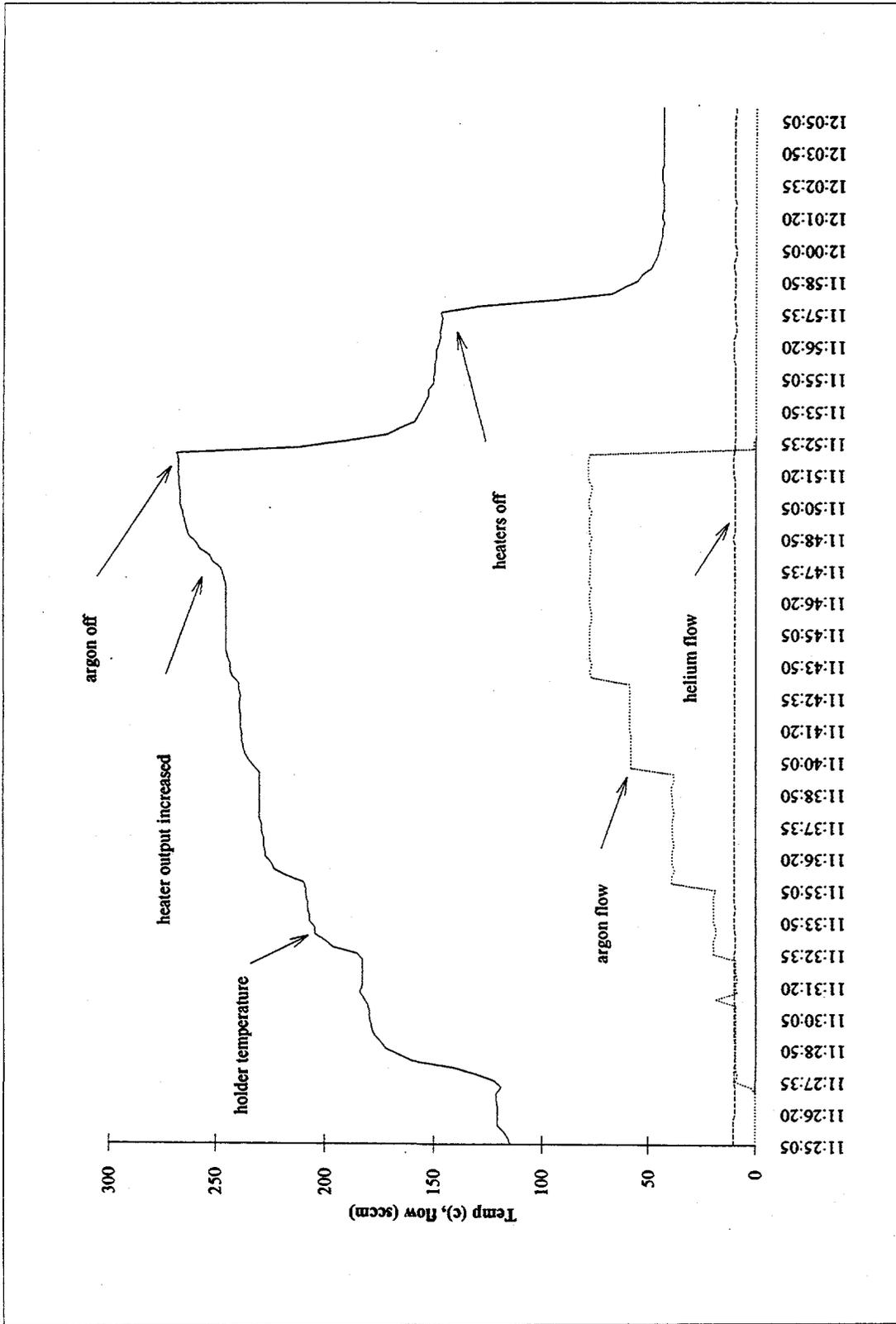


Figure 4. Plot showing the temperature response of the prototype holder to a sudden elimination of argon from the temperature control gas mixture.

currents greater than 14 amps (approximately 400 watts) for extended periods. Temperature gradients of greater than 4 °C/cm can be established across the prototype holder by operating either the upper or lower elements as a group, which is adequate to compensate for the expected temperature gradients.

FUTURE WORK

Heater power output is controlled by regulating the current passing through them. The controllers must have adequate response time to compensate for the temperature changes associated with temperature control gas mixture adjustments and reactor power changes. Avoiding specimen temperature overshoot is a principal requirement of the control system. The testing facility is presently being used to evaluate controllers and a selection is expected soon.

The engineering drawings for the experiment are nearing completion. The final aspect of the design will be to set the outer dimension of the four specimen holders in order to establish the temperature control gas gap. The setting of the holder dimensions is complicated by an unknown heat generation within the europium liners and unknown heat generation rate in beryllium. The operation of the RB-11J and RB-12J capsules is being evaluated to determine the heat generation rate of materials inside the europium liners. The neutron and gamma flux calculations used in the design of RB-11J and RB-12J are being modified to estimate heat generation rate in a beryllium holder inside the new liners as opposed to the aluminum holder material that was assumed in the RB-11J and RB-12J calculations. Heat transfer models are being benchmarked against the prototype tests so that the final holder dimensions can be set as soon as the heat generation rate is established.

Except for a few details, the design is complete. Test welds are to be performed in March 1997 to develop a procedure for sealing the specimens in the holder specimen holes. The specimens are scheduled to be delivered to ORNL in June, at which time assembly will begin. A paper on the final testing results and design is being prepared for presentation at the ICFRM-8 Conference in Japan in October 1997.