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December 13, 1993

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Research/Accident Evaluation Branch
Office of Nuclear Regulatory Research
MS: NLN-344
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Subject: Condensation Test Procedures and Results

Dear Dr. Malliakos:

A series of tests to be conducted in the Surtsey Test Facility will determine igniter effectiveness in rapidly condensing steam environments. These tests will be performed by the Severe Accident Phenomenology Department, 6422, as part of the U. S. Nuclear Regulatory Commission's effort on severe accident research. Experiments with both well-mixed and stratified hydrogen will be performed. The three objectives of the experiments are to determine: (1) if energetic forms of combustion are possible when originally non-flammable hydrogen/air/steam mixtures are ignited while the mixture is de-inerted by water sprays, (2) the effectiveness of water sprays in mixing hydrogen, and (3) the effect of hydrogen stratification on the maximum combustion pressure.

For the combustion tests, the Surtsey vessel is first heated internally with steam and externally with a liquid propane gas burner to ensure steam pressurization and to minimize steam condensation while setting the initial atmosphere conditions. After heatup, the general procedure of the experiments is to initially inert the Surtsey vessel with saturated steam. After inerting the vessel, the vessel will be pressurized with saturated steam (413 K) to about 0.36 MPa. Hot air (413 K) is then added to increase vessel pressure by about 0.12 MPa. The air concentration will be ≈24 mol.%. The gases are mixed using three 1000 cfm pneumatically operated fans installed inside the Surtsey vessel. In the well-mixed experiment, heated hydrogen (413 K) is added with the fans operating until its final concentration is ≈4 mol.%. The final vessel temperature and pressure prior to operation of the sprays will be approximately 413 K and 0.50 MPa. After verifying the glow plug igniters are operating nominally, the water spray will be initiated. The target spray nozzle flow rate and the temperature of the spray water are 23.3 gpm and 323 K. The spray is expected to operate up to and after the combustion event. Enough water is available to provide 21 minutes of spray at the nominal spray flow rate.

The procedure for the stratified experiments is nearly identical to the procedure for the well mixed tests. The main difference is that the hydrogen injection point is located

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Enclosure 3

approximately in the middle of the Surtsey vessel and the mixing fans are turned off prior to the addition of hydrogen. The target conditions are to have stoichiometric mixtures above the injection point and no hydrogen below. This would result in mixtures with ≈ 8 mol.% hydrogen above the injection point before the operation of the sprays.

A well-mixed condensation test was performed on November 19, 1993 after the Surtsey vessel had been instrumented, sealed, and pressure tested. This test was a prerequisite for the igniter effectiveness combustion tests. Figures 1-3 give isometric views of the Surtsey vessel. Figure 1 shows the floor subdividing the vessel to provide a freeboard volume of 59.1 m^3. Figures 2 and 3 show instrumentation and instrument locations. The vessel heatup commenced at 1600 on November 18. The portable steam boiler provided a low-pressure, saturated steam heat source to Surtsey. Initially, the steam that entered Surtsey condensed and provided latent heat to the vessel walls and atmosphere. A steam trap allowed removal of the condensate without removing gases. As the vessel heated, the steam condensation rate decreased and the vessel began to pressurize. The liquid propane gas burner mounted under the dividing floor was controlled to match gas temperatures above and below the floor during the heatup to minimize structural stress and heat loss. The heatup was completed at 0700 on November 19; the vessel pressure and temperature was 0.54 MPa and ≈ 424 K.

The vessel has a small, known leak rate, about 0.0046 MPa/hr. As the vessel is pressurized with steam, small amounts of air and steam leak out. Prior to the test, the vessel was inerted completely with steam to ensure a known initial atmosphere condition. A series of vessel fill and vents was performed. The vessel was vented to near atmospheric pressure and then refilled with steam to a pressure of about 0.25 MPa. This was performed five times and the entire procedure lasted about two hours.

Air (1665 g·moles) and helium (266 g·moles) was then added to the vessel. Standard compressed gas cylinder are used. The gases pass through a heat exchanger, where they were heated to 403 K prior to entering the vessel. Since this was about 10 K below the saturation temperature, some steam condensed and it was necessary to add a small amount of steam after the noncondensible gases were added.

The initial test pressure in the Surtsey vessel was 0.4750 MPa and the gas temperature was 419 K. The initial vessel atmosphere concentrations were 76.05 mol.% steam, 20.65 mol.% air, 4.32 mol.% oxygen, and 3.30 mol.% helium. Disregard the preliminary gas concentrations reported on December 1. They were estimated based on nominal compressed gas cylinder information reported by the gas supplier. The new concentrations are based on the actual amounts of gas (from pressure and temperature measurements) from the cylinders that were used during the test.

There was a small amount of water on the floor prior to initiating the spray. The use of the steam trap to remove the floor condensate was discontinued during the test due to a non-test related discharge permit problem. The water could be seen with the camera mounted on a level 4 port penetration and it is estimated that the water level was about 3-5 cm. After spray initiation, the camera view showed what appeared to be a 'light rain' inside the vessel. Figures 4 and 5 showed that the vessel pressure and bulk gas temperature steadily decreased

during the spray down. The average bulk gas temperature was calculated by averaging the temperature data obtained from the five vertical thermocouple arrays, shown in Figures 6-10. The bottom thermocouple on each array showed water reaching the 15 cm level at about 9-10 minutes after spray initiation. (Thermocouple 41 on array A is not shown on Figure 6 since its amplifier was used for another purpose during this test.)

Figure 11 shows the vessel floor, wall, and dome temperatures. The three floor thermocouples showed good agreement, indicative of water on the floor. The two 'wetted-wall' thermocouples (Ch38 and Ch88) showed lower and more erratic temperatures due to water streaming down the walls as compared to the upper wall thermocouples (Ch37 and Ch87). These thermocouples were mounted near the upper head flange and were located just above the sprayed-unsprayed transition boundary. The upper wall thermocouples and the dome thermocouple showed good temperature agreement.

Figures 12 and 13 give the spray nozzle flow rate and water temperature. The spray flow rate was 30.5 gpm. This slightly exceeded the target value of 23.3 gpm. The vessel was sprayed with hot (321 K) water for 16.3 minutes, until the spray tank emptied. The total amount of water that was sprayed was 497 gallons. Air (driving the water spray) flowed into the vessel for about one minute after the water spray tank emptied. This caused Surtsey vessel pressure to increase about 0.04 Mpa.

Figures 14 and 15 give the time-dependent vessel steam, oxygen, and helium fractions. The fractions were calculated using the measured pressure and calculated average gas temperature data along with P,V,T ideal-gas law relationships. It was assumed that the air and helium noncondensible gas amounts remained constant at the initial values throughout the test.

The final ($t = 16.3$ min) vessel pressure and temperature was 0.1827 MPa and 367 K. The final atmosphere concentrations were 45.42 mol.% steam, 47.06 mol.% air, 9.84 mol.% oxygen, and 7.72 mol.% helium. Table 1 summarizes the initial and final conditions for the HIT-1 well-mixed condensation experiment.

The noncondensible gas heat exchanger will be modified to ensure that the hot gas entering Surtsey will not condense steam. Also, the pressure regulator that controls the water spray flow rate will be adjusted under nominal, prototypic test conditions to meet the 23.3 gpm target flow rate. Permits have already been obtained that allow the discharge of condensate water and boiler cooling water.

If you have questions or need any further assistance, do not hesitate to call me at (505) 845-3048 or FAX (505) 845-3435.

Sincerely,

Tom Blanchat

Thomas Blanchat
Severe Accident Phenomenology
Department 6422

Table 1
Initial and Final Conditions for the HIT-1 Well-Mixed Condensation Experiment

		Initial (t=0 min)	Final (t=16.3 min)
Absolute pressure in Surtsey (MPa)		0.4750	0.1827
Gas temperature in Surtsey (K)		419	367
Total gas moles in Surtsey (g·moles)		8061	3537
Gas composition in Surtsey (mol.%)	Steam	76.05	45.42
	Air	20.65	47.06
	O_2	4.32	9.84
	H_2	3.30	7.52
Surtsey floor temperature (K)		414	383
Surtsey wall temperature (K)		414	390
Surtsey dome temperature (K)		413	397
Spray nozzle water flowrate (gpm)		30.5	
Spray nozzle water temperature (K)		321	
Freeboard volume inside Surtsey		59.1 m^3	

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NRC C. Tinkler
6429 D. Stamps
6422 M. Allen
6422 R. Nichols

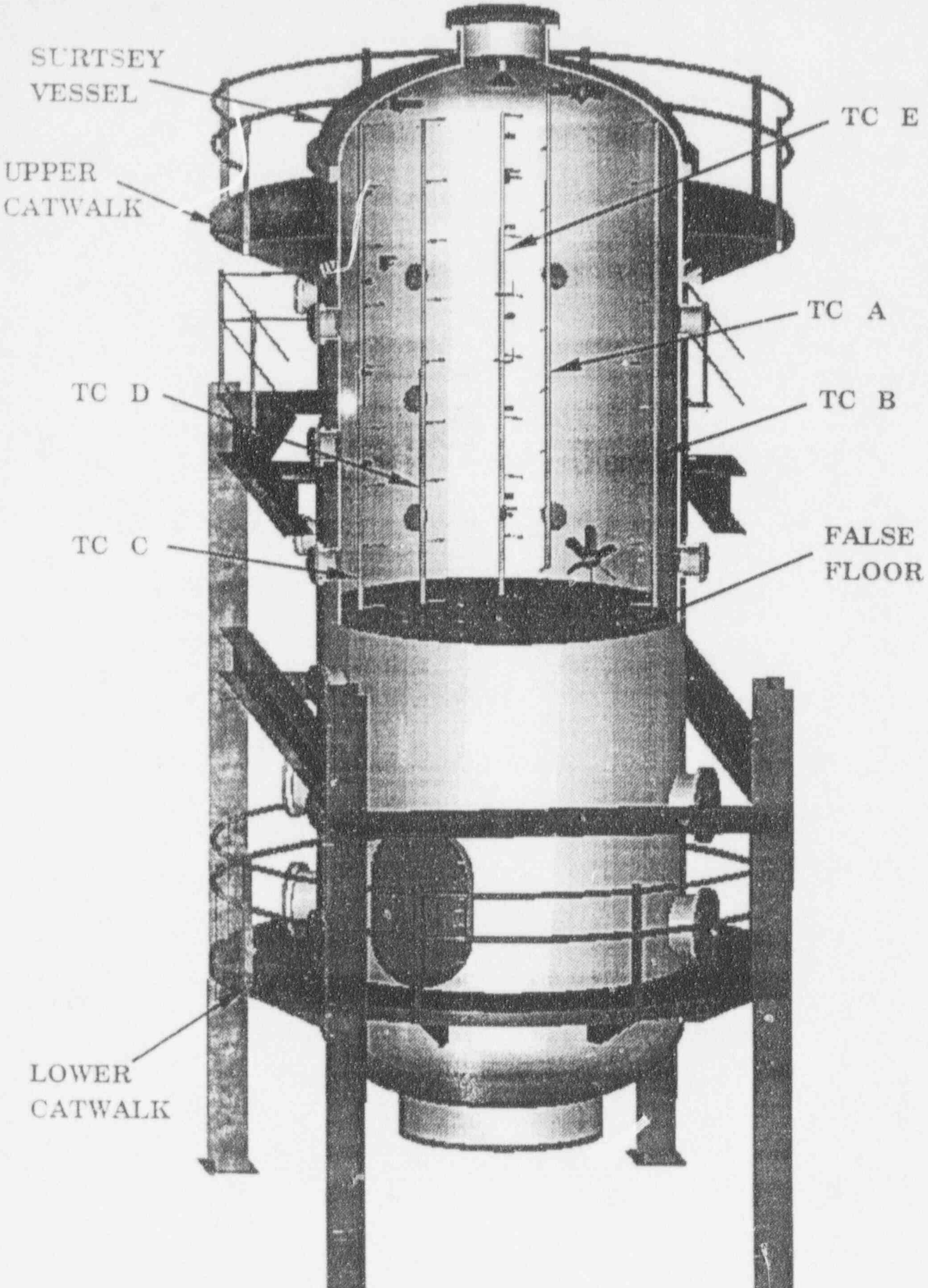

Figure 1. Location of the igniter effectiveness test in the Surtsey vessel.

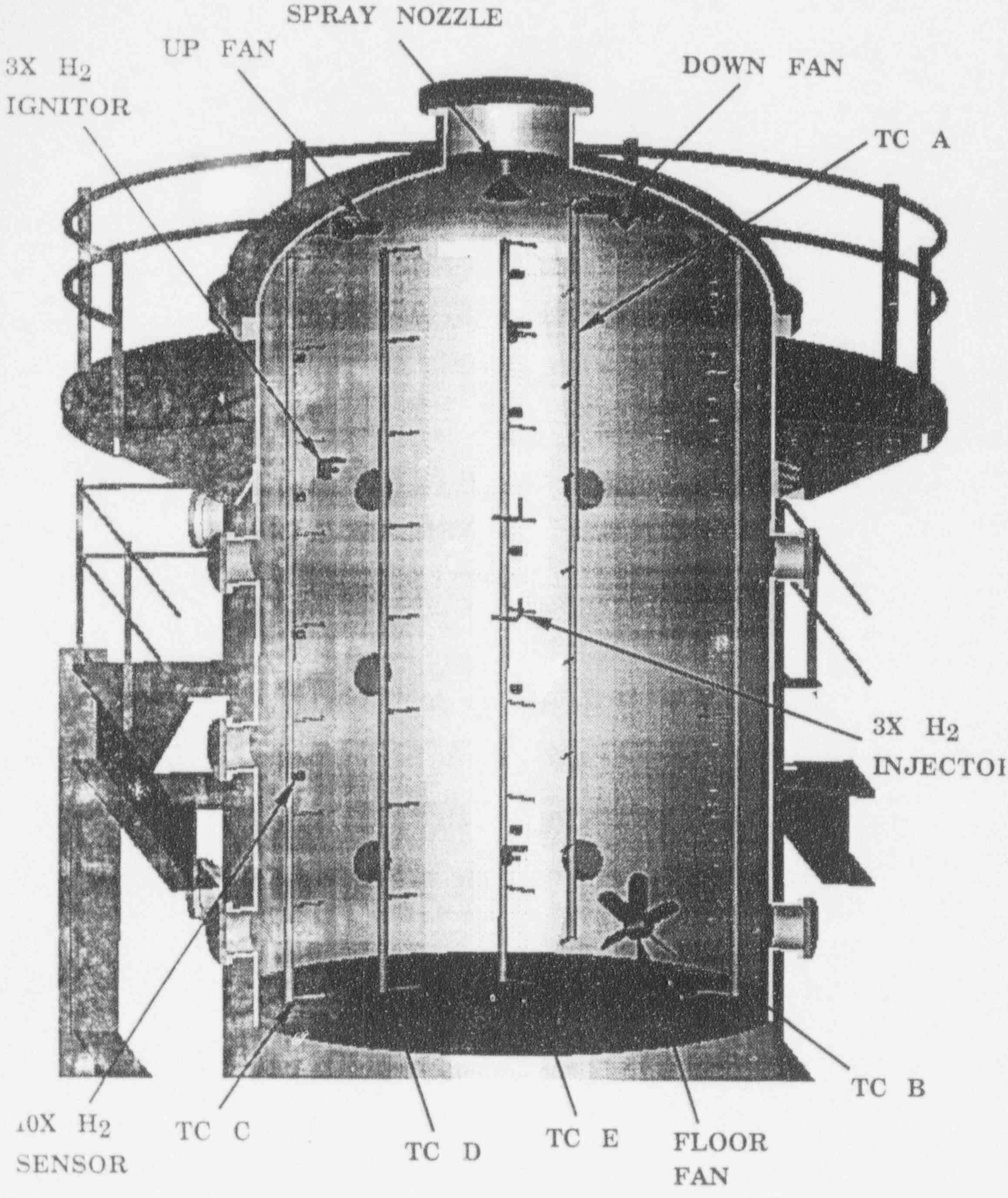

Figure 2. Igniter test instrumentation, mixing fans, hydrogen injectors, and spray nozzle.

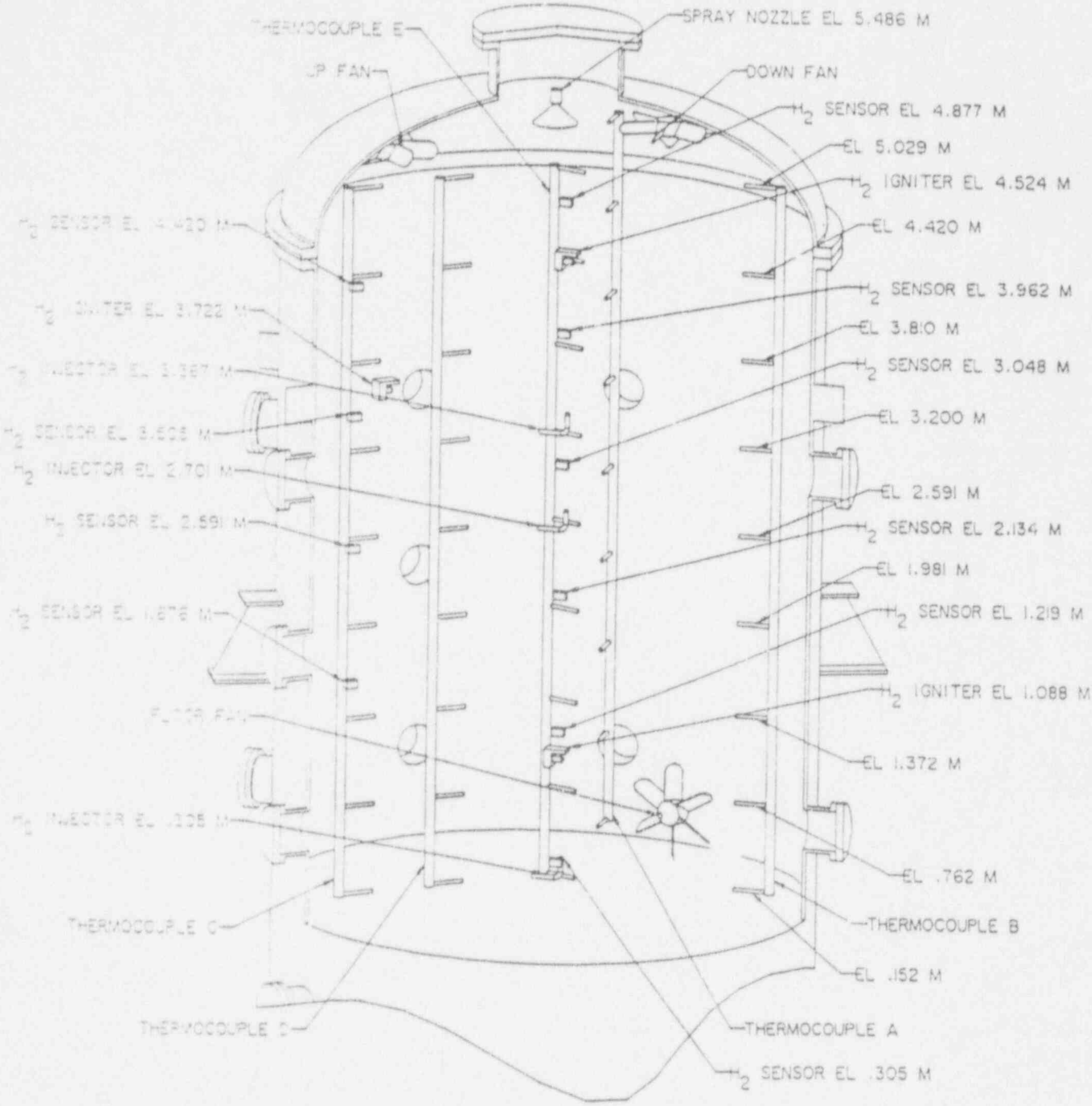

Figure 3. Location of the instrumentation in the igniter effectiveness test.

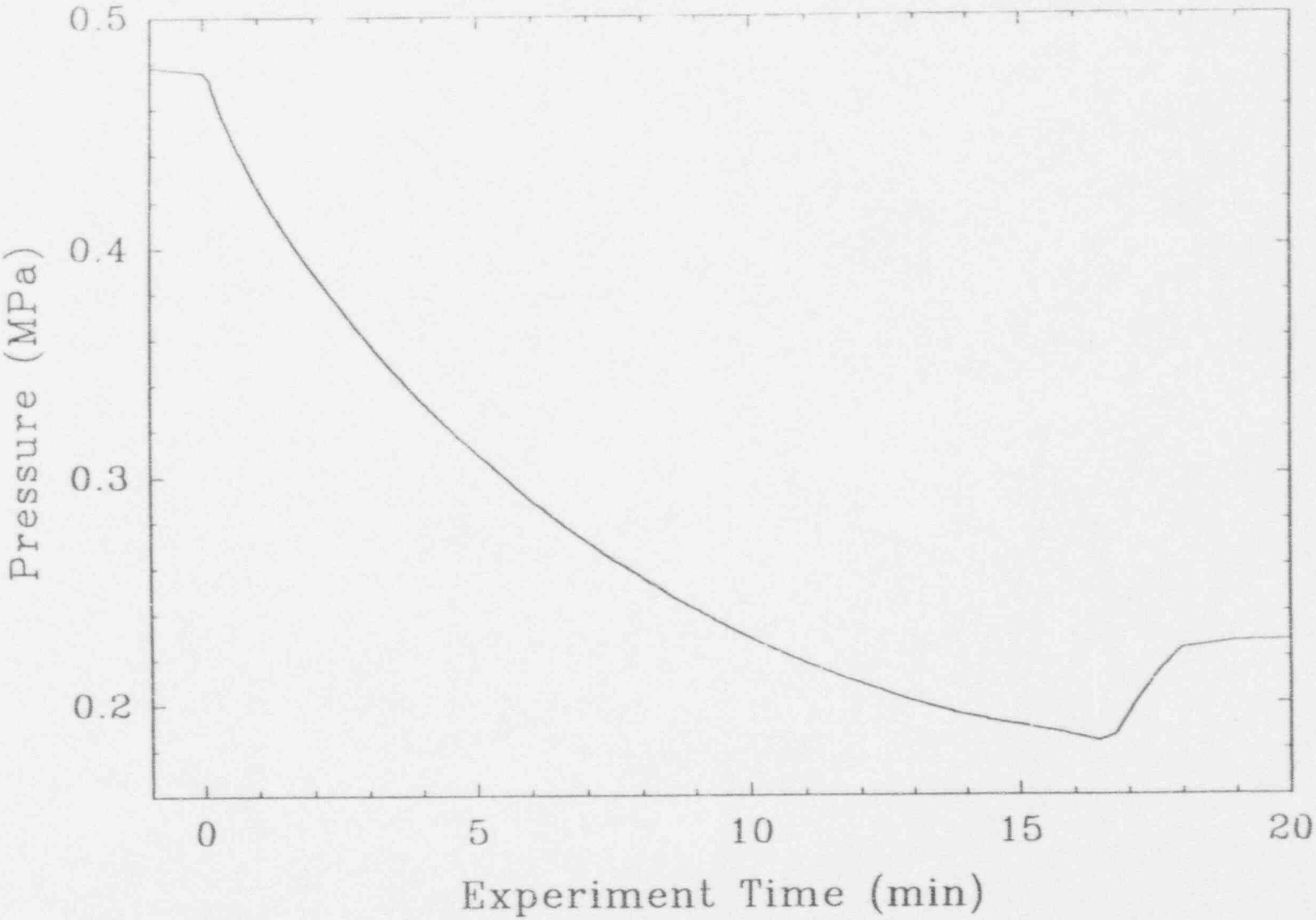

Figure 4. Surtsey vessel pressure in the HIT-1 well-mixed condensation test.

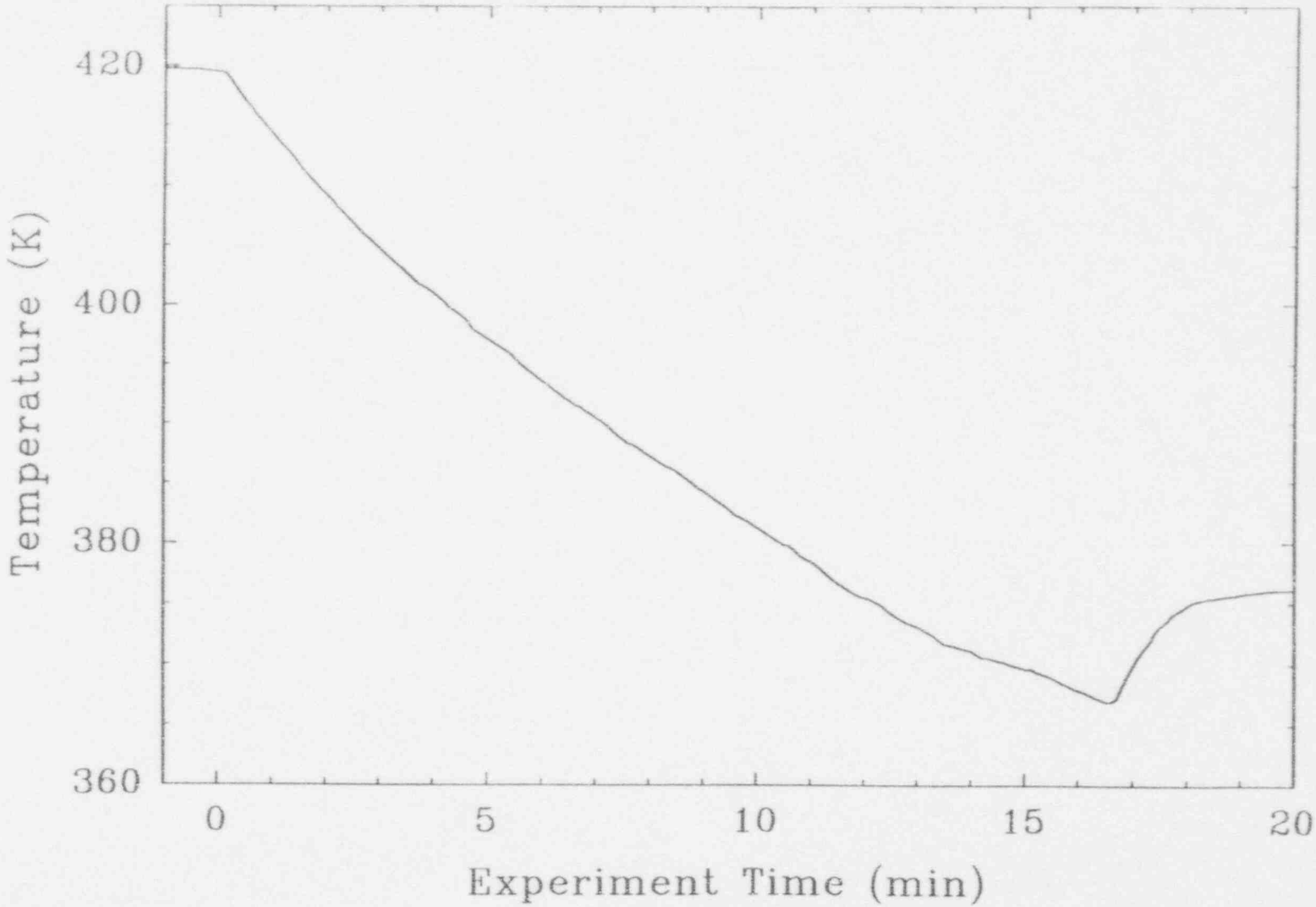

Figure 5. Surtsey vessel average gas temperature in the condensation test.

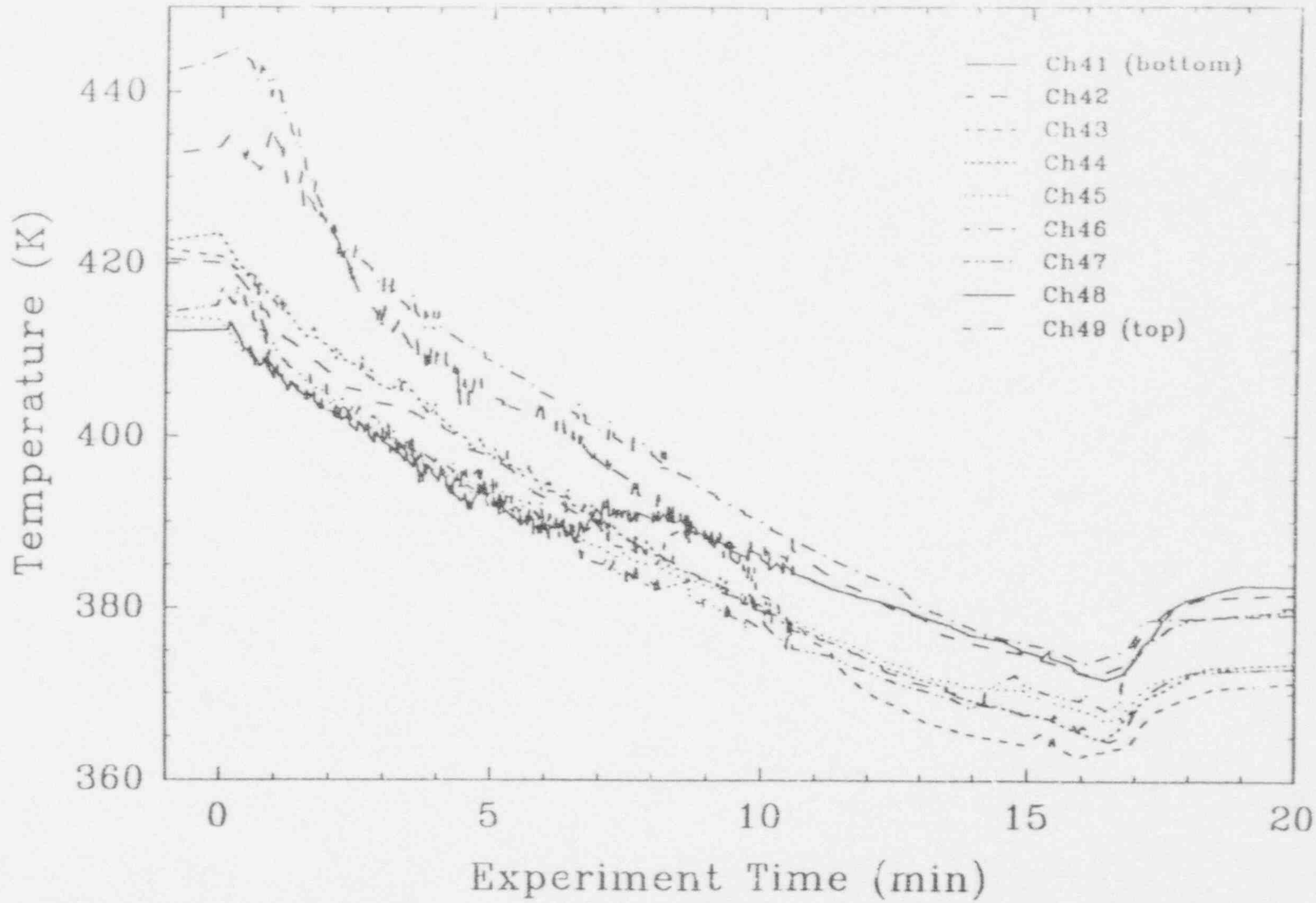

Figure 6. Surtsey vessel gas temperatures from the A thermocouple array in the condensation test.

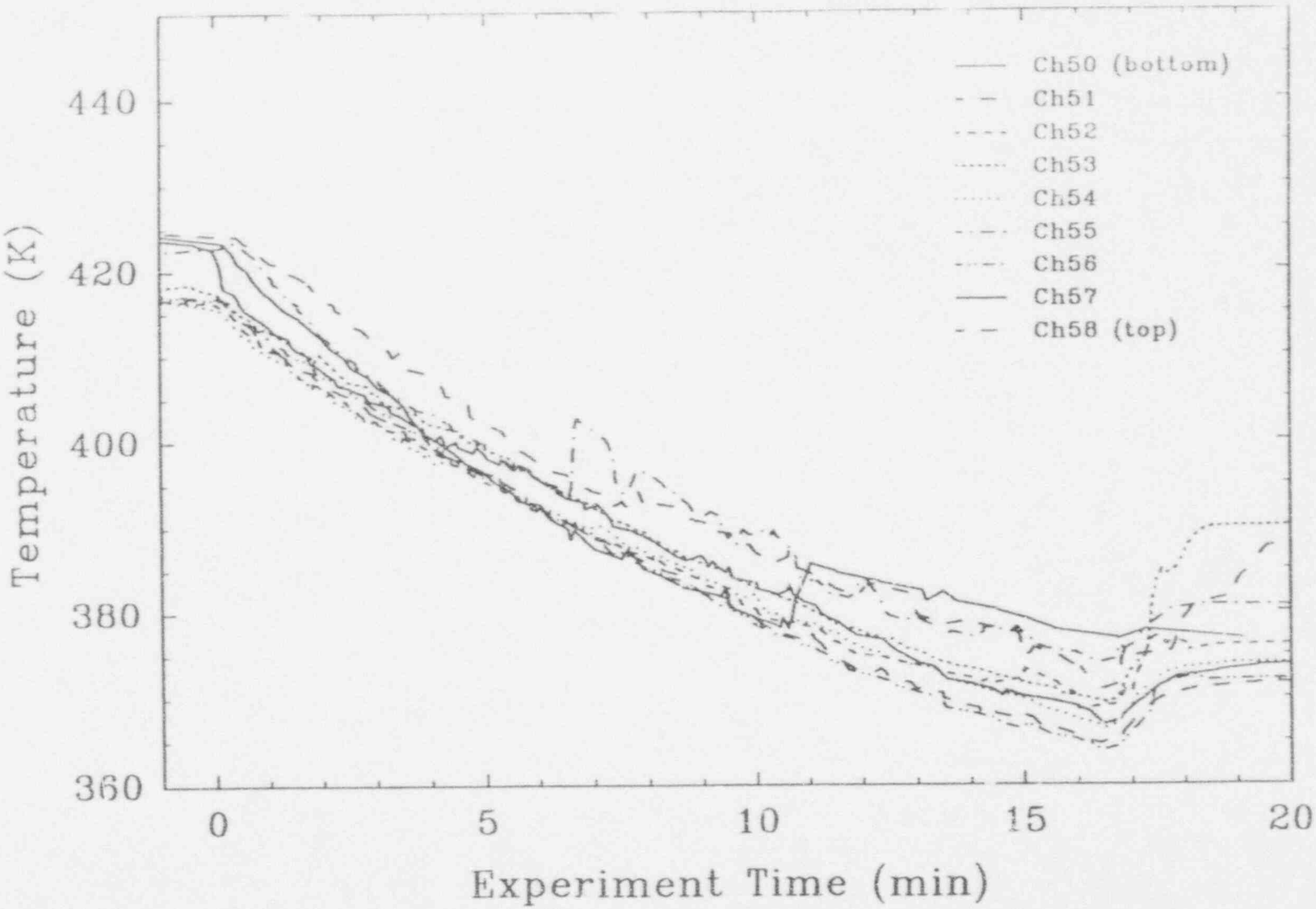

Figure 7. Surtsey vessel gas temperatures from the B thermocouple array in the condensation test.

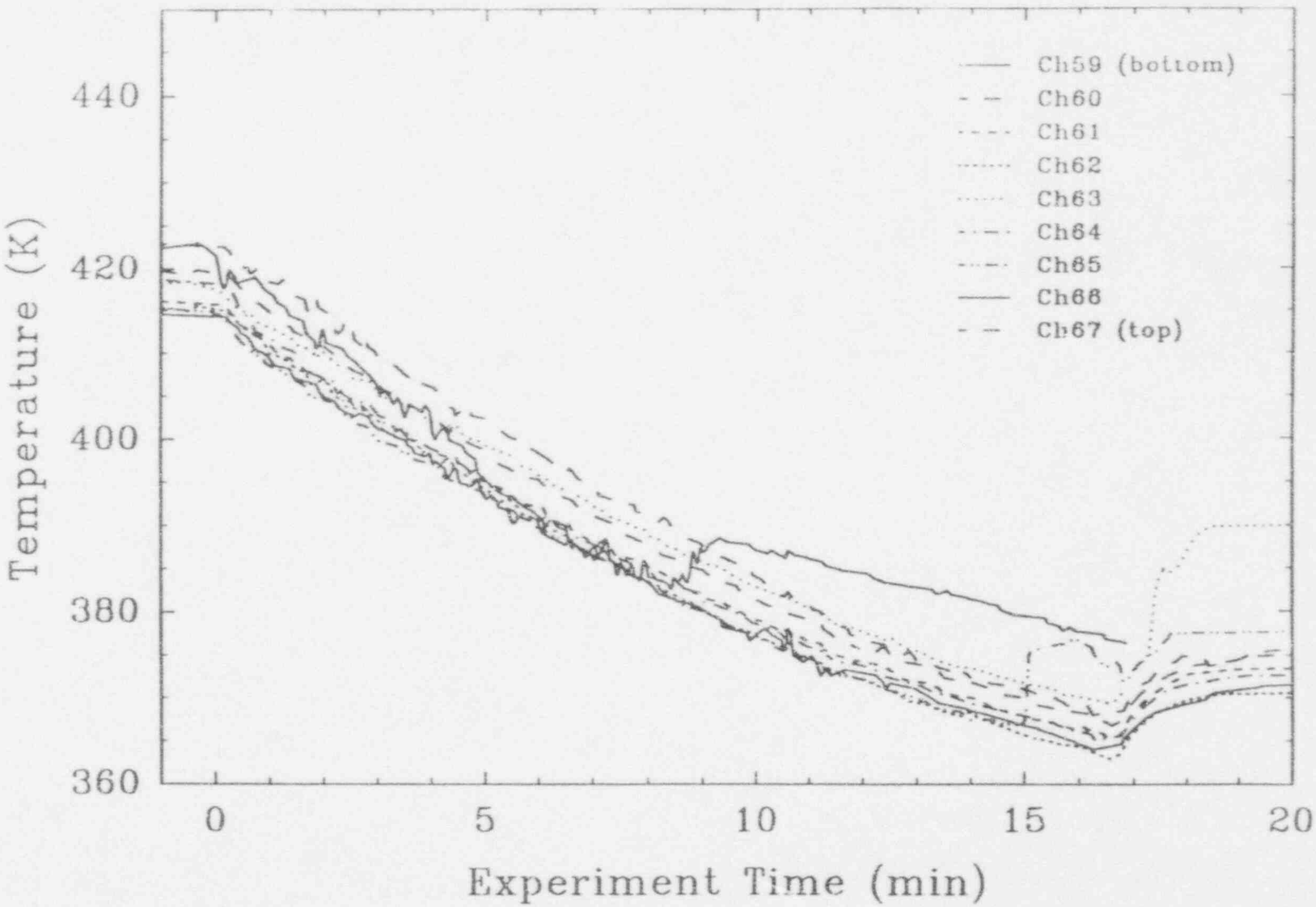

Figure 8. Surtsey vessel gas temperatures from the C thermocouple array in the condensation test.

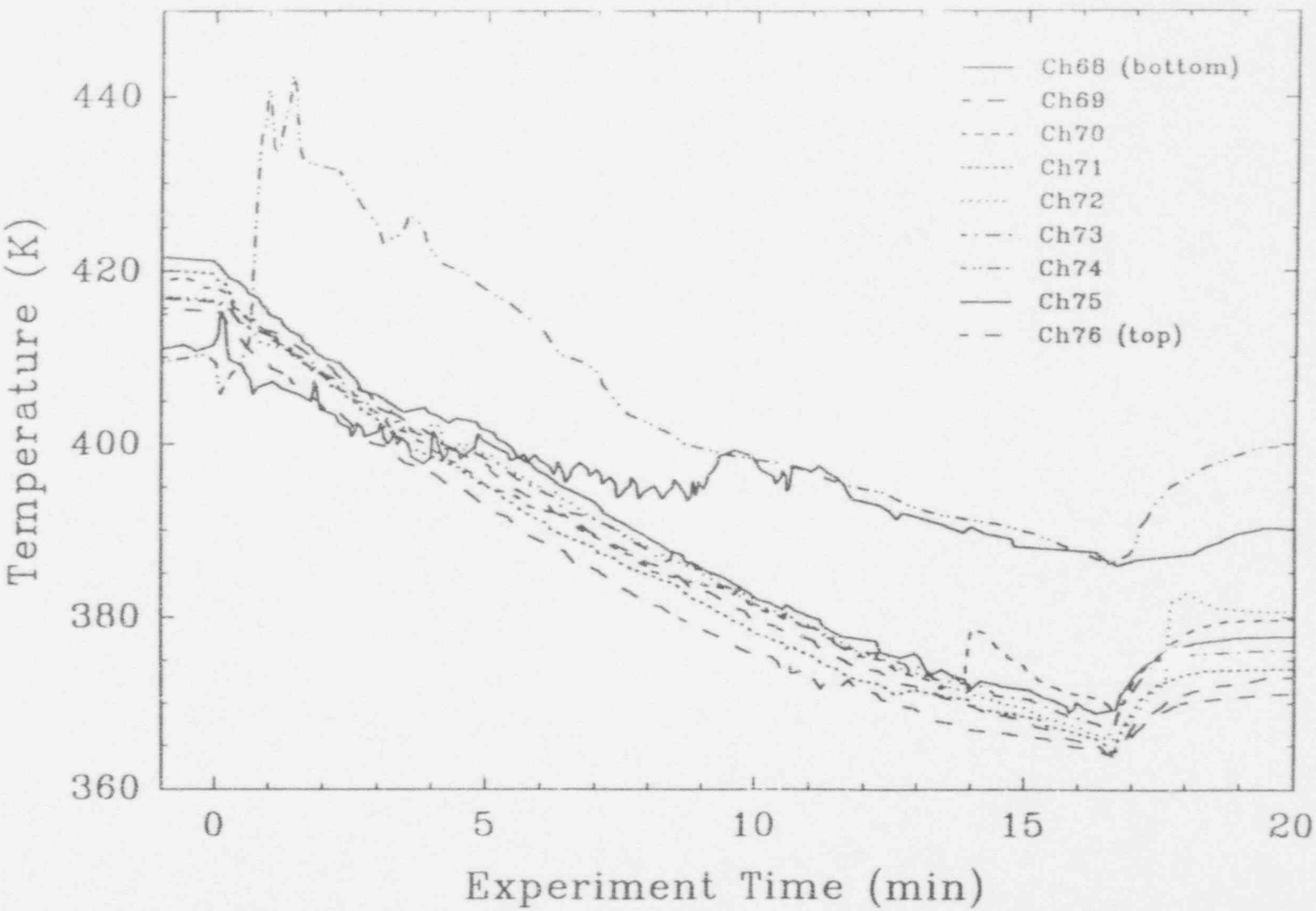

Figure 9. Surtsey vessel gas temperatures from the D thermocouple array in the condensation test.

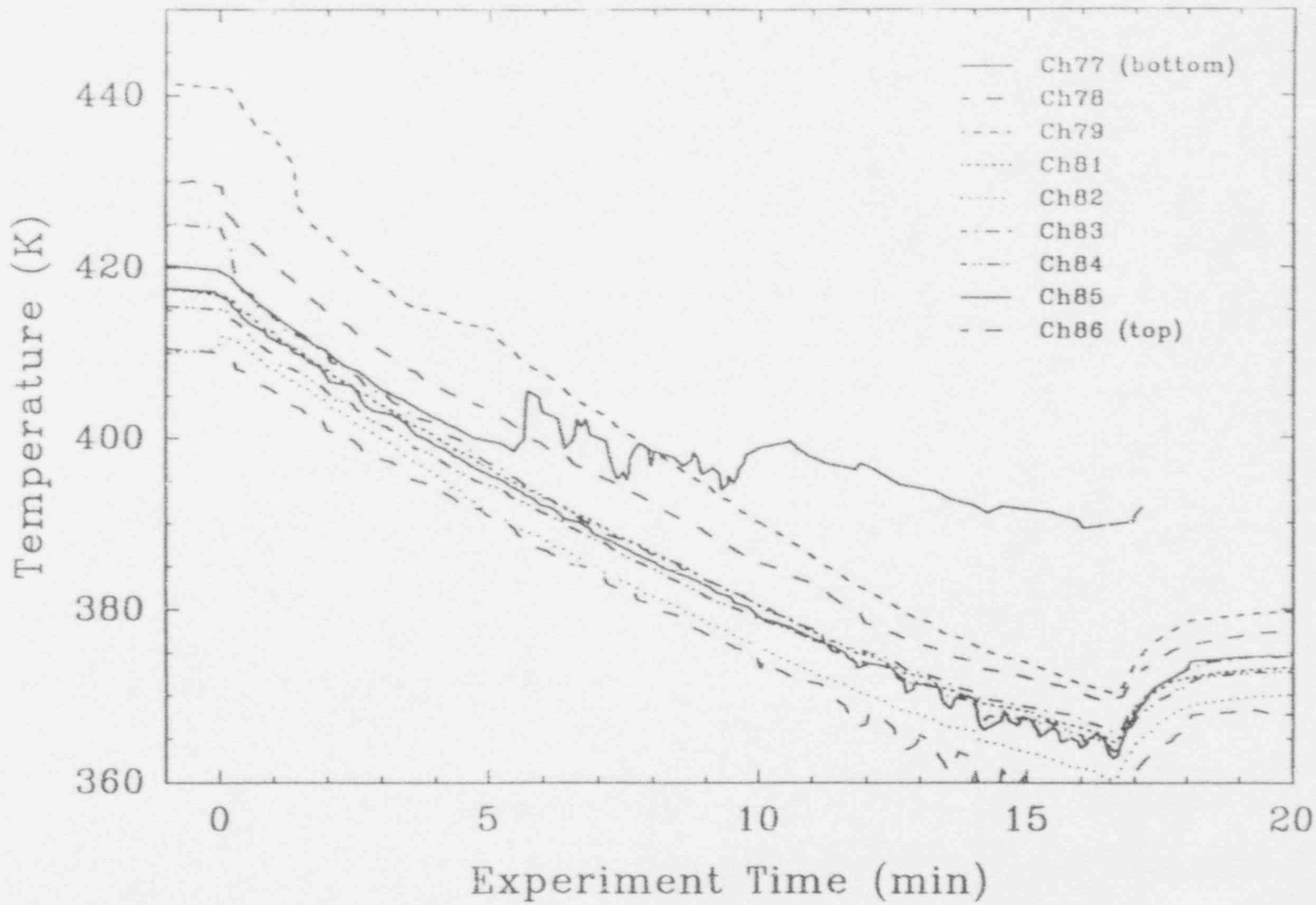

Figure 10. Surtsey vessel gas temperatures from the E thermocouple array in the condensation test.

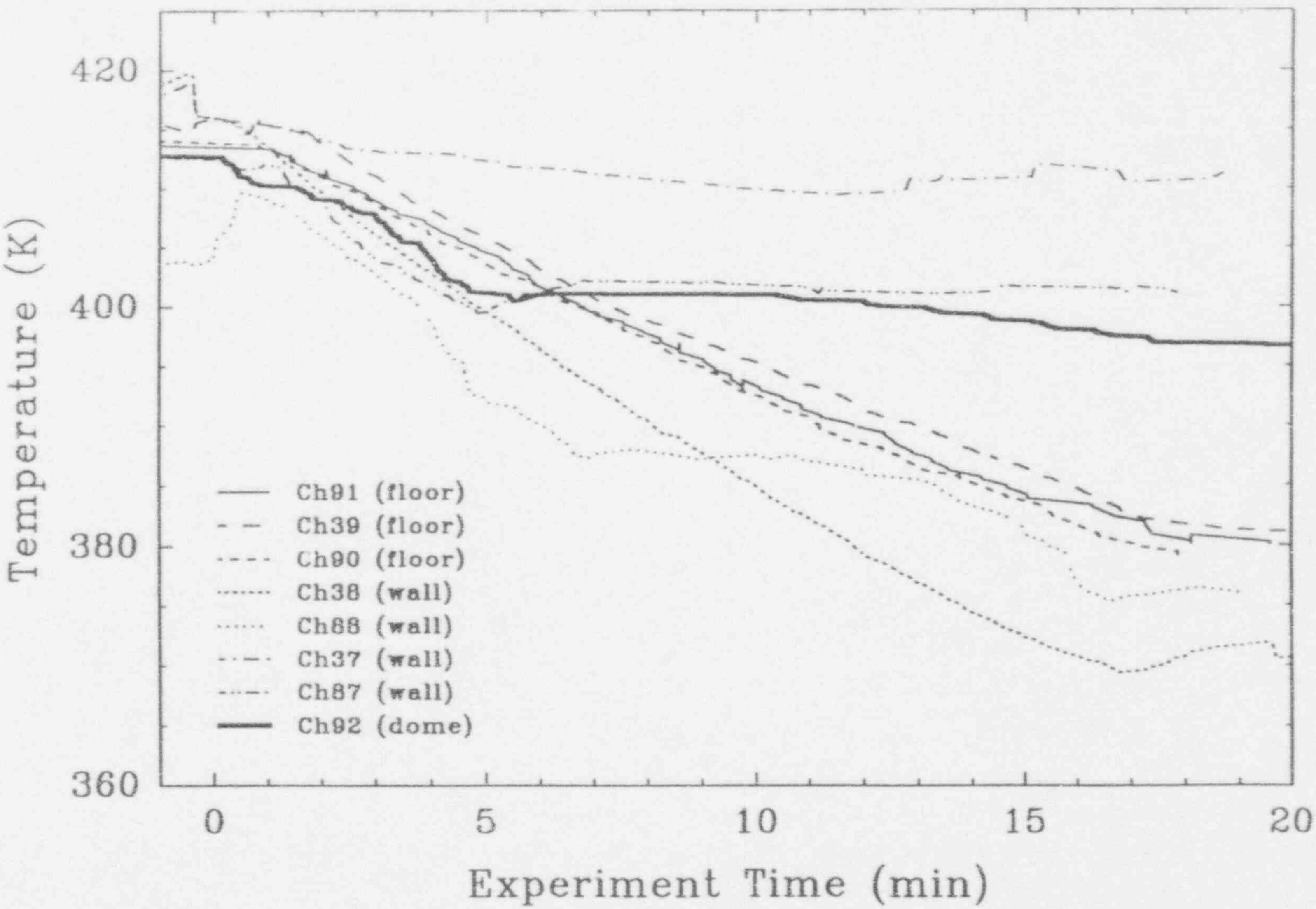

Figure 11. Surtsey vessel floor, wall, and dome temperatures in the condensation test.

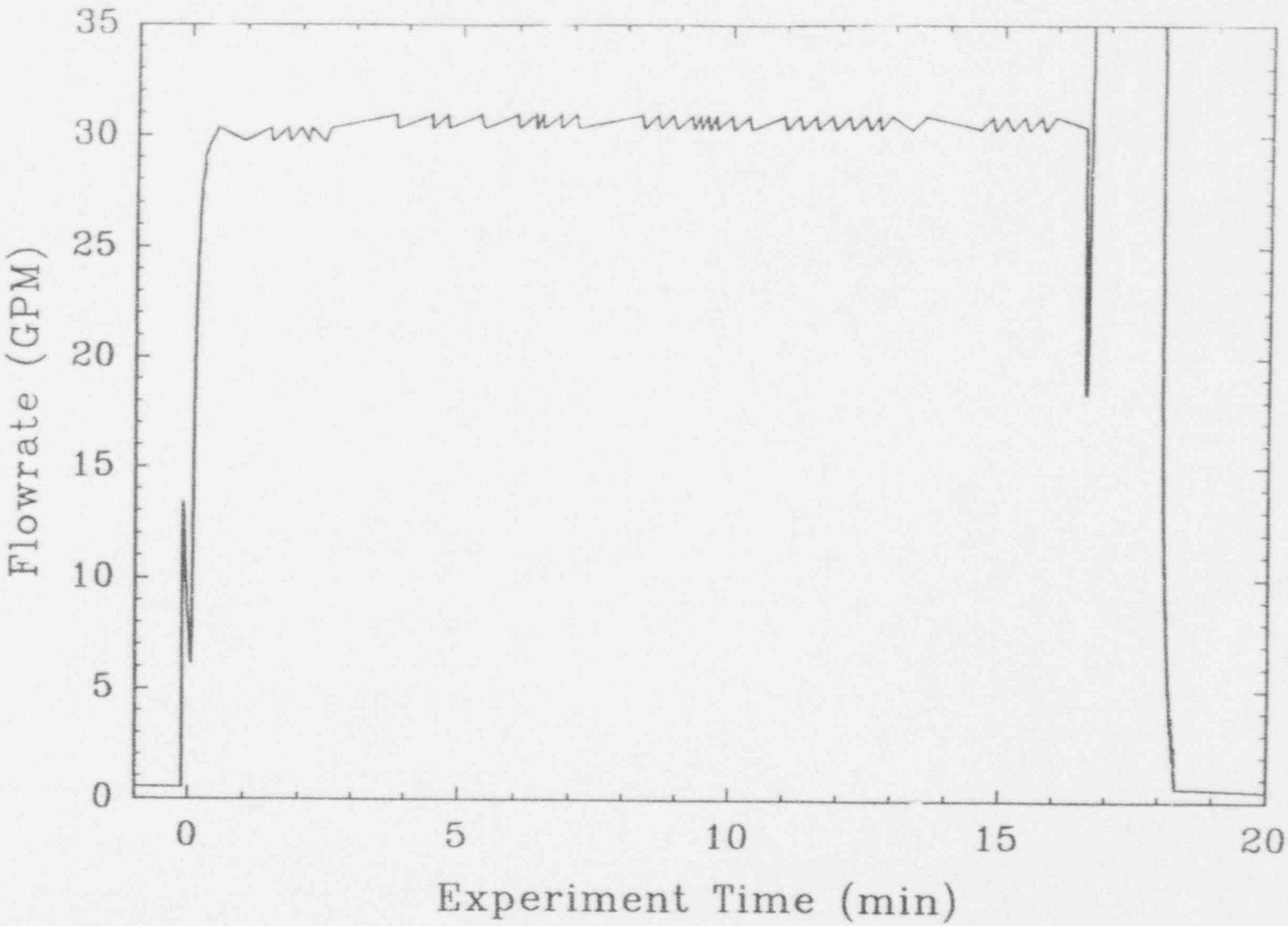

Figure 12. Spray nozzle water flowrate in the condensation test.

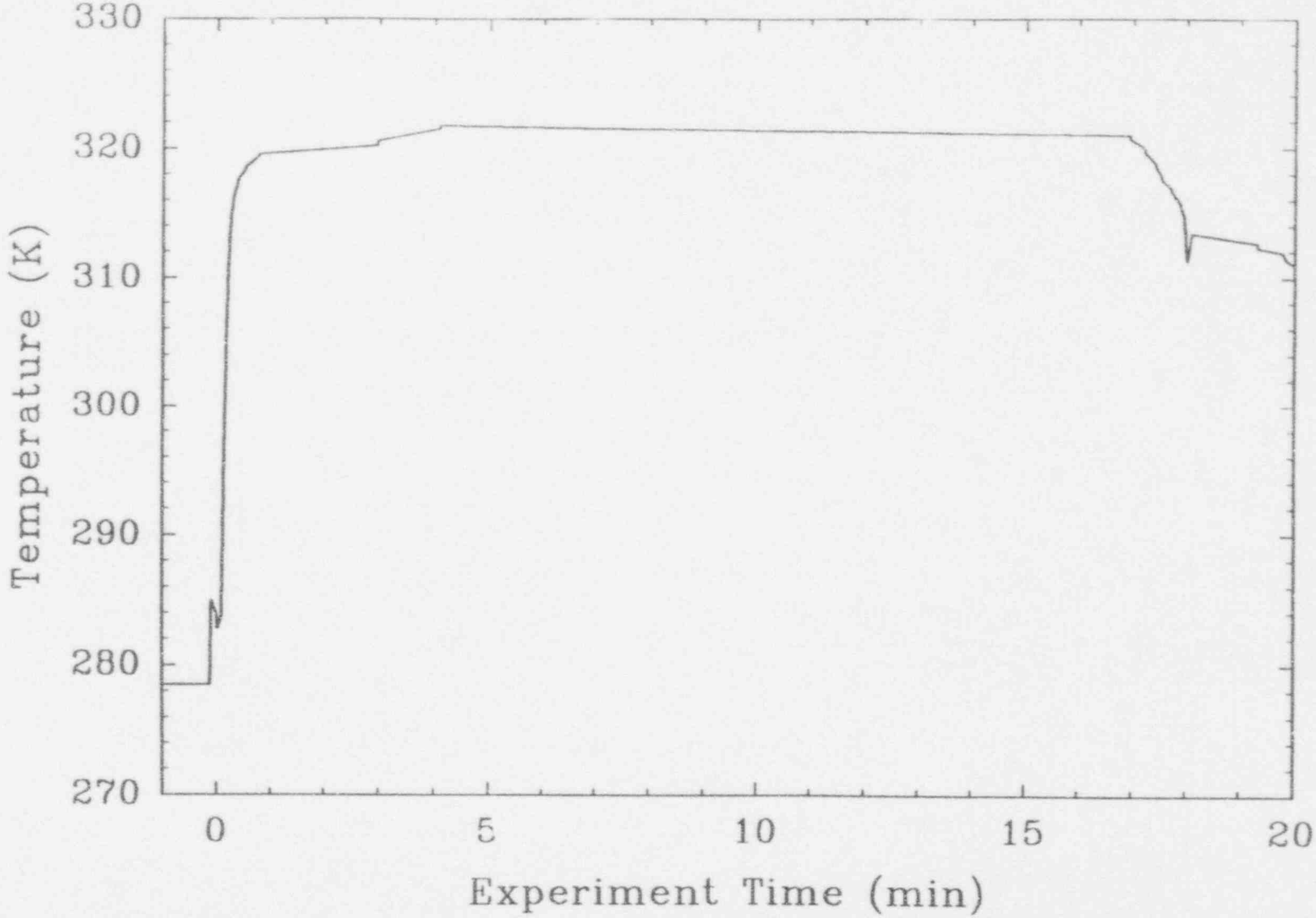

Figure 13. Spray nozzle water temperature in the condensation test.

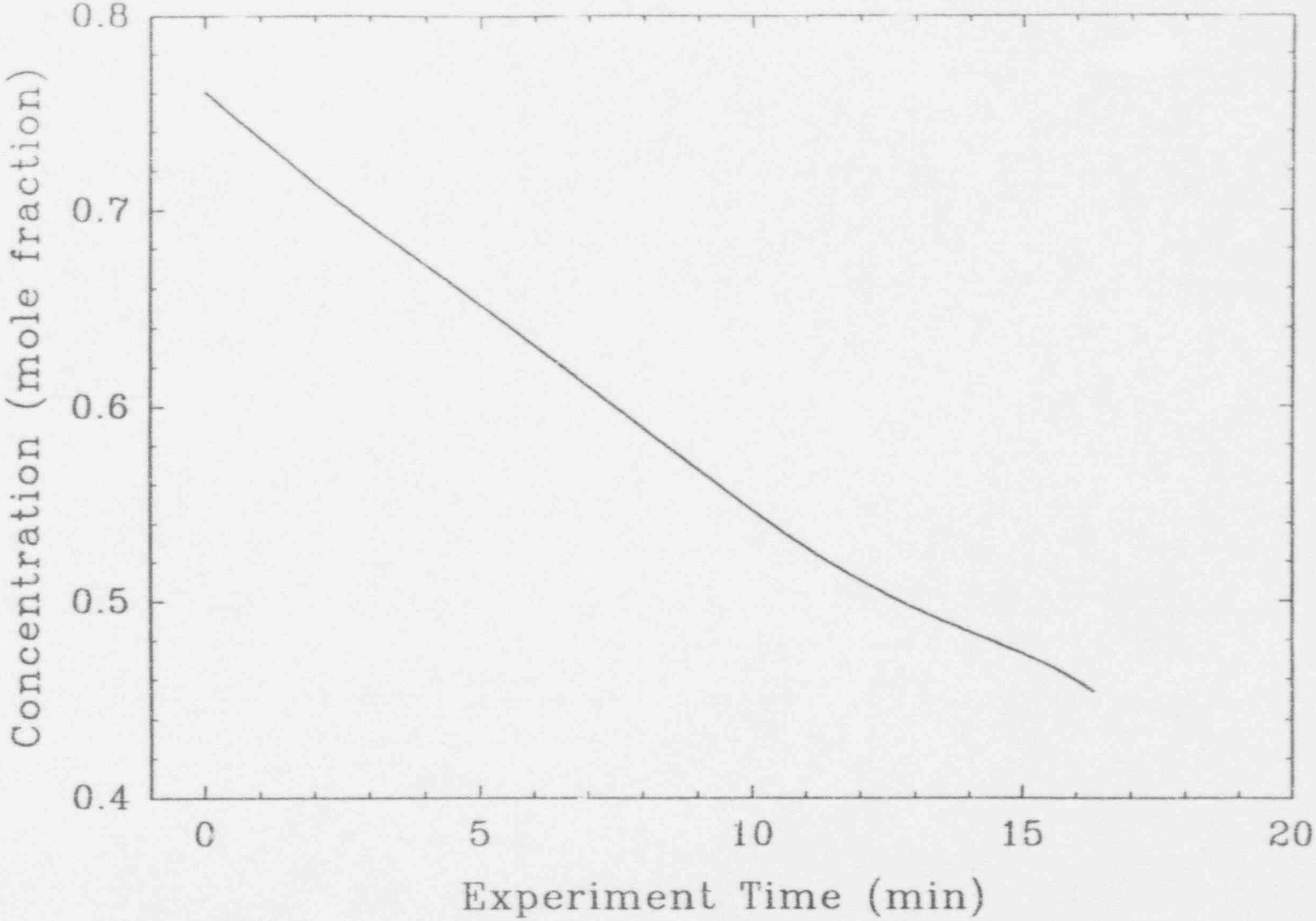

Figure 14. Surtsey vessel steam fraction in the condensation test.

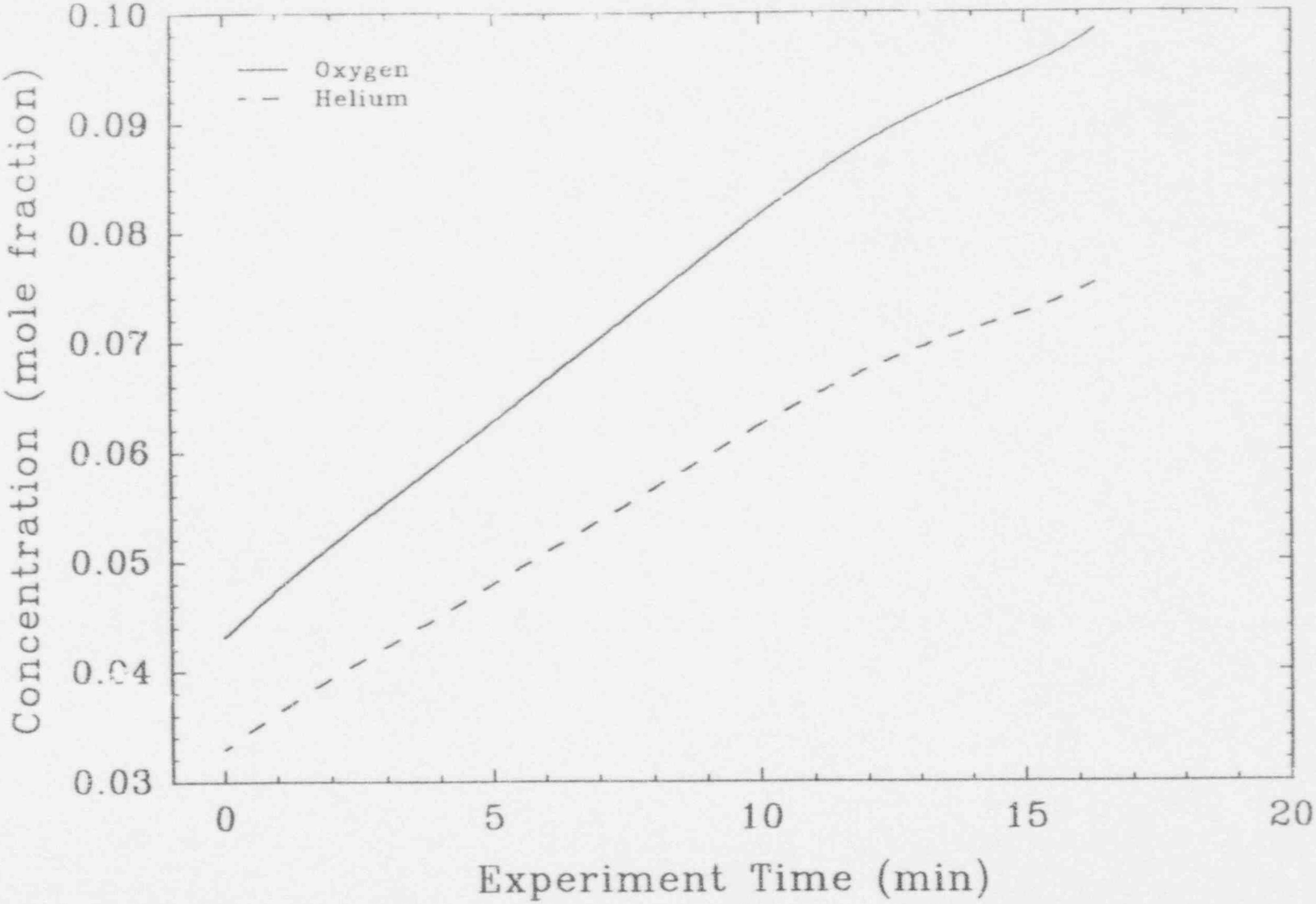

Figure 15. Surtsey vessel oxygen and helium gas fractions in the condensation test.