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**The Effect of Self-Induced
Thermal-Acoustic Oscillations
on Heat Transfer to Hydrogen**

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by

Rodney S. Thurston

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THE EFFECT OF SELF-INDUCED THERMAL-ACOUSTIC OSCILLATIONS ON HEAT TRANSFER TO HYDROGEN

by

Rodney S. Thurston

ABSTRACT

The effect of self-induced thermal-acoustic oscillations on heat transfer to hydrogen in a 0.25-in.-i.d. by 10-ft-long electrically heated stainless steel tube was studied. Pressures were varied from a subcritical 112 psia to a supercritical 265 psia. Two acoustic modes were observed. One, the first harmonic of standing waves in a pipe open at both ends, occurred at frequencies between 70 and 150 cps and was recorded only for pressure. The second was Helmholtz resonance, which is the acoustic analogy to a spring-mass system. Helmholtz oscillations were observed between 4 and 34 cps on records of pressure, temperature, and flow rate. The maximum Helmholtz-mode pressure amplitude was 34 psi peak to peak, and the maximum fluid temperature amplitude was 100°R peak to peak.

Heat transfer to gaseous hydrogen was not affected by axially oriented Helmholtz-mode oscillations with long wavelengths relative to the length of the test section. Heat transfer to two-phase and supercritical hydrogen was influenced by the generation of thermal-acoustic oscillations. Heat transfer improved as the inception of oscillations was approached, but once oscillations occurred, increasing the intensity did not improve the transfer.

1. INTRODUCTION

1.1. Motivation of Investigation

This investigation was concerned with the effect of self-induced thermal-acoustic oscillations on forced convection heat transfer in hydrogen. The development of thermal-acoustic oscillations when hydrogen is heated through a liquid-gas phase change or an equivalent transition above the critical pressure has been reported.^{22,23} Since these oscillations have been observed under conditions which can exist in rocket engines and nuclear reactors, there is an interest in determining their effect on heat transfer to propellants and coolants in these

systems.

1.2. Scope of Investigation

The data of this report were collected simultaneously with those used in the analysis of the inception, frequency, and pressure amplitudes of thermal-acoustic oscillations.²² The system used to induce thermal-acoustic oscillations is shown in Fig. 1.1. Liquid hydrogen entered the test system through an inlet plenum. It was typically evaporated in the inlet 10 to 20% of the test section length by forced convection film boiling. It left the test section as a warm gas through an outlet plenum with an orifice plate at its exit.

Heat transfer to the boiling liquid was studied 20 diameters from the inlet plenum-tube interface. Gaseous heat transfer was studied at 118, 238, and 358 diameters from that interface. Pressures were varied between 112 and 265 psia. Inlet Reynolds numbers ranged from 3.5×10^4 to 90×10^4 .

The analysis of the effect of self-induced thermal-acoustic oscillations was divided into three regions: above 100°R , where hydrogen more nearly approximates an ideal gas; in the gaseous or superheated region below 100°R ; and in the liquid or dense phase of hydrogen.

Fig. 1.1. Flow System for Inducing Oscillations.

1.3. Definitions

1.3.1. Thermal-Acoustic Oscillations. Thermal-acoustic oscillations are self-induced oscillations caused by a coupling among heat transfer, pressure, density, and velocity in a system with special steady boundary conditions. The special boundary conditions are illustrated in Fig. 1.2. They show that the fluid at the inlet of the test section must be in a dense phase, and that the walls of the test section must be hot enough to produce a superheated film adjacent to a core of dense fluid. Oscillations, which occur under these conditions, are called thermal-acoustic oscillations throughout this report.

1.3.2 Properties. A phase is a homogeneous, physically distinct part of a system separated from other parts by definite bounding surfaces. The critical state, for a liquid in equilibrium with its vapor, has identical specific volumes for the liquid and its vapor, and there is no distinction between the saturated liquid and saturated vapor. The critical pressure and critical temperature of a fluid are the pressure and temperature at the critical state. The critical state for parahydrogen is at 187.7 psia and 59.4°R .

Fig. 1.2. Core-Film Model of Flow Cross Section.

Figures 1.3 through 1.7 present hydrogen properties at sub- and supercritical pressures as functions of temperature and pressure in the vicinity of the critical state. These graphs were obtained from a Fortran tabular code of hydrogen properties.⁵ The separation of liquid and gaseous phases at subcritical pressures is identified by the vapor pressure curve. The locus of specific heat maxima where,

$$\left(\frac{\partial c}{\partial T} \right)_p = 0$$

has frequently been used as the dividing line between liquid and gaseous behavior of a fluid at supercritical pressures. Fig. 1.8 shows specific heat maxima of parahydrogen at supercritical pressures. The locus of these maxima joins smoothly with the vapor pressure curve. In this investigation, conventional definitions involving phases and vaporization have been liberalized to apply to liquid and gaseous behavior at sub- and supercritical pressures. The dense phase temperature is below the saturated liquid temperature at subcritical pressures or below the temperature at which specific heat is a maximum at supercritical pressures. The superheated phase temperature is above that of the dense phase upper boundary for the same pressure.

Fig. 1.3. Enthalpy of Parahydrogen.

Fig. 1.4. Specific Volume of Parahydrogen.

Fig. 1.5. Sonic Velocity of Parahydrogen.

Fig. 1.6. Viscosity of Parahydrogen.

Fig. 1.7. Thermal Conductivity of Parahydrogen.

Fig. 1.8. Specific Heat of Parahydrogen Near the Critical State.

1.3.3. Characteristic Frequencies of Oscillations. The most commonly recognized mode of thermal-acoustic oscillations is that of a uniform pipe open at both ends. The acoustic frequency of a constant-temperature gas in a pipe open at both ends is

$$\omega_p = n \frac{c}{2L}, \quad (1.1)$$

where

c = velocity of sound in the gas, ft/sec,

L = length of the pipe, ft,

$n = 1$ for the first harmonic,

$n = 2, 3, \dots$ for higher harmonics,

and

ω_p = open-open pipe frequency, cps.

If a significant axial variation in sonic velocity exists in the pipe, a more general form of Eq. (1.1) is

$$\omega_p = \frac{n}{2 \int_0^L \frac{dL}{c}} \quad (1.2)$$

A low frequency acoustic mode that has been observed is Helmholtz resonance. A Helmholtz resonator is a cavity connected to an external atmosphere by means of a neck that is short in comparison to the wavelength of the resonant oscillations. The fluid in the cavity is compressed and expanded by the periodic motion of the fluid in the neck. The frequency of a Helmholtz resonator¹⁵ is

$$\omega_H = \frac{1}{2\pi} \sqrt{\frac{1}{MC}}, \quad (1.3)$$

where

A = flow area, ft²

$C = V/\rho c^2$, acoustic compliance,
ft⁴-sec²/slug,

m = mass of fluid, slugs,

$M = m/A^2$, acoustic mass or inertance,
slug/ft⁴,

V = volume of resonator cavity, outlet
plenum plus gaseous portion of heated
tube, ft³,

ρ = density in resonator, slugs/ft³,

and

ω_H = frequency of Helmholtz mode, cps.

If the cross section of the inlet plenum in Fig. 1.1 is large compared to that of the heated channel, the acoustic mass contributed by the inlet plenum is negligible. If, in addition, the volume of the outlet plenum is large compared to the volume of the heated channel, the predominant spring effect is supplied by the outlet plenum, and Eq. (1.3) can be reduced to

$$\omega_H = \frac{1}{2\pi} \sqrt{\frac{\gamma P A}{V' \int_0^L \rho dL}}, \quad (1.4)$$

where

A = flow area of heated channel, ft²

dL = differential length along the heated
tube, ft,

L = length of heated tube, ft,

P = pressure in resonator cavity, lb/ft²,

V' = volume of gas in outlet plenum and
heated tube, ft³,

γ = ratio of specific heats in resonator
cavity,

and

ρ = local density of fluid in heated tube,
slugs/ft³.

The functional dependence of the Helmholtz mode on the variables in Eq. (1.4) was verified experimentally and reported in Ref. 21.

2. AVAILABLE INFORMATION

2.1. The Effect of Oscillations on Forced Convection Heating

In 1942 Andreas¹ obtained a patent for using flow pulsations to improve heat transfer. Since then there has been a growing effort to establish relationships between heat transfer and flow pulsations.

West and Taylor²⁶ observed an increase of up to about 70% for heat transfer film coefficients in water inside tubes by the use of partially damped pulsating flow from a reciprocating pump. The Reynolds number range was 30,000 to 85,000. They cited earlier theses at the University of Washington, which covered a Reynolds number range of 26 to 1375, but showed no improvement in heat transfer. West and Taylor observed an optimum degree of damping beyond which more severe pulsations resulted in decreased heat transfer efficiency and greater

system vibration.

In studies of forced convection heating of gaseous hydrogen and helium at very high wall to bulk temperature ratios, McCarthy and Wolf¹⁷ observed self-induced pressure oscillations under certain conditions. These oscillations were accompanied by a significant increase in heat transfer, which seemed to become independent of Reynolds number, and a noticeable flattening of wall temperature distribution, when compared to flow without oscillations. The frequencies were about 500 cps, corresponding to the first harmonic of the tube between two mixing chambers.

Goldmann^{6,7} reported audible sounds during high flux heat transfer to two-phase and supercritical water. In the presence of oscillations, wall temperature profiles leveled off at values below those obtained without oscillations.

Bayley, Edwards, and Singh² studied the effect of flow pulsations on heat transfer from a flat plate by forced convection of air. They found that heat transfer in pulsating flow could be correlated by the use of a dimensionless parameter defined as the ratio of the half-pressure amplitude to the dynamic head corresponding to average rate of flow. No effect upon heat transfer was found until this parameter achieved a critical value of about twelve. Above this value, the heat transfer rate increased with the 0.23 power of pressure amplitude when frequency was constant. The effect of frequency from 16 to 97 cps was small. The authors speculated that flow reversal was the principal cause of enhanced heat transfer and that the critical amplitude corresponds to the intensity of pulsation necessary to cause the reversal.

Jackson, Purdy, and coworkers have made numerous studies on the effect of resonant pulsating flow on convective heat transfer to air. One of their recent publications¹² contains a complete bibliography of their reports. Their theoretical analysis and experimental results showed that resonant pulsations improved heat transfer in laminar flow with heat transfer maxima occurring at multiples of the half-wavelength of the pulsations. This effect can persist into the turbulent regime with a diminished effect. Above a Reynolds number of 30,000, the resonant pulsations produced poorer

heat transfer with minima where the maxima had been. Their work covered Reynolds numbers up to 80,000.

Koshkin et al.¹⁶ also studied heat transfer to air flowing in a tube in the presence of acoustic resonance. Their data cover Reynolds numbers from 10,000 to 100,000 and resemble the corresponding data of Jackson and Purdy. In addition to studying pulsations with frequencies high enough that structural materials responded only to time average heat transfer variations, Koshkin et al. also studied low frequency pulsations which produced time measured changes in the temperature of the structure. The two cases yielded the same heat transfer dependence on Reynolds number and length to diameter ratio. However, heat transfer with low frequency pulsation was more dependent on the ratio of wall to bulk temperatures.

Hendricks, Simoneau, and Friedman¹¹ reported self-induced oscillations during heat transfer experiments with cryogenic hydrogen between 1000 and 2500 psia. The oscillations were recorded by vibration transducers which measured mechanical movement of their test section. They noted that 800- to 1000-cps oscillations parallel to the flow had no noticeable effect on high pressure heat transfer which correlated with standard gaseous formulae. However, lateral oscillations, with frequencies of 4500 to 8000 cps, substantially augmented heat transfer.

The effect of flow oscillations on heat transfer seems to vary with fluid state, Reynolds number, configuration, and direction of oscillation with respect to the fluid. Further experimental evidence must be assimilated before a general understanding of this subject can be obtained.

2.2. Thermal-Acoustic Oscillation Experiments

A series of experiments had been performed to study the conditions under which self-induced oscillations occur during forced convection heating of dense hydrogen. Data obtained from transient cool-downs in the first series^{20,21} indicated that among the various observed pressure fluctuations were thermal-acoustic oscillations of the Helmholtz mode and the first and second harmonics of the open-open pipe mode. The data also showed that for oscillations to occur, hydrogen had to be present in the test section at below the saturated liquid temperature for subcritical pressures or below the tempera-

ture at which specific heat is a maximum at supercritical pressures.

The second series of experiments^{22,23} used an electrically heated test section. When no heat was generated, the flow of liquid hydrogen through the test section was quiescent. After sufficient heating to generate two-phase flow at the outlet of the test section, oscillations appeared which resembled those associated with a transition in two-phase flow patterns.¹³ These oscillations did not have thermal-acoustic characteristics and subsided as the level of heat generation was increased to produce gaseous flow at the outlet plenum. A period of quiescent flow existed during a further increase in heat generation, until small amplitude, nearly sinusoidal, thermal-acoustic oscillations were observed on records of pressure, fluid temperature, and flow. Increasing the rate of heat generation produced an increase in the amplitude of the oscillations, which eventually lost their nearly sinusoidal appearance but remained periodic. Data from those experiments resulted in several correlations which used dimensionless similarity numbers.

A correlation of oscillation inception conditions, which corresponded to the appearance of 1 psi peak to peak pressure oscillations, was given as

$$(N_{Bo})_i = 0.0045 (N_{Sv})^{-0.75}, \quad (2.1)$$

where

G = mass flux, lb/sec-ft²,

$(N_{Bo})_i = \left(\frac{q}{G\lambda^*} \right)_i$, minimum boiling number

for thermal-acoustic oscillations,

$N_{Sv} = \left(\frac{v_{fg}^*}{v_f^*} \right)$ specific volume number,

q = heat flux to dense phase,
Btu/sec-ft²

v_f^* = equivalent specific volume of
dense phase, ft³/lb,

v_{fg}^* = equivalent change in specific
volume due to vaporization, ft³/lb,

λ^* = equivalent latent enthalpy of
vaporization, Btu/lb.

The "equivalent" quantities are discussed in the following section.

Acoustic frequencies were computed using Eq. (1.2) for the Helmholtz mode and Eq. (1.4) for pipe modes. These equations were derived for acoustic conditions in which the average fluid velocity is zero. Since the average fluid velocity was not zero in the test section, a departure of observed frequencies from computed frequencies occurred. The point of departure was empirically related to a type of Strouhal number which corresponded to the number of oscillations a fluid particle made in transit through the test section. When the particle made at least two oscillations, i.e. the Strouhal number was greater than two, computed frequencies agreed with observed frequencies. For Strouhal numbers less than two, the ratio of these frequencies was represented by the following empirical equation:

$$\frac{\omega_H}{\omega_c} = 1.68 (N_{St})^{-0.75}, \text{ for } N_{St} < 2 \quad (2.2)$$

where

$N_{St} = \omega_c \int_0^L dL/v$, a Strouhal number,

dL = differential length along heated
tube, ft,

L = test section length, ft,

v = velocity, ft/sec,

ω_c = computed acoustic frequency for
Helmholtz mode, cps,

and

ω_H = observed frequency of Helmholtz mode,
cps.

The pressure amplitudes of the oscillations were correlated in terms of an amplitude number, the boiling number, and the inception boiling number given by Eq. (2.1). The correlation was

$$N_{Am} = 0.011 [N_{Bo} - (N_{Bo})_i]^{0.66}, \quad (2.3)$$

where

$N_{Am} = \frac{\tilde{p}_{eq} \omega_H D}{G\lambda^*}$, amplitude number,

$N_{Bo} = \frac{q}{G\lambda^*}$, boiling number,

$(N_{Bo})_i$ = boiling number at inception of
oscillations,

D = test section flow diameter, ft,

$\tilde{p}_{eq}$ = equivalent amplitude, peak to peak,
and
 ω_H = observed frequency of Helmholtz mode,
cps.

The equivalent amplitude was derived from acoustic theory²² by accounting for the energy density of pressure oscillations when superimposed modes were present. The equation for an equivalent amplitude when different modes of oscillations occur simultaneously is

$$\tilde{p}_{eq} = \sqrt{\left(\tilde{p}_H\right)^2 + \frac{\omega}{\omega_H} \left(\tilde{p}_1\right)^2 + \frac{\omega}{\omega_H} \left(\tilde{p}_2\right)^2 + \dots} \quad (2.4)$$

The reference frequency used was the observed Helmholtz frequency

where $\tilde{p}_H$ = amplitude of Helmholtz mode, lb/ft²

$\tilde{p}_1$ = amplitude of pipe mode first harmonic, lb/ft²

$\tilde{p}_2$ = amplitude of pipe mode second harmonic, lb/ft²,

ω_1 = frequency of pipe mode first harmonic, cps,

and

ω_2 = frequency of pipe mode second harmonic, cps.

The data presented in Ref. 22 pertained to the study of pressure oscillations. Heat transfer data were also collected during these experiments, but were not analyzed. This report presents the analysis of those data.

2.3. Equivalent Two-Phase Properties for Hydrogen near the Critical Pressure

Although a distinct separation between liquid and gaseous phases does not exist above the critical pressure, Griffith and Sabersky⁹ and Graham, Hendricks, and Ehlers⁸ have made visual observations of boiling-like phenomena at supercritical pressures. Numerous authors have assigned quasi two-phase properties, such as latent heats and changes in specific volume, to fluids above the critical pressure in order to extend two-phase correlations into that region. Urbakh²⁴ suggested a graphical method to extrapolate liquid and gaseous properties above the critical pressure. An analytical approach was made by Hendricks et al.¹⁰ Their method associates supercritical states with a pseudo quality based on the equilibrium density of the supercritical fluid,

an ideal gas density, and an assumed density of a "heavy species," which represents a liquid-phase extrapolation above the critical pressure. The difference in specific volume between the heavy species and ideal gas, at the temperature of the specific heat maximum, is used with the Clapeyron equation to obtain a supercritical enthalpy difference which corresponds to the latent enthalpy of vaporization at subcritical pressures.

Quasi two-phase properties were also obtained graphically in Ref. 22 by extrapolating curves showing typical liquid and gaseous properties to the saturation temperature for subcritical pressures or to the temperature at which specific heat is a maximum for supercritical pressures.

A comparison of the analytical method presented by Hendricks et al. in a NASA report and the graphical method of Ref. 22 for generating equivalent two-phase properties is shown for the latent enthalpy in Fig. 2.1 and for the relative change in latent specific volume at vaporization in Fig. 2.2. The figures apply to the range of hydrogen pressures covered by this investigation and show that the analytical approach presented in the NASA report could yield a more plausible result by use of a van der Waals gas instead of an ideal gas. The disadvantage of the graphical method is its

Fig. 2.1. Comparative Results for an Equivalent Latent Enthalpy of Vaporization.

lack of precision. Properties generated by these two methods are distinguished within this report by the names chosen by their respective authors. Those analytically generated are called "pseudo two-phase", and those graphically generated are called "quasi two-phase."

Fig. 2.2. Comparative Results for an Equivalent Change in Specific Volume at Vaporization.

2.4. Heat Transfer Correlations

2.4.1. Gaseous Hydrogen Correlation.

Williamson²⁷ has accumulated a bank of hydrogen heat transfer data, which currently uses 12 sources of information. At this writing the most successful correlation for heat transfer to gaseous hydrogen is

$$N_{Nu} = 0.023 N_{Re}^{0.8} N_{Pr}^{0.4} C_1 \left(\frac{T_w}{T_B} \right)^{-C_2}, \quad (2.5)$$

where

N_{Nu} = Nusselt number based on bulk conductivity

N_{Pr} = Prandtl number based on bulk temperature,

N_{Re} = Reynolds number based on total flow rate and bulk viscosity,

T_B = absolute bulk temperature,

and

T_w = absolute inside surface wall temperature.

For $T_w/T_B \leq 1.8$: $C_1 = 1.0$, $C_2 = 0.765$.

For $T_w/T_B > 1.8$: $C_1 = 0.7$, $C_2 = 0.2$.

Equation (2.5) correlated 77% of 610 data points

within $\pm 20\%$.

2.4.2. Two-Phase and Supercritical Hydrogen Correlations. Hendricks et al.¹⁰ present a number of correlations for heat transfer to two-phase and supercritical hydrogen under conditions of film boiling. An equation obtained from their analysis of data at subcritical pressures, using the Martinelli parameter " $x_{tt,x}$ " and a quality " x " based on thermodynamic equilibrium is

$$N_{N_f} = N_{N_c} \left(\frac{1}{0.7 + 2.4 x_{tt,x}} + 0.15 \right), \quad (2.6)$$

where

$$N_{N_c} = 0.021 N_{Re}^{0.8} N_{Pr}^{0.4} \quad (2.7)$$

and

N_{N_f} = Nusselt number based on film conductivity;

N_{Re} = Reynolds number based on bulk velocity, viscosity at film temperature, and mean film density;

N_{Pr} = Prandtl number based on film temperature;

and

$x_{tt,x}$ = Martinelli two-phase flow parameter.

The mean film density is defined by

$$\frac{1}{\rho_{fm}} = \frac{x_2}{\rho_f} + \frac{1-x_2}{\rho_l}, \quad (2.8)$$

where

x_2 = NASA pseudo quality,

ρ_f = film density based on arithmetic mean temperature,

ρ_{fm} = mean film density,

and

ρ_l = liquid density.

Hendricks et al. also present an equation in which the Martinelli parameter is based on their pseudo quality. It is

$$N_{N_w} = N_{N_c} \left(0.12 + \frac{1.0}{0.81 + 2.52 x_{tt}} \right), \quad (2.9)$$

where

N_{N_w} = Nusselt number based on a weighted thermal conductivity, k_t ,

N_{N_c} = uncorrected Nusselt number given by Eq. (2.7),

and

X_{tt} = Martinelli-type parameter, based on pseudo quality.

The weighted thermal conductivity is defined as

$$k_t = A_\ell k_\ell + A_f k_f, \quad (2.10)$$

where

A_f = area fraction of flow assigned to film,

A_ℓ = area fraction of flow assigned to liquid,

k_f = thermal conductivity based on mean film temperature,

k_ℓ = thermal conductivity of liquid,

and

k_t = weighted thermal conductivity.

2.4.3 Two-Phase Water Correlation. Bishop, Sandberg, and Tong⁴ correlated data for water at high subcritical pressures in forced convection film boiling. Their correlation was

$$N_{N_f} = 0.0193 N_{Ref}^{0.8} N_{Prf}^{1.23} \left(\frac{\rho_g}{\rho_b} \right)^{0.68} \left(\frac{\rho_g}{\rho_\ell} \right)^{0.068}, \quad (2.11)$$

where

N_{N_f} = Nusselt number based on film conductivity,

N_{Ref} = Reynolds number based on total flow rate and film viscosity,

N_{Prf} = Prandtl number based on film temperature,

ρ_b = bulk density,

ρ_g = saturated vapor density,

and

ρ_ℓ = saturated liquid density.

2.5. Summary

Numerous efforts have been made to study the effect of flow oscillations on heat transfer by imposing oscillations on flow that would otherwise be quiescent. Experimental results have variously showed improved heat transfer, no effect, or degradation of heat transfer. Self-induced oscillations have also been observed when forced convection heating produces large property gradients. Most of these observations have been made during two-phase and supercritical heat transfer, but self-induced oscillations were also reported during gaseous heat transfer at very high heat fluxes. Self-induced oscillations either improved heat transfer or were shown not to affect it. Hendricks, Simoneau, and

Friedman¹¹ showed that the direction of self-induced oscillations with respect to flow was significant at high pressures.

The generation of thermal-acoustic pressure oscillations has been studied²² to correlate inception conditions, amplitudes, and frequencies. Heat transfer data at sub- and supercritical temperatures from those experiments were not previously analyzed. Quasi two-phase properties were applied in the correlations for pressures near the critical pressure.

Several correlations have been cited for forced convection heat transfer to hydrogen in gaseous, two-phase, and supercritical flow. A correlation based on heat transfer to two-phase water has also been cited. Since these correlations were based on data for which oscillations did not occur or were thought not significant, they will be compared with the data of this investigation.

3. APPARATUS

3.1. Description of Apparatus

3.1.1. Flow System. The flow system is illustrated in Fig. 3.1. The test section was an electrically heated horizontal tube containing hydrogen. The nominal capacity of the dewar was 300 liters, and its maximum rated pressure was 300 psi. Liquid hydrogen was forced into the test section by pressurizing the dewar with gaseous helium. The control valve was locked open during each experimental run; it was used only to control flow to protect the turbine flow meter during purging. Figure 3.2 shows the flow system, as viewed from the outlet end. Electrical leads are shown entering the cylindrical vacuum tank around the test section. The test section was maintained in tension during the experimental runs to prevent buckling under the compressive load caused by atmospheric pressure against the movable outlet end of the vacuum tank.

3.1.2. Power Supply. Electrical power to the test section was provided by a Dresser silicon industrial power supply with a rating of 100 kW dc, 2000 A, 50 V. The unit supplied dc electricity with a 5% ripple. The ripple caused noise in instrumentation channels that recorded thermocouple voltages. An attempt to reduce the ripple by installation of a 0.24-F capacitance in parallel with the test section produced only minor improvement.

Fig. 3.1. Cryogenic Flow System Schematic.

Fig. 3.2. Cryogenic Flow System.

3.1.3. Test Section. The test section consisted of a 0.250-in.-i.d. by 0.155-in.-wall by 10-ft-long stainless steel tube between plenum. Each plenum was 2.5 in. i.d. by 12.25 in. long. The capacity of the outlet plenum could be reduced from 58 to 22 in.³ by means of a volume filling plug. Hydrogen discharged from the outlet plenum through an orifice. Runs analyzed for this report were made with electrodes attached to the plenum faces adjacent to the tube so that heat was generated along the entire length of the tube.

3.2. Instrumentation

3.2.1. General. The general arrangement of test section instrumentation is shown in Fig. 3.3. The axial location of the instrumentation, as measured from the junction of the inlet plenum and heated tube, is given in Table 3.1. Liquid hydrogen flow was measured by means of a Brooks Hydropoise turbine flow meter installed upstream of the test section as shown in Fig. 3.1. The meter had a nomi-

nal range of 1.5 to 15 gpm and a response time of 5

3.2.2. Pressure Instrumentation. Static pressures were measured by Statham Model PA 707 TC absolute pressure transducers with a range of 0 to 300 psia. The transducers were temperature compensated to the extent that zero shift was less than 12% full scale/100°F and static sensitivity was less than 3%/100°F. To minimize thermal shift errors, each transducer was connected to a 0.03-in.-diameter pressure tap in the wall of the test section by a 0.055-in.-i.d. by 6-in.-long stainless steel pressure transmission line, shown in Fig. 3.4. The last inch of the transmission line was a relatively massive block of stainless steel containing a male threaded connection for the pressure transducer. The use of a digital code to calculate pressure transmission line response to oscillations²⁵ indi-

Fig. 3.3. Test Section Instrumentation.

Table 3.1

Axial Location of Instrumentation

Signal	Station	Distance, Inches
Static pressure	Inlet plenum	-0.4
	A	2.5
	B	29.6
	C	59.6
	D	89.6
	E	114.1
	Outlet plenum	120.4
Differential pressure	Inlet-Outlet	-0.4 to 120.4
Platinum resistance Thermometers	Inlet plenum	-1.6
	Outlet plenum	121.6
Thermocouples	A	5.0
	B	33.3
	C	63.3
	D	93.3
	E	112.9
Voltage taps	0	0
	1	35.9
	2	48.4
	3	65.6
	4	78.8
	5	120.0

Fig. 3.4. Installation of Static Pressure Transducers.

cated that output amplitudes would typically be within 10% of input amplitudes up to a frequency of 200 cps. The output phase angle would be within a degree of the input at this frequency. All static pressure transducers were mounted on an instrumentation tray under the heated tube inside the vacuum tank. They were electrically isolated.

Differential pressure between inlet and outlet plena was measured by a Statham Model PM 280 TC differential pressure transducer mounted on a hand-hole cover outside the vacuum tank. The 216-in.-long transmission lines were calculated to yield an output 10% high at 14 cps and to resonate at about 50 cps. The transmission line connected to the high voltage outlet end of the test section contained an electrically insulating coupling.

3.2.3. Temperature Instrumentation. Inlet and outlet plenum temperatures were measured by Rosemount platinum resistance sensors. Time constants of these sensors are about 0.2 sec.

Temperatures in the electrically heated test section were measured by Baldwin-Lima-Hamilton micro-miniature thermocouples with insulated junctions. It was originally planned to use exposed junctions with a 0.05-sec time constant in the fluid stream, but the exposed junction often made electrical contact with the sheath and forced the use of insulated junctions. The thermocouple time constant was estimated to be 0.2 sec. At stations B, C, and D, thermocouples were installed as shown in Fig. 3.5. The location of these thermocouples

appears in Fig. 3.3. Thermocouples designated "bulk" and "film" extended into the center and edge of the fluid stream. Thermocouples designated "deep," "mid 1," and "mid 2" were spring-loaded into the tube wall. Typical depths in the 0.155 in. wall were 0.140 in. for the deep thermocouples and 0.077 in. for the mid thermocouples. The sheaths of these thermocouples were supported by pieces of 0.28 in. o.d. tubing, which also acted as radiation shields. Fig. 3.6 shows the components used to assemble a spring-loaded thermocouple. The loop insulator prevented the spring and connecting wire around the test section from acting as a one-turn transformer.

3.2.4. Recording System. Data was recorded simultaneously on a continuously recording Honey-

Fig. 3.5. Thermocouple Installation.

Fig. 3.6. Components for a Spring-loaded Thermocouple.

well Model 1612 Visicorder oscillograph, four charts, and a Texas Instruments low-high level electronic multiplexer, which sampled data 20 times per second for recording on magnetic tape. Table 3.2 lists the channels continuously recorded on the oscillograph. Electrical current, maximum test section voltage, and dewar level were recorded on the strip charts. For monitoring operating conditions, liquid hydrogen flow and the wall surface temperature at station D were also displayed and recorded on the strip charts. The multiplexer was used to make a parallel recording of all channels except current, dewar level, and wall surface temperature at station D.

4. PROCEDURE

4.1. Calibration of Instrumentation

Pressure transducers were periodically calibrated against a Heise gauge by sealing the exit of the test section with a blind flange and pressurizing the system with helium. This was done while the system was at ambient temperature before an experiment. Attempts to calibrate pressure transducers after the system had been cooled to cryogenic temperatures during the preliminary experiments proved valueless because of leaks through shut-off valves at these temperatures.

All thermocouples were calibrated prior to installation using an ice bath and liquid nitrogen

Table 3.2

Measurements Continuously Recorded on the Visicorder Oscillograph

<u>Signal</u>	<u>Sensor</u>	<u>Location</u>
Static pressure	Statham	Inlet plenum
		A
		B
		C
		D
		E
		Outlet plenum
Differential pressure	Statham	Inlet-Outlet plena
Liquid hydrogen flow	Brooks turbine meter	Upstream of inlet
Fluid temperature	Rosemount	Inlet plenum
		Outlet plenum
	Thermocouple	B bulk
		B film
		C bulk
		C film
		D bulk
		D film
Wall temperature	Thermocouple	A deep
		B deep
		B mid 1
		B mid 2
		B surface
		C deep
		C mid 1
		D deep
		D mid 1
		E surface

as references. The standard deviation of repetitive readings on the same thermocouple was 0.001 mV or 0.12°R. The standard deviation between different thermocouples was 0.006 mV or 0.72°R. The average output between 492° and 134.5°R was 5.53 mV, which compares with 5.52 mV according to National Bureau of Standards (NBS) data.

The manufacturer calibrated the platinum-resistance temperature sensors in terms of temperature versus electrical resistance. After each experiment, known resistances were supplied to the recording system to check its calibration. The NBS cites the calibration of platinum resistance sensors as stable for years.¹⁹

Measured electrical current and voltage were checked by computing a resistance given for a test specimen and comparing it with a resistance measured by a Biddle Megger micro-ohmmeter. At approximately 1000 A and 4V, the calculated resistance was 2% high.

Since facilities were not available for the calibration of a low flow rate turbine meter in liquid hydrogen, the manufacturer's calibration in water was used. Therefore mean flow rates were computed from the measured temperatures and pressures in the inlet and outlet plena and from the electrical power input. The turbine meter was used for observing oscillations in flow rate.

4.2. Calibration of Apparatus

The apparatus was calibrated on gaseous helium before each liquid hydrogen experiment. Checks were made on the consistency of platinum resistance sensors and thermocouples at ambient temperatures by recording temperatures in the test section before helium was admitted to it. Low temperature checks were performed after the experiments by cooling the test section to liquid hydrogen temperatures. Fig. 4.1 shows typical values of temperatures, pressures, and voltages recorded during a calibration run with gaseous helium. The identification of temperatures in Fig. 4.1 corresponds to that of Fig. 3.3. Heat transfer data from the calibration runs were correlated by

$$N_{Nu} = 0.023 N_{Re}^{0.8} N_{Pr}^{0.4}$$

Volumetric analyses of samples from flow experiments, made with a Beckman GC-2A gas chromato-

Fig. 4.1. Typical Data from Calibration Runs Using Helium.

graph, indicated that a fraction of a percent of helium started to appear in the liquid hydrogen flow at the 20% level of the dewar. Consequently all data used in this investigation are for dewar levels greater than 25% of capacity.

4.3. Testing Procedure

In the tests the flow control valve was locked open to prevent the flow control loop from interacting with the oscillations. The adjustable geometrical factors were outlet plenum orifice diameter, outlet plenum volume, and heated portion of the flow channel. For a given geometry, dewar pressure and surface temperature at station D were chosen as the governing variables. Dewar pressures were about 240, 200, 160, and 110 psig in a series of runs. However, variations around these values were often used so that the data actually covered a range of 100 to 250 psig. At a given dewar pressure, electrical power was adjusted manually to obtain a desired temperature on the tube surface at station D. Power was initially adjusted to set this temperature near

650°R, then lowered in 50° to 80°R steps to record data for successive runs. When lowering the power made the oscillations disappear, data were recorded, and the power was slowly adjusted until oscillations reappeared. The absence or presence of oscillations was determined by observing the oscillograph during the adjustment of the electrical power supply. Inception conditions did not depend on approach from oscillating or nonoscillating conditions.

A 5% ripple in the dc power supply produced objectionable noise in thermocouple circuits. This noise was filtered from the circuit of surface temperature D by a tuned, three-stage L-C circuit. The ripple did not affect recordings of pressure, flow rate, and inlet and outlet plenum temperatures measured by the platinum resistance sensors. To record temperatures measured by thermocouples, power was turned off after surface temperature D had stabilized. Data recording was started 5 to 10 sec before the power was turned off, and was continued during the subsequent cooling. For heat transfer analysis, temperatures recorded by this procedure were extrapolated to the time when power was turned off.

5. DATA

5.1. Summary of Test Conditions

All data are from experiments on a 0.25-in.-i.d. by 10-ft-long test section heated over its entire length. Outlet plenum orifices were 0.052, 0.0995, 0.130, 0.181, and 0.201 in. in diameter. Table 5.1 presents the ranges of variables covered.

Table 5.1

Ranges of Data for 120 Inch Heated Length

Variable	Units	Minimum	Maximum
Inlet pressure	psia	112	265
Mean pressure drop	psi	0.5	66
Electrical power	kW	1.44	56.5
Inlet temperature	°R	48	63
Outlet temperature	°R	74	620
Flow rate	lb/sec	0.0022	0.0537
Helmholtz mode frequency	cps	4.2	37.5
Helmholtz mode pressure amplitude	psi	0	34
Frequency of first pipe harmonic	cps	70	150
Pressure amplitude of first pipe harmonic	psi	0	13
Bulk temperature amplitude at B	°R	0	100
Bulk temperature amplitude at C	°R	0	86
Bulk temperature amplitude at D	°R	0	46

The listed amplitudes were measured peak to peak. Fluid temperature amplitudes were observed only for the Helmholtz mode. Pipe mode oscillations were at too high a frequency for the response of the thermo-

couples. Appendix A contains a digital computer code which was used to compare experimental data and correlating equations. Appendixes B and C contain heat transfer data for bulk hydrogen temperatures above and below 100°R, respectively.

5.2. Sample Data

Table 5.2 presents a sample of data recorded during an experiment using a 0.201 in. orifice and a 58 in.³ outlet plenum. The test section was heated over its entire length. Figure 5.1 displays the oscillations observed during that run shortly after power was turned off. For comparison, Fig. 5.2 shows a record made under conditions which produced small amplitude oscillations. The lowest frequency in Figs. 5.1 and 5.2 corresponds to the Helmholtz mode. Figure 5.2 shows the response of thermocouple channels when power was turned off. Thermocouple measurements were possible only when power was off because of the high noise level which otherwise existed. To illustrate phase variations a reference line is aligned with the inlet pressure minimum on Fig. 5.1. Note the scale inversions on

Table 5.2					
Sample Data from Recordings					
(Locations are shown in Fig. 3.3.)					
Record time: 147 sec					
Outlet plenum volume: 57 in. ³					
Variable	Unit	Location	Mean	Amplitudes	
				18.2 cps	120 cps
Static pressure	psia	Inlet plenum	207	8	0
		B	202	10	6
		C	191	10	10
		D	175	10	6
		Outlet plenum	158	8	0
Bulk temperature	°R	Inlet plenum	57	0	
		B	105	20	
		C	202	30	
		D	315	10	
		Outlet plenum	424	3	
Film temperature	°R	B	320	5	
		C	310	3	
		D	400	0	
Wall temperature	°R	A deep	425		
		B deep	355		
		B mid 1	431		
		B mid 2	436		
		B surface	450		
		C deep	386		
		C mid 1	456		
		C mid 2	448		
		C surface	490		
		D deep	468		
		D mid 1	545		
		D surface	576		
		E surface	644		
Voltage	volts	Inlet	0.1		
		1	6.8		
		2	9.4		
		3	13.1		
		4	16.4		
Current	amps	Outlet	27.4		
			1480		
Turbine meter	gpm	Inlet	3.5	0.5	
Pressure drop	psi	Inlet-Outlet	45	30	

pressures and inlet and outlet temperatures. Wall temperatures did not oscillate. Oscillations of fluid film temperatures were small.

Fig. 5.1. Experimental Oscillations with Helmholtz and Pipe Modes.

Fig. 5.2. Experimental Oscillations in the Helmholtz Mode.

6. CALCULATIONS

6.1. Scope of Calculations

This section presents the methods of calculation for the reduction and correlation of experimental data and estimates of experimental precision.

Data recorded on magnetic tape by the multiplexer system were reduced by digital computer to provide a record of absolute temperature, pressure, and voltage versus time. Written calculations were made for flow rate, heat flux, similarity numbers, and precision estimates. The comparisons with heat transfer correlations were made by digital computer.

6.2. Sample Calculations

The following sample calculations use the data of Table 5.2.

6.2.1. Reduction of Data. Flow rate was calculated from an energy balance on the test section by

$$W_1 = (e_{out} - e_{in})(I) / [(1055)(H_{out} - H_{in})], \quad (6.1)$$

where

H_{in} = enthalpy of fluid at inlet to test section, Btu/lb,

H_{out} = enthalpy of fluid at outlet of test section, Btu/lb,

I = current, amps,

e_{in} = voltage at inlet to test section, volts,

e_{out} = voltage at outlet of test section, volts,

W_1 = weight rate of flow based on heat balance, lb/sec,

and

1055 = conversion from Btu/sec to watts.

Data for the sample calculations are:

Inlet plenum	pressure = 207 psia temperature = 57°R enthalpy = -34.2 Btu/lb density = 0.101 slugs/ft ³
Outlet plenum	pressure = 158 psia temperature = 424°R enthalpy = 1387 Btu/lb
Turbine meter	flow rate = 3.5 gpm
Electrical	current = 1480 amps outlet voltage = 27.4 volts inlet voltage = 0.1 volt

The dependent thermodynamic properties were obtained from Reference 5. The calculated flow rate using Eq. (6.1) was

$$W_1 = (27.4 - 0.1)(1480.) / [(1055.)(1387. + 34.)] \\ = 0.0269 \text{ lb/sec.}$$

This flow rate was compared with the turbine meter output by

$$W_2 = 0.07173 Q \rho, \quad (6.2)$$

where

Q = indicated volumetric rate of flow, gpm,

W_2 = computed weight rate of flow, lb/sec,

ρ = density at inlet to test section, slugs/ft³.

The substitution of numerical values gives

$$W_2 = (0.07173)(3.5)(0.101) = 0.025 \text{ lb/sec.}$$

The turbine meter, which was calibrated with water, checked within 7% of the hydrogen flow calculated from the energy balance.

Heat flux to the dense phase was computed from the current and inlet voltage gradient using

$$q = e_{,x}(I) / (1055\pi D), \quad (6.3)$$

where

D = diameter of test section, ft,

L = length of test section, ft,

and

q = heat flux, Btu/sec-ft².

The voltage gradient at the test section inlet was 2.08 V/ft, determined by plotting voltage measurements versus position. From Eq. (6.3), the local heat flux at the inlet of the test section was

$$q = \frac{(2.08)(1480.)}{(1055.)(\pi)(0.25/12)} = 44.6 \text{ Btu/sec-ft}^2.$$

The inner surface temperature of the electrically heated wall was computed from the thermal diffusion equation, the deep-wall thermocouple temperature, and the rate of heat generation. Since the calculations assumed angular symmetry in the tube wall and neglected axial heat conduction, the resulting steady state thermal diffusion equation in cylindrical coordinates is

$$T_{,rr} + \frac{1}{r} T_{,r} + q'/k_w = 0, \quad (6.4)$$

where

k_w = thermal conductivity based on deep-wall temp, Btu/sec-ft²-°R,

q' = volumetric rate of heat generation, Btu/ft³-sec,

r = radius, ft

and

T = temperature, °R.

A solution to Eq. (6.4) is

$$T = -q' r^2 / 4k_w + C_3 \ln r + C_4. \quad (6.5)$$

The constants in Eq. (6.5) were determined

from the deep-wall thermocouple, at a radius of 0.140 in., and by assuming a zero temperature gradient at the outer radius (0.280 in.). The temperature at the inner radius (0.125 in.) was then computed from

$$T_w = T_d - 0.0034 q' / k, \quad (6.6)$$

where

$$T_d = \text{deep-wall temperature, } ^\circ\text{R},$$

and

$$T_w = \text{temperature at inside surface of wall, } ^\circ\text{R}.$$

In Table 5.2 the temperature at "A deep" is given as 425°R. The voltage plots showed no distinction between voltage gradients at the inlet and at station A, which was 5 in. downstream. For a 1480-A current and a 2.08 V/ft voltage gradient, the corresponding volumetric rate of heat generation is given by

$$q' = I^2 \rho_x / [1055\pi (r_o^2 - r_i^2)] \quad (6.7)$$

or

$$q' = (1480)(2.08/12) / [1055\pi(0.0625)] \\ = 1.24 \text{ Btu/sec-in}^3.$$

The thermal conductivity for stainless steel at 452°R was taken from Reference 14 as 8.0 Btu/hr-ft-°R. The substitution of these results into Eq. (6.6) yields

$$T_w = 425 - 0.0034(1.24)(3600)(144)/(8.0) = 402^\circ\text{R}.$$

The experimental heat transfer coefficient was computed from

$$h_{\text{exp}} = q / (T_w - T_B). \quad (6.8)$$

At station A this becomes

$$h_{\text{exp}} = (44.6)(3600)/(402-57) = 467 \text{ Btu/hr-ft}^2\text{-}^\circ\text{R}.$$

Heat transfer correlations were evaluated by supplying information such as T_w , T_B , h_{exp} , pressure, mass flux, diameter, and L/D to a digital computer code such as that listed in Appendix A.

6.2.2. Calculation of Boiling Numbers. In section 2.2 a boiling number was defined as

$$N_{\text{Bo}} = q / G \lambda^* \quad (6.9)$$

From Fig. 2.1, for a pressure of 207 psia, λ^* is 99 Btu/lb. The mass flux is

$$G = 4W_1 / \pi D^2 \quad (6.10)$$

or

$$G = 4(0.0269) / [\pi(0.25)^2 / 144] = 78.7 \text{ lb/sec-ft}^2.$$

The boiling number is

$$N_{\text{Bo}} = 44.6 / (78.7)(99) = 0.00585.$$

The inception boiling number was given as

$$(N_{\text{Bo}})_i = 0.0045 (N_{\text{Sv}})^{-0.75}. \quad (2.1)$$

From Fig. 2.2, for a pressure of 207 psia, N_{Sv} is 1.72. Therefore

$$(N_{\text{Bo}})_i = 0.0045 / (1.72)^{0.75} = 0.00299.$$

The ratio of boiling number to inception boiling number is

$$N_{\text{Bo}} / (N_{\text{Bo}})_i = 0.00585 / 0.00299 = 1.95.$$

6.3. Hydrogen Properties Used in Digital Computations

All the properties for hydrogen at equilibrium used in this report were based on a digital code prepared by Farmer, Springer, and Fisher.⁵ The quasi two-phase properties shown in Figs. 2.1 and 2.2 were fitted by the equations given below.

6.3.1. Equivalent Saturated Liquid Enthalpy.

For pressures between 30 and 90 psia, and p in psia

$$H_f^* = -84.5 + 0.536(p-30), \text{ Btu/lb.} \quad (6.11)$$

For pressures between 90 and 300 psia

$$H_f^* = -129.9 + 0.8678(p) - 0.001464(p)^2, \\ \text{Btu/lb.} \quad (6.12)$$

6.3.2. Equivalent Latent Enthalpy of Vaporization. For pressures between 30

and 90 psia, and p in psia,

$$\lambda^* = 184 - 0.6(p-30), \text{ Btu/lb.} \quad (6.13)$$

For pressures between 90 and 300 psia

$$\lambda^* = 186.5 - 0.425(p), \text{ Btu/lb.} \quad (6.14)$$

6.3.3. Equivalent Saturated Liquid Specific Volume. For pressures between 40 and

100 psia, and p in psia,

$$v_f^* = 0.238 + 0.000643(p-30), \text{ ft}^3/\text{lb.} \quad (6.15)$$

For pressures between 100 and 300 psia,

$$v_f^* = 0.264 + 0.000215(p), \text{ ft}^3/\text{lb.} \quad (6.16)$$

6.3.4. Equivalent Saturated Vapor Specific Volume. For pressures between 40

and 100 psia, and p in psia,

$$v_g^* = 4.72 - 0.0865(p-40) + 0.000639(p-40)^2 \\ \text{ft}^3/\text{lb.} \quad (6.17)$$

For pressures between 100 and 300 psia,

$$v_g^* = v_f^* [12.71 - 0.07275(p) + 0.0001185(p)^2], \\ \text{ft}^3/\text{lb.} \quad (6.18)$$

6.4. Estimated Precision

6.4.1 Precision of Data. The precision of measurements is shown in Table 6.1.

Table 6.1
Precision of Measurements

Variable	Unit	Typical Magnitude	Estimated Precision	Fractional Precision
Outlet voltage	volts	18	0.1	0.006
Current	amps	800	4	0.005
Static pressure	psia	200	2	0.01
Inlet temperature	°R	60	1	0.017
Bulk temperature	°R	200	3	0.015
Wall temperature	°R	300	3	0.01

The propagation of the precision estimates of the measured variables through the calculation of heat transfer coefficients and similarity numbers was investigated using differential calculus.³ This resulted in a typical fraction precision of 0.1 for experimental heat transfer coefficients, and a comparable fractional precision for predicted heat transfer coefficients computed from Eq. (2.5). Consequently the precision associated with the ratio of experimental to predicted heat transfer coefficients was typically $\pm 20\%$. A precision analysis in Reference 22 shows the typical fractional precision for boiling numbers to be 0.15. The precision associated with the ratio of a boiling number to an inception boiling number was typically $\pm 30\%$. The resulting precision obtained from plotting the ratio of heat transfer coefficients versus the ratio of boiling numbers was $\pm 36\%$.

6.4.2. Heat Transfer from Jacket to Test Section.

Heat transferred by thermal radiation, between the outer surface of the test section and the vacuum jacket was computed to be 9.1 W by assuming a shell temperature of 500°R, a tube surface temperature of 60°R, and an emissivity coefficient of 0.2. This rate of heat transfer is 0.63% of 1440 W, which was the minimum electrical power applied to the test section in this investigation. Thermal conduction from the jacket to the test section was calculated to be 0.2 W by using the maximum observed axial gradient of 7°R/in., and 70 Btu/hr-ft²-(°R/in.) for the conductivity of stainless steel. This is 2% of the minimum electric power applied to 1 in. of the test section adjacent to the

inlet plenum. Since the test section was in a vacuum, there was no thermal convection between it and the jacket. Consequently, the effect of omitting heat transfer from the jacket to the test section was negligible compared to the electrical power applied to the test section.

7. RESULTS

7.1. Hydrogen above 100°R

Since most of the data for bulk temperatures greater than 100°R were collected when oscillations were generated, the effect of Helmholtz oscillations on gaseous heat transfer was investigated by comparing these data with a correlation derived from data for nonoscillating flow. Figure 7.1 presents a comparison of heat transfer coefficients, computed from Eq. (2.5), with gaseous coefficients obtained from the data of this investigation. Since 90% of the heat transfer with oscillations agreed within $\pm 20\%$ with a correlation for heat transfer without oscillations, it appears that Helmholtz oscillations, generated in the presence of a liquid or dense phase, do not affect heat transfer to the gaseous phase downstream. The lack of a significant difference in heat transfer between oscillating and non-oscillating gaseous flow is also illustrated by comparison of the 15 nonoscillating flow data points with the remaining points in Fig. 7.1.

Since the hydrogen data bank is subject to further analysis, Eq. (2.5) may be superseded by a better correlation; however, there appears to be no

Fig. 7.1. Comparison of gaseous data with Eq.(2.5).

significant difference between gaseous heat transfer data obtained in the presence of Helmholtz oscillations and that obtained without oscillations.

Since Hendricks, Simoneau, and Friedman¹¹ and Miller, Seader, and Trebes¹⁸ have shown that heat transfer to cryogenic hydrogen at pressures above 1000 psia can be correlated with the same formulae used for gaseous hydrogen, it appears that the heat transfer mechanisms for the two conditions are similar. Hendricks, Simoneau, and Friedman¹¹ have also indicated that self-induced oscillations above 1000 psia affect heat transfer only if they are lateral to the flow. Since Helmholtz-mode oscillations are axial for the gaseous part of the system, the negative results of this report are in agreement with their findings. If the improved heat transfer on the high pressure data of Hendricks, Simoneau, and Friedman is caused solely by lateral flow oscillations and not by the vibration of the tube wall against the flow, an improvement in heat transfer should be anticipated when lateral oscillations develop in gaseous flow.

7.2. Hydrogen below 100°R

7.2.1. Comparison with Correlation for Data above 100°R. A comparison of heat

transfer data for bulk temperatures below 100°R with the correlation given by Eq. (2.5) is shown in Fig. 7.2. The coordinates are the ratio of experimental to predicted heat transfer coefficients versus the ratio of measured bulk temperature to the saturated vapor or maximum specific heat temperature. The graph indicates a gradual decrease in heat transfer coefficient for temperatures below 100°R, and a sharp decrease in the vicinity of the saturated vapor temperature or its supercritical equivalent.

Fig. 7.2. Comparison of Sub 100°R Data with Eq. (2.5).

The notched appearance of the data in Fig. 7.2 implies that the heat transfer coefficients are very sensitive to bulk temperature in this region. The traditional method of obtaining heat transfer coefficients for flow in an electrically heated tube is to measure temperatures at the inlet and outlet of a test section and compute intermediate fluid temperatures from a heat balance using equilibrium assumptions. If there is a tendency to develop a high density core without the mixing necessary to make the equilibrium assumption valid, the computed fluid temperature may be unrealistic. The data bank²⁷ shows a very large scatter of heat transfer coefficients for temperatures below 100°R. Most of its data represent computed fluid temperatures. All of the data in the vapor region of Fig. 7.2. were based on measured fluid temperatures.

7.2.2. Comparison of Data with Dense-Phase Correlations. Station A, being only

20 diameters from the inlet plenum of the test section, was in the vicinity of the source of oscillations. Data from that location were compared with the two-phase and supercritical heat transfer correlations in section 2.4. The NASA correlation given by Eq. (2.9) was used with the pseudo properties derived by Hendricks et al.¹⁰ However inception conditions for thermal-acoustic oscillations have not been correlated with NASA's pseudo properties. Therefore the data of this report were also compared with the earlier NASA correlation for subcritical pressure data, given by Eq. (2.6). Since the correlation was based on equilibrium properties, it might be reasonably extrapolated to supercritical pressures by use of the quasi two-phase properties of Reference 22, which coincide with equilibrium properties at low pressures. The subcritical water correlation given by Eq. (2.11) was also applied using the quasi two-phase properties of Reference 22. The comparison of experimental and predicted heat transfer coefficients showed a noticeable wall to bulk temperature dependence that was not accounted for by any of the correlations. This is shown on Figs. 7.3. through 7.5. The curves indicate the additional temperature ratio dependence of the data. Much of the data upon which the NASA correlations were based have higher wall to bulk temperature ratios than the data given in this report. As Figs. 7.3 and 7.4 indicate, the data obtained in

Fig. 7.3. Dense Hydrogen Data with Pseudo Properties of Reference 10 and Hydrogen Eq. (2.9).

this investigation tend to agree with the NASA type correlations at high wall to bulk temperature ratios. Most of the data upon which the water correlation was based were associated with wall to bulk temperature ratios below 1.4.

7.2.3. Effect of Oscillations on Heat Transfer to Dense Hydrogen.

The effect of oscillations on heat transfer to dense hydrogen was examined by recomputing predicted heat transfer coefficients using the temperature ratio dependent expressions shown in Figs. 7.4 and 7.5, and then plotting the resulting ratio of experimental and predicted heat transfer coefficients versus the

Fig. 7.4. Dense hydrogen data with quasi properties of Reference 22 and hydrogen Eq. (2.6).

Fig. 7.5. Dense hydrogen data with quasi properties of Reference 22 and water Eq. (2.11).

ratio of the boiling number to the inception boiling number. These plots are shown in Fig. 7.6 for the hydrogen correlation, using quasi two-phase properties of Reference 22, and in Fig. 7.7 for the water correlation. Both Figures can be interpreted to indicate that the heat transfer mechanism in the presence of Helmholtz oscillations differs from that with no oscillations. This is in contrast to the gaseous data in section 7.1 where Helmholtz oscillations produce no effect. In the absence of oscillations, heat transfer appears to improve as the conditions for oscillations are approached. Once oscillations are established, increasing their amplitudes by increasing the boiling number produces no significant change in heat transfer. This same effect appears in the hydrogen heat transfer data of Hendricks et al.,¹⁰ as shown in Fig. 7.8. The data shown there are only a sample of

Fig. 7.6. Effect of oscillations on dense hydrogen data using correlation shown on Fig. 7.4.

Fig. 7.7. Effect of oscillations on dense hydrogen data using correlation shown on Fig. 7.5.

Fig. 7.8. Results of treating NASA data with methods used to produce Fig. 7.6.

those presented in their report. The sample was taken from data which Williamson²⁷ selected for his hydrogen heat transfer data bank. Williamson's sample was further reduced by using data below 300 psia and with a bulk quality, based on quasi two-phase properties of Reference 22, that was greater than zero and less than one. The data of Hendricks et al. shown in Fig. 7.8 were treated with the methods used to correlate the data of this report in Fig. 7.6.

Although Helmholtz and pipe mode oscillations are axially oriented, Reference 22 discusses their generation in terms of a lateral response of the film-core boundary, shown in Fig. 1.2, to flow disturbances. An effect on heat transfer caused by the lateral movement, associated with dense-core, superheated film interactions, would concur with the significance of direction found by Hendricks, Simoneau, and Friedman.¹¹

7.2.4. Difference between Water and Hydrogen Correlations. Hendricks et al.¹⁰ re-

ported oscillations during some of their hydrogen experiments, when they were instrumented to observe them. The range of ratios of boiling number to inception boiling number plotted on Fig. 7.8 confirms this. The hydrogen correlation given by Eq. (2.6) is based in part on these data.

Bishop, Sandberg, and Tong⁴ did not observe oscillations during their experiment. The maximum boiling number to inception boiling number ratio that can be computed from their data is 0.54, which also indicates that their data is in the no oscillation category. Consequently, one reason for the difference between the correlations of Eqs. (2.6) and (2.11) is that the former is based on data which appear to be influenced by oscillations, while the latter is based on data collected under conditions that did not generate thermal-acoustic oscillations.

8. CONCLUSIONS

Heat transfer to gaseous hydrogen above 100°R is not affected by axial thermal-acoustic oscillations with wavelengths equal to or greater than the length of the test section.

Gaseous heat transfer near saturated vapor temperature or specific heat maximum is very sensitive to bulk temperature. Heat transfer data in this region should be collected with meticulous care. The use of bulk temperatures based on a heat balance and assumptions of equilibrium in the flow may contribute to the scatter of data in this region.

Heat transfer to two-phase and supercritical hydrogen is influenced by self-induced thermal-acoustic oscillations. Heat transfer improves as the inception of oscillations is approached. Once oscillations occur, increasing their intensity by increasing the boiling number does not improve heat transfer.

Experiments designed to collect data on dense phase heat transfer should also be designed to monitor the possible presence of thermal-acoustic oscillations. The appearance or absence of these oscillations, and their mode and direction, should be reported.

9. NOTATION

<u>Symbol</u>	<u>Units</u>	<u>Meaning</u>
A	ft ²	flow area of test section
A _f		area fraction of flow assigned to film
A _l		area fraction of flow assigned to liquid
c	ft/sec	sonic velocity
c _p	Btu/lb-°R	specific heat at constant pressure
C	ft ⁴ -sec ² /slug	V/ρc ² , acoustic compliance
C ₁ , C ₂		coefficients in Eq. (2.5)
C ₃ , C ₄		coefficients in Eq. (6.5)
D	ft	diameter of flow channel
dL	ft	differential length along heated tube
E	volts	voltage
G	lb/ft ² -sec	mass flux
h	Btu/ft ² -°R-sec	heat transfer coefficient
H _f [*]	Btu/lb	equivalent enthalpy of saturated liquid
H _g [*]	Btu/lb	equivalent enthalpy of saturated vapor
H _{in}	Btu/lb	enthalpy at inlet to test section
H _{out}	Btu/lb	enthalpy at outlet of test section
H _w	Btu/lb	enthalpy, evaluated at wall surface temperature
I	amps	current
k	Btu/ft-°R-sec	thermal conductivity
k _f	Btu/ft-°R-sec	thermal conductivity based on mean film temperature
k _l	Btu/ft-°R-sec	thermal conductivity of liquid
k _t	Btu/ft-°R-sec	weighted thermal conductivity
k _w	Btu/ft-°R-sec	thermal conductivity evaluated at inside wall temperature
L	ft	length of flow channel
m	slugs	mass of fluid in neck of resonator
M	slugs/ft ⁴	acoustic mass or inertance
n		integer corresponding to harmonic number
N _{Am}		$\tilde{p}^w D / (G \lambda^*)$, amplitude number
N _{Bo}		q / (G λ [*]), boiling number
(N _{Bo}) _i		boiling number at inception of oscillations
N _{Nc}		Nusselt number computed from Eq. (2.7)
N _{Nf}		hD/k _f , Nusselt number based on film conductivity
N _{Nu}		hD/k, Nusselt number based on bulk conductivity
N _{Nw}		hD/k, Nusselt number based on weighted conductivity
N _{Pr}		μ _c /k, Prandtl number based on bulk properties
N _{Prf}		Prandtl number based on film properties
N _{Re}		GD/μ, Reynolds number based on bulk viscosity
N _{Ref}		GD/μ _f , Reynolds number based on film viscosity
N _{Refm}		vDP _{fm} /μ _f , Reynolds number used in Eq. (2.7)

N_{St}		$\omega \int_0^L \frac{dL}{v}$, Strouhal number
N_{Sv}		V_{fg}^*/V_f^* , specific volume number
p	lb/ft ²	pressure
$\tilde{p}_H$	lb/ft ²	amplitude of Helmholtz mode, peak to peak
$\tilde{p}_1$	lb/ft ²	amplitude of first harmonic pipe mode, peak to peak
$\tilde{p}_2$	lb/ft ²	amplitude of second harmonic pipe mode, peak to peak
$\tilde{p}_{eq}$	lb/ft ²	equivalent amplitude, peak to peak
q	Btu/ft ² -sec	heat flux
q'	Btu/ft ³ -sec	rate of heat generation per unit volume
Q	gpm	volumetric rate of flow
r	ft	radius
T	°R	temperature
T_B	°R	bulk temperature
T_d	°R	deep wall temperature
T_w	°R	temperature at inside surface of wall
v	ft/sec	velocity
V	ft ³	volume of resonator cavity
V'	ft ³	volume of gas in plenum and flow channel
V_f^*	ft ³ /lb	equivalent specific volume of dense phase
V_{fg}^*	ft ³ /lb	equivalent change in specific volume due to vaporization
V_g^*	ft ³ /lb	equivalent specific volume of saturated vapor
x		quality
x_2		pseudo quality used in Eq. (2.8)
w_1	lb/sec	weight rate of flow based on energy balance
w_2		weight rate of flow based on turbine meter
γ		ratio of specific heat
λ^*	Btu/lb	equivalent latent enthalpy of vaporization
μ	lb-sec/ft ²	viscosity evaluated at bulk temperature
μ_f	lb-sec/ft ²	viscosity evaluated at film temperature
ρ	slugs/ft ³	density
ρ_b	slugs/ft ³	density evaluated at bulk temperature
ρ_f	slugs/ft ³	density evaluated at film temperature
ρ_{fm}	slugs/ft ³	mean film density defined by Eq. (2.8)
ρ_g	slugs/ft ³	density of saturated vapor
ρ_l	slugs/ft ³	liquid density
x_{tt}		Martinelli parameter based on pseudo quality
$x_{tt,x}$		Martinelli parameter
ω_c	cps	computed acoustic frequency
ω_H	cps	frequency of Helmholtz mode
ω_p	cps	frequency of pipe mode
ω_1	cps	first harmonic pipe mode frequency
ω_2	cps	second harmonic pipe mode frequency
$()_r$		first derivative of function with respect to radius
$()_{rr}$		second derivative of function with respect to radius

APPENDIX A
FORTRAN CODE FOR COMPARISON OF DATA WITH CORRELATIONS

This code is a minor modification of one prepared by K. D. Williamson, Jr. to analyze data on heat transfer to hydrogen.²⁷ It contains the correlation given by Eq. (2.5), which was used to produce Figs. 7.1 and 7.2. The other correlations in Section 2 can easily be written into it.

```

HEAT6      - EFN  SOURCE STATEMENT  - IFN(S)  -

      DIMENSION BC1(4), BC2(4), BC3(2), BC4(1), BC5(1), BC6(1),
      *BC7(3), BC8(3), HRTIO(1500), TRTIO(1500), TTB(1500),
      *XXLD(1500), XD(1500), XP(1500), IIPLOT(1500)
      READ(10,10)N
10  FORMAT(15)
      WRITE(9,2)
2   FORMAT(115H1      RUN      TB      TW      T+      P      D      G
      *HEXPT HPRED  HEXPT/HPRED  TW/TB      L/D      RE. NO.  PLOTTING)
      WRITE(9,3)
3   FORMAT(116H      DEG R  DEG H  DEGR PSIA  FT  LB/HR-F
      *2B/HFR  B/HFR      CHARACTER)
      DATA BC1/24HHEXPT, BTU/HR-FT*2-R      , BC2/24HHPRED, BTU/HR-FT*2-R
      CALL DGA(120,980,50,910,0., 2000., 2000.,0.)
      CALL DLN(20,20)
      CALL SLLIN(10,0)
      CALL SBLIN(10,0)
      CALL WLCH(200,980,24,BC1,1)
      CALL WLCV(10,700,24,BC2,1)
      CALL LINCNT(1)
      WRITE(12,9)
9   FORMAT(67H HPRED EQUAL TO 0.0230*(KB/D)(REB**0.8)(PRB**0.4)/(TW/TB),
      *EXP0*COE )
      I=0
      KK=0
      LL=0
      K=0
      L=0
      A=0.
      B=0.
15  READ(10,1)IRUN,IRUM,IRUT,TB,TW,P,D,G,HEXPT,XLD,
      *IPL0T
24  I=I+1
      IF(XLD.GT.10.)GOTO105
      XLD=2.*XLD
105 VELB=G/RHOB
      TVAP=52.10-.000273*(P-100.)**1.9+.0998*(P-100.)
      TRATIO=TW/TB
      TVRAT=TB/TVAP
      TF=(TB+TW)/2.
      CALL TABTP(TB,P,H,Z,GAM,CP,SONIC,ENTRO,XK,XMU,ICE)
35  PH=CP*XMU/XK
      RE=(G*D)/(XMU*3600.*12.)
      TRATIO=TW/TB
      IF(TRATIO.LE.1.8)GOTO130
      COE=.7
      EXP0=.2
      GOTO131
130 COE=1.
      EXP0=.765
131 HPRED=(0.0230*XK*3600.*12./D)*RE**0.8*PR**0.4/(TW/TB)**EXP0*COE
      HRTIO(I)=HRTIO
      TRTIO(I)=TRATIO
      XD(I)=TVRAT
      XXLD(I)=XLD
      TTB(I)=TB
      XP(I)=P
      IIPLOT(I)=IPL0T
      C=(HEXPT-HPRED)**2
      IF(TB-100.)60,55,55
55  A=C+A
      IF(HRTIO-1.20)51,51,56
51  IF(HRTIO-.8)56,52,52
52  KK=KK+1
      GOTO 80
56  LL=LL+1
      GOTO 80

```

```

60 B=C*B
   IF(HRATIO=1.20)61,61,66
61 IF(HRATIO=.8)66,62,62
62 K=K+1
   GOTO 80
66 L=L+1
80 CONTINUE
   CALLPLOT(1,HEXPT,1,HPRED,1,IPL0T,0)
   WRITE(9,4)IRUN,IRUM,IRUT,TB,TN,TF,P,D,G,HEXPT,
*HPRED,HRATIO,TRATIO,XLD,RE,IPL0T
4 FORMAT(3A6,3F6.1,F5.0,F5.4,E10.3,2F6.0,F8.2,F11.2,
*F8.2,E11.3,17)
   IF(1-N)15,17,17
17 CALLADV(2)
   DATABC3/12HHEXPT/HPRED //BC4/6HL/D /
   CALLDGA(120,980,50,910,0,,500,,3,,0.)
   CALDLNLN(10,15)
   CALLSLLN(15,2)
   CALLSBLN(10,2)
   CALLMLCH(200,980,6,BC4,1)
   CALLMLCV(10,700,12,BC3,1)
   CALLLINCNT(1)
   WRITE(12,9)
   DO21 J=1,N
   ICHAR=IIPLOT(J)
21 CALLPLOT(1,XXLD(J),1,HRTIO(J),1,ICAR,0)
   CALLADV(2)
   DATABC5/6HTW/TB /
   CALLDGA(120,980,50,910,0,,10,,3,,0.)
   CALDLNLN(10,15)
   CALLSLLN(15,2)
   CALLSBLN(10,2)
   CALLMLCH(200,980,6,BC5,1)
   CALLMLCV(10,700,12,BC3,1)
   CALLLINCNT(1)
   WRITE(12,9)
   DO23 J=1,N
   ICHAR=IIPLOT(J)
23 CALLPLOT(1,TRTIO(J),1,HRTIO(J),1,ICAR,0)
   CALLADV(2)
   DATABC6/6HTB /
   CALLDGA(120,980,50,910,0,,100,,3,,0.)
   CALDLNLN(10,15)
   CALLSLLN(15,2)
   CALLSBLN(10,1)
   CALLMLCH(200,980,6,BC6,1)
   CALLMLCV(10,700,12,BC3,1)
   CALLLINCNT(1)
   WRITE(12,9)
   DO25 J=1,N
   ICHAR=IIPLOT(J)
25 CALLPLOT(1,TTB(J),1,HRTIO(J),1,ICAR,0)
   CALLADV(2)
   DATARC7/18HTB/TVAPOR /
   CALLDGA(120,980,50,910,0,,2,,3,,0.)
   CALDLNLN(10,15)
   CALLSLLN(15,2)
   CALLSBLN(10,2)
   CALLMLCH(200,980,18,BC7,1)
   CALLMLCV(10,700,12,BC3,1)
   CALLLINCNT(1)
   WRITE(12,9)
   DO27 J=1,N
   ICHAR=IIPLOT(J)
27 CALLPLOT(1,XD(J),1,HRTIO(J),1,ICAR,0)
   CALLADV(2)
   DATABC8/18HPPRESSURE,PSIA /
   CALLDGA(120,980,50,910,0,,300,,3,,0.)
   CALDLNLN(15,15)
   CALLSLLN(15,2)
   CALLSBLN(15,1)
   CALLMLCH(200,980,18,008,1)
   CALLMLCV(10,700,12,BC3,1)
   CALLLINCNT(1)
   WRITE(12,9)
   DO29 J=1,N
   ICHAR=IIPLOT(J)
29 CALLPLOT(1,XP(J),1,HRTIO(J),1,ICAR,0)
   XXXLL=KK+LL
   XKL=K-L
   PLUS=(A/XXXLL)**.5
   XMINUS=(R/XXL)**.5
   WRITE(9,70)KK
70 FORMAT(80H NUMBER OF POINTS WITH HEXPT/HPRED BETWEEN 0.8 AND 1.20
*FOR TB GREATER THAN 100R,19)
   WRITE(9,71)LL
71 FORMAT(80H NUMBER OF POINTS WITH HEXPT/HPRED OUTSIDE 20 PERCENT BA
*ND FOR TB GREATER THAN 100R,15)
   WRITE(9,72)K
72 FORMAT(77H NUMBER OF POINTS WITH HEXPT/HPRED BETWEEN 0.8 AND 1.20
*FOR TB LESS THAN 100R,19)
   WRITE(9,73)L
73 FORMAT(80H NUMBER OF POINTS WITH HEXPT/HPRED OUTSIDE 20 PERCENT BA
*ND FOR TB LESS THAN 100R,15)
   WRITE(9,74)PLUS,XXXLL
74 FORMAT(44H STANDARD DEVIATION FOR TB GREATER THAN 100R,E10.3,17H N
*UMBER OF POINTS,F5.0)
   WRITE(9,75)XMINUS,XKL
75 FORMAT(41H STANDARD DEVIATION FOR TB LESS THAN 100R,E10.3,17H NUME
*ER OF POINTS,F5.0)
   STOP
   END

```


APPENDIX B

DATA ON HYDROGEN ABOVE 100°R

The following data are from an output of the digital code shown in Appendix A. A typical run identification is "RST Q 16.3". "RST" designates the source, i.e. this report. "Q" indicates oscillations; "P" in place of Q indicates no oscillations. "16" cross references data on this run with data from the same run number given in the appendix of Reference 22. The "3" after the decimal point indicates data collected at temperature station C shown in Fig. 3.3 and in Table 3.1. 1 corresponds to station A, 2 to B, 3 to C, and 4 to D.

In addition to the identification code, the input data was as follows:

Symbol	Unit	Meaning
TB	°R	fluid bulk temperature
TW	°R	inside wall temperature
P	psia	fluid pressure
G	lb/hr-ft ²	mass flow rate
HEXPT	Btu/hr-ft-°R	experimental heat transfer coefficient
L/D		length to diameter ratio

RUN	TB	TW	TF	P	D	G	HEXPT	HEXPT	HEXPT/HEXPT	TW/TB	L/D	ME. NO.	PLOTTING CHARACTER
	DEG R	DEG R	DEGR	PSIA	FT	LB/HR-F2B/HFK	B/HFK	B/HFK					
RST Q	1.2	100.0	180.0	140.0	179.0208	0.393E	05	245.	208.	1.18	1.80	118.50	0.11E 00 40
RST Q	1.3	175.0	244.0	209.5	179.0208	0.393E	05	305.	291.	1.05	1.39	238.00	0.801E 05 40
RST Q	1.4	255.0	303.0	279.0	177.0208	0.393E	05	493.	398.	1.24	1.19	358.00	0.621E 05 40
RST Q	2.2	138.0	236.0	187.0	181.0208	0.398E	05	234.	208.	1.14	1.71	118.50	0.65E 05 40
RST Q	2.3	220.0	315.0	267.5	180.0208	0.398E	05	292.	302.	0.97	1.43	238.00	0.625E 05 40
RST Q	2.4	310.0	396.0	353.0	178.0208	0.398E	05	374.	373.	1.00	1.28	358.00	0.494E 05 40
RST Q	3.2	164.0	273.0	218.5	182.0208	0.391E	05	228.	214.	1.07	1.68	118.50	0.705E 05 40
RST Q	3.3	280.0	368.0	324.0	182.0208	0.391E	05	341.	334.	1.02	1.31	238.00	0.499E 05 40
RST Q	3.4	428.0	487.0	457.5	179.0208	0.391E	05	659.	382.	1.72	1.14	358.00	0.367E 05 40
RST Q	4.2	157.0	275.0	216.0	206.0208	0.399E	05	272.	228.	1.19	1.75	118.50	0.625E 05 40
RST Q	4.3	297.0	376.0	331.5	206.0208	0.399E	05	398.	377.	1.06	1.31	238.00	0.551E 05 40
RST Q	4.4	413.0	492.0	452.5	206.0208	0.399E	05	515.	411.	1.25	1.19	358.00	0.433E 05 40
RST Q	5.2	125.0	222.0	173.5	206.0208	0.395E	05	240.	219.	1.10	1.78	118.50	0.101E 06 40
RST Q	5.3	225.0	301.0	263.0	206.0208	0.395E	05	395.	348.	1.13	1.34	238.00	0.678E 05 40
RST Q	5.4	325.0	382.0	353.5	206.0208	0.395E	05	572.	430.	1.33	1.18	358.00	0.522E 05 40
RST Q	6.2	100.0	189.0	144.5	206.0208	0.490E	05	272.	249.	1.09	1.89	118.50	0.142E 06 40
RST Q	6.3	175.0	254.0	214.5	206.0208	0.490E	05	306.	340.	0.90	1.45	238.00	0.996E 05 40
RST Q	6.4	256.0	310.0	283.0	206.0208	0.490E	05	560.	470.	1.19	1.21	358.00	0.771E 05 40
RST Q	7.3	120.0	170.0	145.0	206.0208	0.588E	05	353.	358.	0.99	1.42	238.00	0.155E 06 40
RST Q	7.4	165.0	194.0	179.5	206.0208	0.588E	05	660.	448.	1.47	1.18	358.00	0.124E 06 40
RST P	10.3	115.0	165.0	140.0	258.0208	0.764E	05	400.	493.	0.98	1.43	238.00	0.203E 06 35
RST P	10.4	140.0	190.0	165.0	258.0208	0.764E	05	458.	476.	0.96	1.36	358.00	0.179E 06 35
RST Q	11.2	105.0	178.0	141.5	259.0208	0.698E	05	358.	333.	1.07	1.70	118.50	0.171E 06 40
RST Q	11.3	175.0	251.0	213.0	259.0208	0.698E	05	406.	417.	0.97	1.45	238.00	0.125E 06 40
RST Q	11.4	247.0	302.0	274.5	259.0208	0.698E	05	678.	553.	1.23	1.22	358.00	0.978E 05 40
RST Q	12.2	133.0	241.0	187.0	260.0208	0.497E	05	355.	263.	1.35	1.81	118.50	0.127E 06 40
RST Q	12.3	210.0	329.0	269.5	260.0208	0.497E	05	335.	367.	0.91	1.57	238.00	0.888E 05 40
RST Q	12.4	302.0	418.0	360.0	259.0208	0.497E	05	374.	460.	0.91	1.38	358.00	0.696E 05 40
RST Q	13.2	154.0	268.0	211.0	259.0208	0.468E	05	363.	276.	1.32	1.74	118.50	0.103E 06 40
RST Q	13.3	260.0	368.0	314.0	259.0208	0.468E	05	386.	409.	0.94	1.42	238.00	0.727E 05 40
RST Q	13.4	360.0	483.0	421.5	259.0208	0.468E	05	387.	446.	0.87	1.34	358.00	0.583E 05 40
RST Q	14.2	166.0	272.0	219.0	187.0208	0.390E	05	288.	218.	1.32	1.64	118.50	0.696E 05 40
RST Q	14.3	296.0	373.0	334.5	184.0208	0.390E	05	405.	352.	1.15	1.26	238.00	0.469E 05 40
RST Q	14.4	432.0	494.0	463.0	180.0208	0.390E	05	565.	386.	1.49	1.14	358.00	0.364E 05 40
RST Q	15.2	146.0	239.0	192.5	183.0208	0.395E	05	278.	208.	1.34	1.64	118.50	0.173E 05 40
RST Q	15.3	230.0	330.0	280.0	182.0208	0.395E	05	260.	291.	0.89	1.43	238.00	0.566E 05 40
RST Q	15.4	330.0	422.0	376.0	181.0208	0.395E	05	347.	353.	0.98	1.28	358.00	0.443E 05 40
RST Q	16.2	103.0	179.0	141.0	184.0208	0.396E	05	234.	206.	1.13	1.74	118.50	0.110E 06 40
RST Q	16.3	178.0	244.0	211.0	182.0208	0.396E	05	315.	288.	1.09	1.37	238.00	0.757E 05 40
RST Q	16.4	255.0	294.0	274.5	180.0208	0.396E	05	580.	393.	1.49	1.15	358.00	0.594E 05 40
RST Q	17.3	100.0	162.0	131.0	183.0208	0.617E	05	313.	325.	0.96	1.62	238.00	0.184E 06 40
RST Q	17.4	150.0	193.0	171.5	181.0208	0.617E	05	364.	411.	0.88	1.29	358.00	0.140E 06 40
RST Q	19.2	127.0	220.0	173.5	197.0208	0.295E	05	160.	145.	1.10	1.73	118.50	0.295E 05 40
RST Q	19.3	220.0	297.0	258.5	195.0208	0.295E	05	237.	226.	1.05	1.35	238.00	0.410E 05 40
RST Q	19.4	310.0	365.0	337.5	192.0208	0.295E	05	355.	284.	1.25	1.18	358.00	0.324E 05 40
RST Q	20.2	100.0	172.0	136.0	197.0208	0.294E	05	167.	155.	1.08	1.72	118.50	0.155E 05 40
RST Q	20.3	166.0	233.0	199.5	195.0208	0.294E	05	205.	199.	1.03	1.40	238.00	0.535E 05 40
RST Q	20.4	250.0	297.0	273.5	192.0208	0.294E	05	321.	279.	1.15	1.19	358.00	0.407E 05 40
RST Q	21.4	135.0	173.0	154.0	192.0208	0.292E	05	213.	212.	1.00	1.28	358.00	0.685E 05 40
RST Q	22.3	133.0	238.0	195.5	264.0208	0.394E	05	233.	251.	0.93	1.56	238.00	0.824E 05 40

RST 0	22.4	237.0	288.0	262.5	261.0	0.0208	0.374E	05	426.	371.	1.15	1.22	358.00	0.610E	05	40
RST 0	23.2	121.0	216.0	168.5	267.0	0.0208	0.356E	05	227.	209.	1.08	1.79	118.50	0.712E	05	40
RST 0	23.3	208.0	291.0	249.5	266.0	0.0208	0.356E	05	267.	306.	0.87	1.40	238.00	0.640E	05	40
RST 0	23.4	293.0	358.0	325.5	263.0	0.0208	0.356E	05	419.	385.	1.08	1.22	358.00	0.709E	05	40
RST 0	24.2	140.0	251.0	195.5	265.0	0.0208	0.356E	05	193.	200.	0.56	1.79	118.50	0.780E	05	40
RST 0	24.3	225.0	336.0	280.5	264.0	0.0208	0.356E	05	215.	285.	0.75	1.49	238.00	0.574E	05	40
RST 0	24.4	320.0	414.0	367.0	261.0	0.0208	0.356E	05	339.	354.	0.56	1.29	358.00	0.453E	05	40
RST 0	25.2	139.0	354.0	246.5	259.0	0.0208	0.111E	06	476.	470.	1.01	2.55	118.50	0.261E	06	40
RST 0	25.3	282.0	432.0	357.0	257.0	0.0208	0.111E	06	772.	791.	0.58	1.53	238.00	0.163E	06	40
RST 0	25.4	426.0	583.0	504.5	252.0	0.0208	0.111E	06	882.	877.	1.01	1.37	358.00	0.124E	06	40
RST 0	26.2	121.0	313.0	217.0	258.0	0.0208	0.117E	06	488.	486.	1.00	2.59	118.50	0.301E	06	40
RST 0	26.3	252.0	375.0	313.5	257.0	0.0208	0.117E	06	821.	809.	1.02	1.49	238.00	0.180E	06	40
RST 0	26.4	380.0	480.0	430.0	252.0	0.0208	0.117E	06	1209.	969.	1.25	1.26	358.00	0.140E	06	40
RST 0	27.2	110.0	289.0	199.5	258.0	0.0208	0.124E	06	432.	509.	0.85	2.63	118.50	0.338E	06	40
RST 0	27.3	208.0	330.0	269.0	257.0	0.0208	0.124E	06	812.	751.	1.08	1.59	238.00	0.223E	06	40
RST 0	27.4	322.0	415.0	368.5	252.0	0.0208	0.124E	06	1160.	1007.	1.15	1.29	358.00	0.166E	06	40
RST 0	28.3	190.0	295.0	237.5	260.0	0.0208	0.136E	06	708.	728.	0.87	1.64	238.00	0.269E	06	40
RST 0	28.4	272.0	371.0	321.5	254.0	0.0208	0.136E	06	1032.	1003.	1.03	1.36	358.00	0.203E	06	40
RST P	29.3	121.0	225.0	173.0	260.0	0.0208	0.136E	06	706.	654.	1.08	1.86	238.00	0.401E	06	35
HST P	29.4	210.0	299.0	254.5	254.0	0.0208	0.136E	06	925.	983.	0.54	1.42	358.00	0.279E	06	35
RST 0	31.3	134.0	210.0	172.0	209.0	0.0208	0.137E	06	779.	654.	1.19	1.57	238.00	0.334E	06	40
RST 0	31.4	178.0	252.0	215.0	203.0	0.0208	0.137E	06	791.	796.	0.59	1.42	358.00	0.275E	06	40
RST 0	32.2	108.0	275.0	191.5	211.0	0.0208	0.144E	06	370.	429.	0.86	2.55	118.50	0.294E	06	40
RST 0	32.3	200.0	311.0	255.5	209.0	0.0208	0.144E	06	685.	644.	1.06	1.55	238.00	0.193E	06	40
RST 0	32.4	300.0	396.0	348.0	203.0	0.0208	0.144E	06	888.	856.	1.04	1.32	358.00	0.146E	06	40
RST 0	33.2	117.0	310.0	213.5	212.0	0.0208	0.100E	06	368.	413.	0.89	2.62	118.50	0.266E	06	40
RST 0	33.3	228.0	356.0	292.0	210.0	0.0208	0.100E	06	613.	655.	0.54	1.56	238.00	0.170E	06	40
RST 0	33.4	348.0	461.0	404.5	204.0	0.0208	0.100E	06	885.	823.	1.07	1.32	358.00	0.120E	06	40
RST 0	34.2	143.0	330.0	236.5	212.0	0.0208	0.910E	05	420.	403.	1.04	2.31	118.50	0.212E	06	40
RST 0	34.3	250.0	393.0	321.5	211.0	0.0208	0.910E	05	583.	627.	0.83	1.57	238.00	0.146E	06	40
RST 0	34.4	378.0	516.0	447.0	204.0	0.0208	0.910E	05	763.	744.	1.03	1.37	358.00	0.113E	06	40
RST 0	35.2	126.0	342.0	234.0	213.0	0.0208	0.857E	05	398.	364.	1.09	2.71	118.50	0.210E	06	40
RST 0	35.3	290.0	420.0	355.0	212.0	0.0208	0.857E	05	657.	674.	0.87	1.45	238.00	0.124E	06	40
RST 0	35.4	440.0	572.0	506.0	205.0	0.0208	0.857E	05	844.	740.	1.14	1.30	358.00	0.936E	05	40
RST 0	36.2	145.0	305.0	225.0	172.0	0.0208	0.759E	05	374.	348.	1.07	2.10	118.50	0.170E	06	40
RST 0	36.3	235.0	353.0	294.0	167.0	0.0208	0.759E	05	529.	543.	0.87	1.50	238.00	0.127E	06	40
RST 0	36.4	335.0	461.0	398.0	164.0	0.0208	0.759E	05	620.	641.	0.87	1.38	358.00	0.994E	05	40
RST 0	37.3	180.0	320.0	250.0	168.0	0.0208	0.812E	05	427.	438.	0.88	1.78	238.00	0.163E	06	40
RST 0	37.4	320.0	406.0	363.0	166.0	0.0208	0.812E	05	829.	720.	1.15	1.27	358.00	0.113E	06	40
RST 0	38.3	170.0	282.0	226.0	171.0	0.0208	0.985E	05	456.	521.	0.88	1.66	238.00	0.205E	06	40
RST 0	38.4	251.0	345.0	298.0	169.0	0.0208	0.985E	05	654.	736.	0.89	1.37	358.00	0.158E	06	40
RST 0	41.4	113.0	172.0	142.5	126.0	0.0208	0.901E	05	413.	457.	0.80	1.52	358.00	0.267E	06	40
RST 0	43.2	117.0	346.0	231.5	154.0	0.0208	0.230E	06	626.	739.	0.85	2.96	118.50	0.623E	06	40
RST 0	43.3	250.0	369.0	309.5	147.0	0.0208	0.230E	06	1432.	1367.	1.05	1.48	238.00	0.369E	06	40
RST 0	43.4	340.0	453.0	396.5	135.0	0.0208	0.230E	06	1719.	1590.	1.08	1.33	358.00	0.298E	06	40
RST 0	44.2	112.0	393.0	252.5	154.0	0.0208	0.238E	06	581.	654.	0.89	3.51	118.50	0.581E	06	40
RST 0	44.3	275.0	444.0	359.5	147.0	0.0208	0.268E	06	1100.	1226.	0.80	1.61	238.00	0.312E	06	40
RST 0	44.4	392.0	566.0	479.0	135.0	0.0208	0.268E	06	1303.	1374.	0.85	1.44	358.00	0.744E	06	40
RST 0	45.2	121.0	401.0	261.0	154.0	0.0208	0.196E	06	570.	639.	0.89	3.31	118.50	0.518E	06	40
RST 0	45.3	265.0	459.0	362.0	145.0	0.0208	0.196E	06	981.	1090.	0.80	1.73	238.00	0.302E	06	40
RST 0	45.4	420.0	566.0	493.0	134.0	0.0208	0.196E	06	1549.	1389.	1.12	1.35	358.00	0.220E	06	40
RST 0	46.3	134.0	276.0	205.0	153.0	0.0208	0.267E	06	877.	915.	0.86	2.06	238.00	0.657E	06	40
RST 0	46.4	225.0	322.0	273.5	137.0	0.0208	0.267E	06	1536.	1507.	1.02	1.43	358.00	0.461E	06	40
RST P	47.4	100.0	217.0	158.5	137.0	0.0208	0.501E	06	971.	1480.	0.86	2.17	358.00	0.161E	07	35
RST 0	48.3	230.0	460.0	345.0	220.0	0.0208	0.326E	06	1291.	1453.	0.89	2.00	238.00	0.551E	06	40
RST 0	48.4	360.0	556.0	458.0	206.0	0.0208	0.326E	06	1767.	1882.	0.84	1.54	358.00	0.400E	06	40
RST 0	49.3	170.0	354.0	262.0	218.0	0.0208	0.517E	06	1232.	1780.	0.89	2.08	238.00	0.107E	07	40
RST 0	49.4	270.0	413.0	341.5	200.0	0.0208	0.517E	06	1820.	2642.	0.89	1.53	358.00	0.780E	06	40
RST P	50.3	113.0	253.0	183.0	218.0	0.0208	0.436E	06	1186.	1393.	0.85	2.24	238.00	0.119E	07	35
HST P	50.4	175.0	294.0	234.5	200.0	0.0208	0.436E	06	1612.	1744.	0.82	1.68	358.00	0.887E	06	35
RST P	51.3	127.0	222.0	174.5	214.0	0.0208	0.325E	06	1191.	1204.	0.89	1.75	238.00	0.821E	06	35
RST P	51.4	176.0	261.0	218.5	194.0	0.0208	0.325E	06	1485.	1517.	0.88	1.48	358.00	0.659E	06	35
RST 0	52.2	108.0	347.0	227.5	240.0	0.0208	0.335E	06	955.	1068.	0.89	3.21	118.50	0.933E	06	40
RST 0	52.3	220.0	396.0	308.0	228.0	0.0208	0.335E	06	1522.	1531.	0.89	1.80	238.00	0.583E	06	40
RST 0	52.4	340.0	484.0	412.0	210.0	0.0208	0.335E	06	2104.	2053.	1.03	1.42	358.00	0.434E	06	40
RST 0	53.3	193.0	354.0	273.5	230.0	0.0208	0.362E	06	1463.	1482.	0.89	1.83	238.00	0.368E	06	40
RST 0	53.4	288.0	415.0	351.5	213.0	0.0208	0.362E	06	2229.	2138.	1.04	1.44	358.00	0.325E	06	40
RST 0	54.3	122.0	318.0	220.0	233.0	0.0208	0.406E	06	1115.	1290.	0.86	2.61	238.00	0.105E	07	40
RST 0	54.4	218.0	354.0	286.0	215.0	0.0208	0.406E	06	1750.	1919.	0.81	1.62	358.00	0.711E	06	40
RST 0	55.4	125.0	249.0	187.0	212.0	0.0208	0.505E	06	1445.	1749.	0.83	1.99	358.00	0.144E	07	40
RST 0	56.3	230.0	413.0	321.5	188.0	0.0208	0.271E	06	1238.	1306.	0.85	1.86	238.00	0.459E	06	40
RST 0	56.4	350.0	508.0	429.0	172.0	0.0208	0.271E	06	1702.	1701.	1.00	1.45	358.00	0.343E	06	40
RST 0	57.2	105.0	329.0	217.0	202.0	0.0208	0.263E	06	840.	910.	0.82	3.13	118.50	0.820E	06	40
RST 0	57.3	202.0	377.0	289.5	191.0	0.0208	0.263E	06	1189.	1242.	0.86	1.87	238.00	0.522E	06	40
RST 0	57.4	315.0	462.0	388.5	175.0	0.0208	0.263E	06	1676.	1753.	0.86	1.47	358.00	0.380E	06	40
RST 0	58.3	160.0	319.0	239.5	192.0	0.0208	0.320E	06	1149.	1175.	0.88	1.99	238.00	0.692E	06	40
RST 0	58.4	240.0	384.0	312.0	172.0											

RST Q	68.4	210.0	309.0	259.5	96.0208	0.173E	U6	990.	1004.	0.49	1.47	358.00	U.314E	U6	40
RST Q	69.3	178.0	316.0	247.0	220.0208	0.169E	06	489.	797.	0.41	1.78	238.00	U.339E	06	40
RST Q	69.4	285.0	386.0	335.5	217.0208	0.169E	06	808.	1215.	0.47	1.35	358.00	U.247E	06	40
RST P	70.3	140.0	270.0	205.0	220.0208	0.114E	06	465.	498.	0.43	1.93	238.00	U.264E	06	35
RST P	70.4	230.0	322.0	276.0	216.0208	0.114E	06	742.	795.	0.43	1.40	358.00	U.193E	06	35
RST Q	71.3	170.0	286.0	228.0	196.0208	U.968E	05	455.	513.	0.49	1.68	238.00	U.201E	06	40
RST Q	71.4	250.0	337.0	293.5	192.0208	U.968E	05	769.	738.	1.44	1.35	358.00	U.155E	06	40
RST P	72.3	135.0	228.0	181.5	168.0208	0.905E	05	421.	430.	0.58	1.69	238.00	U.221E	06	35
RST P	72.4	205.0	272.0	238.5	164.0208	0.905E	05	664.	650.	1.42	1.33	358.00	U.166E	06	35
RST Q	73.3	190.0	359.0	274.5	132.0208	0.174E	06	707.	789.	0.40	1.89	238.00	U.337E	06	40
RST Q	73.4	310.0	419.0	364.5	124.0208	0.174E	06	1309.	1259.	1.44	1.35	358.00	U.246E	06	40
RST Q	74.2	115.0	390.0	252.5	140.0208	0.149E	06	495.	499.	0.49	3.39	118.50	U.410E	06	40
RST Q	74.3	265.0	437.0	351.0	133.0208	0.149E	06	837.	908.	0.52	1.65	238.00	U.230E	06	40
RST Q	74.4	425.0	565.0	495.0	124.0208	0.149E	06	1289.	1127.	1.14	1.33	358.00	U.166E	06	40
RST Q	75.2	110.0	354.0	232.0	141.0208	0.164E	06	489.	541.	0.50	3.22	118.50	U.467E	06	40
RST Q	75.3	250.0	392.0	321.0	134.0208	0.164E	06	799.	994.	0.59	1.57	238.00	U.264E	06	40
RST Q	75.4	343.0	484.0	413.5	125.0208	0.164E	06	1102.	1160.	0.55	1.41	358.00	U.212E	06	40
RST Q	76.3	125.0	267.0	196.0	135.0208	0.210E	06	761.	730.	1.44	2.14	238.00	U.245E	06	40
RST Q	76.4	240.0	327.0	283.5	125.0208	0.210E	06	1299.	1324.	0.48	1.36	358.00	U.347E	06	40
RST Q	77.4	135.0	224.0	179.5	127.0208	0.271E	06	960.	1021.	0.44	1.66	358.00	U.666E	06	40
RST Q	79.2	140.0	368.0	254.0	187.0208	0.207E	06	735.	737.	1.40	2.63	118.50	U.491E	06	40
RST Q	79.3	270.0	436.0	353.0	183.0208	0.207E	06	1119.	1217.	0.52	1.61	238.00	U.314E	06	40
RST Q	79.4	397.0	561.0	479.0	168.0208	0.207E	06	1381.	1394.	0.49	1.41	358.00	U.241E	06	40
RST Q	80.2	112.0	330.0	221.0	187.0208	0.227E	06	647.	751.	0.46	2.95	118.50	U.628E	06	40
RST Q	80.3	210.0	375.0	292.5	183.0208	0.227E	06	1087.	1096.	0.49	1.79	238.00	U.404E	06	40
RST Q	80.4	322.0	453.0	387.5	168.0208	0.227E	06	1201.	1215.	0.49	1.41	358.00	U.307E	06	40
RST Q	81.3	130.0	317.0	223.5	183.0208	0.233E	06	790.	861.	0.52	2.44	238.00	U.632E	06	40
RST Q	81.4	240.0	365.0	302.5	168.0208	0.233E	06	1325.	1423.	0.43	1.52	358.00	U.417E	06	40
RST Q	82.2	130.0	375.0	262.5	212.0208	0.241E	06	798.	881.	0.51	2.50	118.50	U.344E	06	40
RST Q	82.3	250.0	424.0	337.0	206.0208	0.241E	06	1154.	1287.	0.40	1.70	238.00	U.386E	06	40
RST Q	82.4	370.0	516.0	443.0	184.0208	0.241E	06	1617.	1595.	1.41	1.39	358.00	U.497E	06	40
RST Q	83.2	110.0	345.0	227.5	214.0208	0.256E	06	754.	848.	0.49	3.14	118.50	U.714E	06	40
RST Q	83.3	230.0	392.0	311.0	207.0208	0.256E	06	1201.	1303.	0.42	1.70	238.00	U.433E	06	40
RST Q	83.4	342.0	476.0	409.0	186.0208	0.256E	06	1692.	1681.	1.41	1.39	358.00	U.331E	06	40
RST Q	84.3	180.0	343.0	261.5	207.0208	0.270E	06	1145.	1109.	1.43	1.91	238.00	U.338E	06	40
RST Q	84.4	280.0	402.0	341.0	186.0208	0.270E	06	1668.	1672.	1.40	1.44	358.00	U.403E	06	40
RST Q	85.3	150.0	313.0	231.5	208.0208	0.279E	06	1028.	1083.	0.55	2.09	238.00	U.677E	06	40
RST Q	85.4	245.0	354.0	299.5	188.0208	0.279E	06	1702.	1711.	0.49	1.44	358.00	U.486E	06	40
RST Q	86.2	147.0	341.0	244.0	156.0208	0.964E	05	392.	412.	0.45	2.32	118.50	U.222E	06	40
RST Q	86.3	272.0	408.0	340.0	152.0208	0.964E	05	697.	696.	1.40	1.50	238.00	U.146E	06	40
RST Q	86.4	393.0	529.0	461.0	147.0208	0.964E	05	815.	784.	1.44	1.35	358.00	U.113E	06	40
RST Q	87.2	110.0	263.0	186.5	157.0208	0.141E	06	377.	458.	0.42	2.39	118.50	U.342E	06	40
RST Q	87.3	178.0	282.0	230.0	156.0208	0.141E	06	648.	651.	1.40	1.58	238.00	U.244E	06	40
RST Q	87.4	260.0	330.0	295.0	152.0208	0.141E	06	1126.	934.	1.21	1.27	358.00	U.189E	06	40
RST Q	88.3	100.0	228.0	164.0	154.0208	0.142E	06	424.	522.	0.41	2.28	238.00	U.429E	06	40
RST Q	88.4	175.0	254.0	214.5	148.0208	0.142E	06	769.	780.	0.49	1.45	358.00	U.291E	06	40
RST Q	89.3	150.0	286.0	218.0	156.0208	0.142E	06	498.	523.	0.55	1.91	238.00	U.278E	06	40
RST Q	89.4	240.0	335.0	287.5	149.0208	0.142E	06	839.	845.	0.49	1.40	358.00	U.201E	06	40
RST Q	90.2	140.0	351.0	245.5	193.0208	0.120E	06	484.	483.	1.40	2.51	118.50	U.284E	06	40
RST Q	90.3	290.0	433.0	361.5	191.0208	0.120E	06	850.	861.	0.49	1.49	238.00	U.173E	06	40
RST Q	90.4	440.0	578.0	509.0	184.0208	0.120E	06	1091.	961.	1.14	1.31	358.00	U.131E	06	40
RST Q	91.2	118.0	334.0	226.0	198.0208	0.126E	06	446.	480.	0.53	2.83	118.50	U.335E	06	40
RST Q	91.3	266.0	399.0	332.5	195.0208	0.126E	06	869.	862.	1.41	1.50	238.00	U.193E	06	40
RST Q	91.4	380.0	513.0	446.5	187.0208	0.126E	06	1026.	973.	1.45	1.35	358.00	U.151E	06	40
RST Q	92.3	200.0	333.0	266.5	198.0208	0.143E	06	739.	786.	0.54	1.66	238.00	U.267E	06	40
RST Q	92.4	295.0	395.0	345.0	189.0208	0.143E	06	1131.	1084.	1.44	1.34	358.00	U.204E	06	40
RST Q	93.3	130.0	279.0	204.5	199.0208	0.159E	06	581.	616.	0.54	2.15	238.00	U.396E	06	40
RST Q	93.4	245.0	321.0	283.0	192.0208	0.159E	06	1304.	1113.	1.17	1.31	358.00	U.258E	06	40
RST Q	94.2	140.0	363.0	251.5	216.0208	0.130E	06	492.	520.	0.55	2.59	118.50	U.307E	06	40
RST Q	94.3	278.0	421.0	349.5	215.0208	0.130E	06	942.	895.	1.45	1.51	238.00	U.193E	06	40
RST Q	94.4	430.0	575.0	502.5	204.0208	0.130E	06	1085.	1010.	1.07	1.34	358.00	U.144E	06	40
RST Q	95.2	120.0	342.0	231.0	216.0208	0.139E	06	457.	531.	0.46	2.85	118.50	U.365E	06	40
RST Q	95.3	255.0	395.0	325.0	214.0208	0.139E	06	801.	897.	0.48	1.55	238.00	U.219E	06	40
RST Q	95.4	363.0	507.0	435.0	204.0208	0.139E	06	1039.	1027.	1.41	1.40	358.00	U.172E	06	40
RST Q	96.2	115.0	320.0	217.5	217.0208	0.148E	06	463.	562.	0.42	2.78	118.50	U.400E	06	40
RST Q	96.3	230.0	361.0	295.5	215.0208	0.148E	06	822.	897.	0.42	1.57	238.00	U.250E	06	40
RST Q	96.4	328.0	442.0	385.0	203.0208	0.148E	06	1201.	1114.	1.40	1.35	358.00	U.197E	06	40
RST Q	97.3	195.0	330.0	262.5	216.0208	0.160E	06	728.	833.	0.47	1.69	238.00	U.302E	06	40
RST Q	97.4	298.0	396.0	347.0	205.0208	0.160E	06	1296.	1199.	1.48	1.33	358.00	U.226E	06	40
RST Q	99.2	135.0	367.0	251.0	265.0208	0.167E	06	576.	640.	0.50	2.72	118.50	U.397E	06	40
RST Q	99.3	264.0	433.0	348.5	260.0208	0.167E	06	950.	1016.	0.53	1.64	238.00	U.257E	06	40
RST Q	99.4	400.0	563.0	481.5	257.0208	0.167E	06	1169.	1187.	0.58	1.41	358.00	U.193E	06	40
RST Q	100.2	120.0	346.0	233.0	264.0208	0.178E	06	535.	668.	0.40	2.88	118.50	U.459E	06	40
RST Q	100.3	252.0	400.0	326.0	261.0208	0.178E	06	1050.	1078.	0.47	1.59	238.00	U.282E	06	40
RST Q	100.4	365.0	501.0	433.0	252.0208	0.178E	06	1297.	1274.	1.42	1.37	358.00	U.220E	06	40
RST Q	101.3	205.0	358.0	281.5	262.0208	0.165E	06	932.	958.	0.47	1.75	238.00	U.336E	06	40
RST Q	101.4	320.0	440.0	380.0	253.0208	0.165E	06	1355.	1320.	1.43	1.38	358.00	U.249E	06	40

NUMBER OF POINTS WITH HEXPT/HPRED BETWEEN 0.8 AND 1.20 FOR TB GREATER THAN 1000 200
 NUMBER OF POINTS WITH HEXPT/HPRED OUTSIDE 20 PERCENT BAND FOR TB GREATER THAN 1000 23
 NUMBER OF POINTS WITH HEXPT/HPRED BETWEEN 0.8 AND 1.20 FOR TB LESS THAN 1000 0
 NUMBER OF POINTS WITH HEXPT/HPRED OUTSIDE 20 PERCENT BAND FOR TB LESS THAN 1000 0
 STANDARD DEVIATION FOR TB GREATER THAN 1000 0.120E 03 NUMBER OF POINTS 223
 STANDARD DEVIATION FOR TB LESS THAN 1000 0. NUMBER OF POINTS 0.

EXECUTION BEGAN - 094449
 585 LINES OUTPUT. - 094463

APPENDIX C DATA ON HYDROGEN BELOW 100°R

The following data are from an output of the digital code shown in Appendix A. The data appear in Fig. 7.2. The identification and input data are the same as in Appendix B except that the observation of oscillations is designated by "O", and their absence by "N".

RUN	TR DEG R	TW DEG R	TF DEGR	P PSIA	D FT	G LB/HR-F2B/RFH	HEXPT F2B/RFH	HMED G/HFH	HEXPT/F2B/F2D	1W/TB	L/D	RE. NO.	PLUING CHARACTER
RST O	1.1	56.0	190.0	123.0	179.0208	0.343E 05	127.	263.	0.48	3.39	20.00	0.534E 05	3E
RST O	2.1	56.0	254.0	155.0	181.0208	0.358E 05	110.	229.	0.48	4.54	20.00	0.484E 05	3E
RST O	3.1	57.0	290.0	173.5	182.0208	0.353E 05	102.	229.	0.45	5.09	20.00	0.484E 05	3E
RST O	4.1	59.0	272.0	165.5	206.0208	0.349E 05	129.	368.	0.35	4.61	20.00	0.636E 05	3E
RST O	5.1	59.0	216.0	137.5	206.0208	0.349E 05	141.	398.	0.35	3.66	20.00	0.663E 05	3E
RST O	6.1	59.0	178.0	118.5	206.0208	0.440E 05	177.	492.	0.36	3.02	20.00	0.422E 05	3E
RST O	7.1	59.0	121.0	90.0	206.0208	0.568E 05	220.	615.	0.36	2.05	20.00	0.987E 05	3E
RST O	7.2	87.0	108.0	97.5	206.0208	0.568E 05	681.	418.	1.43	1.24	118.50	0.191E 06	3E
RST N	8.1	55.0	115.0	85.0	218.0208	0.138E 06	135.	518.	0.26	2.09	20.00	0.168E 06	37
RST N	8.2	60.0	87.0	73.5	218.0208	0.138E 06	295.	1617.	0.18	1.45	118.50	0.248E 06	37
RST N	8.3	60.0	108.0	84.0	218.0208	0.138E 06	199.	1370.	0.15	1.80	238.00	0.248E 06	37
RST N	8.4	60.0	111.0	85.5	217.0208	0.138E 06	194.	1355.	0.14	1.85	358.00	0.250E 06	37
RST N	9.1	56.0	80.0	72.0	258.0208	0.104E 06	411.	555.	0.74	1.57	20.00	0.128E 06	37
RST N	9.2	65.0	86.0	75.5	258.0208	0.104E 06	643.	1299.	0.60	1.32	118.50	0.274E 06	37
RST N	9.3	70.0	105.0	87.5	258.0208	0.104E 06	378.	822.	0.46	1.50	238.00	0.332E 06	37
RST N	9.4	80.0	111.0	95.5	258.0208	0.104E 06	482.	706.	0.48	1.39	358.00	0.333E 06	37
RST N	10.1	57.0	125.0	91.0	258.0208	0.764E 05	249.	489.	0.61	2.19	20.00	0.496E 05	37
RST N	10.2	77.0	100.0	88.5	258.0208	0.764E 05	728.	606.	1.20	1.30	118.50	0.245E 06	37
RST O	11.1	62.0	155.0	108.5	259.0208	0.608E 05	220.	560.	0.39	2.50	20.00	0.110E 06	3E
RST O	12.1	61.0	200.0	130.5	260.0208	0.497E 05	214.	390.	0.55	3.28	20.00	0.818E 05	3E
RST O	13.1	61.0	244.0	152.5	259.0208	0.468E 05	184.	360.	0.51	4.00	20.00	0.773E 05	3E
RST O	14.1	59.0	320.0	189.5	187.0208	0.330E 05	93.	355.	0.26	5.42	20.00	0.586E 05	3E
RST O	15.1	57.0	288.0	172.5	183.0208	0.335E 05	91.	231.	0.39	5.05	20.00	0.489E 05	3E
RST O	16.1	56.0	201.0	128.5	184.0208	0.374E 05	112.	248.	0.45	3.59	20.00	0.511E 05	3E
RST O	17.1	56.0	154.0	105.0	184.0208	0.617E 05	114.	388.	0.29	2.75	20.00	0.839E 05	3E
RST O	17.2	60.0	96.6	78.3	184.0208	0.617E 05	305.	951.	0.32	1.61	118.50	0.204E 06	3E
RST N	18.1	57.0	155.0	106.0	172.0208	0.557E 05	91.	415.	0.22	2.72	20.00	0.835E 05	37
RST N	18.2	60.0	100.0	80.0	172.0208	0.557E 05	96.	531.	0.18	1.67	118.50	0.204E 06	37
RST O	19.1	59.0	186.0	122.5	198.0208	0.235E 05	98.	290.	0.24	3.15	20.00	0.401E 05	3E
RST O	20.1	56.0	160.0	108.0	198.0208	0.234E 05	108.	183.	0.59	2.86	20.00	0.337E 05	3E
RST O	21.1	57.0	148.0	102.5	198.0208	0.262E 05	75.	218.	0.34	2.60	20.00	0.398E 05	3E
RST O	21.2	64.0	103.0	83.5	197.0208	0.262E 05	175.	277.	0.63	1.61	118.50	0.102E 06	3E
RST O	21.3	97.0	142.0	119.5	194.0208	0.262E 05	159.	191.	0.63	1.46	238.00	0.855E 05	3E
RST O	22.1	63.0	137.0	100.0	267.0208	0.374E 05	181.	401.	0.45	2.17	20.00	0.726E 05	3E
RST O	22.2	91.0	174.0	132.5	266.0208	0.374E 05	191.	223.	0.66	1.91	118.50	0.113E 06	3E
RST O	23.1	62.0	154.0	108.0	268.0208	0.376E 05	184.	339.	0.54	2.48	20.00	0.623E 05	3E
RST O	24.1	63.0	178.0	120.5	266.0208	0.336E 05	172.	352.	0.49	2.83	20.00	0.656E 05	3E
RST O	25.1	57.0	360.0	208.5	259.0208	0.111E 06	277.	532.	0.52	6.32	20.00	0.144E 06	3E
RST O	26.1	58.0	319.0	188.5	258.0208	0.117E 06	299.	680.	0.24	5.50	20.00	0.163E 06	3E
RST O	27.1	56.0	295.0	175.5	258.0208	0.124E 06	299.	453.	0.66	5.27	20.00	0.152E 06	3E
RST O	28.1	52.0	255.0	153.5	262.0208	0.136E 06	341.	509.	0.67	4.90	20.00	0.142E 06	3E
RST O	28.2	90.0	249.0	169.5	262.0208	0.136E 06	485.	583.	0.63	2.77	118.50	0.413E 06	3E
RST N	29.1	52.0	199.0	125.5	262.0208	0.156E 06	381.	597.	0.44	3.83	20.00	0.163E 06	37
RST N	29.2	60.0	197.0	128.5	262.0208	0.156E 06	443.	852.	0.52	3.28	118.50	0.237E 06	37
RST N	30.1	48.0	133.0	90.5	217.0208	0.208E 06	338.	704.	0.48	2.77	20.00	0.192E 06	37
RST N	30.2	55.0	94.0	74.5	217.0208	0.208E 06	795.	787.	1.01	1.71	118.50	0.254E 06	37
RST N	30.3	70.0	97.0	83.5	216.0208	0.208E 06	1256.	1335.	0.54	1.39	238.00	0.733E 06	37
RST N	30.4	80.0	130.0	105.0	210.0208	0.208E 06	798.	998.	0.60	1.63	358.00	0.712E 06	37
RST O	31.1	51.0	185.0	118.0	211.0208	0.137E 06	319.	558.	0.57	3.63	20.00	0.142E 06	3E
RST O	31.2	68.0	161.0	114.5	211.0208	0.137E 06	508.	755.	0.67	2.37	118.50	0.485E 06	3E
RST O	32.1	55.0	281.0	168.0	211.0208	0.104E 06	241.	335.	0.72	5.11	20.00	0.128E 06	3E
RST O	33.1	55.0	316.0	185.5	212.0208	0.100E 06	254.	318.	0.60	5.75	20.00	0.123E 06	3E
RST O	34.1	55.0	328.0	191.5	212.0208	0.910E 05	249.	293.	0.65	5.96	20.00	0.112E 06	3E
RST O	35.1	54.0	332.0	193.0	213.0208	0.857E 05	255.	311.	0.62	6.15	20.00	0.101E 06	3E
RST O	36.1	54.0	307.0	180.5	172.0208	0.759E 05	195.	364.	0.54	5.69	20.00	0.940E 05	3E
RST O	37.1	53.0	304.0	178.5	171.0208	0.812E 05	187.	361.	0.52	5.74	20.00	0.950E 05	3E
RST O	37.2	90.0	292.0	191.0	171.0208	0.812E 05	269.	326.	0.62	3.24	118.50	0.262E 06	3E
RST O	38.1	54.0	257.0	155.5	173.0208	0.985E 05	215.	463.	0.46	4.76	20.00	0.122E 06	3E
RST O	38.2	90.0	254.0	172.0	173.0208	0.985E 05	282.	393.	0.72	2.82	118.50	0.317E 06	3E
RST O	39.1	48.0	215.0	131.5	173.0208	0.140E 06	144.	482.	0.20	4.48	20.00	0.133E 06	3E
RST O	39.2	63.0	105.0	84.0	172.0208	0.140E 06	561.	886.	0.63	1.67	118.50	0.241E 06	3E
RST O	39.3	75.0	117.0	96.0	170.0208	0.140E 06	723.	705.	1.02	1.56	238.00	0.507E 06	3E
RST O	39.4	95.0	158.0	126.5	165.0208	0.140E 06	522.	602.	0.67	1.66	358.00	0.436E 06	3E
RST N	40.1	42.0	112.0	77.0	172.0208	0.424E 06	174.	1099.	0.16	2.67	20.00	0.317E 06	37
RST N	40.2	50.0	70.0	60.0	172.0208	0.424E 06	707.	1059.	0.18	1.40	118.50	0.435E 06	37
RST N	40.3	52.0	79.0	65.5	168.0208	0.424E 06	587.	1862.	0.72	1.52	238.00	0.476E 06	37
RST N	40.4	55.0	85.0	70.0	166.0208	0.424E 06	569.	2201.	0.26	1.55	358.00	0.558E 06	37
RST O	41.1	51.0	236.0	143.5	128.0208	0.961E 05	105.	410.	0.26	4.63	20.00	0.107E 06	3E
RST O	41.2	65.0	141.0	103.0	128.0208	0.961E 05	288.	443.	0.45	2.17	118.50	0.394E 06	3E
RST O	41.3	85.0	150.0	117.5	127.0208	0.961E 05	320.	409.	0.78	1.76	238.00	0.324E 06	3E

RST N	42.1	48.0	113.0	80.5	128.0	0.0208	0.149E	06	198.	588.	0.34	2.35	20.00	0.140E	06	37
RST N	42.2	55.0	137.0	96.0	128.0	0.0208	0.149E	06	174.	918.	0.19	2.49	118.50	0.640E	06	37
RST N	42.3	70.0	101.0	85.5	127.0	0.0208	0.149E	06	454.	745.	0.41	1.44	238.00	0.583E	06	37
RST N	42.4	75.0	107.0	91.0	126.0	0.0208	0.149E	06	512.	711.	0.72	1.43	358.00	0.557E	06	37
RST O	43.1	56.0	400.0	228.0	158.0	0.0208	0.230E	06	389.	1001.	0.39	7.14	20.00	0.329E	06	38
RST O	44.1	57.0	447.0	252.0	158.0	0.0208	0.208E	06	387.	1025.	0.38	7.84	20.00	0.323E	06	38
RST O	45.1	57.0	454.0	255.5	158.0	0.0208	0.146E	06	380.	974.	0.39	7.96	20.00	0.309E	06	38
RST O	46.1	56.0	349.0	202.5	162.0	0.0208	0.207E	06	364.	1139.	0.32	6.23	20.00	0.378E	06	38
RST O	46.2	65.0	262.0	163.5	158.0	0.0208	0.267E	06	602.	1017.	0.59	4.03	118.50	0.105E	07	38
RST N	47.1	52.0	314.0	183.0	162.0	0.0208	0.531E	06	302.	1505.	0.20	6.04	20.00	0.600E	06	37
RST N	47.2	65.0	169.0	117.0	158.0	0.0208	0.531E	06	889.	1925.	0.46	2.60	118.50	0.209E	07	37
RST N	47.3	70.0	196.0	133.0	153.0	0.0208	0.531E	06	772.	1697.	0.45	2.80	238.00	0.203E	07	37
RST O	48.1	57.0	470.0	263.5	242.0	0.0208	0.326E	06	542.	1271.	0.43	8.25	20.00	0.436E	06	38
RST O	48.2	90.0	383.0	236.5	234.0	0.0208	0.326E	06	866.	1038.	0.63	4.26	118.50	0.101E	07	38
RST O	49.1	57.0	396.0	226.5	236.0	0.0208	0.517E	06	528.	1941.	0.27	6.95	20.00	0.697E	06	38
RST O	49.2	80.0	309.0	194.5	232.0	0.0208	0.517E	06	835.	1669.	0.50	3.86	118.50	0.171E	07	38
RST N	50.1	58.0	257.0	157.5	237.0	0.0208	0.436E	06	676.	1705.	0.40	4.43	20.00	0.612E	06	37
RST N	50.2	70.0	223.0	146.5	230.0	0.0208	0.436E	06	935.	1798.	0.52	3.19	118.50	0.149E	07	37
RST N	51.1	61.0	174.0	117.5	238.0	0.0208	0.325E	06	775.	2216.	0.35	2.85	20.00	0.587E	06	37
RST N	51.2	70.0	172.0	121.0	227.0	0.0208	0.325E	06	976.	1484.	0.66	2.46	118.50	0.112E	07	37
RST O	52.1	58.0	468.0	263.0	248.0	0.0208	0.335E	06	488.	1201.	0.41	8.07	20.00	0.462E	06	38
RST O	53.1	57.0	418.0	237.5	248.0	0.0208	0.362E	06	533.	1385.	0.38	7.33	20.00	0.479E	06	38
RST O	53.2	85.0	316.0	200.5	242.0	0.0208	0.362E	06	922.	1206.	0.76	3.72	118.50	0.113E	07	38
RST O	54.1	58.0	375.0	216.5	247.0	0.0208	0.406E	06	527.	1467.	0.36	6.47	20.00	0.560E	06	38
RST O	54.2	62.0	285.0	173.5	242.0	0.0208	0.406E	06	798.	2576.	0.31	4.60	118.50	0.814E	06	38
RST O	55.1	56.0	155.0	105.5	246.0	0.0208	0.565E	06	1180.	1628.	0.72	2.77	20.00	0.701E	06	38
RST O	55.2	66.0	182.0	124.0	240.0	0.0208	0.565E	06	1010.	2767.	0.37	2.76	118.50	0.177E	07	38
RST O	55.3	92.0	195.0	143.5	230.0	0.0208	0.565E	06	1805.	1822.	0.59	2.12	238.00	0.174E	07	38
RST O	56.1	58.0	430.0	244.0	205.0	0.0208	0.271E	06	507.	929.	0.55	7.41	20.00	0.400E	06	38
RST O	56.2	90.0	373.0	231.5	197.0	0.0208	0.271E	06	691.	852.	0.61	4.14	118.50	0.862E	06	38
RST O	57.1	57.0	402.0	229.5	207.0	0.0208	0.283E	06	467.	1056.	0.44	7.05	20.00	0.393E	06	38
RST O	58.1	57.0	363.0	210.0	207.0	0.0208	0.320E	06	482.	1189.	0.40	6.37	20.00	0.444E	06	38
RST O	58.2	65.0	285.0	175.0	202.0	0.0208	0.320E	06	728.	1445.	0.51	4.38	118.50	0.114E	07	38
RST N	59.1	58.0	280.0	169.0	206.0	0.0208	0.377E	06	549.	1336.	0.41	4.83	20.00	0.556E	06	37
RST N	59.2	60.0	237.0	148.5	200.0	0.0208	0.377E	06	691.	3525.	0.20	3.95	118.50	0.806E	06	37
RST O	60.1	57.0	421.0	239.0	166.0	0.0208	0.213E	06	470.	1044.	0.45	7.39	20.00	0.325E	06	38
RST O	61.1	57.0	407.0	232.0	166.0	0.0208	0.227E	06	373.	1106.	0.34	7.14	20.00	0.347E	06	38
RST O	62.1	58.0	381.0	219.5	167.0	0.0208	0.247E	06	404.	769.	0.53	6.57	20.00	0.896E	06	38
RST O	62.2	90.0	316.0	203.0	163.0	0.0208	0.247E	06	609.	771.	0.79	3.51	118.50	0.799E	06	38
RST O	63.1	58.0	362.0	210.0	173.0	0.0208	0.282E	06	382.	1588.	0.24	6.24	20.00	0.479E	06	38
RST O	63.2	80.0	285.0	182.5	166.0	0.0208	0.282E	06	574.	903.	0.64	3.56	118.50	0.984E	06	38
RST O	64.1	58.0	314.0	186.0	170.0	0.0208	0.326E	06	426.	1884.	0.23	5.41	20.00	0.359E	06	38
RST O	64.2	60.0	243.0	151.5	167.0	0.0208	0.326E	06	609.	1673.	0.36	4.05	118.50	0.123E	07	38
RST O	65.1	52.0	304.0	178.0	170.0	0.0208	0.387E	06	343.	1171.	0.29	5.85	20.00	0.434E	06	38
RST O	65.2	60.0	185.0	122.5	168.0	0.0208	0.387E	06	691.	2059.	0.34	3.08	118.50	0.148E	07	38
RST O	65.3	80.0	211.0	145.5	162.0	0.0208	0.387E	06	836.	1225.	0.68	2.64	238.00	0.135E	07	38
RST N	66.1	49.0	97.0	73.0	170.0	0.0208	0.957E	06	1106.	2733.	0.40	1.98	20.00	0.945E	06	37
RST N	66.2	51.0	84.0	67.5	167.0	0.0208	0.957E	06	1796.	3258.	0.55	1.65	118.50	0.103E	07	37
RST N	66.3	53.0	88.0	70.5	160.0	0.0208	0.957E	06	2230.	3631.	0.61	1.66	238.00	0.114E	07	37
RST N	66.4	55.0	97.0	76.0	147.0	0.0208	0.957E	06	2024.	4002.	0.51	1.76	358.00	0.130E	07	37
RST O	67.1	53.0	500.0	276.5	117.0	0.0208	0.135E	06	242.	514.	0.47	9.43	20.00	0.169E	06	38
RST O	68.1	52.0	309.0	180.5	112.0	0.0208	0.173E	06	268.	665.	0.40	5.94	20.00	0.207E	06	38
RST O	68.2	75.0	254.0	164.5	111.0	0.0208	0.173E	06	412.	553.	0.75	3.39	118.50	0.654E	06	38
RST O	69.1	61.0	258.0	159.5	223.0	0.0208	0.169E	06	258.	1429.	0.18	4.23	20.00	0.337E	06	38
RST O	69.2	80.0	262.0	171.0	222.0	0.0208	0.169E	06	329.	692.	0.48	3.27	118.50	0.568E	06	38
RST N	70.1	61.0	221.0	141.0	223.0	0.0208	0.114E	06	290.	1076.	0.27	3.62	20.00	0.229E	06	37
RST N	70.2	65.0	235.0	150.0	222.0	0.0208	0.114E	06	309.	692.	0.45	3.62	118.50	0.377E	06	37
RST O	71.1	60.0	199.0	129.5	202.0	0.0208	0.968E	05	384.	1190.	0.26	3.32	20.00	0.202E	06	38
RST O	71.2	85.0	244.0	164.5	198.0	0.0208	0.968E	05	279.	414.	0.67	2.87	118.50	0.319E	06	38
RST N	72.1	58.0	250.0	154.0	173.0	0.0208	0.905E	05	158.	689.	0.23	4.31	20.00	0.151E	06	37
RST N	72.2	65.0	191.0	128.0	171.0	0.0208	0.905E	05	265.	491.	0.54	2.94	118.50	0.340E	06	37
RST O	73.1	55.0	354.0	204.5	140.0	0.0208	0.174E	06	348.	784.	0.44	6.44	20.00	0.240E	06	38
RST O	73.2	80.0	323.0	201.5	137.0	0.0208	0.174E	06	431.	561.	0.77	4.04	118.50	0.618E	06	38
RST O	74.1	55.0	410.0	232.5	143.0	0.0208	0.149E	06	339.	664.	0.51	7.45	20.00	0.204E	06	38
RST O	75.1	56.0	391.0	223.5	146.0	0.0208	0.164E	06	326.	803.	0.41	6.98	20.00	0.241E	06	38
RST O	76.1	56.0	336.0	196.0	142.0	0.0208	0.210E	06	300.	1140.	0.26	6.00	20.00	0.860E	06	38
RST O	76.2	60.0	265.0	162.5	140.0	0.0208	0.210E	06	416.	874.	0.48	4.42	118.50	0.878E	06	38
RST O	77.1	56.0	283.0	169.5	144.0	0.0208	0.271E	06	244.	1288.	0.50	5.05	20.00	0.400E	06	38
RST O	77.2	60.0	189.0	124.5	141.0	0.0208	0.271E	06	529.	1156.	0.46	3.15	118.50	0.113E	07	38
RST O	77.3	90.0	216.0	153.0	137.0	0.0208	0.271E	06	609.	857.	0.71	2.40	238.00	0.887E	06	38
RST O	79.1	58.0	404.0	231.0	192.0	0.0208	0.207E	06	453.	1031.	0.44	6.97	20.00	0.321E	06	38
RST O	80.1	58.0	369.0	213.5	192.0	0.0208	0.227E	06	445.	1130.	0.39	6.36	20.00	0.352E	06	38
RST O	81.1	58.0	337.0	197.5	193.0	0.0208	0.253E	06	414.	1245.	0.33	5.81	20.00	0.391E	06	38
RST O	81.2	65.0	290.0	177.5	187.0	0.0208	0.253E	06	578.	1114.	0.52	4.46	118.50	0.934E	06	38
RST O	82.1	59.0	377.0	218.0	215.0	0.0208	0.241E	06	532.	1241.	0.43	6.39	20.00	0.384E	06	38
RST O	83.1	58.0	378.0	218.0	216.0	0.0208	0.256E	06	506.	1010.	0.50	6.52	20.00	0.372E	06	38
RST O	84.1	58.0	356.0	207.0	216.0	0.0208	0.270E	06	484.	1067.	0.45	6.14	20.00	0.392E	06	38
RST O	84.2	70.0	323.0	196.5	214.0	0.0208	0.270E	06	569.	1082.						

RST O	97.2	95.0	295.0	195.0	218..0208	0.160E 06	456.	597.	0.76	3.11	118.50	0.488E 06	38
RST N	98.1	50.0	90.0	70.0	218..0208	0.294E 06	997.	1148.	0.87	1.80	20.00	0.292E 06	37
RST N	98.2	55.0	89.0	72.0	216..0208	0.294E 06	1357.	1078.	1.26	1.62	118.50	0.359E 06	37
RST N	98.3	60.0	112.0	86.0	215..0208	0.294E 06	1033.	2574.	0.40	1.87	238.00	0.540E 06	37
RST N	98.4	80.0	136.0	108.0	207..0208	0.294E 06	1073.	1264.	0.85	1.70	358.00	0.101E 07	37
RST O	99.1	61.0	417.0	239.0	267..0208	0.167E 06	352.	843.	0.42	6.84	20.00	0.264E 06	38
RST O	100.1	60.0	373.0	216.5	265..0208	0.178E 06	359.	829.	0.43	6.22	20.00	0.264E 06	38
RST O	101.2	95.0	317.0	206.0	264..0208	0.165E 06	516.	699.	0.74	3.34	118.50	0.548E 06	38
RST O	101.1	56.0	335.0	195.5	266..0208	0.165E 06	376.	631.	0.60	5.98	20.00	0.225E 06	38

NUMBER OF POINTS WITH HEXPT/HPRED BETWEEN 0.8 AND 1.20 FOR TB GREATER THAN 100R 0
 NUMBER OF POINTS WITH HEXPT/HPRED OUTSIDE 20 PERCENT BAND FOR TB GREATER THAN 100R 0
 NUMBER OF POINTS WITH HEXPT/HPRED BETWEEN 0.8 AND 1.20 FOR TB LESS THAN 100R 16
 NUMBER OF POINTS WITH HEXPT/HPRED OUTSIDE 20 PERCENT BAND FOR TB LESS THAN 100R 159
 STANDARD DEVIATION FOR TB GREATER THAN 100R 0. NUMBER OF POINTS 0.
 STANDARD DEVIATION FOR TB LESS THAN 100R 0.692E 03 NUMBER OF POINTS 175.

EXECUTION BEGAN - 113259
 536 LINES OUTPUT. - 113271

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