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Performance of RHIC Refrigerator I: Flowmeters

K. C. Wu

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Collider Accelerator Department
Brookhaven National Laboratory

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Brookhaven National Laboratory

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ABSTRACT

In February 1996, the RHIC Refrigerator was successfully cooled to liquid helium temperature with 10 kilowatts of heat input at 4.5 K, 53 kilowatts of heat input at 60 K and 44 grams per second of liquid extraction. A comprehensive analysis was performed to evaluate the performance of the refrigerator including the turbines, the cold vacuum compressor and the heat exchangers. Because of the amount of data and the number of charts involved, the report is divided into five technical notes on, respectively: 1). Flowmeters, 2). Turbines, 3). Cold Vacuum Compressor, 4). Heat Exchangers and 5). Refrigerator Overall Performance.

I. Introduction

Pressure, temperature and flow measurements are crucial to the performance evaluation of the refrigerator. Pressure transducers have been calibrated before operation and can be re-calibrated during, or after the operation. Therefore it is easy to know if the pressure readings are "Good" or not during steady state operation, since there are only three pressure levels in the refrigerator. The temperature sensors were calibrated before installation and can not be re-calibrated without removing the sensor. However in practice, it is also not hard to tell if a temperature reading is "Reasonable" or not. On the other hand, flow measurements are not as easy to interpret. Therefore the flow measurements were investigated to establish confidence for the evaluation of the refrigerator.

The flowmeters installed on the RHIC refrigerator are either venturi or orifice plate types. The flow rate is calculated from the constant associated with each flowmeter and the square root of the helium density multiplied by the differential pressure. In application, the ideal gas density is used for flowmeters in Cold Boxes 1, 2 and 3. The density is calculated from the helium property program for flowmeters in Cold Boxes 4 and 5. Prior to the refrigerator start up, all differential transmitters were calibrated to ensure "Best" measurements possible.

When electric power is introduced as the dummy heat load, the flow through the 4.5 K and the Shield Calorimeters can be calculated independently from the heat input and terminal temperatures. One flowmeter can be compared with another if they are in series. The total flow from Turbine 1B2 and the Shield Calorimeter was compared with the flow through Turbine 2B1. The readings from flowmeters F71H and F91H were found to exceed the range of the differential pressure transmitter over extended periods of time

during the test, indicating the range of the transmitter is not adequate. The sum of flows through the cold end of the refrigerator and the turbines is compared with flow supplied to the refrigerator.

The test results indicate meaningful flow measurements have been obtained for the evaluation of the refrigerator. Flow measurements from the over sized meters in the cold end of the refrigerator should be ignored. The constant used in calculating flow rate for venturi flowmeter F1H have been corrected. The ranges for F71H and F91H should be increased.

II. Comparison of Flow through the 4.5 K Calorimeter and F35H

During the test, the helium flow through the 4.5 K Calorimeter comes from the make-up valve H86A. When electric power is introduced to the calorimeter, the flow rate can be calculated from the heat input and the inlet and the exit temperatures of the calorimeter. This provides an opportunity to compare flow calculated from the calorimeter and the venturi flowmeter F35H located upstream of H86A. As shown in figure 1, the calorimeter flow increases linearly with the F35H. As shown in figure 2, the flow rate from the two independent measurements are typically between 95 and 105 % of one another. In figure 1 and 2, an estimated 175 watts is added to account for the background heat load and temperature off sets in the thermal calculation and amounts to approximately 2 % improvement in the comparison of the flow ratio.

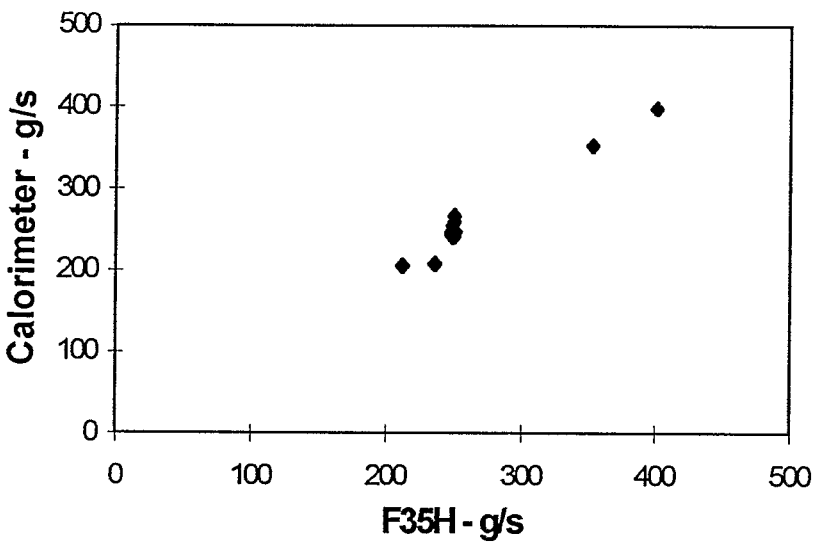

Figure 1 Comparison of Calorimeter Flow and F35H

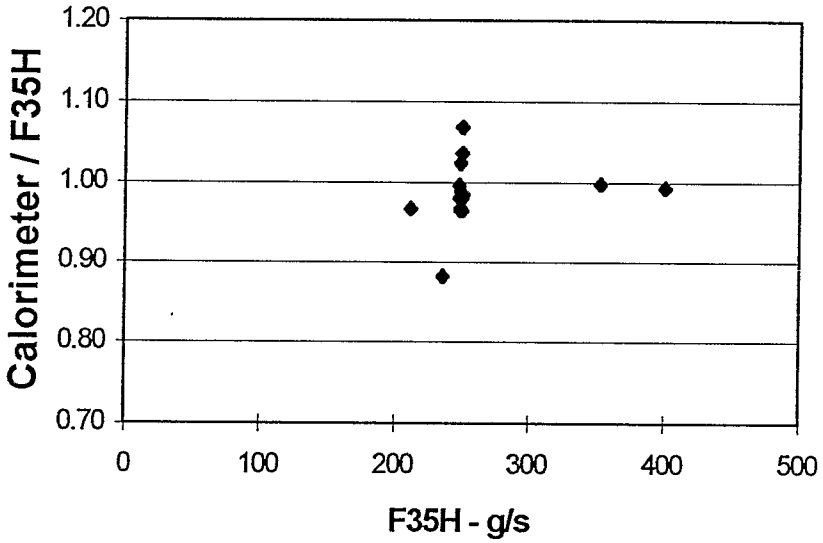

Figure 2 Ratio of Calorimeter Flow to F35H

III. F41H and F211H

Flowmeters F41H and F211H are located in series in the discharge side of the Cold Vacuum Compressor. Between F41H and F211H, there is a by pass flow from the compressor discharge, through valve H40A, to the suction of the unit for surge prevention. During the test, a "small" flow is used to maintain the associated piping cold. Therefore it provides a "good" condition for comparing the flows through F41H and F211H. As shown in Figure 3, the flow through F211H increases with that through F41H with fluctuations on some data points. As shown in Figure 4, the ratio of the flow through F211H to that through F41H is given. It is not clear whether these fluctuations result from the occasional opening of the by-pass valve or unstable operating conditions. However, the numbers seem to suggest that the flow through F41H is about 14 % higher than that through F211H over many data points.

F211H is used to measure the low pressure return flow from the Cold Vacuum Compressor. This low pressure return flow can also be calculated from flow through the calorimeter minus the lead flow and with the addition of the vapor return from the Low and Intermediate Pots. A comparison between F211H and the calculated flow is given in Figure 5. As can be seen from Figure 5, the deviation is in the neighborhood of 10 %.

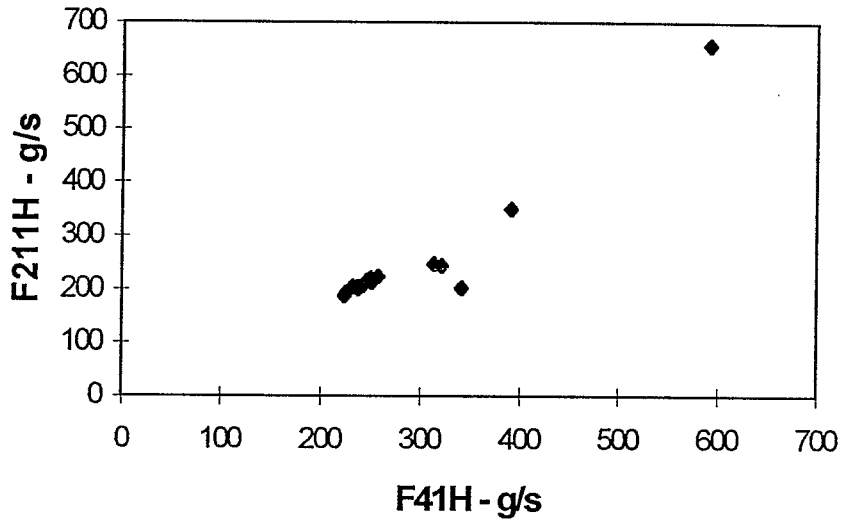

Figure 3 Comparison of F41H and F211H

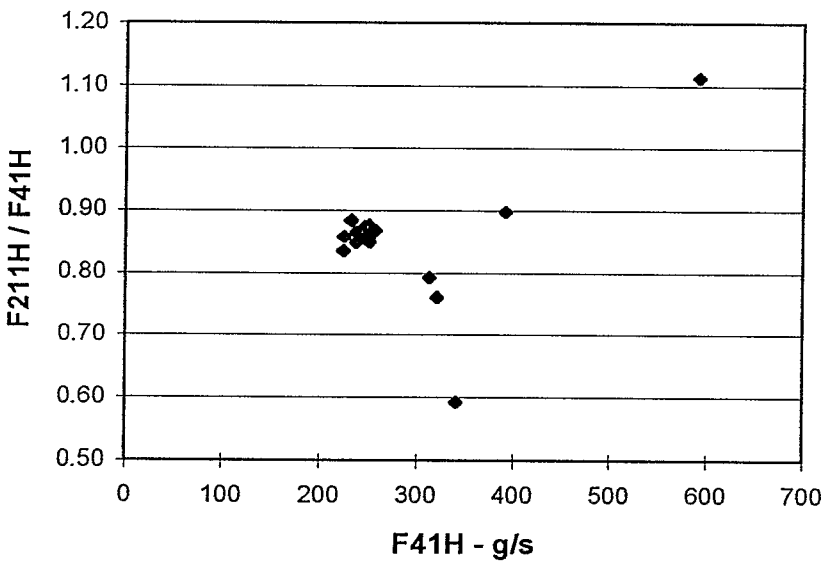

Figure 4 Ratio of F211H to F41H

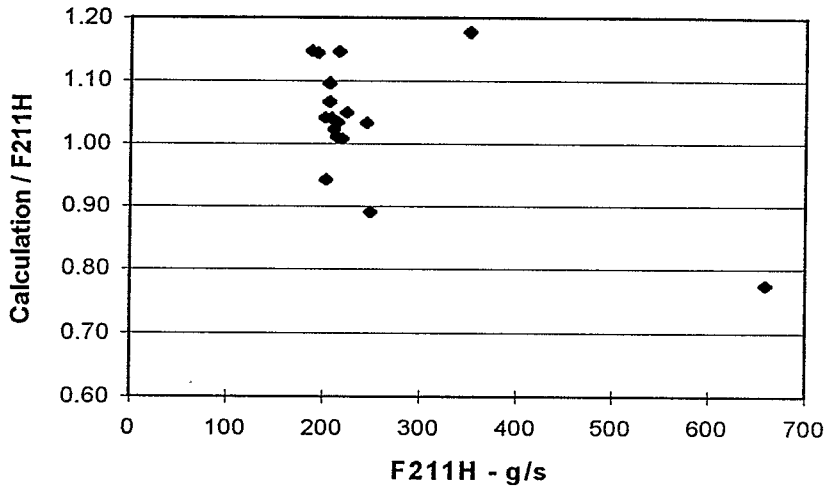

Figure 5 Ratio of Calculated Flow to F211H

IV. Flow through the Shield Calorimeter and Venturi F476H

The helium flow through the Shield Calorimeter can be calculated from the heat input whenever electric power is introduced to the Shield Calorimeter. The correlation between the flow calculated from the calorimeter and the flow from the venturi is shown in Figure 6, and shows a linear relationship. In Figure 7, the ratios of flow from the two independent measurements are shown to agree within 96 to 104 %. In both Figure 6 and 7, a 0.6 kilo-watt heat input is subtracted for the overall background contribution from the heat load and sensors and amounts to about a 1% improvement in the comparison of the flow ratios.

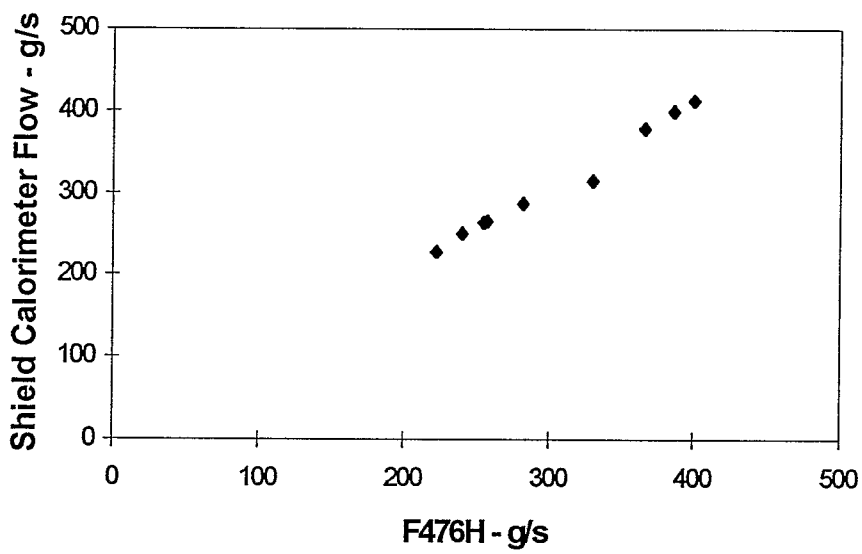

Figure 6 Comparison of Shield Calorimeter Flow and F476H

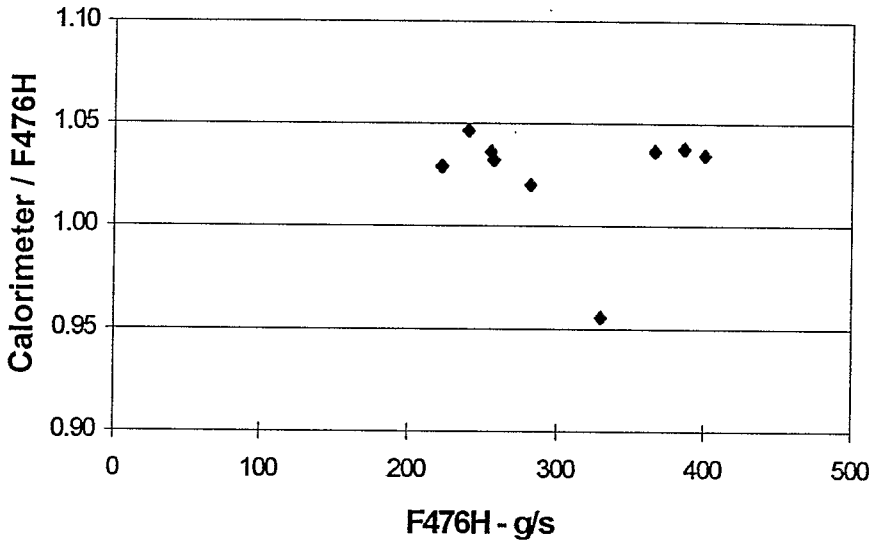

Figure 7 Ratio of Calorimeter to F476H

V. F725H, F476H and F748H

On the RHIC refrigerator, the flow from F476H and the flow from F725H combine to form the flow through F748H. Since the accuracy of F476H has been demonstrated from the calorimeter measurements, a comparison for (F725H + F748H) and F748H is given in Figure 8. As can be seen, the ratios of flows are essentially between 98 and 99%.

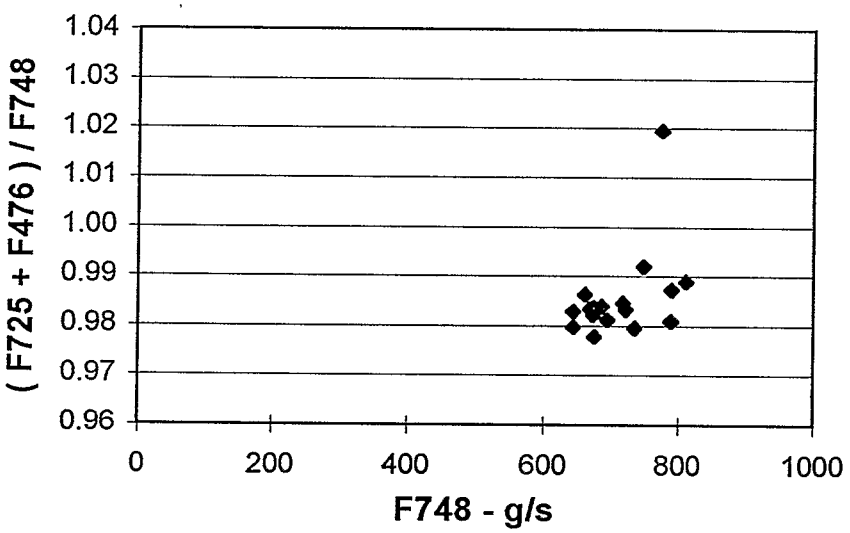

Figure 8 Ratio of (F725 + F476) to F748

VI. F71H and F91H

Flowmeter F71H is located up stream of Turbine 5. The original differential pressure transmitter had a full scale of 20 inches of water. Because of an anticipated lower flow for RHIC, differential pressure transmitter with a full scale of 3 inch of water was installed to improve accuracy. However when the speed of Turbine 5 reached about 29,000 rpm, the differential pressure exceeded the full range of this transmitter. The 20 inch full scale transmitter or a dual range transmitter should be installed for operating Turbine 5 at speeds above 29,000 rpm. For the total flow calculation in Section VIII, a correction for F71H is made from the extrapolated performance of Turbine 5 at speeds above 29,000 rpm.

Flowmeter F91H is located on the low pressure return line between Heat Exchangers 9 and 18. The differential pressure transmitter has a full scale of 20 inches of water. During the test, this transmitter reached or exceeded its full scale value for extended periods of time. The transmitter for F91H should be replaced by one with a greater range. It is also suggested to have the computer alarm the operator whenever these differential pressure transmitters reach full scale.

VII. F64H, F214H, F126H, F175H and F229H

The flowmeters F64H, F214H, F126H and F175H were designed for use in the ISABELLE machine. These flowmeters are too large for RHIC and can not be altered easily. Therefore it is best to ignore their readings.

Flowmeter F229H is used to measure the cooldown by-pass flow. This flowmeter is properly sized. However during the test, the flow reading from F229H could not be interpreted meaningfully. An investigation is needed to determine if the valves located downstream of F229H leak or not. The flow through F229H is included in the total flow calculation in Section VIII.

VIII. F1H

The total flow supplied to the refrigerator plant was calculated from flows through flowmeters F725H, Turbine 1, through F476H, Shield Calorimeter, through F782H, Turbine 3, and through F35H, F71H and F229H in the cold end of the refrigerator. A comparison between the total flow evaluated from the sum of these flowmeters and from the low loss venturi flowmeter F1H was made. The flow measured by F1H was found to be lower than that obtained from the sum of the flows through the individual flowmeters by almost 20 %.

Because of this large discrepancy, the design parameters and the performance curve provided by the original vendor, Delta P Industries, for F1H were re-examined. A second performance curve was obtained from Atiken Inc. Both performance curves give higher flow readings than those currently being used on the RHIC refrigerator process control computer. The curve provided by Atiken appears to be more consistent with the design calculations and is recommended for use.

The total flow, measured from F1H and corrected according to the performance curve given by Atiken, is compared with the sum of individual flows. As shown in Figure 9, the flow measured from F1H increases linearly with the sum of the flows from the other flowmeters. In Figure 10, the flow measured by F1H is about 7% less than the sum of individual flows. This agreement is considered quite good since only the accuracy of F476H and F35H have been demonstrated. The 12 % discrepancy for data at flows above 3000 g/s may be caused by over corrections made on F71H as discussed in the Section VII. A more accurate comparison will be made during the next refrigerator run when a transmitter of larger range for F71H is installed and the "suspected" leaky valves in the line downstream of F229H are corrected.

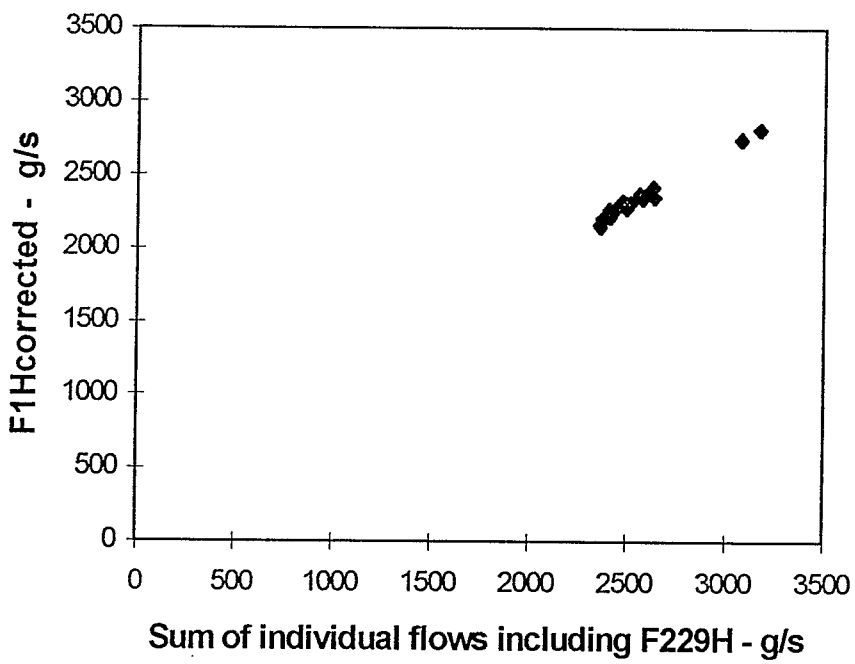

Figure 9 Comparison of F1 to Sum of Individual Flow Readings

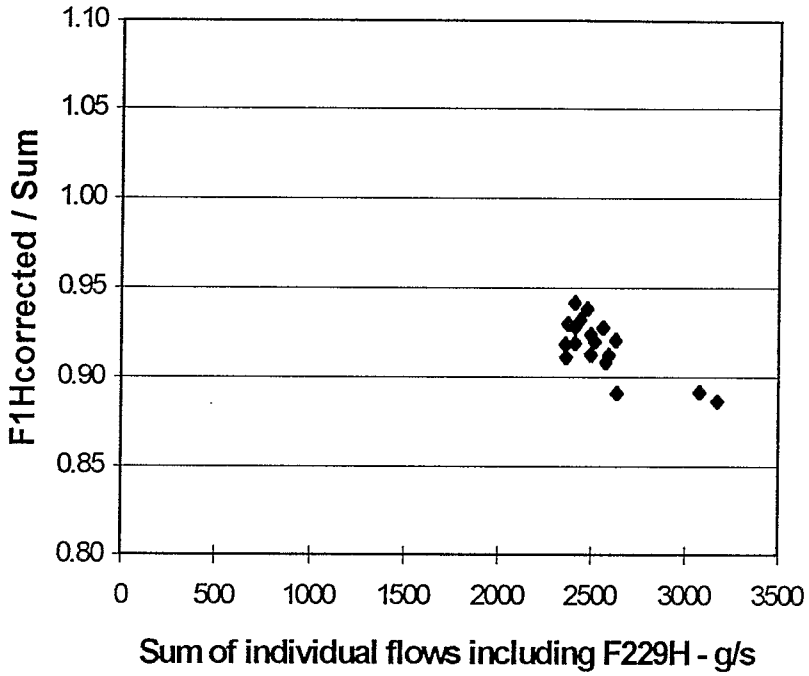

Figure 10 Ratio of F1 to Sum of Individual Flow Readings

IX. Summary

From the above test results, the performance of the flowmeters is summarized in Table 1 below with comments

Table 1. Performance Summary of Flowmeters in the RHIC Refrigerator

Flowmeter	Comments
F35H	Accurate as compared with the 4.5 K Calorimeter.
F41H F211H	Reasonably agree with each other and F35H.
F476H	Accurate as compared with the Shield Calorimeter.
F725H F748H	Agree with each other and F476H.
F325H F348H	Identical to F725H and F748H.
F71H F91H	Exceed differential pressure range on several occasions. Performance seems reasonable, but their accuracy can not be determined at this time. Need greater range transmitter.
F782H	Accuracy has not been determined. But seems reasonable from the performance of the Turbines 3 and 4.
F382H	Identical to F782H.
F1H	With the latest performance curve given by Atiken Inc., F1H reads low by about 7 % as compared with the sum of individual flows. More accurate comparisons can be made in the next refrigerator run.
F64H	Originally sized for ISABELLE machine.
F214H	Over sized for RHIC.
F126H	Can not be altered easily.
F175H	Best to ignore the reading.
F229H	Consistently indicates a flow on the order of 150 g/s. Can not determine if the flow reading is real. Need to investigate prior to next cooldown.

ACKNOWLEDGMENT

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