C-A Unreviewed Safety Issue (USI) Form

Title of USI: Addition of RHIC Helium Reliquifer System

Description of USI (use attachments if necessary):

See attached description of reliquifer and associated ODH calculations for Buildings 1005E and 1006B.

1. RHIC Helium Reliquifer Description (10/29/02)
2. R. Karol, Building 1005E ODH Classification **(Revised),** December 26, 2001 **(Revised May 6, 2002)**
3. R. Karol, Building 1006B ODH Classification with Helium Reliquifier Operating, September 20, 2002

Title and Date of Relevant SAD: RHIC SAD (12/30/99)

Committee Chair or ESHQ Division Head must initial all items. Leave no blanks:

ITEM	APPLIES	DOES NOT APPLY
Decision to not revise the current SAD and/or ASE at this time:	ETL	
The hazard associated with the proposed work or event is covered within an existing SAD and/or ASE.	ETL	
SAD Title and Date: RHIC SAD 12-13-99		
This Form and attachments, if necessary, shall be used to document the USI until the next revision of the appropriate SAD.	ETL	
Decision to submit a revised SAD and/or ASE to the BNL ESH Committee:		ETL
The hazard associated with the proposed work is not appropriately included in an SAD.		ETL

Ray Karol
Signature of C-A Committee Chair or C-A ESHQ Division Head

10-31-02
Date

Edward T Lessard
Signature of C-A Associate Chair for ESHQ

10-31-02
Date

RHIC Helium Reliquifer Description (10/29/02)

This system re-liquefies helium boil-off from the helium storage dewers located outside Building 1006B. It can also purify the helium gas from the Helium Tank Farm. The system equipment is located in Buildings 1005E (west end) and 1006B with the controls located in 1005H. The compressor and helium purifier are located in Building 1005E, the refrigerator in Building 1006B and liquid helium storage tank outside Building 1006B. Building 1005E has three ODH exhaust fans, which start at 18% oxygen concentration. Two-out-of-three of these fans must be operable to maintain the ODH 0 classification requirements for Building 1005E. The ODH control PLC is on the same pier as the 1005R and 1005H ODH controls to help maintain the 1005E system operable during RHIC shutdowns without requiring the RHIC tunnel ODH system to be operable. Building 1006B, where the expander or refrigerator is located, has an existing ODH system designed for the larger ODH hazard present when the main RHIC helium refrigerator is supplying cold helium to the Collider magnet circuit.

There is 90 gallons UCON heat transfer fluid used in the compressor in Building 1005E. The floor of 1005E will be sealed with epoxy paint and the building wall-to-floor joints are sealed to prevent spillage of UCON fluid through this joint. The roll-up door on the west side of the building is sealed with absorbent socks when the door is not in use to prevent spillage past the door. The compressor cooling water system has its own metal cooling tower located outside 1005E with blowdown connected to an existing, monitored drain system. There is currently no plan to add water treatment chemicals to the cooling water system since this system is only operated for relatively short intervals when the main refrigerator is shutdown. It is noted that as long as currently approved water treatment chemicals are used, no further reviews would be necessary if chemical treatment is eventually initiated.

The C-AD Cryogenic Operations Group operates the reliquifer using approved C-A OPMs. This system will not be continuously manned and the Collider Accelerator Support (CAS) Watch will monitor operation during off-hours. Both Cryogenics Operators and CAS Watch standers are trained on the operation of the reliquifier.

The system electrical design and installation satisfies applicable electrical code requirements. The reliquifer motor control center in 1005E is commercially supplied and has standard protection circuitry. The existing Collider emergency diesel generator supplies emergency power for the ODH exhaust fans and air inlet louvers. The three ODH fans may also be manually started.

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BROOKHAVEN NATIONAL LABORATORY

managed by Brookhaven Science Associates
for the U.S. Department of Energy

Memo

Date: December 26, 2001 **(Revised May 6, 2002)**

To: R. Diaz

From: R. Karol

Subject: Building 1005E ODH Classification **(Revised)**

Purpose

To compute the appropriate ODH classification for Collider Building 1005E. Oxygen deficiency can be caused by a leak of helium or nitrogen present in this building. The helium source is the compressor for the helium refrigerator and the nitrogen source is from the nitrogen cooled helium gas purifier.

Summary and Conclusions

The goal of this calculation was to determine the Oxygen Deficiency Hazard (ODH) risk for Collider Building1005E by estimating the fatality rate for a major nitrogen or helium release. A spectrum of events may cause an oxygen deficiency. A major nitrogen system failure, causing an introduction of 2500 CFM of gas into the west end of the building [1] has been chosen to bound the consequences of all credible failures. The west end of the building is sealed from the rest of the building, precluding ODH issues in those areas. The probability chosen for pressure boundary failure, once per week or every 168 hours, was based upon a very conservative estimate that resulted in a reasonable ODH exhaust fan capacity and significantly simplified the analysis.

There will be three 5,000 CFM exhaust fans installed in Building 1005E as opposed to the original configuration of two 10,000 CFM fans. At least two-out-of-three fans must be operable to maintain this building at the ODH 0 classification.

Applicable Criteria

The method and criteria in the BNL ODH Subject Area were used to determine the ODH classification.

Assumptions

1. The maximum gas introduction rate into Building 1005E is 2500 CFM of nitrogen [1]. A smaller amount of helium could enter the building, but the nitrogen spill rate is bounding.

2. The free volume of the building is ~30,000 ft^3. This conservatively ignores the roof peak volume.

3. The building exhaust fans start when the building oxygen concentration is reduced to 18%. It is conservatively assumed that it takes 60 seconds for the fans to start and reach their full capacity. Once started, the fans will continue to run until operator intervention.

4. Outside air drawn into the building has a 21% oxygen concentration.

5. The building pressure remains constant and very near atmospheric pressure through the use of louvers.

6. The oxygen concentration in the building is found by assuming uniform instantaneous mixing of the air and nitrogen in the building volume as per the SBMS guidance.

7. The probability per hour of a major nitrogen pressure boundary failure has been selected to be the unrealistic value of 5.95×10^{-3} (once per week). This is very conservative but simplifies the analysis and results in a reasonable ODH exhaust fan capacity.

Detailed Calculation and Analyses

The SBMS ODH Model is a prescribed method to determine the necessary level of hazard control for a building having the potential for oxygen deficiency. The fatality rate in the model is the product of two numbers. One quantity is the probability per hour of an event causing an oxygen deficiency. The other quantity is found by estimating the minimum oxygen concentration during the transient, assuming uniform instantaneous mixing of the air and nitrogen in the building volume, and is represented by a factor between 0 and 1 (see Figure 1). The computed fatality rate is then used to define the ODH class necessary to protect personnel.

The Oxygen Deficiency Hazard fatality rate is defined as:

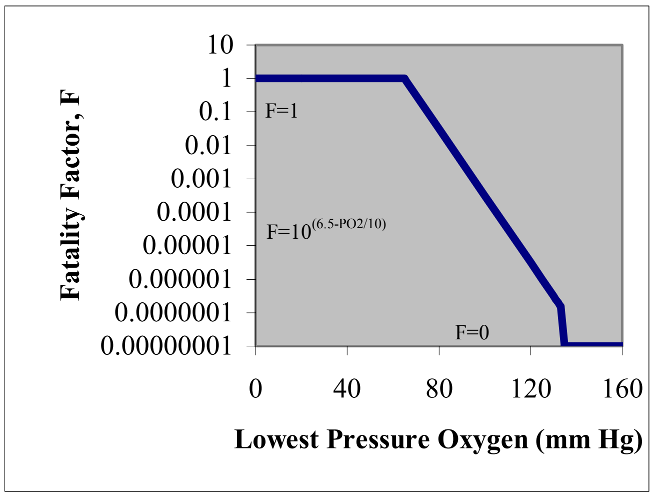
$$\Phi = PF$$

where Φ = the ODH fatality rate per hour
P = the expected rate of the event per hour, i.e. initiator frequency
F = the fatality factor for the event

The value of P, the initiator frequency, was conservatively selected to be once per week (5.95×10^{-3}/hr). This selection, which simplifies the analyses, is far larger than any practical design would experience. Experience with cryogenic systems at BNL and elsewhere easily support this conclusion.

The value of the fatality factor, F, is the probability that a fatality will result if the design basis bounding nitrogen release occurs. Figure 1 from Reference 2 defines the relationship between the value of F and the computed oxygen partial pressure. The partial pressure is found by multiplying the mole fraction of oxygen in the building atmosphere by 760 mmHg. If the oxygen concentration is greater than 18% (~137 mmHg), then the value of F is defined to be zero. That is, all exposures above 18% are defined to be safe and do not contribute to fatality. If the oxygen concentration is 18%, then the value of F is defined to be 10^{-7}. At decreasing concentrations the value of F increases until, at some point, the probability of fatality becomes unity. That point is defined to be 8.8% (~67 mmHg) oxygen in the SBMS model, the concentration at which one minute of consciousness is expected.

Figure 1. Graph of the Fatality Factor (logarithmic scale) versus the Computed Oxygen Partial Pressure.



The value of Φ, the fatality rate, is then used to determine the ODH class of the building as follows [2]:

ODH Class	Fatality Rate (per hour)
NA	$<10^{-9}$
0	$\geq 10^{-9}$ but $<10^{-7}$
1	$\geq 10^{-7}$ but $<10^{-5}$
2	$\geq 10^{-5}$ but $<10^{-3}$
3	$\geq 10^{-3}$ but $<10^{-1}$
4	$\geq 10^{-1}$

The oxygen concentration in the building during a release of nitrogen gas is approximated by solving the following differential equations [2]:

(a) If the exhaust fan is on and the spill rate of nitrogen (R) is less than the exhaust fan capacity (Q):

$$V\frac{dC}{dt} = 0.21\,(Q - R) - QC$$

Where

V = building volume (ft^3)
C = oxygen concentration (mole fraction)
t = time (minutes)
Q = exhaust fan(s) flow rate (CFM)
R = nitrogen spill rate into building (CFM)

(b) If the exhaust fan is off :

$$V\frac{dC}{dt} = -RC$$

Thus, it will take about 110 seconds for the room oxygen concentration to fall to 18%, signaling the ODH fans to start. Assuming a 60-second delay until the fan starts results in an oxygen concentration of about ~16.6% when the fan is at full capacity (two fans at 5000 CFM each is assumed). It is noted that all personnel should have evacuated over this one-minute period, however, if no evacuation occurred, an individual would be exposed to a minimum oxygen concentration (steady-state) of:

$$0 = 0.21\,(Q - R) - QC$$
$$C_{ss} = 0.21\,(Q - R) / Q$$
$$C_{ss} = 15.75\ \%\ \text{(2 fans)}$$

This steady state (and minimum) value of oxygen concentration results in a Fatality Factor of 3.39×10^{-6} (2 fans). Thus the ODH fatality rate per hour, Φ, is:

$$\Phi = PF$$
$$\Phi = (5.95 \times 10^{-3}/hr)\,(3.39 \times 10^{-6}) = 2 \times 10^{-8}/hr\ \text{(2 fans)}$$

Since at least two exhaust fans are required to be operable, Φ is less than 10^{-7}/hr and the building is classified as ODH 0. It is noted that the minimum flow rate to maintain the building at ODH 0 is ~8500 CFM.

A. Etkin checked this calculation.

References

1. E-Mail from M. Iarocci to R. Karol dated 12/26/01.
2. BNL Standards Based Management System Subject Area, “Oxygen Deficiency Hazards”.

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managed by Brookhaven Science Associates
for the U.S. Department of Energy

Memo

Date: September 20, 2002

To: T. Nicoletti

From: R. Karol

Subject: Building 1006B ODH Classification with Helium Reliquifier Operating

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Purpose

To compute the appropriate ODH classification for Collider Building 1006B when the Helium Reliquifier is operating. This is a separate consideration from the normal RHIC Helium Refrigerator during superconducting magnet operation and the soon to be installed 80K Helium Cooler for use during RHIC shutdowns. Oxygen deficiency can be caused by a leak of helium or nitrogen present in this building. During reliquifer operation, the helium source is the gas circulating through the reliquifier refrigerator and the nitrogen source is from the liquid nitrogen that cools the helium in the refrigerator.

Summary and Conclusions

The goal of this calculation was to determine the Oxygen Deficiency Hazard (ODH) risk for Collider Building1006B by estimating the fatality rate for a major liquid nitrogen release. A spectrum of events may cause an oxygen deficiency. A major nitrogen system failure, causing an introduction of 12000 CFM of gas into the west end of the building [1] has been chosen to bound the consequences of all credible failures. The probability chosen for pressure boundary failure was based upon the failure rates given in the BNL SBMS on Oxygen Deficiency Hazards. Building 1006B has two existing 16000 CFM ODH exhaust fans. Four ODH conditions were examined:

1. Both ODH fans operable.
2. One ODH fan fails on demand.
3. One ODH fan is known to be out of service.
4. An automatic LN_2 supply valve is assumed to be located outside Building 1006B, which closes when the PASS ODH sensors trip at 18%. This assumption was examined to see the affect on the ODH classification.

Applicable Criteria

The method and criteria in the BNL ODH Subject Area were used to determine the ODH classification.

Assumptions

1. The maximum nitrogen gas introduction rate into Building 1006B from evaporation of LN_2 escaping from the refrigerator liquid nitrogen supply line is 12000 CFM [1]. A smaller amount of reliquifer helium gas could enter the building, but the nitrogen spill rate is bounding.

2. The free volume of the building is 85,000 ft^3. Two ODH exhaust fans, part of the existing PASS, each operates at 16000 CFM [2].

3. The building exhaust fans start when the building oxygen concentration is reduced to 18%. It is assumed that it takes 60-seconds for the fans to start and reach their full capacity. Once started, the fans will continue to run until operator intervention.

4. Outside air drawn into the building has a 21% oxygen concentration.

5. The building pressure remains constant and very near atmospheric pressure through the use of louvers.

6. The oxygen concentration in the building is found by assuming uniform instantaneous mixing of the air and nitrogen in the building volume as per the SBMS guidance.

7. The probability of the accident for each of the four assumptions is as follows. The equipment failure rates given in the BNL SBMS, Oxygen Deficiency Hazard, were used as the basis to determine these probabilities:

    A. Both ODH fans operable:

    There are two cryogenic pipe sections and one cryogenic flex line between the building penetration and the connection to the refrigerator. Each pipe section has a failure rate of 2×10^{-8}/hr. The flex line is not listed in the SBMS but is conservatively judged to have a failure rate10 times that of a cryogenic line or 2×10^{-7}/hr. The connection to the refrigerator is via a bayonet but this would only be removed/installed if the liquid nitrogen line were first isolated. Weld failures (leaks) in the line have a failure rate of 3×10^{-9}/hr. Since there are only 3 welds, this failure rate is 1×10^{-8}/hr. The refrigerator is considered as a Dewar or a tank (closure). A failure rate for the LN_2 tank was found by averaging a Dewar (1×10^{-6}/hr) and a closure (3×10^{-7}/hr) failure. Thus a value of 6.5×10^{-7}/hr was used for the refrigerator pressure boundary failure. These failure rates are added to obtain a pressure boundary failure rate value of 9×10^{-7}/hr.

    B. One ODH fan fails on demand:

    This failure rate is dominated by the failure rate of the ODH fan to run on demand. This rate is 3×10^{-4}/demand. This is multiplied by the pressure boundary failure rate obtained in Case A above to obtain a value of 2.7×10^{-10}/hr. This value alone is $< 10^{-9}$/hr, thus this sequence need not be considered because even with a fatality factor of 1, the area would not be classified as an ODH area.

C. One ODH fan know to be out of service:

The failure rate for this case is the same a that given in Case A above or 9×10^{-7}/hr.

D. A Fail-Safe automatic LN_2 supply valve is assumed to be located outside Building 1006B that closes when the PASS ODH sensors trip at 18%:

In this case the pressure boundary failure rate is the same as that in section a. above or 9×10^{-7}/hr. To determine the failure rate of the automatic valve, either a sensor failure (1×10^{-6}/hr) or a low power solid state device failure to function (1×10^{-6}/hr) or a failure of the normally-open-auto-close LN_2 supply valve (a conservative failure rate of a SOV or MOV is used, which is 1×10^{-3}/demand) may cause this valve to fail open on demand. This results in a failure rate of 1×10^{-3}/demand for the automatic valve. Thus the probability of the failure of the pressure boundary followed by failure of the automatic LN_2 supply valve to close would be 9×10^{-10}/hr. Therefore for this sequence, even with a fatality factor of 1, the area would not be classified as an ODH area.

Detailed Calculation and Analyses

The SBMS ODH Model is a prescribed method to determine the necessary level of hazard control for a building having the potential for oxygen deficiency. The fatality rate in the model is the product of two numbers. One quantity is the probability per hour of an event causing an oxygen deficiency. The other quantity is found by estimating the minimum oxygen concentration during the transient, assuming uniform instantaneous mixing of the air and nitrogen in the building volume, and is represented by a factor between 0 and 1 (see Figure 1). The computed fatality rate is then used to define the ODH class necessary to protect personnel.

The Oxygen Deficiency Hazard fatality rate is defined as:

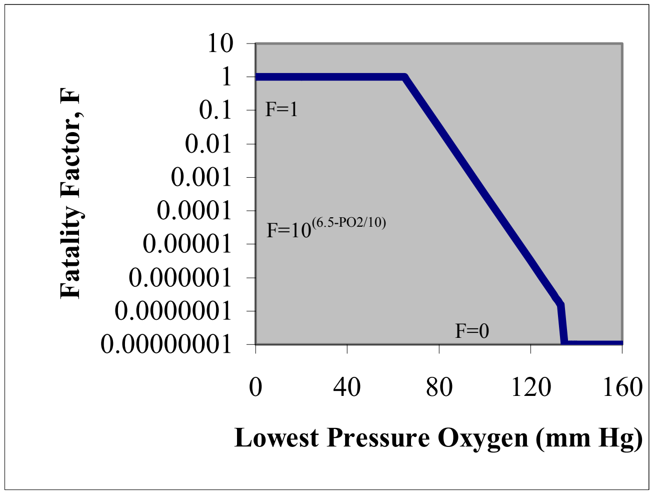
$$\Phi = PF$$

where Φ = the ODH fatality rate per hour
P = the expected rate of the event per hour, i.e. initiator frequency
F = the fatality factor for the event

The value of P, the initiator frequency, was found to be 9×10^{-7}/hr for Cases A (both ODH fans operable) and C (one ODH fan known to be out of service).

The value of the fatality factor, F, is the probability that a fatality will result if the design basis bounding nitrogen release occurs. Figure 1 from Reference 3 defines the relationship between the value of F and the computed oxygen partial pressure. The partial pressure is found by multiplying the mole fraction of oxygen in the building atmosphere by 760 mmHg. If the oxygen concentration is greater than 18% (~137 mmHg), then the value of F is defined to be zero. That is, all exposures above 18% are defined to be safe and do not contribute to fatality. If the oxygen concentration is 18%, then the value of F is defined to be 10^{-7}. At decreasing concentrations the value of F increases until, at some point, the probability of fatality becomes unity. That point is defined to be 8.8% (~67 mmHg) oxygen in the SBMS model, the concentration at which one minute of consciousness is expected.

Figure 1. Graph of the Fatality Factor (logarithmic scale) versus the Computed Oxygen Partial Pressure.



The value of Φ, the fatality rate, is then used to determine the ODH class of the building as follows [3]:

ODH Class	Fatality Rate (per hour)
NA	$<10^{-9}$
0	$\geq 10^{-9}$ but $<10^{-7}$
1	$\geq 10^{-7}$ but $<10^{-5}$
2	$\geq 10^{-5}$ but $<10^{-3}$
3	$\geq 10^{-3}$ but $<10^{-1}$
4	$\geq 10^{-1}$

The oxygen concentration in the building during a release of nitrogen gas is approximated by solving the following differential equations [3]:

(a) If the exhaust fan is on and the spill rate of nitrogen (R) is less than the exhaust fan capacity (Q):

$$V\frac{dC}{dt} = 0.21\,(Q - R) - QC$$

Where

V = building volume (ft^3)
C = oxygen concentration (mole fraction)
t = time (minutes)
Q = exhaust fan(s) flow rate (CFM)
R = nitrogen spill rate into building (CFM)

(b) If the exhaust fan is off:

$$V\frac{dC}{dt} = -RC$$

Solving for the fan off condition when the spill starts yields:

$$C(t) = C_0 \, e^{-(R/V)\,t}$$

The time to reach 18% oxygen is found to be 1.09 minutes. Assuming that the fans take 60-seconds to reach full capacity, yields an oxygen concentration of 15.63% when the fan(s) start.

Once the fan(s) are running, the following equation determines the oxygen concentration transient:

$$C(t) = 0.1563 \, e^{-(Q/V)\,t1} + [0.21(Q-R)/Q] \, (1 - e^{-(Q/V)\,t1})$$

Where t1 = (t – 2.09) minutes. For the two fans Case A, Q is 32000 CFM. For the one fan Case C, Q is 16000 CFM.

The following tables summarize the results for Cases A and C.

Case A – Two Operable ODH Fans ($P = 9 \times 10^{-7}$/hr)

t (minutes)	Oxygen Concentration (%)	O_2 Partial Pressure	Fatality Factor	Fatality Rate (hr^{-1})	ODH Classification
1.09	18	136.8	0	0	NA
2.09	15.63	118.82	4.15×10^{-6}	$< 10^{-9}$	NA
5	13.96	106.12	7.73×10^{-5}	$< 10^{-9}$	NA
10	13.25	100.72	2.68×10^{-4}	$< 10^{-9}$	NA
15	13.14	99.9	3.24×10^{-4}	$< 10^{-9}$	NA
∞	13.13	99.75	3.35×10^{-4}	$< 10^{-9}$	NA

Case C – One Operable ODH Fan ($P = 9 \times 10^{-7}$/hr)

t (minutes)	Oxygen Concentration (%)	O_2 Partial Pressure	Fatality Factor	Fatality Rate (hr^{-1})	ODH Classification
1.09	18	136.8	0	0	NA
2.09	15.63	118.82	4.15×10^{-6}	$< 10^{-9}$	NA
3	14	106.4	7.26×10^{-5}	$< 10^{-9}$	NA
5	11.25	85.53	8.85×10^{-3}	7.96×10^{-9}	0
6	10.22	77.7	5.37×10^{-2}	4.83×10^{-8}	0
7	9.37	71.22	2.39×10^{-1}	2.15×10^{-7}	1
8	8.66	65.84	1	9×10^{-7}	1
10	7.59	57.7	1	9×10^{-7}	1
∞	5.25	39.9	1	9×10^{-7}	1

Thus for Case A (both fans operable), there is no ODH classification required. For Case B, when one of the two ODH fans are known to be out of service because of failure or maintenance, the building must be posted as an ODH 1 area.

If the automatic liquid nitrogen valve is installed (Case D), the minimum oxygen concentration will be 15.63%, assuming that the valve closes when the PASS ODH sensors detect 18% oxygen concentration and it takes 60-seconds for the valve to close. This is not needed for adequate personnel protection as shown by this calculation.

This calculation has been checked by A. Etkin.

References

1. T. Nicoletti, Flow rate of N2 into building 1006B in the event of a pipe rupture in transfer line connecting Liquid Nitrogen Dewar to Reliquifer Refrigerator (attached).
2. RHIC SAD USI 1, Discovery of RHIC SAD ODH Calculation, April 19, 2000.
3. BNL Standards Based Management System Subject Area, "Oxygen Deficiency Hazards".

Flow Rate of N2 into building 1006B in the event of a pipe rupture
in transfer line connecting Liquid Nitrogen Dewar to Refliqiefier Refrigerator

Assumptions

Tank at normal operating pressure:	51.45	psia
Discharges to atmospheric pressure	14.7	psia
Temperature at discharge:	90	k

Assume gas remains at initial density - worst case

Inlet gas density

P=	51.45	psi
T=	90	K
Density=	0.75	g/cc

Pressure drop in line:	36.75	psid
	253391	pascal
	2533913	g/sec^2-cm

Piping from LN2 to just inside 1006B:

Length:	100	ft		
diameter:	1.68	in		
	4.27	cm	LN2 viscosity:	1.14E+07 poise
				1.14E+06 pascal-sec

Equivalent length from bends/angles

8	90 bends	20	ft
1	3/4" valves	28	ft
2	1.5" valves	20	ft
	total length:	168	ft

total length: 168 ft — 5130.8 cm

Assume Friction Factor: f= 0.013

From D'Arcy Equation:

flow	7055.2	g/s	0.001255 g/cc	stp density of N2
	5622974	scc/sec		
	343135	sin/sec		
	199	scf/sec		
	11914	**scf/min**		

Back calculate Reynolds Number

1.88E-04
1.88E-05
f= 0.013 checks