

APPENDIX L—HR2 TEST APPARATUS AND EQUIPMENT DETAILS

This document contains information and supplemental material pertinent to referenced paragraphs. Drawings in this document are not mechanical but used as a reference to illustrate component dimensions. If the HR2 is used to monitor smoke emissions, refer to section L.4 HR2 SMOKE MONITORING SYSTEM at the end of this appendix.

L.1. METHANE GAS (CH₄)

- Methane, CP Grade (99.0%) or product of similar specification or function has been found suitable.

L.1.1 HEAT RELEASE RATE APPARATUS

L.1.1.1 Insulation Material

- High Temperature Insulation Board: Mineral Wool, 1 in Thick, 24 in W, 4 ft Lg, Brown, R-Value: 4

Ordering: Grainger; Catalog Page 2724

Brand: ROXUL

Item: 19NE81

Mfr. Model: 40260

Insulation Board Material: Mineral Wool

Facing Material: FSK Facing

Overall Width: 24in

Overall Length: 4 ft

Thickness: 1in

Insulation R-Value: 4

Density: 8 lb/cu ft

- K-FLEX USA Pipe Insulation Tape: FSK, 150 ft Overall Lg, 3 in Overall Wd, 6.8 mil Thick, Silver

Ordering: Grainger

Item: 45AR23

Mfr. Model: 800-TAPE-ALFSK-3A

Backing Material: FSK

Adhesive Material: Acrylic

Overall Length: 150 ft

Overall Width: 3 in

Thickness: 6.8 mil

Color: Silver

- Thermafiber® FireSpan® 90 Mineral Wool Insulation (8 pcf) [Owens Corning] or product of similar specification or function has been found suitable.

(Update January 2025)

THERMAFIBER, INC.
ONE OWENS CORNING PARKWAY
TOLEDO, OHIO, USA 43659
888-TFIBER1 [834-2371]
www.thermafiber.com

L.1.1.2 High Temperature Gasket Material (above the second stage plate)

- High-Temperature High-Pressure (1/8th inch thickness) Graphite Gasket Material (McMaster-Carr #95715K93) or product of similar specification or function has been found suitable.
- Flexible Fiberglass Insulation Paper; McMaster-Carr P/N 9323K21 (1/8th inch thickness) or product of similar specification or function has been found suitable.
- Fiberfrax® 970 Series, Type J, Ceramic Fiber Paper (1/8th inch thickness) or product of similar specification or function has been found suitable.

Unifrax I LLC
600 Riverwalk Parkway
Suite 120
Tonawanda, New York 14150
Telephone: (716) 768-6500
Internet: www.unifrax.com
Email: info@unifrax.com

- 907GF-7 (Resbond) Smooth, Fine Grade Adhesive and Sealant Putty 11 oz. Cartridge

Cotronics Corp.
131 47th Street
Brooklyn NY 11232
USA
Telephone: 718-788-5533

L.1.1.3 Low Temperature Gasket Material (below the second stage plate)

- Rubber, Silicone 0.125 inches (3.2 mm) thickness or product of similar specification or function has been found suitable in cooler areas of apparatus.

Table L-1. Component metal thickness and tolerances for cold rolled stainless steel and aluminum

0.25 inch Aluminum	Holding Chamber Door
	Lower Plenum Air Distribution Plate
0.036 ± 0.003 Aluminum	Exhaust Stack Sheathing/Shroud
0.125 ± 0.005-inch Stainless Steel	Sample Holder Retaining Rod

(Update January 2025)

0.048 ± 0.004-inch Stainless Steel	Main Body/Main Body Flange
	Rear Global Pan
	Holding Chamber
	Second Stage Air Distribution Plate
	Lower Plenum/Lower Plenum Flange
	Exhaust Stack Doubler
0.042 ± 0.004-inch Stainless Steel	Diamond-Shaped Mask
0.036 ± 0.003-inch Stainless Steel	Global Reflector
	Sample Holder Injection Mechanism Plate
0.030 ± 0.003-inch Stainless Steel	Inner Radiation Doors (2)
0.018 ± 0.002-inch Stainless Steel	Pyramid-Shaped Exhaust Stack and Stiffening Flange
	Sample Holder
	Sample Holder Retaining Ring
	Sample Holder Spring Plate
	Sample Holder Drip Pan

Table L-2. Tolerance table

(Except as noted)

1 PLACE	± 0.125 inch [3.2 mm]
2 PLACE	± 0.063 inch [1.6 mm]
3 PLACE	± 0.031 inch [0.8 mm]
ANGULAR TOLERANCE	± 1 degree
BEND TOLERANCE	± 1 degree

L.1.1.4 Holding Chamber

(Update January 2025)

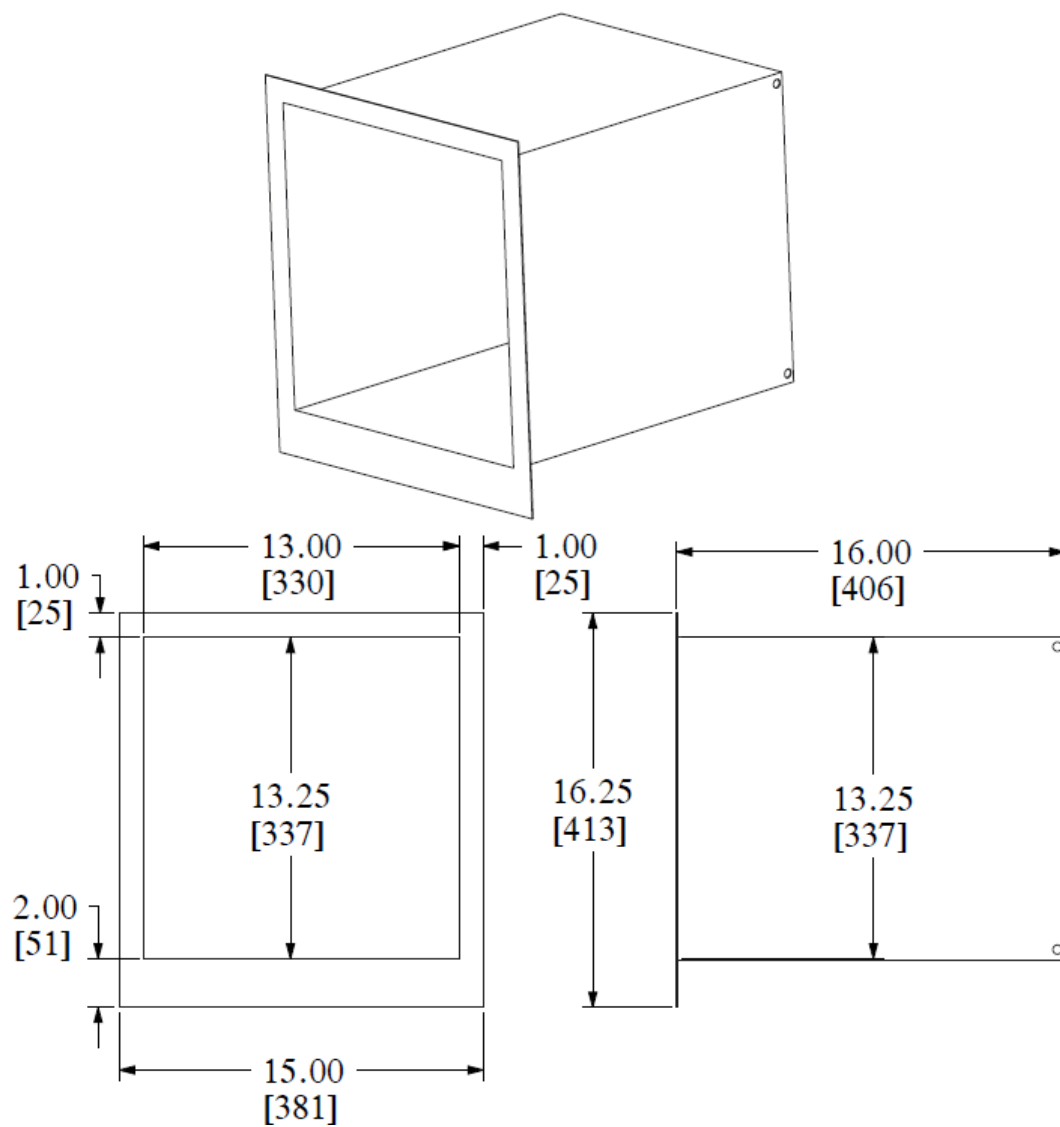


Figure L-1. Dimensioned drawing of the holding chamber

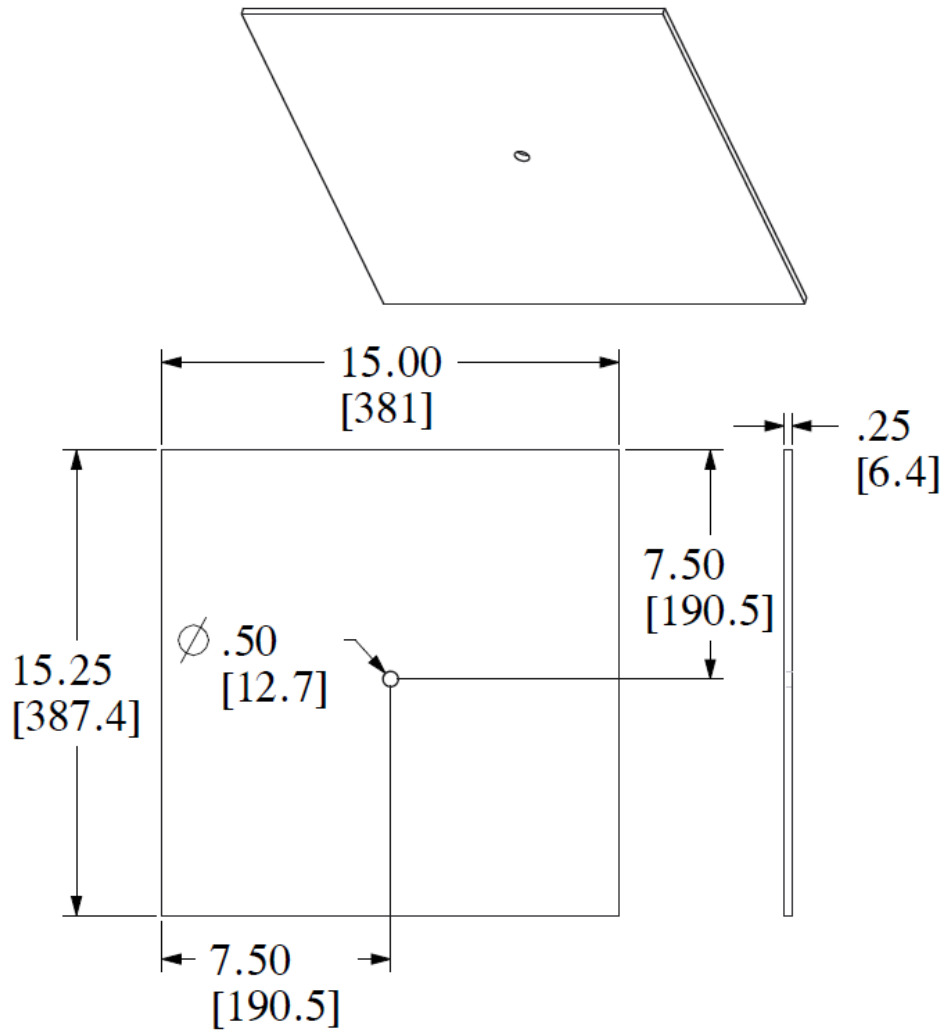


Figure L-2. Dimensioned drawing of the holding chamber door

L.1.1.5 Environmental Chamber

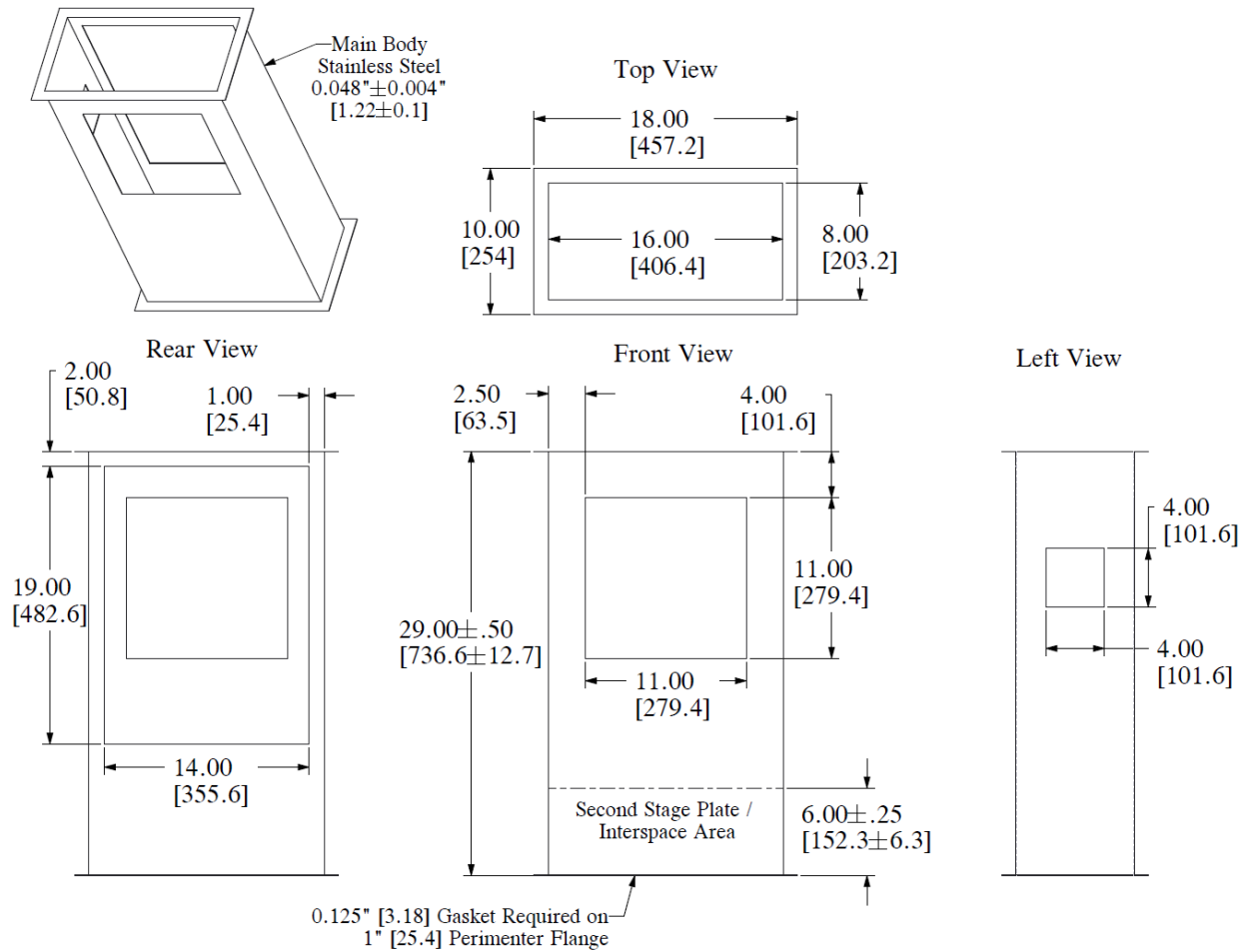
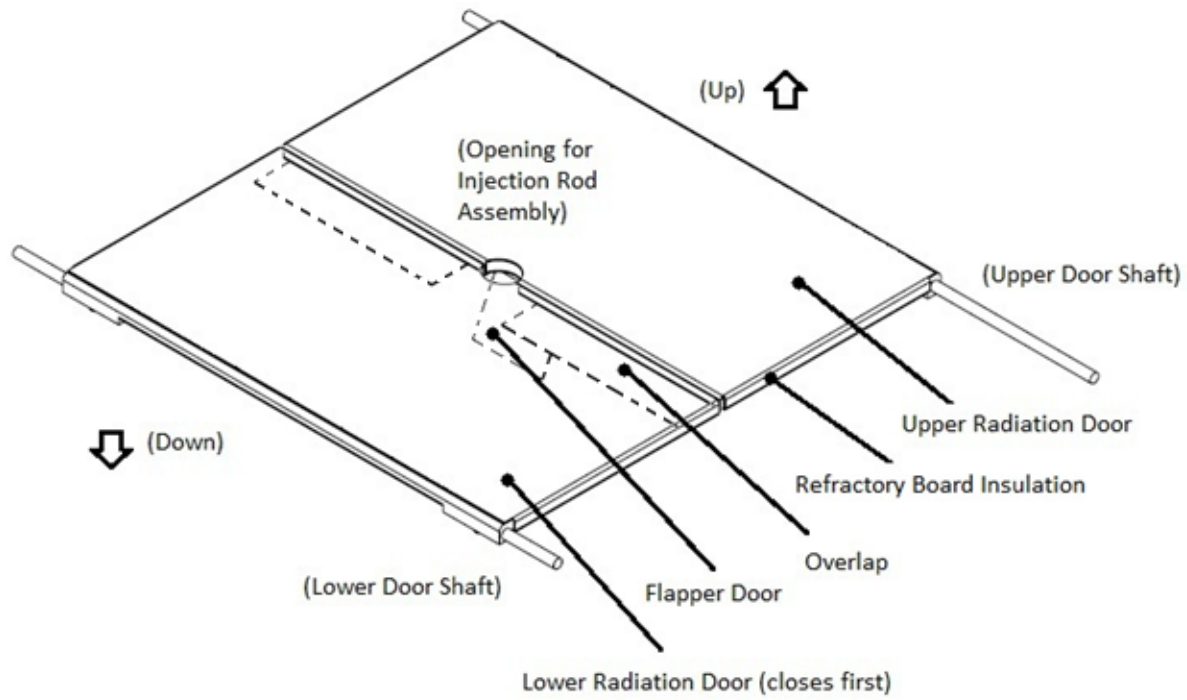


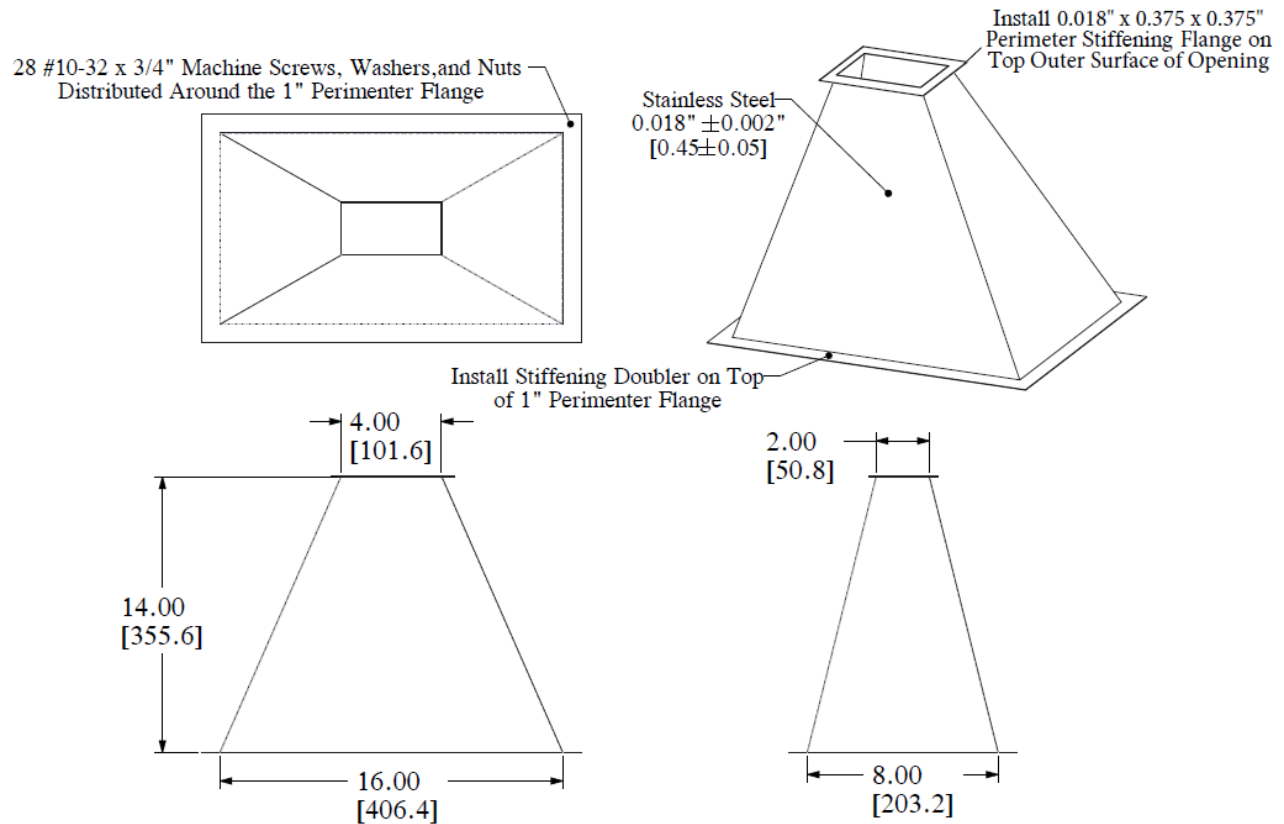
Figure L-3. Dimensioned drawing of the main body



**Figure L-4. Schematic of the radiation door assembly
(view from inside environmental chamber)**

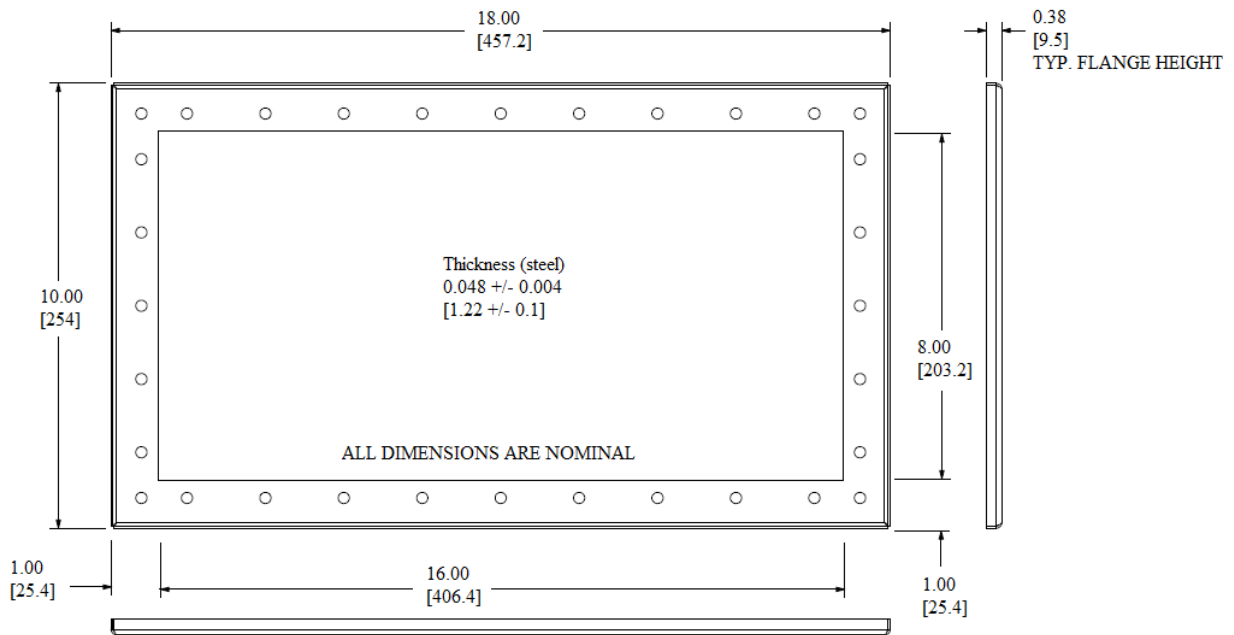
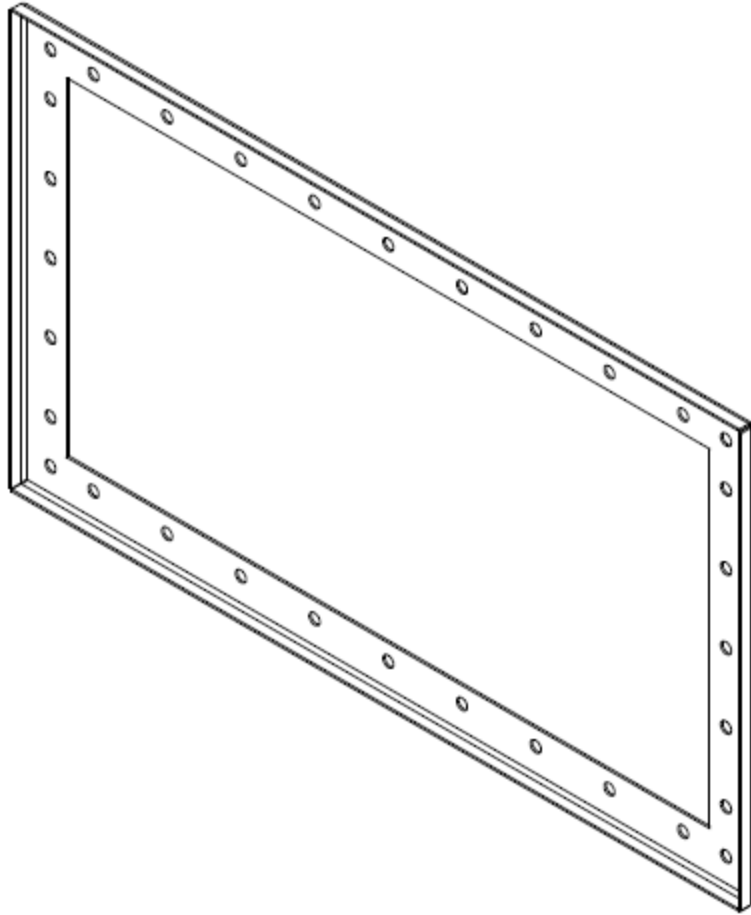
L.1.1.6 Pyramidal Section

- The exhaust stack opening requires an external perimeter flange to help maintain square edged dimensions (2 inch x 4 inch) and prevent warpage in this high heat area. The flange is to be made of a single piece of 0.018 inch stainless steel having a 3/8 inch vertical flange (tack welded to the exterior of the stack) and a 3/8 inch horizontal flange which is flush with the exhaust opening on top.



NOTE: It is extremely important that the exhaust opening is square (90 degrees) in all four-corner dimensions of the top opening.

Figure L-5. Dimensioned drawing of the pyramidal section



(Update January 2025)

Figure L-6. Dimensioned drawing of the stiffening doubler

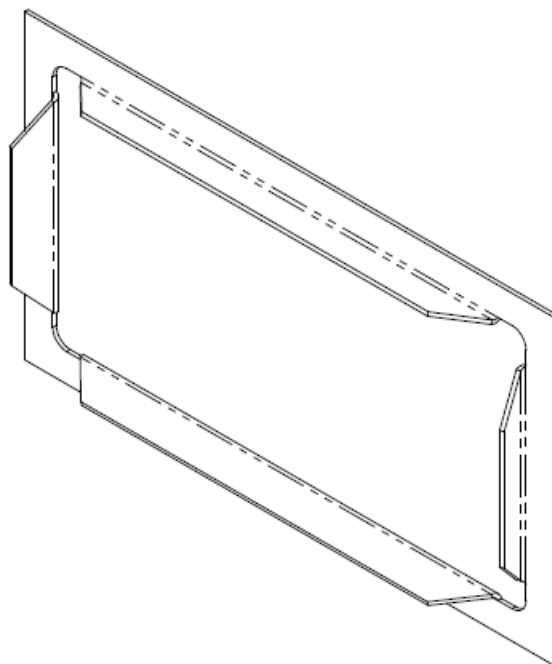
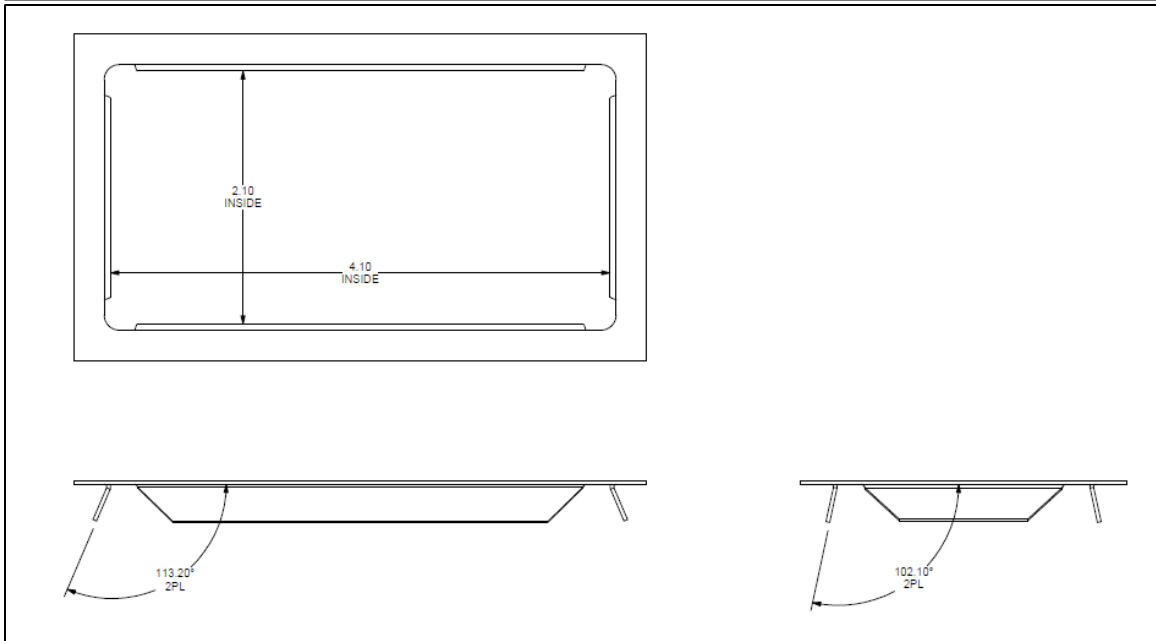
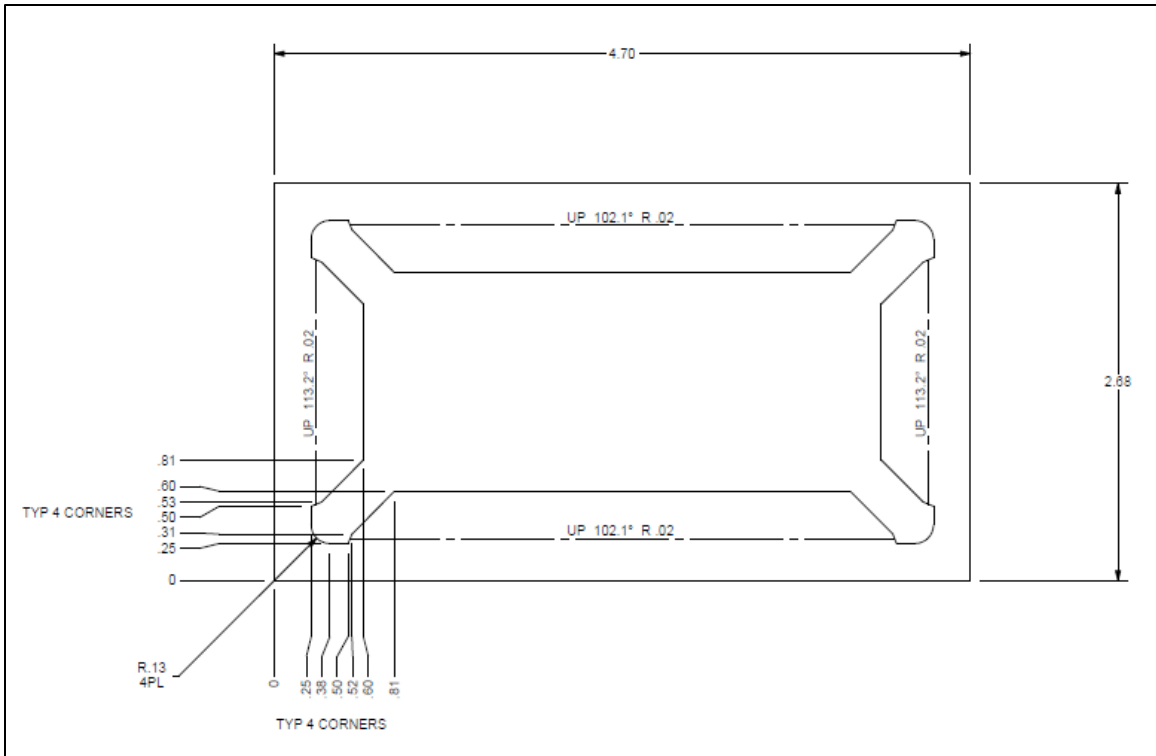


Figure L-7. Exhaust Cone Stiffening Flange



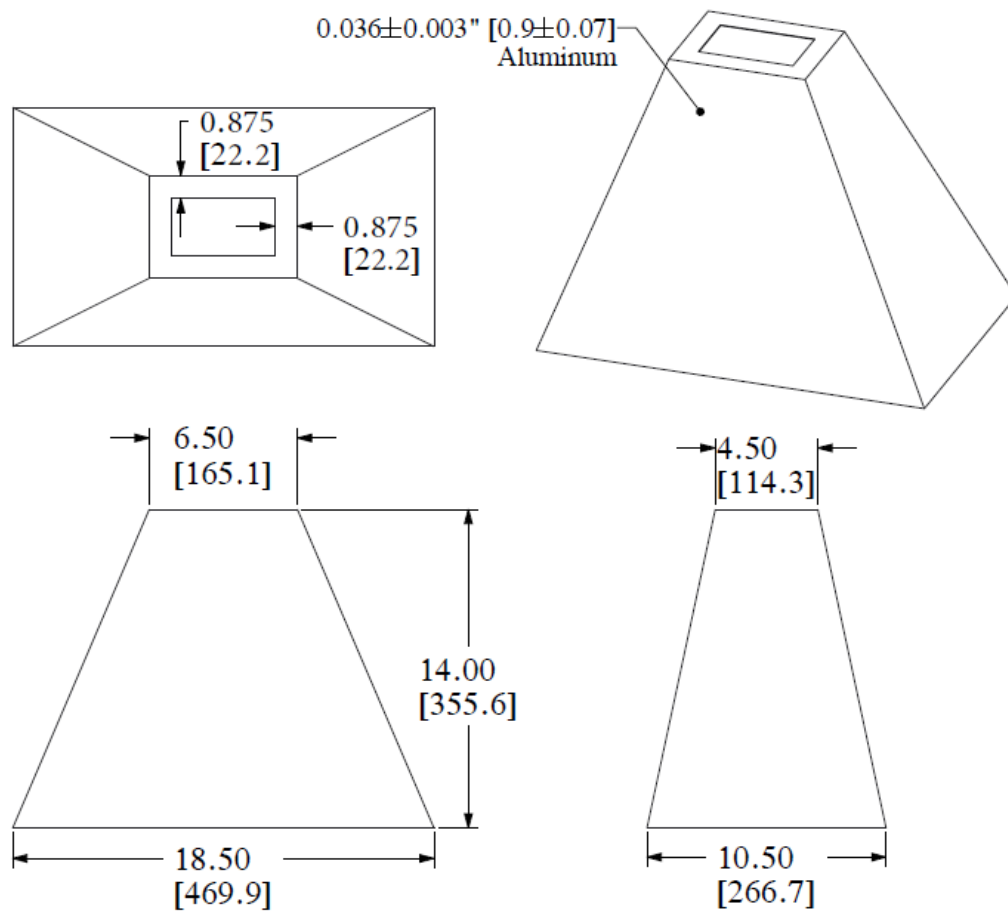


Figure L-8. Dimensioned drawing of the outer pyramidal shroud section

L.1.1.7 Radiation Source

- Globar [Kanthal Corp.] SDO-3-16-300-500-1.40-1515 or product of similar specification or function has been found suitable.

Sandvik Heating Technology USA
495 Commerce Drive, Suite 7
Amherst, NY 14228 USA
Phone: (716) 691-4010 / Fax: (716) 691 – 7850
Email: sales.bethel@sandvik.com
URL: <http://www.kanthal.com>

- Marinite I Board 1-inch (25.4 mm) thickness or product of similar specification or function has been found suitable.

BNZ Materials, Inc.
400 Iron Horse Park
North Billerica, MA 01862
Phone: (800) 888-0061 / Fax: (978) 663 – 2735
URL: <http://www.bnzmaterals.com/contact-us/>

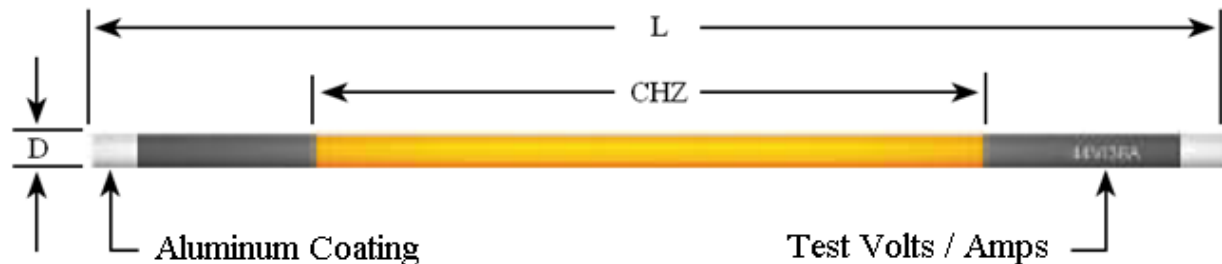


Figure L-9. Silicon carbide globar

L = 20 inches (508 mm)
D = 0.63 inch (16 mm)
CHZ = 12 inches (305 mm)
Nominal Resistance at 1000°C = 1.4 Ohms ± 15%

Note: All globar dimensions are approximate.

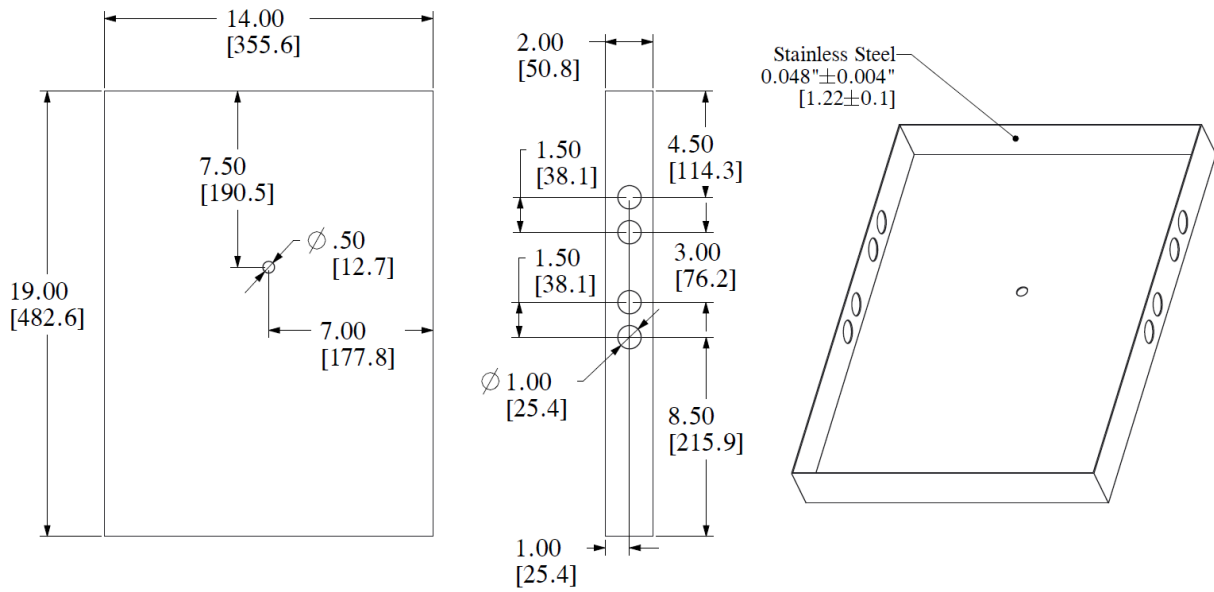


Figure L-10. Dimensioned drawing of the Gobar pan

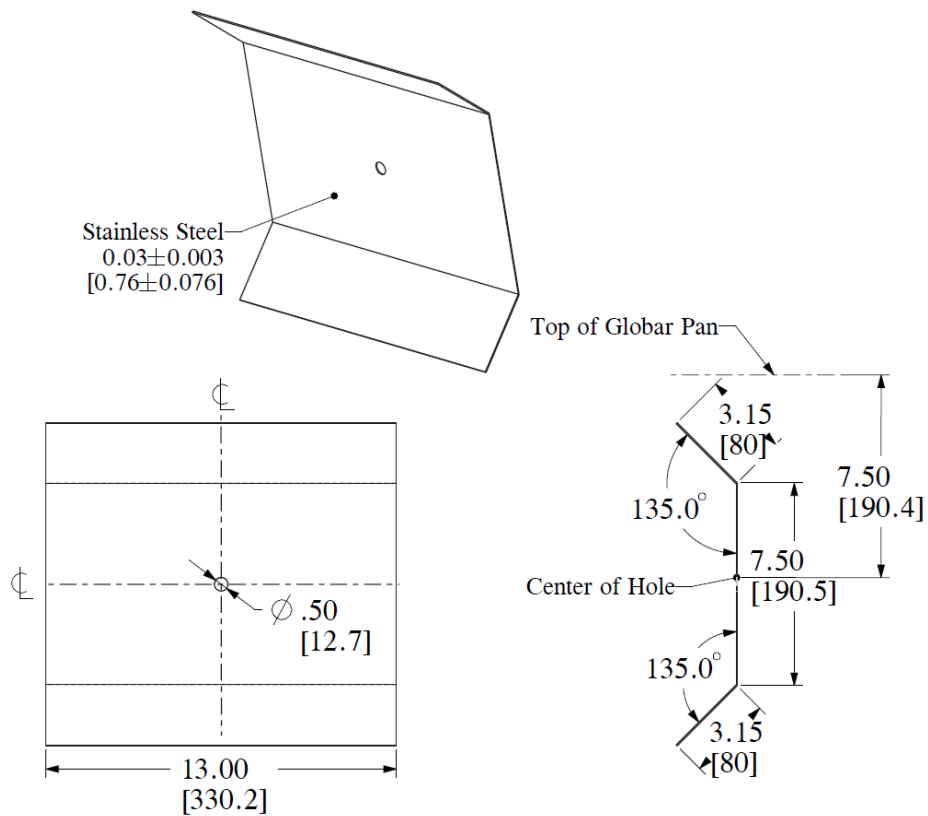


Figure L-11. Dimensioned drawing of the reflector plate

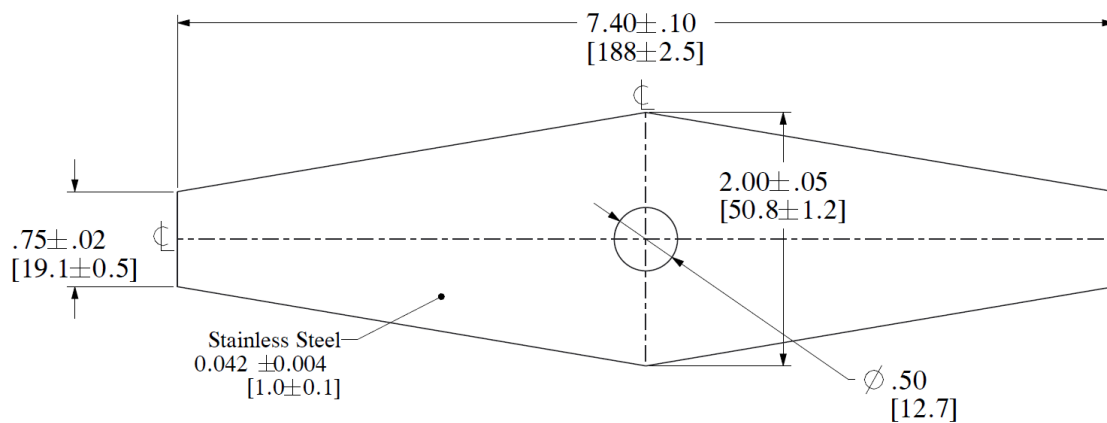


Figure L-12. Dimensioned drawing of the diamond-shaped mask

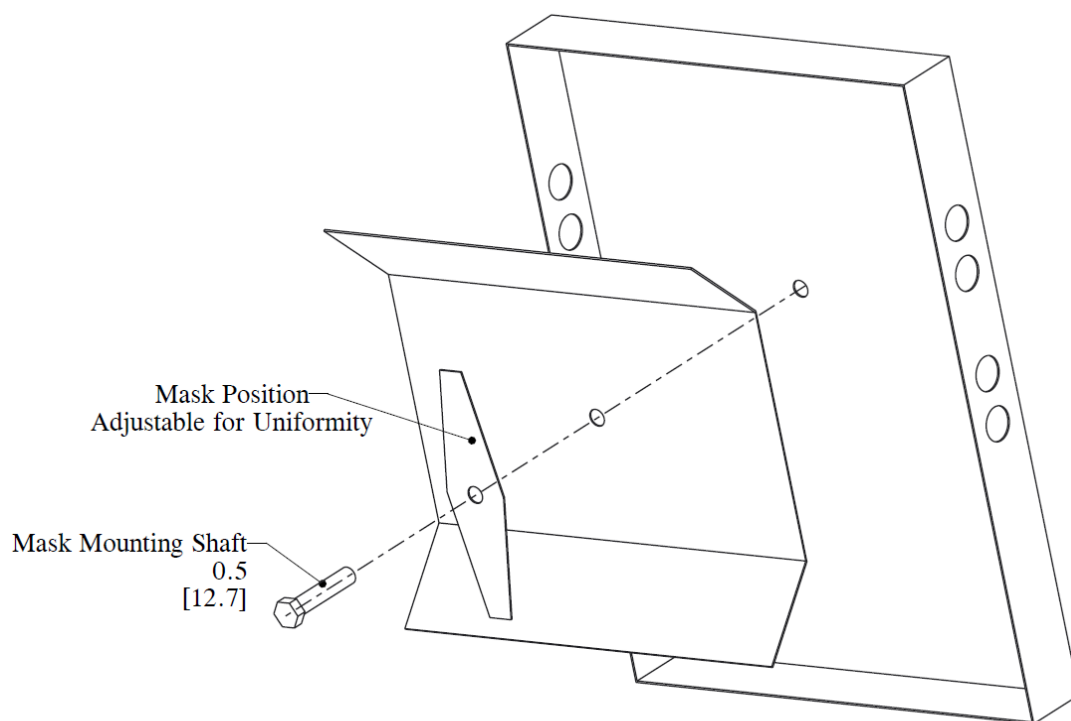


Figure L-13. Relative position of the mask, reflector plate, and Globar pan

L.1.1.8 Thermopile

- Ensure thermocouples read correctly when mounted into position. Grounding problems can have an impact on readings. The use of an insulating material may be required when mounting (electronically isolated).
- The following illustration depicts the acceptable condition of the thermocouples when in use. Wires separated with residual insulation material removed.

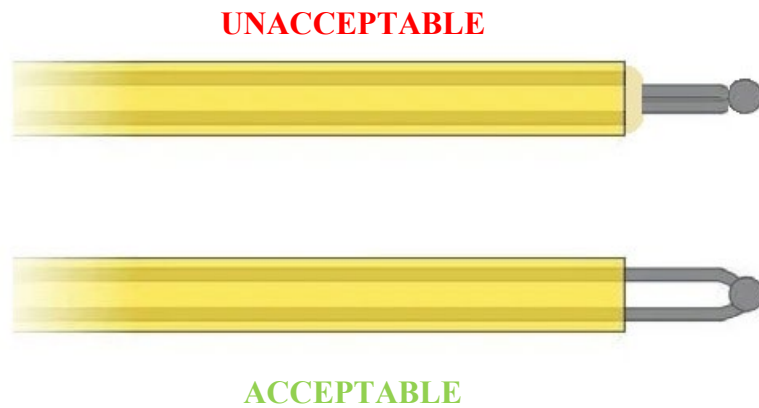


Figure L-14. Thermocouple Criteria

- An alignment jig similar to the one below should allow all 5 thermocouples in the hot zone to be adjusted and positions verified simultaneously with the unit at operating temperature.
- Hot zone thermocouples should be routed as seen in the illustration below.

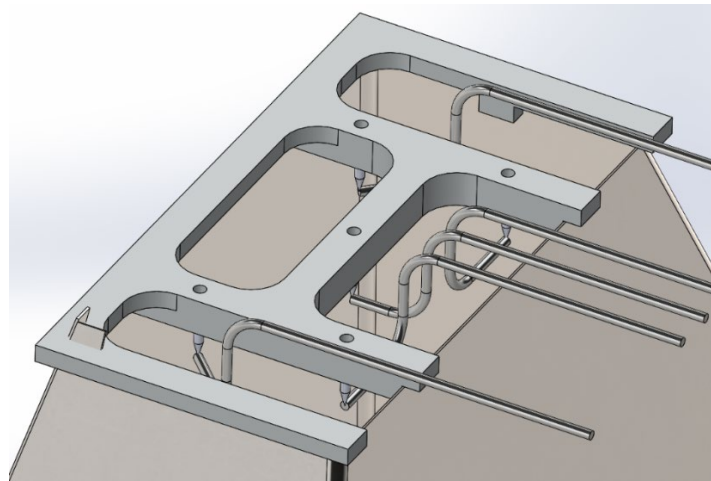
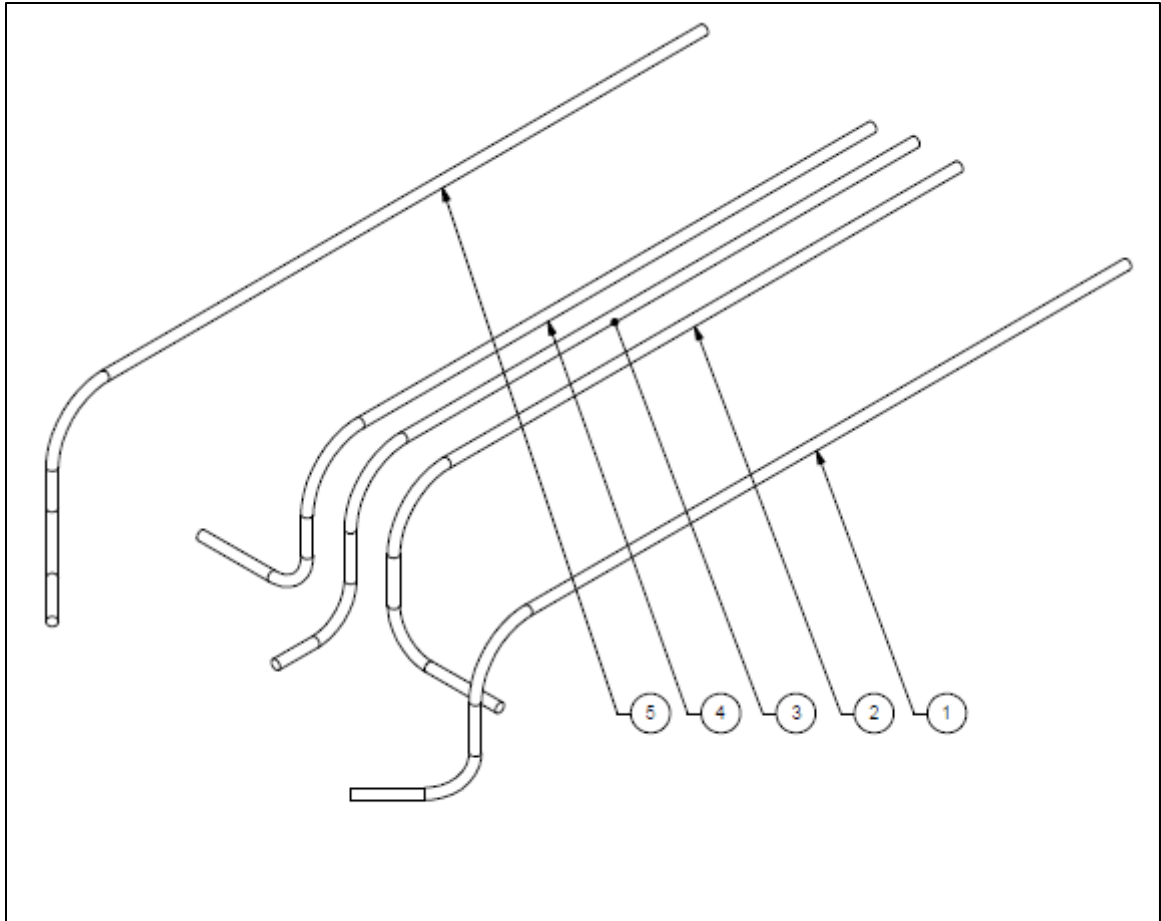
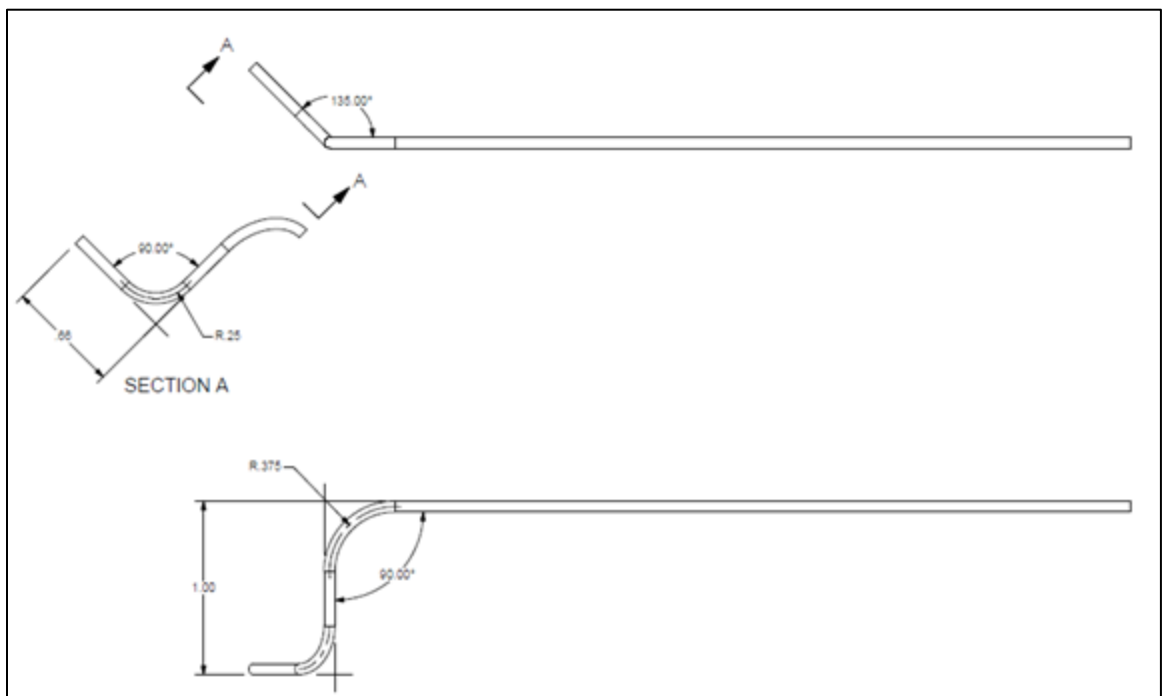


Figure L-15. Standardized Thermocouple Routing and Alignment Jig

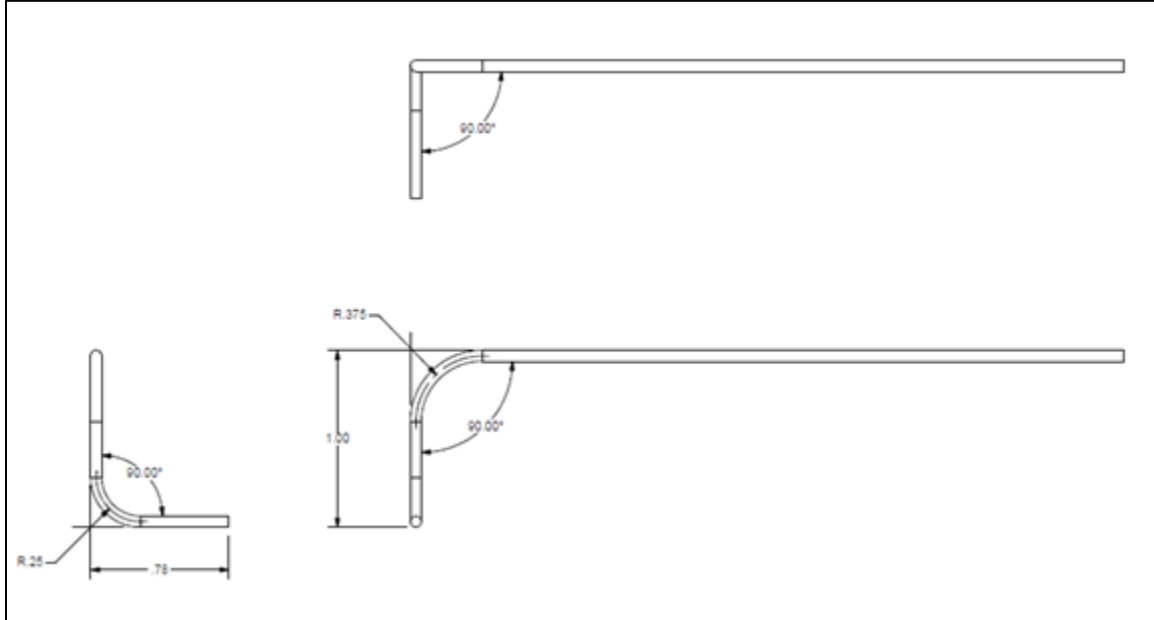


Overview

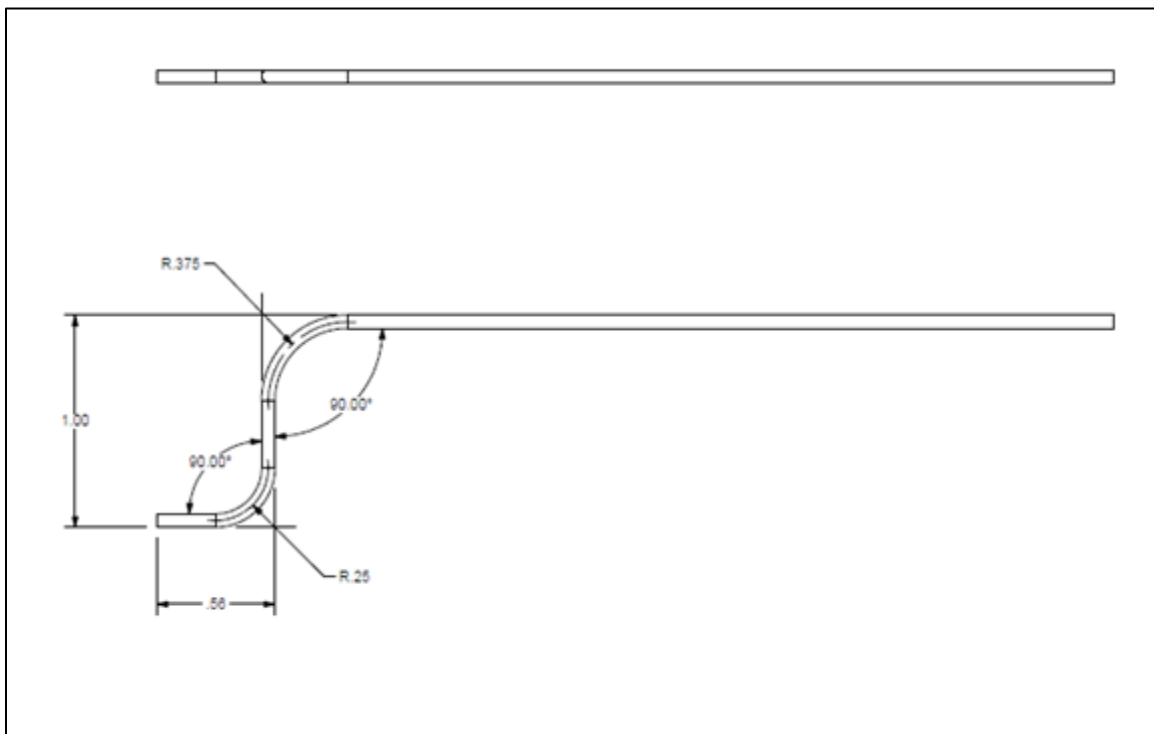


(Update January 2025)

#1 Thermocouple (Left, Rear)

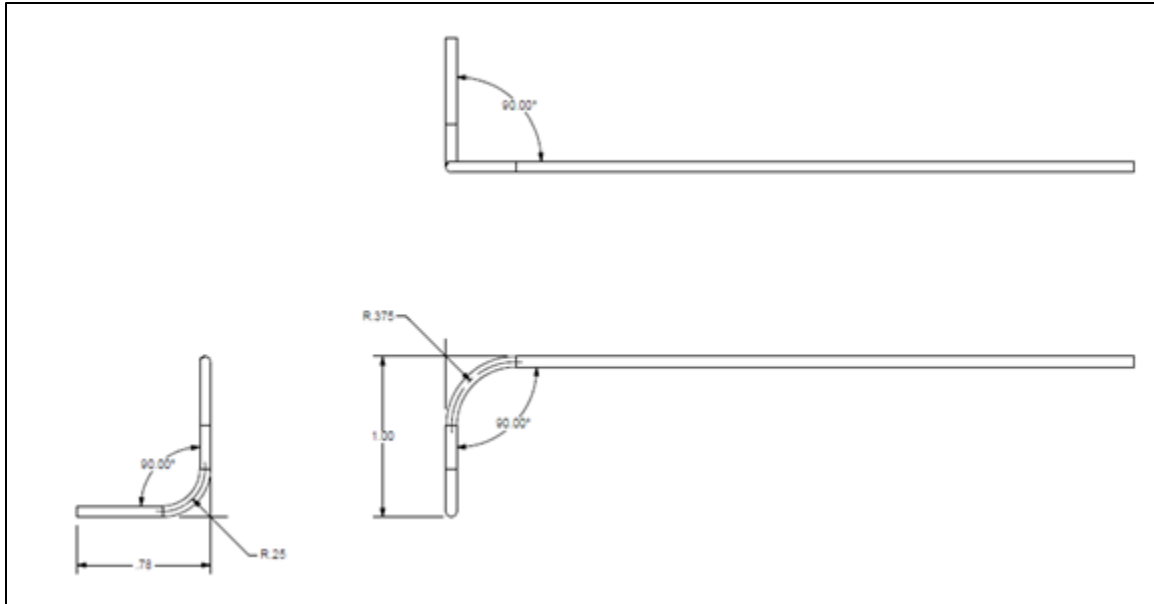


#2 Thermocouple (Left, Front)

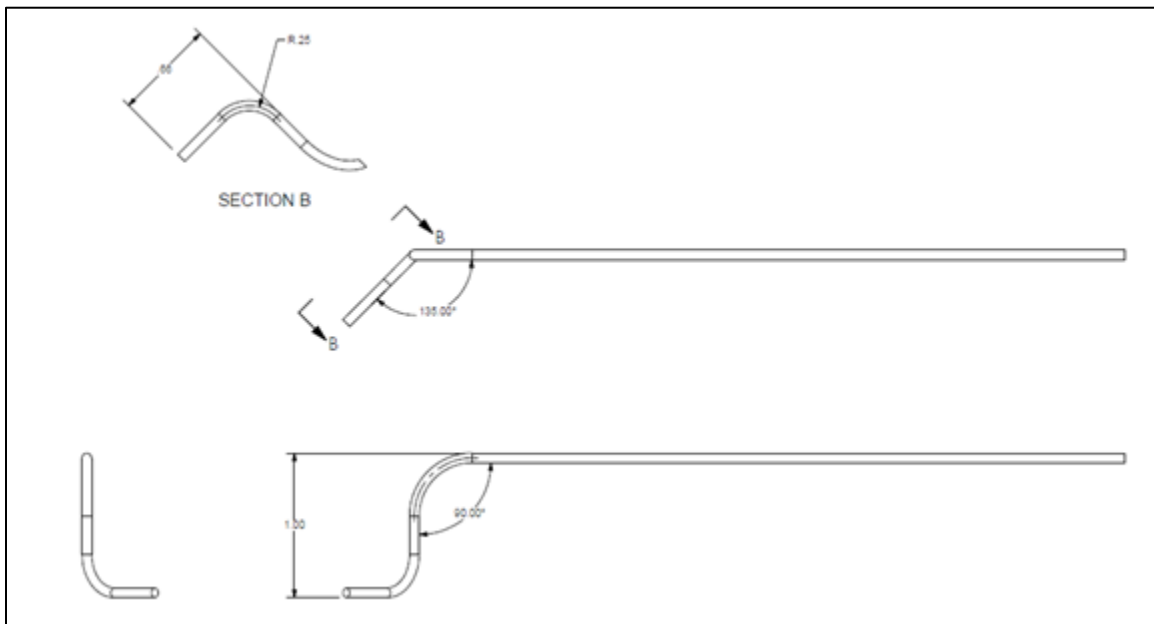


#3 Thermocouple (Center)

(Update January 2025)



#4 Thermocouple (Right, Front)



#5 Thermocouple (Right, Rear)

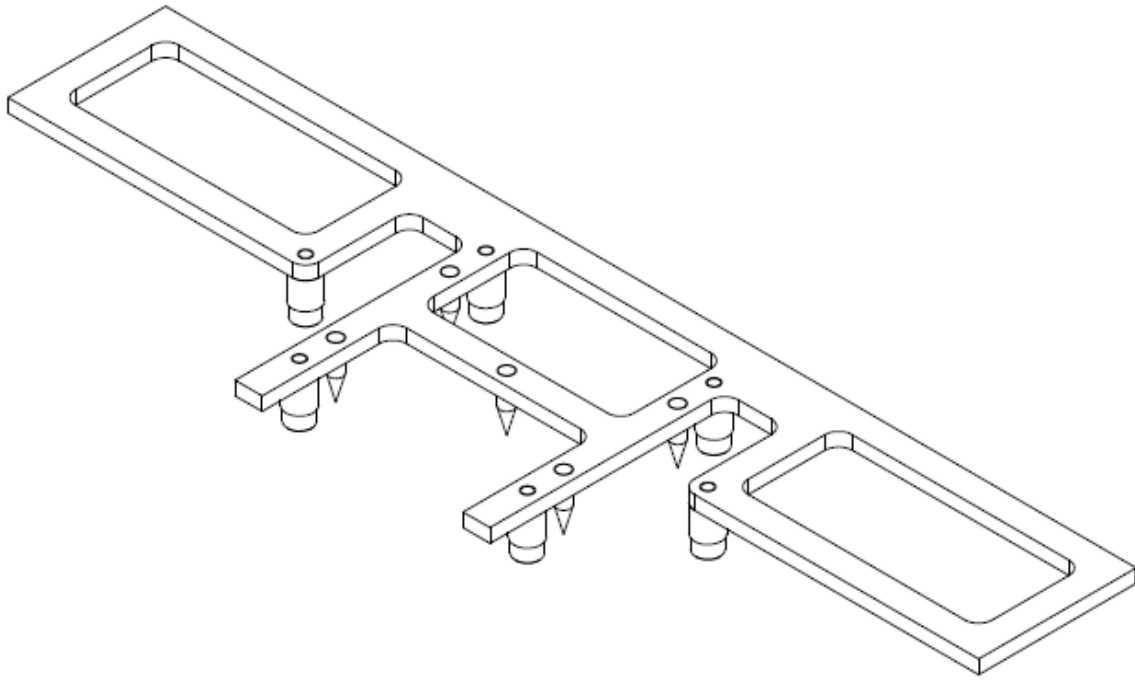
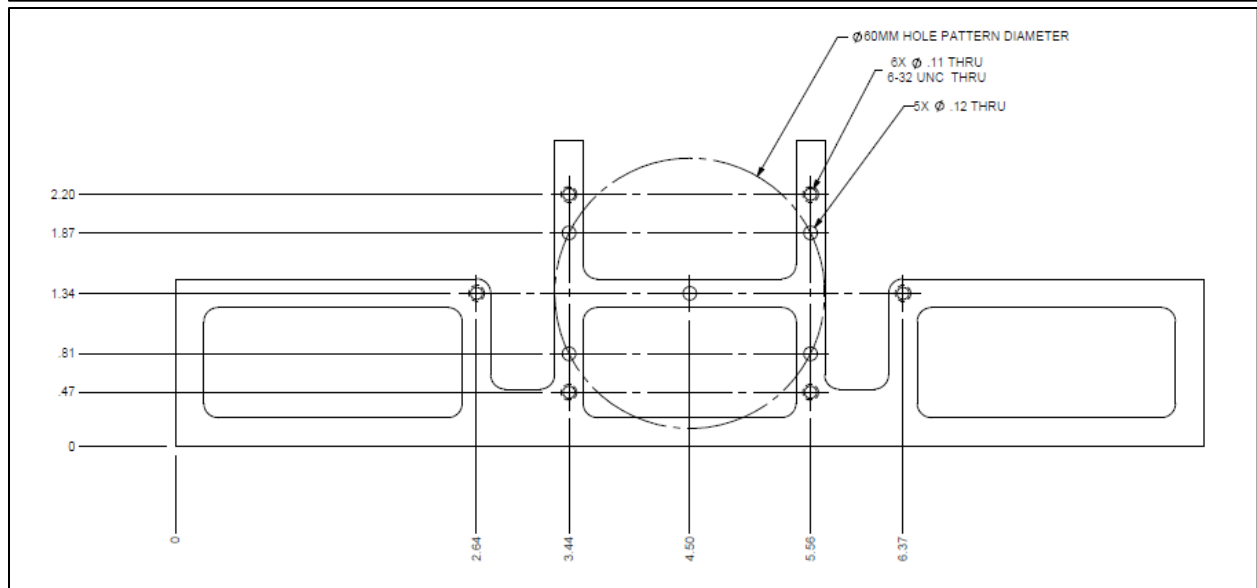
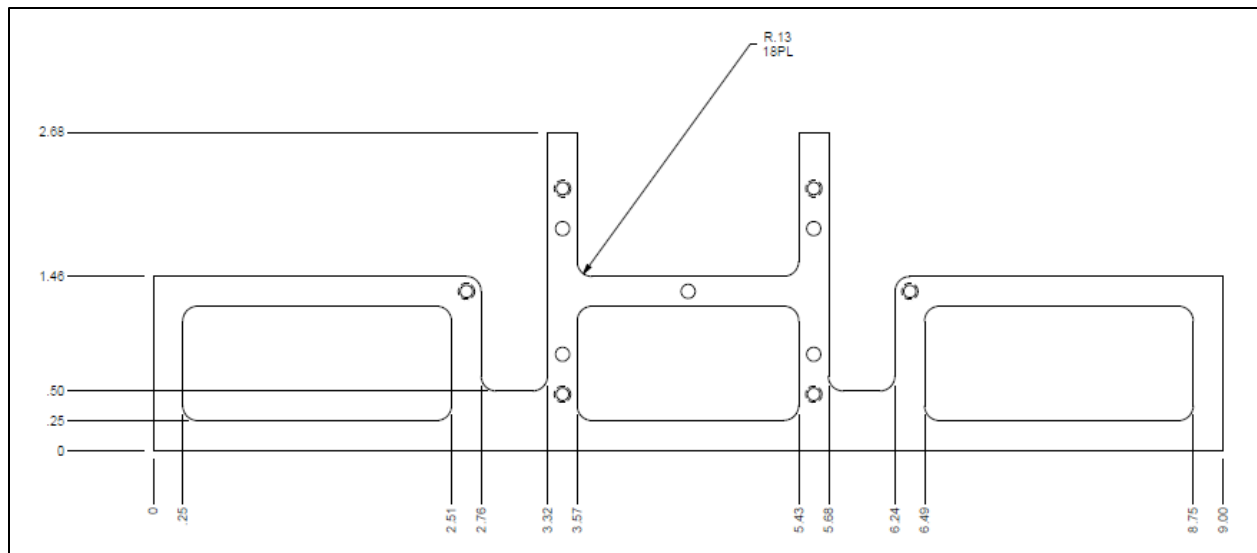
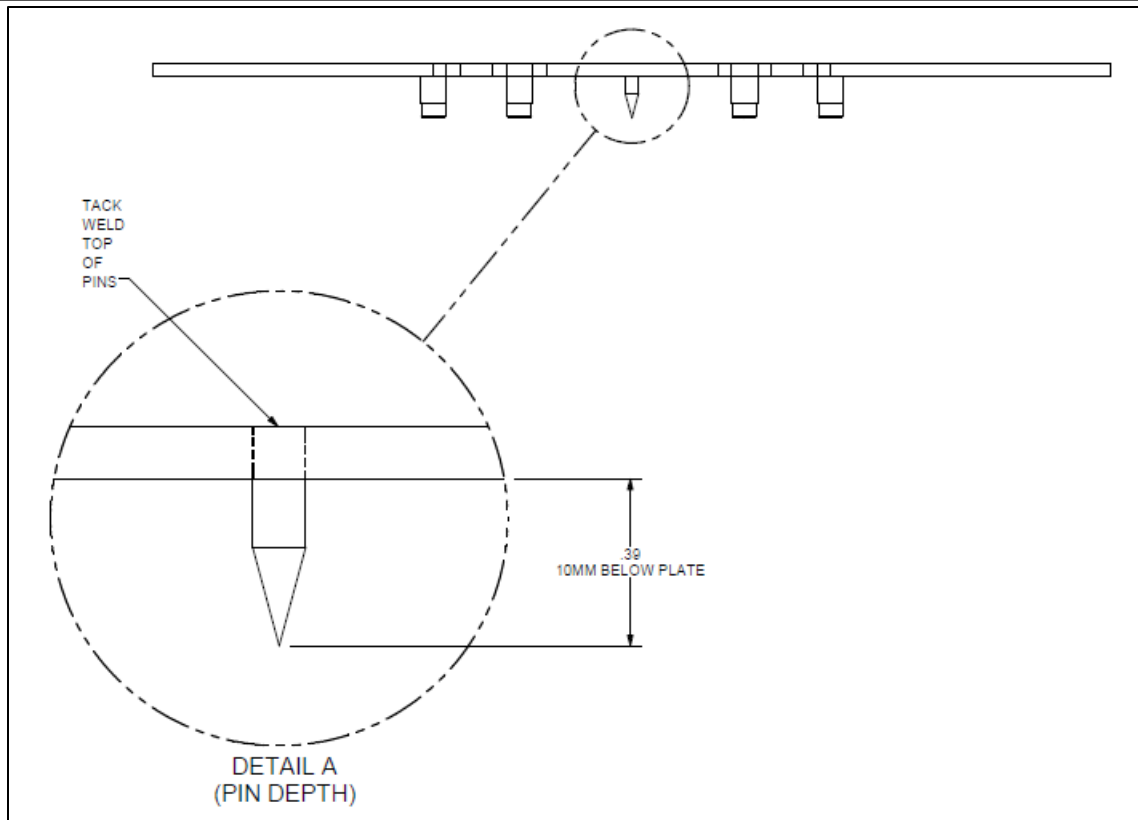
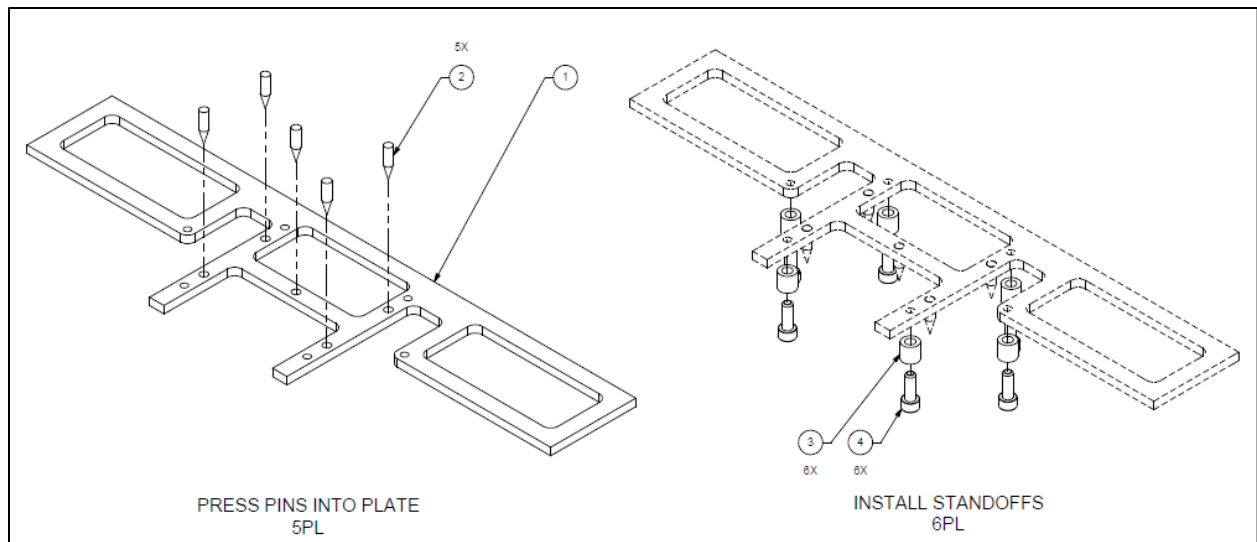


Figure L-16. Alignment Jig





- Thermocouple [Omega] KMQSS-062E-8 or product of similar specification or function has been found suitable.
- Thermocouple Bead size is typically determined by:
 - Wire diameter (0.01 inch) x 2.5 = 0.025 inch
- Thermocouple Grade Wire [Omega] TT-K-24 or product of similar specification or function has been found suitable.

Omega Engineering, Inc.

(Update January 2025)

1 Omega Drive, Box 4047
Stamford, CT 06907-0047 USA
Phone: (203) 359-1660 / Fax: (203) 359 – 7700
Email: sales@omega.com
URL: <http://www.omega.com>

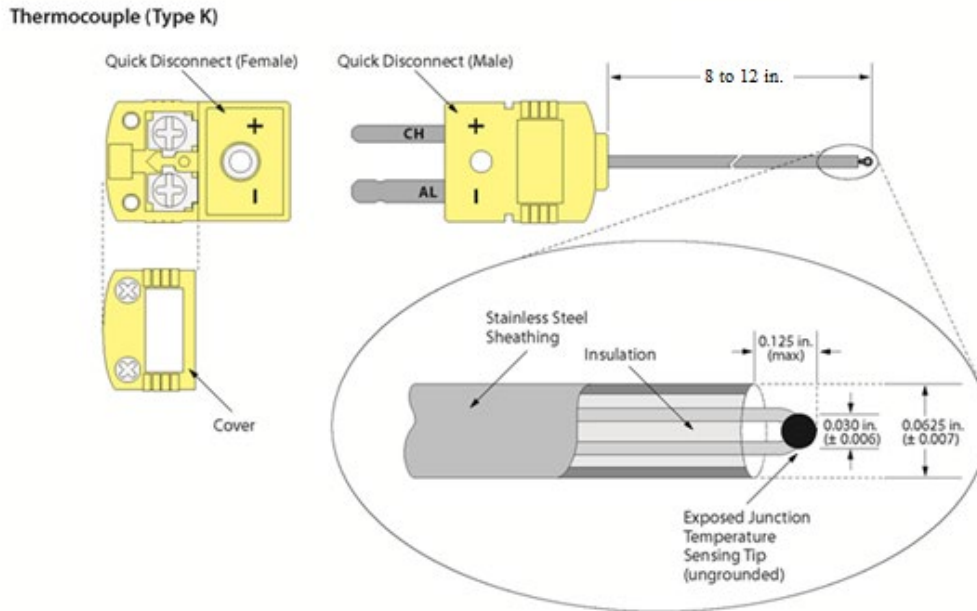


Figure L-17. Typical Thermocouple Dimensions

Thermopile System

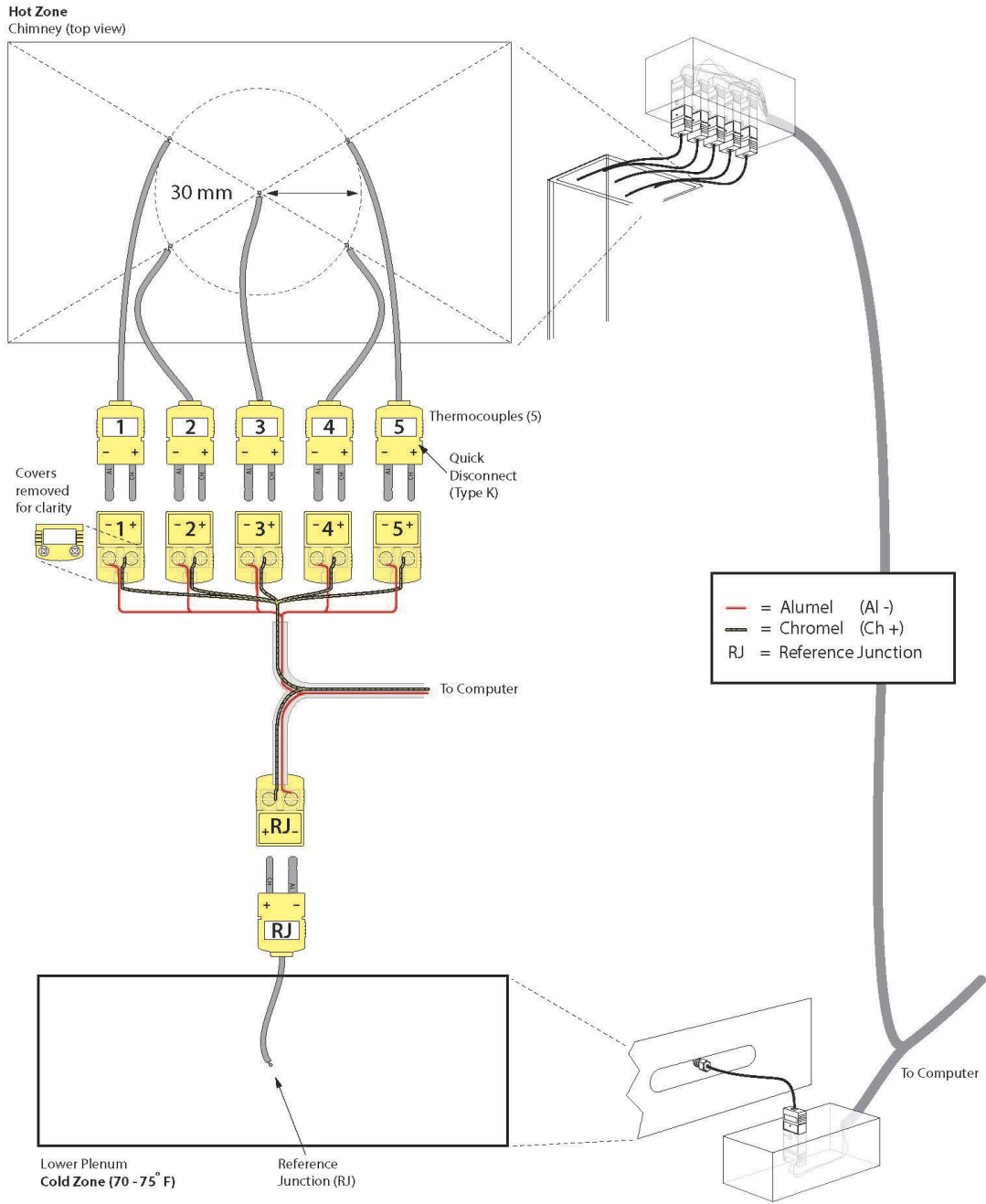


Figure L-18. Thermopile system

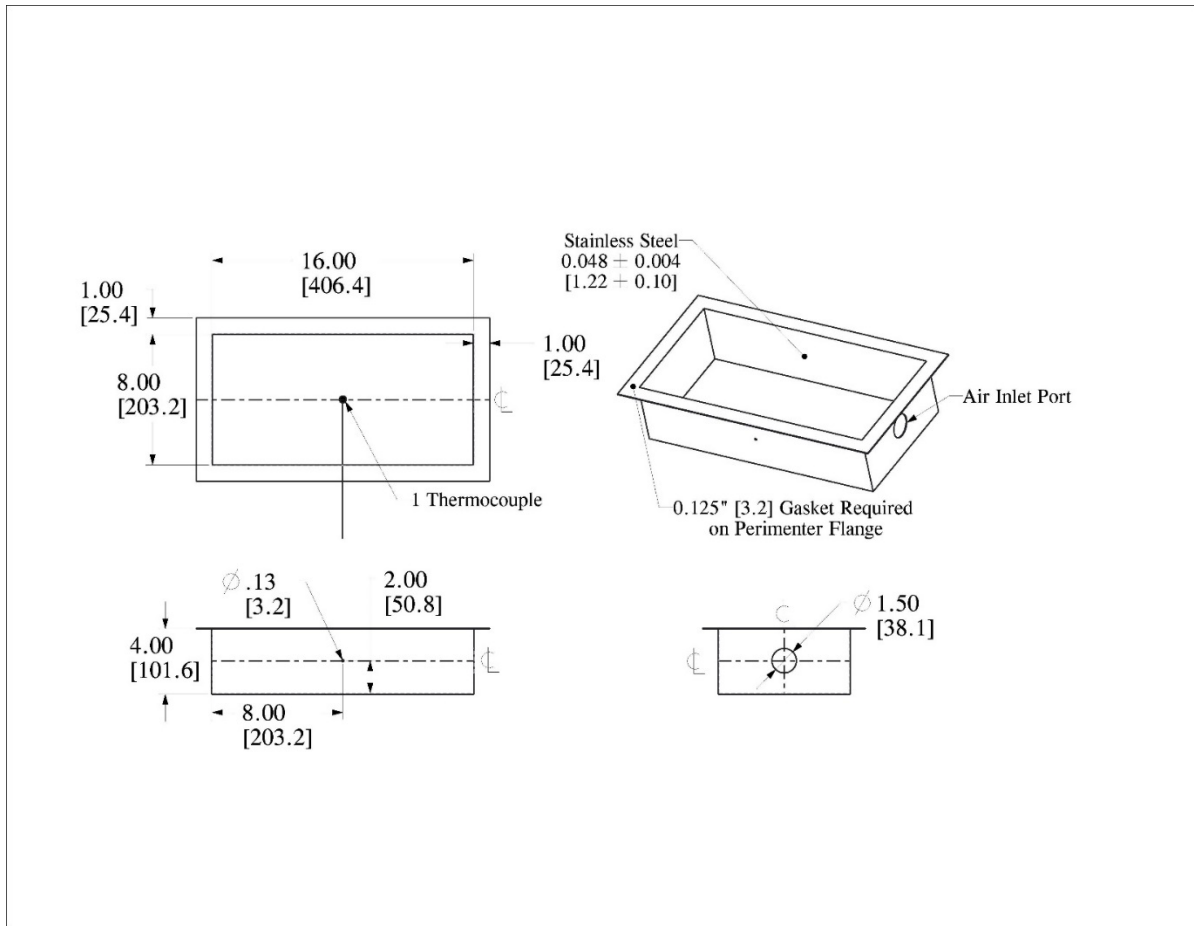


Figure L-19. Dimensioned drawing of the lower air plenum

- An optional pressure port may be added to the lower plenum or inlet piping downstream of the main air MFC to acquire pressure readings in this area. To obtain pressure readings in the interspace area (6 inch space between main air distribution plate and second stage plate), a thin tube may be inserted approximately 3 inches downward into any one of the 120 holes. Pressure readings are in units of inches of water column (INWC).

L.1.1.9 Lower Pilot Burner

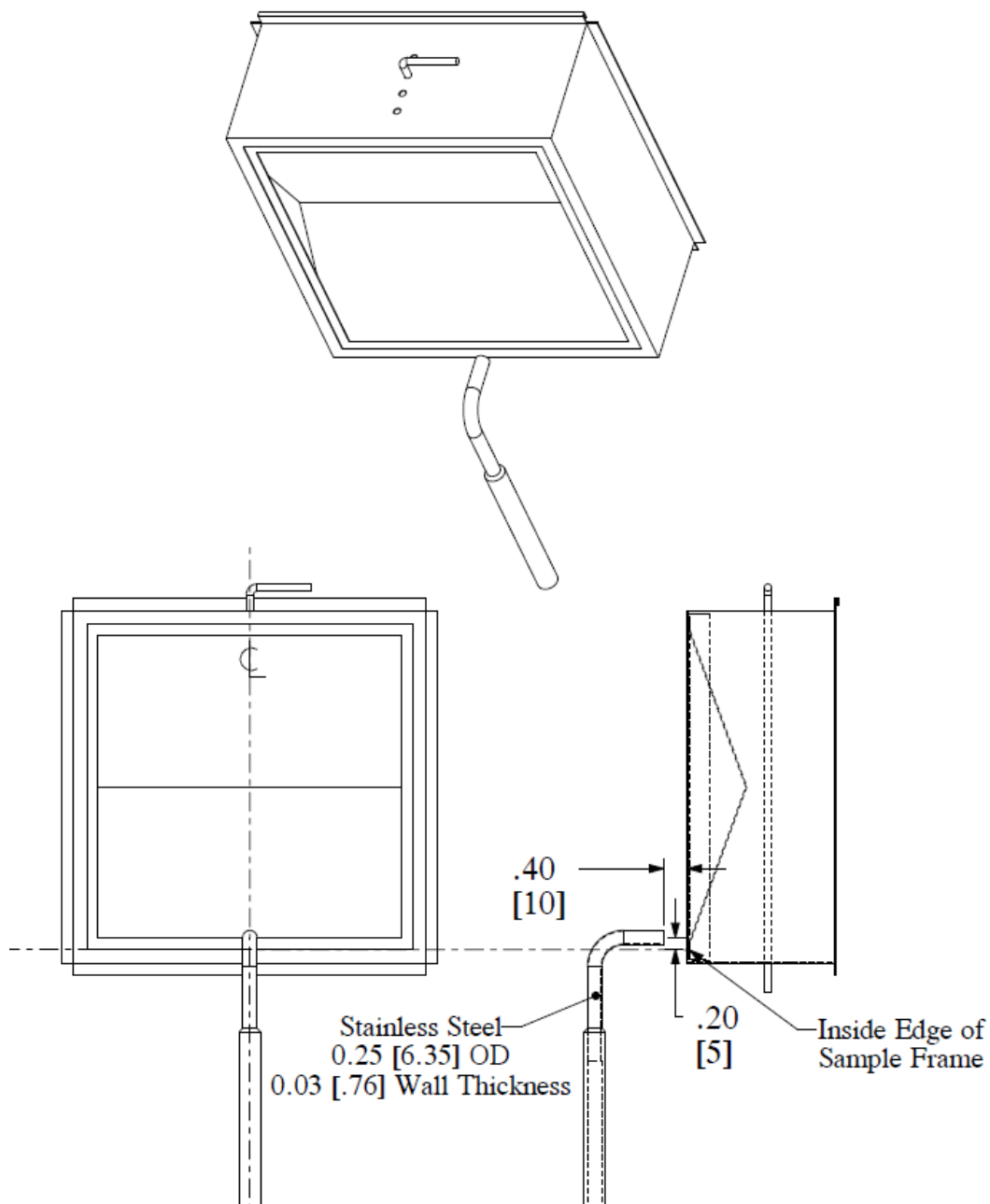


Figure L-20. Dimensioned drawing of the lower pilot burner relative to the sample holder

L.1.1.10 Upper Pilot Burner

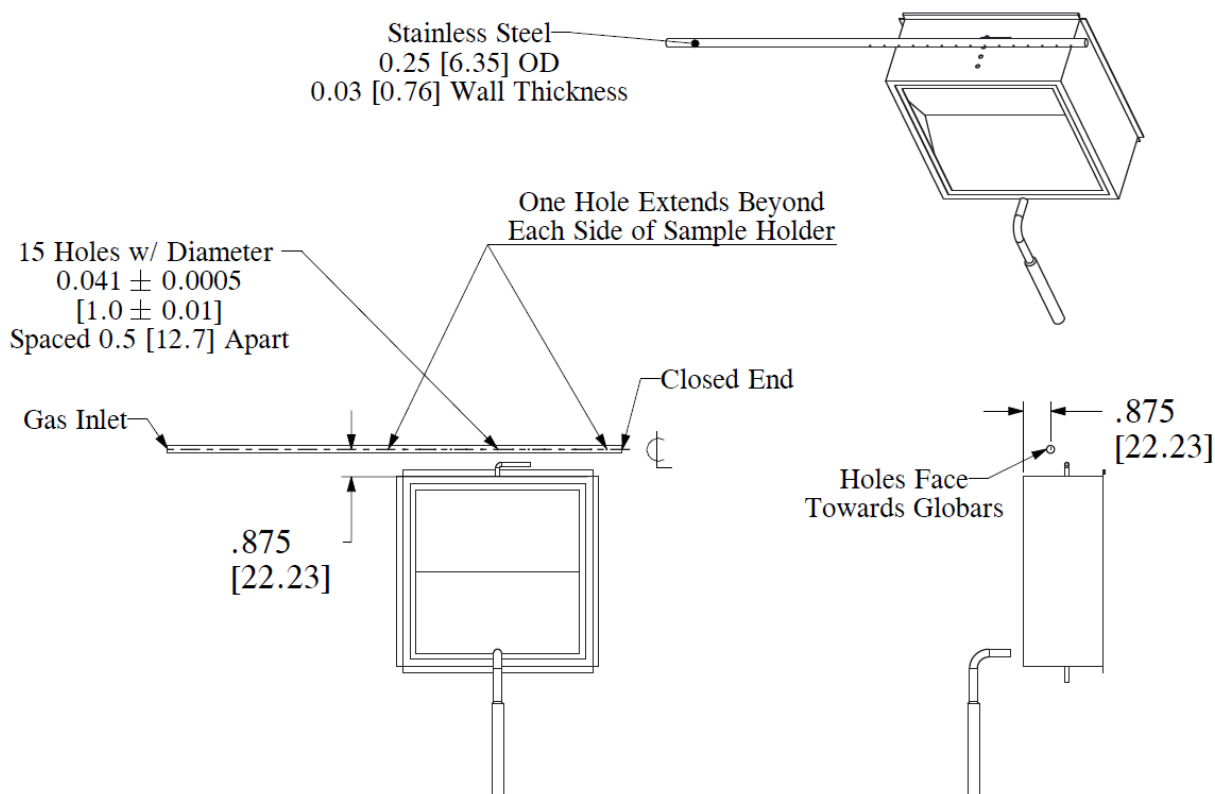


Figure L-21. Dimensioned drawing of the upper pilot burner relative to the sample holder

- Sierra Instruments Model C100L or product of similar specification or function has been found suitable (MFC: upper pilot mixing airflow controller).

Part Number: C100L-NR-2-OV1-SV1-PV2-V1-S1-C3

Typical Accuracy: $\pm 0.2\%$ of F.S. for 2 to 20% F.S.

$\pm 1\%$ of setpoint for 20 to 100% F.S. / 2 second response time

Range: 5000 sccm Air

Fittings: 0.25-inch compression

Seals: Viton

SIERRA INSTRUMENTS, NORTH AMERICA

5 Harris Court, Building L

Monterey, CA 93940 USA

Phone: (831) 373-0200

URL: <http://www.sierrainstruments.com>

NOTE: Calibrate at 0°C and 760 mmHg (Torr) reference conditions.

L.1.1.10.1 Upper Pilot Burner Hot Surface Igniter (HSI)

- Non-Porous High-Alumina Ceramic Rod; McMaster-Carr P/N 87065K42 or product of similar specification or function has been found suitable.
- Marlin Engineering Bracket P/N ME1240-45 or product of similar specification or function has been found suitable.

Marlin Engineering, Inc.
2200 Division Street, Suite A
Bellingham, WA 98226 USA
Phone: (360) 671-0155
Email: sales@marlinengineer.com
URL: <http://www.marlinengineer.com>

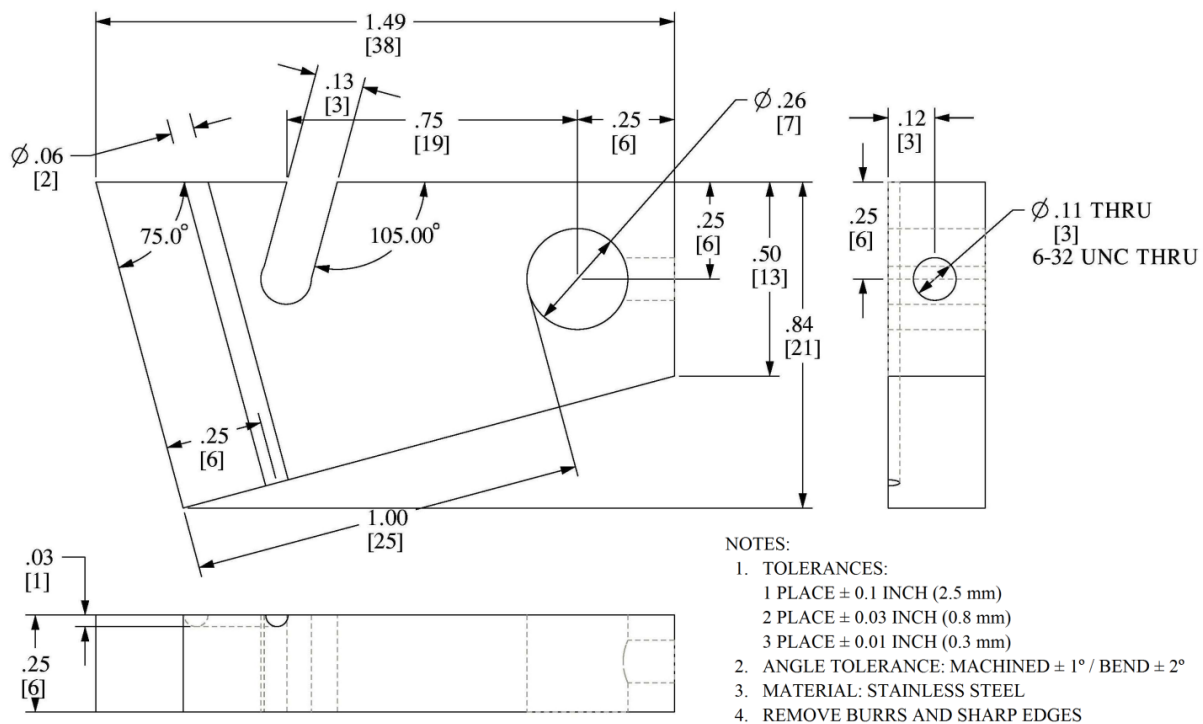


Figure L-22. Upper pilot burner HSI bracket

L.1.1.11 Igniter System

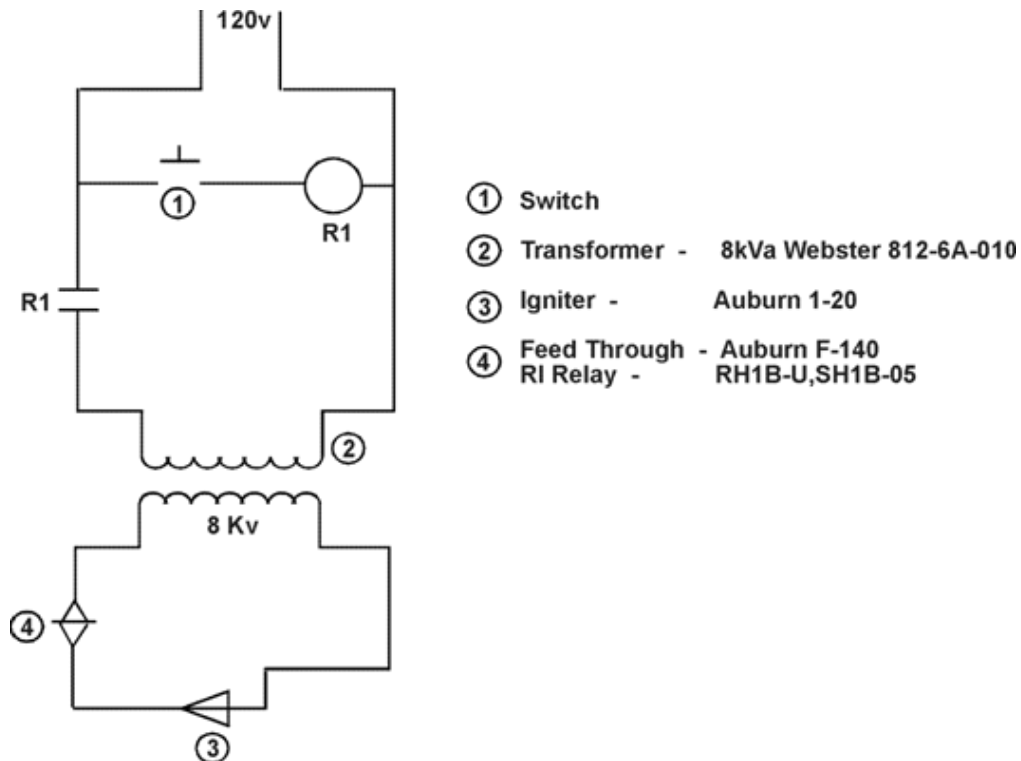


Figure L-23. Igniter schematic

L.1.1.11.1 Air Distribution System

- Alicat Mass Flow Controller: P/N MCR-500SLPM-D/5M or product of similar specification or function has been found suitable.

Body and sensor engineered for 0-500 SLPM full scale range
Range: (20 SCFM) 0 - 650 SLPM (30% custom range added)
Tuned pressure: P₁ (In): 20 PSIG / P₂ (Out): 0.5 PSIG
Reference Temperature and Pressure: 0°C & 1 ATM
Display: LRV-67x51
Standard Accuracy: ± (0.8% of reading + 0.2% of full scale)
3/4" NPT female process connections

Alicat Scientific, Inc.
7641 N Business Park Dr
Tucson, AZ 85743 USA
ph: 1-520-290-6060
orders@alicat.com
alicat.com

Note: It is recommended to have the MFC returned to manufacturer for calibration.

(Update January 2025)

- Sierra Instruments, Inc. Mass Flow Controller: C100H1-NR-16-OV1-SV1-PV2-V1-S1-C3 or product of similar specification or function has been found suitable.

Typical Accuracy: $\pm 2.0\%$ of F.S.

Range: 800 slpm Air

Fittings: 0.75-inch female NPT

Seals: Viton

SIERRA INSTRUMENTS, NORTH AMERICA

5 Harris Court, Building L

Monterey, CA 93940 USA

Phone: (831) 373-0200

URL: <http://www.sierrainstruments.com>

Note: It is recommended to have the MFC returned to manufacturer for calibration.

- AB Type Heat Exchanger
Thermal Transfer Products
www.thermaltransfer.com
P/N AB-405-85099

L.1.1.11.2 Air Distribution Plate

- Piping: PVC, 1.5-inch (38.1 mm) diameter, Schedule 80 pipe or product of similar specification or function has been found suitable.
- Locking hardware recommendation in lower plenum area: It is recommended using locking hardware in the lower main body flange, air distribution plate & lower plenum flange hardware torqued to the proper specification (recommended by the manufacturer).

NOTE: The hole diameters mentioned in this plate (8) are extremely critical. Incorrect sizing may cause high or low backpressure in the main air supply (lower plenum pressure) resulting in increased or decreased air velocities through each orifice. This may impact peak heat release rate (PHRR), time to PHRR and Total HR of materials during testing. Precision manufacturing is highly recommended.

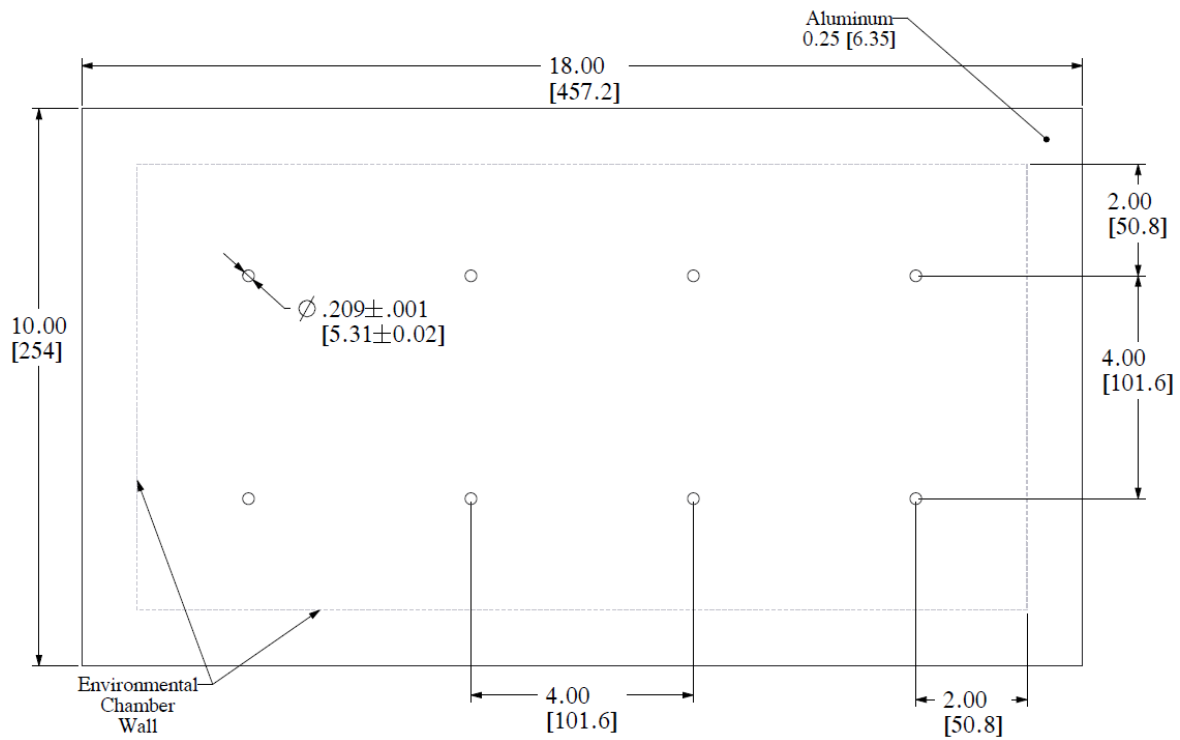


Figure L-24. Dimensioned drawing of the air distribution plate

L.1.1.11.3 Second Stage Plate

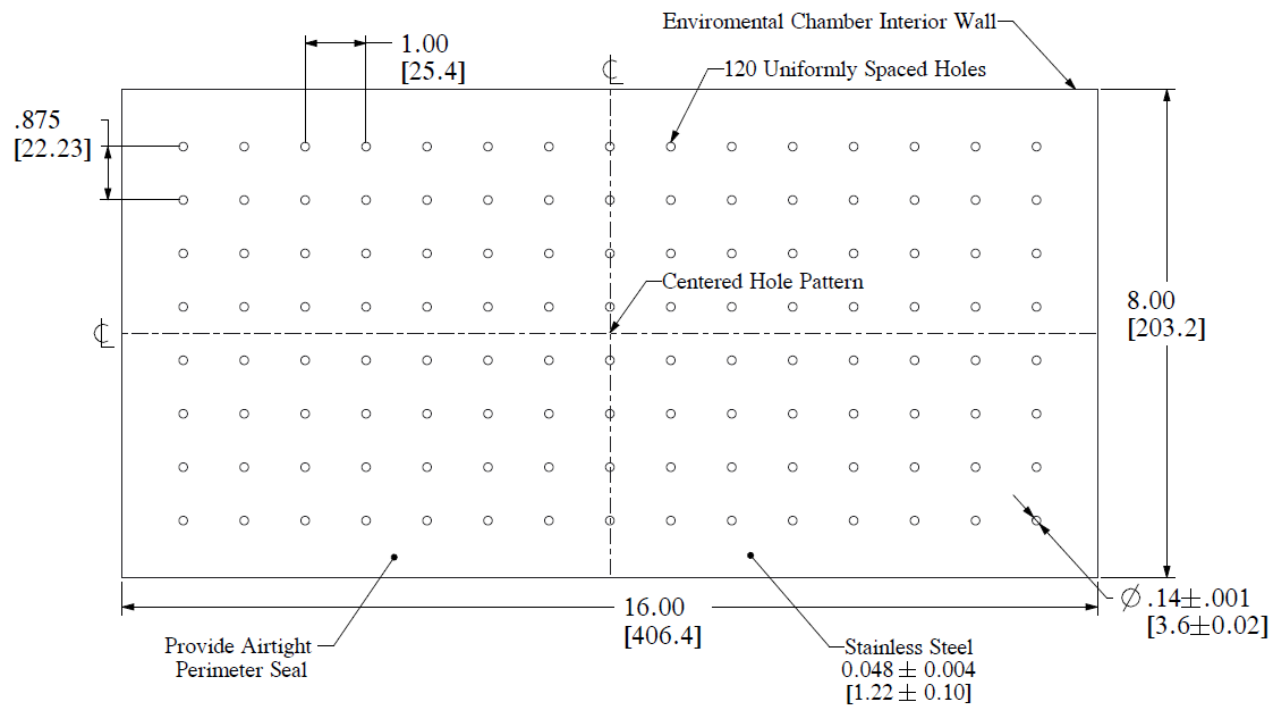


Figure L-25. Dimensioned drawing of the second stage plate

L.1.1.12 Specimen Holder

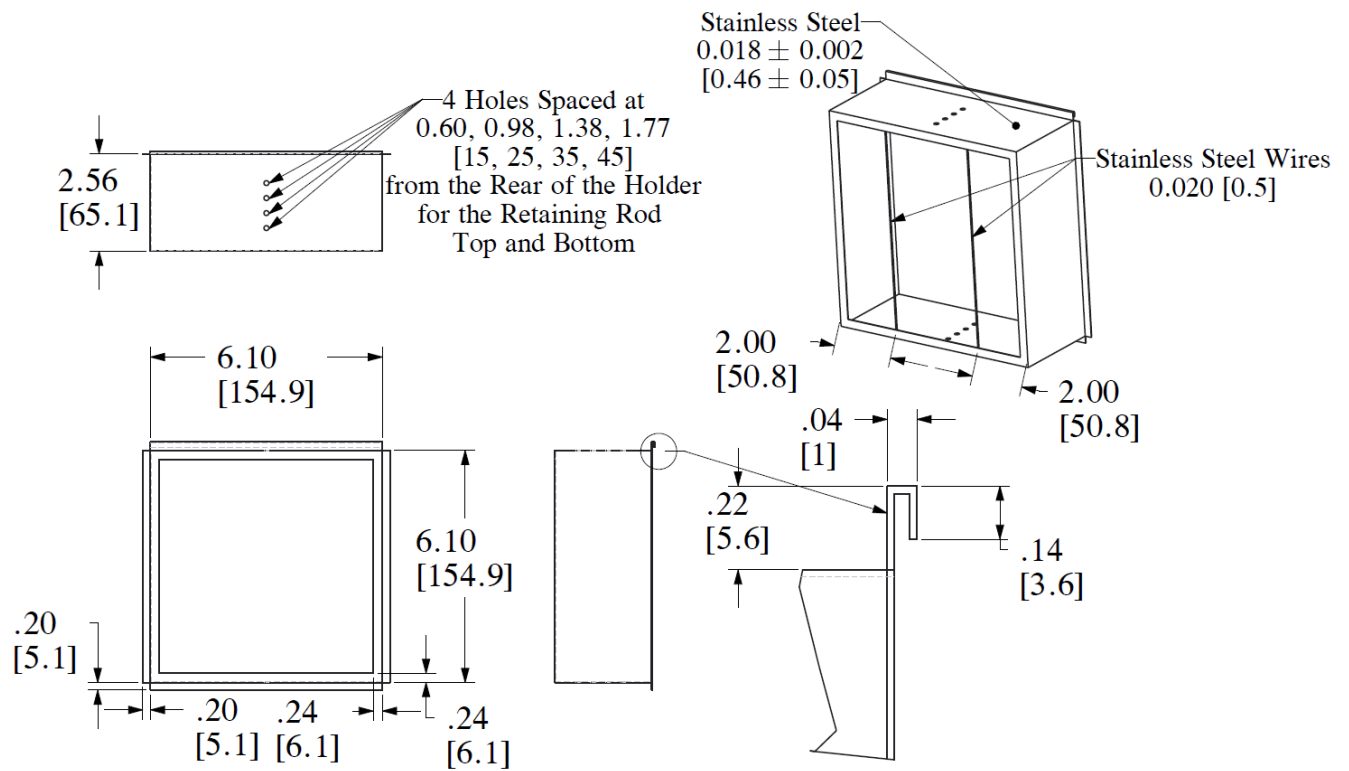


Figure L-26. Dimensioned drawing of the specimen holder

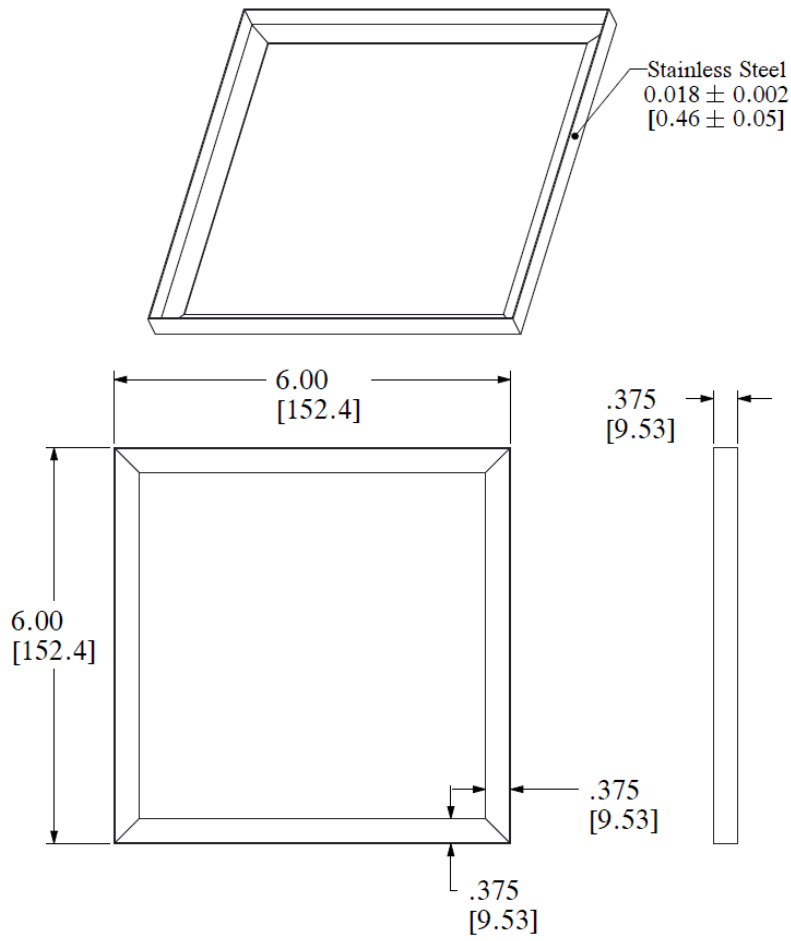


Figure L-27. Dimensioned drawing of the retainer frame

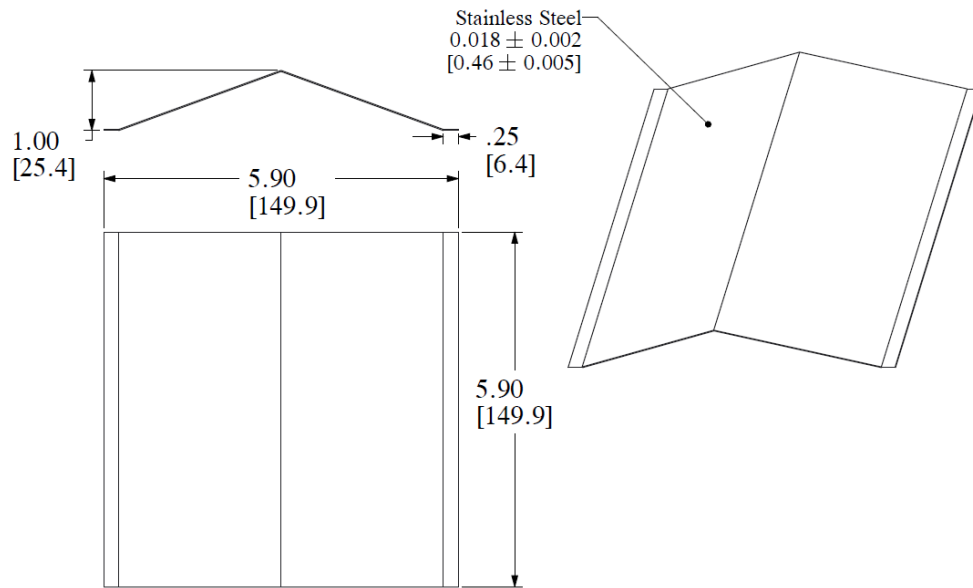


Figure L-28. Dimensioned drawing of the spring

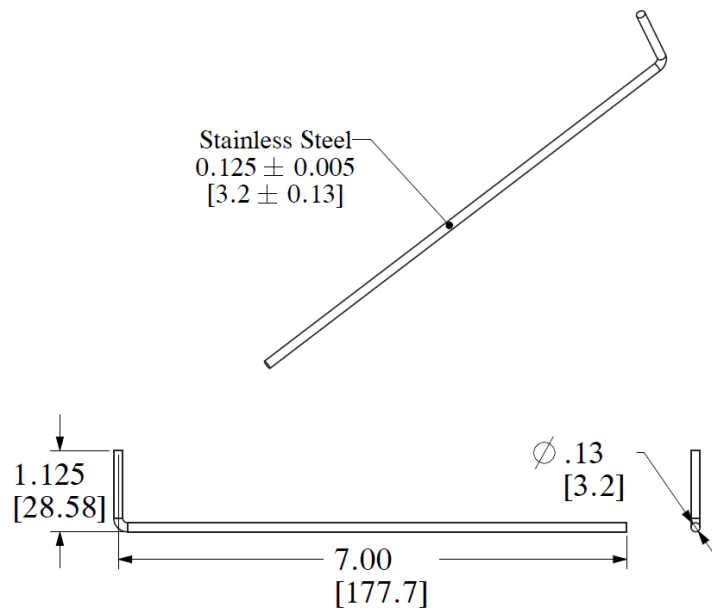


Figure L-29. Dimensioned drawing of the retaining rod

L.1.1.12.1 Drip Pan

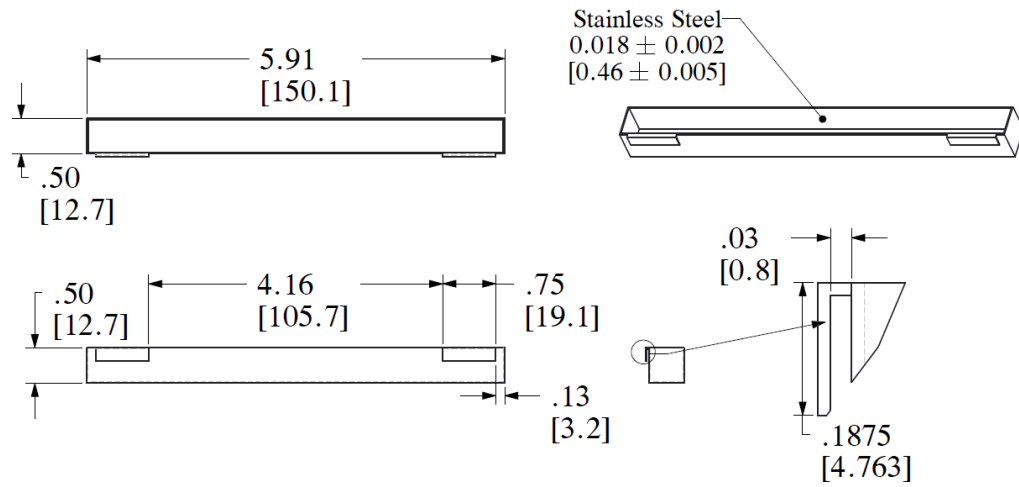


Figure L-30. Dimensioned drawing of the drip pan

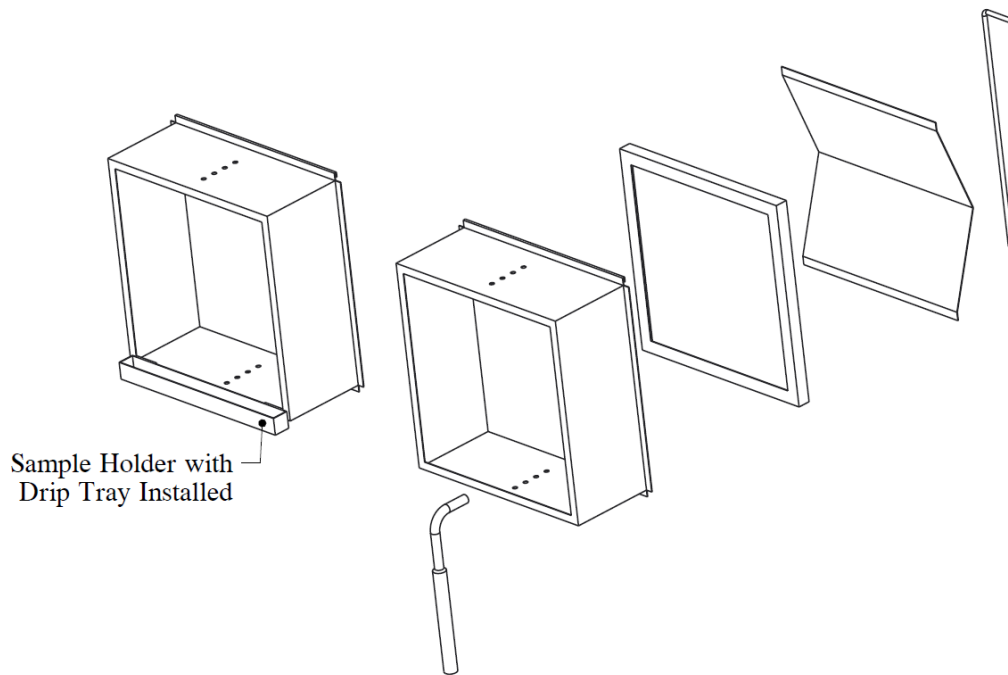


Figure L-31. Exploded view of the sample holder assembly, with and without the drip tray installed

L.1.1.12.2 Holding Chamber/Injection Mechanism

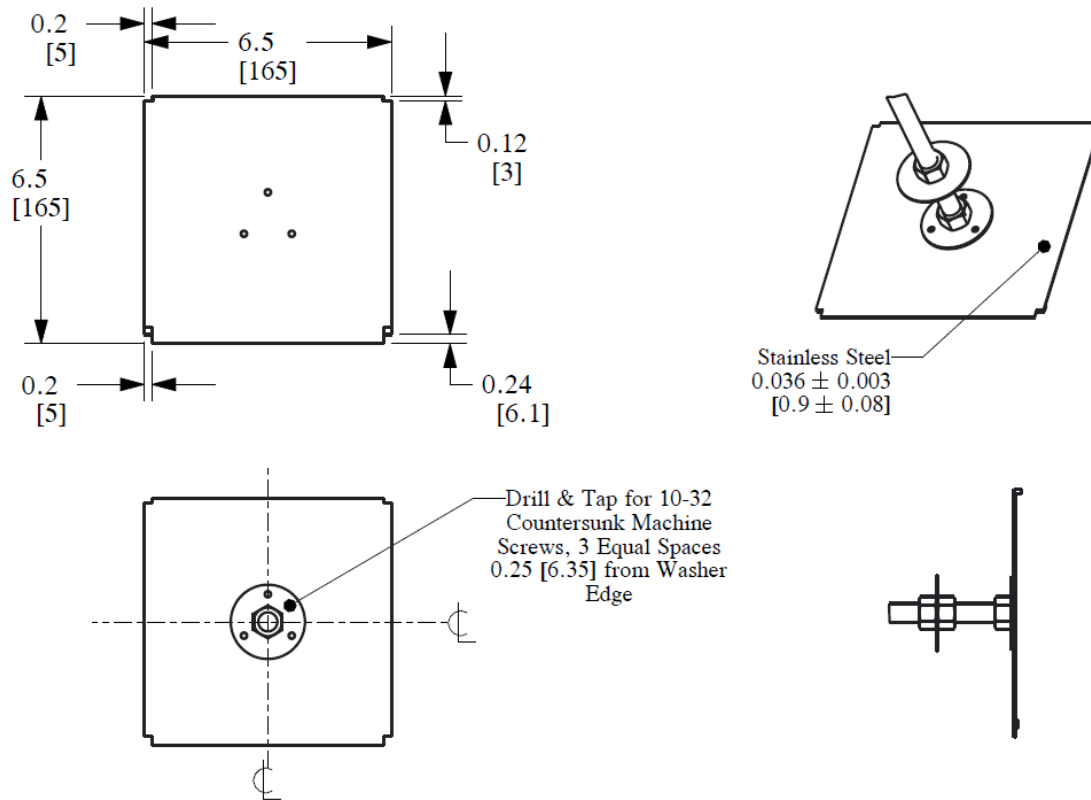


Figure L-32. Dimensioned drawing of the sample holder plate

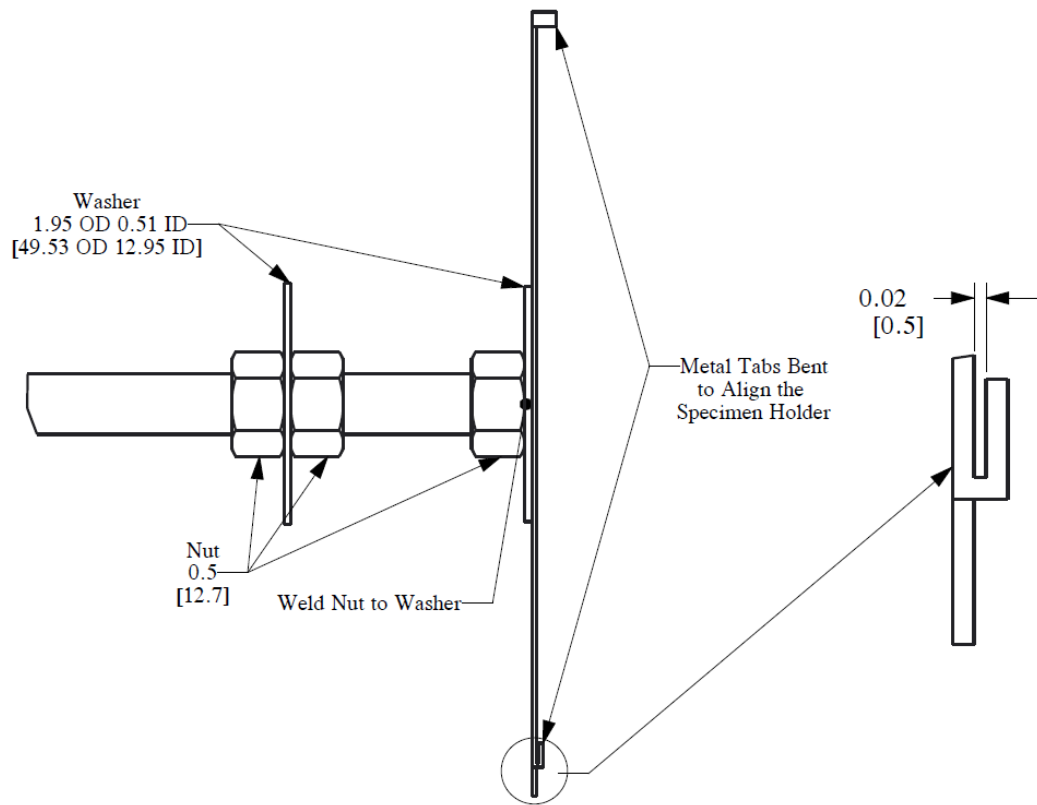


Figure L-33. Detailed view of the sample holder plate

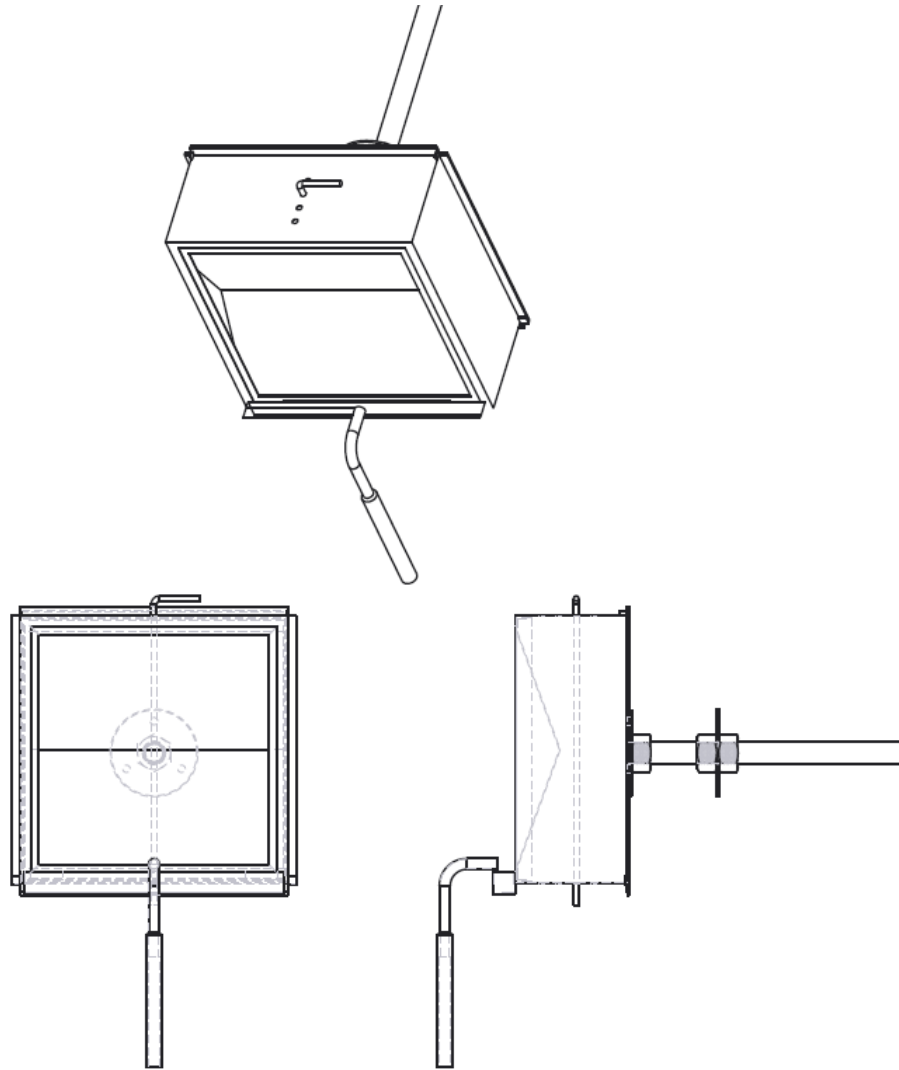


Figure L-34. Views of the sample holder, injection mechanism, and lower pilot burner

L.1.1.1.13 Heat Flux Gauge

- Marinite I Board 0.5-inch (12.7 mm) thickness or product of similar specification or function has been found suitable.

BNZ Materials, Inc.
400 Iron Horse Park
North Billerica, MA 01862
Phone: (800) 888-0061 / Fax: (978) 663 – 2735
URL: <http://www.bnzmaterals.com/contact-us/>

MEDTHERM CORPORATION

- Schmidt-Boelter Heat Flux Gauge (water-cooled)
P/N 64-5SB-20 (smooth body with flange)
P/N 64-5SB-18 (smooth body no flange)
- Gardon Heat Flux Gauge (water-cooled)
P/N 64-5GG-20 (smooth body with flange)
P/N 64-5GG-18 (smooth body no flange)

Medtherm Corporation
P.O. Box 412, Huntsville, AL 35804 USA
Phone: (256) 837-2000 / Fax: (256) 837-2001
Email: MEDTHERM@comcast.net

- VATELL CORPORATION

Gardon Heat Flux Gauge (water-cooled)
P/N TG1000-0 (smooth body with flange)
P/N TG1000-1 (smooth body no flange)
P/N TG1000-0S (center: straight cooling water tubes)
P/N TG1000-1B (corner: bent cooling water tubes)

Vatell Corporation
P.O. Box 66, Christiansburg, VA 24068 USA
Phone: (540) 961-3576 / Fax: (256) 837-2001
Email: mkt@vatell.com

Vatell Corporation
240 Jennelle Road, Christiansburg, VA 24073 USA
Phone: (540) 961-3576 / Fax: (256) 837-2001
Email: mkt@vatell.com

L.1.1.1.14 Calibration Gas Mass Flow Controller (MFC: Methane)

- Sierra Instruments Model C100L or product of similar specification or function has been found suitable.

Part Number: C100L-NR-2-OV1-SV1-PV2-V1-S1-C3
Typical Accuracy: $\pm 0.2\%$ of F.S. for 2 to 20% F.S.
 $\pm 1\%$ of setpoint for 20 to 100% F.S. / 2 second response time
Range: 5000 sccm CH₄
Fittings: 0.25-inch compression
Seals: Viton

Sierra Instruments
5 Harris Court, Building L

(Update January 2025)

Monterey, CA 93940
Phone: (831) 373-0200
www.sierrainstruments.com

Note: Calibrate at 0°C and 760 mmHg (Torr) reference conditions. Calibrate points 1.5 SLPM and 3.0 SLPM when possible. It is recommended to have the MFC returned to manufacturer for calibration.

- Marinite I Board 0.5-inch (12.7 mm) thickness or product of similar specification or function has been found suitable.

BNZ Materials, Inc.
400 Iron Horse Park
North Billerica, MA 01862
Phone: (800) 888-0061 / Fax: (978) 663-2735
URL: <http://www.bnzmaterials.com/contact-us/>

L.1.1.1.15 Efficiency Estimation of Globar Heating and Unit Insulation.

This data is acquired when the system is at the proper heat flux level, stable, with no flame present. This efficiency value can be monitored over time for system stability purposes.

T_{out} = Average exhaust gas temperature = (Enter value) °C

ρ = Air density at STP = 1.2 kg/m³

C_p = Specific heat of air = 1006 J/kg °C

$\dot{V}$ = Volumetric airflow rate = 0.00944 m³/s (20 SCFM)

$\dot{Q}$ = Sensible heat = Globar total power = (Enter value) W

Fraction of effective heat lost to calorimeter (HR2) body = χ_L %

$$\chi_L = \frac{T_{out} \times \rho \times C_p \times \dot{V}}{\dot{Q}} = \frac{(\text{Enter } T_{out} \text{ value}) ^\circ\text{C} \times 1.2 \frac{\text{kg}}{\text{m}^3} \times 1006 \frac{\text{J}}{\text{kg} ^\circ\text{C}} \times 0.00944 \frac{\text{m}^3}{\text{s}}}{(\text{Enter } \dot{Q} \text{ value}) W}$$

L.1.2 SPECIMEN PREPARATION

- Reynolds Wrap® Heavy Duty Aluminum Foil (23.62 microns or 0.001-inch thickness) or product of similar specification or function has been found suitable.

L.1.3 HEAT RELEASE RATE

Example—For any point in time during test:

$$(\text{Thermopile}_{\text{C}} - \text{Baseline}_{\text{C}}) \times \left(\frac{K_H \div 1000}{0.02323 \text{ m}^2} \right) \text{ kW/m}^2$$

(Update January 2025)

If:

Baseline_{°C} = 280.0 [Average thermopile temperature reading at baseline (°C)]
Thermopile_{°C} = 368.0 [Thermopile temperature reading at any point during test (°C)]
K_H = 20.0 [Applied calibration factor (W/°C)]
Sample Area = 0.02323 [Total calculated area of test specimen (m²)]

Then:

$$\begin{aligned}\text{Heat Release Rate} &= (368.0 - 280.0) \times \left(\frac{20.0 \div 1000}{0.02323} \right) \text{ kW/m}^2 \\ &= (88.0) \times (0.86) \text{ kW/m}^2 \\ &= 75.8 \text{ kW/m}^2\end{aligned}$$

L.1.4 TOTAL HEAT RELEASE

Example – For a data collection frequency of 1 Hz or 1 scan per second:

$$\frac{\sum_{t=0}^{n-1} (\text{Thermopile } ^\circ\text{C} - \text{Baseline } ^\circ\text{C}) \times \left(\frac{K_H \div 1000}{0.02323 \text{ m}^2} \right)}{x} \text{ kW} \cdot \text{min/m}^2$$

If:

n = 120 [Total number of data collection points in 2 minutes]
t = 0 [Data point collected at 0 seconds]
x = 60 [Total number of data collection points in 1 minute]
Baseline_{°C} = 280 [Average thermopile temperature reading at baseline (°C)]
Thermopile_{°C} = 368.0 [Thermopile temperature reading at any point during test (°C)]
K_H = 20.0 [Applied calibration factor (W/°C)]
Sample Area = 0.02323 [Total calculated area of test specimen (m²)]

Scan #	Heat Release Rate / 60
T = 0	1.26
T = 1	1.26
.	1.26
.	1.26
.	1.26
T = 119	1.26
TOTAL	151.5

Then:

$$\text{Total Heat Release (After 2 minutes)} = 151.5 \text{ kW} \cdot \text{min/m}^2$$

L.2. REQUIREMENTS

Table L-3. Example

Total Samples Tested	Must Pass	%
3	3	100%
4	4	100%
5	4	80%
6	5	83%
7	6	86%
8	7	88%
9	8	89%
10	8	80%
Continued...	Continued...	Continued...

L.3 MISCELLANEOUS

- Test Specimens (System checks) - P/N S2221 6-by-6-by-1/8th-inch core panel or product of similar specification or function has been found suitable.

Schneller, LLC.
6019 Powdermill Rd.
Kent, OH 44240
USA
Phone: 330-676-7127
Fax: 330-673-6374
URL: <http://www.schneller.com>

- Hole size Go/No-Go drill guide

Table L-4.

Component	Drill Size		Tolerance (Inches)
	Go Drill	No-Go Drill	
Upper Pilot Burner (15 holes)	# 59	# 58	0.041 ± 0.0005
Second Stage Plate (120 holes)	# 28	# 27	0.140 ± 0.001
Air Distribution Plate (8 holes)	# 4	# 3	0.209 ± 0.001

L.4 HR2 SMOKE MONITORING SYSTEM

A prototype system, developed for monitoring smoke emissions during heat release rate testing, employed optical equipment found below. Products of similar specification or function have been found suitable.

Edmund Optics: Laser Product List
(2" wide, flat beam, laser configuration)

Point of Contact:

Richard Joyce: Product Support Engineer

Edmund Optics® Headquarters

RJoyce@edmundoptics.com

Item #1

Coherent® StingRay™ Line Generator 1231508 | 660nm, 35mW, 30° Fan Angle

<https://www.edmundoptics.com/p/660nm-35mw-30deg-fan-angle-stingray-line-generator/29287/>

Stock # 86-866

2023 Cost: \$680

Item #2

5V Universal Power Supply

<https://www.edmundoptics.com/p/5v-universal-power-supply-59099/15847/>

Stock # 59-099

2023 Cost: \$66.50

Item #3

50.0mm Dia. x 200.0mm FL, MgF2 Coated, Plano-Convex Lens

<https://www.edmundoptics.com/p/500mm-dia-x-2000mm-fl-mgfsb2sub-coated-plano-convex-lens/5642/>

Stock # 45-152

2023 Cost: \$52.50

Item #4

50.8mm Optic Dia. Thin Mirror Mount, 8-32

<https://www.edmundoptics.com/p/508mm-optic-dia-thin-mirror-mount-832/47066/>

Stock # 17-713

2023 Cost: \$28

Item #5

Coherent® StingRay™ 1222896 | Laser Diode Module Mount

<https://www.edmundoptics.com/p/mounting-bracket-for-stingray-laser-diode-modules/29305/>

Stock # 86-879

2023 Cost: \$130

Item #6

(Update January 2025)

Silicon Based Touchscreen Portable Laser Power Meter (preferred)
<https://www.edmundoptics.com/p/silicon-based-touchscreen-portable-laser-power-meter/3878/>
Stock # 34-514
Model: Touch LPM 800mW
Data Transfer Download: ProntoDataTransfer found at <https://gentec-eo.com/downloads>
2023 Cost: \$1660

OR

Item #6a [ALTERNATIVE, LOW-COST SILICON DETECTOR]
Normal Response, 0.20mm², Silicon Detector
<https://www.edmundoptics.com/p/normal-response-020mmsup2sup-silicon-detector/14340/>
Stock # 57-506
2023 Cost: \$35

OR

Item #6b [ALTERNATIVE THERMOPILE BASED POWER METER]

Thermopile Based Touchscreen Portable Laser Power Meter
<https://www.edmundoptics.com/p/thermopile-based-touchscreen-portable-laser-power-meter/3880/>
Stock # 34-515
2023 Cost: \$1220

Item #7
660nm CWL, 25mm Dia., Hard Coated, 4.0 OD, 10nm Bandpass Filter
Stock # 86-089
<https://www.meetoptics.com/filters/dielectric/bandpass-filter/s/edmund-optics/p/86-089>
2023 Cost: \$240

Item #8
12.5/12.7mm Optic Dia., SM05 Thin Mount, 8-32
<https://www.edmundoptics.com/p/1-dia-thin-mirror-mount-833/42144/>
Stock # 13-591
2023 Cost: \$19

Item #9
Calibrated Neutral Density Filters
SCHOTT NG11 633nm 50mm Sq., 0.3 OD ND Filter
<https://www.edmundoptics.com/p/schott-ng11-633nm-50mm-sq-03-od-nd-filter/48954/>
Stock No. #21-371
Specific Optical Density = 39.6 Ds
% Light Transmission = 50.12%
2023 Cost: \$165

(Update January 2025)

SCHOTT NG11 633nm 50mm Sq., 0.5 OD ND Filter
<https://www.edmundoptics.com/p/schott-ng5-633nm-50mm-sq-05-od-nd-filter/48955/>
Stock No. #21-372
Specific Optical Density = 66.0 Ds
% Light Transmission = 31.62%
2023 Cost: \$165

SCHOTT NG11 633nm 50mm Sq., 1.0 OD ND Filter
<https://www.edmundoptics.com/p/schott-ng4-633nm-50mm-sq-10-od-nd-filter/48956/>
Stock No. #21-373
Specific Optical Density = 132.0 Ds
% Light Transmission = 10.00%
2023 Cost: \$165

Item #10 (If desire to focus beam to a custom aperture)
Gentec-EO SM1 threaded adaptor for PRONTO-Si
Part No. # 203502
<https://www.gentec-eo.com/products/threaded-adaptor-for-pronto-si>
2023 Cost: \$150

SM1 End cap with drill point
<https://www.thorlabs.com/drawings/d4a9309bdc676566-D070D664-A3A4-5805-7B620FF9154F0C5A/SM1CP2M-AutoCADPDF.PDF>
Part No. # SM1CP2M
Externally SM1-Threaded End Cap for Machining
2023 Cost: \$21

L4.1 Background

Federal Aviation Administration regulations required that for airplanes with capacity exceeding 20 passengers, specific cabin interior components with large surface areas must meet the requirements of a heat release rate fire test and a smoke emission test intended to improve survivability in the event of a post-crash fire. A notice of proposed rulemaking (NPRM) issued in 2019 proposed to remove the requirement for testing of smoke emissions, as FAA research data has demonstrated that heat release rate of cabin materials is the primary impact factor affecting occupant survivability rather than smoke emission (Interior parts and components fire protection for transport category airplanes, 2019). The data do not correlate smoke emission test results with post-crash survivability as they do with heat release test results, and therefore the FAA concluded that the smoke emission test requirement does not add to post-crash fire safety and therefore would be removed from the routine method of compliance. However, in theory there may exist a material with a low heat release rate but high smoke output, so the FAA included provisions in the NPRM to establish general performance standards for interior components which influence occupant survivability during a post-crash fire. Continual monitoring of material smoke output is recommended, either by the existing FAA smoke emission test, or another means of demonstrating that smoke emission does not impact post-crash survivability.

This section describes an alternative smoke monitoring system using a laser/sensor means of measuring cumulative smoke release, analogous to specific optical density D_s as measured in the FAA smoke emission test (refer to report DOT/FAA/TCTN-23/62).

L4.2 Principle of the Method

This system uses a continuous wavelength 660nm, 35mW, 30° fan angle laser and an optical power meter mounted opposite each other on a platform above the HR2 exhaust opening. Between the two devices, two convex lenses allow the light beam to be straightened and to span the entire 2-inch by 4-inch exhaust opening of the HR2. Smoke particles generated by pyrolysis of materials in the test chamber obscure the signal to the power meter therefore effectively reducing the light beams intensity. This reduction in power is applied to an equation which calculates specific optical density (D_s) also referred to as Smoke Release Rate (SRR).

L4.3 Apparatus

L4.3.1 Laser

A 660nm wavelength, 35mW, 30° fan angle laser, otherwise referred to as a line generator, was mounted in a laser module mount. The unit was powered using a regulated 24vdc power supply and power/communication cable.

L4.3.2 Power meter

A silicon based, touchscreen, portable laser power meter was mounted in place using optical support hardware affixed to an elevated support platform. A USB power/communication cable provided signal output to the data acquisition system (DAQ).

L4.3.3 Convex lens (2)

Two coated, plano-convex lenses were mounted opposite each other using optical support hardware mounted to the platform.

L4.3.4 Bandpass filter

A hard coated, 4.0 OD, 10nm Bandpass Filter was mounted between a plano-convex lens and the power meter using optical support hardware mounted to the platform.

L4.3.5 Platform

An extruded aluminum platform was constructed and positioned to provide a mounting surface for accurate elevation (height above exhaust opening) and lateral positioning of the optical equipment. In its design, the platform was rigid however removable to facilitate maintenance if required (see Figure 7 & 8). On the prototype unit, tight fitting

slots were cut into four vertical leg supports which allowed the assembly to clip firmly to the exhaust flange (see Figure 1).



Figure 1: Platform Vertical Leg Support (and slot)

L4.3.6 Enclosure

For laser safety and to alleviate ambient light noise, two aluminum enclosures were fabricated using thin sheet metal (see Figure 2). The enclosures were easily removable, and each provided snug fitting protrusion areas for power/communication cables. The power meter was mounted externally to one enclosure; however, a slot allowed the sensing portion of the meter to be positioned within the enclosure (see Figure 3). Each enclosure had a window mounted inline to provide protection from soot and other contaminants. The window did not interfere with the laser signal and was durable enough for daily cleaning. The windows were removeable in the event they required replacement as a result of damage or scratching. The interior of each enclosure was painted with ultra flat black paint to reduce reflection of the light signal.



Figure 2: Prototype Platform and Enclosures Above HR2 Exhaust



Figure 3: Platform and Power Meter (Protruding from Enclosure)

L4.3.7 Neutral Density Filters

Neutral density (ND) filters were used as a means of validating the smoke measurement system. The filters attenuated the light signal between the light source and the sensor by a fixed and known amount when placed in the light path (see Figure 4). Three filters, 0.3 OD, 0.5 OD, and 1.0 OD, corresponding to percent light transmittance values of 50.3,

31.6, and 10.6, respectively, were used individually and stacked together to provide percent light transmittance values from 100% down to 0% (see Table 1). A fixture was fabricated to locate the filter combinations between the convex lens and the bandpass filter just prior to the power meter.



Figure 4: Calibrated ND Filters

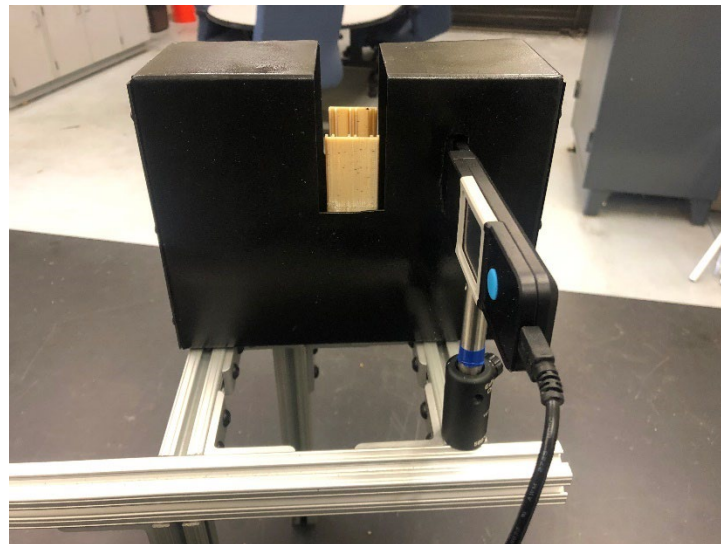


Figure 5: ND Filter Fixture and Power Meter

OD		% LT (%)		SOD (Ds)		% Delta
Target	Calibrated	Measured	Calculated	Measured	Calculated	
0.00	0.000	100.0%	100.0%	0.0	0.0	0.0%

(Update January 2025)

0.30	0.298	48.9%	50.3%	41.0	39.4	4.1%
0.50	0.501	30.9%	31.6%	67.2	66.1	1.7%
0.80	0.799	15.2%	15.9%	107.9	105.5	2.3%
1.00	0.975	11.0%	10.6%	126.6	128.7	-1.6%
1.30	1.273	5.4%	5.3%	167.7	168.1	-0.2%
1.50	1.476	3.4%	3.3%	194.2	194.9	-0.4%
1.80	1.774	1.6%	1.7%	236.4	234.3	0.9%

Table 1: Prototype ND Filter Data Table

L4.3.8 Alignment

The laser beam light signal exits the line generator at a 30° angle. The two convex lenses straighten the light beam which travels horizontally across the HR2 exhaust opening before being refocused to enter the power meter 10mm by 10mm aperture. Adjustments were made to ensure maximum coverage of the sensor. The sketch below (top view) illustrates the recommended lateral dimensions for each component (see Figure 6). The light beam travels through the exhaust stream approximately 1 inch or less above the exhaust opening.

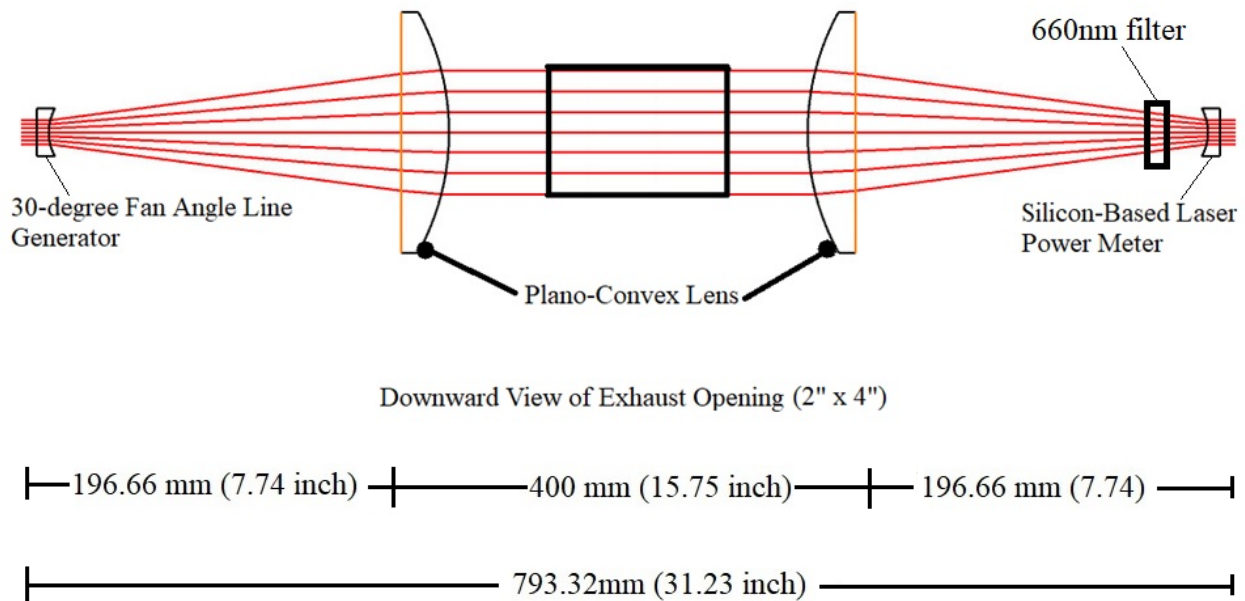


Figure 6: Smoke Monitoring System Layout (Top View)



Figure 7: Platform and Components Shown Without Enclosures (Flat Beam Laser in Red)



Figure 8: Prototype Shown Without Enclosure (Front View)

L4.4 Digital Data Collection

The DAQ system collection rate for the smoke monitoring system is 1 scan per second (1 hertz). The prototype power meter had an auto-range feature; however, the range slightly above the average baseline power reading was selected and auto-range was disabled.

The power meter output is in terms of watts and recorded as:

- Span (Laser off; 0% light transmission) – Wait approximately 30 seconds before ‘zeroing’ the power meter.

- Baseline or 100% clear visibility (Laser on; 100% light transmission) – Wait approximately 30 seconds before recording the 10 second baseline power reading average.

L4.5 Determination of Smoke Release Rate (SRR)

Specific optical density, D_s , is the metric used in the NBS smoke test to assess a material's smoke production. It is a dimensionless measure of the amount of smoke produced per unit area by a material when it is burned. D_s is calculated with knowledge of the percentage of light transmittance (%LT) as shown:

$$D_s = 132 \log_{10} (100/\%LT) \quad (1)$$

As smoke or other media enter the laser light path, the light is reflected, refracted, or absorbed, reducing the amount of light received by the sensor and thus reducing the wattage output. The percent light transmittance is determined as the difference between the sensor baseline, with only clear air between the laser and sensor, and the test measurement, when an obscuration or filter may be present in the light path, reducing the sensor output signal below the baseline.

The cumulative smoke release (CSR) over a specified time interval was calculated by determining the area under the curve of the SRR plotted against time. This metric is analogous to the D_s calculated in the NBS smoke test, which considers the accumulation of smoke over time inside the smoke chamber.

L4.6 Preparation for Testing

Both the laser and power meter are turned on and permitted to stabilize for 30 minutes to facilitate thermal stabilization. Windows on each enclosure are cleaned using distilled water.

L4.7 Test Procedure

Sequencing of the heat release rate test and the smoke monitoring must be aligned. It is important to know when the sample is inserted into the hot zone of the chamber to initiate the start time of the smoke monitoring software. The smoke monitoring system is calibrated immediately prior to the sample being inserted into the holding chamber for heat release rate testing using the following procedure:

L4.6.1

Power to the laser is turned off.

L4.6.2

After 30 seconds, the power meter is sent a “zero” command via USB communication.

L4.6.3

Once the zero command is completed, power to the laser is restored.

L4.6.4

After 30 seconds or once the power meter measurement is stabilized, a 10 second power reading is collected to establish a baseline value for 100% light transmission.

L4.6.5

The test is initiated and the power value in Watts is collected from the power meter once per second for the test duration of the 5-minute test (300 samples) during which:

- % Light Transmission is calculated as $(\text{Observed Watts} / \text{Baseline Watts}) * 100$
- Optical Density is calculated as $\text{Log}_{10} (100 / \% \text{ Light Transmission})$
- Specific Optical Density (Ds) is calculated as $\text{Optical Density} * 132$

L4.6.1

Once the test is completed, CSR is calculated by totaling each Ds value collected during the 5-minute test and dividing by 60.

L4.8 Preparation of Further Test Runs

Soot cleaning of the enclosure windows was accomplished using a lint free cloth with distilled water prior to subsequent testing.

L4.9 Presentation of Results

L4.9.1 Peak Smoke Release Rate (PSRR)

The maximum observed Ds is determined for the duration of the 5-minute test and reported as Peak Smoke Release Rate (Ds/m^2).

L4.9.2 Total Smoke Release (CSR)

The CSR is determined for the duration of the 5-minute test and reported as Cumulative Smoke Release ($\text{Ds} * \text{min}/\text{m}^2$).