UNITED STATES DEPARTMENT OF COMMERCE
National Institute of Standards and Technology
Gaithersburg, Maryland 20899

November 14, 1989

MEMORANDUM FOR Laboratories within ISO using Cone Calorimeters (No. 1a)

From: Vytenis Babrauskas
Marc Janssens

Subject: Computation of time-averaged data

During the course of the ISO round robin, specific instructions to those participating laboratories were issued on how time-averaged data should be computed (M. Janssens letter of June 19, 1989). As a result of concerns raised in ASTM about recording correct data for specimens which may never 'ignite,' but which show positive heat release, a slightly modified calculation has been developed. Please adopt the instructions below for future work.

- Remove any spurious spikes or dips from the data prior to performing any further operations. Some data collection systems are more prone than others to collect occasional implausible scans. These may be unexpected zero-readings, values greater than physically possible from the instrument, etc. This procedure may be done by an automated purging routine in the software; visual inspection of results should confirm spurious glitches are not being included.

- All calculations of average heat release values are to start at the first scan following ignition. (Ignition has been defined as sustained flaming for at least 10 s; the time of ignition is the time when this sustained flaming period **begins**, not when the 10 s flame verification interval has elapsed). Use the trapezoidal rule to calculate integrated values. For example, if the scan interval is 5 s, the 180 s mean heat release rate is obtained as:
    1. Sum up the rate of heat release at the 2nd through the 36th scan after ignition. Note that if the test is completed before the 180 s period is elapsed, all of remaining points are to be set = 0, but the number of scans being averaged is **unchanged.**
    2. Add half of the rate of heat release measured at the first scan and at the 37th scan after ignition.
    3. Multiply the sum obtained in Step 2 by the scan interval (5 s) and divide it by 180.

- The total heat released is computed also by using the trapezoidal rule to calculate integrated values. In this case the first scan to be used is the one after the last negative rate of heat release reading occurring at the beginning of the test. (There will be negative readings, in general, since before the specimen starts burning the output is $0 \pm$ noise). The last scan to be used is the last reading recorded for the test.

- The total mass lost is determined by subtracting the final mass from the initial mass. The final mass is the last mass reading recorded for the test. To determine the initial mass can be difficult, since it takes some finite amount of time for the load cell to settle down, once the specimen is placed upon it. The following procedure should be used to determine the initial mass.
    1. Make sure that the damping of the load cell is correctly adjusted, as described in the User's Guide.
    2. Find the maximum value of mass indicated over the period of 1st scan to 5th scan. (The first scan is the one immediately after the specimen has been inserted and the data system started). Record this maximum value as the initial mass. Set all scans prior to this scan to be equal to that same value.

UNITED STATES DEPARTMENT OF COMMERCE
National Institute of Standards and Technology
Gaithersburg, Maryland 20899

November 14, 1989

MEMORANDUM FOR Laboratories using Cone Calorimeters (No. 1b)

From: Vytenis Babrauskas
Marc Janssens

Subject: Computation of time-averaged data

During the course of the ISO round robin, specific instructions to those participating laboratories were issued on how time-averaged data should be computed. This straightened out some problems the laboratories in the ISO work had experienced with consistency of data. The same information needs to be transmitted to U.S. laboratories and to others not participating in the ISO work. The instructions are as follows:

- Remove any spurious spikes or dips from the data prior to performing any further operations. Some data collection systems are more prone than others to collect occasional implausible scans. These may be unexpected zero-readings, values greater than physically possible from the instrument, etc. This procedure may be done by an automated purging routine in the software; visual inspection of results should confirm spurious glitches are not being included.

- All calculations of average heat release values are to start at the first scan following ignition. (Ignition has been defined as sustained flaming for at least 10 s; the time of ignition is the time when this sustained flaming period **begins**, not when the 10 s flame verification interval has elapsed). Use the trapezoidal rule to calculate integrated values. For example, if the scan interval is 5 s, the 180 s mean heat release rate is obtained as:
    1. Sum up the rate of heat release at the 2^{nd} through the 36^{th} scan after ignition. Note that if the test is completed before the 180 s period is elapsed, all of the remaining points are to be set = 0, but the number of scans being averaged is **unchanged.**
    2. Add half of the rate of heat release measured at the first scan and at the 37^{th} scan after ignition.
    3. Multiply the sum obtained in Step 2 by the scan interval (5 s) and divide it by 180.

- The total heat released is computed also by using the trapezoidal rule to calculate integrated values. In this case the first scan to be used is the one after the last negative rate of heat release reading occurring at the beginning of the test. (There will be negative readings, in general, since before the specimen starts burning the output is 0 ± noise). The last scan to be used is the last reading recorded for the test.

- The total mass lost is determined by subtracting the final mass from the initial mass. The final mass is the last mass reading recorded for the test. To determine the initial mass can be difficult, since it takes some finite amount of time for the load cell to settle down, once the specimen is placed upon it. The following procedure should be used to determine the initial mass.
  1. Make sure that the damping of the load cell is correctly adjusted, as described in the User's Guide.
  2. Find the maximum value of mass indicated over the period of 1st scan to 5th scan. (The first scan is the one immediately after the specimen has been inserted and the data system started). Record this maximum value as the initial mass. Set all scans prior to this scan to be equal to that same value.

UNITED STATES DEPARTMENT OF COMMERCE
National Institute of Standards and Technology
Gaithersburg, Maryland 20899

20 September 1990

MEMORANDUM FOR Laboratories using Cone Calorimeters (No. 2)

From: Vytenis Babrauskas
Head, Fire Toxicity Measurement

Subject: Correct position for spark plug in vertical orientation

The vertical specimen orientation is normally used only for special research investigations and not for standard product testing. Nonetheless, laboratories that do conduct vertical orientation tests must be able to do them correctly. An incorrectly positioned spark plug will result in overly long or irreproducible times to ignition. I have recently noticed that spark plugs are not correctly situated for vertical orientation testing at several laboratories I have visited. Thus, to make certain that all users know the correct operation and the correct procedures, I will summarize the requirements. (The instructions below are *only* for vertical orientation testing; I have not observed any laboratories to have problems in spark plug arrangements for horizontal orientation testing.)

The position in the vertical plane

The spark gap must be located 5 mm above the top of the vertical specimen holder. Please note that the spark plug electrodes must be of such design that they do not touch or hit the specimen holder when the gap is situated in the correct location. Also make sure that there is no spurious high voltage discharge between the electrodes and the metalwork when the gap is at the correct height. It may be impossible for users to try to adapt off-the-shelf single-electrode plugs successfully to meet this requirement. A coaxial plug which is known to work successfully in this application is described in the Construction Drawings.

The position in the horizontal plane

In the horizontal plane, the standard specifies that the gap must be in the plane of the specimen face. The purpose of this requirement is to make sure that the gap is located at the point in the plume where the highest concentration of pyrolysis gases exists. It may also be all right to arrange the spark plug so the gap is closer to the front face of the specimen holder than to the plane of the specimen (which is 1.6 mm inside the holder). In any case, the correct location must be verified by actually examining the location of the spark gap with respect to the pyrolysis gas plume – the spark gap must be close to the center of this plume. If it is not, please correct it.

UNITED STATES DEPARTMENT OF COMMERCE
National Institute of Standards and Technology
Gaithersburg, Maryland 20899
Bldg. 224 Room A363
Phone: (301) 975-6681
Fax: (301) 975-4052

9 September 1990

MEMORANDUM FOR Laboratories using Cone Calorimeters (No. 3)

From: Vytenis Babrauskas
Head, Fire Toxicity Measurement

Subject: How to use smoke variables to describe product performance

During the recent Cone Calorimeter workshop in Canterbury it became evident that manufacturers are seeking a viable means of providing a product 'quality index' based on smoke measurements in the Cone Calorimeter. There seems to be considerable confusion in this regard, thus, I will try to provide some consistent guidelines. I consider that there are two objectives:

- Provide a simple product description which correctly quantifies the expected goodness of the product's smoke performance.

- Presents information in units which are dimensionally correct and are derived with the proper treatment of smoke optics.

The basic quantity which is measured in the cone is the *yield* of smoke, which is expressed as the *specific extinction area*, σ_f. The units of σ_f are (m^2/kg). This corresponds to m^2 of smoke obscuration area evolved from a unit mass of fuel pyrolyzed.

To simplify our task, we note that, so far, a great deal of predictive meaningfulness has not been attached to the time-variant aspect of σ_f. Thus, while plots of σ_f versus time are available, we mostly use the test average value. (We note that this is *not* the value averaged over test time, but rather the mass-weighted average. This mass-weighted average for the entire test is trivial to compute since it is merely: (total smoke m^2 evolved)/(total specimen mass lost).)

The concern of the product manufacturers is, of course, that σ_f is just the *smokiness* of the smoke from the product; it is *not* the rate at which a hazardous combustion product – smoke – is being produced. Thus, if a manufacturer would just simply report values of σ_f according to which to judge his product, the *rate* at which the product burns would be completely ignored. This obviously will not be the right way to make a 'quality index.'

We can approach things from the other direction. It is paramount that manufacturers give their clients information on heat release rate, $\dot{q}''$ (kW/m^2). This can be reported as a curve of $\dot{q}''$ versus time, or as some average or peak value. Until a specific method for a given product category is available for use, what time-period to use will not be known. It is expected that manufacturers will be reporting, at least, the peak $\dot{q}''$ values and the 180-s average values.

Given that $\dot{q}''$ will always be available and given to the client, there has been a desire by manufacturers to be able to use this, as opposed to some other, measure for the product burning rate.

For smoke hazard evaluation, what is needed is something we will call *smoke production rate*. For convenience, we will abbreviate this as SPR. The units are:

$$\frac{(m^2 \;\; smoke \;\; produced)}{(m^2 \;\; specimen \;\; surface)\;(s)}$$

We note that this is, properly, the *rate* at which smoke is actually being evolved from the given specimen, and, thus, it should be what corresponds to the driving force for hazard. From the designer's point of view, when there is more or less product in the full-scale environment, what varies is the exposed surface area. This differs from the concern of the scientist, who more often needs variables normalized per unit mass. We note that the SPR, as defined above, is scaled according to exposed surface area. Thus, to estimate the smoke production rate in the full-scale fire, we would multiply the SPR by the exposed, burning surface area. The amount of surface area which is burning at any one time is, of course, difficult to determine and must be done in the context of the hazard prediction method being established for a particular product category.

To evaluate SPR using our available $\dot{q}''$ we need to consider the form:

$$\frac{\sigma_f \;\; (m^2/kg)}{\Delta h_c \;\; (kJ/kg)} \times \dot{q}'' \; (kW/m^2) \;\; = \;\; SPR \; (1/s)$$

Thus, it is easy to report the desired SPR if σ_f and Δh_c are available. The test-average σ_f is, as stated, already being tracked. The effective heat of combustion, Δh_c, is also routinely tabulated in everyone's test reports. For purposes of data tabulation, we may note that the units of $\sigma_f/\Delta h_c$ are (m^2/kJ); this combined parameter is, effectively, the 'smoke/heat ratio.'

Thus, in summary, the message becomes simple: (1) report to clients the SPR. (2) Obtain the SPR by means of your already-tabulated $\dot{q}''$, σ_f, and Δh_c values (or using the combined 'smoke/heat ratio' tabulations in place of σ_f and Δh_c separately).

UNITED STATES DEPARTMENT OF COMMERCE
National Institute of Standards and Technology
Gaithersburg, Maryland 20899

9 January 1991

MEMORANDUM FOR U.K. laboratories with Cone Calorimeters (No. 4)

From: Vytenis Babrauskas
Head, Fire Toxicity Measurement

Subject: Smoke meter functioning

A number of UK laboratories will be shortly conducting inter-laboratory trials on the Cone Calorimeter. Since some of them are new to the use of laser smoke measuring systems, we would like to anticipate and prevent any problems prior to occurrence.

The most common faults that occur with the smoke meter are misalignment and deposition of soot on the optics. The latter will almost never be a problem with suitably trained operators, but may cause difficulties for novices. The point to remember is that the smoke meter contains an air purge circuit which functions solely by pressure differential. This means it does not work when the fan is shut off! Thus, the *caveats* here are obvious: (1) Never shut down the fan until all smoke has been thoroughly cleared from the apparatus. (2) Do not use burn anything under the Cone hood unless the fan is running, and, in fact, successfully clearing smoke.

Misalignment of the smoke meter optics can occur from several causes, including careless leaning against or bending of the assembly and also from sustained heating or overheating. This requires significant expertise to re-align once misalignment has taken place, but at least we can outline a simple procedure for all operators, whereby they can determine whether the system is still in good order. The way to do this is to set up a white optical target about 1 to 2 m in front of the endcap of the photometer. Often a room wall will serve nicely. Remove the endcap and let the laser beam shine on the target. Watch to see that there is only one, bright, circular pin-spot, with a second much dimmer one. You must **not** see three or four spots or a general brightness over a wide area. You must, especially, not see any rings around the spot. Now go over to the laser and **gently** move the laser head up and down and to each side. The spot should move slightly when you do this. It should not jump and should not dim or black out. Now, put some translucent plastic over the open end of the beam tube and look at the image formed on this piece of plastic (DO NOT STARE INTO THE BEAM ITSELF). There must not be an aurora or an overall bright glow inside the beam tube. All that is not the main spot or the second spot should be very dim.

If you find that anything is not the way it should be described, based on the description above, the time has come for disassembly and repair. The user should, as a minimum, consult the appropriate sections within the USER'S GUIDE FOR THE CONE CALORIMETER (which all operators should have and should keep readily available). I must point out, however, that repairs to the smoke meter are not among the easiest tasks for an operator. It will be greatly to your advantage if you can review these procedures with a service representative of the manufacturer of your unit. I would urge that all new purchasers do this at the first visit of their service representative, even if there is no malady of the smoke meter. This will allow them to review exactly what the 'normal' conditions are with someone who is knowledgeable.

UNITED STATES DEPARTMENT OF COMMERCE
National Institute of Standards and Technology
Gaithersburg, Maryland 20899

Bldg. 224 Room A345
Phone: (301) 975-6681
Fax: (301) 975-4052

25 September 1991

MEMORANDUM FOR Laboratories using Cone Calorimeters (No. 5)

From: Vytenis Babrauskas

Subject: Correct use of PMMA calibration specimens

The USER'S GUIDE FOR THE CONE CALORIMETER gives detailed instructions on how to prepare black PMMA specimens which are used for checking the proper calibration and operation of the Cone Calorimeter. I have noted that several laboratories have interpreted these instructions not in the way they were meant to be interpreted. The **only** thing different about preparing a black PMMA calibration specimen from the way things are done for normal testing samples is the edge condition. A normal testing sample is wrapped with aluminum foil. The calibration sample is not wrapped in aluminum foil, but, instead, has cardboard sides glued onto it. [The reason for this is that, by means of this special preparation technique, a more steady-burning plateau can be reached. The technique is, conversely, not used for test samples since it would be incompatible with most other types of products.]

It is especially to be emphasized that the specimen holder must contain a layer of refractory fiber blanket on the bottom when burning these calibration samples, just the same as it does for normal specimen testing.

UNITED STATES DEPARTMENT OF COMMERCE
National Institute of Standards and Technology
Gaithersburg, Maryland 20899
Bldg. 224 Room A345
Phone: (301) 975-6681
Fax: (301) 975-4052

25 September 1991

MEMORANDUM FOR Laboratories using Cone Calorimeters (No. 6)

From: Vytenis Babrauskas

Subject: Electric power to the spark plug

Both the ASTM and the ISO standards on the Cone Calorimeter prescribe certain details of how the spark plug is to be used. These instructions are functionally identical. Neither one involves using an intermittent (on-off-on-off-on, ...) spark pattern. Thus, intermittent spark operation **must not be used**.

I believe this problem is restricted only to instruments manufactured by PL and the University of Ghent, but all users should check this to make sure. Spark power is to be applied full time until the specimen has ignited.

UNITED STATES DEPARTMENT OF COMMERCE
National Institute of Standards and Technology
Gaithersburg, Maryland 20899
Bldg. 224 Room A345
Phone: (301) 975-6681
Fax: (301) 975-4052

25 September 1991

MEMORANDUM FOR Laboratories using Cone Calorimeters (No. 7)

From: Vytenis Babrauskas

Subject: Reporting of time-average values for heat release rate

The ASTM standard on the Cone Calorimeter mandates that time-average values of HRR be reported for periods which begin with the time of ignition and end 60, 180, and 300 s later. Similarly, the ISO standard mandates reporting of 180 and 300 s time-average HRR values.

It has come to my attention that reports are being generated by some laboratories where zeros or some indication of 'cannot compute' are being given for these averages instead of reporting true averages. These averages can only be zero if the specimen did not ignite at all. If it ignited and burned, there will be a legitimate 60, 180, 300 s, etc. value even if flame-out occurs at, say 45 s. The reason is that specimen will ever thereafter produce a 0 HRR, regardless if we are recording the data or not.

Both test standards contain analogous instructions on how to determine the end of the test. It is perfectly proper to record that the end of test was at, say, 260 s, but a correct, non-zero value is still computed and reported for $\dot{q}''_{300}$. The 'end of the test' means merely that this is time that, according to the relevant standards, data reporting can be stopped because the specimen has become, effectively, non-burning. Data are then required to be collected for 2 min more. The actual tabulation sheets where data are printed every, typically, 5 s will not contain this extra 2 min period. It is necessary, however, so that proper time shifts can be made, so that proper smoothed derivatives for mass loss could be computed, and other necessary computations. One these computations are made, the reported data sheet is chopped at the 'end of test' time. If the end of test was at, say, 260 s, then the HRR for the remaining time increments will be set =0 so that the 300 s average could be reported. These time-averaged HRR values then become the only reporting entity which 'goes beyond the end of the test.'

Manufacturers should be urged to correct any software that needs correcting, so that proper computations could be done. In the meantime, laboratories needing to report these data can perform a very simple hand calculation. For example, if data collection stopped before 300 s and a $\dot{q}''_{300}$ was not reported, to compute the $\dot{q}''_{300}$ by hand, find the value of total heat released at the test q" (MJ/m^2). Divide this by 300 s. Then multiply the results by 1000 to convert from MW to kW; this gives the desired result in units of kW/m^2.

The lack of significance of flame-out time

This is also a good opportunity to emphasize an important point about the HRR of products. In a well-designed HRR calorimeter quantities such as the time to ignition or the various time-average values of HRR are reproducible. The fine performance of the Cone Calorimeter on the ISO and the ASTM round robins certainly demonstrates that. The time to flame-out, however, is not a variable which is expected to be reproducible. This fact has nothing to do with the Cone Calorimeter, *per se*, but is a general phenomenon of combustion. A number of factors can contribute to this. Small variations in burning rate during the course of the test can prolong or shorten the time. Non-uniformities in specimen manufacture can result in flame-out variations. Most commonly, however, smoldering products or composite products show very substantive differences in flame-out time. This usually shows up as a small, localized flame lodged in one part of the specimen at the end of rapid burning period. Such a flamelet can take a highly variable amount of time to go out.

The lesson from all this is that it is unwise to create any reporting variables or engineering variables which use the flame-out time. There are fire models being developed which require an *effective burning time*, but that must be computed in a different way. Usually, in such a model this effective burning time would be computed by first defining a characteristic HRR (in the Cleary/Quintiere model, for example, 90% of $\dot{q}''_{max}$ is used for this), then obtaining the effective burning time by dividing the total heat released by the characteristic HRR. Such an effective burning time will, invariably, be shorter than the flame-out time.

Detailed instructions on how to compute time-average HRR

The explanations for this were originally sent to the laboratories in November 1989. For convenience, we repeat here these same instructions.

- Remove any spurious spikes or dips from the data prior to performing any further operations. Some data collection systems are more prone than others to collect occasional implausible scans. These may be unexpected zero-readings, values greater than physically possible from the instrument, etc. This procedure may be done by an automated purging routine in the software; visual inspection of results should confirm spurious glitches are not being included.

- All calculations of average heat release values are to start at the first scan following ignition. (Ignition has been defined as sustained flaming for at least 10 s; the time of ignition is the time when this sustained flaming period **begins**, not when the 10 s flame verification interval has elapsed). Use the trapezoidal rule to calculate integrated values. For example, if the scan interval is 5 s, the 180 s mean heat release rate is obtained as:
  1. Sum up the rate of heat release at the 2nd through the 36th scan after ignition. Note that if the test is completed before the 180 s period is elapsed, all of remaining points are to be set = 0, but the number of scans being averaged is **unchanged.**
  2. Add half of the rate of heat release measured at the first scan and at the 37th scan after ignition.
  3. Multiply the sum obtained in Step 2 by the scan interval (5 s) and divide it by 180.

- The total heat released is computed also by using the trapezoidal rule to calculate integrated values. In this case the first scan to be used is the one after the last negative rate of heat release reading occurring at the beginning of the test. (There will be negative readings, in general, since before the specimen starts burning the output is 0 ± noise). The last scan to be used is the last reading recorded for the test.

- The total mass lost is determined by subtracting the final mass from the initial mass. The final mass is the last mass reading recorded for the test. To determine the initial mass can be difficult, since it takes some finite amount of time for the load cell to settle down, once the specimen is placed upon it. The following procedure should be used to determine the initial mass.
  1. Make sure that the damping of the load cell is correctly adjusted, as described in the User's Guide.
  2. Find the maximum value of mass indicated over the period of 1st scan to 5th scan. (The first scan is the one immediately after the specimen has been inserted and the data system started). Record this maximum value as the initial mass. Set all scans prior to this scan to be equal to that same value.

UNITED STATES DEPARTMENT OF COMMERCE
National Institute of Standards and Technology
Gaithersburg, Maryland 20899

Bldg. 224 Room A345
Phone: (301) 975-6681
Fax: (301) 975-4052

18 December 1991

MEMORANDUM FOR Laboratories using Cone Calorimeters (No. 8)

From: Vytenis Babrauskas

Subject: Use of molecular sieve for removing CO_2

Some laboratories have proposed the use of molecular sieve instead of Ascarite as the media to use for removing CO_2 from the sample gas fed to the oxygen meter. We have explored this possibility and have not found satisfactory results. The molecular sieve used was Type 4A, Form 8x12 beads. This alternate sorbent was substituted in the same sorbent trap as used for Ascarite. It was found that both heat release rate and total heat release values reported for PMMA were substantially altered. We understand this to be because the molecular sieve beads (which were slightly smaller than the Ascarite granules and, thus, would have had more effective surface area) are not as effective at removing CO_2 flowing through at high flow rates. Molecular sieve is often the proper media of choice for certain chromatography applications, but the difference should be pointed out that there the flow rates are normally much smaller.

We urge that no Cone Calorimeter users should go over to using a molecular sieve product as their CO_2 sorbent without very carefully determining that benchmark PMMA values are unchanged.

UNITED STATES DEPARTMENT OF COMMERCE
National Institute of Standards and Technology
Gaithersburg, Maryland 20899

Bldg. 224 Room A345
Phone: (301) 975-6681
Fax: (301) 975-4052

19 October 1992

MEMORANDUM FOR Laboratories using Cone Calorimeters (No. 9)

From: Vytenis Babrauskas

Subject: Software errors regarding baseline oxygen values

Recently it came to my attention that a software error was present in the PL Cone software. The symptoms were abnormally high heats of combustion being reported for wood combustion. During the final stages of the combustion of a wood material, the primary reaction is oxidation of carbon. This has an effective heat of combustion of *ca.* 32 MJ/kg. For the erroneously reduced data I examined, values in excess of 50 MJ/kg were being reported for this period.

The problem was identified to be in the baseline oxygen value used by the data reduction software—a fixed value of 20.95% oxygen was being used. In the actual operation of the Cone Calorimeter, it is both difficult and unnecessary for the operator to tweak the span adjustment to record exactly 20.95% for the baseline period. Minor differences in the starting value should, however, be handled correctly by the software. Apart from the incorrect way of assuming 20.95% was the actual baseline, there are two alternative ways of handling the data, both acceptable. (1) In all the equations, use the actual reading baseline oxygen reading, as measured during the pre-test baseline. (2) Use a nominal value of 20.95% in the equations, but scale all the oxygen data values for the entire test by a scaling factor which will result in the starting value being exactly 20.95. The first of these two methods is clearer to understand and easier to implement, but either will lead to acceptable results.

I have only examined two manufacturers' instruments in connection with this issue: PL Thermal Sciences (which had the problem) and Dark Star Research (which did not). Users of other systems should investigate whether their systems might have this problem. PL instrument users, of course, should request corrected software from the manufacturer.

To investigate for the presence of this problem, one simply recreates the conditions leading to its occurrence. Select a wood specimen for testing. Deliberately mis-adjust the oxygen analyzer reading to be low (say, 20.80%) while sampling room air. Run the sample and reduce the data. The effective heat of combustion during the period when the specimen is flamelessly glowing, but prior to being burned out, should be, very roughly, 30 MJ/kg. Values greatly higher (say, 50 MJ/kg) indicate incorrect handling of baseline readings and a need to take remedial action.

Construction Drawings for the Cone Calorimeter

First issued: April 2, 1985
Revision A: November 30, 1985
Revision B: May 1, 1986
Revision C: June 17, 1988
Revision D: July 23, 1990

Construction Drawings for the Cone Calorimeter

First issued: April 2, 1985
Revision A: November 30, 1985
Revision B: May 1, 1986
Revision C: June 17, 1988
Revision D: July 23, 1990

Construction Drawings for the Cone Calorimeter

National Institute of Standards and Technology
Bldg. 224 Room A-363
Gaithersburg, MD 20899
USA
Attn: Dr. Vytenis Babrauskas

Contents

Page

Tables

Page

Assembly drawings

Construction drawings

Electronics drawings

Page

Tool drawings

Page

1. List of revisions

The following is a list of the salient revisions made after the publication of Report NBSIR 82-2611.

- Heater coil winding

  The windings for the coil have been increased from 7-1/2 turns to 8-1/2 turns, in order to improve mechanical stability. Spacer blocks are now used along the bottom of the coil for support to guard against element sag. A new arrangement for thermocouple mounting was developed, and involves sheathed type thermocouples being placed in contact, but not welded to, the rear surface of the coil.

- Voltage supply

  To achieve a full 100 kW/m^2 specimen irradiance (normally somewhat in excess of that, approximately 110 kW/m^2 can be obtained), the wiring should be such that a full 240 VAC can be delivered to the heater. If a boost transformer is needed, it must be wired to the line, not the load, side of the power controller.

- Cone orientation and raising/lowering

  The original design involved a vertical position lock bracket to which the cone was manually screwed onto for the vertical orientation. This has been replaced by a spring clip, which is more easily workable; the vertical position lock bracket is no longer necessary. The means of fixing the cone height was originally a pair of thumb screws used in the cone sliding cone support bracket. An improved chain elevator assembly has been designed; since friction is no longer used in this arrangement to facilitate raising, the clearances for the Teflon[1] sleeve have been increased.

- Exhaust system

  New drawings are provided for the design of the mixing orifice plate, at the point where the hood is joined to the horizontal exhaust duct, and for the measuring orifice in the stack. Both orifice plates are now easily removable for cleaning and maintenance.

- Horizontal specimen holder

  A drawing is given for a wire grid to be used when testing intumescing specimens. This is to be used with the edge frame, which is not necessary for routine testing of horizontal specimens. The same wire grid can also be used in vertical orientation testing.

---

[1] Certain commercial products and materials are identified in this document in order to adequately specify the experimental procedure. In no case does such identification imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the product or material identified is the best available for the purpose.

- Corrosion-resistive cold trap

  Drawings are shown for an improved cold trap. The design should be executed using Teflon-coated aluminum, or, alternatively, from the corrosion resistive nickel alloy Hastelloy B-2 (without coating). For the Teflon-coated design, the coating must be by a DuPont approved specialist.

- Improved soot filter holder

  The soot filter used for removing soot from the oxygen sampling line (not to be confused with the soot filter used for measuring soot, described below) has been redesigned to permit easy bolting down to a horizontal surface.

- Gas sampling train

  The scheme used in the original report for barometric compensation involved a mechanical absolute back pressure regulator. This did not do an adequate job and has been replaced by electric pressure compensation, described in the drawings and in Table 1.

- Smoke extinction beam

  This is a new design; smoke measurement capabilities were not given in the original report. A small, 0.5 mW helium-neon laser beam is projected across the exhaust duct. The two halves of the device are rigidly coupled together, and are mounted to the exhaust duct by the use of refractory felt gasketing. Two purge tubes must be welded onto the exhaust duct. The design does not use windows, to eliminate window soot deposition problems, and instead relies on convective purging, maintained by the exhaust blower suction. The long purge tubes allow sufficient length to deposit soot on the tube walls before reaching the optics in case of transient failure of the purging. A compensation detector is needed since small He-Ne lasers do not show high stability. The signal conditioning electronics provides logarithm and baseline ratio functions, giving output directly as an extinction coefficient, in units of m^{-1}.

- Improved spark plug holder

  An entirely new design for a motor-driven spark plug holder is included. This allows easier change between horizontal and vertical orientations. The previous brackets for both spark plug locations (but not the bracket for the heat flux meter) are now eliminated.

- Trapping of condensables in soot sampler

  Condensable tars are likely to be trapped in the soot mass controller unless they are effectively removed earlier. For this purpose (Fig. A18) a backup glass fiber filter has been provided, as has a length of condenser tubing, where the tars can be deposited prior to reaching the mass controller. This condenser is equipped with easily removable end fittings for cleanout purposes.

- Pyrex enclosure

  The enclosure shown in earlier versions of these drawings has been substantially redesigned in actual use. A new drawing is not yet available. We recommend, however, that if an enclosure is used that at least two doors, front and back, be provided, that they swing open from hinges (not counterweight system), that they seal against gaskets, and that they be removable from the hinges for uses when controlled atmospheres are not required. For cleaning and maintenance purposes, it is desirable that all four sides can be removed. If experiments are to be run where a rapid insertion of a specimen into a non-ambient atmosphere is to be done, then it may be necessary to design a retractable cold-plate shutter. For the horizontal orientation, this can be done easily by making a motion path to the side.

  A narrative description of such an enclosure has been prepared as a journal article. Construction drawings for a controlled-atmospheres unit have *not* been prepared and are not available.

- Computer software

  Details of the operating software used on Hewlett-Packard computers are given in the first edition of the **User's Guide for the Cone Calorimeter**. This software is being replaced by software intended to run on IBM computers. Instructions on how to use the new software will be a part of Edition 2 of the User's Guide.

- Smoke extinction beam modifications

  Several optional improvements in the smoke meter mechanical arrangements have recently been developed. There was some tendency for the main beam detector to exhibit non-linearity due to high light levels. This is most conveniently eliminated by installing a second beamsplitter, in front of the main beam detector. [There is an additional advantage of this arrangement, in that a more nearly fully-balanced circuit is created.] The original calibration procedures, using neutral density filters, were somewhat tedious due to a need to disassemble some ducting. For this purpose, a design has been evolved which incorporates permanent slots for filters, along with mating filter holders. Two slots are used: one in front of the main beam, for the primary calibration, and a second one in front of the laser, to check the operation of the reference beam circuitry. To minimize erroneous reflections, this new version calls for the filter holders to hold the filters at an off-perpendicular angle. Finally, the modified arrangement contains thermal shielding for the photodiodes, to minimize slight thermal currents from affecting the readings. [This improvement has been developed in conjunction with CSI].

  Revised drawings are given in Figures C26, C28, C29, and C30. Table 4 itemizes the changes in mechanical parts.

- Spark circuit

  A suitable filter for the suppression of electromagnetic interference is now specified for the spark plug circuit; the intermittent spark selection is deleted.

- Soot sampler sampling ratio

  The sampling ratio has been adjusted for a minimum of approximately 1000:1, instead of 400:1. This involved changing resistors R26, R27, and R28.

- Thermocouple for photometer

  A change has been made to the smoke extinction beam photometer. The change consists of providing an additional thermocouple, located close to the photometer, for more accurately deriving the actual volume flow rate quantity pertinent to smoke data analysis. Figure A19 illustrates the location of the thermocouple. The thermocouple type is listed in Table 1.

  The data collection routine must be modified to collect the additional temperature channel, T_s. The data reduction routine must be modified so that the specific extinction area, σ_m, is calculated as:

$$\sigma_m = \frac{k \dot{V} T_s}{\dot{m} T_d}$$

  where k is the extinction beam reading (m^{-1}); $\dot{V}$ is the duct volume flow rate (m^3/s), as determined at the location of the orifice plate flowmeter; $\dot{m}$ is the specimen pyrolysis rate (g/s); T_s is the temperature at the photometer (K); and T_d is the temperature at the orifice plate flowmeter (K).

- Improved photodiodes for photometer

  A significantly improved photodiode type was found for this application. This is a Hamamatsu diode, which is mechanically compatible with the previously used UDT type. For identification, see Table 3. By substituting this diode, a very significant improvement in baseline stability is achieved, and spurious influence of temperature is minimized. To make this change, only a recalibration is necessary after installation.

- Spark plug motor

  The electrical motor originally specified for the spark plug was not fast enough to enable rapid insertion. This has been replaced by an air motor, as listed in Table 1. The motor is controlled by electrically-operated air valves. Mechanical drawings are shown in Figures A11, A12, and C11.

- SSDC logarithmic amplifier electronics

  An improved circuit has been developed by SSDC, Inc., for the laser smoke extinction beam. This circuit is substantially easier to calibrate and results in a better “common mode rejection,” *i.e.*, immunity to laser power fluctuations than the original NIST design.

While a schematic drawing for this circuit is provided, courtesy of Richard Saxon, as Figure E7, it is not recommended that the laboratory construct this circuit themselves. The circuit requires a number of selected and matched components and careful layout techniques due to the high-impedances involved. This logarithmic amplifier can, instead, be purchased from SSDC directly, at the address given in Table 6.

- Thermocouples

The size of the thermocouples has been standardized to 1.5 mm for all the thermocouples used on the instrument. See Table 1 for further details of the present specification. The ASTM and ISO standards permit other configurations; those are for backwards compatibility only and are not recommended for new construction.

2. The design team

The NIST personnel involved with the design of the calorimeter were:

Vytenis Babrauskas
Emil Braun
Nelson Bryner
Morgan Hurley
Marc Janssens (Research Associate, Natl. Forest Products Assn.)
Gerald L. King
Gregory Michaels
George Mulholland
William J. Parker
Antonio Silva-Rosario
David E. Swanson
William H. Twilley
Sidney Weiser

3. Additional documents

- Report NBSIR 82-2611

  The original NBS report describing the construction of the cone calorimeter was issued in November 1982, Report NBSIR 82-2611. The construction drawings contained there were subsequently modified, and a supplementary document, entitled "Supplementary Details on the Construction of the Cone Calorimeter" was issued and revised from time to time. The last revision was dated 25 November 1984. All the drawings contained in Report NBSIR 82-2611 and in the Supplement have now been consolidated into the present document, and the Supplement is obsolete and no longer required. The **text portion** of Report NBSIR 82-2611 is **not** replaced by the present document and is still valid.

- ASTM E 1354 Standard

  Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products using an Oxygen Consumption Calorimeter (ASTM E 1354). American Society for Testing and Materials, Philadelphia (1990).

- ISO DIS 5660 Draft International Standard

  Fire Tests - Reaction to Fire - Rate of Heat Release from Building Products (ISO DIS 5660). This method is similar to the one from ASTM, except for the fact that the smoke measurement procedures have not been included. Users adhering to the ISO protocol who wish to make smoke measurements should consult the ASTM document.

- User's Guide for the Cone Calorimeter (NBS Special Publication 745)

  This document has been prepared describing additional details of set-up, calibration, test conduct, and troubleshooting not contained in the ASTM document. It is envisioned that various versions of this document would be available, each tailored specifically by the manufacturer of the Calorimeter to his instrument. SP 745, however, focuses on the operational details of the hardware as installed at NIST, which may be significantly different from that on commercial instruments.

  A substantial amount of instructions for maintenance operations, which were previously given as part of this construction drawings package, have been expanded and moved to the User's Guide, which should be consulted.

4. Complete instruments

There are at least five manufacturers offering complete Cone Calorimeter units for sale. The units available from the different manufacturers are substantially different in the completeness of the equipment included with the unit. Some units also offer enhanced functional features not included in the basic ASTM specification. NIST does not, of course, give a recommendation to any of the commercial manufacturers.

The currently active manufacturers are:

- Custom Scientific Instruments
- Dark Star Research Ltd
- PL Thermal Sciences Ltd (*formerly* Stanton-Redcroft Ltd)
- University of Gent
- VTEC

Manufacturers' addresses are listed in Table 6.

5. The conical heater

The heater is to be wound by hand, using the mandrel shown in Figure T1, on a lathe. Figure T2 shows how the tool is to be used. The coil should be wound so that the two end connectors terminate at about a similar distance. It is very easy to wind the element by hand the first time, however, once bent, the element work-hardens and it may not be possible to adequate straighten an incorrectly bent element.

The elements, as used in the Cone Calorimeter, are long-lived, and should typically last more than a year. Usually failure comes not from outright burnout, but rather because of excessive twisting. The element is subjected to thermal stresses as the unit heats up and cools down. This causes some motion of the windings. After enough motion has resulted, a layer of the winding may slip out of its row. This can often be set right by disassembling the unit and straightening that layer. The unit should not be operated if any winding rows are misaligned, since this can cause flux uniformity to degrade.

6. Special construction notes

Horizontal alignment of heater

The lower plate for the cone heater assembly has two small "ears" detailed on the edge (Fig. C2). The purpose of these ears is to allow the heater assembly to be set up to be exactly horizontal, when placed in the horizontal orientation. With a proper type of piano hinge installed, the when first assembled, the heater will not quite drop down into a correctly horizontal orientation. The ears are then to be filed carefully until a fully horizontal orientation results. If the unit droops below horizontal when assembled, an error has probably been made in selecting the type of hinge, or the hinge has been improperly assembled. To correct, replace with hinge which does not result in an excessive gap (Fig. A10).

When the assembly has been correctly accomplished, place the heater in its horizontal orientation and verify that the vertical centerline is properly established: the cone heater, bracket 'A', and the load cell should all be aligned.

Blower installation

A number of users have had some quality control problems with the specified blower. Several items must be checked by the person building the instrument. (1) There must be a "heat slinger" present on the shaft, just in front of where it enters the blower housing. This device serves to dissipate heat coming into the shaft from the wheel. It also serves to minimize air leakage at the shaft entrance. Proper alignment consists of moving it as close as possible to the housing, just short of where it would scrape against the housing. (2) The shaft bearings are often not aligned at the factory, resulting in the wheel not being centered within the housing. This is fixed by installing shim plates of suitable thickness under the bearing supports. (3) The wheel may not be properly balanced. To remedy, take out shaft and wheel and have it dynamically balanced by a machine shop specializing in shaft balancing.

7. Computer software

At NIST different versions of software have been written for the following computers: Tektronix 4052 (Basic), Perkin-Elmer 3242 (FORTRAN), and Hewlett-Packard Series 200/300 (Basic). Development is currently under way on a version for IBM 80286 and 80386 machines. When this version is completed, the previous version will **not** be supported. Data management software has also started to be developed. This will allow a proper database storage for the data, along with extensive graphics capabilities. Again, this new software will be developed *only* for the IBM machines.

Users wishing to use this new software will need to purchase two packages:

(1) CONERUN

This is the software which actually operated the Cone Calorimeter computer and stores the data in the proper format. It is available from Dark Star, Ltd. (see Table 6).

(2) FDMS

This is the software which the user uses to reduce the raw data, to store it in standard reduced-data formats, to print out test reports, to exchange data, etc. It is available from the Fire Research Station (see Table 6).

8. Example test output

The following page illustrates the current information being outputted on the NIST data acquisition system for routine testing. The sheet illustrates only the summary data; it is followed by several pages which contain the detailed data for each scan interval.

(We retain this section for completeness in documenting the previous version of the computer software. The formats from the new FDMS software, listed in the previous page, are expanded and improved. Complete documentation of the FDMS formats is available as part of the computer program package.)

1in. PMMA (cb) system check

Irradiance=50 kW/m^2
Orientation=horizontal

Pre-test comments:
H_2O meter reads 0.5 percent high at outset

Soot=.013267 g/g
Time to ignition=28.5 sec
Initial mass=295.00 g; final mass=0.7 g; % mass pyrolyzed=100.0%
Peak heat release rate=685.8 kW/m^2 at 374.0 sec
Avg. ext. area=102.7 m^2/kg
Avg. heat of comb.=24.53 MJ/kg
Avg. CO=.0007 kg/kg
Avg. CO_2=2.0718 kg/kg
Avg. H_2O=.9409 kg/kg
Avg. HCL=0.0000 kg/kg
Avg. H'carbs=.0005 kg/kg

Average during period: Ignition to Ignition +

	60 sec	120 sec	180 sec	240 sec	300 sec	360 sec
Avg. Heat Rel. (kW/m^2)	415.1	506.1	543.2	563.7	578.5	593.4
Heat of Comb. (MJ/kg)	23.33	24.33	24.26	23.95	24.32	24.37
CO (kg/kg)	.0001	.0002	.0002	.0003	.0003	.0003
CO_2 (kg/kg)	2.2170	2.1084	2.0813	2.0787	2.0721	2.0686
H_2O (kg/kg)	1.2590	1.0847	1.0315	1.0054	.9895	.9795
HCL (kg/kg)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H'carbs (kg/kg)	.0033	.0016	.0011	.0009	.0007	.0007
Ext. Area (m^2/kg)	113.22	114.60	107.88	104.18	104.16	107.36

At Fraction of (Initial Mass - Final Mass)

	20%	40%	60%	80%
Avg. Heat Rel. (kW/m^2)	517.2	579.1	601.4	611.3
Heat of Comb (MJ/kg)	24.61	24.74	24.30	24.37
CO (kg/kg)	.0003	.0003	.0004	.0004
CO_2 (kg/kg)	2.0777	2.0742	2.0736	2.0692
H_2O (kg/kg)	1.0012	.9698	.9582	.9522
HCL (kg/kg)	0.000	0.0000	0.0000	0.0000
H'carbs (kg/kg)	.0008	.0005	.0004	.0004
Ext. area (m^2/kg)	102.5	103.8	100.8	100.9

9. Computer hardware used at NIST

Various data acquisition systems can be used to gather the required raw data from the apparatus, and, indeed the requirements are not highly demanding. The basic requirements are for a system able to gather data to 5-1/2 significant places for at least 6 channels, once every 5 seconds, and, preferably, every 3 seconds. The system must also be able to record the real-time clock data. Our preference is to use a "system DVM" as the analog-to-digital converter, since it has to have the capability for using different ranges for different instruments, and of using thermocouple inputs. In some cases a user may desire to record the data using a D-to-A in the form of a circuit board inserted into a personal computer.

Development work on this type of approach has not been done at NIST, however, several cautionary points need to be made. The noise deviations of the oxygen meter are 20 ppm; this translates into a needed range of 50,000:1. Thus it would seem that a 16-bit D-to-A, with a range of 65,536:1 would be ample. For this to be realistically usable, however, the D-to-A has to have flawless linearity (which most units do not) and all the inputs have to be manually range-scaled so that no dynamic range is wasted.

Earlier implementations at NIST used computers made by Hewlett-Packard. Currently, a changeover is being made to IBM computers, of the PS/2 family. The basic configuration involves:

Data collection computer

- IBM PS/2 Model 50Z (8550-031). This is the most economical choice for computer if it planned to reduce and store data on another computer, dedicated to these latter tasks.

- IBM PS/2 Model 80. This is the most appropriate choice if only a single computer is to be used, on which data collection, reduction, and storage are all to be done. Note, however, that in such an arrangement, one person will not be able to be reducing, printing, plotting, etc., the data while a second operator is in the process of running a test. This IBM model comes in various hard disk sizes; a capacity appropriate to the data collection should be chosen.

  In all cases, at least 2 MBytes of memory is required.

Accessory equipment

- Display monitor. Model 8514 is recommenced. Alternatively, models 8513 may be used, but has a very small screen.

- Numeric coprocessor. This is mandatory for the machine on which data reduction takes place. Use 80387 for model 80, 80287 for models 50 and 60.

- Pointing device (mouse). The Microsoft Mouse is used for data reduction and graphics presentation.

- Network cards. If an arrangement is adopted where there are separate computers for data collection, data storage, and ones serving as workstations, a network system is needed. Any network compatible with the NetBios (*e.g.*, 3Com's 3+Share or IBM's PC LAN program, but **not** Novell Netware) will be suitable [note that the PC LAN program can operate cards from many additional manufacturers, not just ones sold by IBM].

IEEE-488 controller card

Model "Personal 488/2" card, from IO Tech, Inc., is appropriate for those computers that use the Micro Channel bus. For earlier machines, *e.g.* the IBM AT, which use the PC bus, the model is "Personal 488." Both include necessary DOS device drivers for the card.

Tape cartridge drive

The field of tape cartridge drives is changing extremely rapidly. Most users will need to keep substantially more old test data available than can be accommodated on the hard disk. These are commonly available in 60, 125, 150, and 240 MByte capacities. Since the 240 MB drives are still not readily available, we are writing the software to a 150 MB drive made by CaliPer (Model CP-150-SAEH-GREY). This needs a SCSI bus adapter, model MCS-350-DNK from Future Domain.

Laser printer / plotter

It is desirable to use a single laser graphics printer for doing both printouts and plots. The unit must be capable of a reasonably full emulation of the HPGL graphics standard. To do this, the Hewlett-Packard LaserJet printer (Series II, or higher) is used, with at least 2 Megabytes of supplemental memory.

Voltmeter / scanner system

To properly determine the system to be specified, the user must first ascertain the total number of channels which will be used. Typically, these will include

- load cell
- oxygen analyzer
- exhaust duct pressure transducer
- exhaust duct thermocouple
- laser photometer
- photometer thermocouple

Some installations will include also

- additional gas analyzers
- monitoring channel for cone heater temperature
- monitoring channel for heat flux meter
- monitoring channel for methane calibration flow controller
- monitoring channels for methane metering dry test meter (temperature and pressure)

- flow rate monitor for soot mass sampler

Simplest system: Hewlett-Packard 3421A data acquisition and control unit, with options 201 and 022. Note that this lowest cost option is extremely limited; basically, it does not have the speed to handle any Cone Calorimeter installation that is beyond the bare-bones ASTM minimum. Thus, users planning to install additional gas analyzers, etc., should consider not this option. Higher capacity system: Hewlett-Packard 3497A data acquisition and control unit, with options 001 (voltmeter function) and K20 (20 channel multiplexer).

Commercial software

Certain items of commercial software are needed. These include:

- IBM DOS 4.0 operating system software.

10. Users group

In the early development of the Cone Calorimeter, the appropriate task groups/working groups of ASTM and ISO were the focus of where users could share operating experiences. With the widening use of the Cone Calorimeter, this function is being taken over by the International Heat Release Association. For further information contact Stephen Grayson or Carole Franks, at:

International Heat Release Association
PO Box 904
London SE13 5SN
ENGLAND

Telephone (44) 81 318 4610
Fax (44) 81 318 3932

11. Acid gas analysis procedure using ion chromatography

Since the Cone Calorimeter represents a well-controlled combustion environment to which specimens can be exposed, it became advantageous to also use it for the measurement of gaseous species yields. Thus, fixed gas analyzers for O_2, CO, CO_2, total hydrocarbons, and H_2O vapor are implemented. For the testing of some materials, however, it is also necessary to characterize the yields of certain acid gases – HCl, HBr, and HCN. For these, commercial on-line gas analyzers are not available on the existing calorimeter, thus a batch sampling technique is employed.

A portion of the gaseous products and soot in the main exhaust duct of the Cone Calorimeter is collected by replacing the soot collection filter with a gas sampling apparatus. Figure A21 shows a diagram of the gas sampling apparatus. The gaseous products are collected in tared 250 mL glass impinger bottles containing approximately 125 mL of 5 mM KOH. (If long collection times or high concentrations of the acid gases are expected, 10 mM KOH should be substituted for the 5 mM KOH.) To maximize the collection efficiency, two impingers are used in series, separated by a 45 mm diameter PTFE filter (0.45 μm nominal porosity) to collect the sample from the exhaust stream. The second impinger serves to trap any gases that might break through the PTFE filter. If only a small amount of breakthrough is detected for certain samples, the second impinger can be eliminated. The flow of gases through the impinger(s) is controlled by the existing mass flow controller used for soot collection. The ratio of gases collected to gases exhausted is nominally 1:1000; however, the exact value for each test is recorded and used in computations. Sample collection starts when the specimen is placed on the load cell of the calorimeter; the collection is stopped when the specimen stops burning and no more smoke is being evolved.

After the collection is completed, the impingers are weighed and the contents transferred to plastic containers. Prior to analysis, the filter containing the soot is placed into the solution in the first impinger. The pH of the unknown solutions is determined to make sure that it does not drop below the pK_a of the particular acid gas. The samples are then analyzed for the expected anion(s) by the procedure described below.

A commercially available ion chromatograph (Waters Model ILC-1 Ion/Liquid Chromatograph) equipped with a Waters 430 Total Conductivity Detector and a Waters 460 Electrochemical Detector is used to analyze for Br^-, Cl^-, and CN^-. The electrochemical detector (specifically used for CN^- and small concentrations of Br^- in the absence of CN^-) is used with an Ag working electrode and a saturated $KC\ell$ reference electrode. An anion column (ICPAK-A) preceded by an Anion Guard-Pak Precolumn Module, both available from Waters, is used. Chromatograms are recorded on an Integrator.

All chemicals used in this work are of reagent grade quality. The water used is conditioned to 18.3 MΩ-cm and passed through a 0.45 μm nominal porosity filter. The eluent for the ion chromatograph is 5 mM KOH. Stock solutions of Br^-, Cl^-, and CN^-, nominally 1000 ppm, are prepared by dissolving 0.1489 g of KBr, 0.2100 g of $KC\ell$, and 0.2502 g of KCN, respectively, in 100 mL of the eluent described above. Calibration solutions of 1.0 to 5.0 ppm for Br^- and

Cl^- and 0.01 to 0.03 ppm for CN^- are prepared by serial dilution of the stock solutions with the eluent.

The eluent flow rate through the system is 1.0 to 1.2 mL/min. The sample loop has a volume of 100 µL. Unknowns are diluted with eluent to 1:10 for Br^- and Cl^- and 1:100 for CN^-. (Some unknowns might require a 1:500 or 1:1000 dilution for CN^-.) Samples and standards are loaded into the loop using a syringe and a 0.45 µm syringe filter. The sample loop is rinsed with *ca.* 1 mL of the analyte solution before the sample is injected onto the column. The procedure, as evolved and described above, is successful in minimizing any mutual interferences among the three anions of interest.

Table 1: List of Major Parts

Mechanical

- Exhaust ducts, orifice plates, ring sampler

  Constructed of Type 304 or 316 stainless steel. If used predominantly for testing chlorinated plastics, construction with the nickel alloy Hastelloy B-2 should be considered. The configuration of the ducting can be changed as needed to suit physical arrangements; however, minimum distances ahead and in back of ring sampler and measuring orifice should be observed.

- Heater element

  Length =3.38 m; diameter =8 mm; sheath material =Incoloy; voltage rating =240 V; power rating =5000 W. Wellman Co. "Calrod" TY 3272 (must specify "minimum heater length=133", minimum over-all length, including screw terminals, =135").

- Temperature controller

  Digital, electronic, proportional/reset/rate (3-mode) type; output =0 to 10 VDC, reverse acting (or as appropriate to drive the power controller); Type K thermocouple input (range 0 to 1200°C). Barber-Colman 5645-02-035-330-0-00.

- Power controller

  Time proportioning type, output 240 VAC at up to 25 A; input 0-10 VDC or as appropriate to the temperature controller. Robicon 313-233-49.

- Fan, cast iron

  Cast iron fan with cast iron impeller, should have capacity to provide at least 50 L/sec at top motor speed; inlet and outlet nominal outside diameter =0.114 m; outlet to be flanged, inlet to be welded as shown in drawings; to be pulley driven from variable speed motor, located below fan. Fan and motor to be mounted on resilient vibration-isolating supports. Howden-Sirocco model 504, with cast-iron wheel, based on design BAY9657-1. Must include shaft heat slinger.

- Motor

  DC permanent magnet type, 3/4 HP, 90 VDC. Baldor CDP3440.

- Motor speed control

  Solid state speed controller for DC motor of 3/4 HP rating, speed adjustment potentiometer must be linear, untapped, and not multiple-gang. This is modified in the drawings to provide an optional constant-mass mode. Cleveland Machine Controls, Pacemaster 1.

- Heat flux gauge

Schmidt-Boelter type, 12.5 mm diameter, leads and water tubes to be to the side, 25 mm length of water tube and lead sheathing; nominal rating of 75 to 110 kW/m^2 (a 75 kW/m^2 gauge can be over-ranged to 110 kW/m^2). Medtherm Co. GTW-7-32-485A (with 10" water and signal tubes).

- Pressure transducer

Electro-capacitive type, differential response, capacity 10 Torr, resolution ±0.01% F.S. (to be located in a constant temperature environment, since the transducer is not thermostatted). MKS Instruments 223BD-00010-AAB, bidirectional.

- Spark plug

A long-reach spark plug is required, as shown in the drawings. Do not connect the outside to system ground; a hole must be drilled and tapped on plug base to connect an insulated ground wire back to the transformer.

If high voltage and system grounds are joined, potentially serious noise problems can arise on the data lines. Eclipse Combustion 12568.

- Spark plug air motor

A rotary actuator using high-pressure air is used to rotate the spark plug into position. Rotomation Inc. Part No. A01-45-CWS25A2V, A-option on left end cap, 1-1/8" shaft flat 6 o'clock, clockwise rotation. Also needs 3-way air solenoid: Humphrey Products Part No. 062-4E1-21-36-70-120V. (Specify 240V instead, if for 240 V service). And also conversion fitting for 10-32 thread to 1/4" tube (Part No. 68P-4-1-32) and street elbow (Part No. SFL-10).

- Ignition transformer

Secondary =10,000 V at 22 mA. Dongan Electric Co. Model LJH-90-A for 120 V primary; Model LJH-90-C for 240 V primary. Should also provide a power line noise filter at the primary.

- Load cell

The required load cell is a complete weighing system which includes a rigid platform and is designed to not jam when torques or eccentric loads are introduced; do not substitute with a simple axial force transducer.

Weighing range, electric =500 g; mechanical zero adjustment range =3.5 kg. This allows use of heavy specimen holders of varying weights to be used without diminishing the weight resolution. Automatic Timing and Controls 6005D06E1XX. The dashpot fluid in this load cell may need to be replaced with a higher viscosity fluid (an assortment of damping fluids of various centistoke ratings is available from the manufacturer).

- Load cell power supply/amplifier

  This should match the load cell and should be procured from the same manufacturer. Automatic Timing and Controls 650-BE-1-CYX-X-X-X-B. Certain modifications are desirable: (1) add a digital panel meter, reading in grams, (2) add a multi-turn front panel zero set potentiometer; eliminate the range-restricting fixed resistors, if supplied, (3) install a 0.3 μfd capacitor across the op amp feedback resistor (this helps to slow down the system response and reduce noise).

- Calibration flowmeter

  A calibration flowmeter is used to meter in methane for heat release rate calibrations. For simplest operation, a dry test meter is adequate, having a capacity of approximately 1 L/s, and equipped with temperature and pressure gauges. For quicker operation, the reference dry test meter can be supplemented with an electronic mass flow controller, which is much easier to use for daily work, since once calibrated with the dry test meter, a pre-set flow rate can be toggled on and off.

  Singer/American dry test meter model DTM-115-3 is suitable. Electronic mass flow controller from a number of makers can be used, and should have a capacity of at least 23 SLPM methane. It is not necessary to get a manufacturer's calibration for these, since they have to be calibrated in use. MKS Instruments 1259B-50,000-5V.

- Thermocouples

  Three identical thermocouples are used for the orifice plate flowmeter, the cold trap, and the laser extinction beam photometer. The thermocouples are Type K, sheathed with an Inconel 600 sheath, with the junction being fully sheathed, but not grounded to the sheath. The overall outside diameter is 1.6 mm. Internal wire diameter is 0.254 mm. This thermocouple is available as item KQIN-116U-6"-length from Omega Engineering, Inc.

  The thermocouple used for the heater is identical in type, but of a different length. It should be specified as item KQIN-116U-30"-length for Omega Engineering, Inc.

Oxygen Sampling

- Oxygen analyzer

  The oxygen analyzer should be a paramagnetic type, with a scale of 0 to 25%, and should exhibit noise + short term drift of approximately ±50 ppm, or less. An instrument of this kind is sensitive to atmospheric pressure variations. To eliminate this, either an absolute back-pressure regulator should be installed at the outlet; or an absolute pressure transducer should be fitted inside the instrument case, connected to the detector outflow, and the electrical analyzer output should be divided by the pressure reading. An instrument already so configured is available from Servomex; if the Beckman instrument is used, plans for making the adaptation are given in the drawings. Any instrument used for this application must have both the case and the detector temperature thermostatically controlled in order to achieve the best stability. Servomex X540A-A100003 (517B) (800) X=SPR290; Beckman 755 (0-25% range).

  For the Servomex instrument, the following additional precautions are important: (1) Case heating temperature control must be set so that a case temperature of 55°C is maintained. (2) A back pressure at least equal to the minimum specified in the manual is maintained, by the use of a throttling valve at the analyzer outlet port. (3) The bypass venting system (packaged with some versions of the analyzer) is not effective with the Cone Calorimeter, and, if present, should be replaced with the plumbing shown in Figure A14. (4) The main electrical output is not to be used as the signal output (the op amp in that circuit is a source of drift); instead, take a 0-10V output directly from the module 517B terminal No. 1 marked "O_2." (5) The sample line inside the meter is rather short and does not provide enough heat transfer surface to fully equilibrate the specimen temperature. This is easily improved by running an additional length of stainless steel sample line on a path around the inside of the case. The Servomex number cited above is a special part, recently developed at NIST behest, and includes modifications #3 - #5, thus these modifications do not be made for such a unit. For the stock units, Part No. X540A-A101003 (517B) (800), all five modifications should be done.

- Absolute pressure transducer

  An absolute pressure transducer is needed only if the Beckman analyzer is used, or an equivalent analyzer which does not contain built-in pressure compensation. Electro-capacitive type transducer, range =0 to 1000 Torr, absolute. To be small enough to fit inside the case of the oxygen analyzer. MKS Instruments 222-BA-01000-AC.

  Note that paramagnetic oxygen analyzers require both good flow rate regulation and detector cell pressure regulation/compensation. Thus, the inclusion of an absolute pressure transducer does not obviate the need for maintaining a constant flow rate through the analyzer, using not just a needle valve, but, rather, a flow regulator, as specified below.

- Flow regulator

  A mechanical flow regulator (referenced to constant pressure at the outlet type) is, as a minimum, specified. The sizing of the flow rates depends on the gas sampling train arrangements. If only a single O_2 analyzer is run, or if any additional instruments are picked off up-stream, as suggested in Fig. A14, then only a range adequate for the oxygen analyzer itself is required (see manufacturer's recommendations).

  Moore Products 63BDL is suitable. Alternatively, an electronic mass flow controller, of the same capacity, can be fitted.

- Sample pump

  A Teflon-lined stainless steel diaphragm pump is used, flow capacity =13 std L/min at zero pressure differential. KNF Neuberger N010-STP.

- Waste regulator

  This is a pressure relief regulator, with an adjustment available for setting a pressure to be maintained at its inlet; any inlet pressure greater than the setpoint is relieved by flow into the waste line. A pressure setting range of 50 to 500 Torr is suitable. Norgren V06-221-N-NA has a brass body, which can be used if highly corrosive specimens are not being tested.

- Gas stream cold trap

  Option a: Thermoelectric cooling

  ▷Thermoelectric cooling modules

  Two modules are required, each having a cold surface 70 mm by 109 mm and rated for a cooling power of 25 W, at a cold surface temperature of 0° C and a water supply temperature of 25° C. A water flow rate of 0.8 L/min is needed. Interconnection Products (formerly Cambion Thermionic) 806-1001-01.

  ▷Thermoelectric cold trap power supply and controller

  The cold trap needs a maximum of 14 VDC at 9 A, but this has to be varied so as to maintain the thermocouple at approximately 0° to -3° C. The simplest arrangement is a temperature indicator with a manually adjustable power supply. For convenience, it may be desirable to use a temperature controller. The specifications for a controller are not restrictive – mainly it should cover a range of at least -25° C to +25° C, using a Type K thermocouple, have a digital temperature readout, and provide an output appropriate to the power supply being used. Power supply ATR-250 from Electronic Measurements, Inc., is suitable; so is model ATE 15-15 M from Kepco, although it is substantially more costly. Temperature controller 5645-02-013-320-0-00 from Barber-Colman is suitable.

Option b: Sample line refrigeration unit

It is possible to substitute a complete commercial gas stream refrigeration unit; however, the user should ensure that the gas stream can be cooled to at least 0° C by this means. The relevant flow rates are a capability to cool a minimum of 5 L/min from 30° C to 0° C. Bühler model EGK is suitable (sold in the U.S. as Leybold-Heraeus EGK/7611).

- Soot filter support disc

  This is a thin perforated stainless steel disc, 90 mm diameter, used to support the filter discs. Millipore YY22-090-64.

- Filter discs for instrument line

  Glass fiber type, 90 mm diameter. Whatman, Type GF/A, 90 mm.

- Final filter

  A final filter should be used at the input to the oxygen analyzer, since a paramagnetic analyzer can be damaged by particulates lodged into the detector. A 7 μm stainless steel tubular filter is used. Nupro SS-4FW-7.

- Supplemental drier

  A supplemental drier is used to remove any residual moisture from the stream, prior to the oxygen analyzer. It should be used to fill a flow-through cylinder, roughly 15 mm by 200 mm long. W. A. Hammond Co. "Drierite."

- CO_2 removal media

  The oxygen consumption equations require that either the CO_2 concentrations be measured, or that CO_2 be removed from the oxygen meter stream. If a CO_2 meter is not used, then CO_2 removal media must be used, filled in a similar cylinder as used for the supplemental drier media. Thomas Scientific "Ascarite."

Laser extinction beam electronics

- Extinction beam logarithmic amplifier

  A complete unit is available from SSDC, Inc., as model SSDCL02.

- Optical calibration filters

  Optical calibration filters are needed in at least two values, typically 0.3 and 0.8 optical density (O.D.) units. Glass discs, 25 mm diameter, are used; these must be calibrated at the He-Ne wavelength by the manufacturer. Melles-Griot 03FSG013, or equivalent.

Optional supplemental gas analyzers

The gas analyzers listed below are not necessary for normal operation of the cone calorimeter. They are useful for research purposes, and are listed here solely for convenience.

Special note: The total unburned hydrocarbons, water vapor, and hydrogen chloride analyzers require that heated sample lines be used and a heated soot filter at the start of that sample line be fitted. A T-fitting is made very shortly after the ring sampler outlet where the heated and the unheated lines are split. The heated lines are thermostatted to 175°C. Complete heated line assemblies (Teflon material) are available from Heater Specialties, Inc. and from Technical Heaters, Inc. The user will still, generally, need to provide some own-built short heated stubs at the inlet T and also at the analyzer connections. These can be made up using stainless steel tubing, heated by being wrapped with a heating cord, and insulated. A small, self-contained AC-powered temperature controller is used. A heated soot filter assembly, using 70 mm disc filters, is available from Environmental Tectonics Corporation as part no. D-20252-007. One can also be custom-made by incorporating a 70 mm stainless steel filter holder into a small oven.

For the hydrogen chloride analyzer, in addition to a heated sample line, the gas sample needs to have the moisture removed from it. This is done by using a Perma Pure Products membrane drier, model no. MO-250-48FF. The first half of the drier's length **only** is heated with a heating cord. This must be done carefully so as to not overheat the plastic parts of the drier. Drier purging is done from a vacuum source, in a counter-flow direction. The Teflon tubing connecting the outlet of the drier to the inlet of the analyzer is **not** heated.

- Carbon monoxide

  Maihak DEFOR gas analyzer (to have gas filter cuvettes, 0-10 VDC output, 0-2% CO full-scale range).

- Carbon dioxide

  Maihak DEFOR gas analyzer (to have gas filter cuvettes, 0-10 VDC output, 0-10% CO_2 full-scale range).

- Total unburned hydrocarbons

  Heated analyzer, Siemens Fidamat K, M52044-D2210-B200. Note that this is available only in a 220 V version.

- Water vapor

  Leybold-Heraeus infra-red analyzer "Binos" for 0-10% water vapor, model BINOS 4B.1-102-201682-0013-5030-7333. Note that this model number does not include a gas pump, which will be needed somewhere in the gas train.

- Hydrogen chloride

  Thermo Environmental gas-filter-correlation analyzer, Model 15, with electric span/zero solenoids.

  An HCl analyzer also requires a drying system, the components of which include
  Membrane dryer, Perma Pure Products, model MD-250-48FF.
  Temperature controller, Omega Engineering, model 6102-K-0/500 F.
  Heating tape, Omega Engineering, model FGS051-040.

Soot Sampling

- Soot filter

  A stainless steel 47 mm diameter filter holder is used. Millipore model XX50 047 00. The filters used must be chosen for a minimum of hygroscopic tendencies; in practice, glass fiber overcoated with PTFE material is chosen. Pallflex T60A20 (47mm).

- Mass flow controller

  This is indicated, along with the electrical parts, in Table 5.

- Vacuum source

  A low-vacuum source should be available either from house vacuum or from a pump. If a pump is specified, it should have the capability of pumping up to 10 L/min through the associated piping, and should not be readily damageable by moist, corrosive gas streams.

- Electronic microbalance

  A microbalance resolving to 0.001 mg is needed to weigh the soot filters. Mettler M3 is adequate; a special pan for weighing 47 mm discs is available and should be specified.

Table 2: Motor Speed Controller Parts List

QUANTITY	DESCRIPTION
Resistors	
1	220Ω, 1/4 watt
1	400Ω, 1/4 watt
3	680Ω, 1/4 watt
1	1K, 1/4 watt
1	5.1K, 1/4 watt
1	22K, 1/4 watt
1	90K, 1/4 watt
1	1K, 0.5 watt, 25 turn nominal, PC mount
1	10K, 0.5 watt, 25 turn nominal, PC mount
1	1K, Bourns model 36105-1, 10 turn, panel mount
2	2K, Bourns model 36105-1, 10 turn, panel mount
Switches	
1	SPST, normally closed momentary pushbutton
1	SPST, normally open, momentary pushbutton
2	Reed relay, DPDT contacts
1	250V, 30 amp breaker
Electronic Components	
1	Power-Trol (former name: Time-Trol) millivolt controller, model 6127LA312OM2X1 (as modified). Remove and discard the enclosure.
1	Cleveland Machine Controls "Pacemaster I" adjustable speed drive model M050-02567-0000 with dynamic braking module MO-02785-100. Remove and discard the enclosure.
1	Texmate Inc. digital panel meter, model RP3500 with edge connector
1	Semiconductor Circuits, Inc. ± 5VDC, 100 mA power supply with mating socket
1	Motorola opto-coupler 4N35
2	LED, red, 1.4V, 10 mA
1	Chassis, Lansing Research Corp. 1/2 wide electronic enclosure No. B2H16-001 with rack mount kit No. K2RMX-001
1	Fuse holder, 3AG
1	0.5A, 250V, 3AG fuse
1	Lemo connector No. FZ-304-TEF-8/5.2
1	Lemo panel mount connector RA2.304-TEF
1	3-terminal barrier connector

Table 3: Photometer Parts List – SSDC version

DESIG.	VALUE	RATING		DESCRIPTION
Resistors – fixed				
R01	1.07 M	0.1%	0.5 W	matched
R02	1.00 K	1%	0.5 W	50 ppm
R03	10.0 K	1%	0.5 W	50 ppm
R04	4.99 K	1%	0.5 W	50 ppm
R05	47.0 K	1%	0.5 W	matched
R06	121 K	1%	0.5 W	50 ppm
R07	10.0 K	1%	0.5 W	selected by mfg
R08	130 Ω	1%	0.5 W	selected by mfg
R09	1.07 M	1%	0.5 W	matched
R10	1.00 K	1%	0.5 W	50 ppm
R11	10.0 K	1%	0.5 W	50 ppm
R12	4.99 K	1%	0.5 W	50 ppm
R13	47.0 K	1%	0.5 W	matched
R14	121 K	1%	0.5 W	50 ppm
R15	130 Ω	1%	0.5 W	selected by mfg
R16	261 Ω	1%	0.5 W	50 ppm
R19	121 K	1%	0.5 W	50 ppm
R20	121 K	1%	0.5 W	50 ppm
R21	267 Ω	1%	0.5 W	50 ppm
R22	121 K	1%	0.5 W	50 ppm
R23	121 K	1%	0.5 W	50 ppm
R24	22.0 K	1%	0.5 W	50 ppm
R25	220 Ω	5%	0.5 W	
R27	220 Ω	5%	0.5 W	
Resistors – variable				
RV01	50 K			10-turn (bal.) low t.c.
RV02	10 K			10-turn (cmr) low t.c.
RV03	100 K			10-turn (slope) low t.c.
RV04	50 K			10-turn (gain) low t.c.
RV05	50 K			10-turn (zero) low t.c.

Table 3: Photometer Parts List (continued)

Desig.	Value	Rating	Description
Capacitors			
C01	0.01 μf	100 V	poly
C02	0.01 μf	100 V	poly
C03	100 pf	100 V	mylar
C05	15 μf	50 V	solid tantalum
C06	0.1 μf	100 V	poly
C07	4.7 μf	35 V	tantalum
C08	4.7 μf	35 V	tantalum
Diodes			
D01	1N914A	200 V	selected
D02	1N914A	200 V	selected
D03	1N914A	200 V	selected
D04	1N914A	200 V	selected
Integrated circuits			
IC01	42J		Analog Devices electrometer amp module
IC02	42J		Analog Devices electrometer amp module
IC03	AD751N		Analog Devices logging element
IC04	BB3308		Burr Brown
IC05	BB3308		or AD40L
Relays			
K01	SPST	5 V	DIP, gold, shielded
K02	SPST	5 V	DIP, gold, shielded
K03	SPST	5 V	DIP, gold, shielded
K04	SPST	5 V	DIP, gold, shielded
K05	SPST	5 V	DIP, gold
K06	SPST	5 V	DIP, gold
Switches			
S01	SPDT		min. toggle, gold
S02	SPDT		min. toggle, gold
LED's			
LED01	red LED		
LED02	red LED		

Table 3: Photometer Parts List (continued)

QUANTITY	DESCRIPTION
Miscellaneous components	
2	Photodiodes: Hamamatsu S1336-44BK (or, S1336-44BQ)
1	Aerotech helium-neon Laser, 0.5 mW, model No. OEM-05P. Must be linearly polarized.
1	Aerotech power supply, No. LSS-05
1	Texmate, Inc. 4 1/2 digit digital panel meter No. RP-4500D with edge connector
1	Semiconductor Circuits, Inc. ± 15v, 300 mA power supply with mating socket
2	Zener Diode, IN967B, 18V
2	GE Varistor, No. 130L208. To be connected between neutral and hot on the 110 V. A.C. line to both the electronics and the laser power supply.
Optics parts	
2	Beamsplitter: microscope slide, plain glass
2	Diffusors for detectors: opal glass
Hardware	
1	Alden Products Co., connector No. 8102 FP, with 2 feet coaxial cord
2	Fuse holder, 3 AG
2	1.0A, 250V, 3 AG fuse
1	Female, banana type panel connector
1	Lemo connector No. FZ-304-TEF-8/5.2
1	Lemo Panel Mount Connector No. RA2.304-TEF
1	Robinson-Nugent Socket No. DP-5178-A with retaining rings
–	Wire for detectors - must be Teflon insulated, coaxial type, RG-188A/U or similar.

Table 4: Updated Mechanical Parts List for the Extinction Beam

NUMBER	DESCRIPTION	MATERIAL	QUANTITY
1	Main body, laser side	Blackened Stainless Steel	1
2	**Main body, detector side**	**Blackened Stainless Steel**	1
3	**Laser adapter**	**Aluminum 6061-T6 Alloy**	1
4	Beam splitter, laser side	Aluminum 6061-T6 & plain glass	1
5	Compensation detector holder	**Aluminum 6061-T6 & opal glass**	1
6	Standoff	Aluminum 6061-T6	4/3
7	Positioning spring	Aluminum 6061-T6	2
8	Socket ring	Aluminum 6061-T6	2
9	Cable clamp (1)	Aluminum 6061-T6	2
10	Cable clamp (2)	Aluminum 6061-T6	2
11	*Main detector holder*	*Aluminum 6061-T6*	1
12	*Detector retaining ring*	*Aluminum 6061-T6*	2
13	*Detector assembly cover*	*Aluminum 2024-T3*	2
14	*Filter slot, laser side*	*Aluminum 6061-T6*	1
15	*Filter slot, detector side*	*Aluminum 6061-T6*	1
16	*Filter slot cover*	*Aluminum 2024-T3*	2
17	*Cap*	*Blackened Stainless Steel*	1
18	*Filter holder*	*Aluminum 6061-T6*	1
19	*Filter holder positioner*	*Aluminum 6061-T6*	2
20	*Filter retaining ring*	*Aluminum 6061-T6*	1
21	*Beam splitter, detector side*	*Aluminum 6061-T6 & plain glass*	1

Normal = existing part
Italics = new part
Bold face = replacement for an existing part
Note: All aluminum parts are to black anodized.

Additional Parts Required:
Vlier "stubby" spring plungers (NM-53-N) – 12 required
1/4" x 1/4" standoff – 6 required
1/4" x 3/4" standoff – 6 required

Table 5: Soot Sampler Parts List

QUANTITY	DESCRIPTION
Resistors – fixed	
2	75Ω, 1/4 watt
2	680Ω, 1/4 watt
2	2.0K, 1/4 watt
1	7.1K, 1/4 watt
1	8.2K, 1/4 watt
1	9.1K, 1/4 watt
3	10K, 1/4 watt
1	12K, 1/4 watt
1	13K, 1/4 watt
3	20K, 1/4 watt
2	100K, 1/4 watt
Resistors – variable	
1	500Ω, 0.5 watt, 25 turn nominal, PC mount
1	1K, 0.5 watt, 25 turn nominal, PC mount
1	5K, 0.5 watt, 25 turn nominal, PC Mount
3	10K, 0.5 watt, 25 turn nominal, PC mount
2	10K, Bourns model 36105-1, 10 turn, panel mount
Capacitors	
8	0.1 μfd, 50 WVDC ceramic
1	0.47 μfd, 200 WVDC polypropylene
3	1.0 μfd, 200 WVDC polypropylene
1	5.0 μfd, 200 WVDC polypropylene
Switches & Relays	
1	SPST, normally closed momentary pushbutton
2	SPST, normally open, momentary pushbutton
2	Reed relay, DPDT contacts

Table 5: Soot Sampler Parts List (continued)

Quantity	Description
Electronic Components	
1	Semiconductor Circuits, Inc. ± 5V, 500 mA power supply with mating socket
1	Semiconductor Circuits, Inc., ± 15V, 300 mA power supply with mating socket
1	Analog Devices, thermocouple signal conditioner No. 2B50A with mating socket
1	Analog Devices "divide-by" module 433J, with mating socket
2	Analog Devices Op Amp AD OP07AH, with mating socket
1	Teledyne-Hastings mass flow controller HFC-202 (0 to 10 LPM)
1	Data Tech digital panel meter, model 479A, 4-1/2 digit, 0-20V range with edge connector
2	LED, red, 1.4V, 10 mA.
1	Solenoid operated valve, normally closed, 1/4" tube fittings, stainless steel or Teflon.
Hardware	
1	Chassis, Lansing Research Corp. 1/2 wide electronic enclosure No. B2H16-001 with rack mount kit No. K2RMX-001
1	Fuse holder, 3AG
1	0.5A, 250V 3AG fuse
1	Omega, female panel mount thermocouple connector No. JP-K-F
1	Lemo connector No. FZ-304-TEF-8/5.2
1	Lemo panel mount connector RA2.304-TEF
2	Female, banana type panel connector
1	Type D, 25 contact, solder type panel connector, for mass flow controller
1	Stainless steel filter holder, 47 mm Millipore XX50 047 00
Filters	
–	Teflon-coated quartz fiber filters, 47 mm Pallflex T60A20

Table 6: Manufacturers' Addresses

Aerotech, Inc.
101 Zeta Drive
Pittsburgh, PA 15238
(412) 963-7470

Alden Products
P. O. Box 860
Brockton, MA 02403
(617) 361-3700

Analog Devices, Inc.
P. O. Box 280
Norwood, MA 02062
(617) 329-4700

Analog Devices, Inc.
P. O. Box 280
Norwood, MA 02062
(617) 329-4700

Automatic Timing & Controls
201 Gulph Road
King of Prussia, PA 19406
(215) 337-5500

Baldor Electric Co.
Fort Smith, AK 72902
(501) 646-4711

Barber-Colman Co.
1700 Rock Street
Rockford, IL 61101
(814) 877-0241

Beckman Instruments, Inc.
2500 Harbor Blvd.
Fullerton, CA 92634
(412) 871-4848

Benton Corp.
P. O. Box 678
Manor, PA 15665
(412) 935-1583

Winfred M. Berg, Inc.
499 Ocean Avenue
East Rockaway, NY 11518
(516) 599-5010

Bourns Inc.
1200 Columbia Avenue
Riverside, CA 92507
(714) 781-5050

Brooks Instruments
407 W. Vine Street
Hatfield, PA 19440
(215) 362-3500

Burr-Brown Research Corp. Tucson Blvd.
Tucson, AZ 85734
(602) 746-1111

Caig Laboratories
P. O. Box J
Escondido, CA 92025
(619) 743-7143

CaliPer
19701 S. Vermont Ave.
Torrance, CA 90502
(213) 538-1030

Cleveland Machine Controls, Inc.
7550 Hub Parkway
Cleveland, OH 44125
(216) 524-8800

Corcom, Inc.
1600 Winchester Road
Libertyville, IL 60048
(312) 680-7400

Custom Scientific Instruments
13 Wing Drive
Cedar Knolls, NJ 07927
(201) 538-8500

Dark Star Research Ltd.
Park Lane
Penley nr. Wrexham, Clwyd LL13 0LT
UNITED KINGDOM
(44) 948-74536

Data Tech
P. O. Box 5131
Santa Ana, CA 92704
(714) 546-7160

Dongan Electric Mfg. Co.
2987 Franklin Street
Detroit, MI 48207
(313) 567-8500

Eclipse Combustion
1665 Elmwood Road
Rockford, IL 61103
(815) 877-3031

Electronic Measurements, Inc. 405 Essex Road
Neptune, NJ 07753
(201) 922-9300

Environmental Tectonics Corp.
County Line Industrial Park
Southampton, PA 18966
(215) 355-9100

Fire Research Station
Borehamwood, Herts WD6 2BL
ENGLAND
(44) 81-923-665180
attn: Mr. S.A. Ames

Future Domain Corp.
1582 Parkway Loop
Tustin, CA 92680
(714) 259-0400

Gralex Industries
155 Marine Street
Farmingdale, NY 11735
(516) 694-3600

Hamamatsu Corp.
360 Foothill Road
Bridgewater, NJ 08807-0910
(201) 231-0960

W.A. Hammond Drierite Co.
P.O. Box 460
Xenia, OH 45385
(513) 376-2927

Heater Specialties, Inc.
1234 Viscaya Parkway
Cape Coral, FL 33990
(813) 772-4070

Hewlett-Packard
(consult your local
sales office.)

Howden-Sirocco, Inc.
1 Westinghouse Plaza
Hyde Park, MA 02136
(617) 361-3700

Humphrey Products
P.O. Box 2008
Kalamazoo, MI 49003
(616) 381-5500

Interconnection Products, Inc.
1601 N. Powerine Road
Pompano Beach, FL 33069
(305) 979-2050

International Business Machines
(consult your local
sales office.)

IO Tech, Inc.
23400 Aurora Road
Cleveland, OH 44146
(216) 439-4091

Kepco, Inc.
131-38 Sanford Avenue
Flushing, NY 11352
(212) 461-7000

KNF Neuberger, Inc.
P. O. Box 4060
Princeton, NJ 08540
(609) 799-4350

Lansing Research Corp.
P. O. Box 730
Ithaca, NY 14850
(607) 272-3265

Lemo USA, Inc.
P.O. Box 11006
Santa Barbara, CA 95406
(707) 578-8811

Leybold-Heraeus/Inficon
c/o Rosemount Analytical
600 S. Harbor Blvd.
La Habra, CA 90631
(213) 690-7214

Maihak/Westinghouse
now handled by:
Fluid Data - AMSCOR
2512 North Velasco
ANgleton, TX 77515
(409) 849-2344

Medtherm Corp.
P. O. Box 41
Huntsville, AL 35804
(205) 837-2000

Melles-Griot
1770 Kettering Street
Irvine, CA 92714
(714) 261-5600

Mettler Instrument Corp.
P.O. Box 71
Hightstown, NJ 08520
(609) 448-3000

MicroSoft Corp.
Box 97017
Redmond, WA 98073-9717
(206) 882-8080

Millipore Corp.
80 Ashby Road
Bedford, MA 01730
(617) 275-9200

MKS Instruments, Inc.
6 Shattuck Road
Andover, MA 01810
(508) 975-2350

Moore Products Co.
Spring House, PA 19477
(215) 646-7400

Motorola, Inc.
P. O. Box 20912
Phoenix, AZ 85008
(607) 272-3265

MSA-Mine Safety Appliances Co.
600 Penn Center Blvd.
Pittsburgh, PA 15235
(412) 273-5098

C. A. Norgren Co.
Littleton, CO 80120
(303) 794-2611

Nupro Co.
4800 E. 345th Street
Willoughby, OH 44094
(216) 951-7100

Omega Engineering, Inc.
P.O. Box 4047
Stamford, CT 06907
(203) 359-1660

Pallflex Corp.
Kennedy Dr.
Putnam, CT 06260
(203) 928-7761

Perma Pure Products, Inc.
P.O. Box 2105
Toms River, NJ 08754
(201) 244-0010

PL Thermal Sciences Ltd
[formerly Stanton Redcroft]
Surrey Business Park
Kiln Lane, Epsom
Surrey KT17 1JF
ENGLAND
(44) 372-743386

Power-Trol, Inc.
7732 Burnet Avenue
Van Nuys, CA 91405
(818) 781-3202

Robicon Corp.
Plum Industrial Park
Pittsburgh, PA 15239
(412) 327-7000

Rotomation Inc.
525 Carswell Avenue, Unit M
Daytona Beach, FL 32017
(904) 255-1101

Semiconductor Circuits, Inc.
Route 111
Windham, NH 03087
(603) 893-2330

Servomex Co.
90 Kerry Place
Norwood, MA 02062
(617) 769-7710

Siemens
c/o E.S. Industries
8 S. Maple Street
Marlton, NJ 08053
(609) 983-3616

Singer Co.
American Meter Division
13500 Philmont Avenue
Philadelphia, PA 19106
(215) 673-2100

SSDC, Inc.
Box 414
Basking Ridge, NJ 07920
(201) 766-7659

Sytron Corp.
135 Maple Street
Marlboro, MA 01752
(617) 460-0106

Technical Heaters, Inc.
710 Jessie Street
San Fernando, CA 91340
(818) 365-9435

Teledyne-Hastings
P. O. Box 1275
Hampton, VA 23661
(804) 723-6531

Texmate, Inc.
P. O. Box 2000
Solana Beach, CA 92075
(619) 481-7177

Thermo Environmental Instruments
8 W. Forge Parkway
Franklin, MA 02038
(617) 520-0430

Thomas Scientific
99 High Hill Road
Swedesboro, NJ 08085
(609) 467-2000

University of Gent
Lab. voor Aanwending der
Branstoffen en Warmteoverdracht
Ottergemsesteenweg 711
B-9000 Gent
BELGIUM
(32) 91-22-2550

VTEC Laboratories
212 Manida Street.
Bronx, NY 10474
(212) 542-8248

Waters Chromatography Div.
34 Maple Street
Milford, MA 01757
(508) 478-2000

Wellman Thermal Systems Corp.
2 Progress Road
Shelbyville, IN 46176
(317) 398-4411

Whatman Inc.
9 Bridewell Place
Clifton, NJ 07014
(201) 773-5800

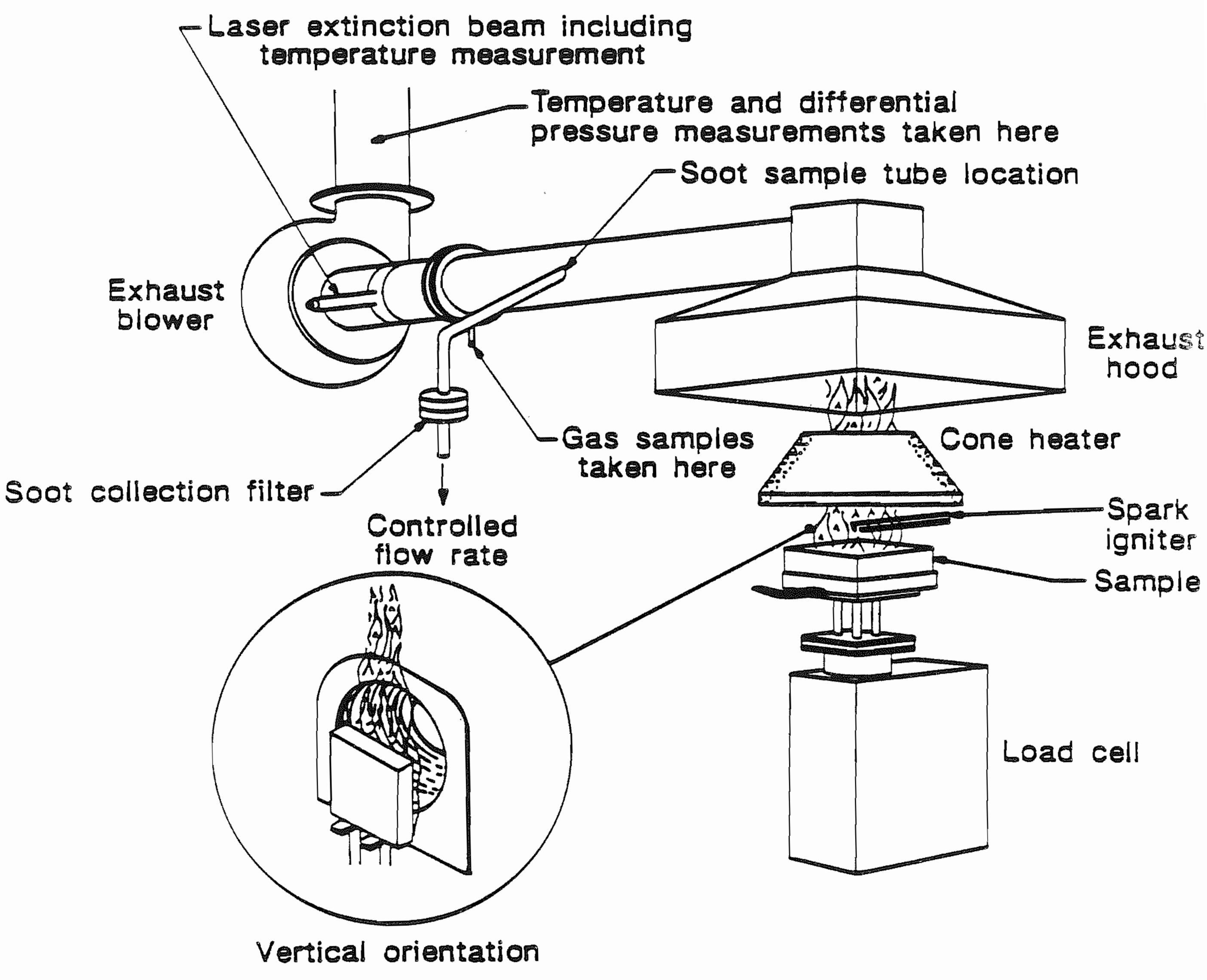


Figure A1. Conceptual view

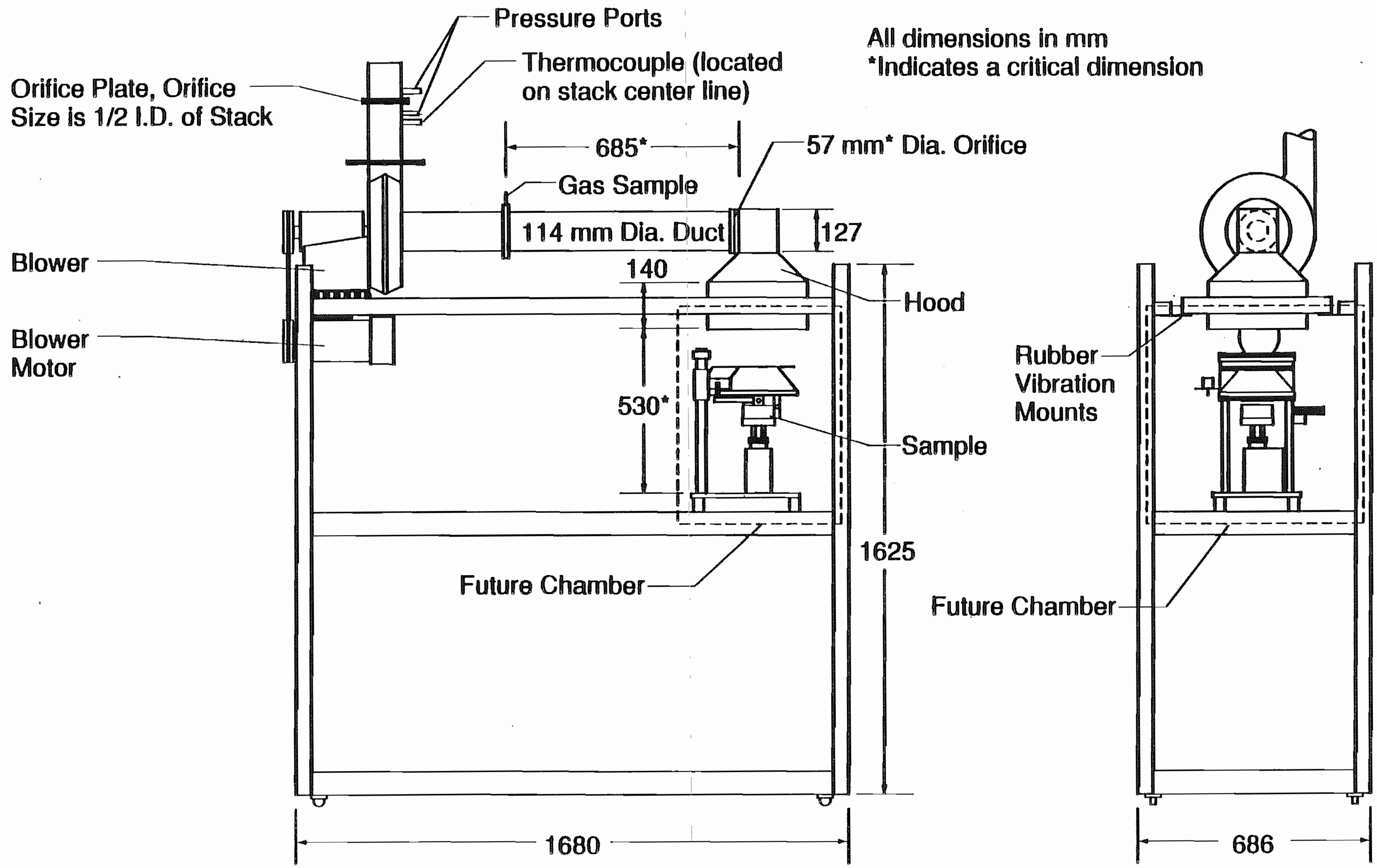


Figure A2. General view and assembly instructions

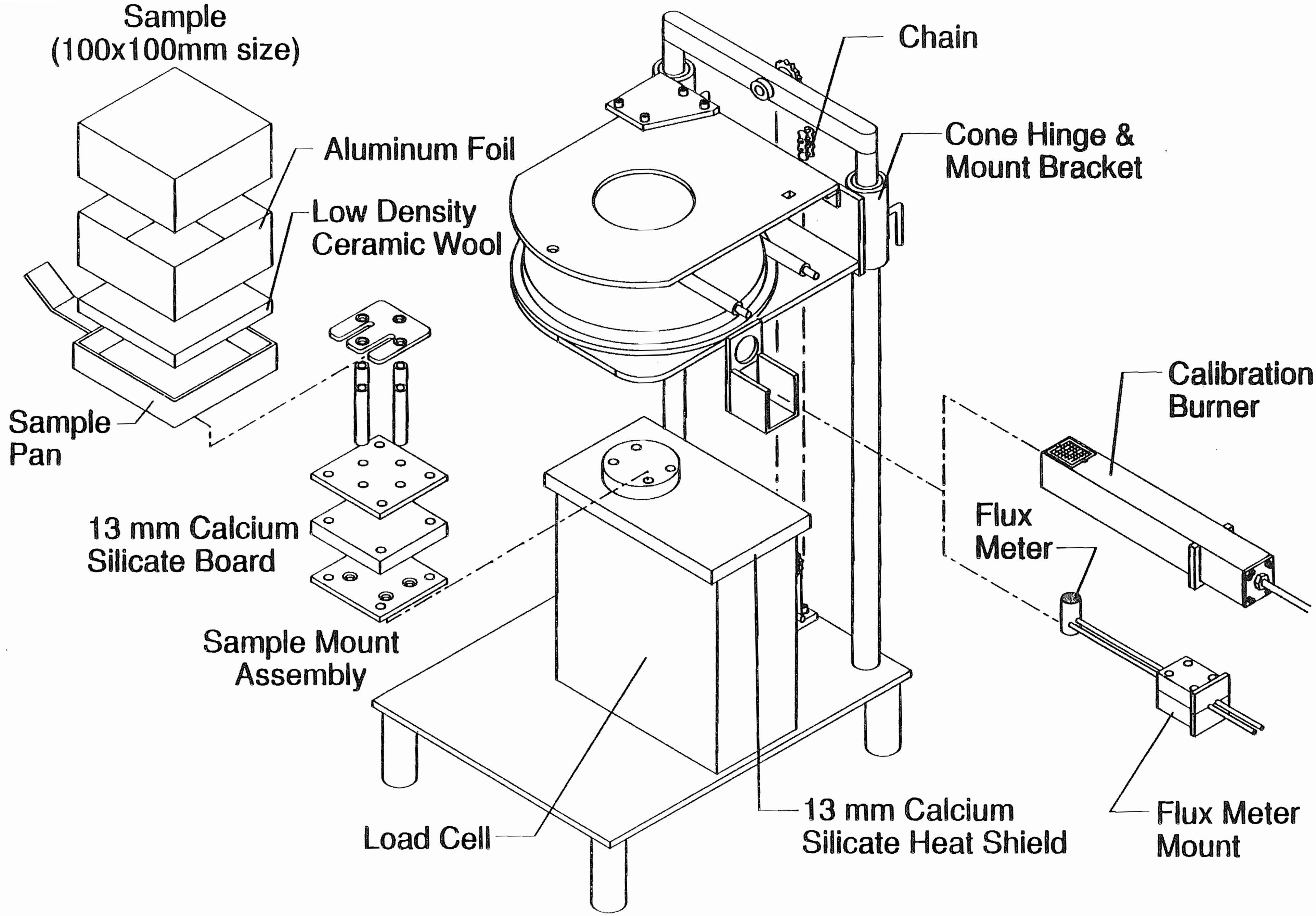


Figure A3. Horizontal orientation, exploded view

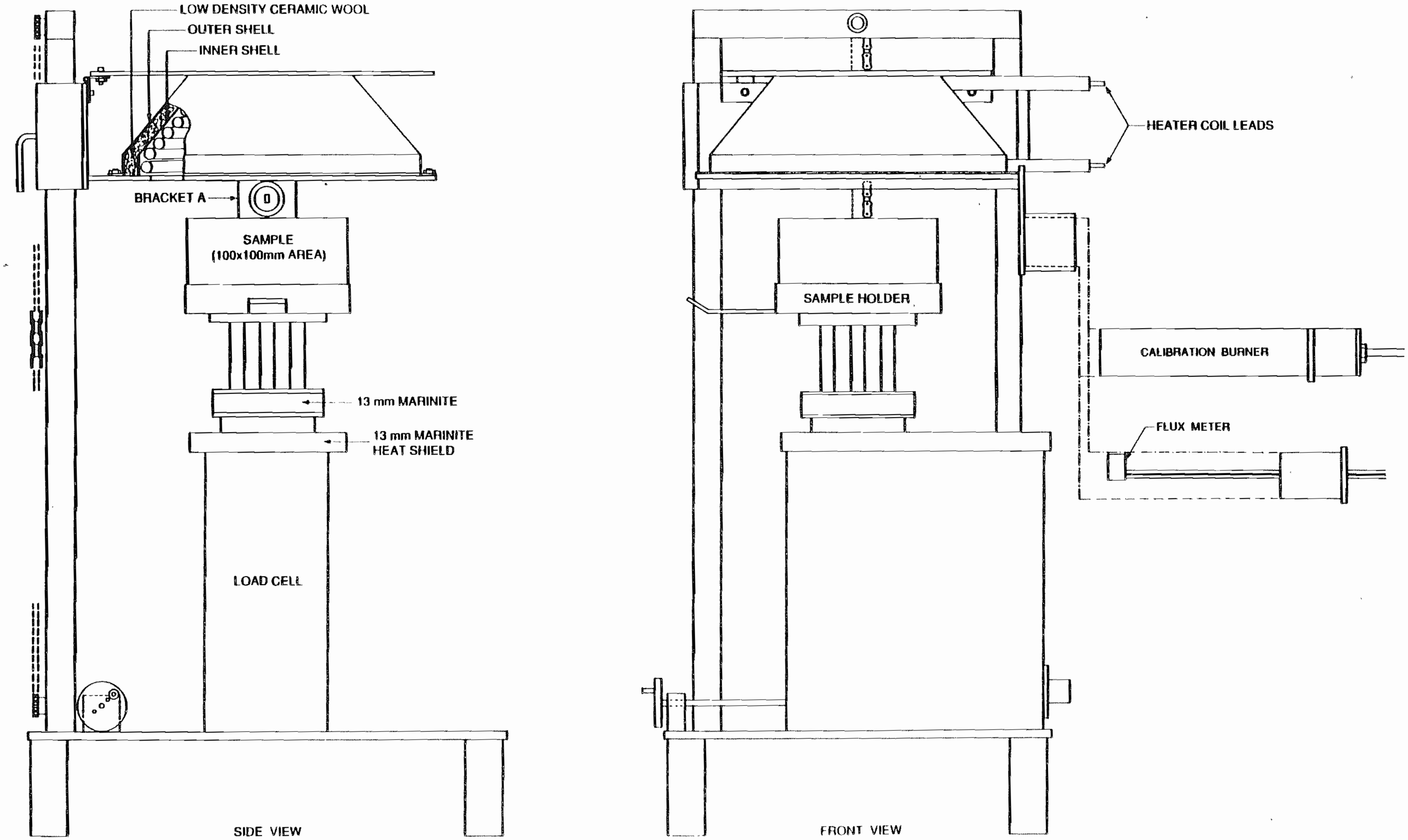


Figure A4. Horizontal orientation, section and elevation

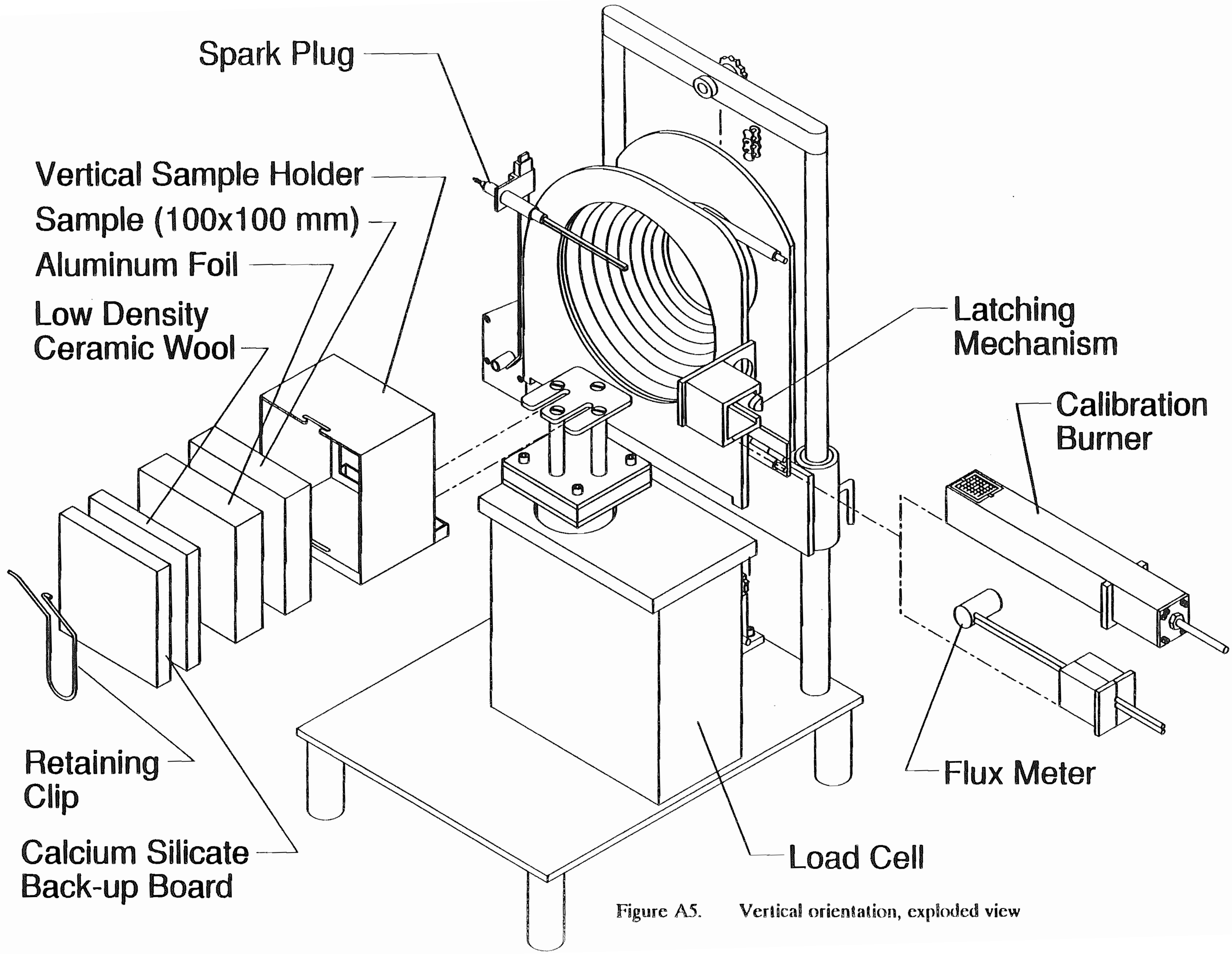


Figure A5. Vertical orientation, exploded view

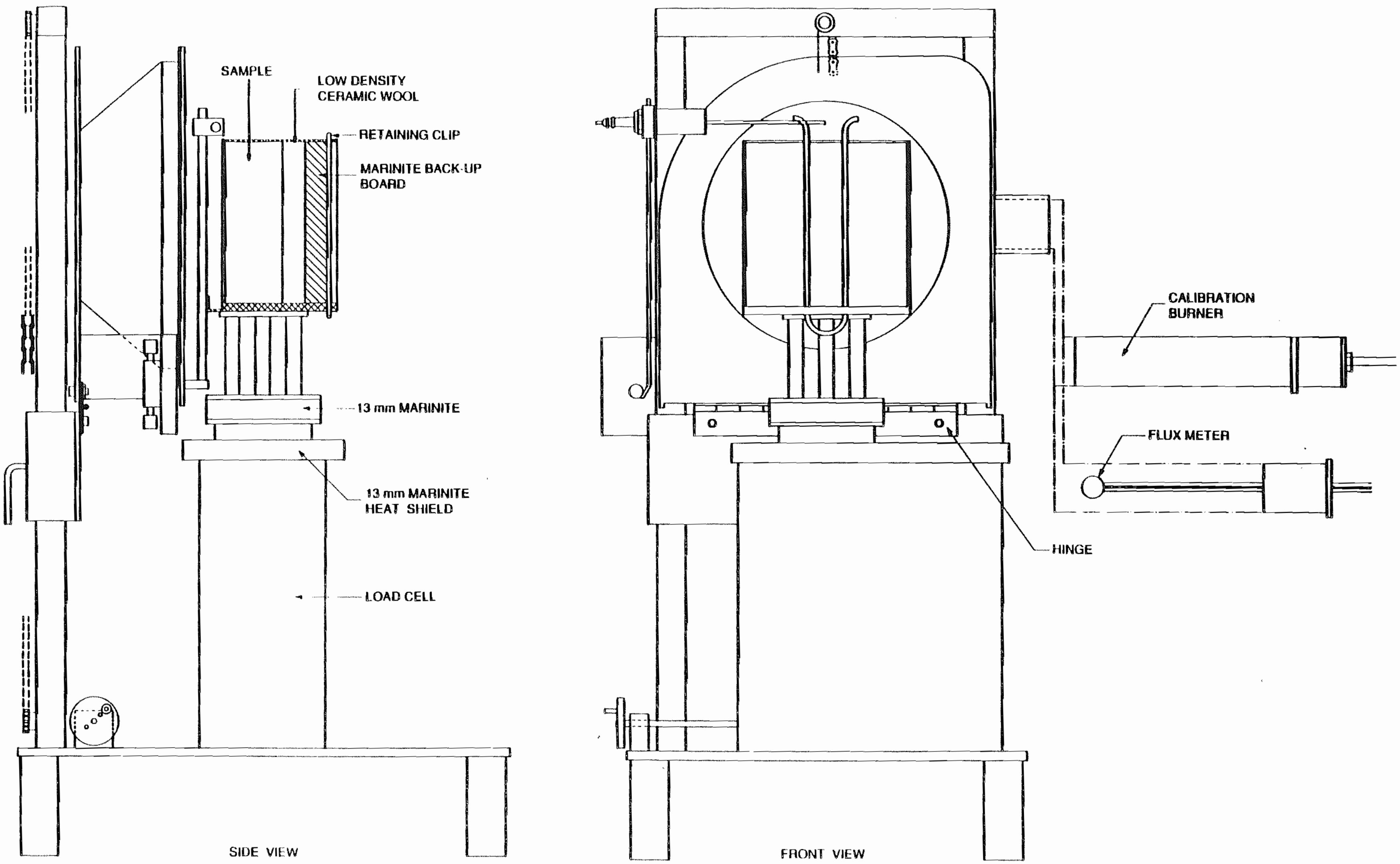


Figure A6. Vertical orientation, section and elevation

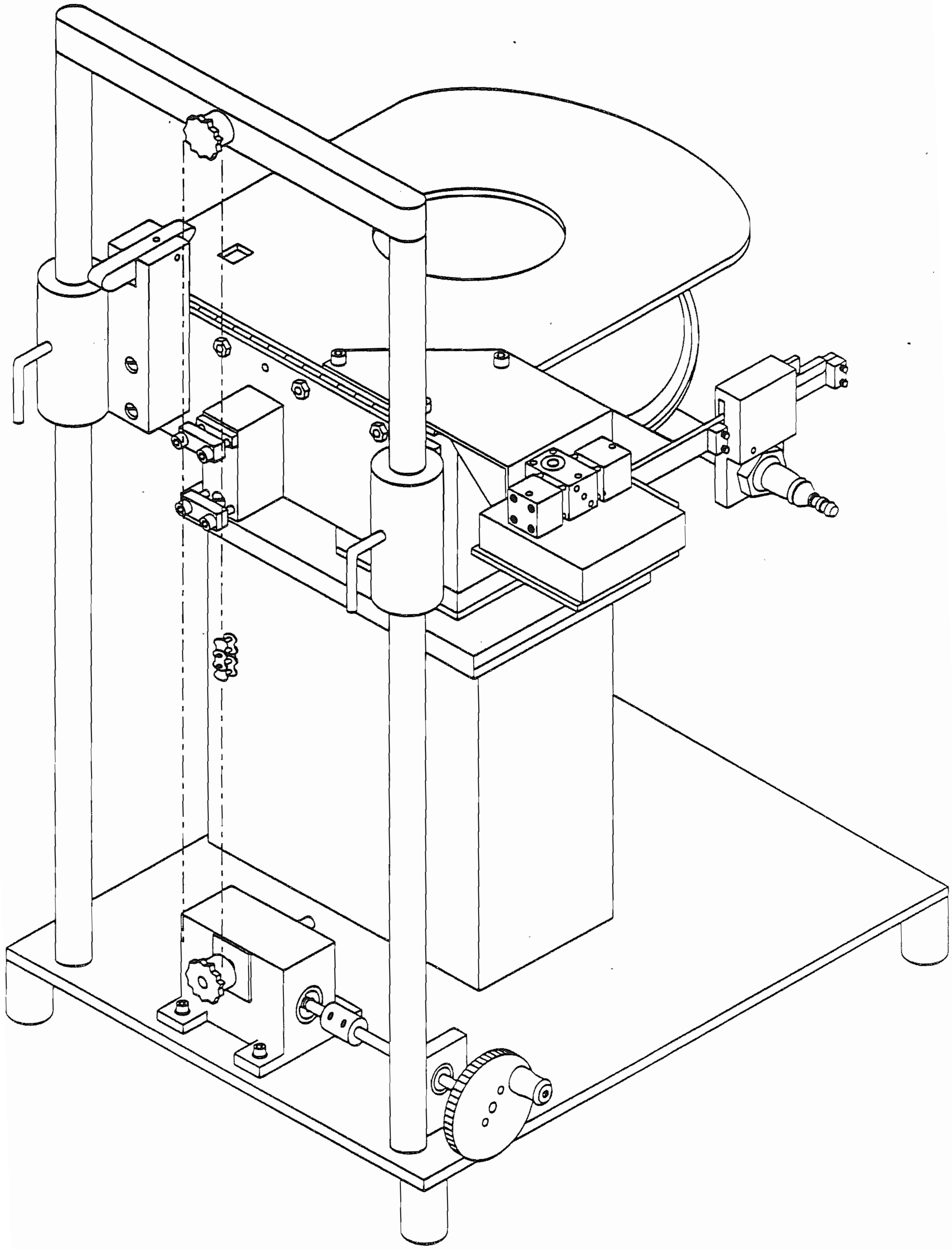


Figure A7. Installation of latching mechanism and chain lift mechanism

Figure A8. Deleted

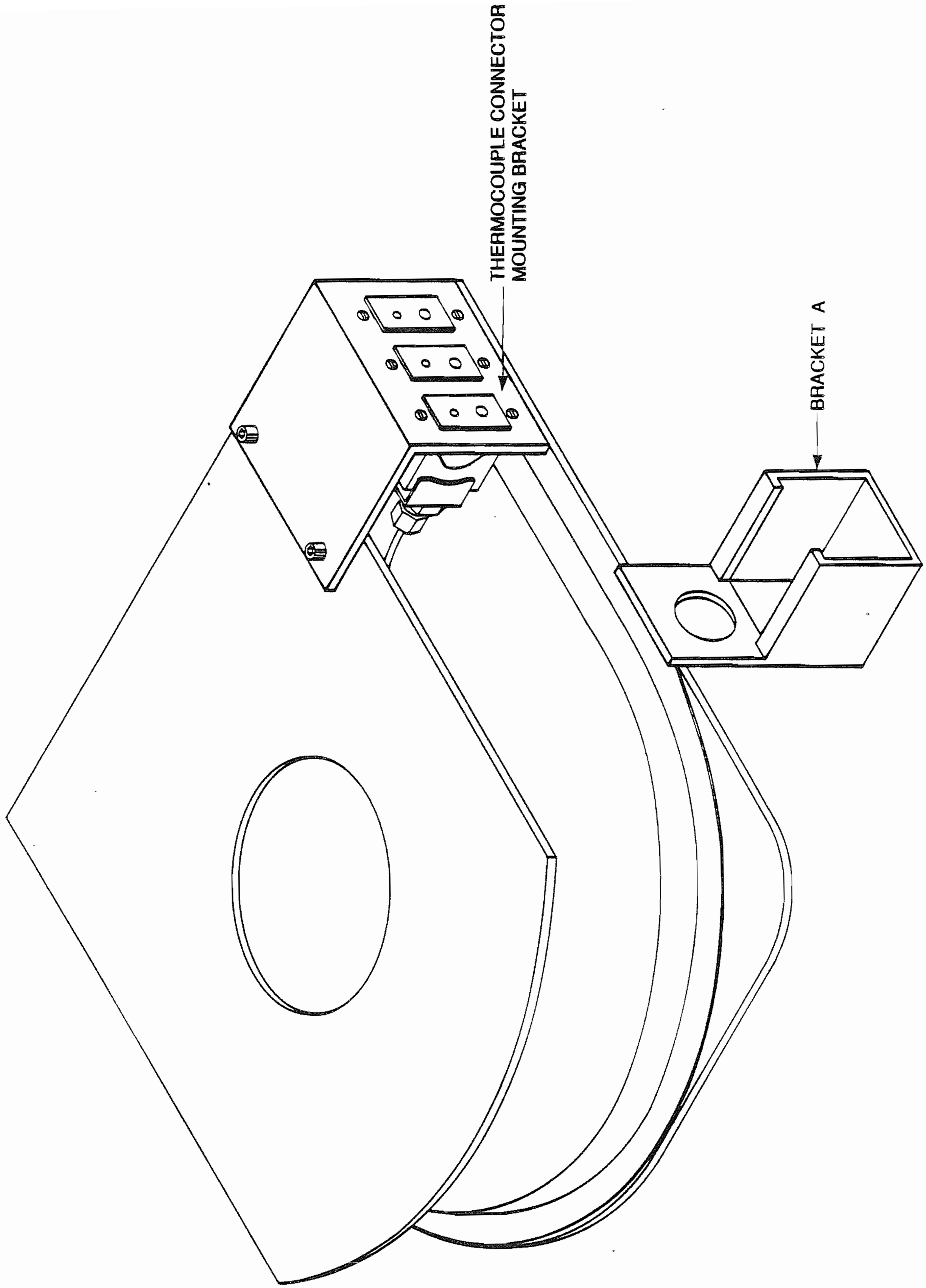


Figure A9. Location of thermocouple bracket

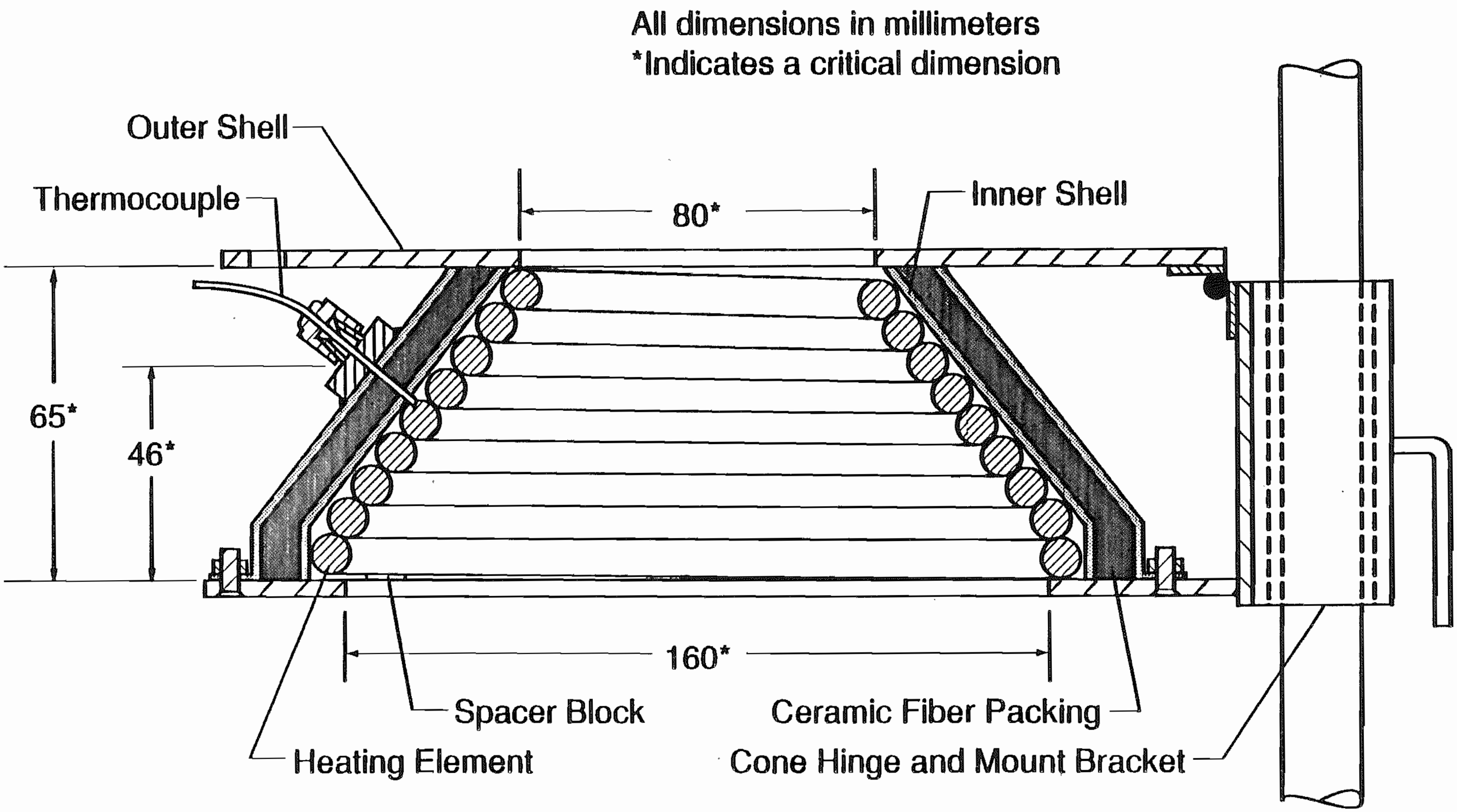


Figure A10. Section through cone heater

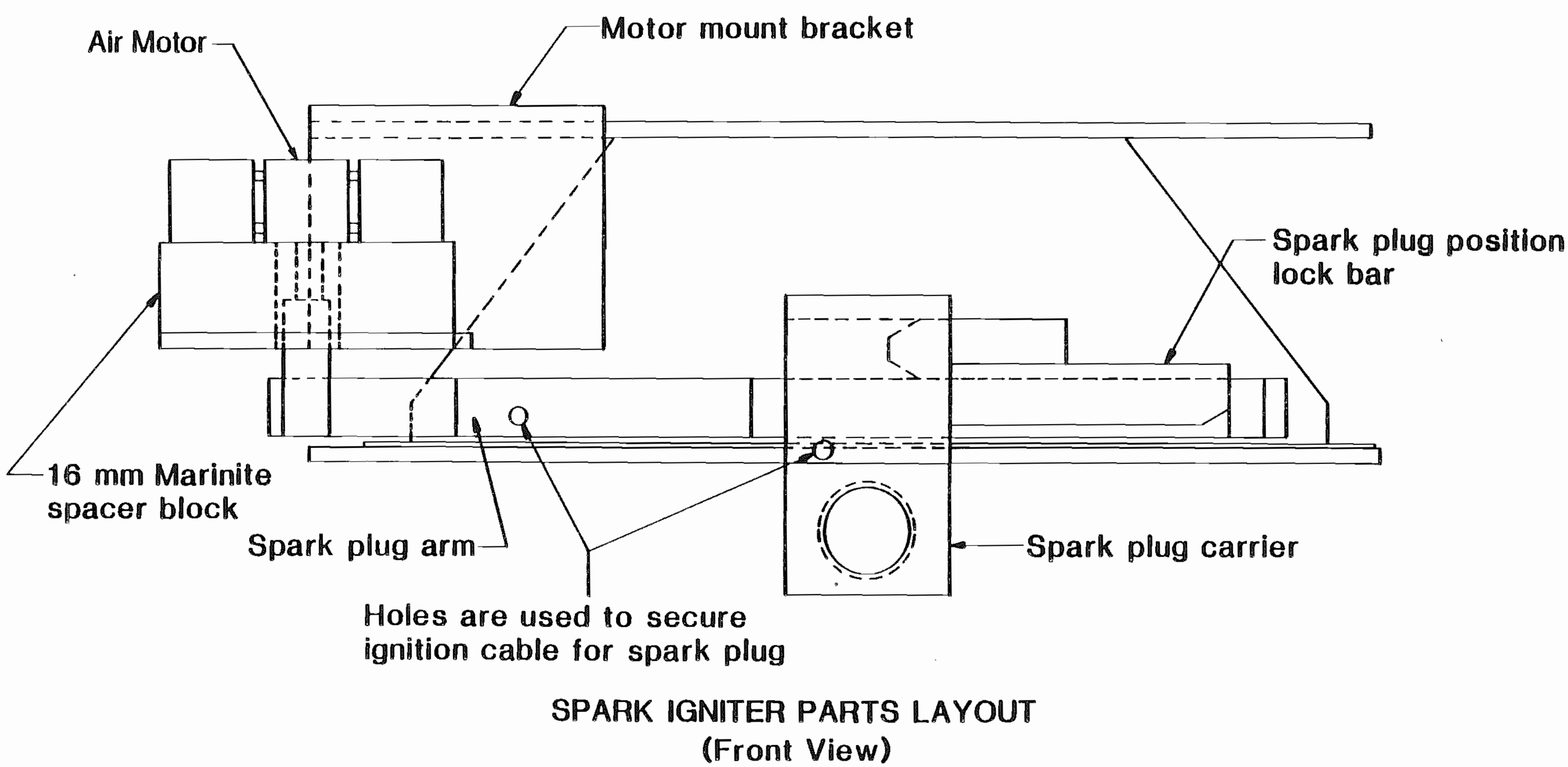


Figure A11. Spark igniter parts layout, front view

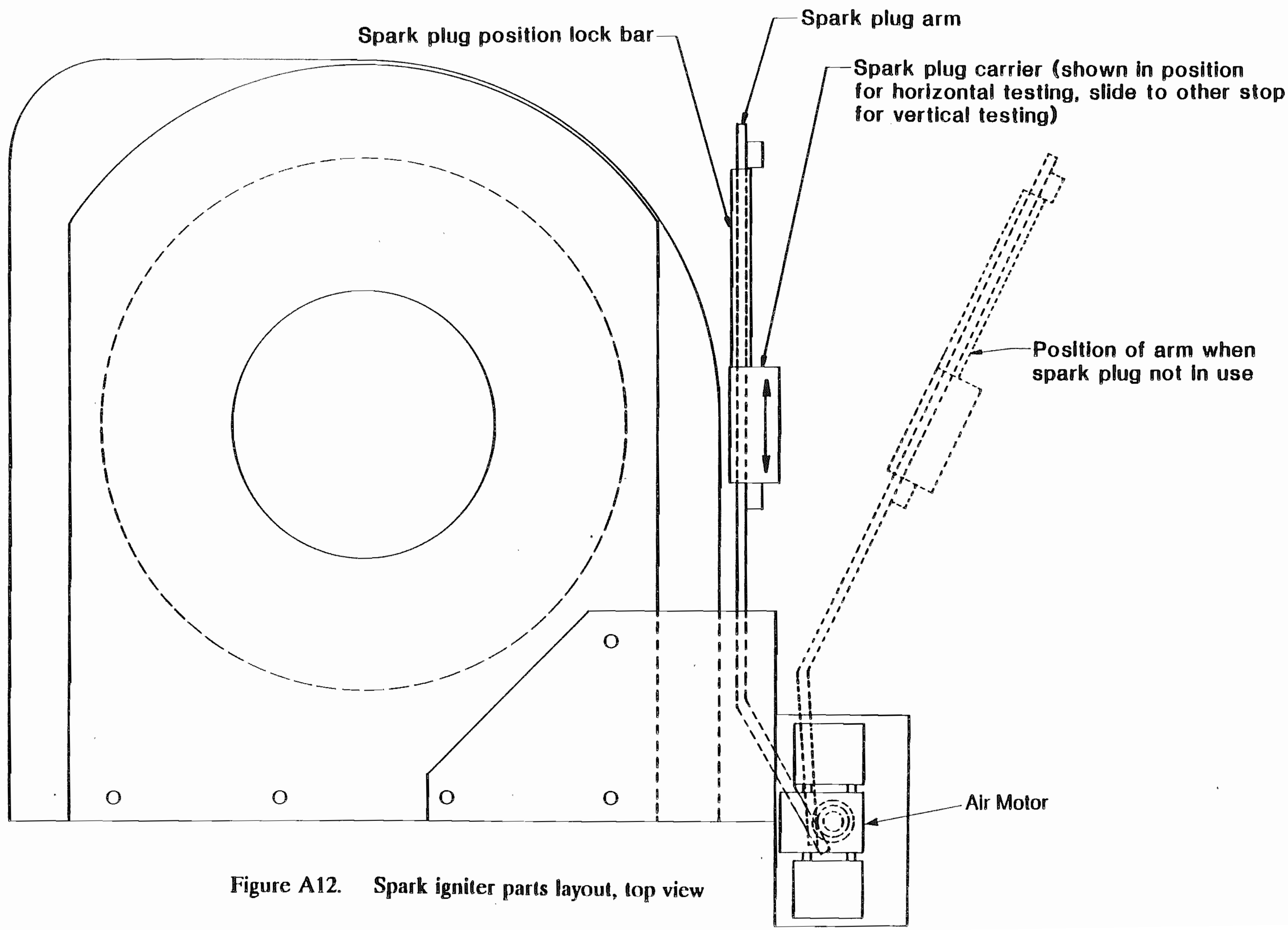


Figure A12. Spark igniter parts layout, top view

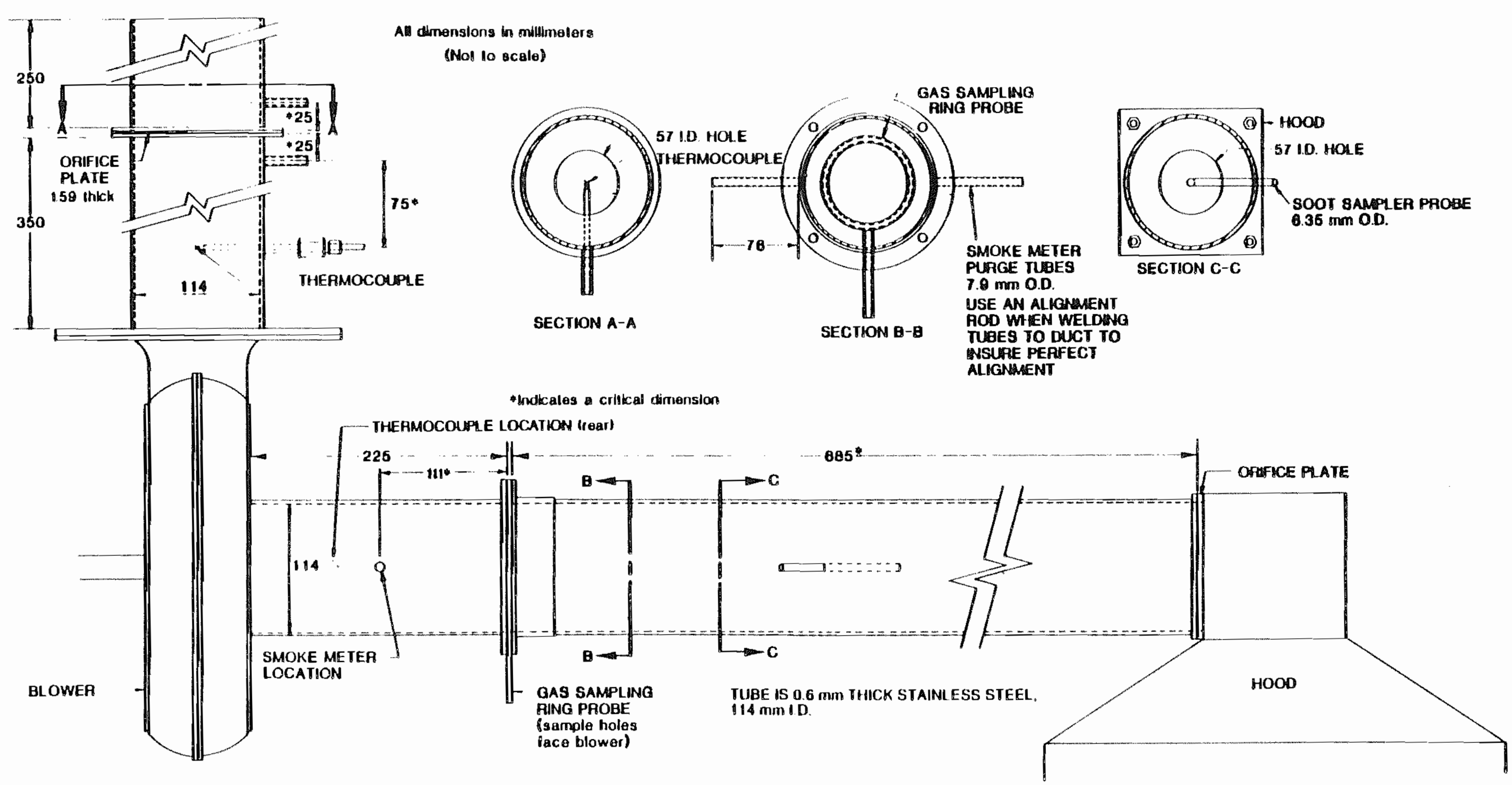


Figure A13. Assembly details for the exhaust system

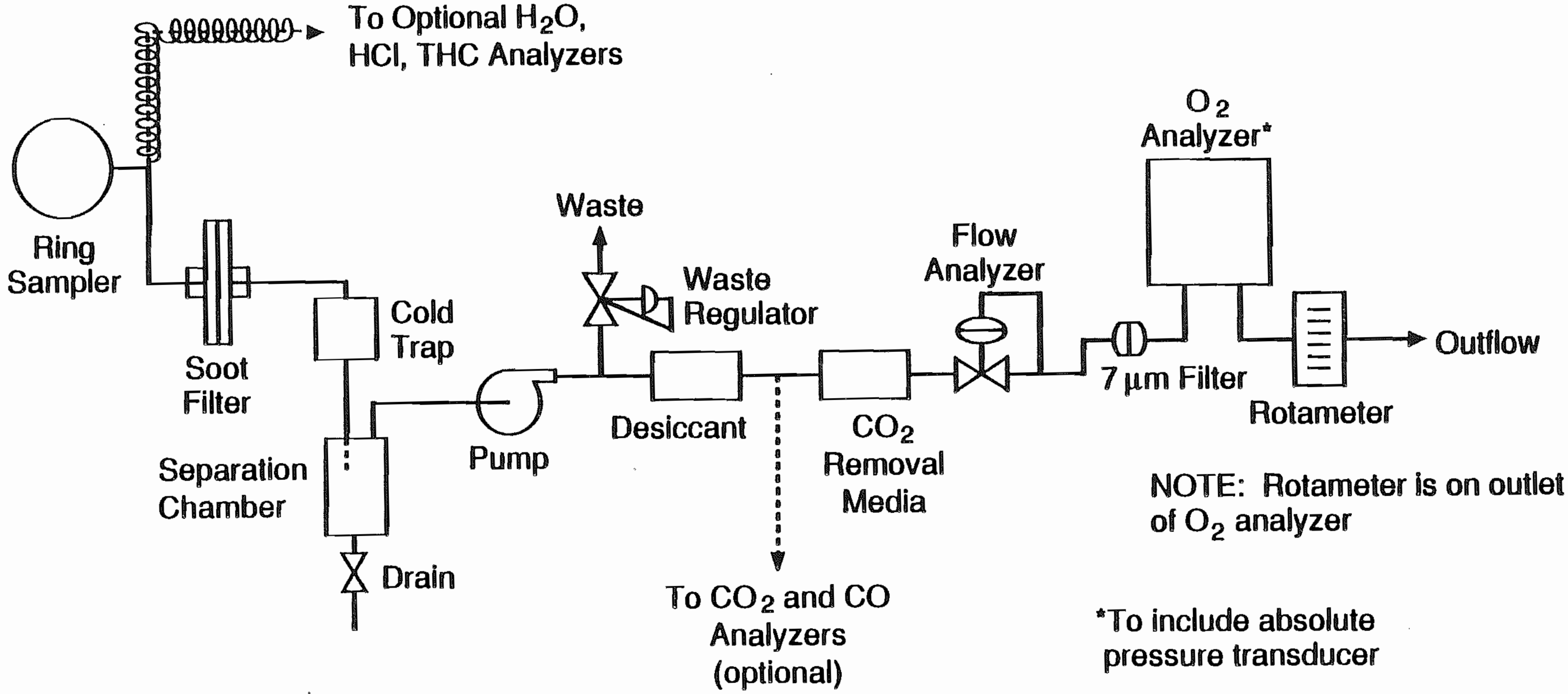


Figure A14. Gas sampling train (ambient temperature analyzers)

A - Hood to collect smoke from burning sample
B - Exhaust duct
C - Variable speed exhaust blower
D - Heat wrapped stainless steel probe line
E - T-junction
F - Heated particulate filter
G - Sample transfer line (PTFE)
H - Dryer (Perma-Pure)
I - Throttling valve
J - To a source of vacuum to remove spent purge gas
K - Heat wrapping
L - Sample gas inlet at analyzer
M - GFC analyzer with built-in sampling pump
N - Room air inlet for purge flow

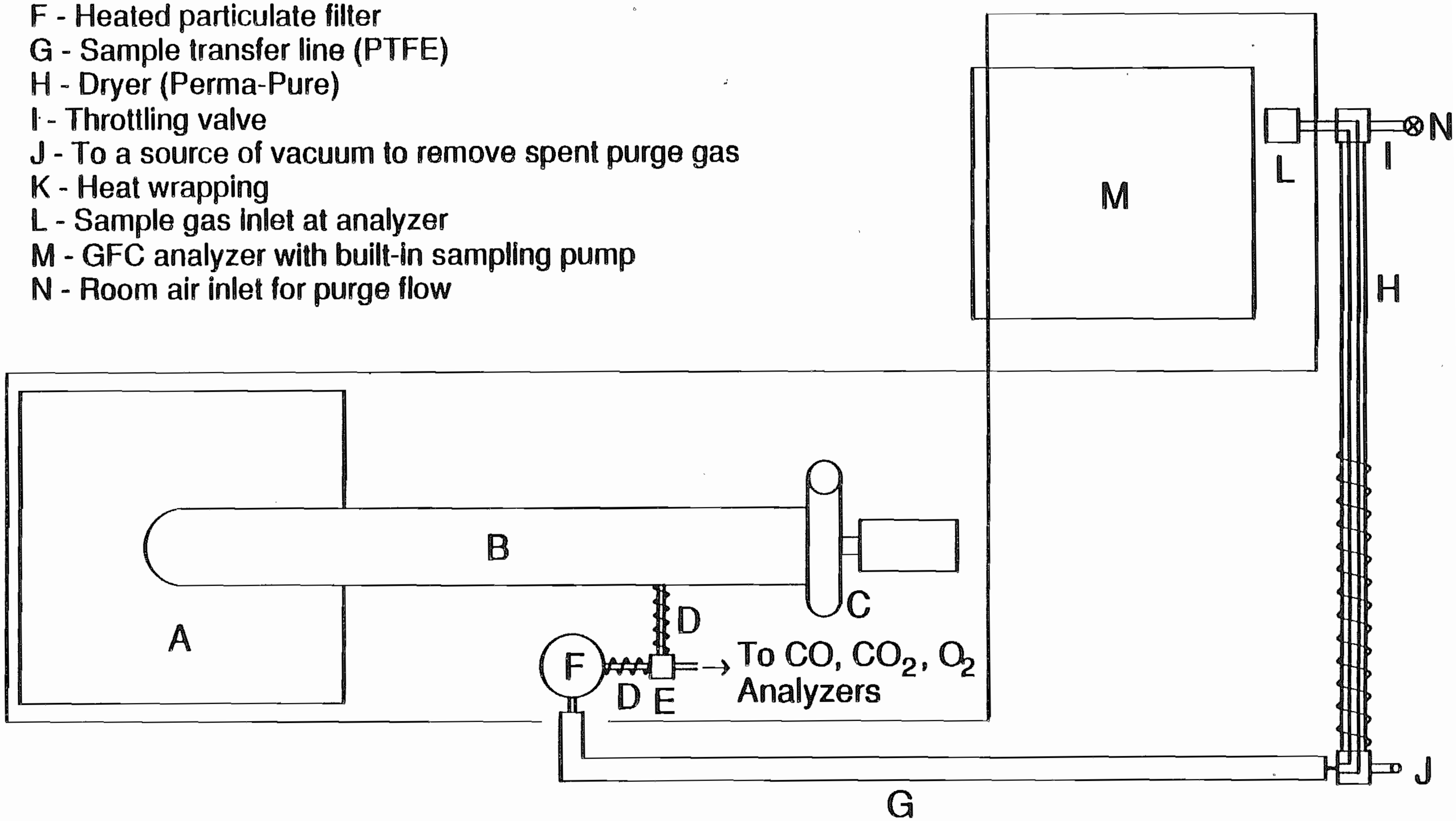


Figure A14-A. Gas sampling train (heated analyzers)

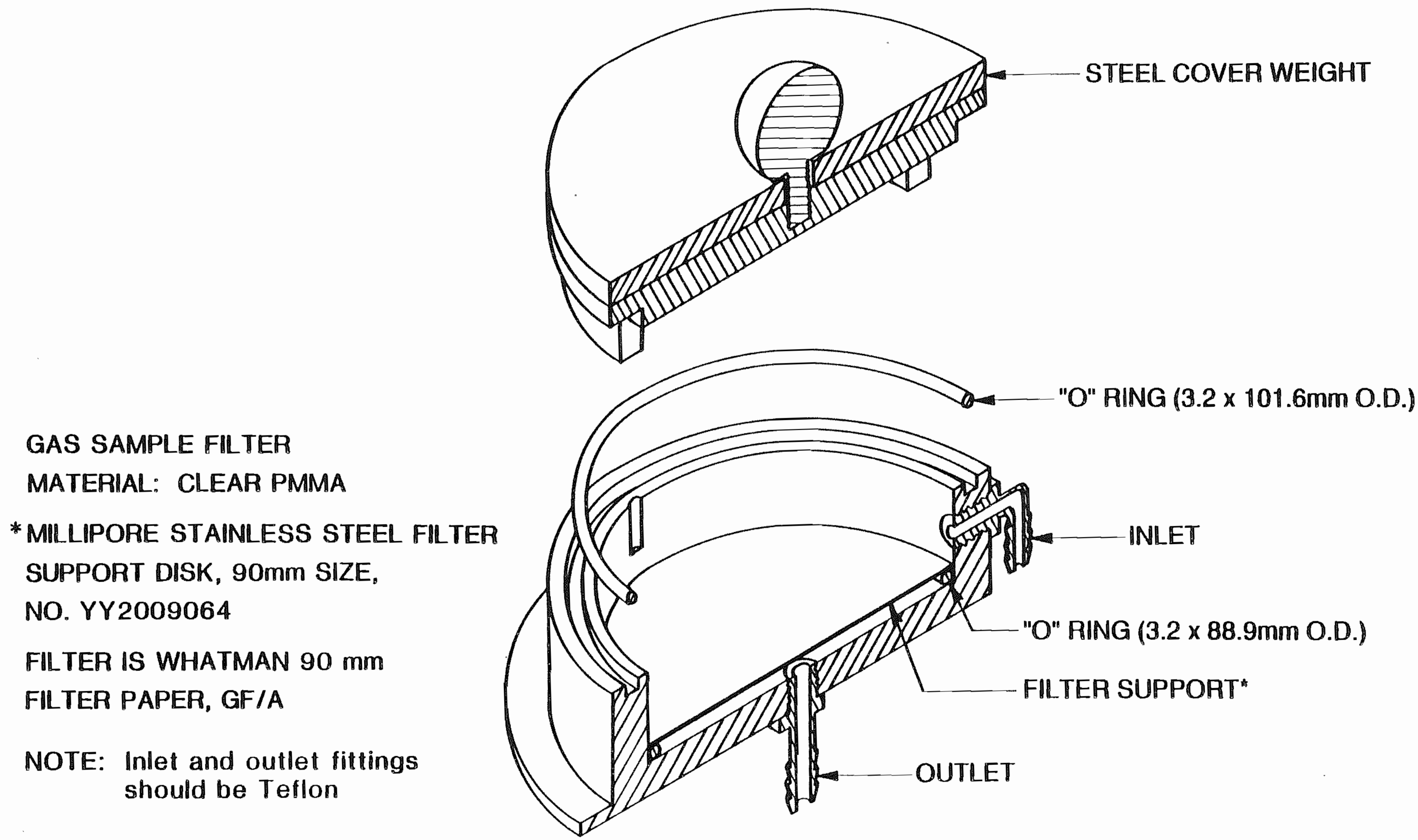


Figure A15. Filter holder for removing soot from gas sampling line

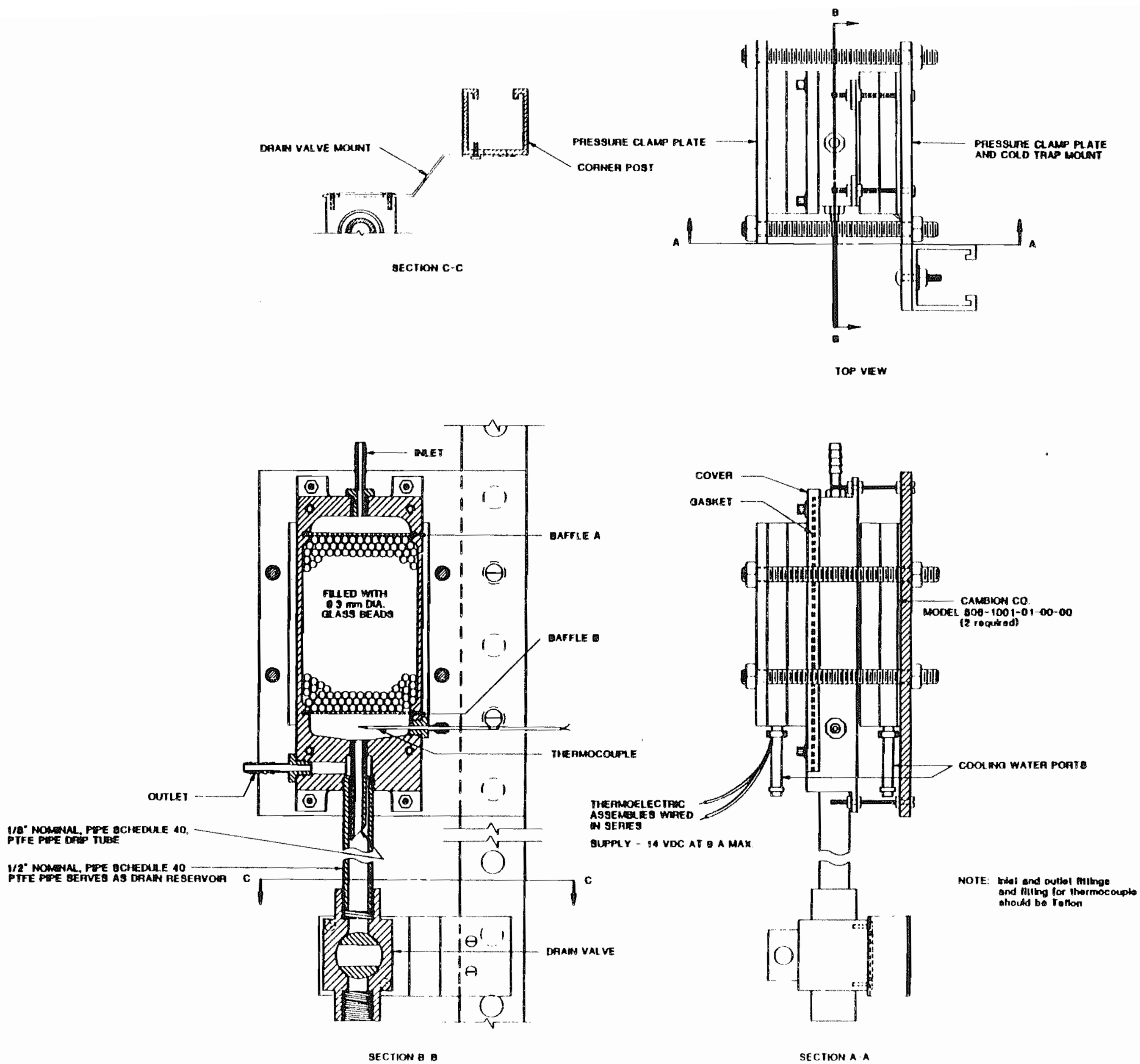


Figure A16. Thermoelectric cold trap and pressure clamp plate with mounts

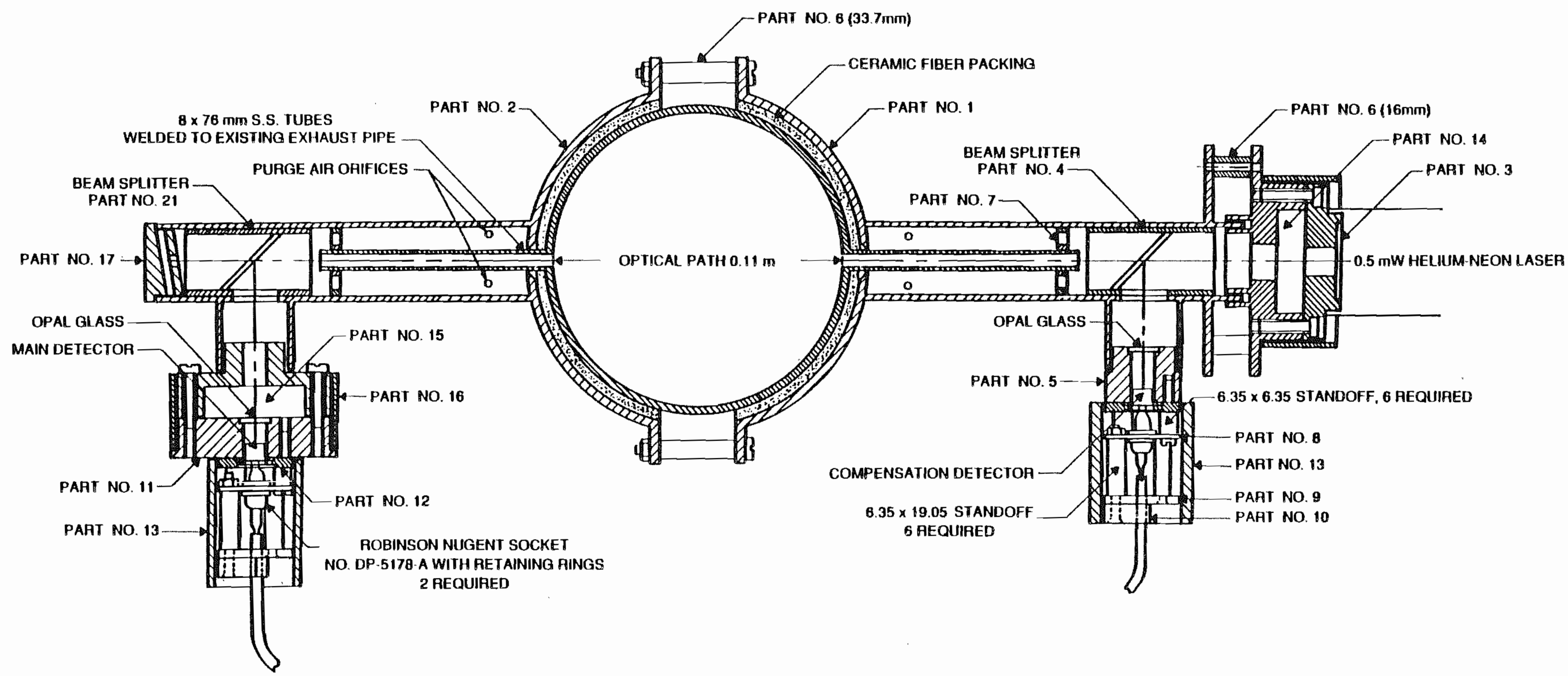


Figure A17. Laser extinction beam

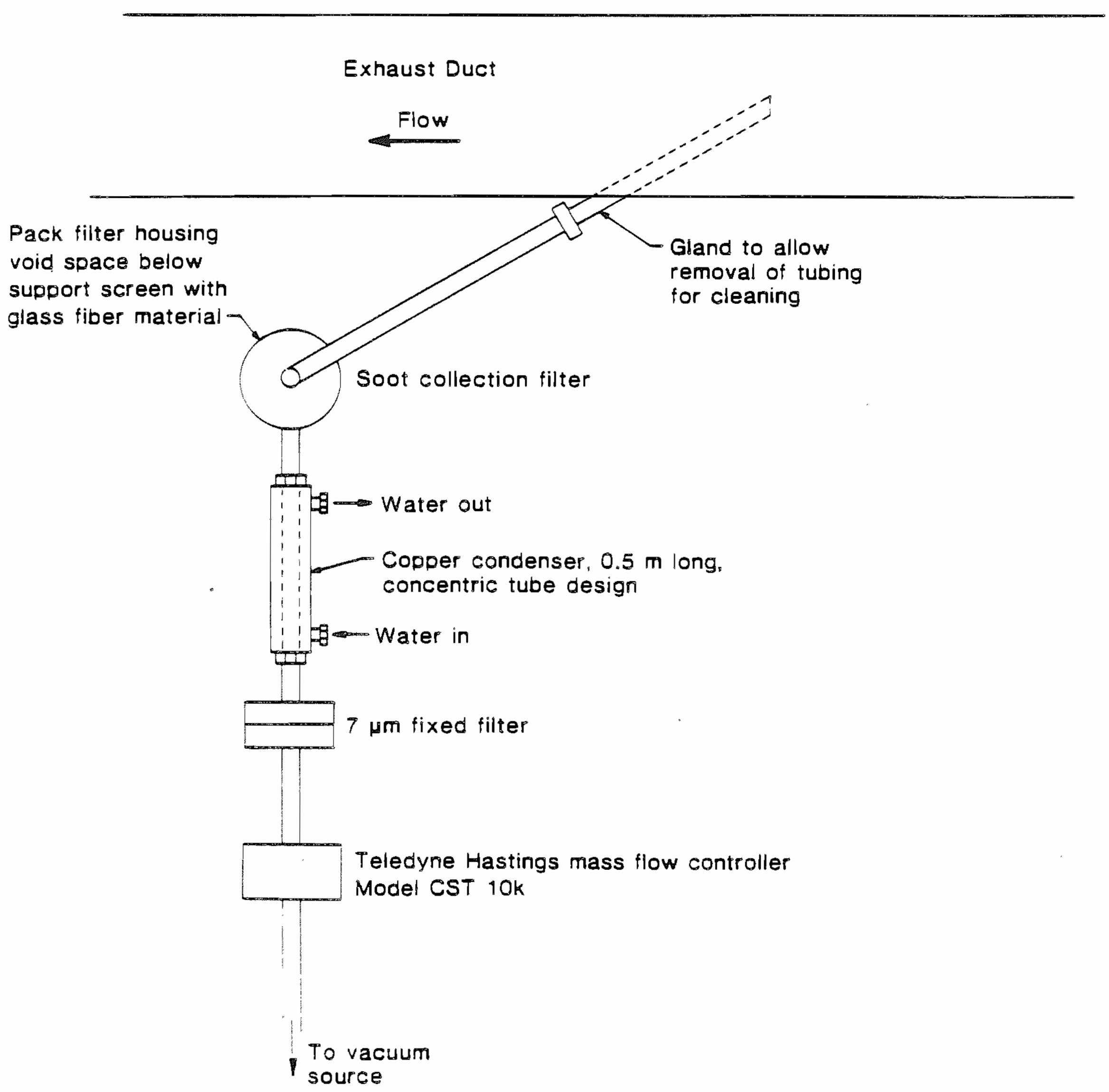


Figure A18. Sampling train for collecting soot samples

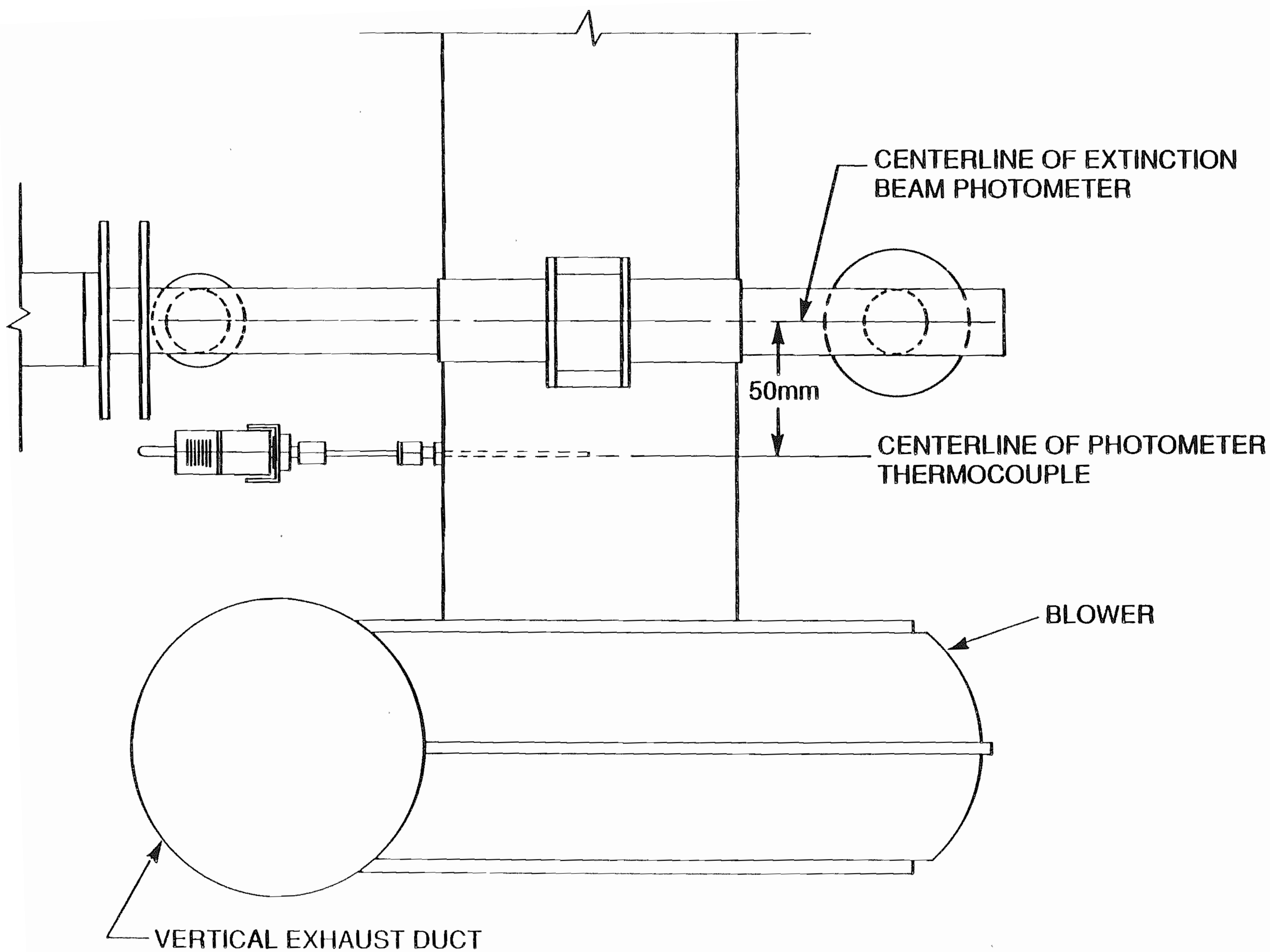


Figure A19. Thermocouple location for laser extinction beam

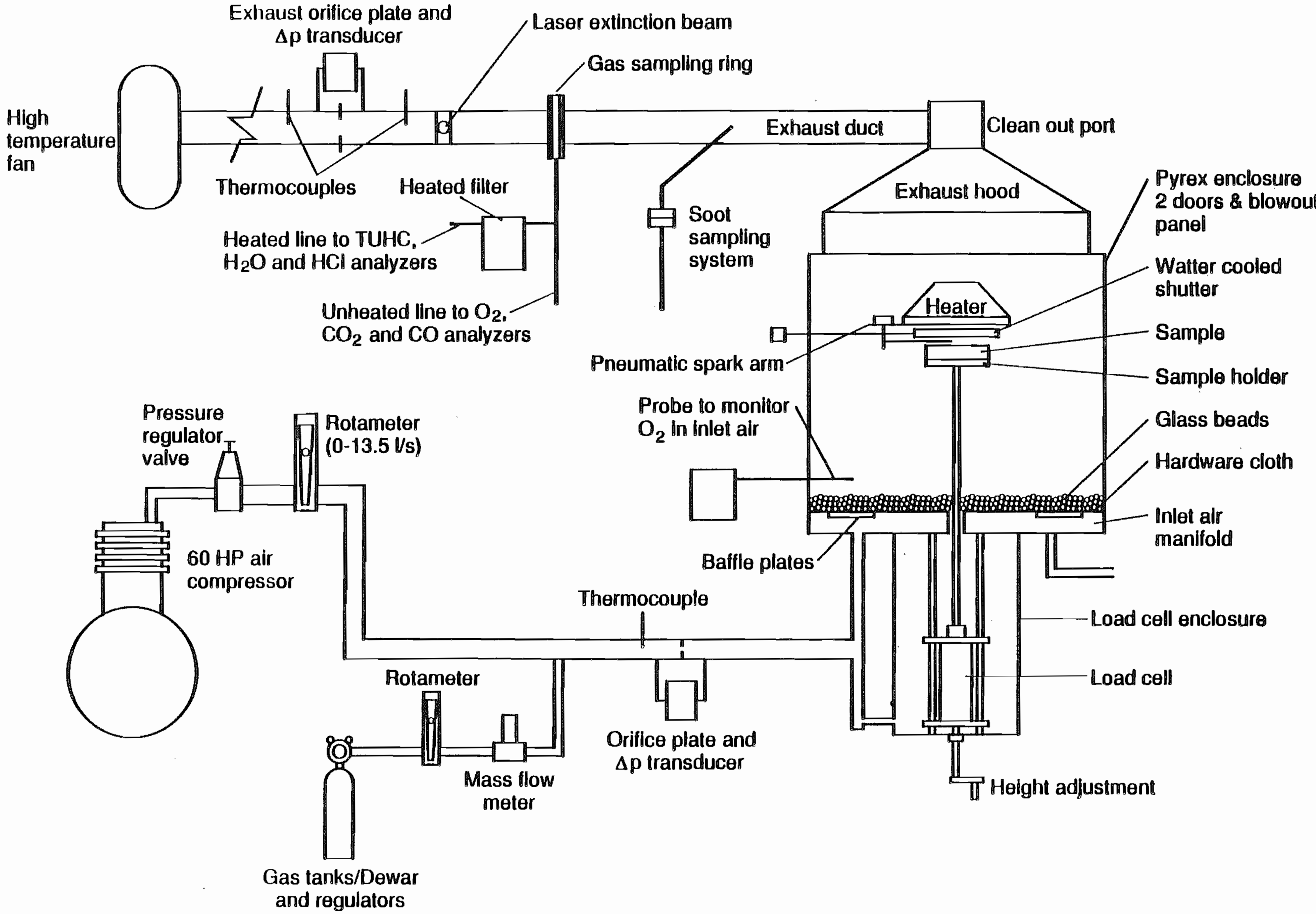


Figure A20. Conceptual view of controlled-atmospheres unit

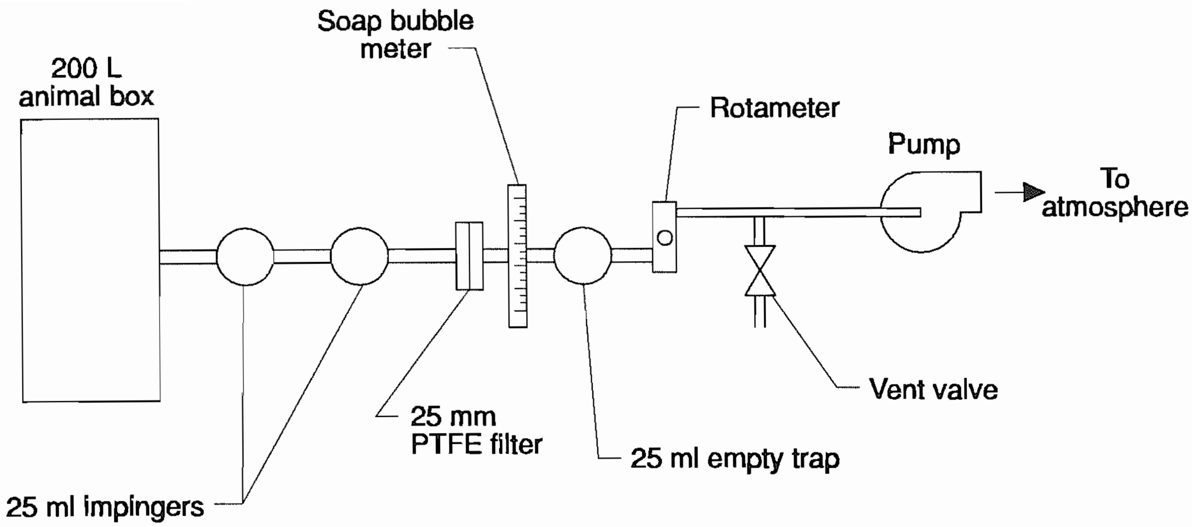


Figure A21. Gas sampling apparatus for ion chromatography

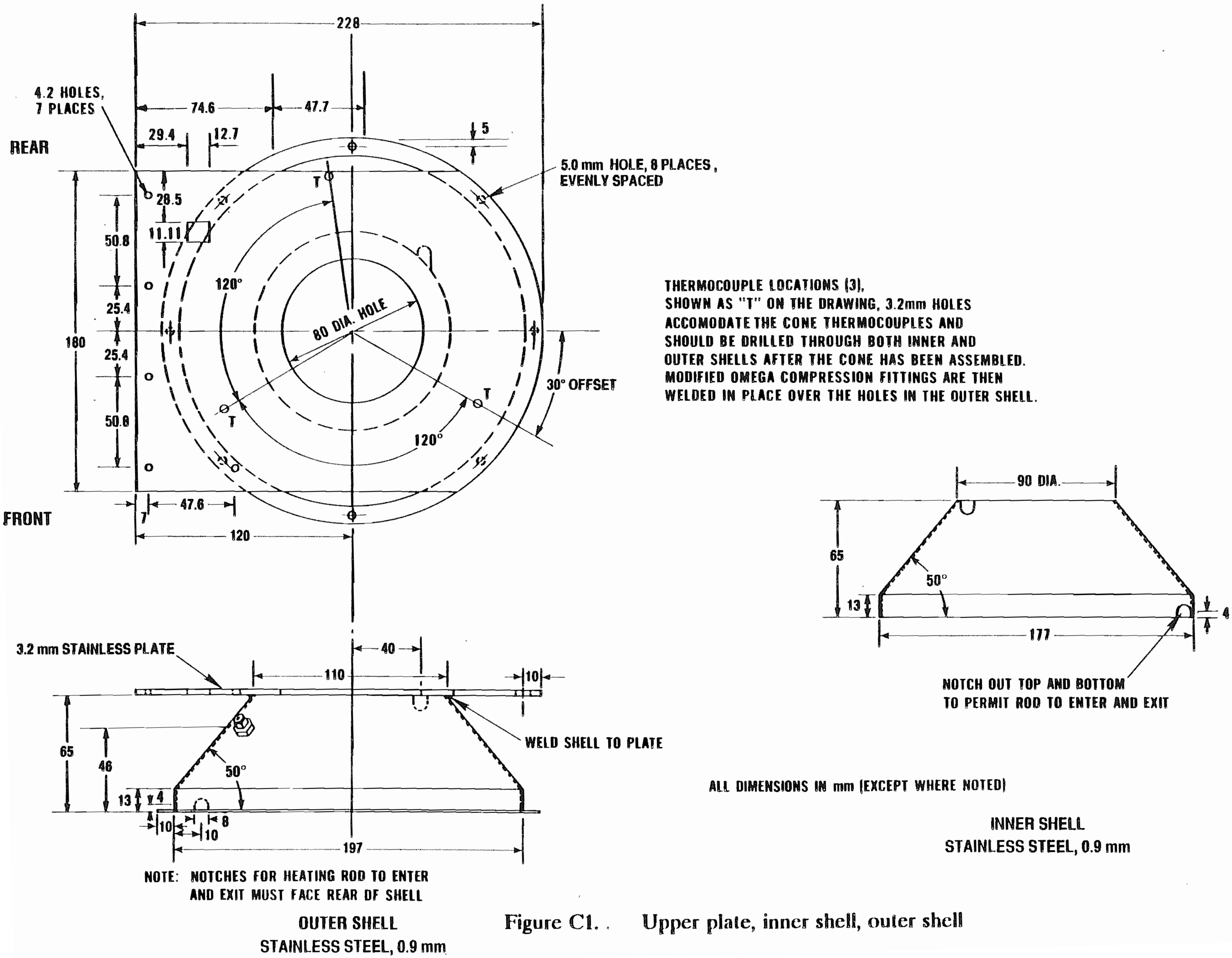


Figure C1. Upper plate, inner shell, outer shell

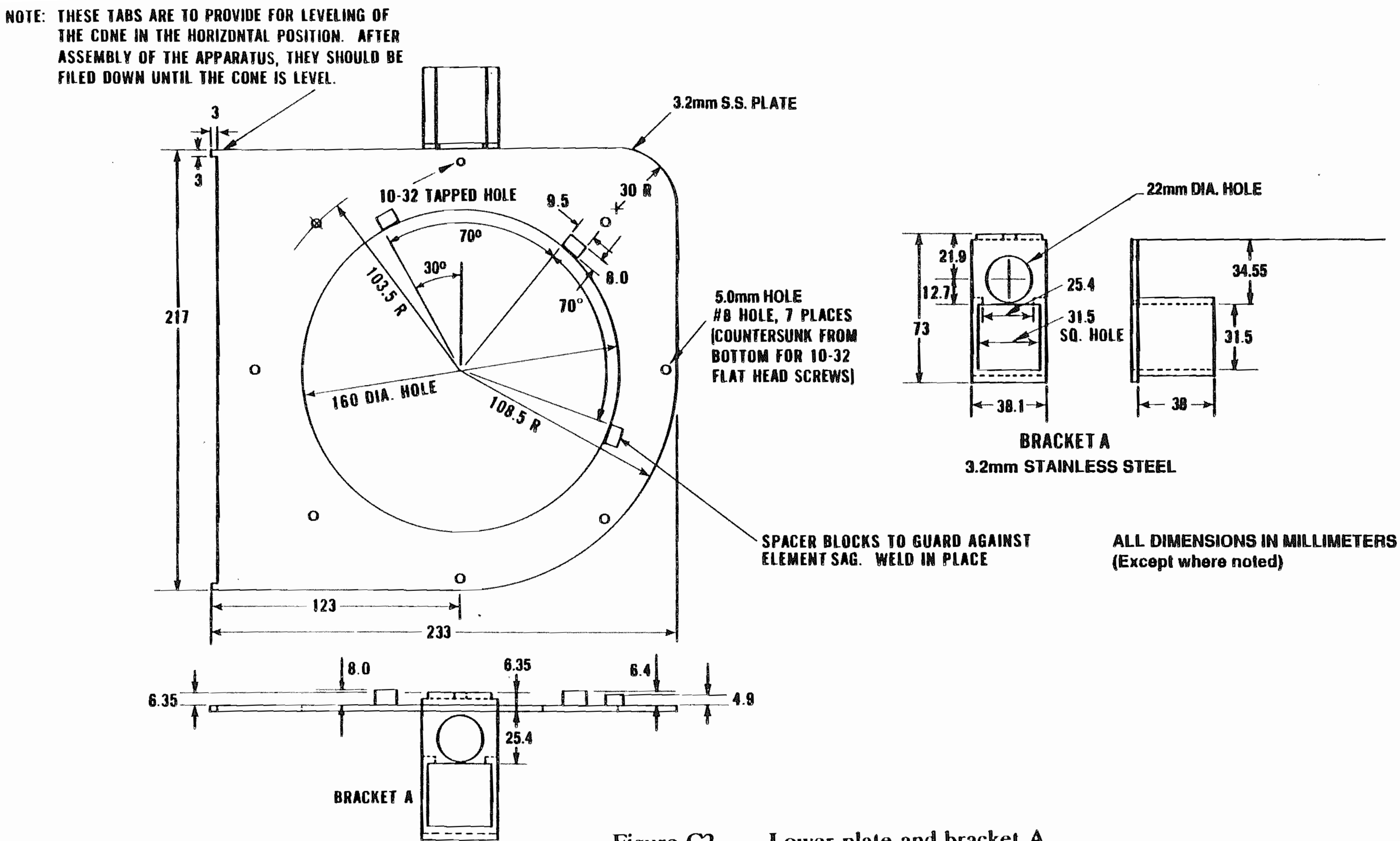
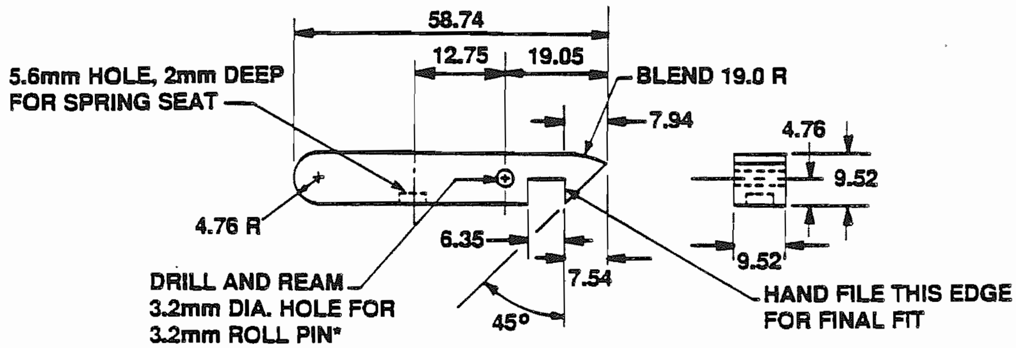


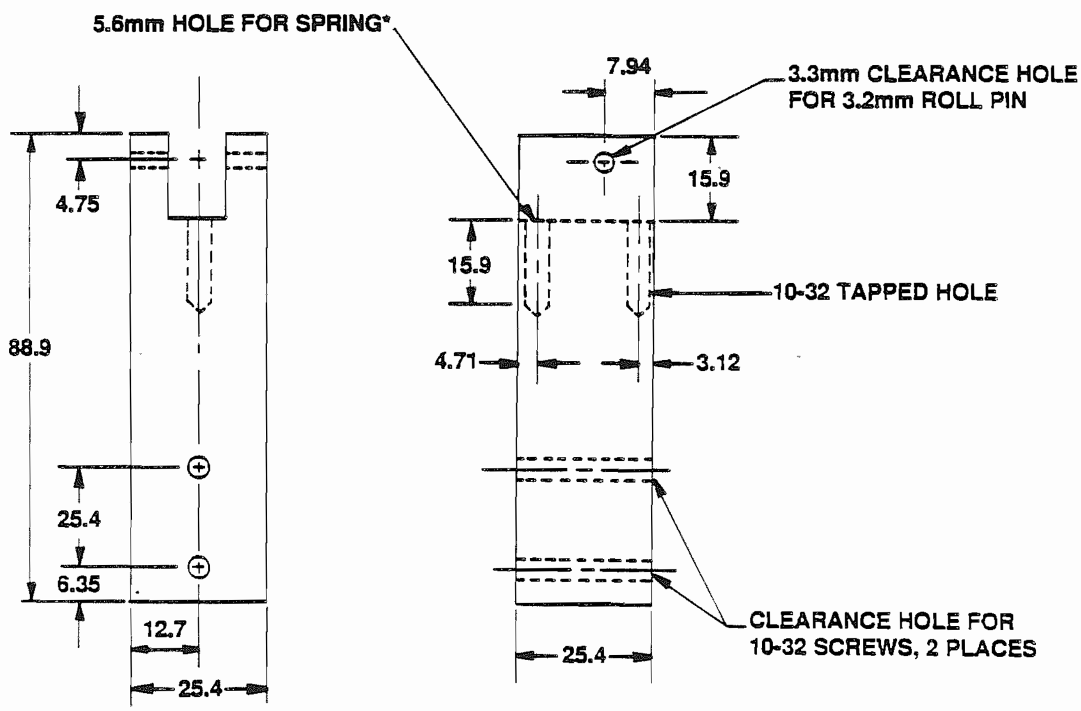
Figure C2. Lower plate and bracket A



CATCH
MATERIAL: 9.5 x 9.5mm STAINLESS STEEL

*1 ROLL PIN REQUIRED.
IT IS 3.2mm DIA. STAINLESS STEEL ROD, 25.4mm LONG

ALL DIMENSIONS IN MILLIMETERS
(Except where noted)



PIVOT BLOCK
MATERIAL: 25.4 x 25.4
STAINLESS STEEL

*ONE SPRING REQUIRED, WOUND WITH 1.0mm S.S. WIRE, SHOULD BE 5.3mm O.D. x 25.4mm LONG AND REQUIRE APPROX. 4 KG TO COMPRESS TO 22.2mm

Figure C3. Latching mechanism

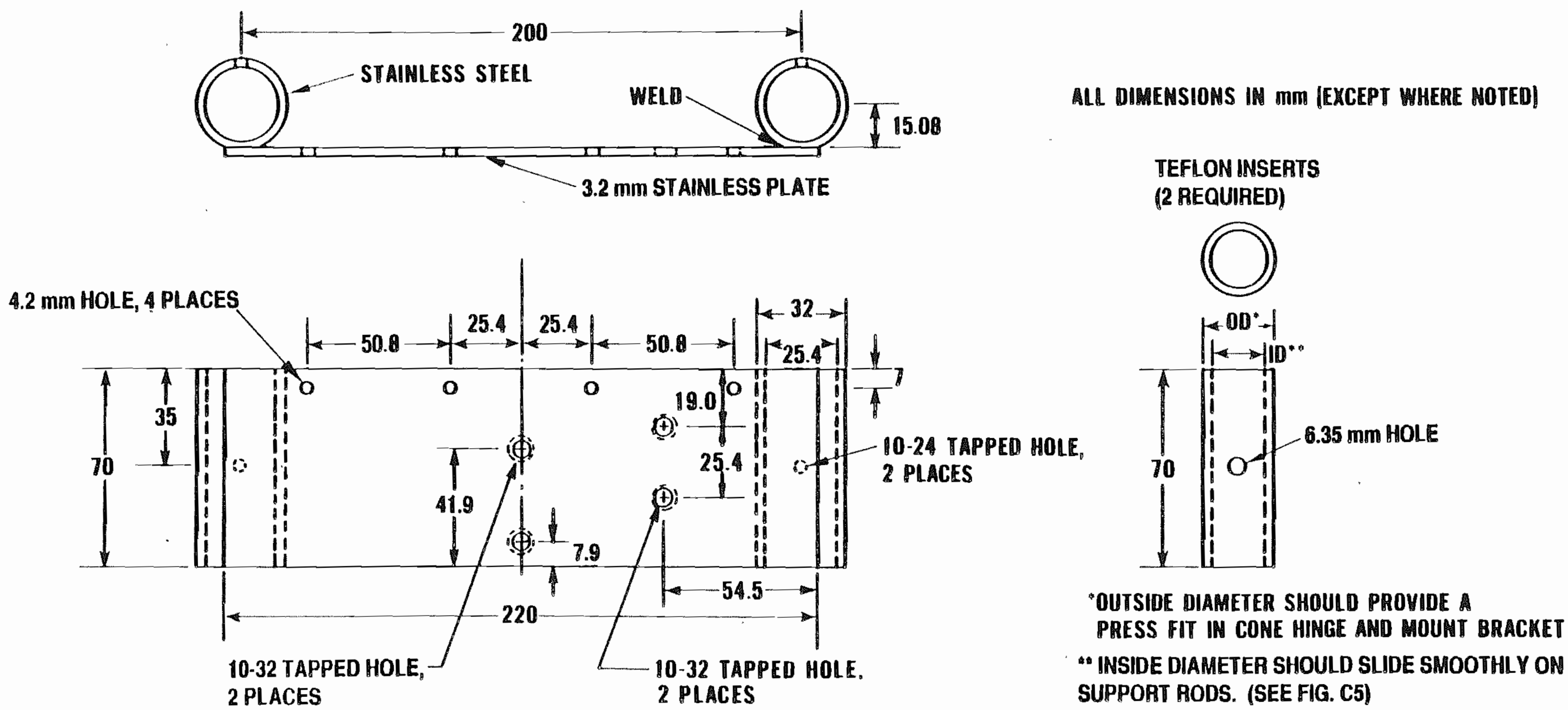


Figure C4. Sliding bracket

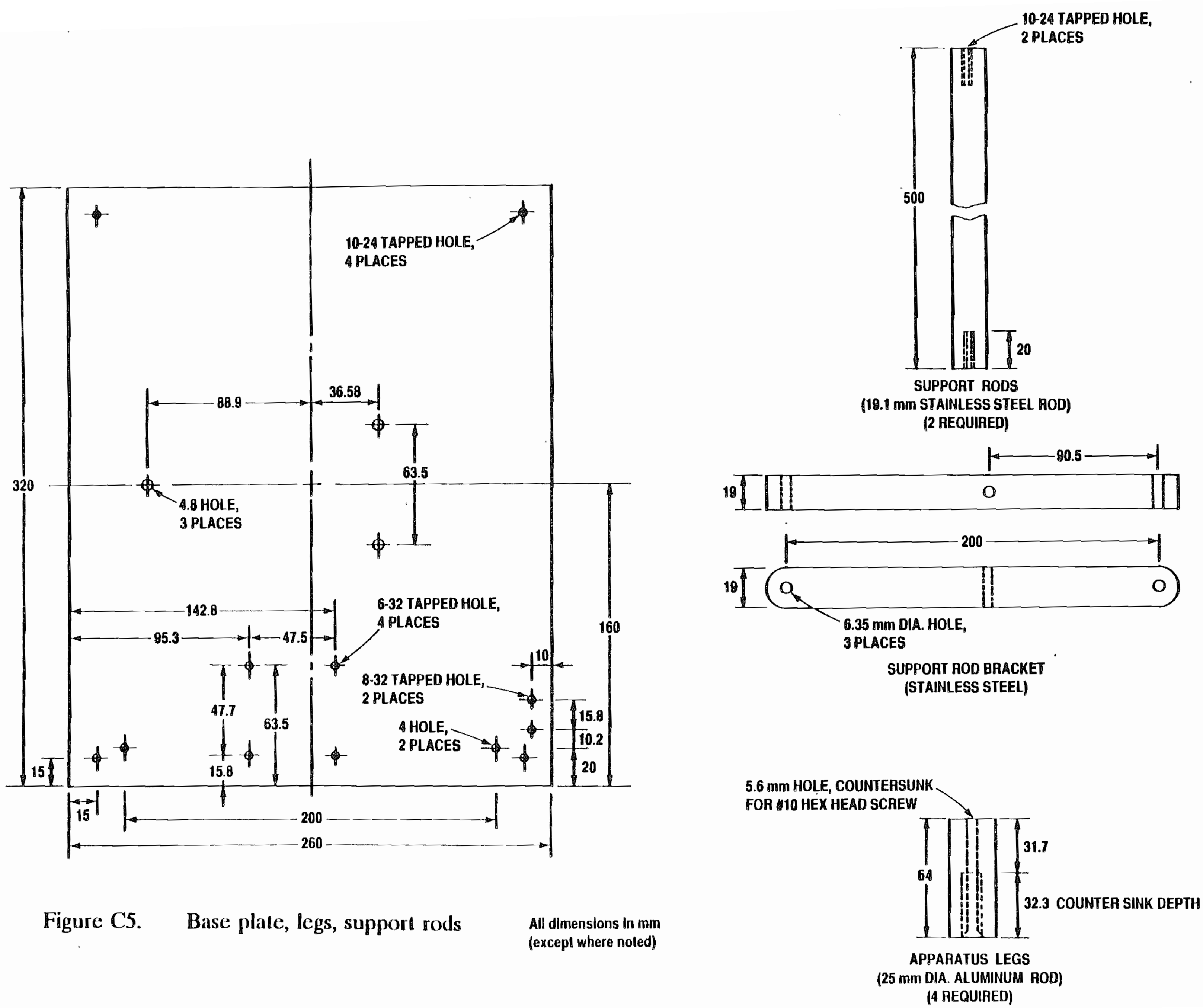
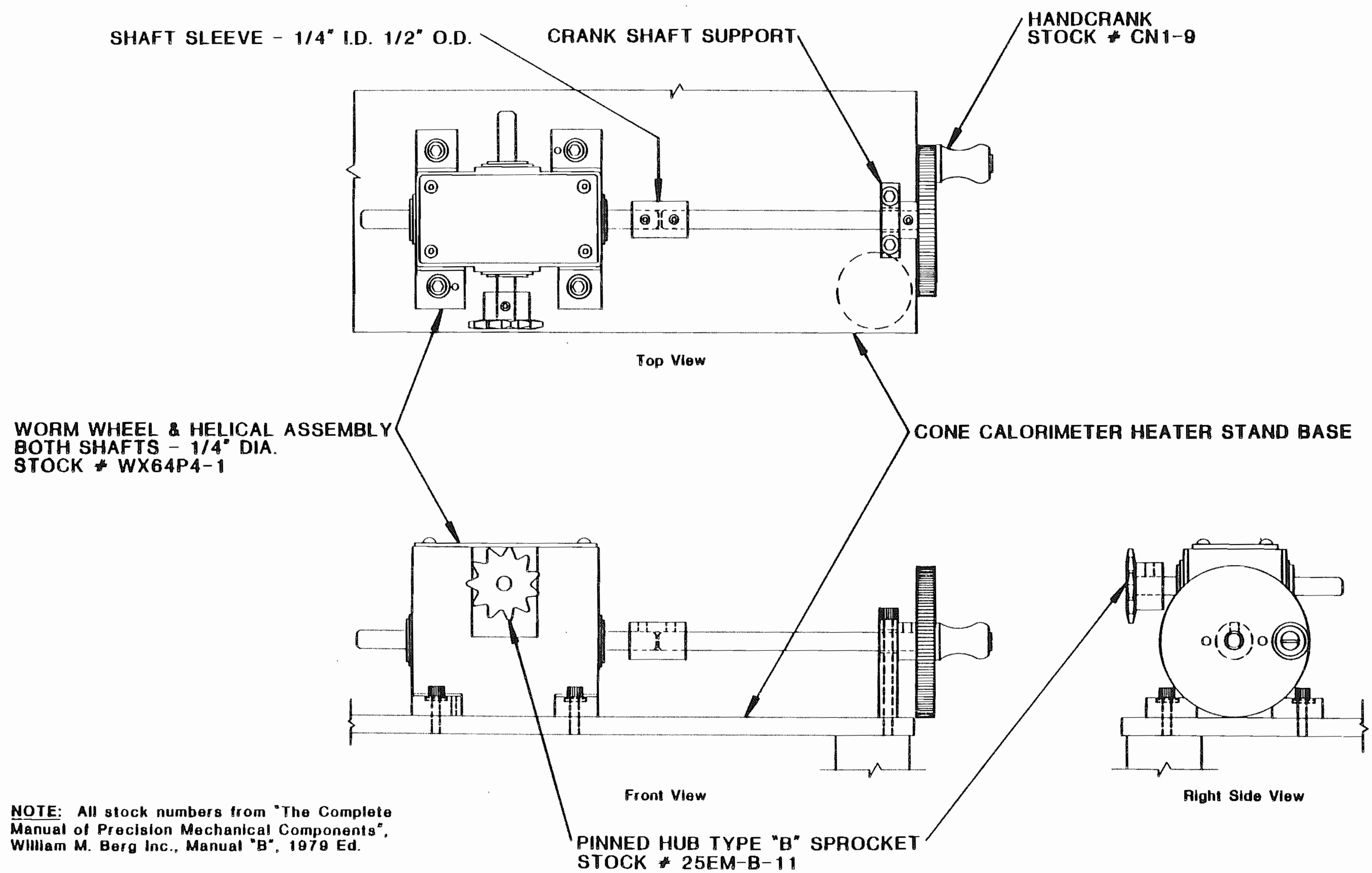


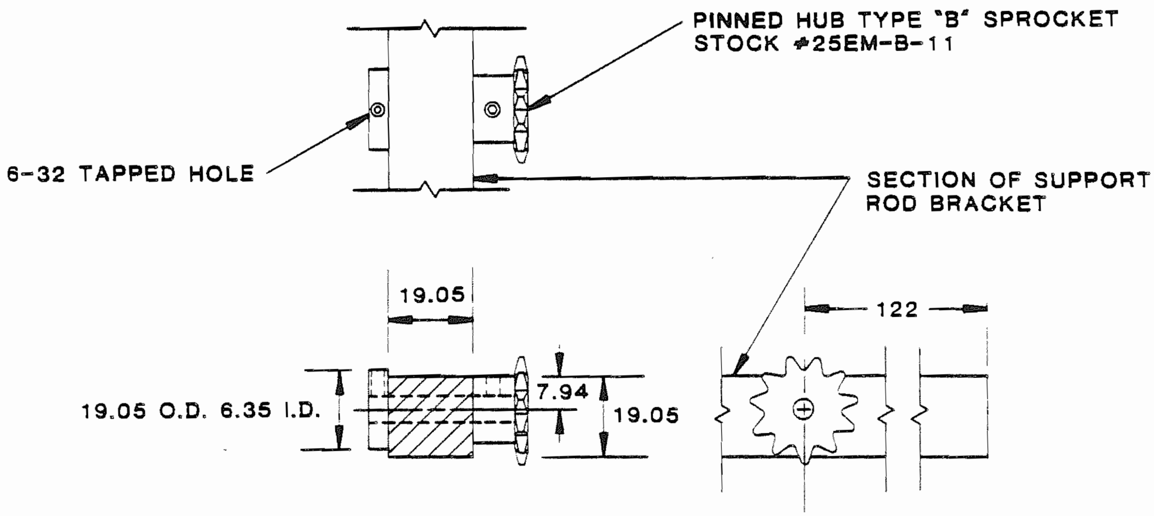
Figure C5. Base plate, legs, support rods

All dimensions in mm
(except where noted)



NOTE: All stock numbers from "The Complete Manual of Precision Mechanical Components", William M. Berg Inc., Manual "B", 1979 Ed.

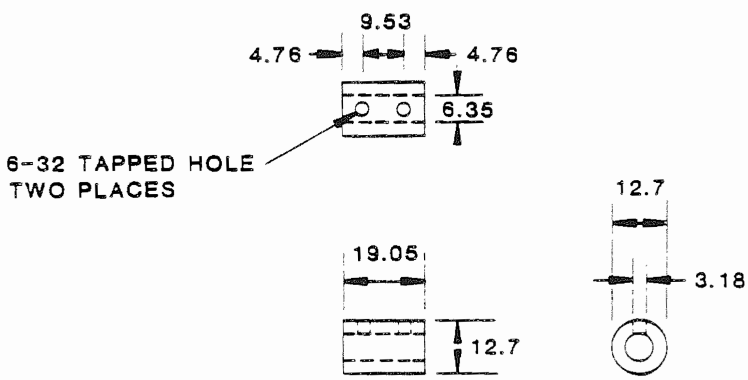
Figure C6-A. Chain lift mechanism (crank)



UPPER SPROCKET FOR CHAIN LIFT MECHANISM

Material: Stainless Steel

All dimensions in millimeters (Except where noted)

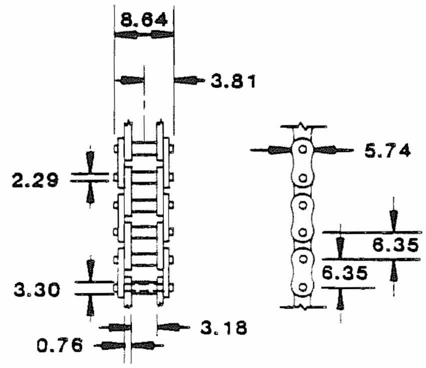


CRANK SHAFT SLEEVE CONNECTOR

Material: Bronze

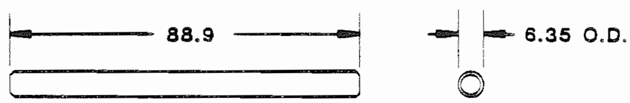
NOTE: All stock numbers are from "The Complete Manual of Precision Mechanical Components", Winfred M. Berg Inc., Manual "B", 1979 Ed.

Figure C6-B. Chain lift mechanism (misc.)



CHAIN STOCK #RC25SS

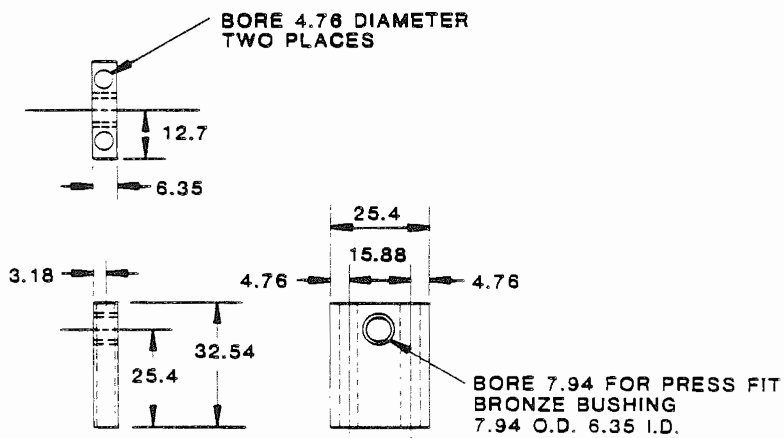
Material: Stainless Steel



CRANK SHAFT EXTENSION

Material: Stainless Steel

All dimensions in millimeters (Except where noted)



CRANK SHAFT SUPPORT

Material: Stainless Steel

NOTE: All stock numbers are from "The Complete Manual of Precision Mechanical Components", Winfred M. Berg Inc., Manual "B", 1979 Ed.

Figure C6-C. Chain lift mechanism (misc.)

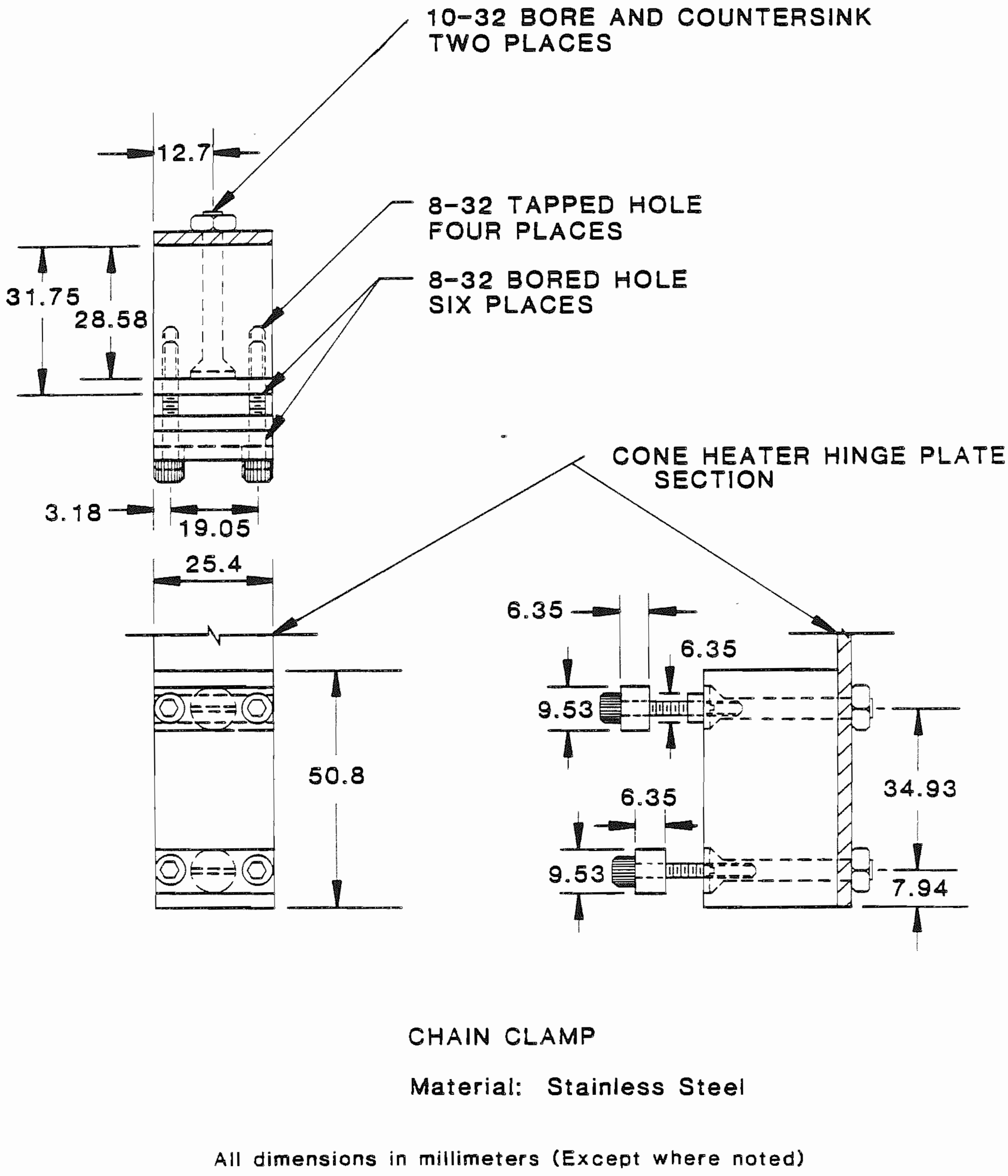


Figure C6-D. Chain lift mechanism (chain clamp)

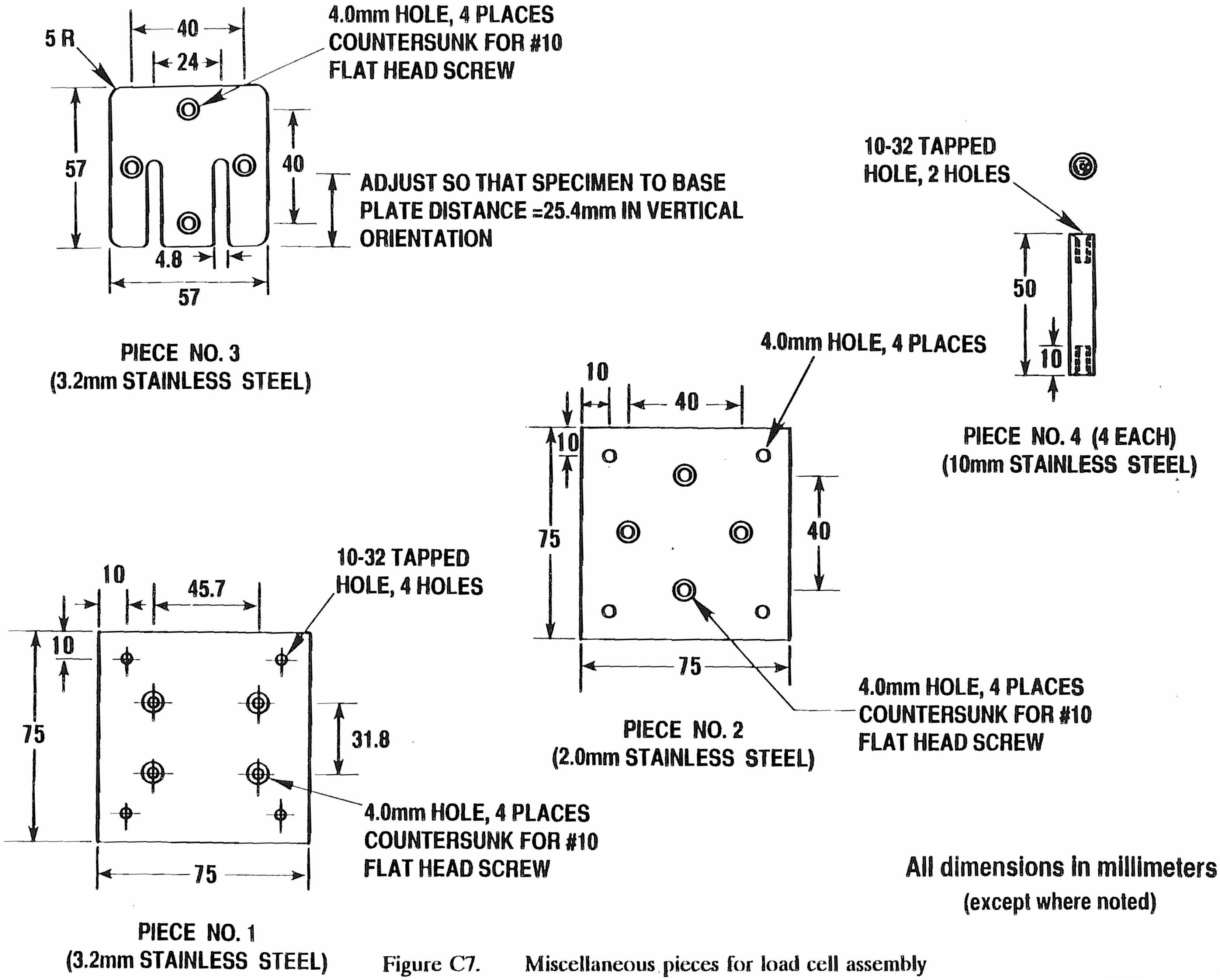


Figure C7. Miscellaneous pieces for load cell assembly

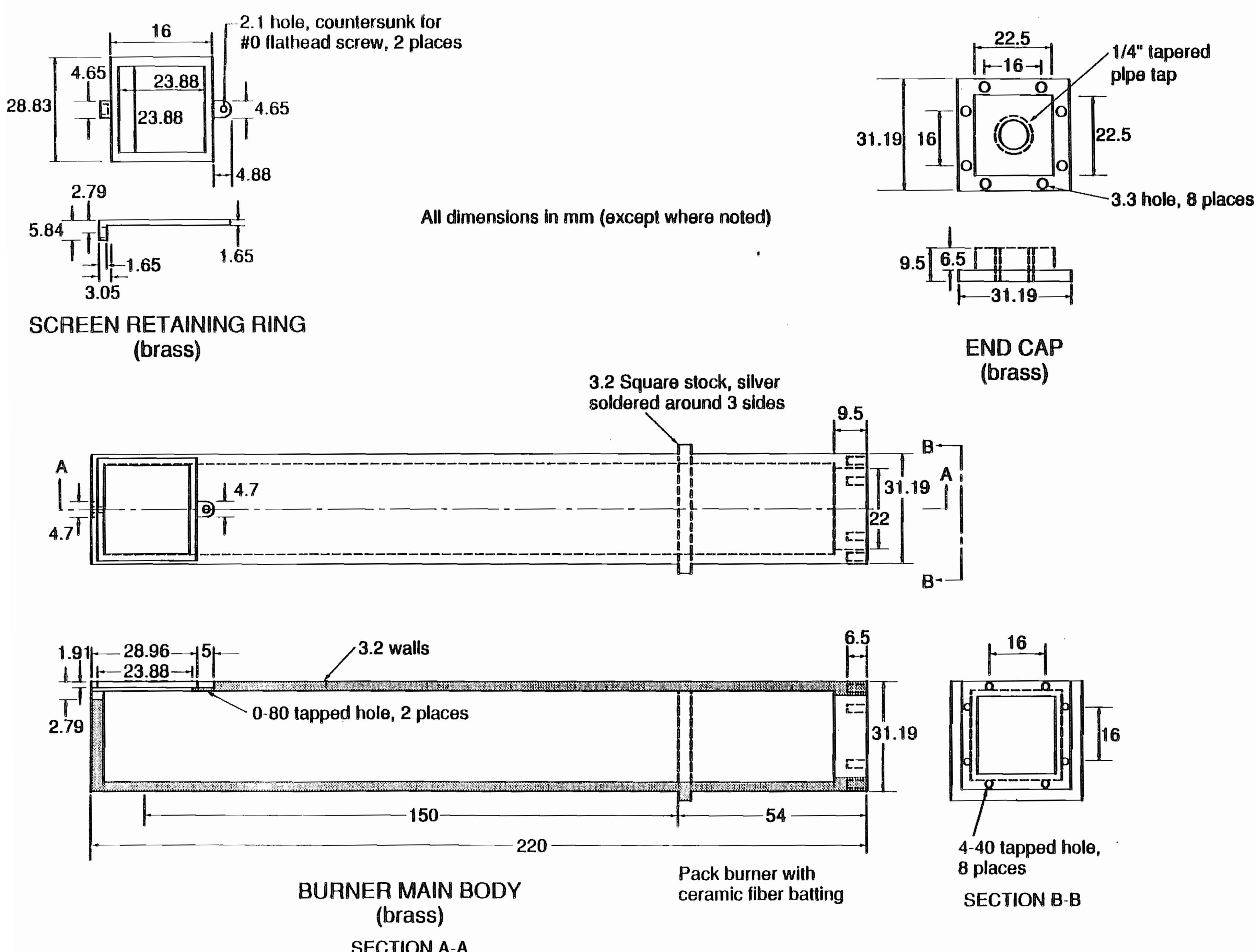


Figure C8. Calibration burner

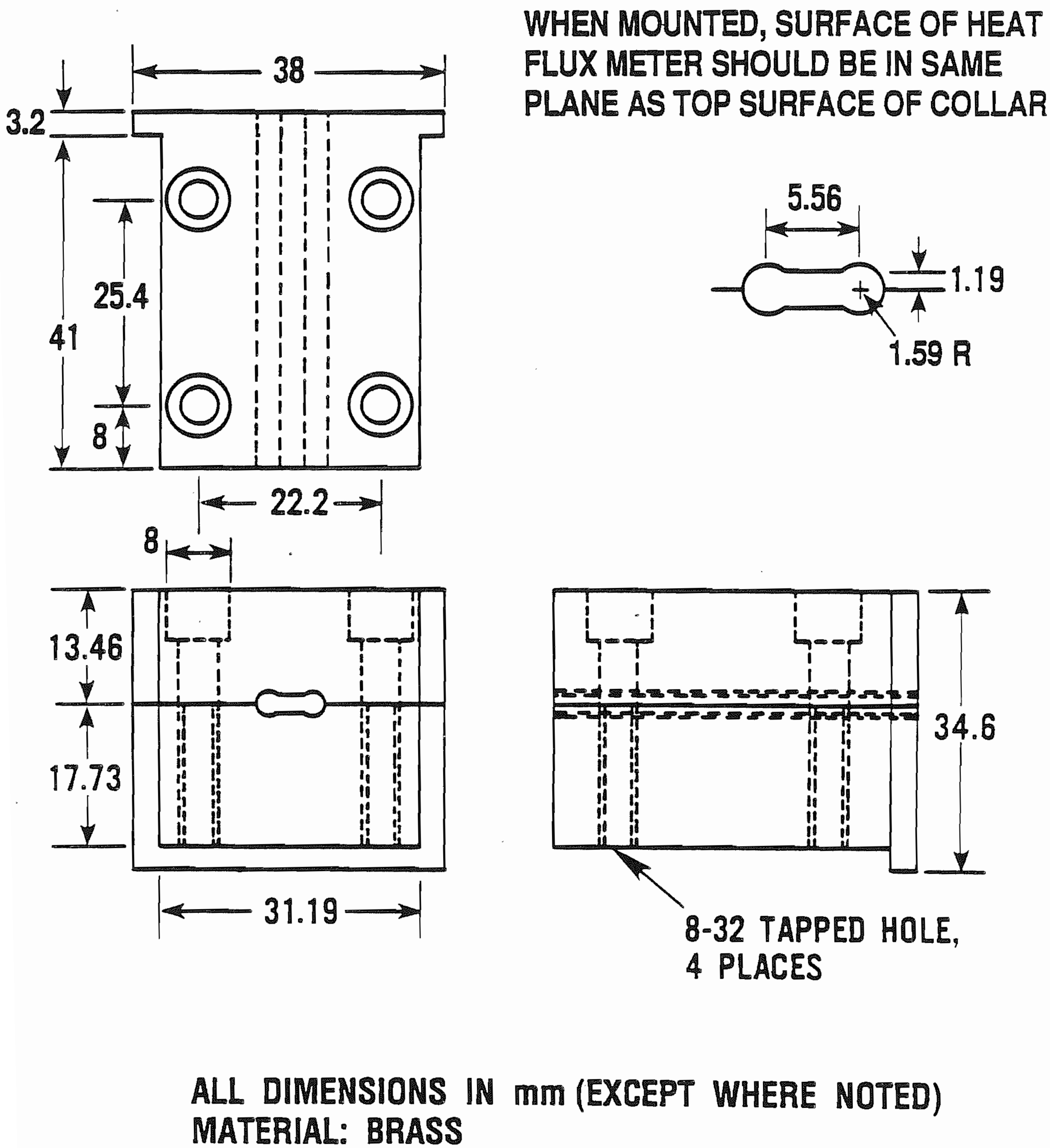
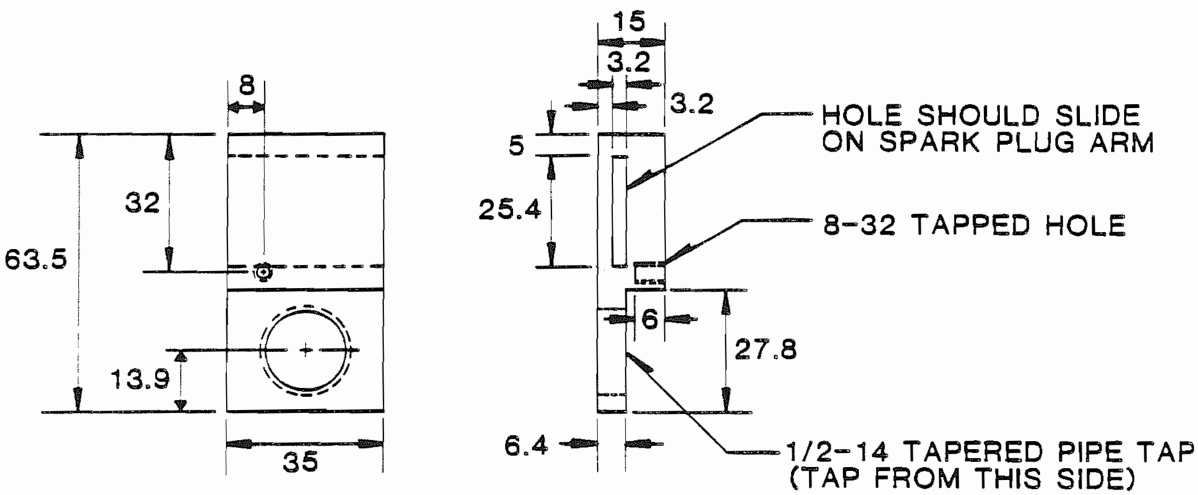
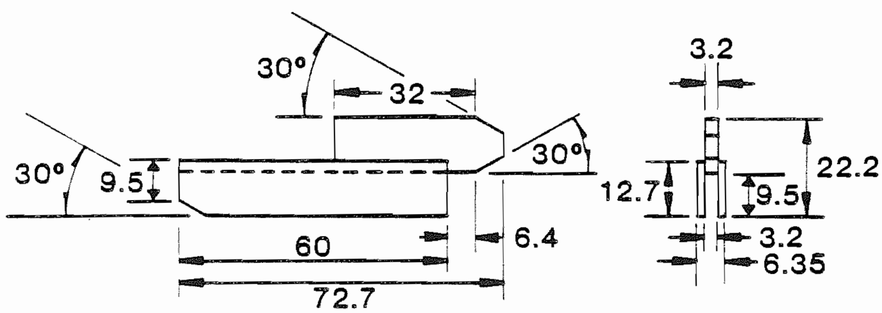


Figure C9. Heat flux gage collar



SPARK PLUG CARRIER
MATERIAL: TEFLON



SPARK PLUG POSITION LOCK BAR
MATERIAL: ALUMINUM 6061

All Dimensions in Millimeters

Figure C10. Spark plug carrier and position lock bar

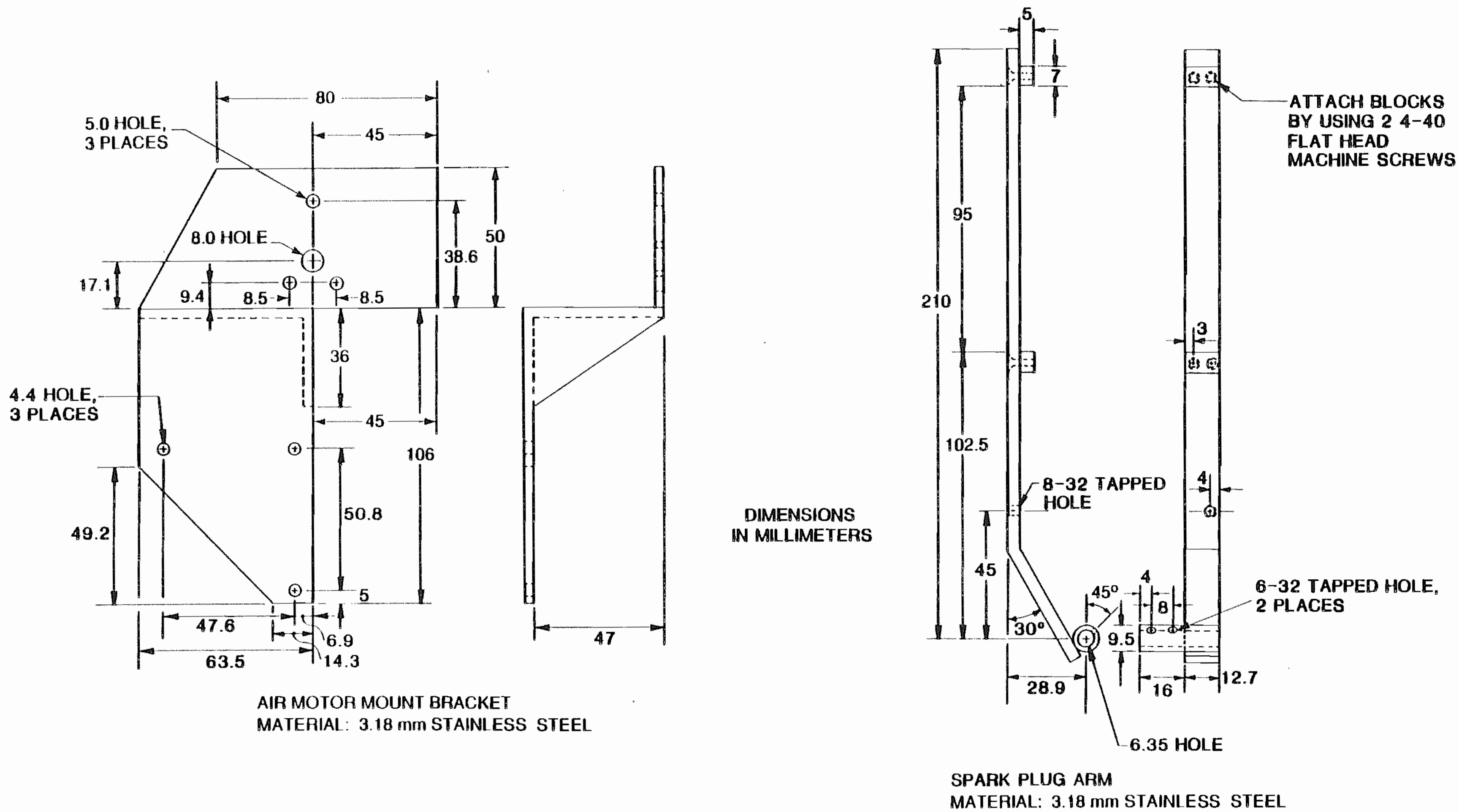


Figure C11. Mount for spark plug motor and spark plug arm

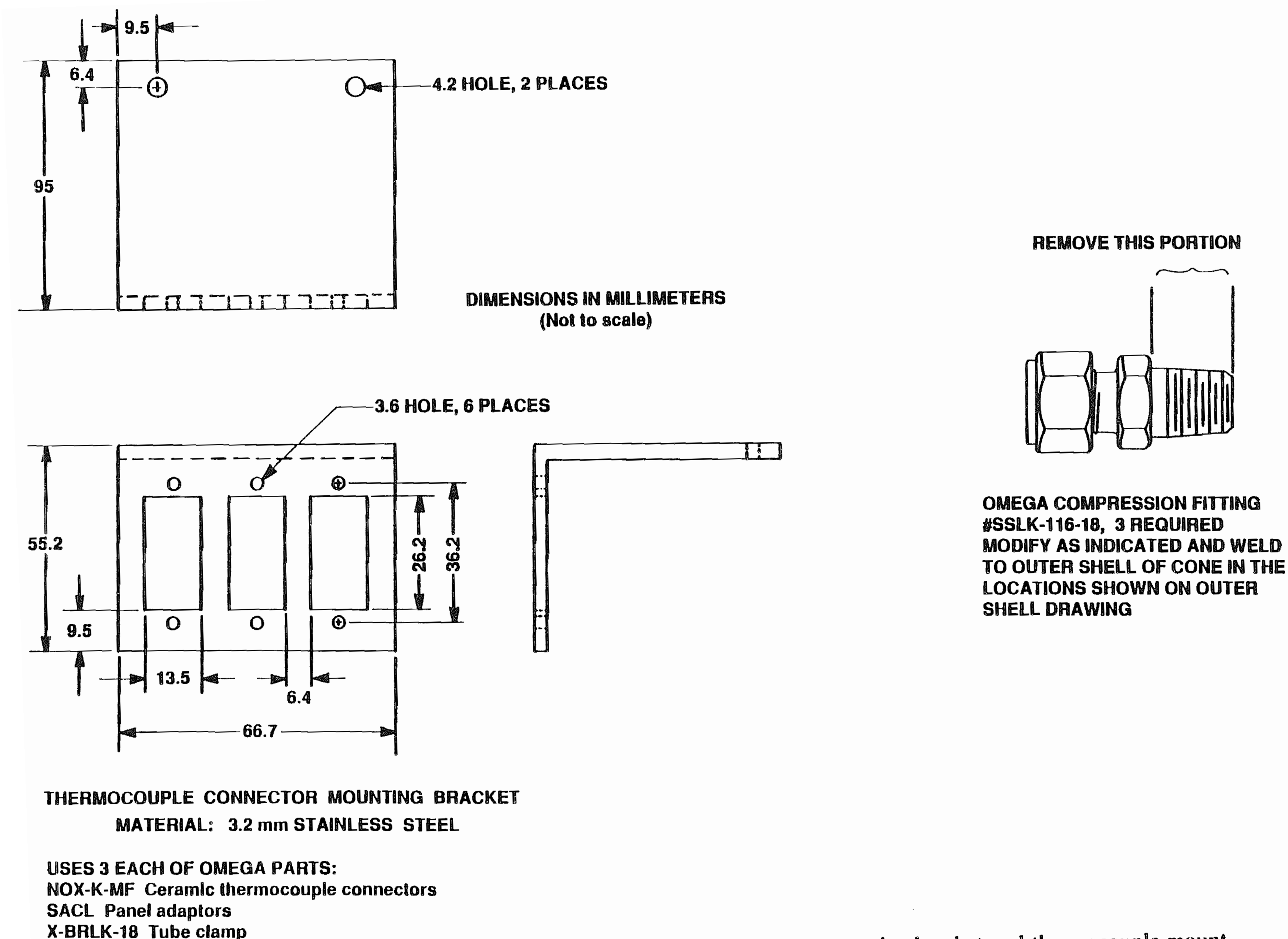


Figure C12. Thermocouple connector mounting bracket and thermocouple mount

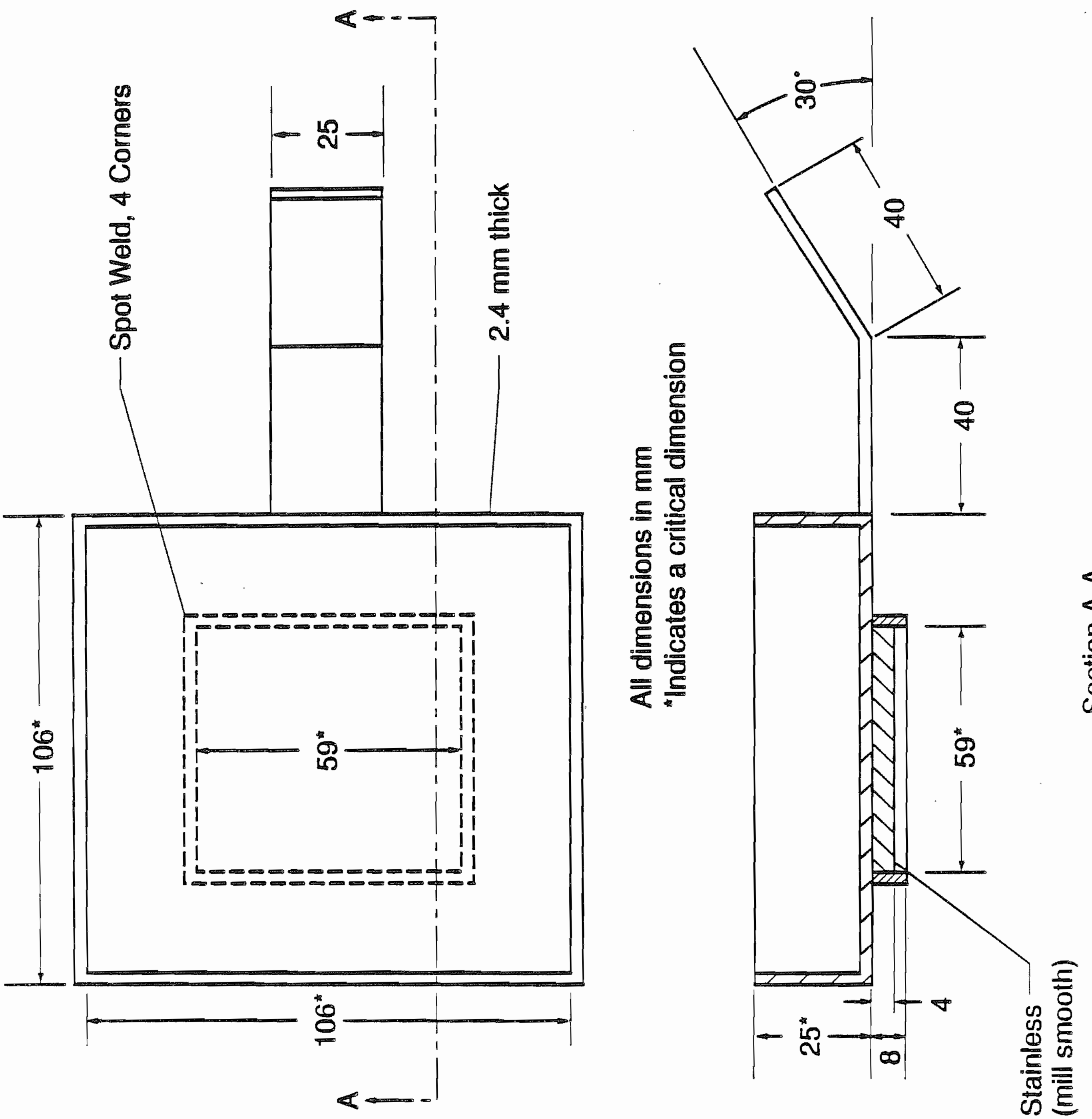


Figure C13. Horizontal specimen holder

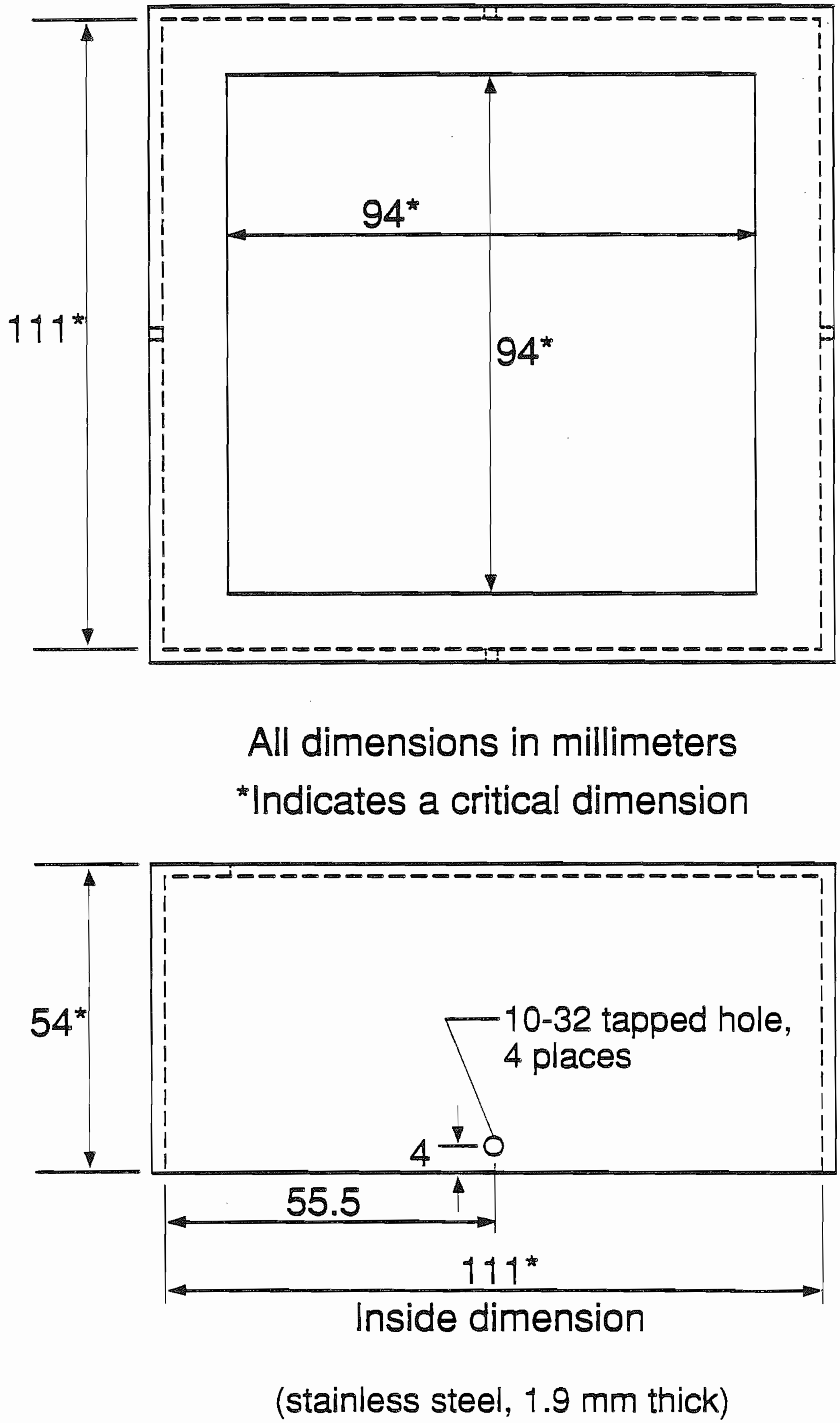


Figure C14. Retainer frame for horizontal ignitability testing

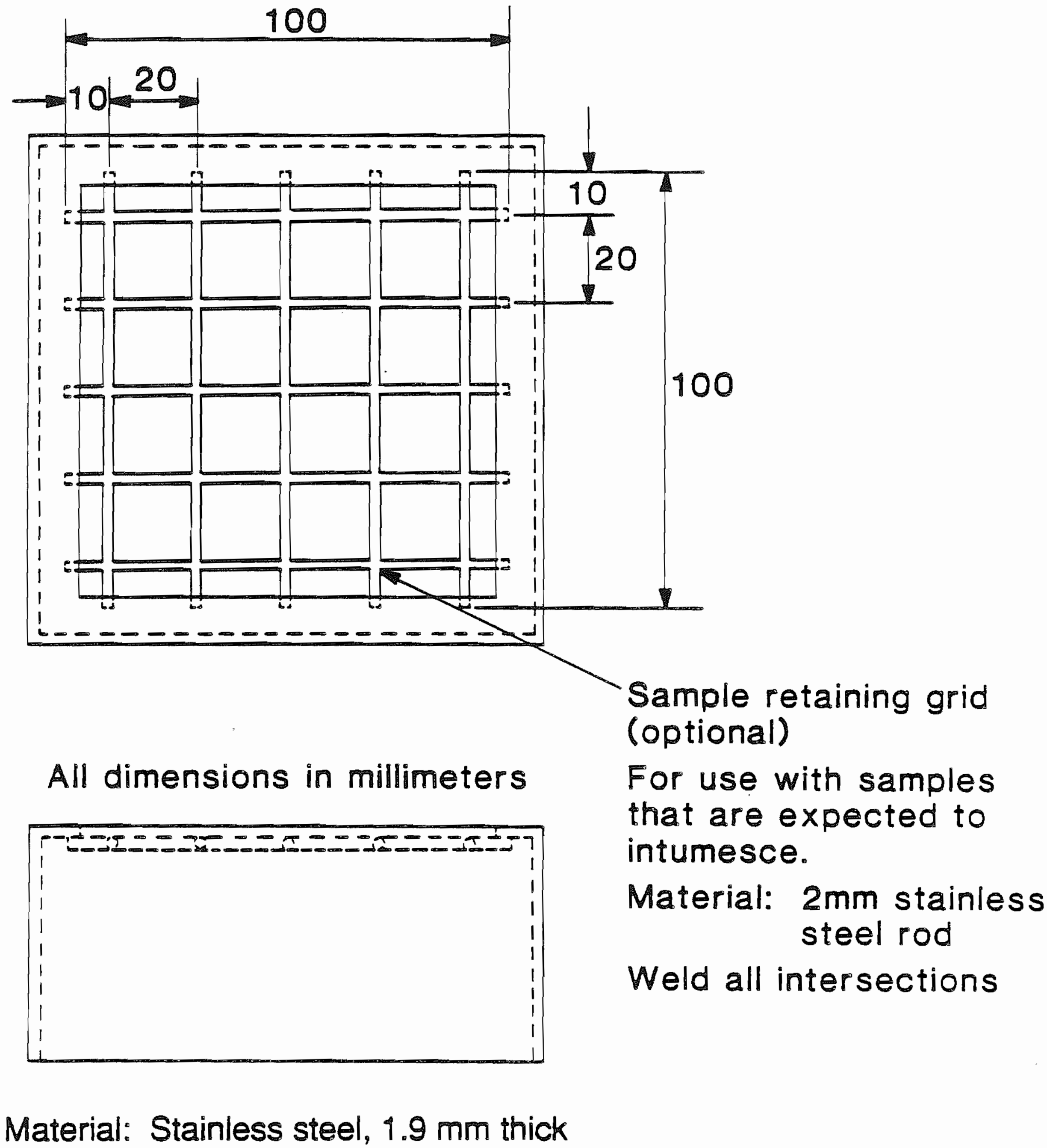


Figure C15. Horizontal specimen frame and wire grid

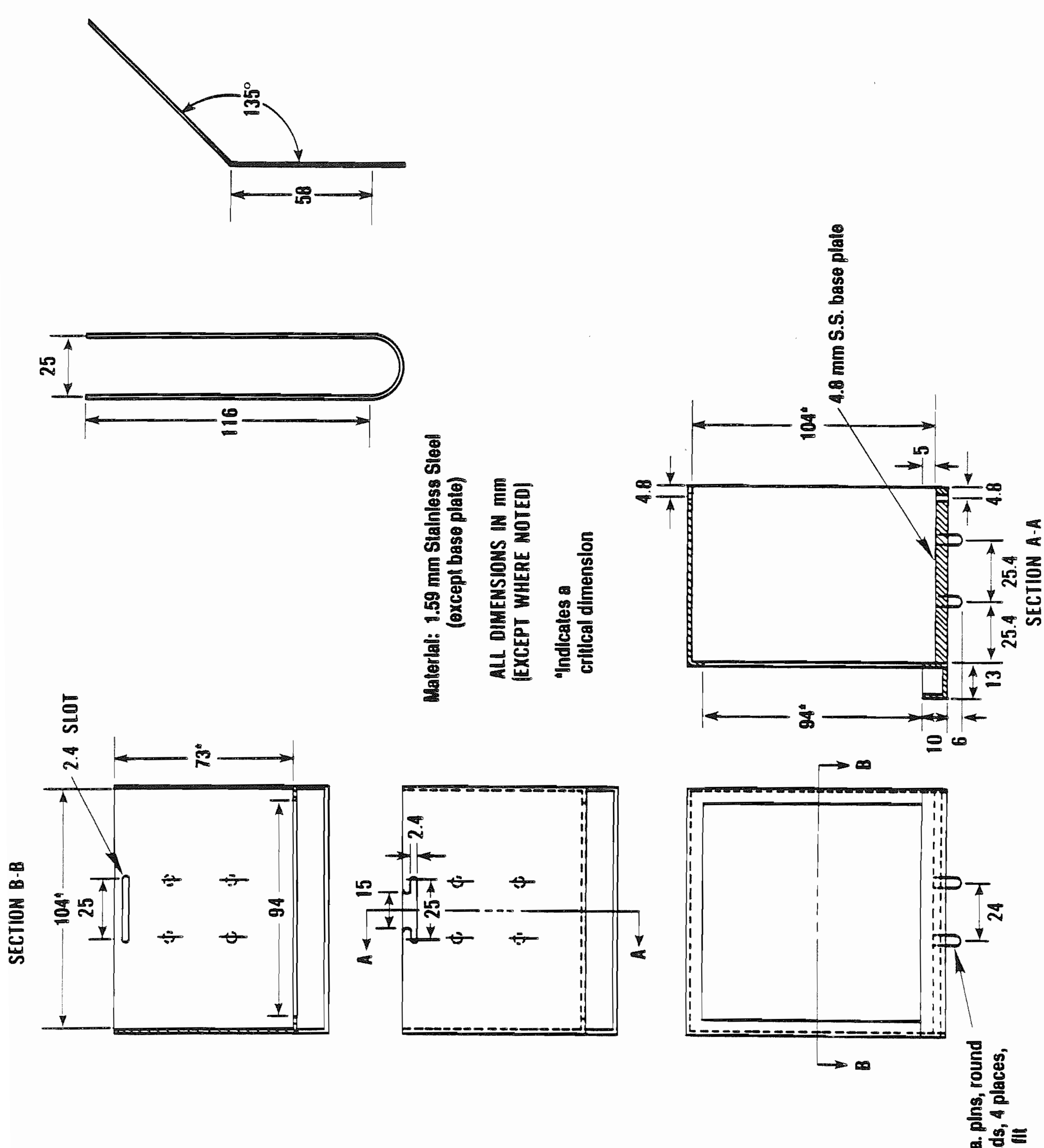


Figure C16. Vertical specimen holder

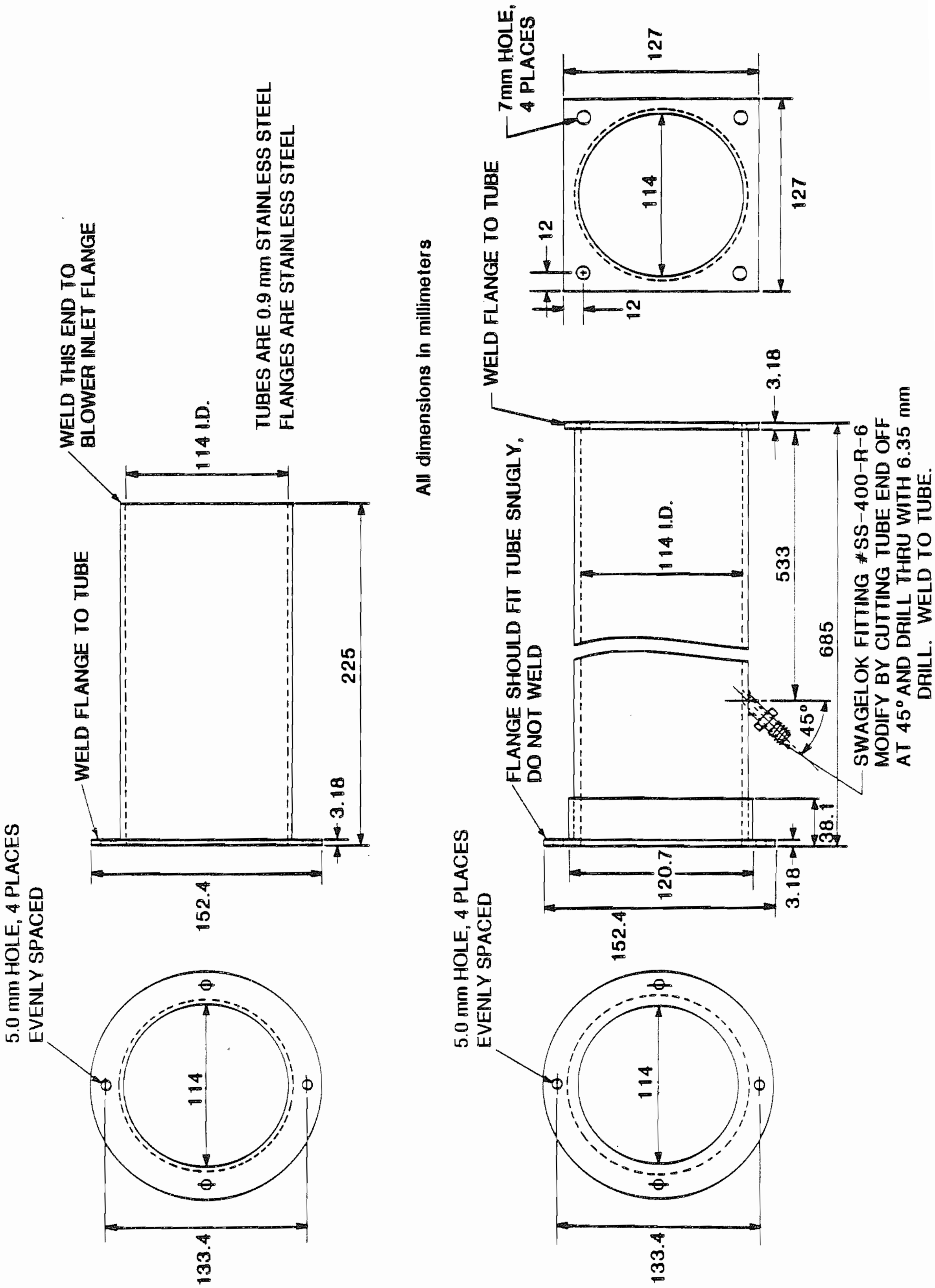


Figure C17. Horizontal ducts

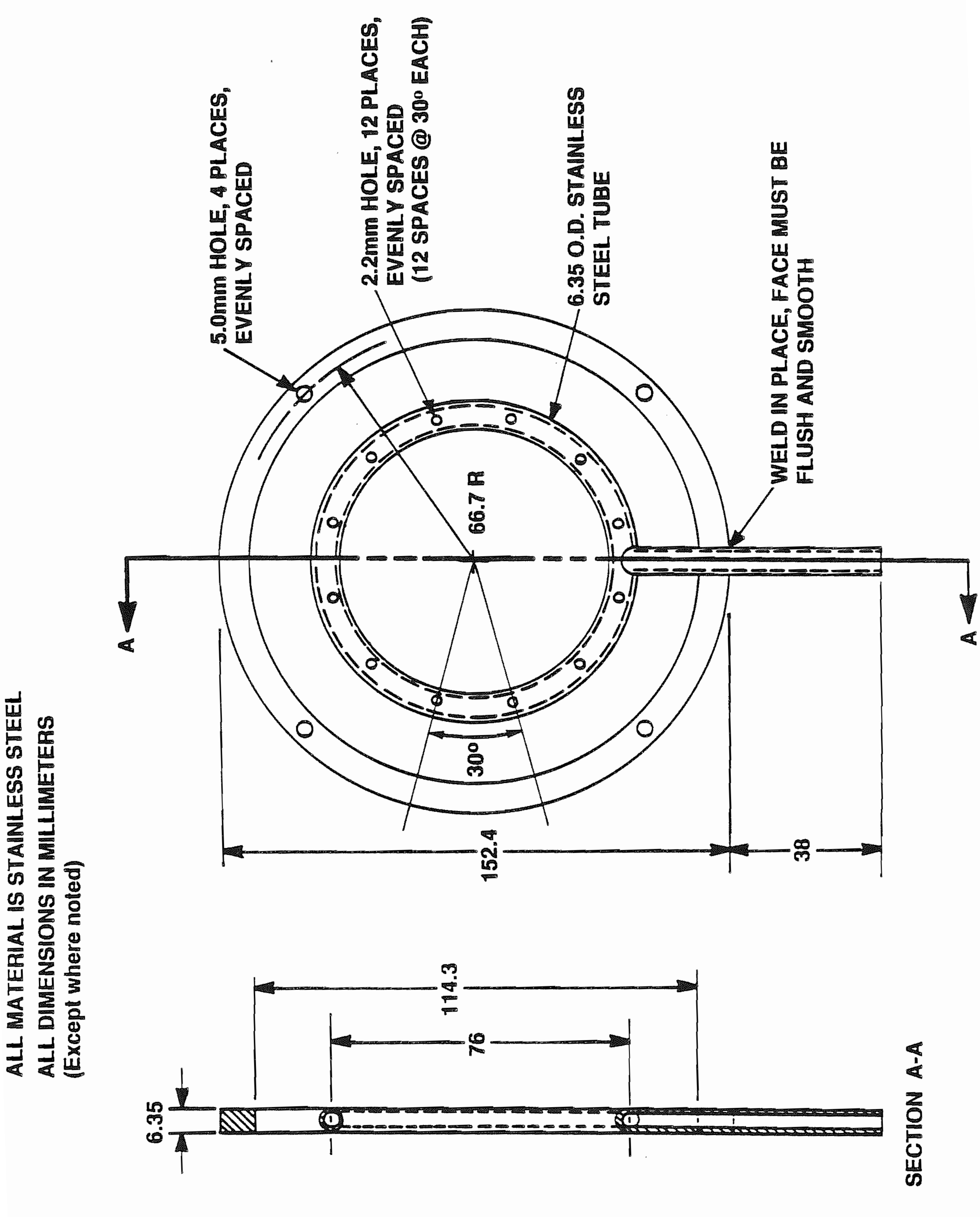


Figure C18. Ring sampler

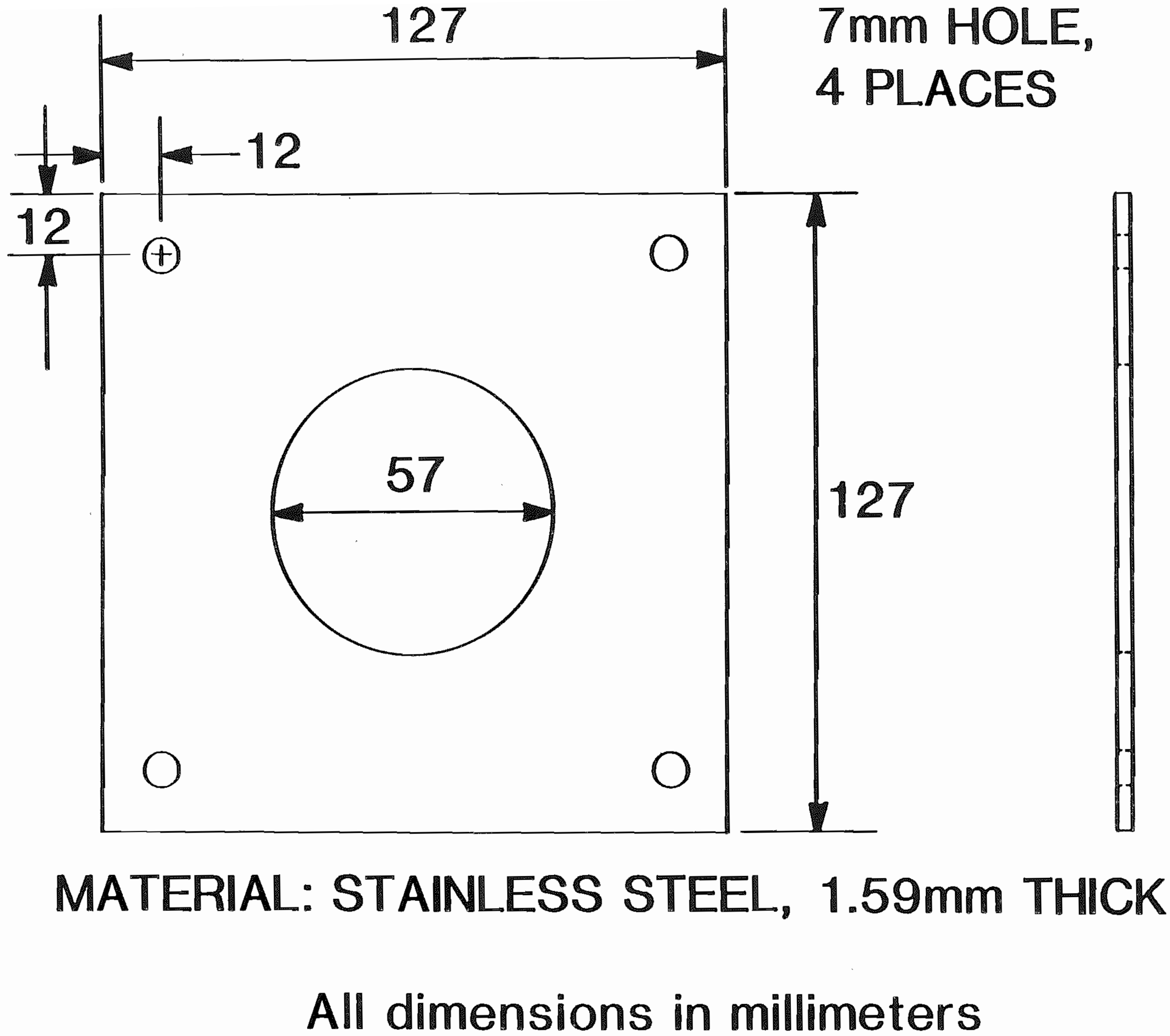


Figure C19. **Mixing orifice plate**

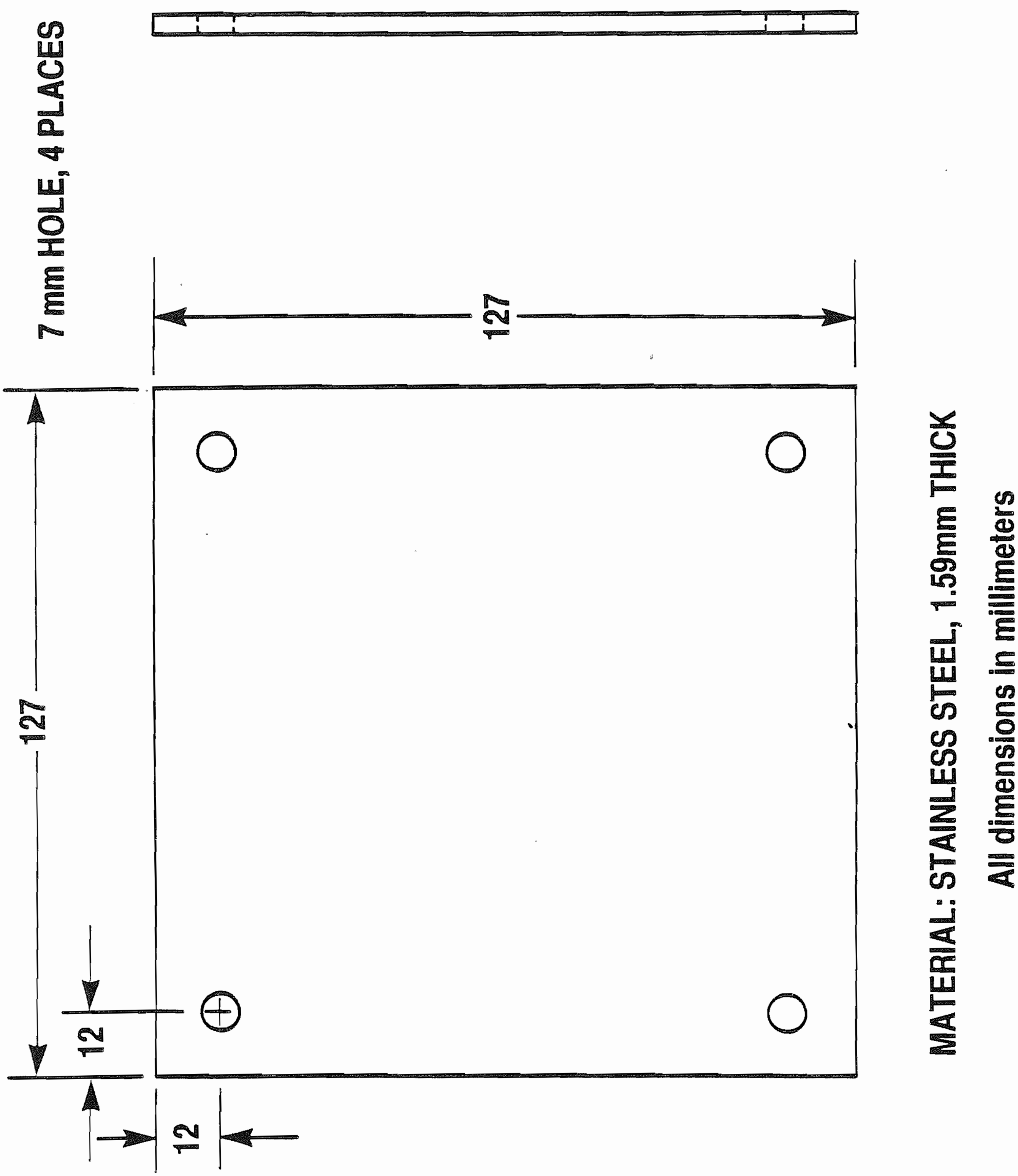


Figure C19-A. Cleanout port cover

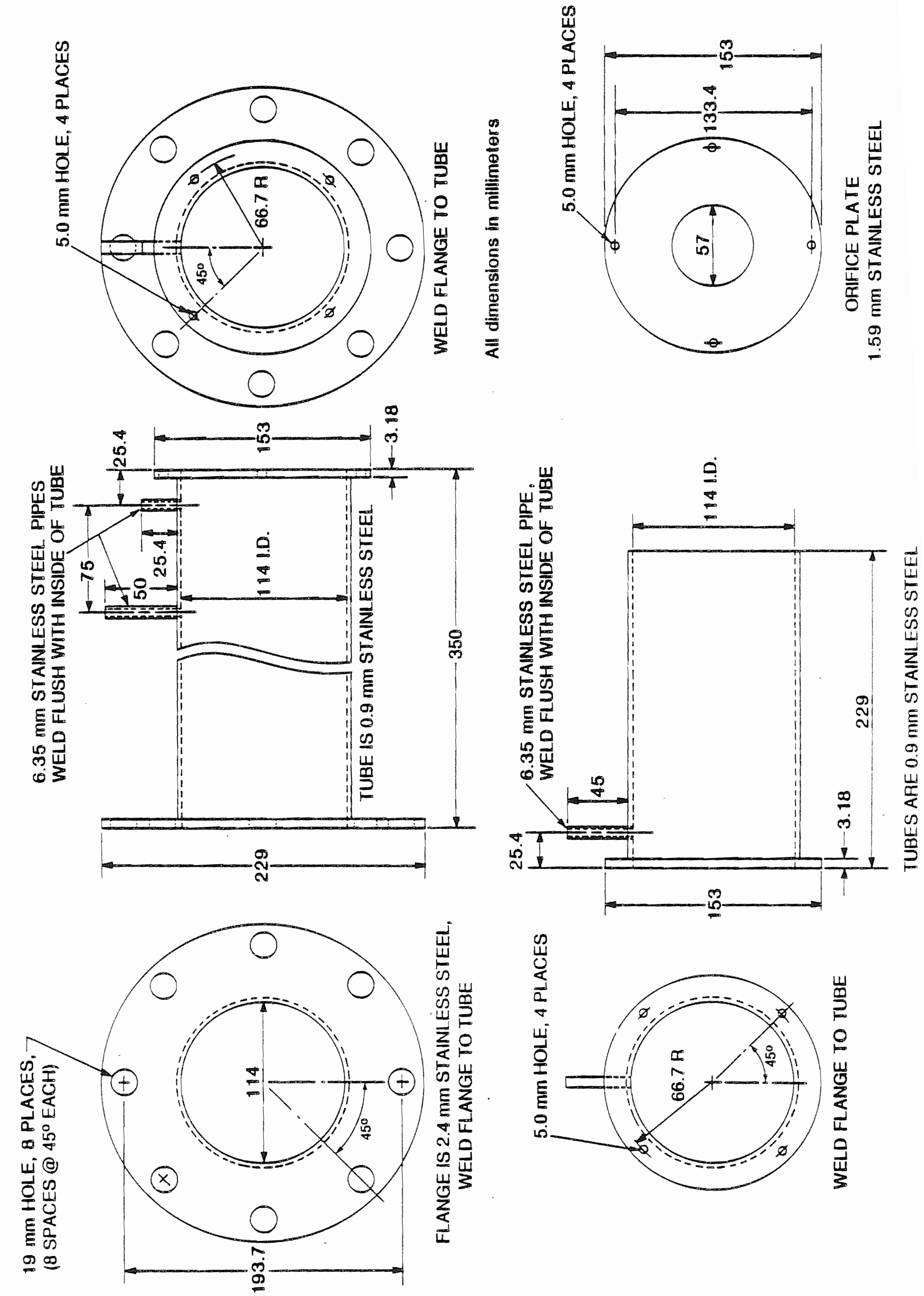
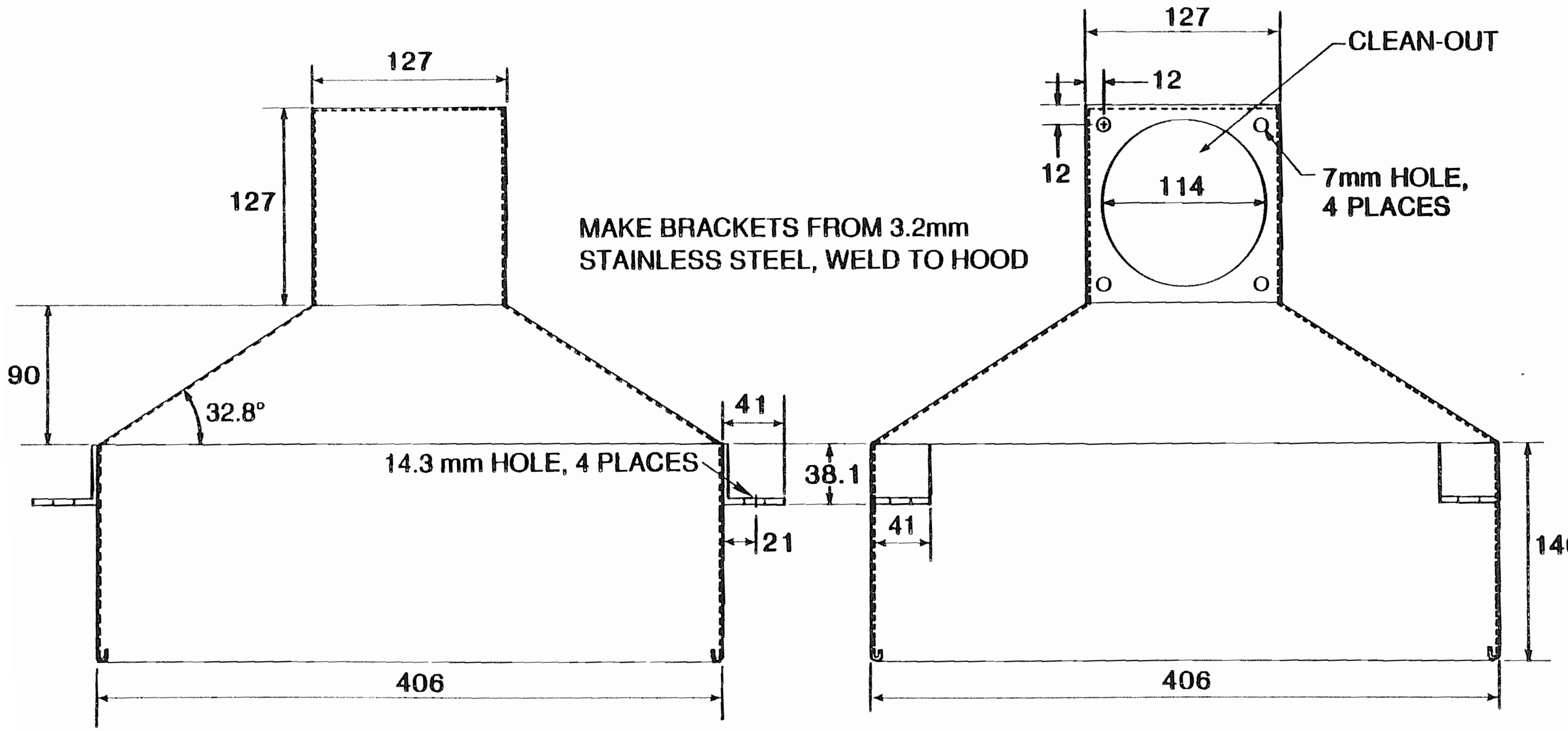


Figure C20. Exhaust duct vertical sections and measuring orifice plate



All dimensions in mm (Except where noted)

Material: Stainless Steel 0.64mm Thick

Figure C21. Exhaust hood

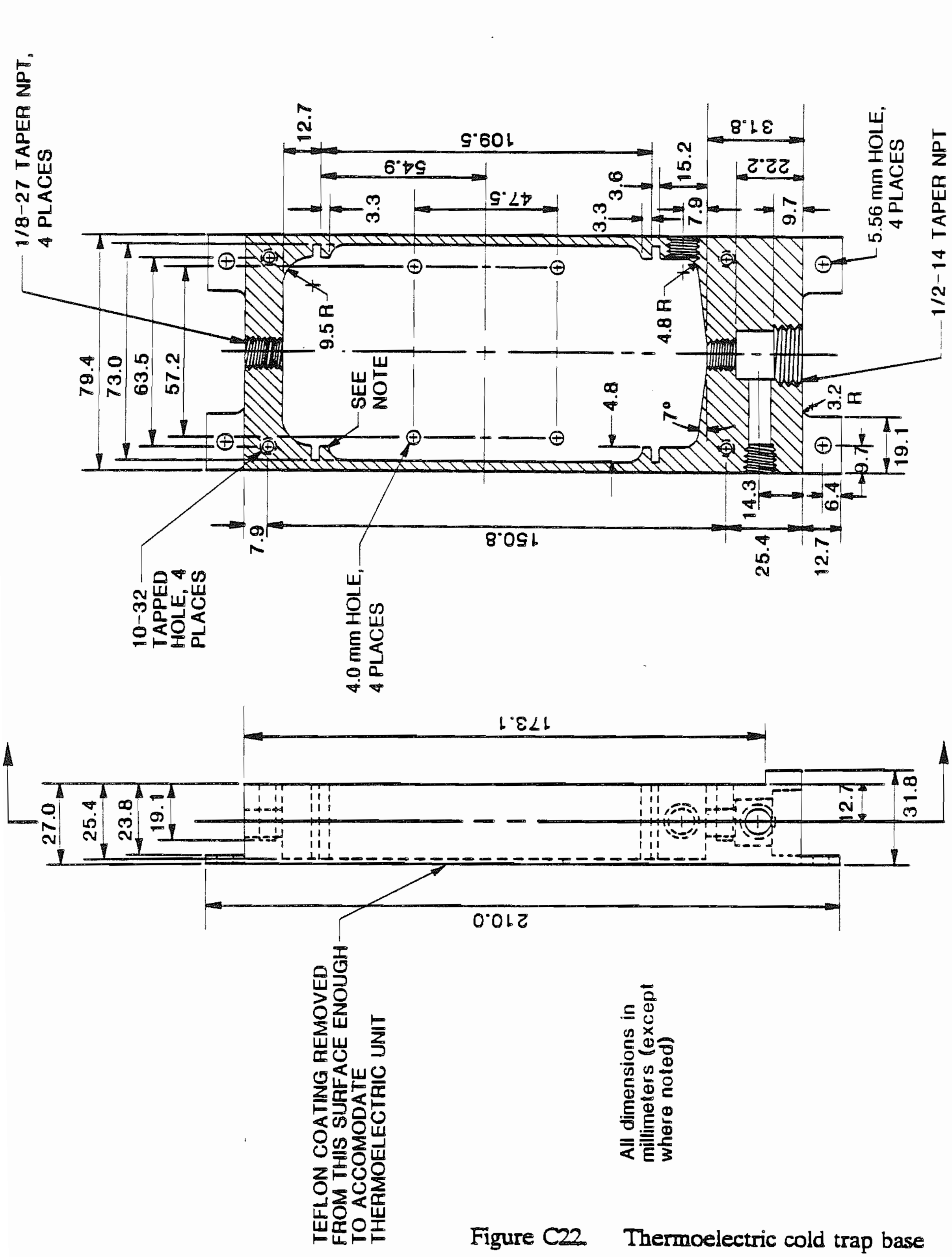


Figure C22. Thermoelectric cold trap base

MATERIAL: 2024 ALUMINUM ALLOY, TEFLON COATED, EXCEPT WHERE SURFACE MATES WITH THERMOELECTRIC UNIT

NOTE: All outside corners on the inside of the box have a 0.80 radius

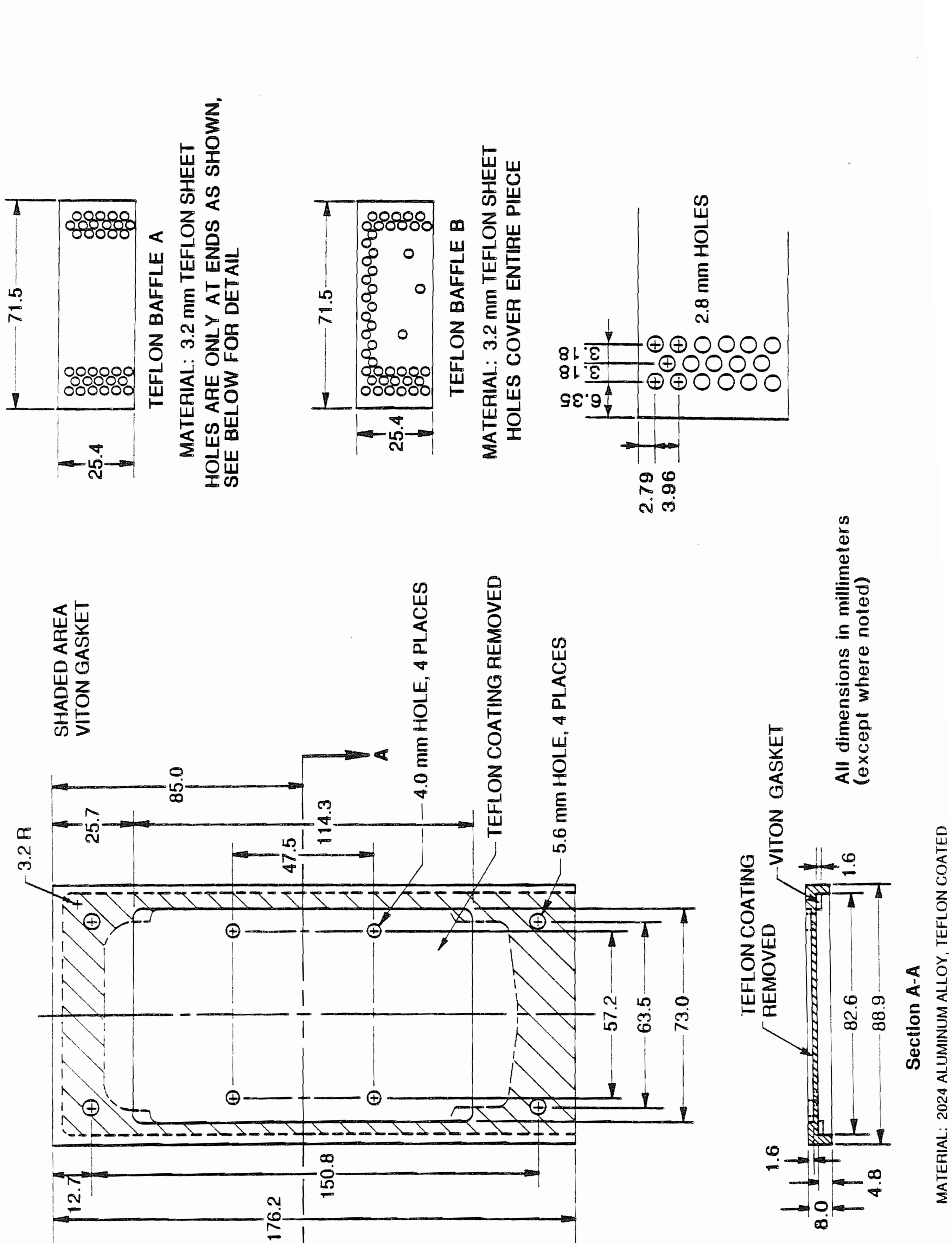


Figure C23. Thermoelectric cold trap cover and baffles

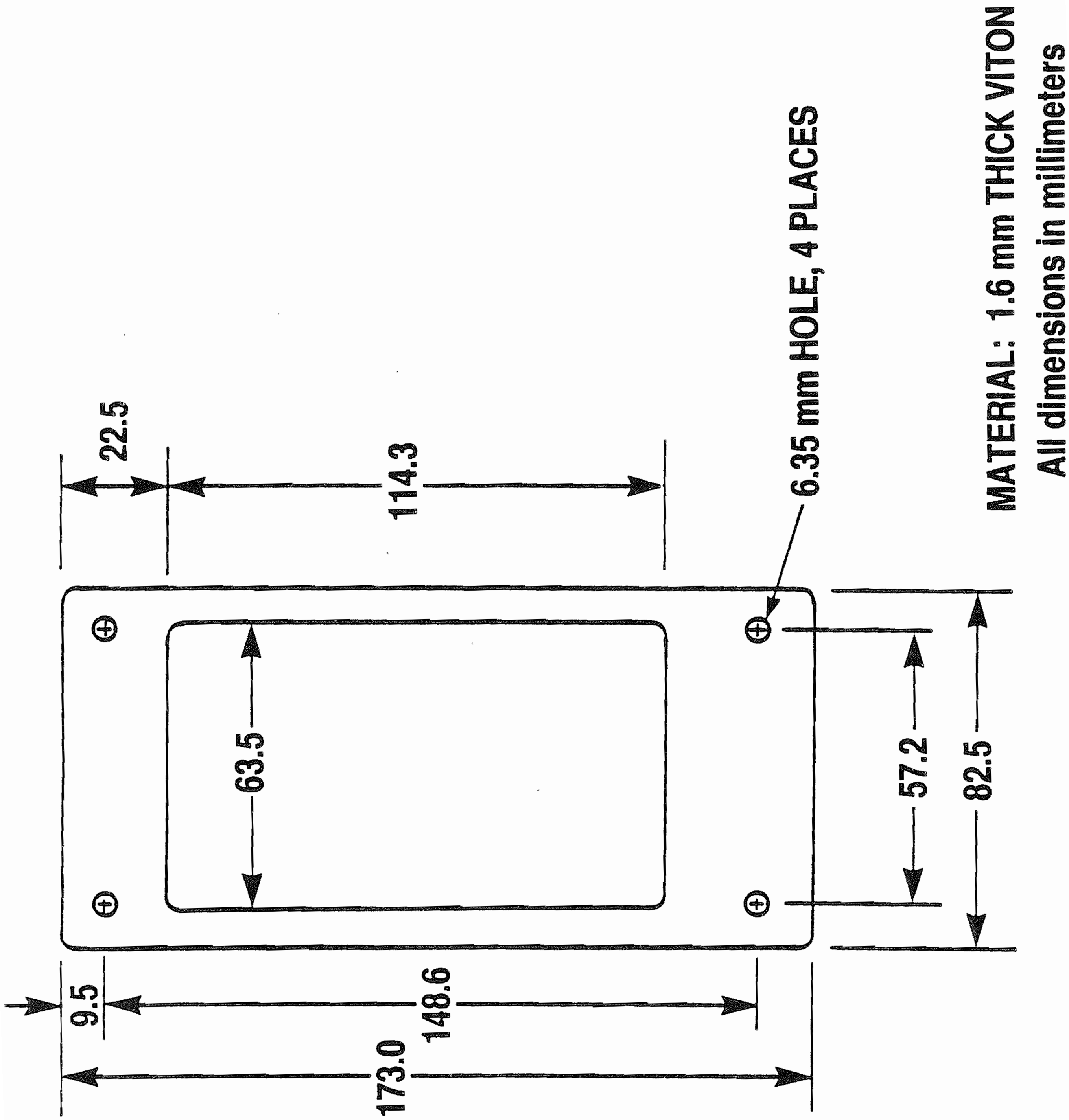


Figure C23-A. Gasket for thermoelectric cold trap cover

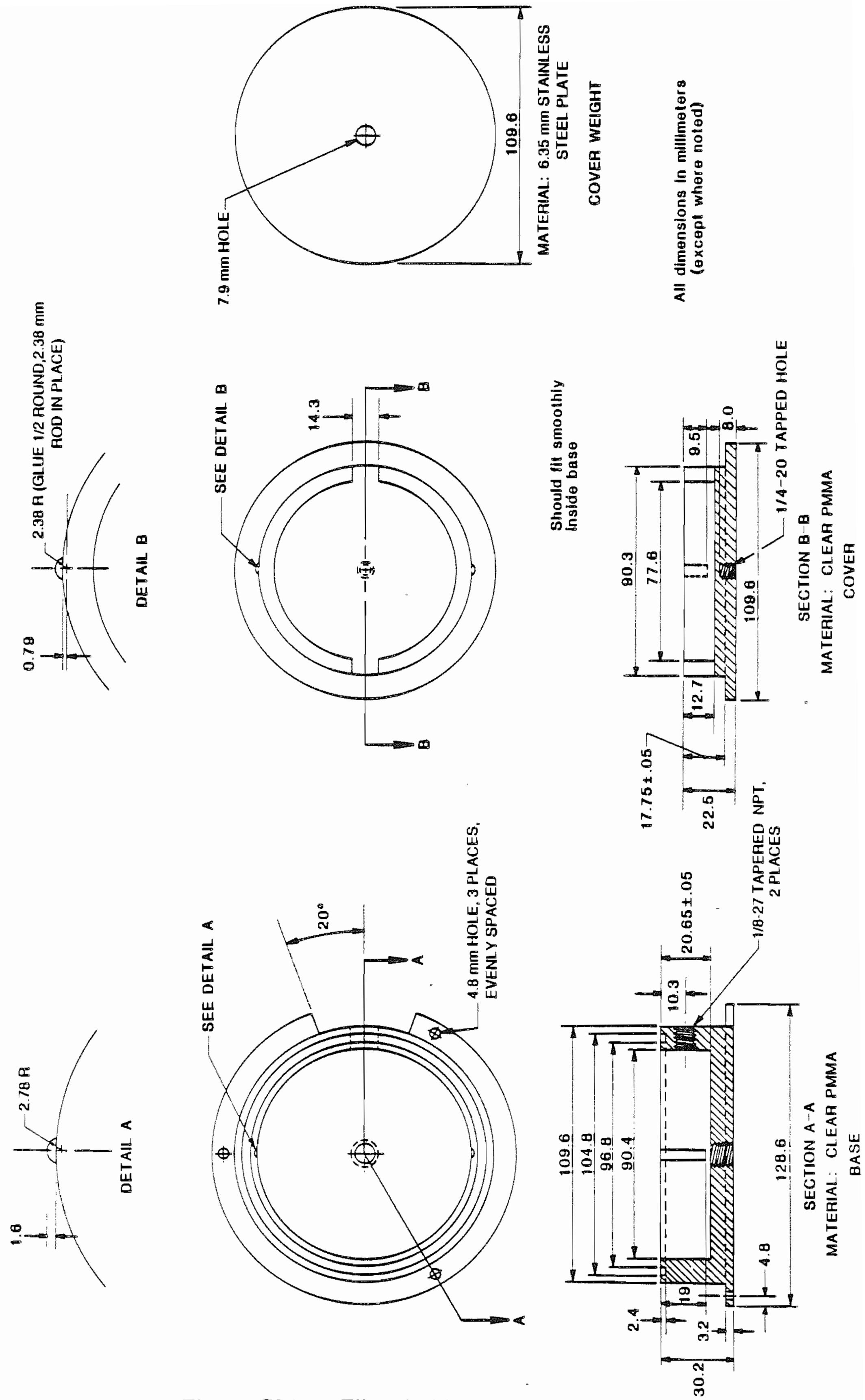


Figure C24. Filter holder

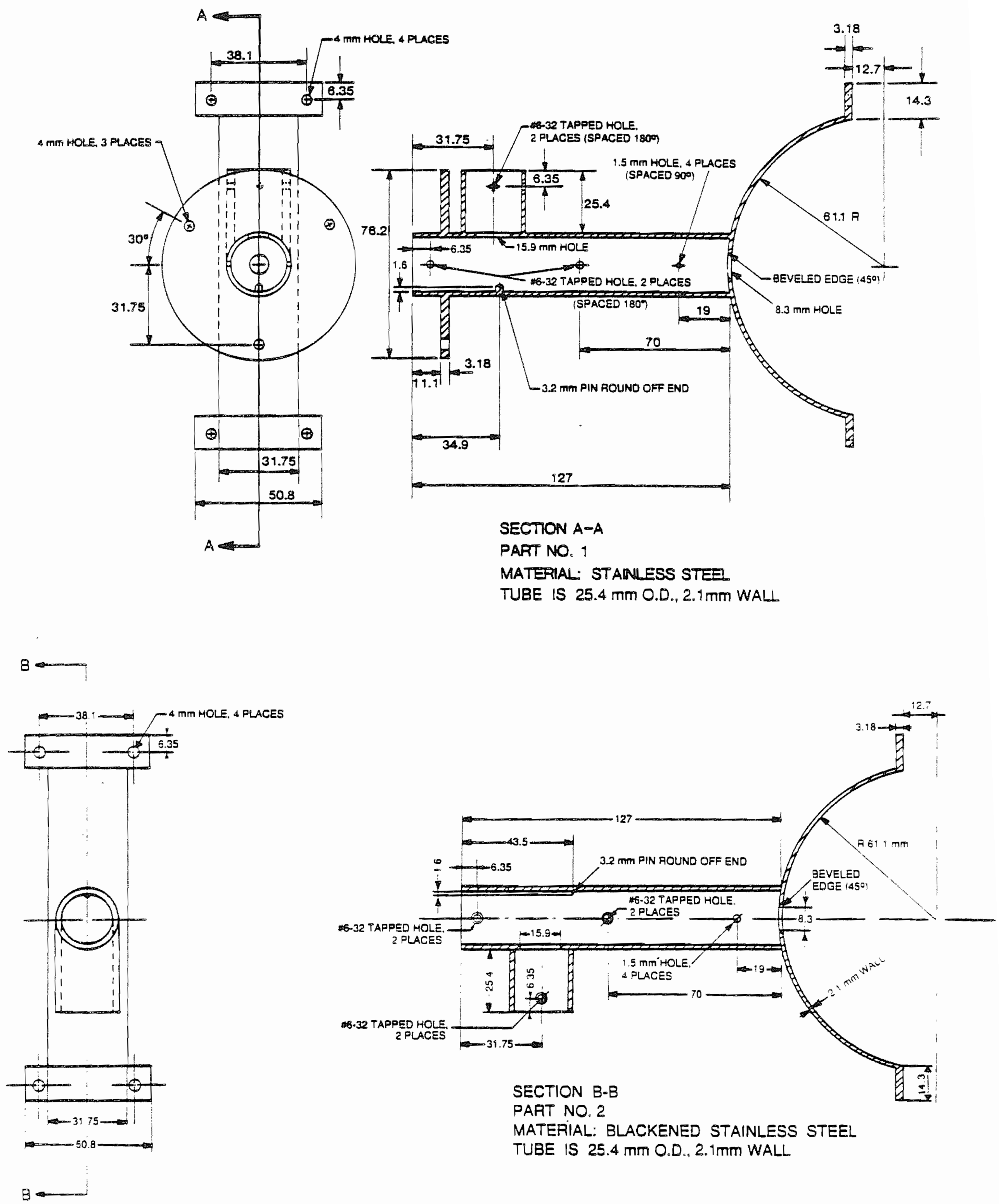


Figure C25. Main body sections for extinction beam

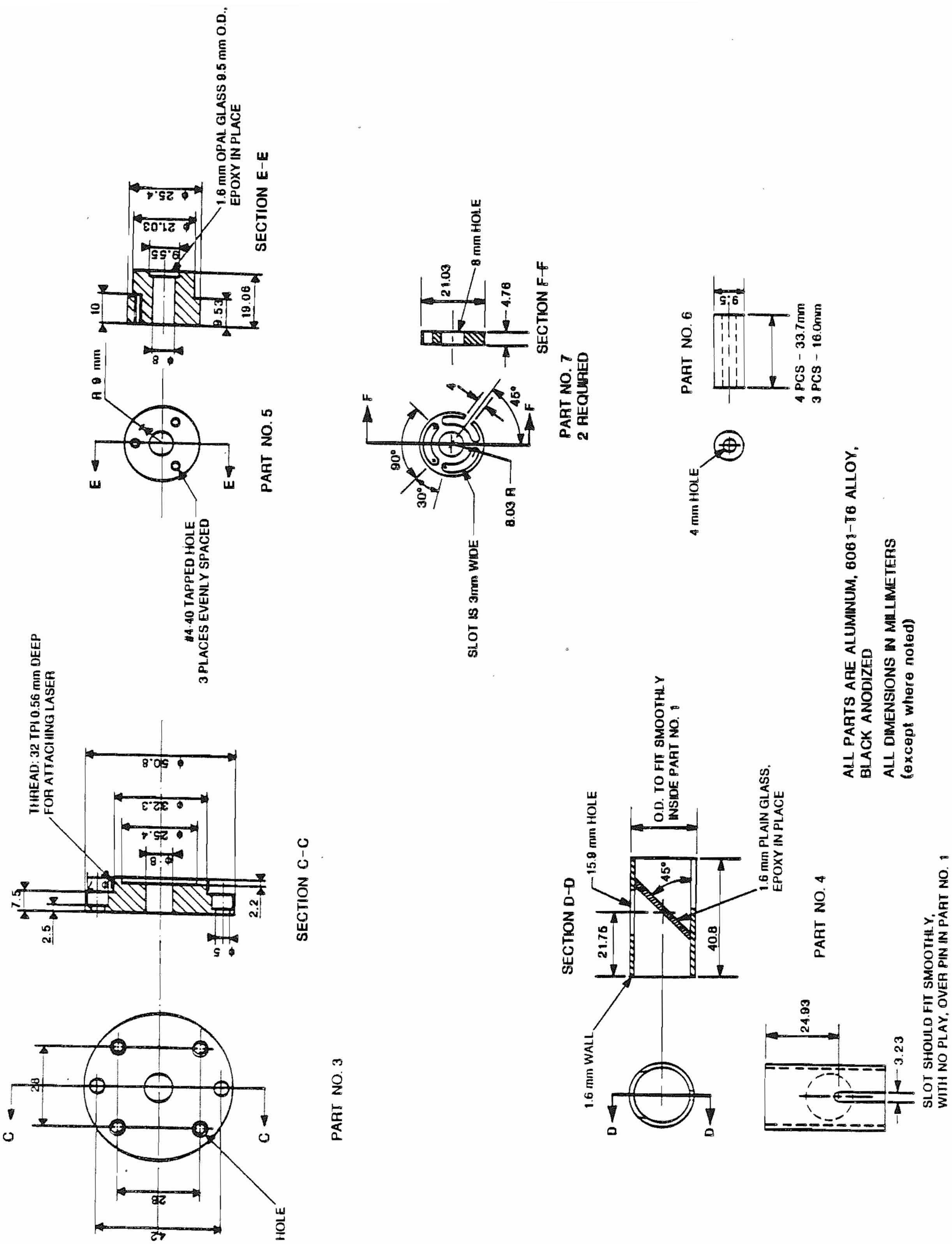


Figure C26. Extinction beam parts 3,4,5,6,7

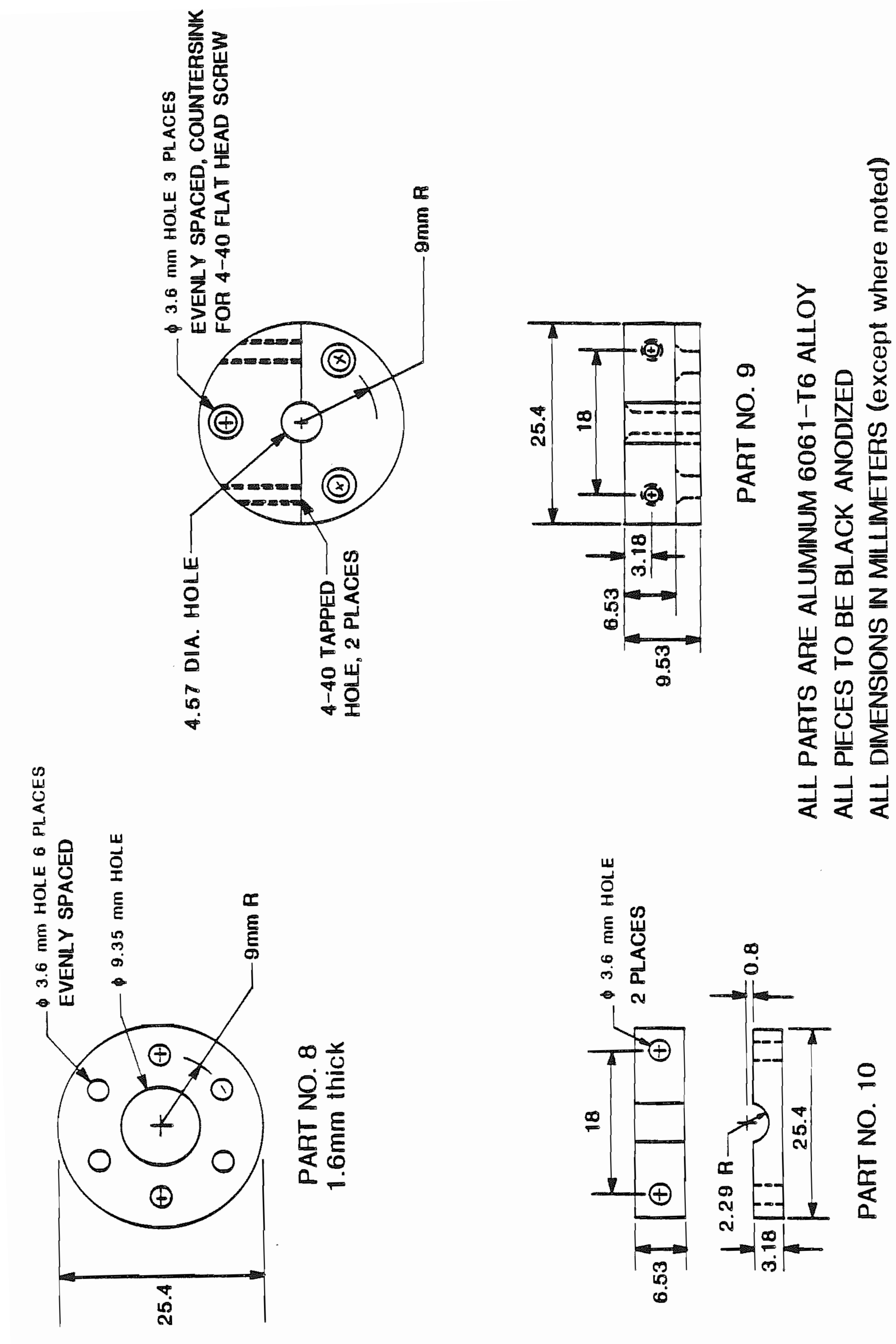


Figure C27. Extinction beam parts 8,9,10

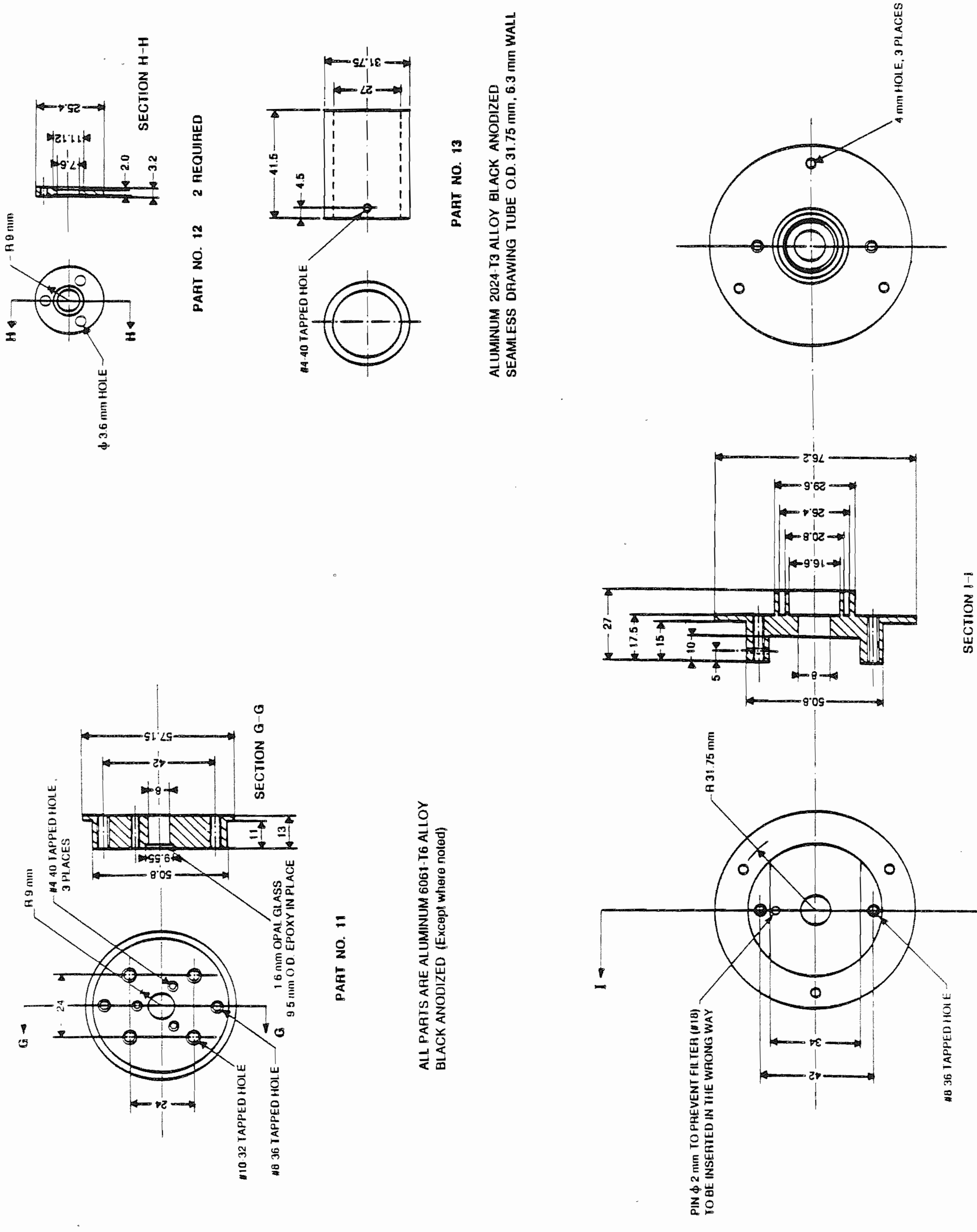


Figure C28. Extinction beam parts 11,12,13,14

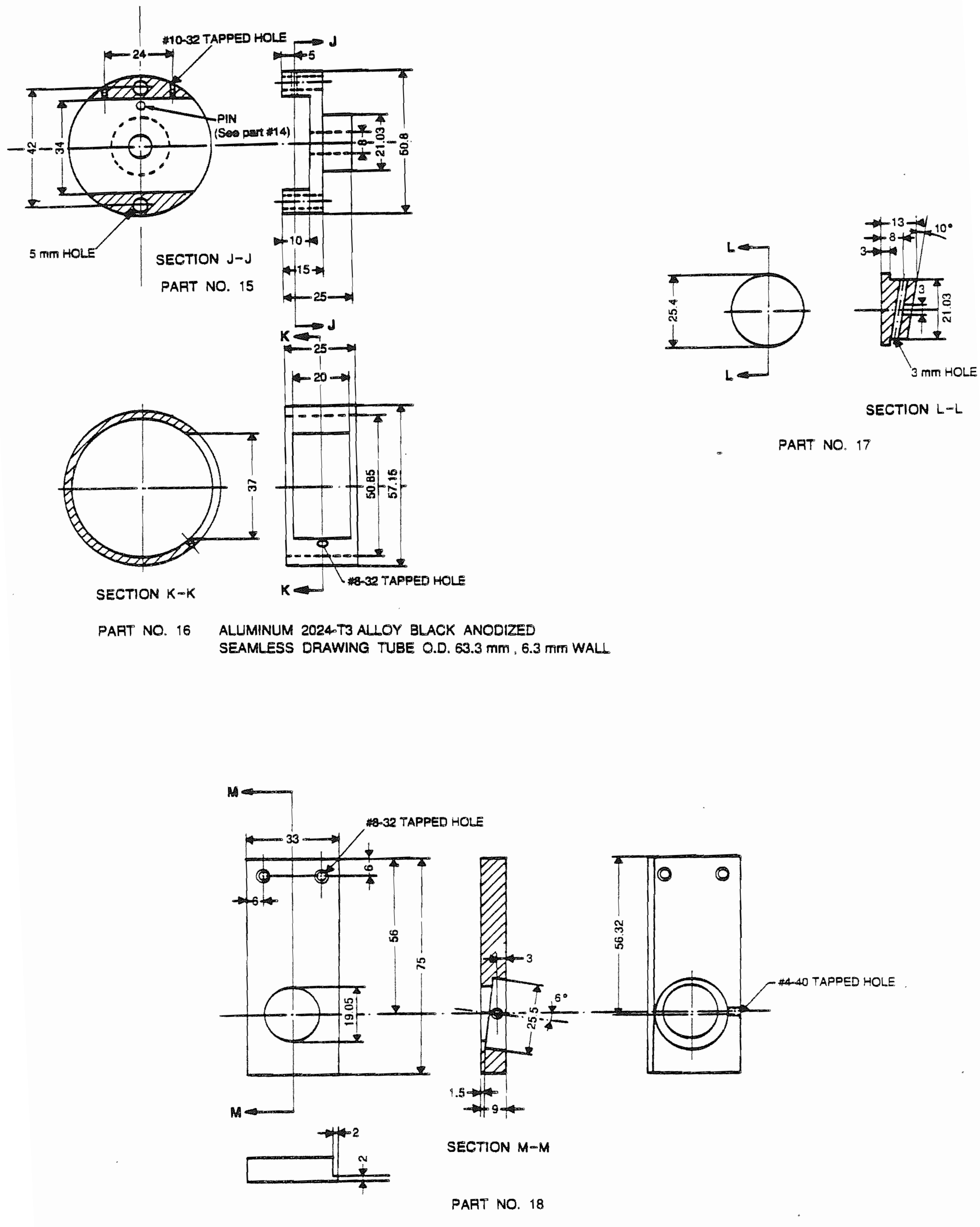


Figure C29. Extinction beam parts 15,16,17,18

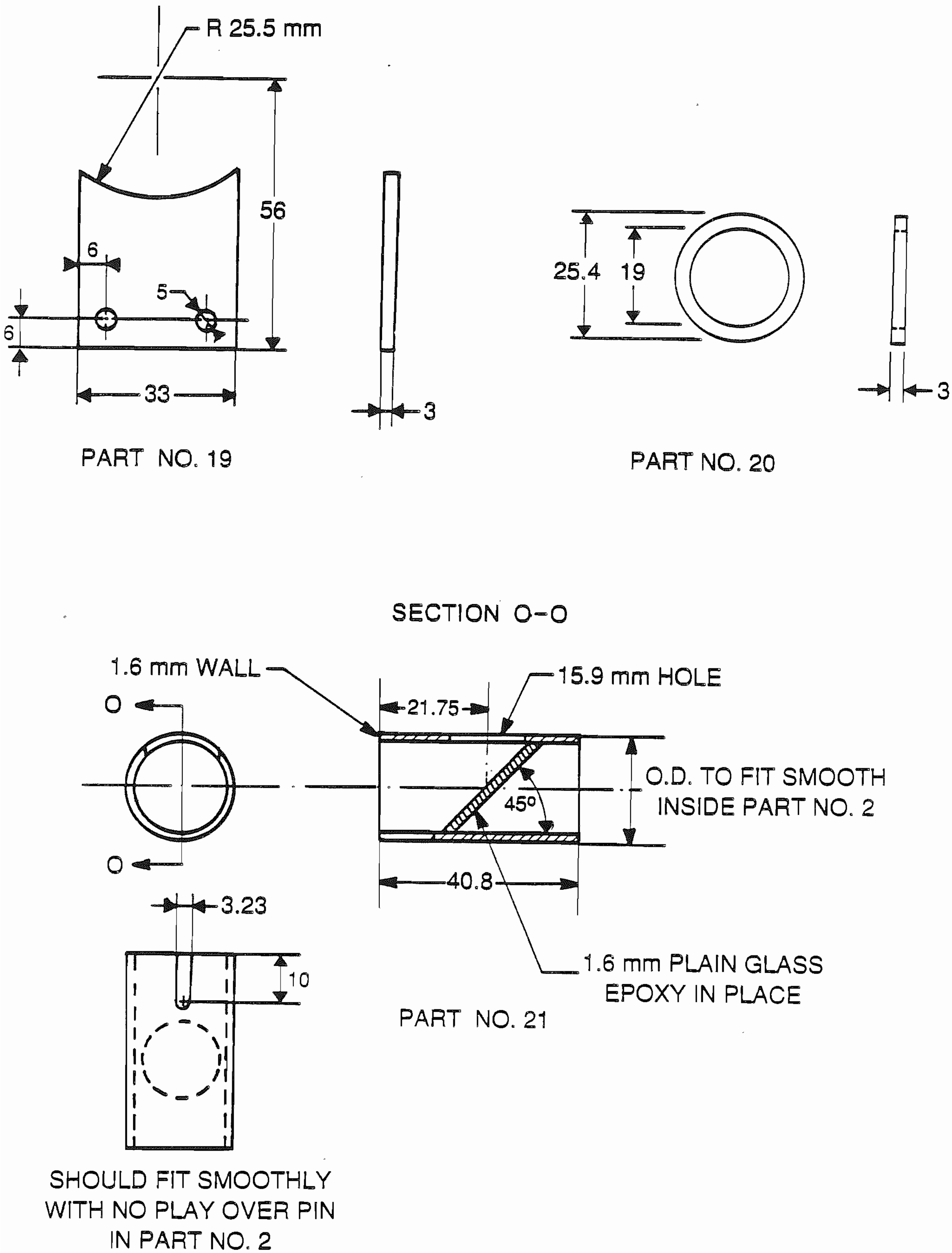


Figure C30. Extinction beam parts 19,20,21

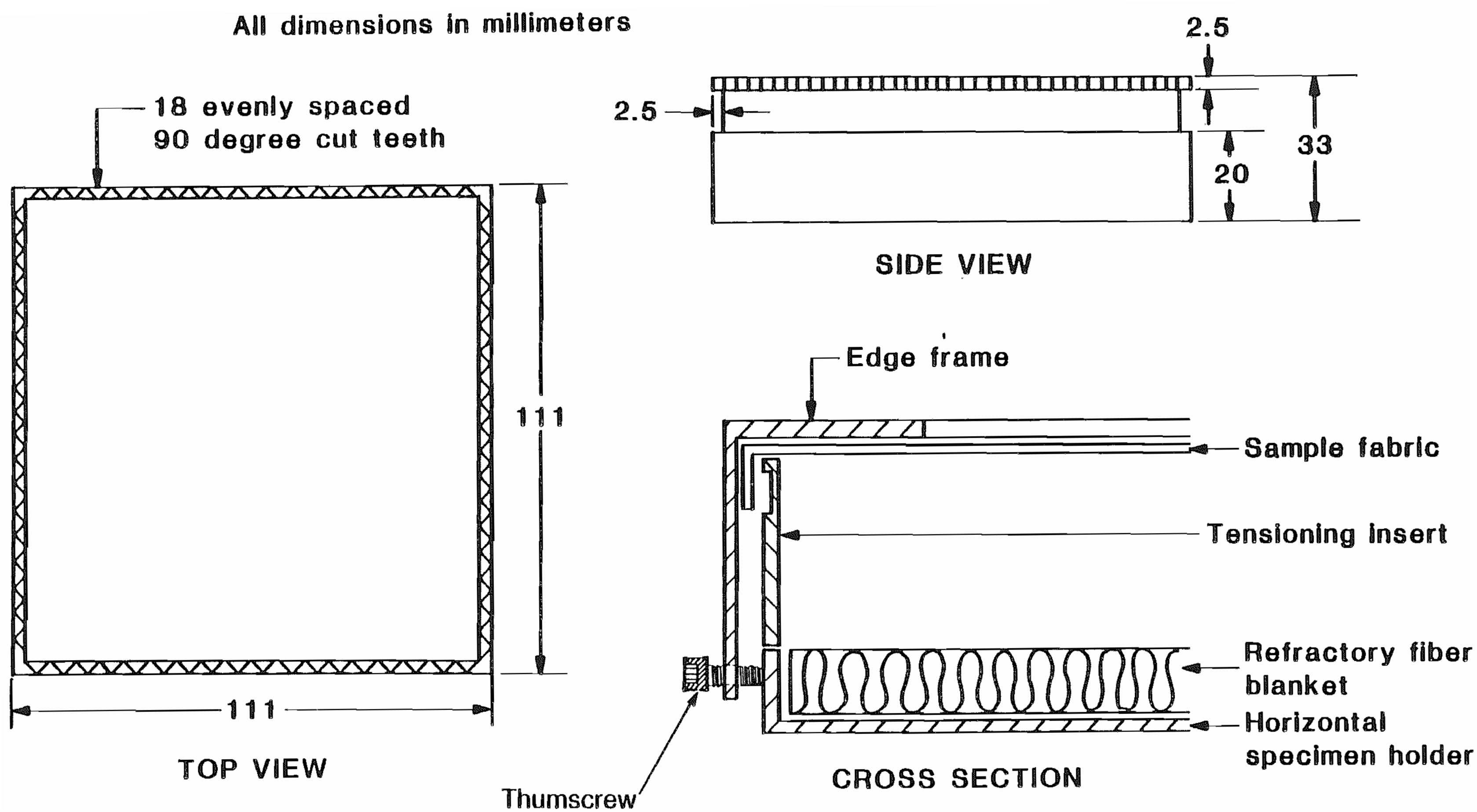


Figure C31. Tensioning insert for testing fabrics

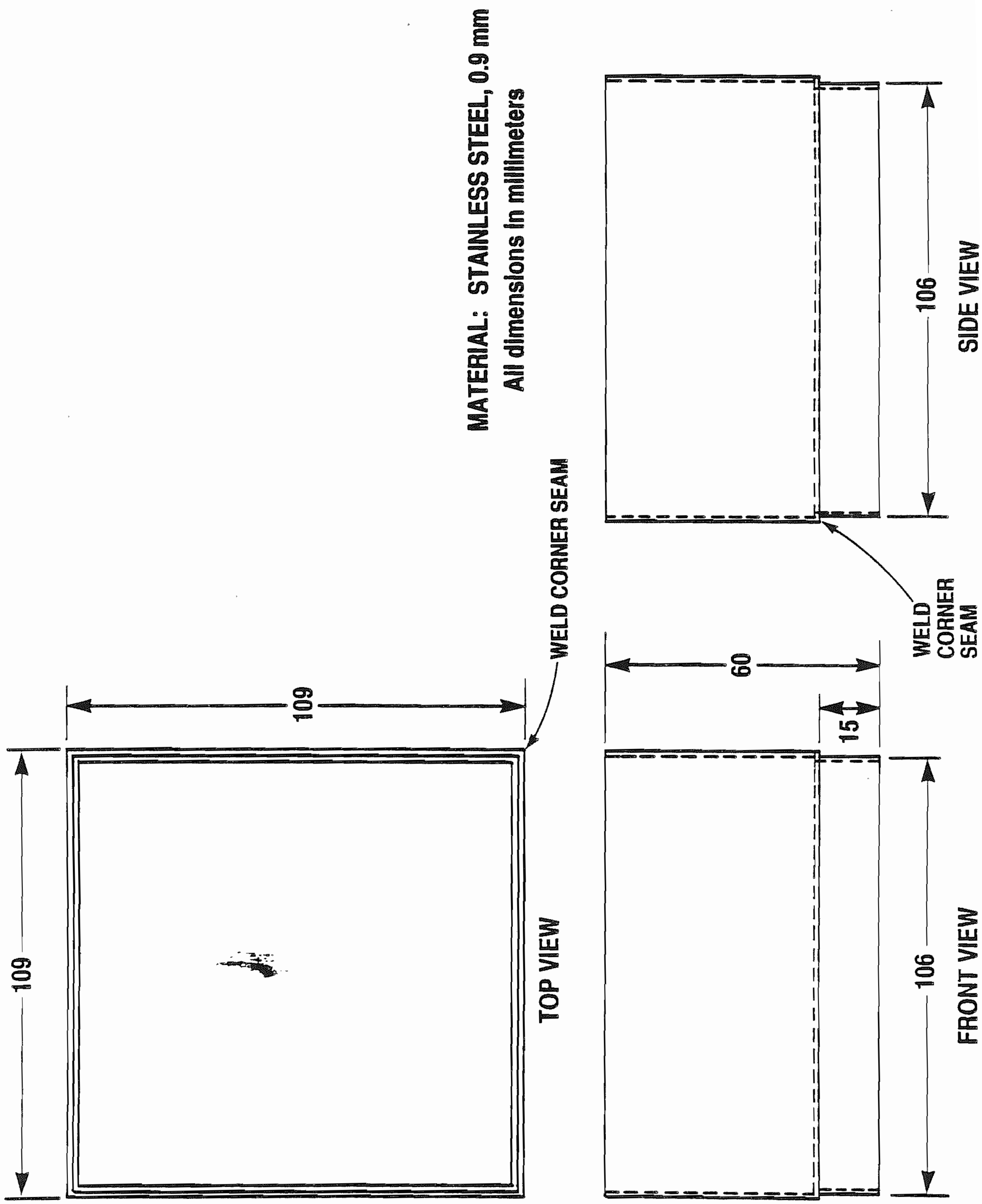


Figure C32. Special specimen holder for materials which both intumesce and melt

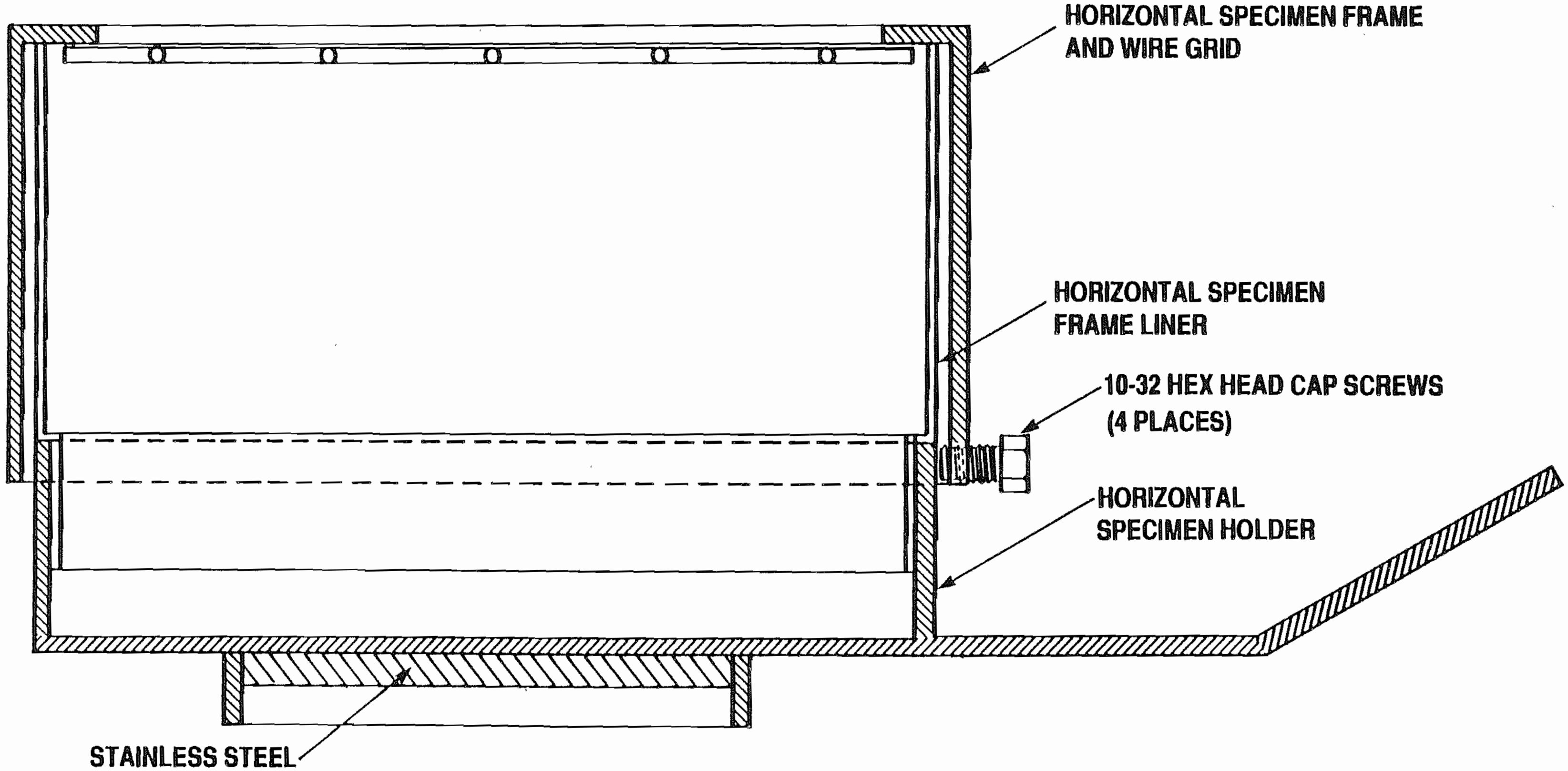


Figure C33. Cross sectional view of specimen holder arrangement for intumescing and melting materials

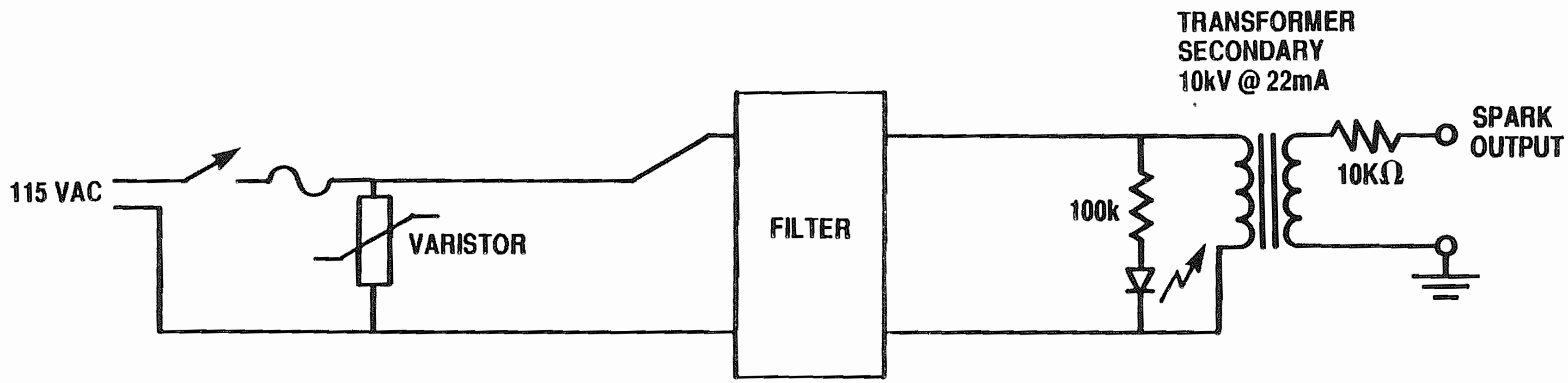


Figure E1. Power supply for spark plug

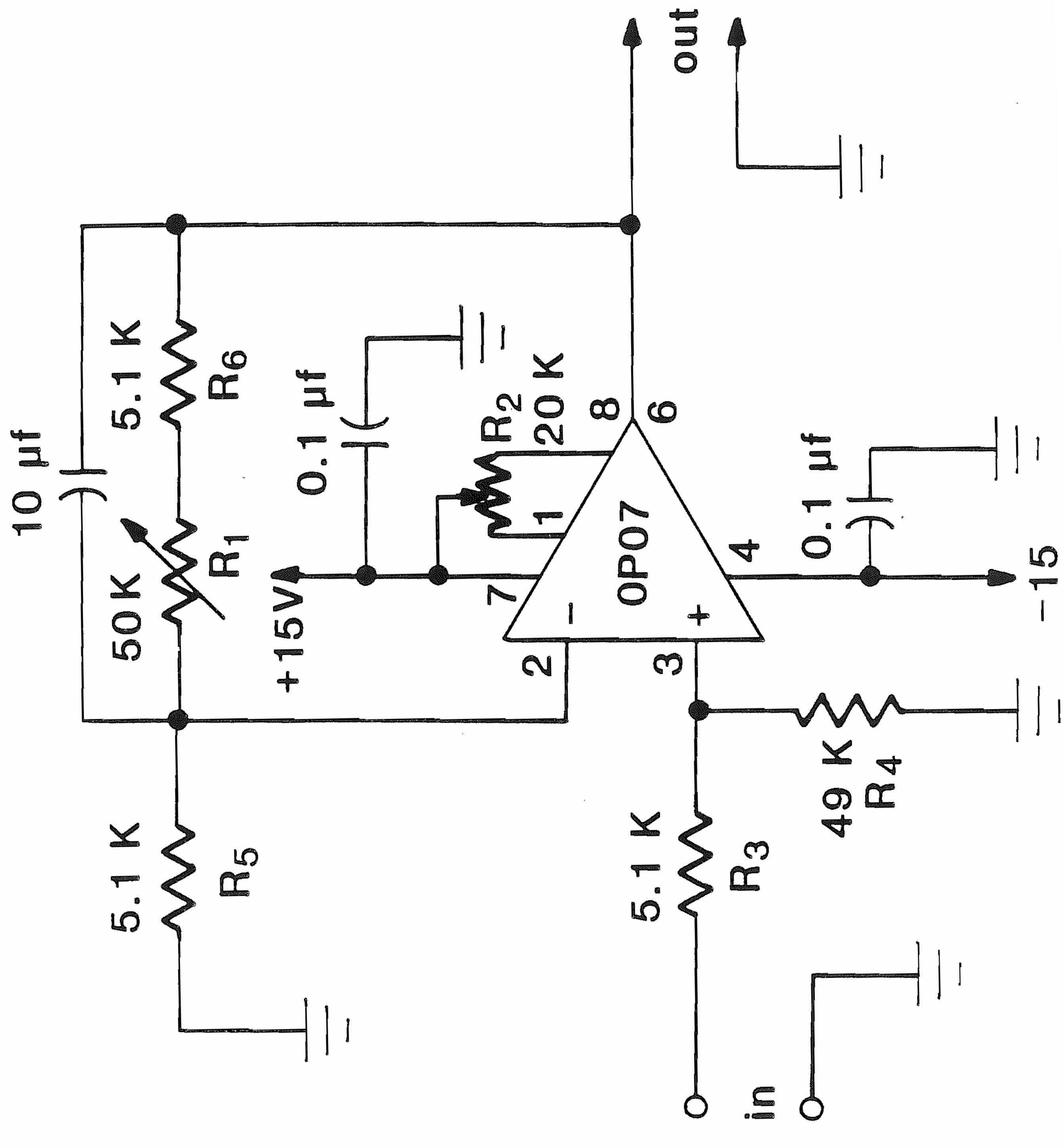


Figure E2. Smoothing amplifier for △P transducer

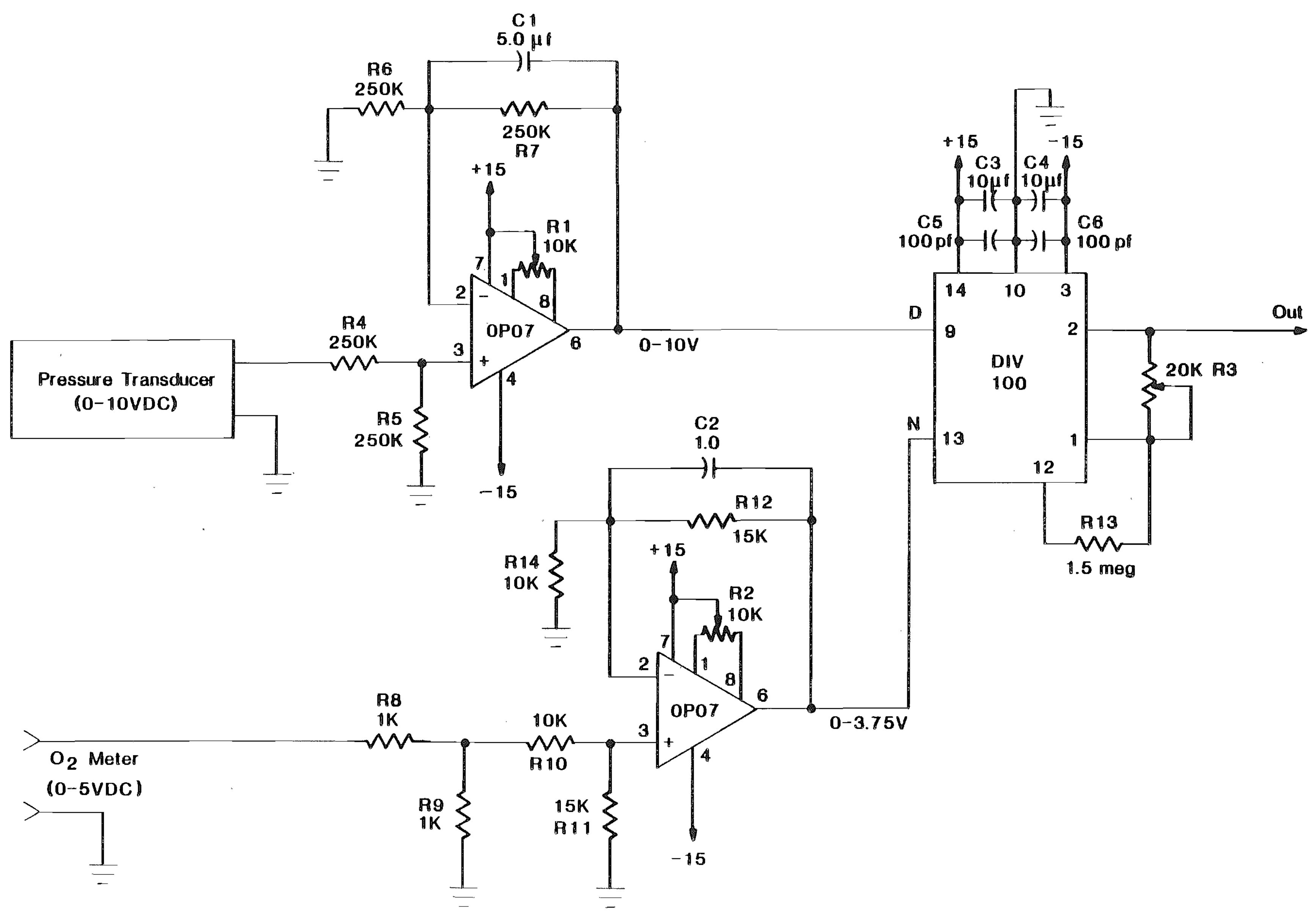
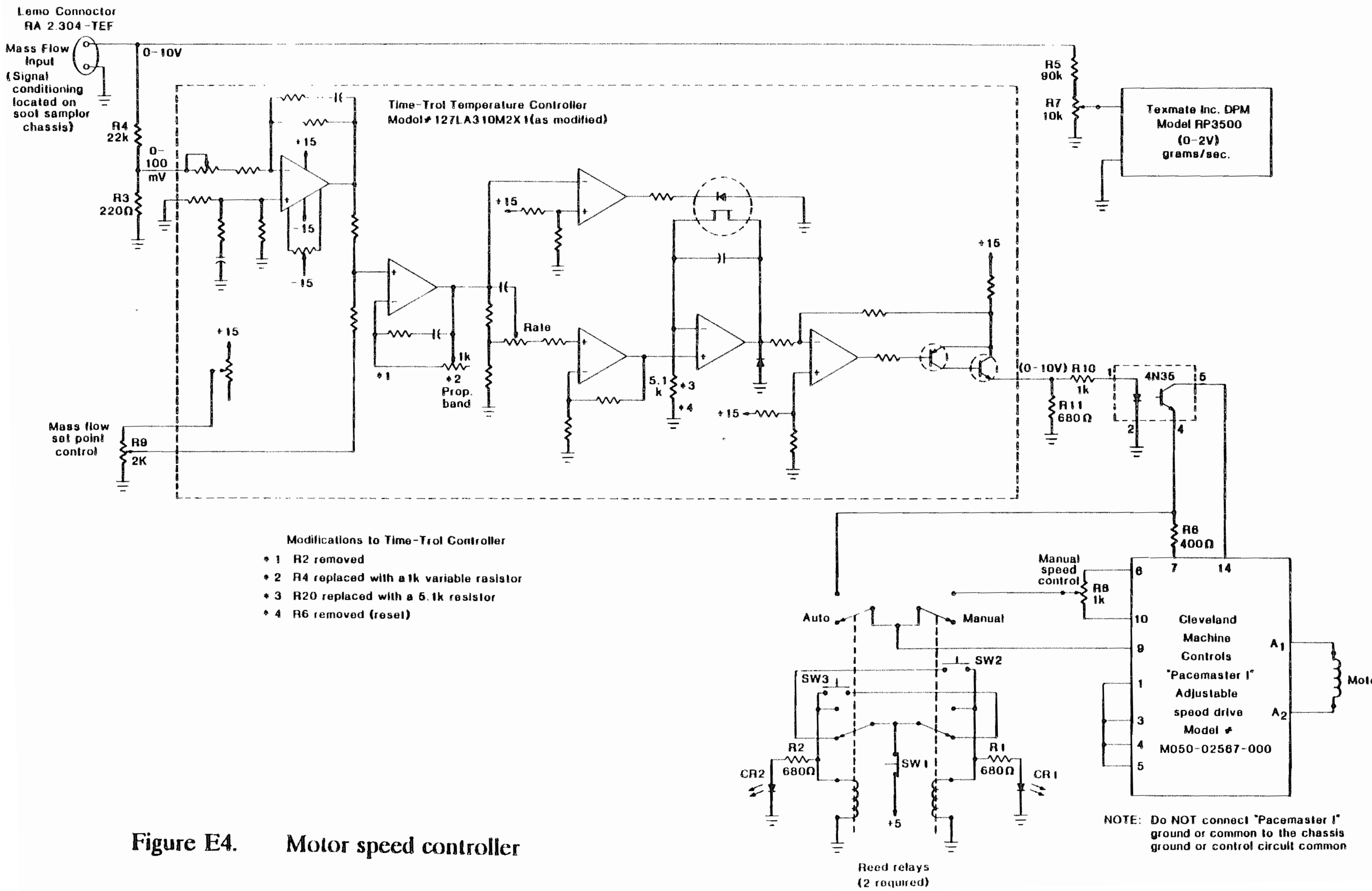


Figure E3. Oxygen meter pressure compensation for Beckman oxygen analyzer



Modifications to Time-Trol Controller

- \#1 R2 removed
- \#2 R4 replaced with a 1k variable resistor
- \#3 R20 replaced with a 5.1k resistor
- \#4 R6 removed (reset)

Figure E4. Motor speed controller

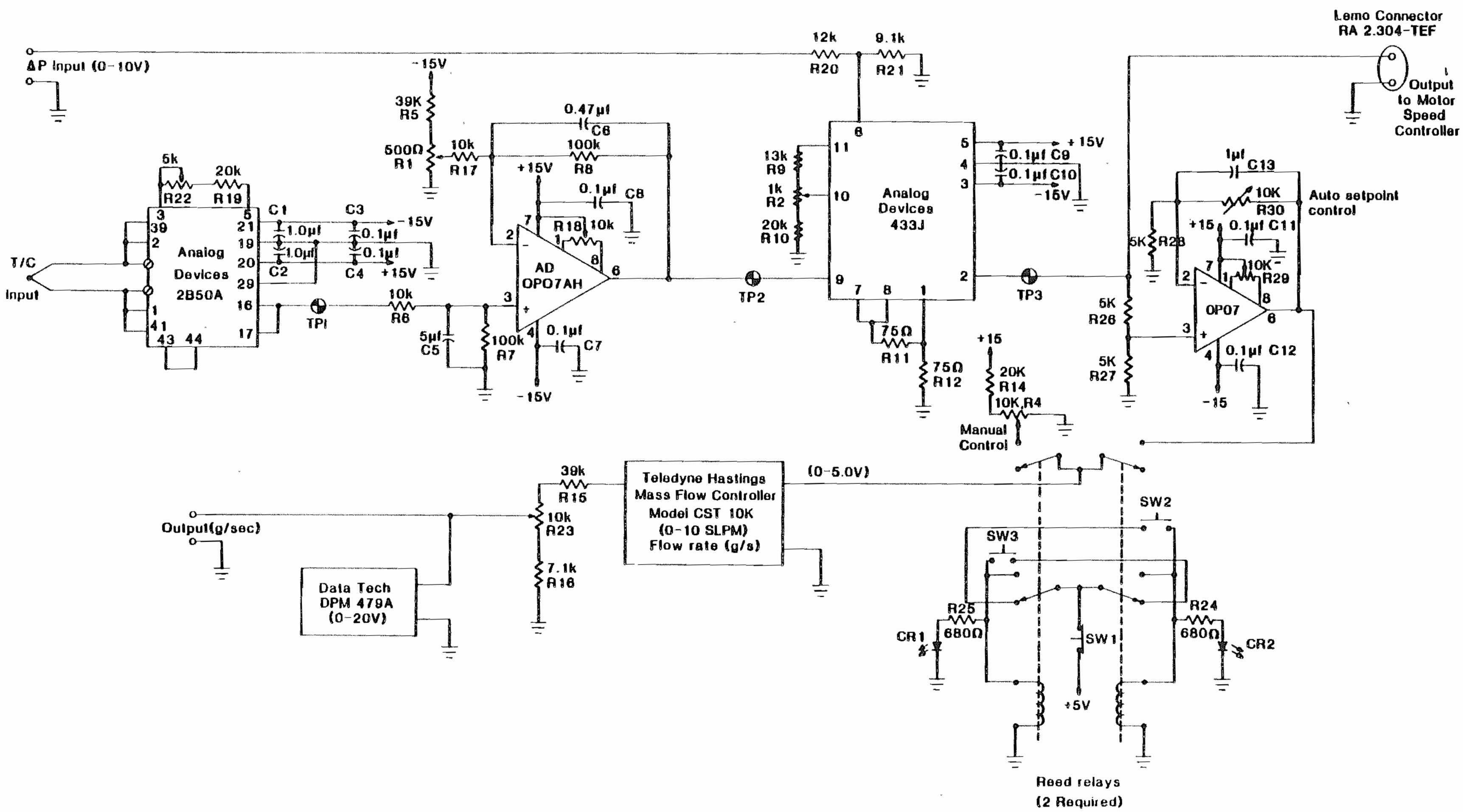


Figure E5. Soot mass sampler controller

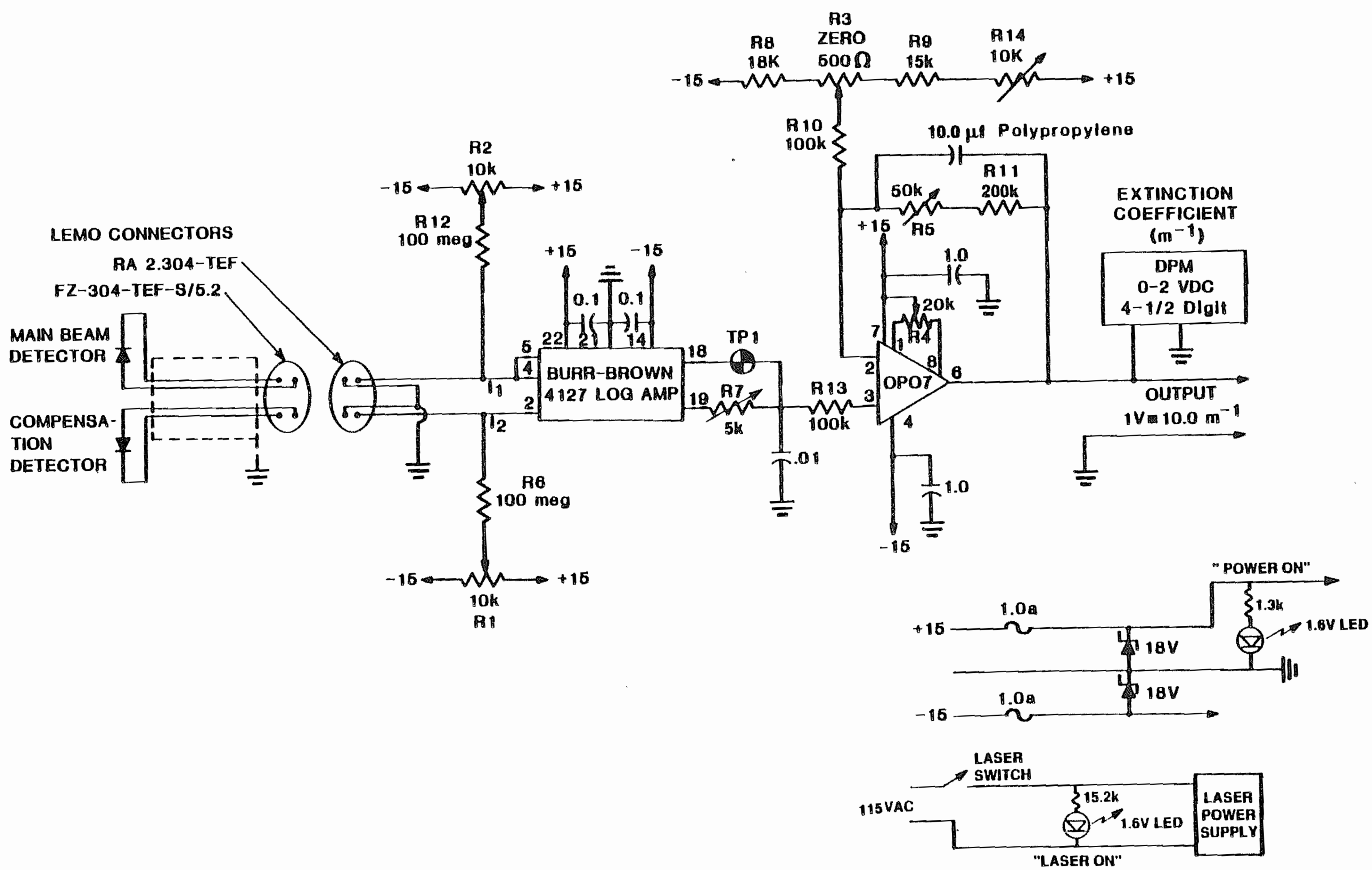


Figure E6. Logarithmic amplifier for laser extinction beam (NIST version)