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Conceptual Design for the STAR Barrel Electromagnetic Calorimeter Support Rings

E. Bielick*, T. Fornek*, H. Spinka, and D. Underwood

High Energy Physics Division
Argonne National Laboratory, Argonne, Illinois 60439

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I) *Introduction*

The STAR electromagnetic calorimeter (EMC) will be used to measure the energy of photons and electrons from collisions of beams of particles in the RHIC accelerator under construction at Brookhaven National Laboratory. The present design is documented in the EMC Conceptual Design Report,[1] and consists of a cylindrical barrel and two flat endcap calorimeter sections, as shown in Fig. 1. The barrel EMC will consist of 120 modules, each subtending 6° in azimuthal angle about the beam (ϕ), and half the barrel length. Each module will be subdivided into "towers" of alternating scintillator and lead, which project to the nominal interaction point.

There is a strong coupling between the designs for the EMC and for the conventional solenoidal magnet, which will be located immediately outside the barrel EMC. For example, the inner radius of the magnet must be minimized to lower costs and to reduce the STAR detector's outer diameter to fit within constraints of the existing detector building. This condition requires the calorimeter modules to be just thick enough to accomplish physics goals and to support their weight with small deflections. Some of the other considerations for the magnet and calorimeter designs are described in Ref. 2 (STAR Note # 115).

* *E. Bielick and T. Fornek are on loan from Argonne's Technology Development Division.*

The method to support the barrel EMC was developed in collaboration with the STAR magnet subgroup engineers at Brookhaven. The present design consists of a set of nine large rings located between the solenoidal magnet coils, as shown in Fig. 1. Attached to the rings will be 60 "rails" running parallel to the particle beams, with a spacing of 6° in ϕ between rail centers (Fig. 2). The barrel EMC modules will slide in from the ends of the STAR detector on the rails. Tolerances on the module dimensions and rail spacings are critical in order to minimize the clearance required between modules; the larger the gap, the poorer the EMC physics performance.

This note describes progress in the design of the EMC support rings. Several ring designs and methods of construction have been considered. Modifications to the earlier design discussed in Ref. 2 were required due to costs. In addition, installation and alignment problems for both the rings and the rails have been considered in more depth. Finally, revised stress calculations for the recommended ring designs have been performed. Most of this work has been done in close collaboration with the STAR magnet subgroup.

II) Solid Ring Design

The first design considered for the EMC support rings was based on the concept presented in Ref. 2. This concept (Fig. 3) has eight aluminum rings of thickness 121 mm = 4.75", and a single ring 165 mm = 6.5" thick at the center of the barrel. The rings are assumed to be equally spaced along the beam direction (z), with 620 mm between ring center planes. A total of 60 slots or grooves in the eight 4.75" rings and sixty 76 mm = 3" diameter holes in the 6.5" center rings were assumed for routing of plastic optical fibers. These fibers will transmit scintillation light from the EMC modules to photomultipliers located outside the magnet. The slots or grooves in the 4.75" thick rings would be 51 mm ≅ 2" deep and 100 mm ≅ 4" wide, covering only a small fraction of the ring surface area (see Fig. 4). The large surface area was considered important, since it was assumed earlier that the magnet coils would be compressed between the rings.

Analytical and finite element calculations described in Ref. 2 indicated that solid 76 mm = 3" aluminum rings could support the weight of the barrel electromagnetic calorimeter (~ 190 tons total) and the weight of the copper magnet coils (~ 220 tons). Both the stresses and deflections were estimated to be acceptable if the rings were supported from the magnet flux return bars (or backleg steel bars) in several locations around the ring outer circumference. Since that time, aluminum has been adopted for the magnet coil material instead of copper.

It was assumed that these rings would be machined from large, 5"-thick aluminum plates, or from smaller plates welded together. Both the plates and the machining would be very expensive because of the large ring diameter.

Several cost estimates were made for the solid ring design in Fig. 3. One was a coarse estimate by an Argonne Manufacturing Engineer, a second by E. Bielick (see Table 1), and a third by a commercial machine shop (Vendor A). The first two estimates, assuming labor costs of $100 per hour for the large size of the rings, were $105,000 and $78,000 per ring. The third estimate was $71,000 per ring, however the labor rate per hour is not stated. The close agreement between the detailed estimate in Table 1 and the quote from Vendor A suggests that the total cost for the nine rings would probably be ≈ $650,000 - $750,000. The solid ring design was rejected because of this high cost.

A slightly modified solid ring design, with a 76 mm = 3" thick aluminum ring and no slots or grooves, was also too expensive. Vendor A estimated $49,500 per ring, or a total of $450,000.

III) Rings from 12° Segments

An alternate method of constructing the EMC support rings was suggested by Brookhaven engineers. There are to be 30 magnet flux return bars (backleg steel bars) parallel to the colliding beams, and located outside the solenoidal magnet coils as shown in Fig. 4. These bars provide a path for the magnetic flux on the outside of the magnet, and also support the barrel calorimeter and magnet coils. It was suggested to construct the EMC support rings of 12° segments as shown in Fig. 5, with each segment attached to a single magnet flux return bar. One advantage would be the ease of estimating loads applied to the magnet flux return bars due to the EMC modules. Preliminary analytic calculations of stresses by Brookhaven engineers indicated no serious problems with the design in Fig. 5.

Some changes had also occurred in the magnet design that were incorporated into drawings for the 12° segments. For example, the revised method of compressing the magnet coils in z, parallel to the colliding beams, involved "bumpers" or spacers that were independent of the rings; 127 mm = 5" diameter holes in the center of the 12° segments were included for these bumpers. Also, instead of routing some plastic optical fibers through holes in the magnet flux return bars, it was requested to route all fibers through the gaps between the bars. As a result, fiber routing guides were included in some of the 12° segment designs. The fiber lengths would increase by about 36 cm ≅ 14", causing additional light attenuation and some degradation in the EMC energy resolution.

One method for constructing the 12° segments is shown in Fig. 5. It was suggested by a Brookhaven engineer, and includes machining of stock material and welding. A finite element calculation of stresses and deflections due to gravitational loads from the EMC modules was performed using the ALGOR computer code (version SSAPOH, dated 12/30/92) with a 486/33 personal computer with 80 Mb available hard disk space. The 12° segment was modeled with plate elements. The module gravitational loads were transmitted from the module center of gravity to the segments by very stiff and massless plate elements as shown in Fig. 6a. The loads were assumed to correspond to the computed fraction of the module weight supported by the ring nearest to the end of the barrel, or ~ 1650 lb. The modules and 12° ring segment were assumed to be near the 3 and 12 o'clock positions in ϕ, with the largest stresses occurring at the 3 o'clock position. The maximum stress was estimated to be ~ 12,700 psi (see Fig. 6b) and the maximum deflection on the segment ~ 0.20 mm = 0.008". The addition of seismic loads in the two horizontal directions of 0.15 times the module weight increased the maximum stress to ~ 15,200 psi (see Fig. 6c) and the maximum deflection on the segment to ~ 1.12 mm = 0.044". The seismic loads were included for safety, and correspond closely to frictional loads during module installation. The highest stresses are located near the plates which are attached to the magnet flux return bars; these stresses can probably be reduced to acceptable levels by adding reinforcing gussets.

A modification of the design in Fig. 5 would perhaps allow the segments to be installed after the magnet coils and bumpers were in place. The hole for the bumper would be replaced by a slot in the 12° segment as shown in Fig. 7. However, shimming the segments and bolting them to the magnet flux return bars would be difficult due to interference with the optical fiber guides or coils from inside the magnet or due to access problems from outside the bars. Also, special parts to guide the plastic optical fibers 90° around a 2" radius would probably be required at the boundaries between EMC modules on the segments for any of the 12° segment designs.

A somewhat different conceptual design for the 12° segments was developed, based on casting and some machining as shown in Figs. 8-10. Fiber routing guides are included. The only machining required would be on the "top" and "bottom" of the segments, and holes to mount the segments to the bars and the rails. A complete ring is shown in Fig. 10.

The cost of rings of 12° segments is expected to be substantially less than for solid rings. The machining costs would be reduced because each segment is relatively small, and the amount of aluminum would also be less. Cost estimates for machining the 12° segments (Fig. 9) were obtained from Vendors A and B, and for casting (Fig. 8) from Vendors C, D, and E. Estimates for constructing the wooden casting patterns were $750, $1450, and $3530, and for the cost of each casting were $125, $171, and $220 from Vendors C, D, and E, respectively. The range of costs for producing one pattern for the center ring, one pattern for the other rings, and for casting 300 pieces (two for each center ring segment) was $39,000 - $73,060 from Vendors C and E. The machining costs were estimated to be $67.50 and $395 apiece from vendors A and B, respectively, or $20,250 and $118,500 for 300 pieces. The total cost estimates for the nine EMC support rings made of 12° segments had a considerable price range, from $59,250 to $191,560. Note that these costs do not include a special segment with a shape other than as shown in Figs. 8-10 if the segments must be installed after the magnet is completely assembled.

One concern with the use of the 12° segments for the EMC support rings is the potential difficulty of aligning the rails to desired tolerances. The tolerances are most stringent in the ϕ or azimuthal direction. Adjacent rails need to be parallel and positioned to $\lesssim \pm 0.25$ mm = $\pm$ 0.010" so that the gap between EMC modules can be minimized; the goal is $\lesssim 1$ mm for the gap. However, variations from the ideal locations of the 30 magnet flux return bars (backleg steel bars), the sizes and relative locations of the 270 individual 12° segments, and the positions of the 60 rails relative to the segments will all be present. The time and effort estimates for installation, survey, and alignment will be discussed further in Sec. VI.

IV) Rings from 60° Segments

A third method of constructing the EMC support rings involved casting and machining 60° segments, and attaching these together to form a complete ring. The 60° segments reduce the number of pieces in a ring compared to the 12° segments, yet are not so large to require very specialized and costly machines as in the solid ring case. The conceptual design for the 60° segments is shown in Figs. 11-13. The casting would include guides and the 1-3/4" radius for routing the plastic optical fibers, and 127 mm = 5" diameter holes for the holding magnet bumpers; see Fig. 11. Some machining would be needed on the inner and outer radius, and on the ends for the lap joints between adjacent segments (Fig. 12). After the machining of each segment was complete, they would be clamped together in 180° sections as in Fig. 13, adjusted to meet overall dimensional tolerances, and finally pinned together. Then pairs of 180° sections would be assembled, pinned, and labeled in the shops, disassembled and shipped to Brookhaven as 180° sections, and finally reassembled.

Finite element calculations for stresses and deflections of these rings were performed. The ring cross sections were 44 mm = 1.75" and 70 mm = 2.75", instead of 2" and 3" for the center and remaining rings, respectively, to provide clearance between the magnet coils and rings. This clearance was included at the request of the STAR magnet subgroup engineers. The calculation used plate elements to represent the rings. As before, the module gravitational loads were transmitted from the module center of gravity to the rings by stiff and massless plate elements. Including seismic loads in the horizontal plane of 0.15 times the gravitational loads, the estimated maximum stresses were ~ 10,200 and ~ 10,400 psi (see Figs. 14c and 15c) and maximum deflections to the rings of ~ 0.68 mm = 0.027" and ~ 1.37 mm = 0.054" for the 1.75" and 2.75" rings, respectively. Note that the estimated weight from the EMC modules on the center ring was only ~ 363 lb. per module. The highest stresses occurred near the connection to the EMC modules. Stresses were only ~ 2000-3000 psi elsewhere. A realistic connection of the EMC modules to the rings was not modeled, and the expected stress is lower.

Cost estimates for the 60° segments were obtained from the same vendors as the 12° segments, except that Vendor D could not cast such a large piece. The wood casting patterns were estimated to cost $2750 and $5570 apiece, and the individual castings were $1000 and $1482 from Vendors C and E. The machining costs were $2140 and $3231 per piece from Vendors A and B. The total estimated costs for a pattern for the center ring and a pattern for the other eight rings, and for casting and machining 60 pieces (two pieces for each segment in the center ring) ranged from $193,000 to $293,920. These prices are higher than the 12° segments, but smaller than the solid rings. Also, the price range is smaller, both in absolute value and percentage, than for the 12° segments.

Two methods of mounting the rings to the bars were considered as shown in Figs. 16 and 17. In one case, mounting brackets are attached to the sides of the bars, one screw (positioner) pushes against the ring from the bracket, and a second screw pulls the ring toward the bracket, locking it in place. In the other method, a long threaded rod extends through two brackets clamped onto the edges of the magnet flux return bars and into the ring. Both of these methods are considerably easier to locate the rings than the 12° segments.

Finally, another option with 60° segments was also considered. In this case, the 60° segments would not be pinned together, but would be independent (as in the 12° segment rings). The costs for machining were significantly reduced by $64,200 for Vendor A, and $83,620 for Vendor B. The resulting total ring cost would range from $129,700 to $210,300. Alignment and survey difficulties would be between those for the 12° segments and the pinned 60° segment cases.

V) *Installation of the Rings*

The different ring designs permit various methods of installing the EMC support rings and the magnet coils. In all cases, the bottom half (15) of the magnet flux return bars and the end iron rings will be in place before the coils or rings are installed. The top bars can only be installed after all the coils are in place.

The slotted 12° segments in Fig. 7 could be installed and bolted to the bottom magnet flux return bars before the next coil was installed. Alternately, the slotted segments could be installed from inside the magnet after the coils, bumpers, and bars are all in place. If these segments are bolted directly to the bars, the bolts will be located the ring thickness ($\simeq$ 356 mm = 14") from the inner radius and access would be primarily through the 51 mm = 2" plastic optical fiber routing gap. If the segments are bolted to brackets from the outside of the bars as in Fig. 16, the bolts will be located $\simeq$ 610 mm = 24" from the outside of the bars. In either situation, shimming between the magnet flux return bars and the ring segments might be difficult.

The cast and machined 12° segments in Figs. 8-10 would need to be installed at the same time as the magnet coils if the bumpers are rigidly connected to the coils. This installation requirement arises because the bumpers are "located" in the segment holes, and the coils would presumably need to be aligned in z while they are being installed. The bottom 15 ring segments could be easily bolted to the bars before the next coil was installed. However, there are problems similar to the 12° slotted segment case to attach the top segments to the top bars. If the magnet was assembled from the center to the ends, there would be no additional problems. On the other hand, if the magnet must be assembled from the ends to the middle, this type segment could work for the center ring only if the bumpers could be inserted along with the segment. In order to provide sufficient space for the magnet coil installation fixture, the requirement to assemble the magnet from the ends to the middle might be imposed. A preliminary installation scenario for this case is presented in Appendix I.

The complete ring of pinned 60° segments (Figs. 11-13) also has holes for the bumpers, and thus has similar requirements to the non-slotted 12° segments. For ease of installation and preliminary positioning, it would probably be advantageous to have the bumpers on the side of the coil away from the ring being installed. Alternately, if the bumpers must be attached to both sides of the coil, it would be preferable to have the shorter bumper section on the side of the coil closest to the ring being installed, or to have the ring clamped to the coil so both are installed at the same time.

It is presently planned to have three or four alignment pins for the rings of 60° segments. These pins would be located at approximately 3, 6, 9, and perhaps 12 o'clock around the outer radius of the ring. The bottom one would fit into a hole in the bottom magnet flux return bar. These holes would be precisely drilled in order to obtain the proper z location for each ring. The pins near 3 and 9 o'clock would slide into slots in the magnet flux return bars to keep the rings plumb. In addition, the complete rings of 60° segments would probably require a reinforcing installation fixture to keep the ring circular while being moved with a crane. This fixture might be a relatively light "spider" that could be removed from inside the magnet after the ring was in place. A preliminary installation scenario for this case is given in Appendix II. Additional description of the alignment is given in the next section as well.

Combinations of the various types of rings could also be considered for reasons of cost or from other constraints on the installation procedure. For example, if the coils must be installed from the ends to the middle in order to have room for the coil installation fixture while placing the last coil, the complete rings of 60° segments could be used for all but the center ring and the slotted 12° segments for the center ring. Alternately, perhaps the center ring segments would be in two pieces. Five such 60° sections could be pinned together and installed at the same time as the last two magnet coils, leaving the top 60° free for the coil installation fixture. The remaining 60° segment plus bumpers could be lowered into place after the coil installation fixture was removed.

VI *Ring and Rail Alignment*

The time and effort to align parts of the STAR detector must be considered as well as the manufacturing and assembly effort and costs. For the electromagnetic calorimeter performance, it is important to align the modules so that there is a minimal gap in ϕ between adjacent modules. Particles traversing the gap are not registered in the calorimeter, which causes a degradation in the EMC energy resolution. To meet the goal of a nominal gap of $\lesssim$ 1 mm requires tolerances in alignment of the module rails to $\lesssim \pm 0.25$ mm = ± 0.010" in the ϕ direction. To meet this same goal, the radial position of the rings (r) must be kept within ± 10.2 mm = ± 0.40". The tolerance on the z position for the rings can also be large, since slots along z can be machined in the rail attachment pieces. The main limitation on z is from the clearance between the coils and the rings, or ± 3.2 mm = ± 0.125".

An estimate was made of the expected variations in positioning of the rail mounting holes in the rings using preliminary drawings of the magnet flux return bars and iron rings, dated 14 May 1993, and of the 12° ring segments. These are described below in terms of cylindrical coordinates, r, ϕ, and z.

- The tolerances for the end iron rings include: A) ± 0.005" in the ϕ and z directions for machining of the bar mounting holes, and b) ± 0.020" in r for machining the ring radius on the surface to which bars are mounted.
- The magnet flux return bar or backleg steel bar tolerances are: a) ± 0.032" in the ϕ and z directions from clearance in the screw holes to mount the bars onto the end iron rings, b) ± 0.005" also in ϕ and z for machining the EMC support ring mounting holes relative to the holes for the end iron rings, and c) ± 0.010" due to gravity loading distortions of the bars in the r and ϕ directions. No other tolerances for twist or warpage of the bars have been included.
- The tolerances for the 12° segments of the EMC support ring include: a) ± 0.032" in the ϕ and z directions due to clearance in the screw holes to mount the segments to the bars, b) ± 0.003" in ϕ and z for the location of the rail mounting holes relative to the holes to the bars, c) ± 0.003" in r for machining the inner relative to the outer radial surfaces of the segments, and d) ± 0.009" in z for possible tilt of the segments. The last contribution assumes a tolerance of ± 0.002" on the 3" flat part of the ring outer radius, which is magnified by the ratio of the ring height to the 3" distance.
- An additional ± 0.010" tolerance is assumed for mating of the bars and end rings, and ± 0.010" for mating of the segments and bars, both in the r direction.

The contributions above to variations of the positions of rail mounting holes in the EMC support rings are summarized in Table 2 for the 12° segments, for either the slotted or non-slotted cases. The expected tolerances are ± 0.053" in r, ± 0.087" in ϕ, and ± 0.086" in z. The radial variations are not critically important, and the variations in z could be handled with slots in the rails. However, the ϕ variations are significant, and will require a method to align the segments or the rails to the segments. Perhaps this could be achieved with slots in the segments in the ϕ direction for mounting them to the magnet flux return bars.

The expected variations in the location of the rail mounting holes with the rings of pinned 60° segments depend more on the machining and assembly of the rings themselves than on the end iron rings and magnet flux return bars. As noted in Section V, the z alignment of these rings comes from the locating pin holes machined in the bottom magnet flux return bar; the end iron rings affect only the absolute location of all the rings and not their relative location. Thus, the contribution to the uncertainty in locations of the rail mounting holes are:

- The bottom magnet flux return bar tolerances are: a) ± 0.005" in the ϕ and z directions for machining the locating pin holes for the rings, and b) ± 0.010" in the r direction due to gravity loading distortion of the bar. No other tolerances for twist or warpage of the bar have been included.
- The "3" and "9" o'clock magnet flux return bars have important tolerances only in the z direction: a) ± 0.005" for locations of the machined slots, and b) ± 0.010" for locating these bars relative to the bottom bar by survey methods.
- The tolerances for the EMC support rings include: a) ± 0.032" in the z direction for flatness of the rings after pinning, b) ± 0.005" in z for machining the locating holes for the pins, c) ± 0.005" for machining the rail mounting holes relative to the locating holes for the pins in the ϕ direction, d) ± 0.010" in the ϕ direction for aligning adjacent segments before pinning or ± 0.005" for machining the rail mounting holes in a single segment, and e) ± 0.020" in r for machining the ring radius and for aligning adjacent ring segments.
- An additional ± 0.010" is assumed for mating of the rings and the bottom magnet flux return bar in r.

The contributions above to variations of the rail mounting hole positions are summarized in Table 3 for the 60° segments. The expected tolerances are ± 0.040" in r, ± 0.020" in ϕ, and ± 0.057" in z. As before for the 12° segments, the radial variations are not critically important, and the variations in z can be handled with slots in the rails for the mounting screws. The ϕ variations for the rings of 60° segments are significantly less than in the 12° segment case, and may be small enough to be handled with clearance in the slots for the rail mounting screws.

After installation, the rings will need to be positioned sufficiently accurately so that the rails can be installed and aligned to $\lesssim$ ± 0.25 mm = ± 0.010" in the ϕ direction. For the case of the rings made of 60° segments, the bottom magnet flux return bar needs to be carefully aligned with respect to reference survey marks, so that the holes for the alignment pins from the rings are on the nominal beamline when the STAR detector is moved into place. The two bars with slots, near 3 and 9 o'clock in ϕ, need to be carefully positioned in z relative to the bottom bar during their installation. Alternately, the slots could be machined in long aluminum bar stock which could be positioned relative to the bottom bar and then bolted in place. The additional time for special survey and alignment of these three bars might be two days for a survey team of four people. The time to install, survey, and align each ring is estimated to be approximately one day with the same survey team.

The effort to position the EMC support rings of 12° segments will be concentrated on different tasks than for the 60° segment rings. For example, the careful positioning of the three magnet flux return bars may not be required. Even though each 12° segment is relatively small and light, there will be at least four mounting screws per segment. Thus there are many more screws per ring, and as a result, the installation time for the two types of rings may be similar. However, the total survey and alignment time is expected to be considerably higher for the 12° segments. A number of surveyors at Argonne and Brookhaven were consulted about this time. The estimated times to install, survey, and align the EMC support rings of 12° segments ranged from four to ten days for each complete ring, requiring more than a team of four surveyors plus a machinist to fabricate shims. This corresponds to about 1-3 hours for each of the 270 12° segments. The larger team of surveyors, perhaps 5 or 6 in number, is needed to handle the extra degrees of freedom compared to the case of the 60° segment rings.

In summary, the total effort to install, survey, and align the rings of 12° and 60° segments is $\gtrsim$ 180-450 and ~ 44 person days, respectively. The corresponding times are ~ 36-90 and ~ 11 days, or ~ 7-18 and ~ 2 weeks. At a labor cost of ~ \$50 per hour or ~\$400 per day for surveyors and machinists, the 12° segment ring costs are greater by $\gtrsim$ \$54,000 - \$162,000, depending on the number of surveyors required. In effect, the higher cost to manufacture, align, and pin the rings of 60° segments will probably be offset by costs to survey and align each of the 12° segments and by the added time during STAR assembly.

VII) Rails

The present concept for the rails is a commercial dual shaft rail system by Thomson Industries, Inc. (The Quickslide 2DA-16 system). The rails are precision ground 1.00" = 25.4 mm diameter steel rods with an extruded aluminum alloy rail support. A cross sectional view of the rails and a drawing of the ring mounting holes is shown in Fig. 18. Commercial carriages with rulon plastic bushings will be mounted to the EMC barrel module backplate as shown in Fig. 19. The mounting of the rails to the rings is also illustrated. Six 5/8" bolts are required to attach the rail to each ring except at the center; spatial limitations prevent fewer bolts of larger diameter or a more optimum location of the bolts with respect to the rings.

The effort and time to install, survey, and align each rail have not been estimated, but are expected to be the same for rings of either 12° or 60° segments aligned as described in Section VI. A special alignment fixture would certainly be required, and it may be a precision machined ring of pinned 60° segments or perhaps the installation fixture.

VIII) Conclusions

Conceptual designs for the STAR electromagnetic calorimeter support rings were presented. One design involved 270 independent 12° segments in 9 rings (see Figs. 5, 7-10), each segment attached to a single magnet flux return bar. The manufacturing cost is low, but installation, survey, and alignment costs and times are high. An alternate design has nine complete rings assembled from 60° segments as shown in Figs. 11-13. These rings are more expensive to build, but cheaper to install and align. Finite element calculations indicate that stresses and deflections can probably be kept within acceptable limits with either design. Other ring designs were also described.

It is suggested to adopt a support system for the barrel EMC with at least some rings of 60° segments, perhaps the center and end rings. This will make the alignment of the rails and other rings easier. The remaining rings might also be constructed of 60° segments or perhaps of 12° segments. The final choice will depend on a number of factors, such as the adopted magnet assembly sequence (ends to center or center to ends), other requirements from the magnet design, limitations on manufacturing costs, and available time for ring alignment.

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References

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Table 1
Solid Ring Cost Estimate

Packaging and Shipping

Days	Activity
1	Shipping Strategy
2	Design Fixture
15	Order and Fabricate
1	Delivery
3	Load Fixtures and Rings on Rail Cars
7	Travel
1	Unload at BNL
30	TOTAL

30 days for 9 rings = approximately 3 days each

Fabrication Schedule

Days	Activity
1	Ring Arrival, Unloading, and Storage
1	Planning, Scheduling, Make Tapes, and Test
1	Move to Machine Shop
8	Rough Machine I.D., O.D., and Thickness
10	Rough Machine Slots
6	Rough Machine Radius
3	Heat Treat
3	Measure, Plan and Schedule
8	Final Machine I.D., O.D., and Thickness
10	Final Machine Slots
8	Final Machine Radius
10	Machine Holes
4	Machine Flatness
2	Deburr and Cleanup
3	Inspection
3	Packaging and Shipping
81	TOTAL

81 days @ 8 hours each = 648 hours	
648 hours @ 100 each =	$64,800 per ring
Purchased stock = 6600 # @ $2 each =	$13,200 per ring
TOTAL COST	$78,000 per ring
	× 9 rings
	$702,000

Table 2

Estimated Contributions to Tolerances in the Location of Rail Mounting Holes for the Case of 12° Segment EMC Support Rings

r

± 0.020"	End iron ring outer radius
± 0.010"	Bar distortion from gravity loading
± 0.003"	Segment machining
± 0.010"	End iron ring to bar separation
± 0.010"	Bar to segment separation
± 0.053"	TOTAL

φ

± 0.005"	Machining of holes in end iron rings
± 0.032"	Clearance in holes to mount bars to end iron rings
± 0.005"	Machining of holes in bars
± 0.010"	Bar distortion from gravity loading
± 0.032"	Clearance in holes to mount segments to bars
± 0.003"	Machining of holes in segments
± 0.087"	TOTAL

z

± 0.005"	Machining of holes in end iron rings
± 0.032"	Clearance in holes to mount bars to end iron rings
± 0.005"	Machining of holes in bars
± 0.032"	Clearance in holes to mount segments to bars
± 0.003"	Machining of holes in segments
± 0.009"	Tilt of segments from the vertical
± 0.086"	TOTAL

Table 3

Estimated Contributions to Tolerances in the Location of Rail Mounting Holes for the Case of 60° Segment EMC Support Rings

r

± 0.010"	Bar distortion from gravity loading
± 0.020"	Machining segment radius and pinning
± 0.010"	Ring to bar separation
± 0.040"	TOTAL

ϕ

± 0.005"	Machining of pin holes in bottom bar
± 0.010"	Aligning adjacent segments in a ring
± 0.005"	Machining of holes in rings
± 0.020"	TOTAL

z

± 0.005"	Machining of pin holes in bottom bar
± 0.005"	Machining of slots
± 0.010"	Location of slots relative to pin holes in bottom bars
± 0.032"	Flatness of rings
± 0.005"	Machining of pin holes in rings
± 0.057"	TOTAL

Figure Captions

1) Drawing of a quarter section of the STAR detector showing the magnet coils, electromagnetic calorimeter, rings, etc.

2) Sketch showing solid rings with slots for plastic optical fiber routing, rails for installation of EMC modules, and magnet flux return bars during assembly.

3) Sketch of a solid ring with grooves or slots and holes for mounting the rails. This drawing was used to obtain cost estimates for this method of ring construction.

4) Cross sectional view showing EMC modules, rings with grooves or slots for plastic optical fiber routing, and magnet flux return bars.

5) Sketch of a possible design for 12° segments by a Brookhaven engineer.

6a) Finite element model of a 12° segment support for the EMC.

6b) Results of a finite element calculations of stresses within a 12° segment under gravitational loads only.

6c) Results of a finite element calculation of stresses within a 12° segment under gravitational loads from the EMC modules and horizontal seismic loads of 0.15g.

7) Sketch of a possible design for 12° segments with a slot to fit around magnet coil bumpers or spacers.

8) Possible design for casting a 12° segment a) without, and b) with guides for routing plastic optical fibers. This drawing was used to obtain cost estimates for casting these parts.

9) Sketch for machining the cast 12° segments of Fig. 8, used to obtain cost estimates.

10) Drawing of a cross sectional view showing a ring of independent 12° segments, EMC modules, and magnet flux return bars.

11) Possible design for casting a 60° segment, used to obtain cost estimates.

12) Sketch for machining the cast 60° segments of Fig. 12, also used to obtain cost estimates.

13) Drawing of three 60° segments pinned into a half ring assembly.

14a) Portion of the finite model used for calculation of stresses within a half of the center ring formed of 60° segments under gravitational and 0.15g seismic loads from the EMC modules.

14b) Results of a finite element calculation of stresses within a half of the center ring formed of 60° segments under gravitational and 0.15g seismic loads from the EMC modules.

14c) Results of the finite element calculation of stresses within a 1-3/4" ring formed of 60° segments under gravitational and 0.15g seismic leads from the EMC modules showing the region of highest stress near the 3 o'clock position.

15a) Portion of the finite element calculation of stresses within a 4-3/4" ring formed of 60° segments under gravitational and 0.15g seismic loads from the EMC modules.

15b) Results of the finite element calculation of stresses within a 4-3/4" ring formed of 60° segments under gravitational and 0.15g seismic loads from the EMC modules.

15c) Results of the finite element calculation of stresses within a 4-3/4" ring formed of 60° segments under gravitational and 0.15g seismic loads from the EMC modules showing the region of highest stress near 3:00.

16) A possible method to mount and adjust the position of rings of 60° segments. One bolt (positioner) pushes against the ring from the bracket, while the other pulls the ring toward the bracket, locking it in place.

17) An alternate method to mount and adjust the position of 60° segment rings. Two positioner screws, and a long threaded rod for locking the ring in place are included. These mountings are held in place by friction; no welding or bolting to the magnet flux return bars are required.

18) Sketch showing the location of holes for mounting screws in the Thomson Quickslide 2DA-16 dual rail system.

19) A drawing showing the rails, an EMC module with five attached carriages, and the EMC support rings.

LBL DRAWING NUMBER	REV	STAR DRAWING NUMBER	REV	RHIC DRAWING NUMBER	REV
24A1401	2	XXXXXX-X-X	—	XXXXXXXXXX	—

LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA - BERKELEY

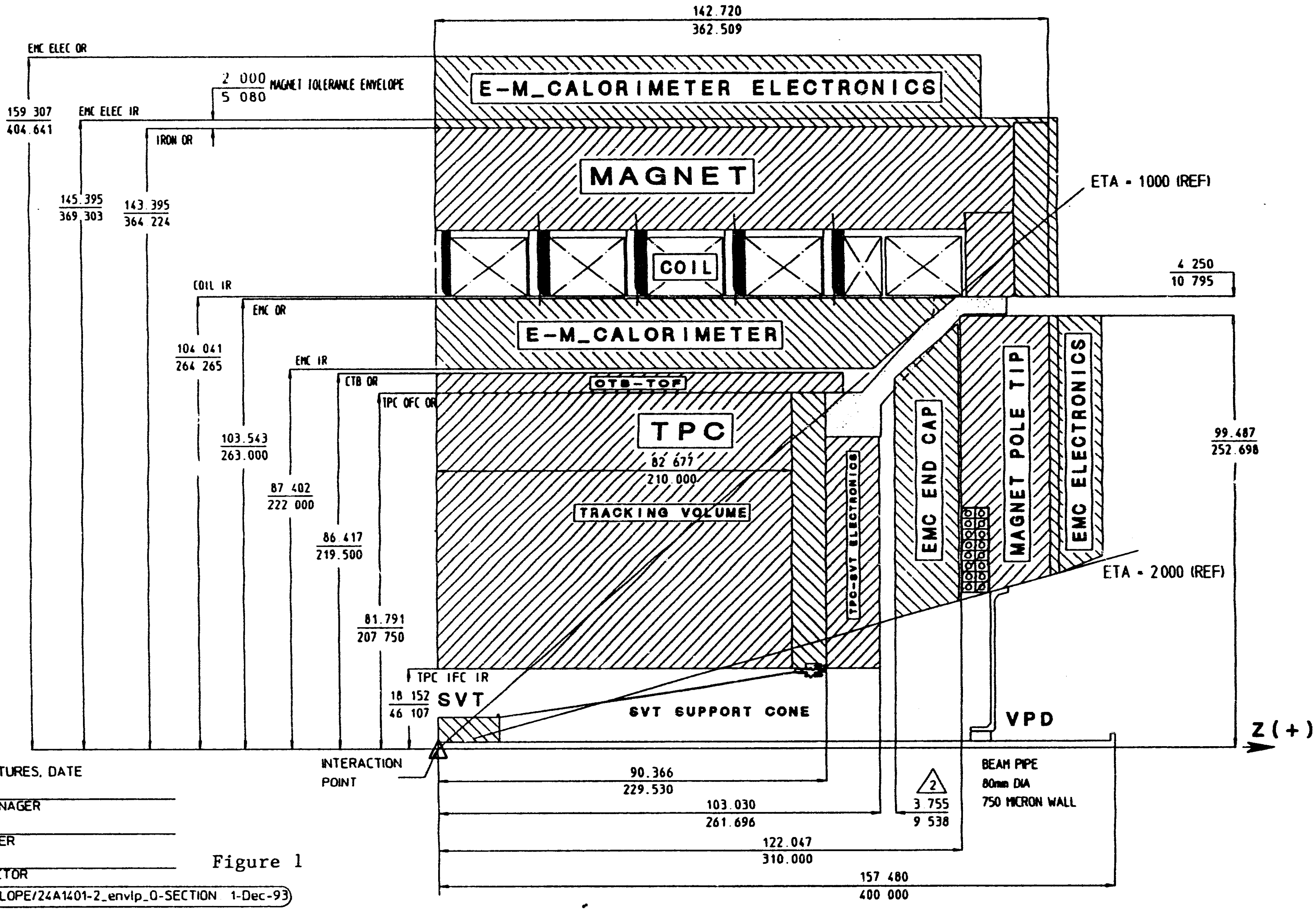
DRWN BY	DATE	CHECK BY	DATE	ALL DIMENSIONS ARE	
Doug Fritz	8/26/93	JER	8/26/93	INCHES / CENTIMETERS	

REV.	DWN.	CHK.	DATE	CHANGES
1	RJC	JER	10-11-93	UPDATED
2	RJC	JER	12-1-93	3.755 WAS 3.250

RHIC/STAR DETECTOR - S.I.

MECHANICAL COMPONENTS

QUARTER SECTION INTERFACE ENVELOPE



REQUIRED SIGNATURES, DATE

INTEGRATION MANAGER

PROJECT MANAGER

TECHNICAL DIRECTOR

Figure 1

(/star/fritz/ENVELOPE/24A1401-2_envlp_Q-SECTION 1-Dec-93)

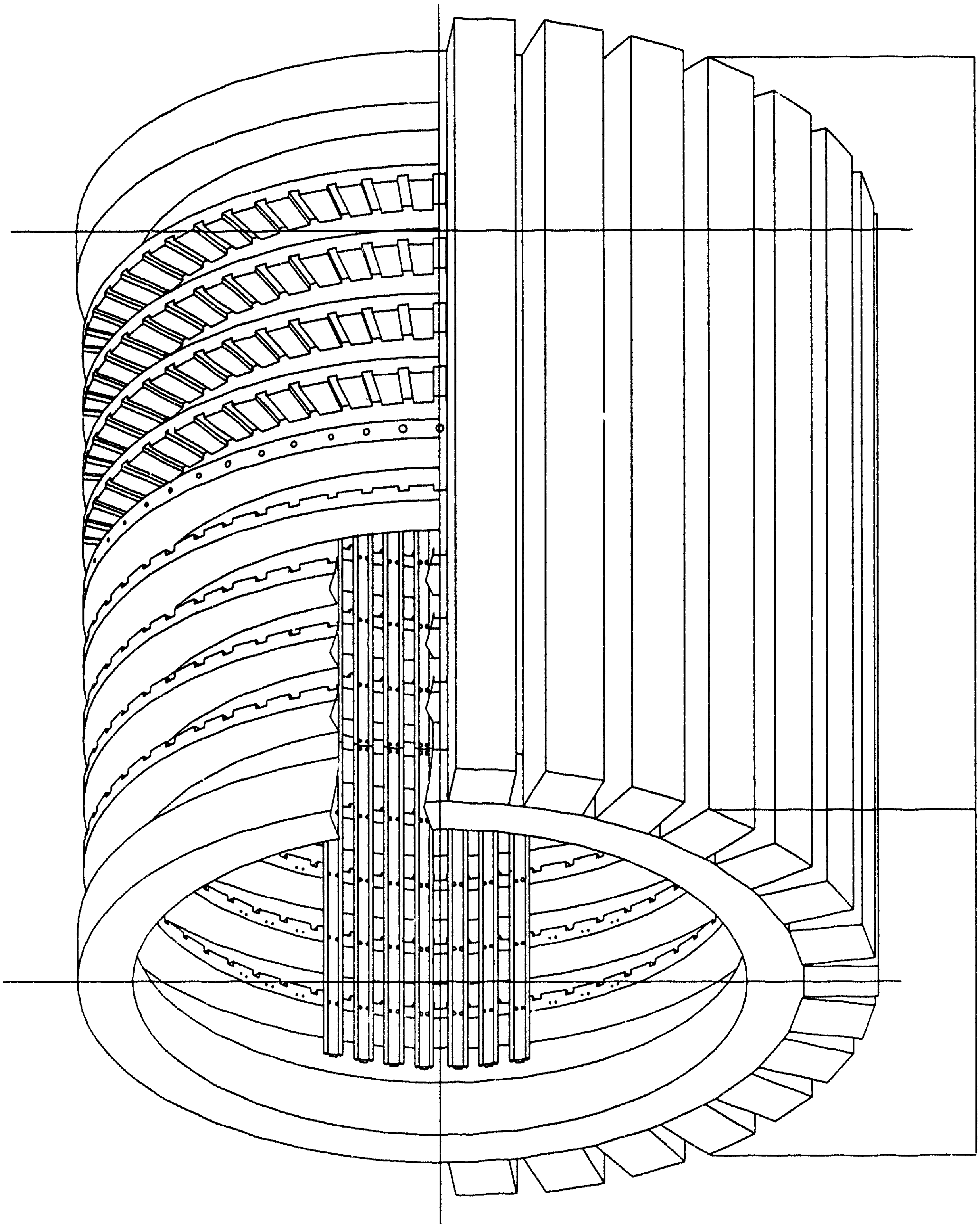
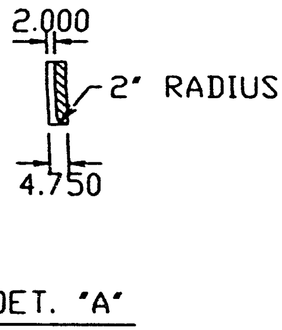
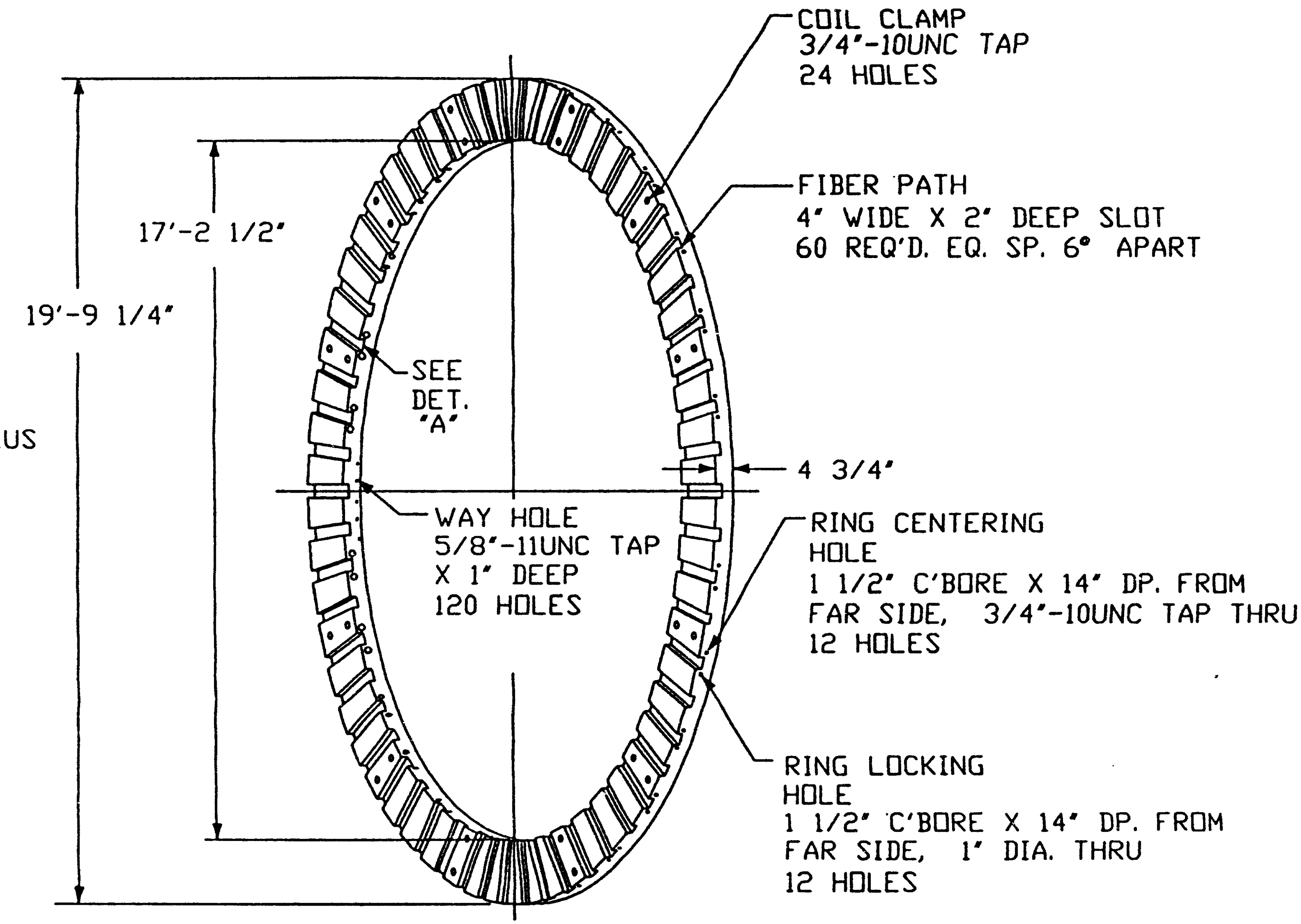


Figure 2





6061-T2 ALUMINUM RING

APPROX. WT. 4500 #
NO. REQ'D. 9
TOLERANCE +/-.032
RING FACES TO BE FLAT WITHIN .062"

Figure 3

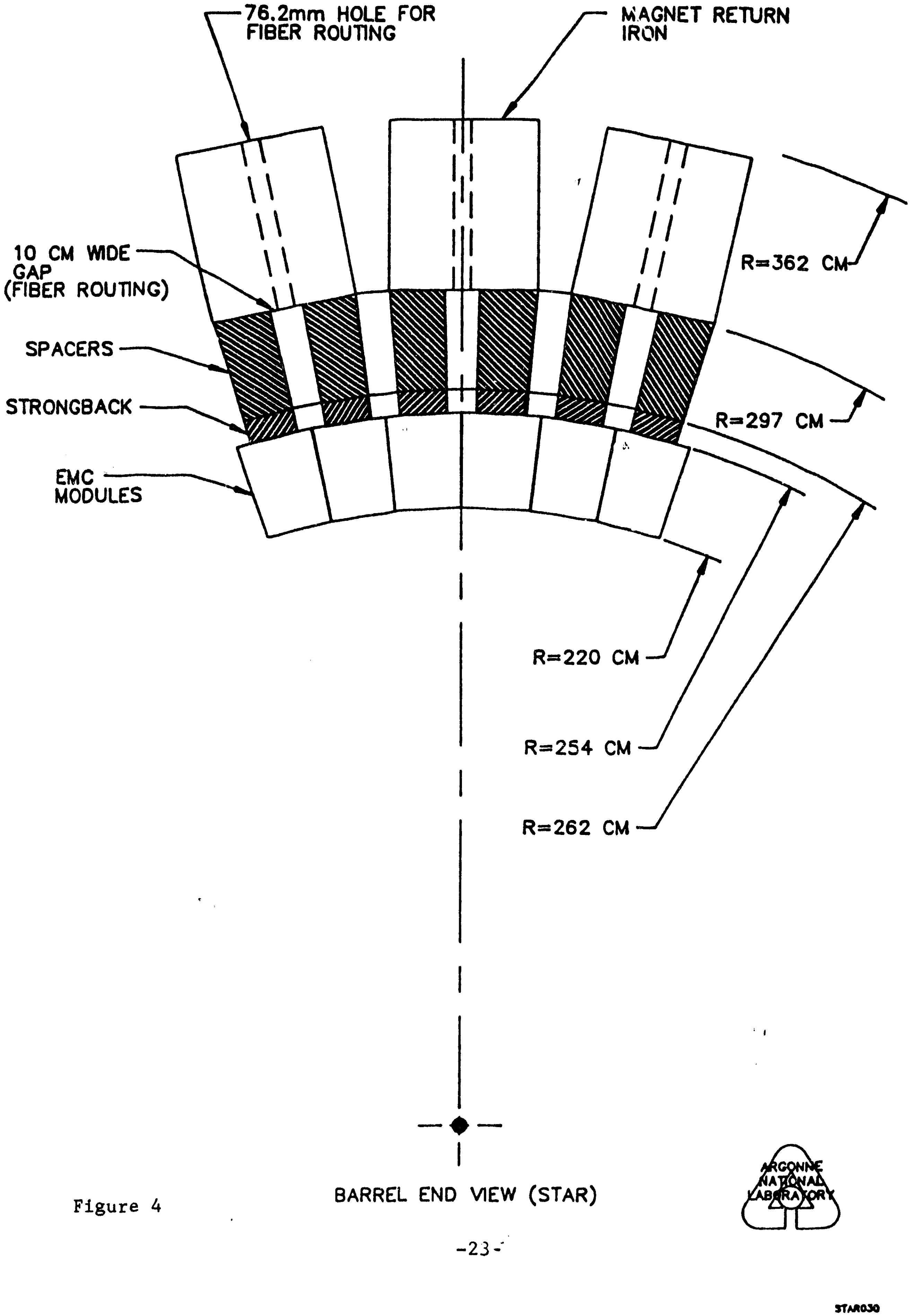

76.2mm HOLE FOR
FIBER ROUTING
MAGNET RETURN
IRON
10 CM WIDE
GAP
(FIBER ROUTING)
SPACERS
STRONGBACK
EMC
MODULES
R=362 CM
R=297 CM
R=220 CM
R=254 CM
R=262 CM
BARREL END VIEW (STAR)
ARGONNE
NATIONAL
LABORATORY
STAR030

Figure 4

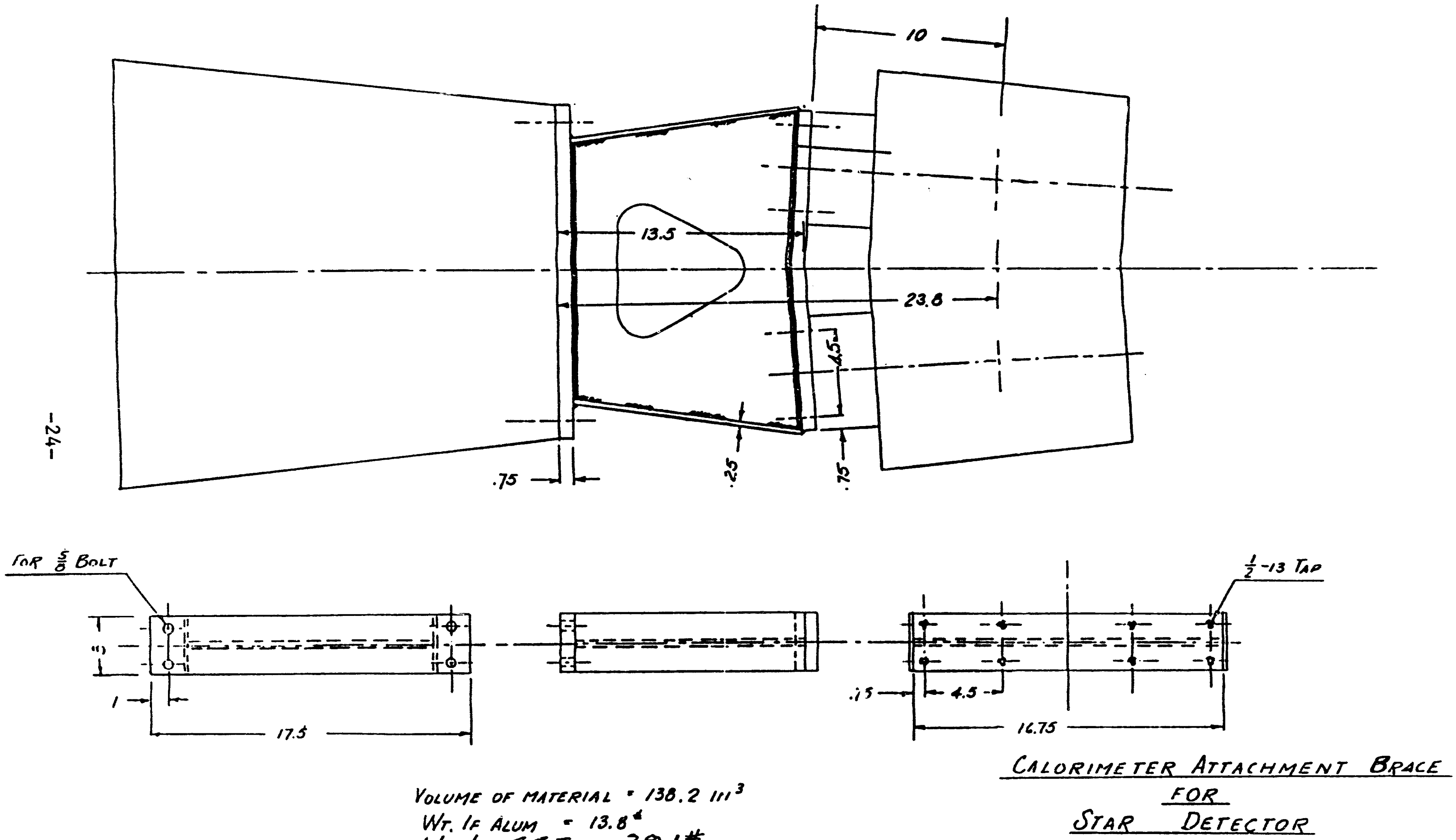

10
13.5
23.8
4.5
.75
.25
.75
FOR 5/8 BOLT
3
1
17.5
.75
4.5
16.75
1/2-13 TAP
VOLUME OF MATERIAL = 138.2 IN³
WT. IF ALUM = 13.8#
WT. IF SST = 39.1#
CALORIMETER ATTACHMENT BRACE
FOR
STAR DETECTOR

Figure 5

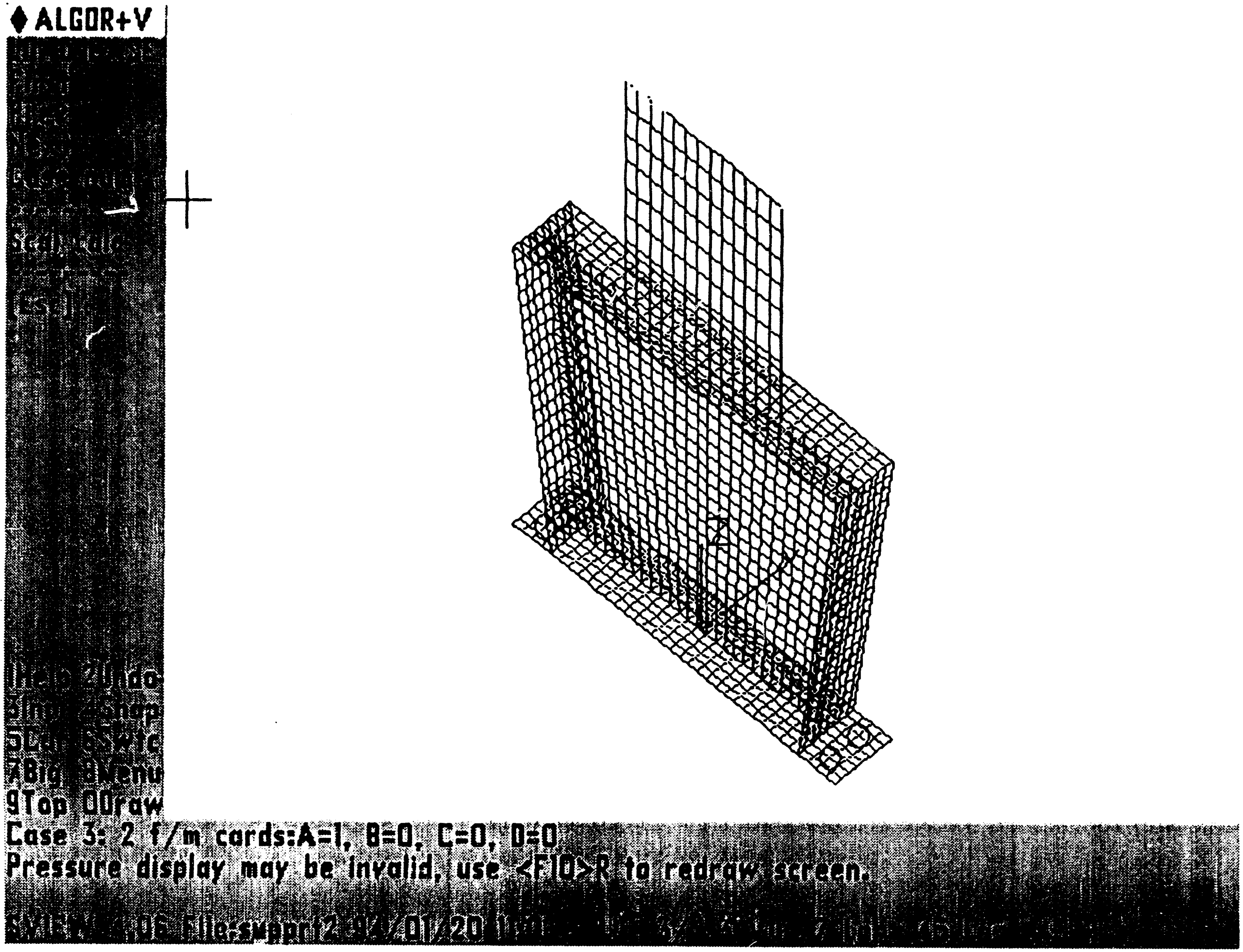

ALGOR+V
9Top 0Draw
Case 3: 2 f/m cards:A=1, B=0, C=0, D=0
Pressure display may be invalid, use <F10>R to redraw screen.

Figure 6a

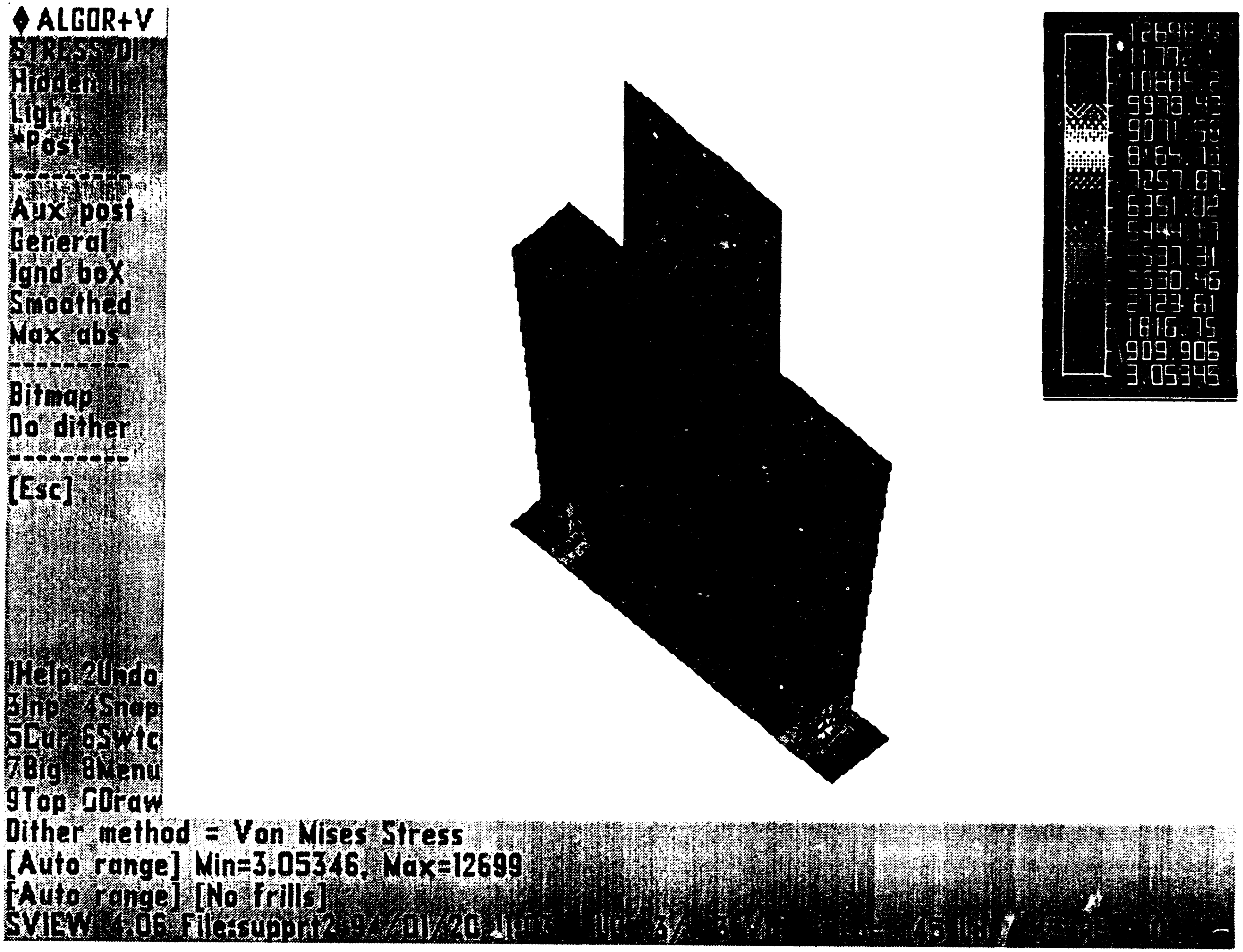

ALGOR+V
Aux post
General
lgnd boX
Smoothed
Max abs
Bitmap
Do dither
[Esc]
1Help 2Undo
9Top 0Draw
Dither method = Von Mises Stress
[Auto range] Min=3.05346, Max=12699
[Auto range] [No frills]
909.906
3.05345

Figure 6b

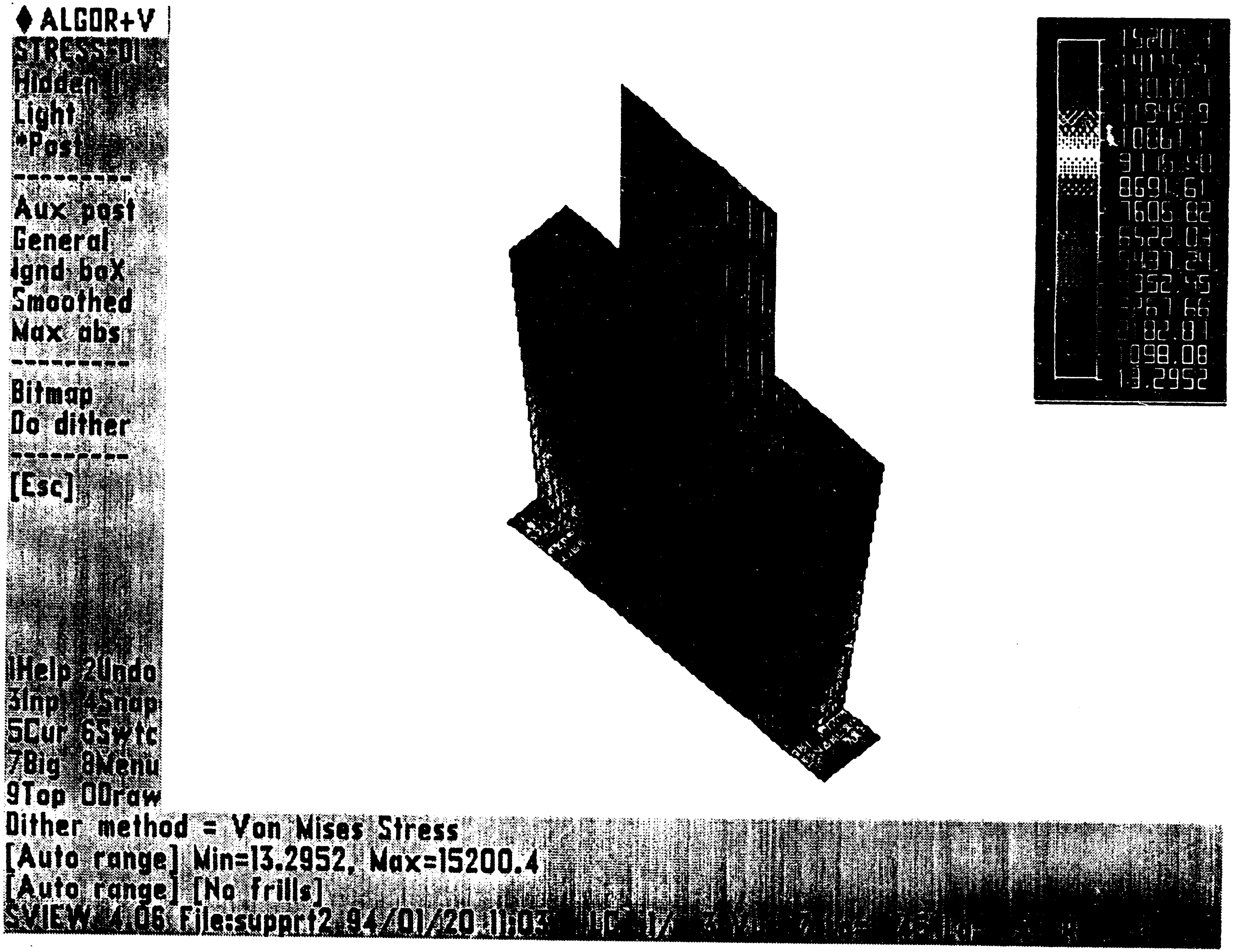

ALGOR+V
Light
Aux post
General
lgnd boX
Smoothed
Max abs
Bitmap
Do dither
[Esc]
1Help 2Undo
3Inp 4Snap
5Cur 6Swtc
7Big 8Menu
9Top 0Draw
8691.61
7605.82
1098.08
13.2952
Dither method = Von Mises Stress
[Auto range] Min=13.2952, Max=15200.4
[Auto range] [No frills]

Figure 6c

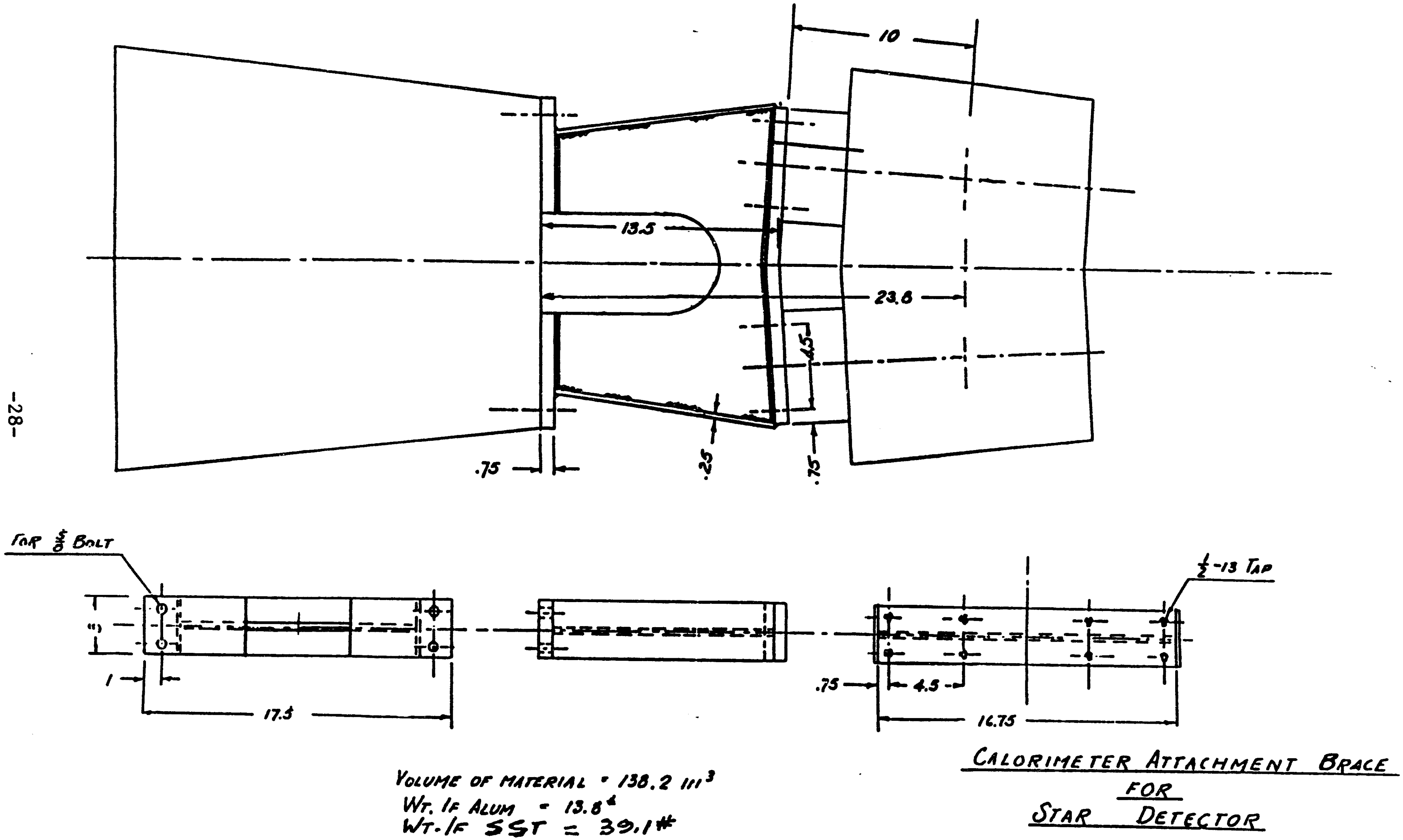

10
13.5
23.8
4.5
.75
.25
.75
FOR 3/8 BOLT
1
17.5
1/2-13 TAP
.75
4.5
16.75
VOLUME OF MATERIAL = 138.2 in³
WT. IF ALUM = 13.8#
WT. IF SST = 39.1#
CALORIMETER ATTACHMENT BRACE
FOR
STAR DETECTOR

Figure 7

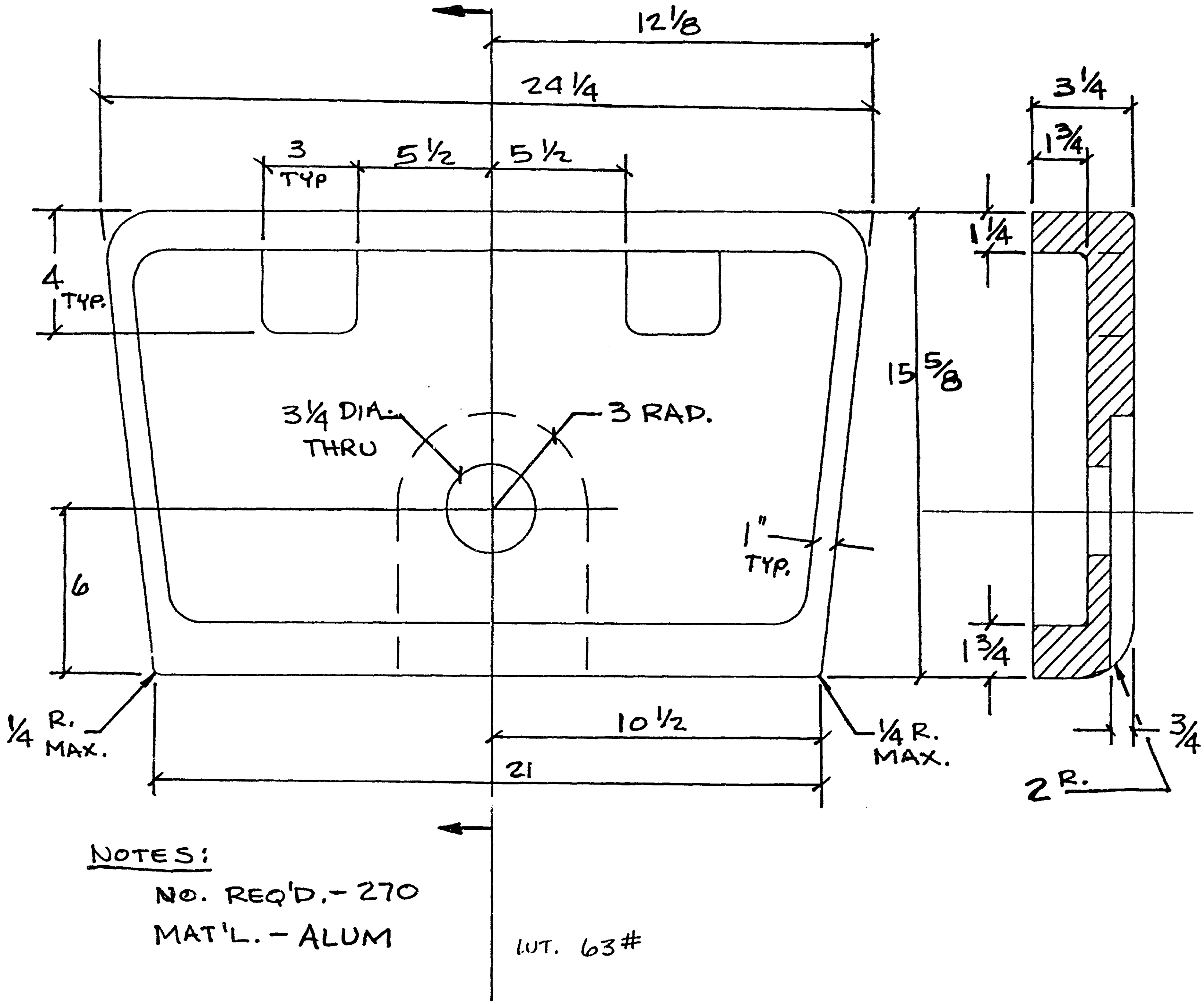
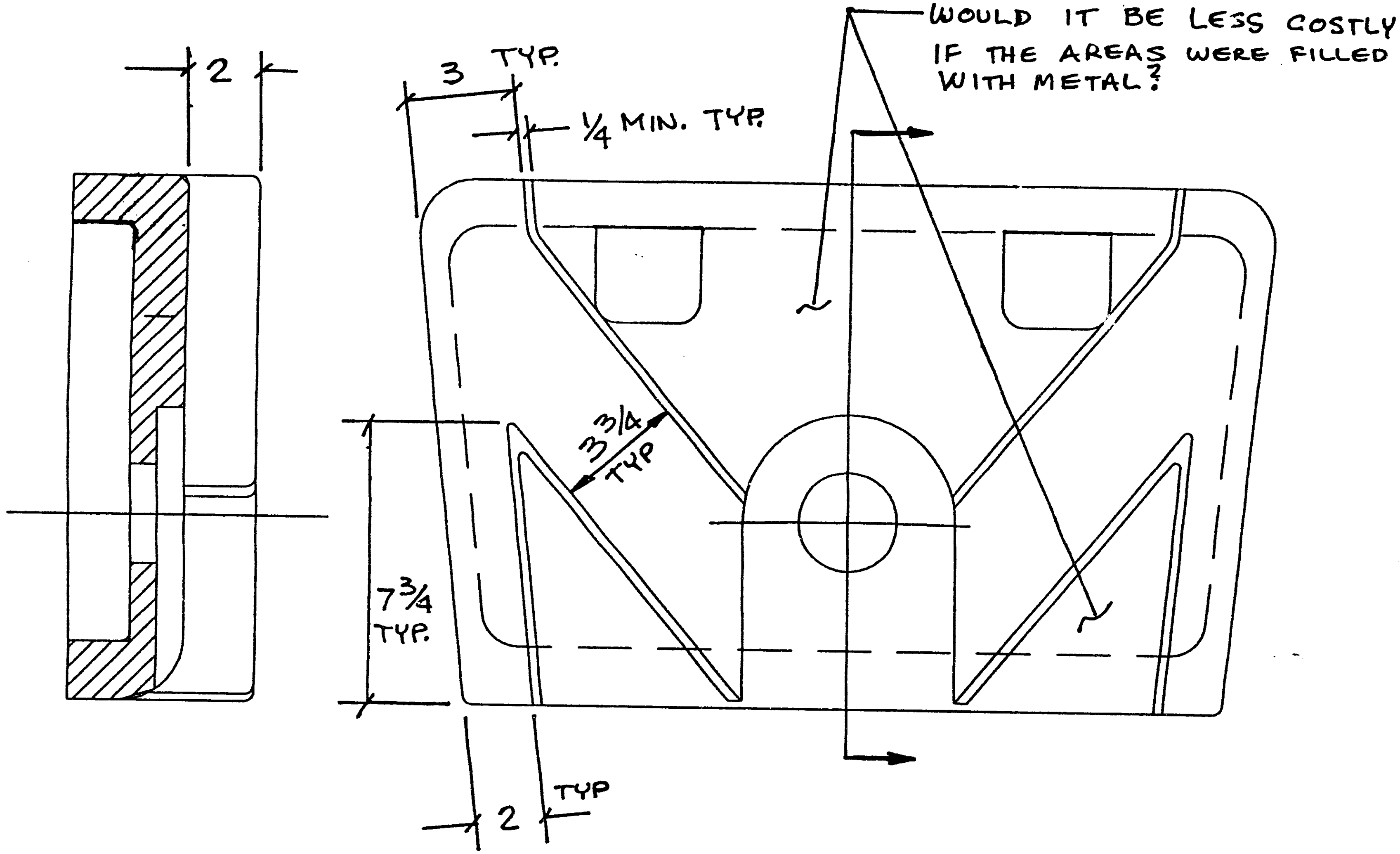

12 1/8
24 1/4
3 TYP
5 1/2
5 1/2
4 TYP.
3 1/4 DIA. THRU
3 RAD.
15 5/8
1" TYP.
6
1/4 R. MAX.
10 1/2
21
1/4 R. MAX.
3 1/4
1 3/4
1 1/4
1 3/4
3/4
2 R.
NOTES:
NO. REQ'D.- 270
MAT'L.- ALUM
WT. 63#

Figure 8a

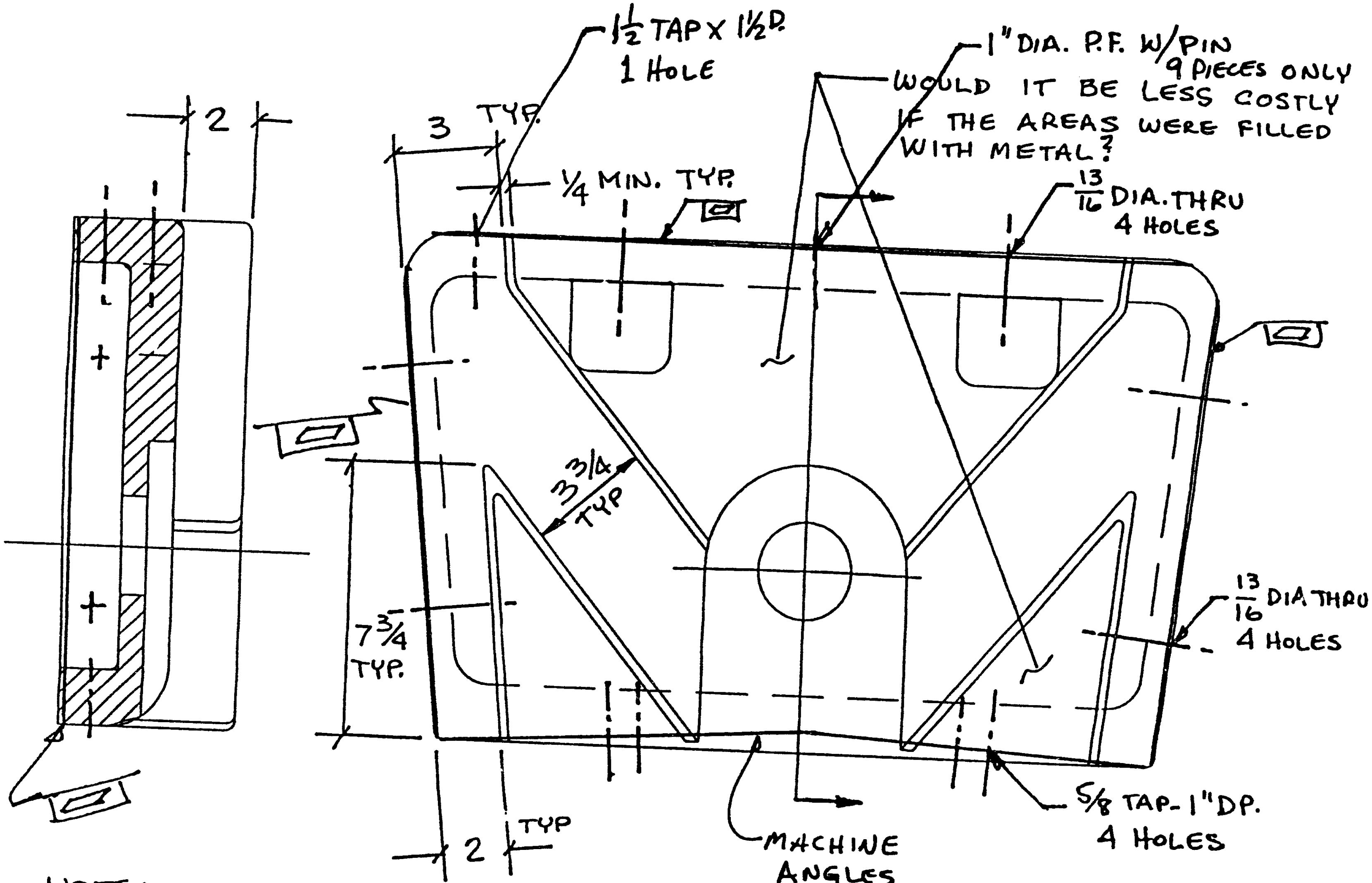


NOTE:

THIS IS AN ALTERNATE DESIGN TO SKETCH HEP 0020. ALL INFORMATION ON SKETCH HEP 0020 IS RELEVANT.

WT. 69#

Figure 8b



NOTE:

THIS IS AN ALTERNATE DESIGN TO SKETCH HEP 0020. ALL INFORMATION ON SKETCH HEP 0020 IS RELEVANT.

WT - 69 #

Figure 9

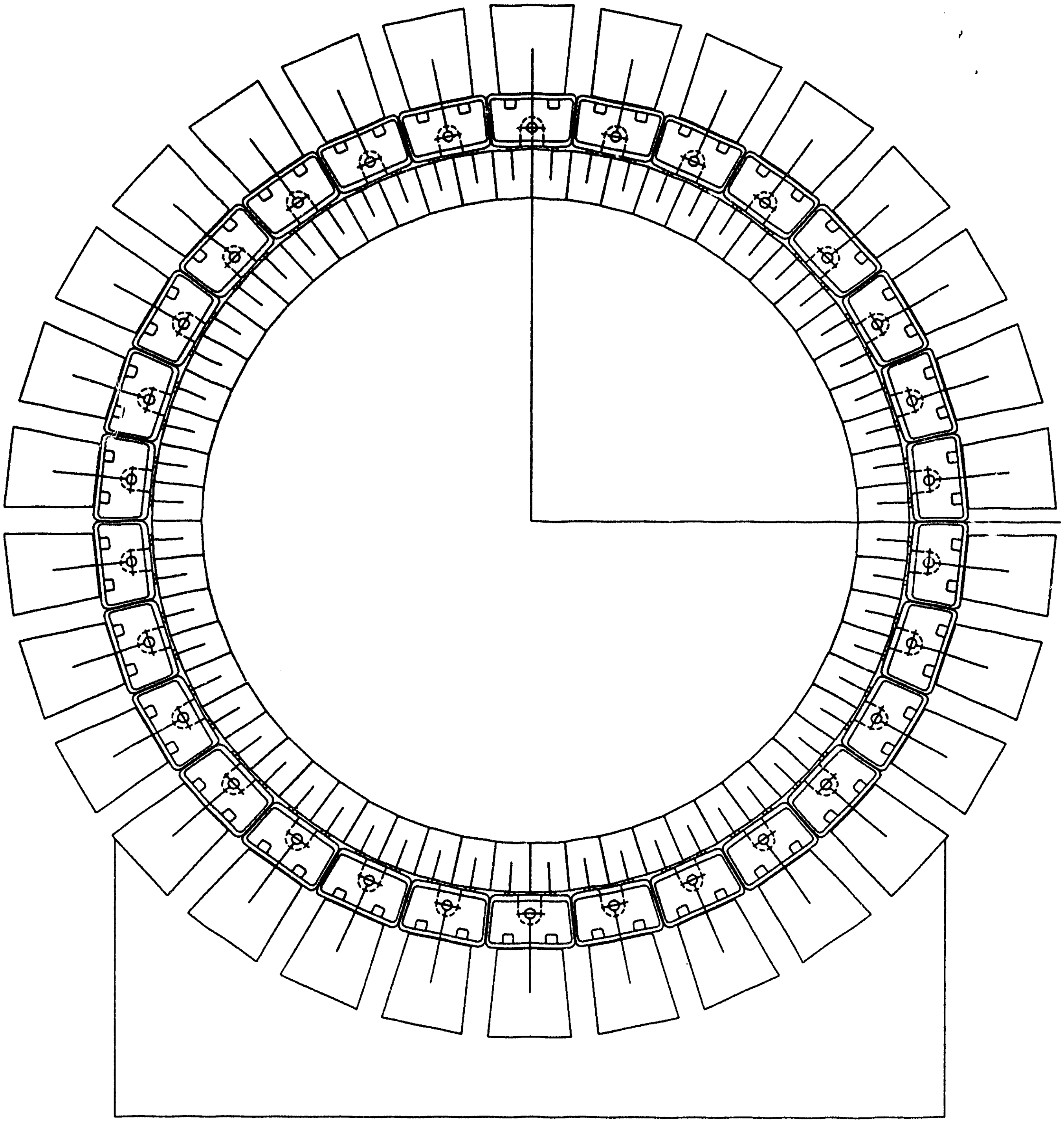
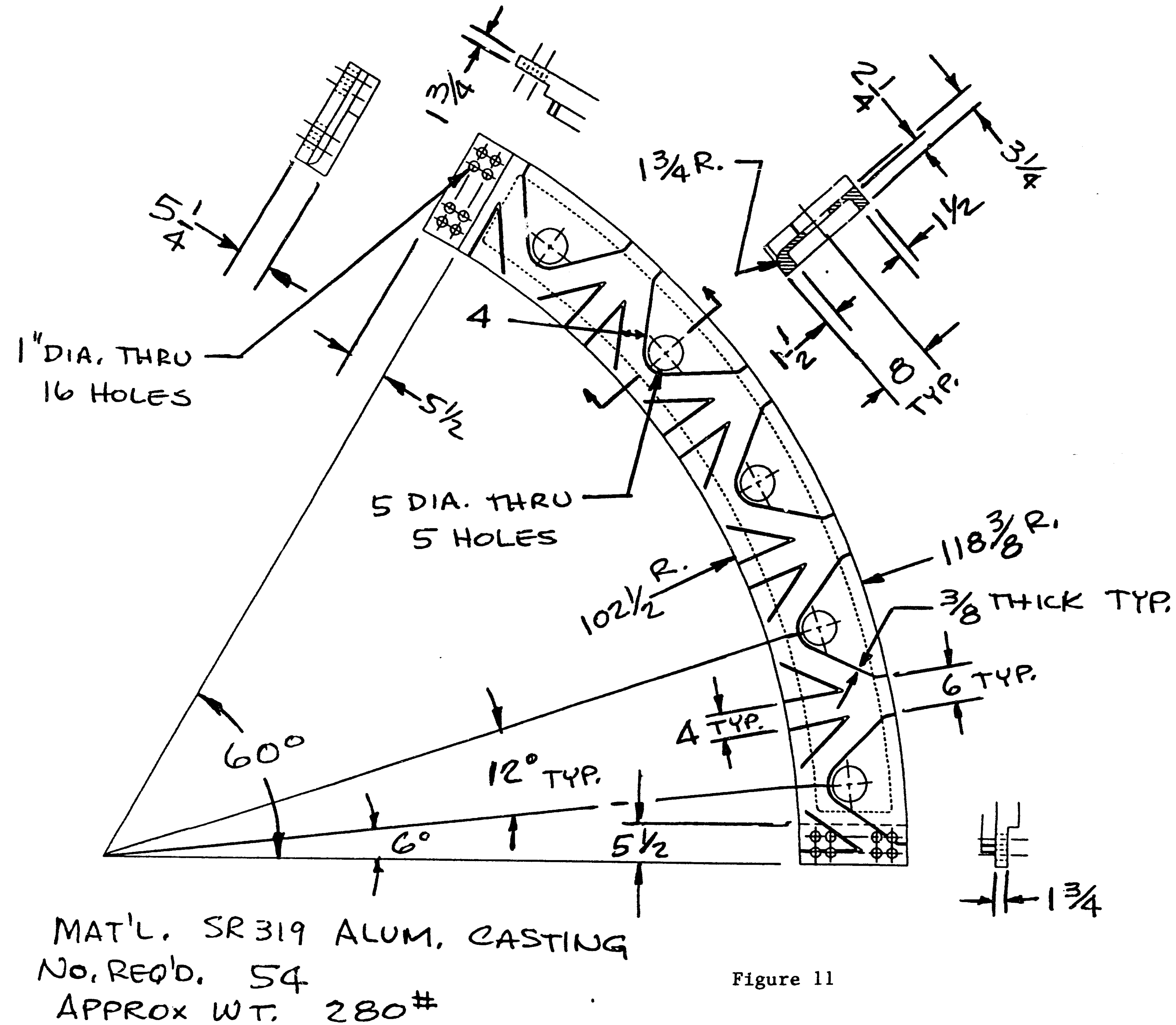
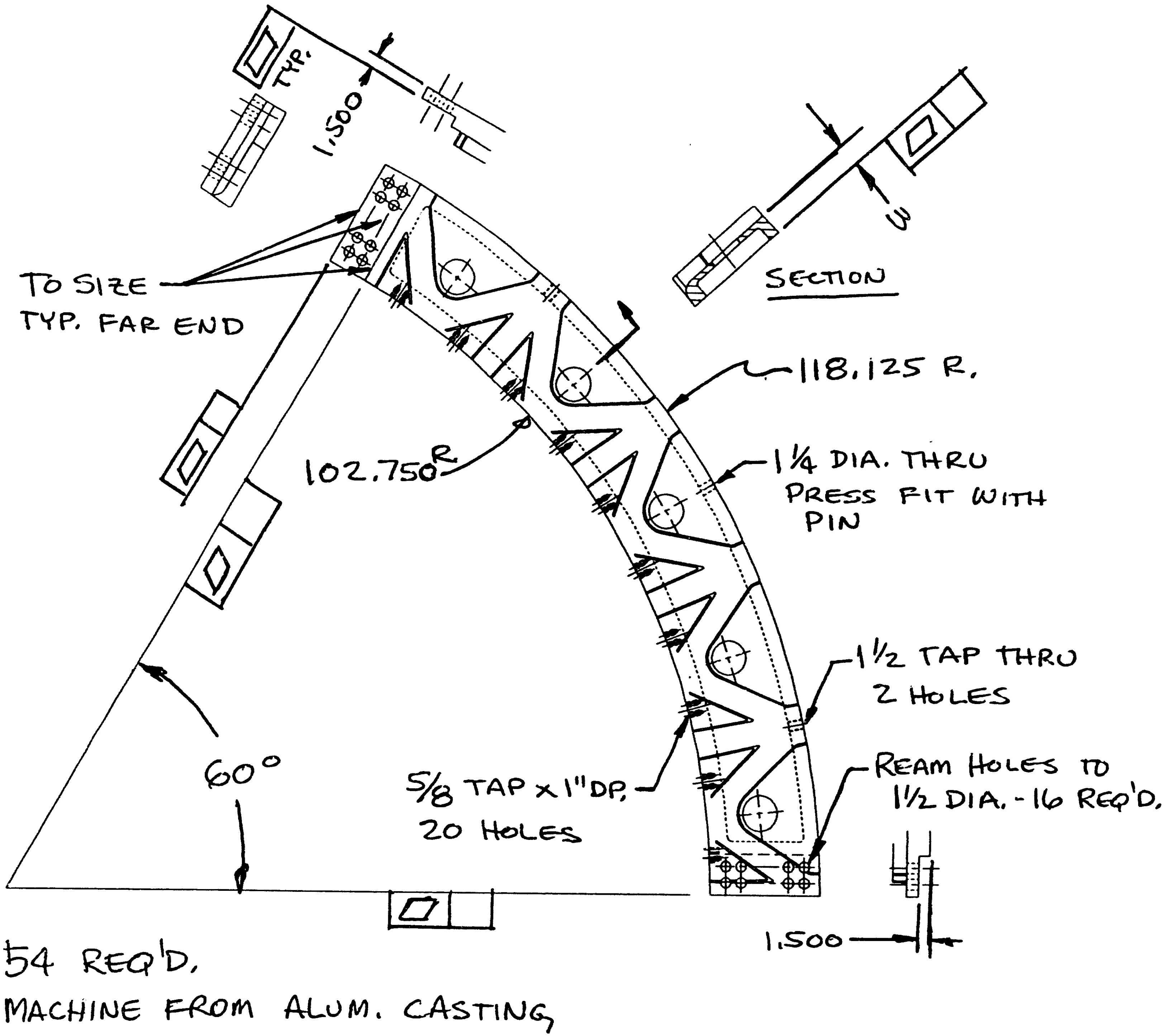


Figure 10



5 1/4
1 3/4
2 1/4
3 1/4
1 3/4 R.
1 1/2
1/2
8 TYP.
4
1" DIA. THRU
16 HOLES
5 1/2
5 DIA. THRU
5 HOLES
118 3/8 R.
102 1/2 R.
3/8 THICK TYP.
6 TYP.
4 TYP.
60°
12° TYP.
6°
5 1/2
1 3/4
MAT'L. SR 319 ALUM. CASTING
No. REQ'D. 54
APPROX WT. 280#

Figure 11



TYP.
1.500
SECTION
3
TO SIZE
TYP. FAR END
118.125 R.
102.750R
1¼ DIA. THRU
PRESS FIT WITH
PIN
1½ TAP THRU
2 HOLES
REAM HOLES TO
1½ DIA. - 16 REQ'D.
5/8 TAP x 1" DP.
20 HOLES
60°
1.500
54 REQ'D.
MACHINE FROM ALUM. CASTING

Figure 12

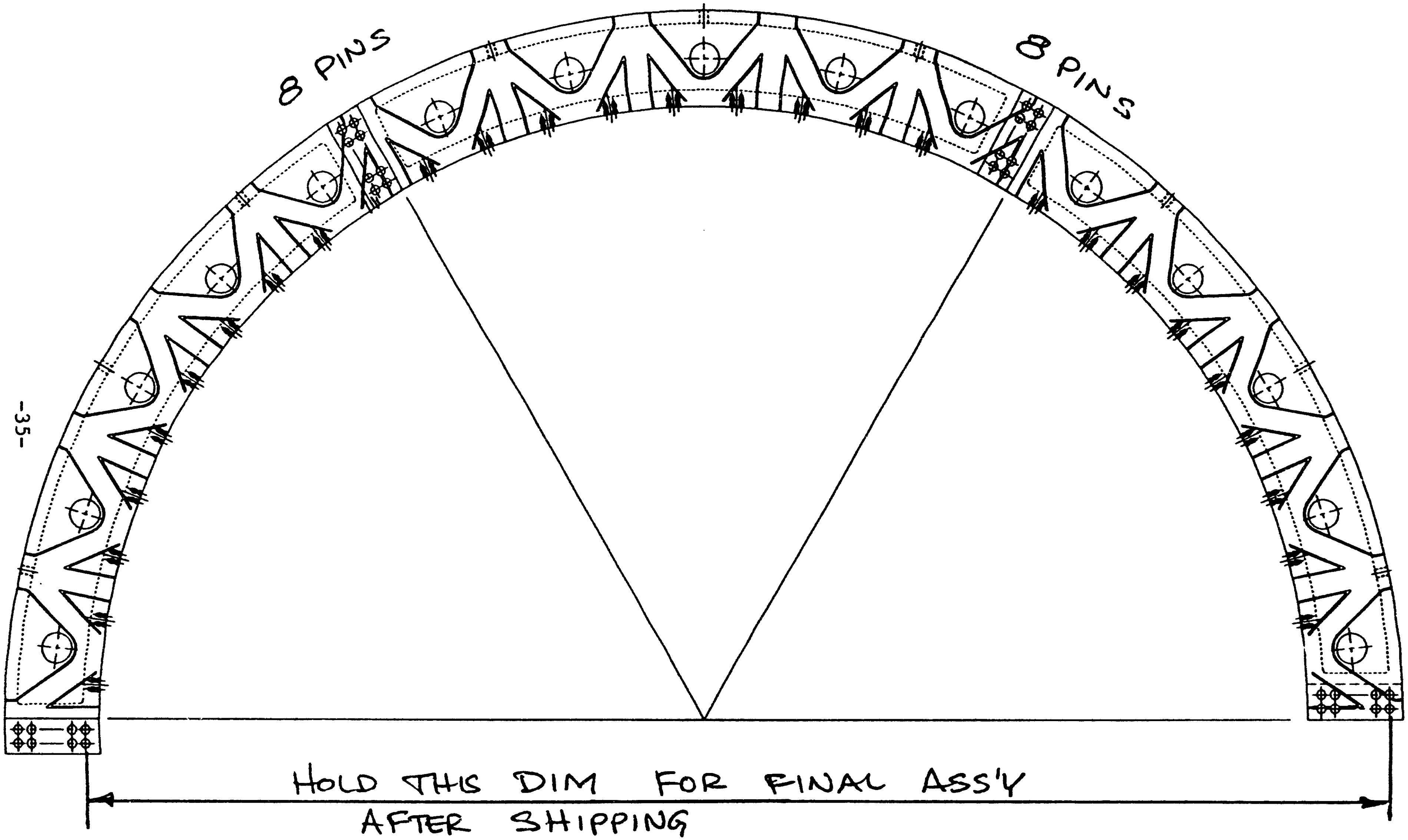


Figure 13

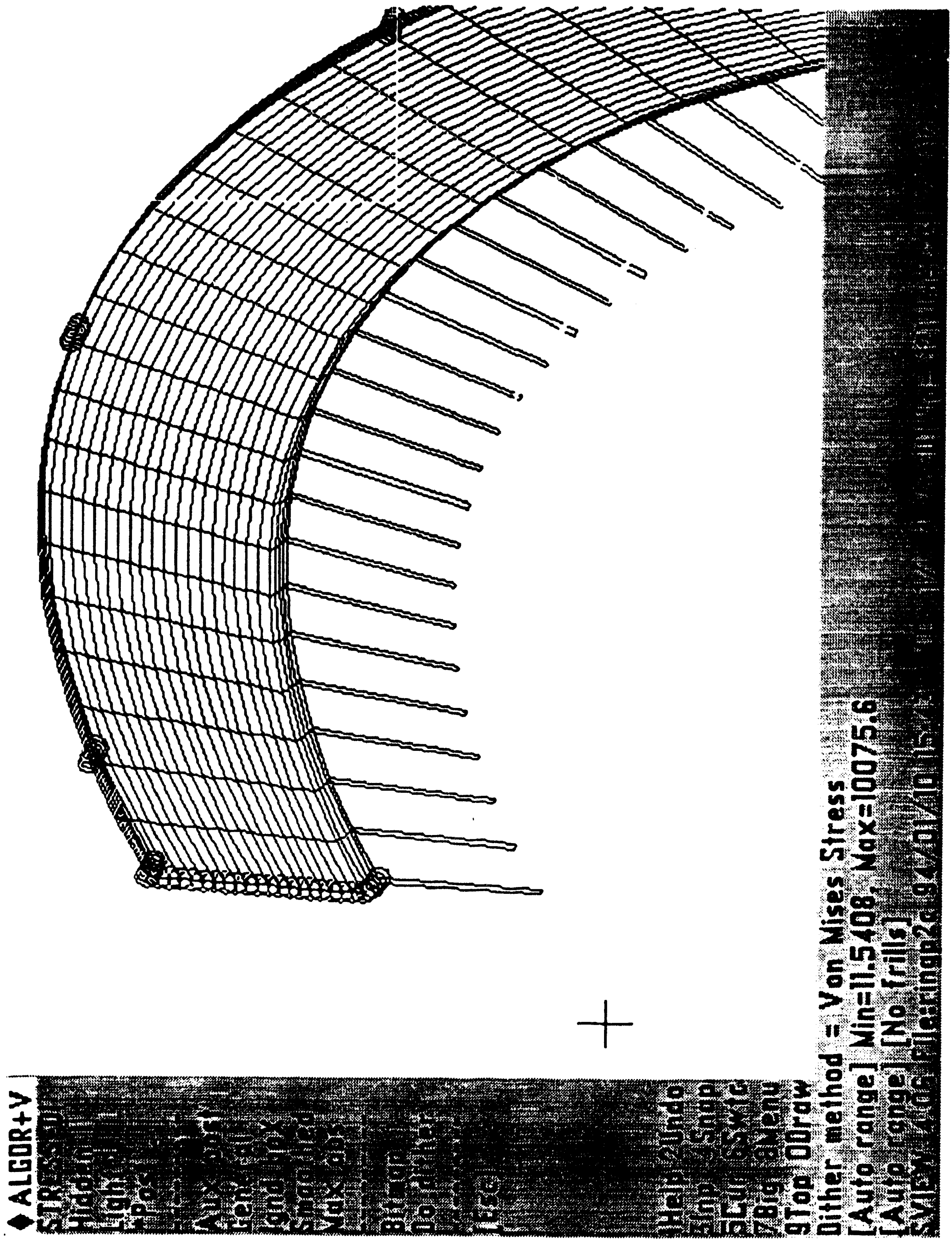

ALGOR+V
Dither method = Von Mises Stress
[Auto range] Min=11.5408, Max=10075.6
[Auto range] [No frills]

Figure 14a

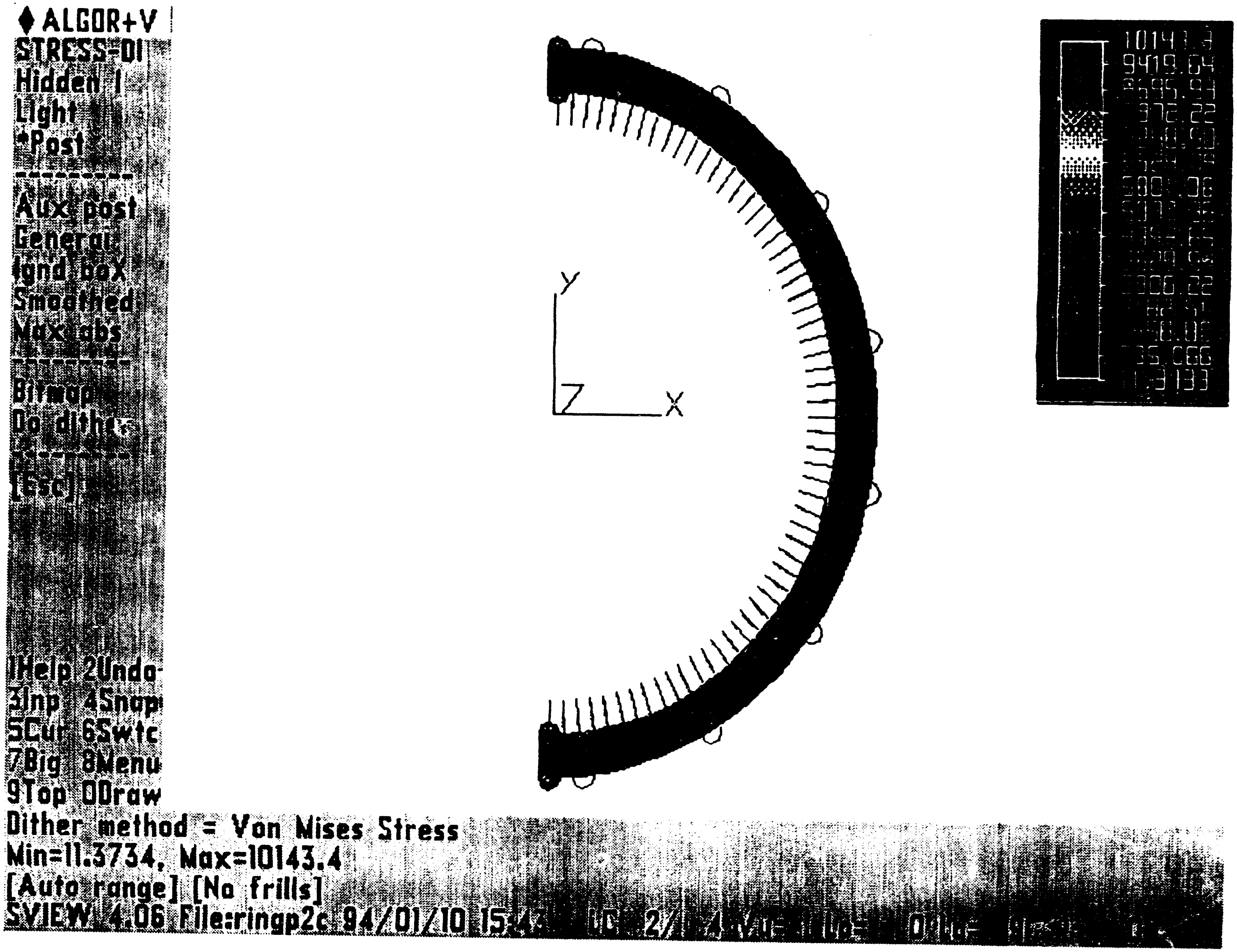

ALGOR+V
STRESS-DI
Hidden I
Light
Post
Aux post
General
lgnd boX
Smoothed
Max abs
Bitmap
Do dithe
[Esc]
1Help 2Undo
3Inp 4Snap
5Cur 6Swtc
7Big 8Menu
9Top 0Draw
Dither method = Von Mises Stress
Min=11.3734, Max=10143.4
[Auto range] [No frills]
SVIEW 4.06 File:ringp2c 94/01/10
Y
Z
X
9419.64
1006.22
735.066

Figure 14b

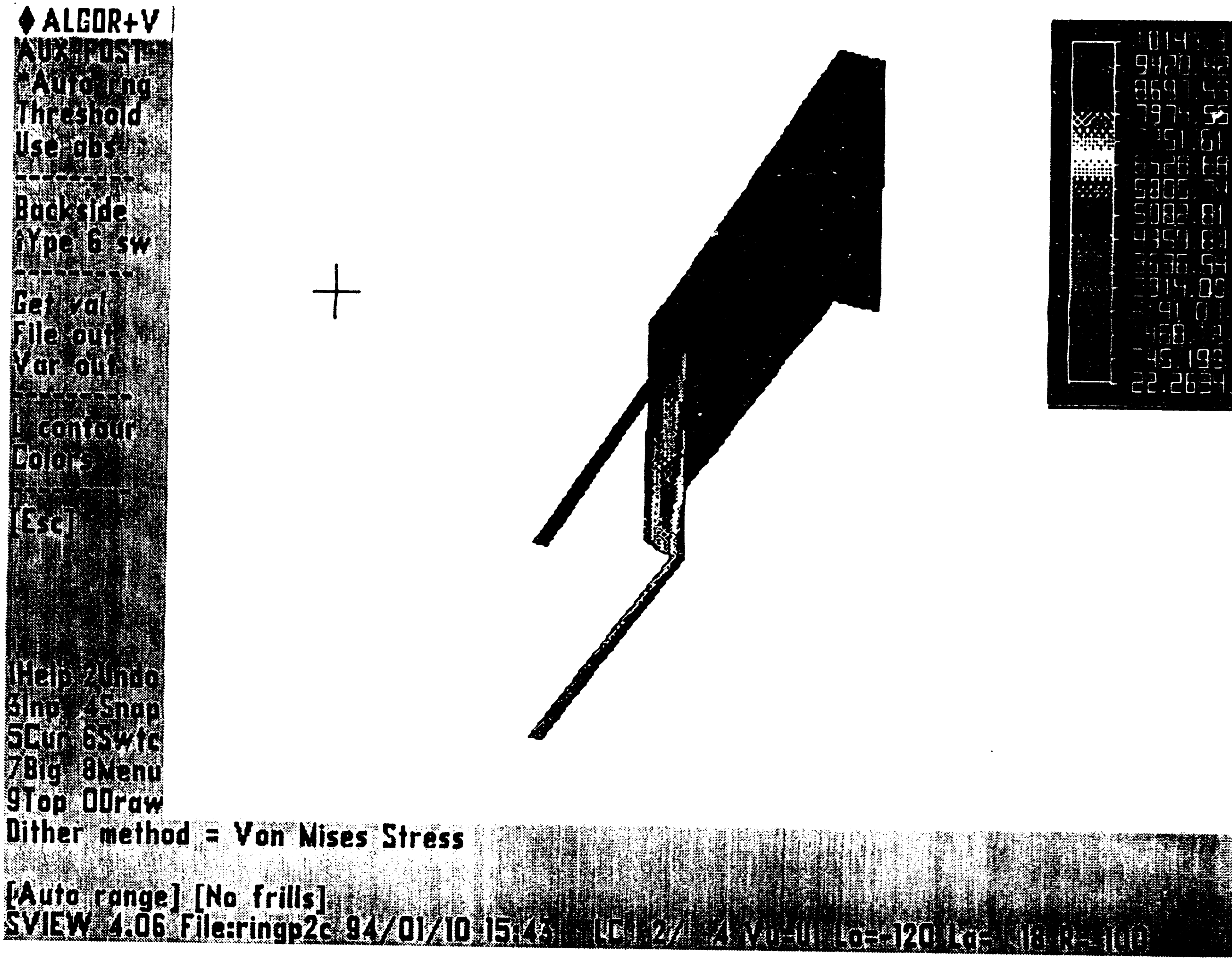

ALGOR+V
AUX POST
Autorng
Threshold
Use abs
Backside
Type 6 sw
Get val
File out
Var out
contour
Colors
[Esc]
1Help 2Undo
3Inp 4Snap
5Cur 6Swtc
7Big 8Menu
9Top 0Draw
22.2634
Dither method = Von Mises Stress
[Auto range] [No frills]
SVIEW 4.06 File:ringp2c 94/01/10 15:43

Figure 14c

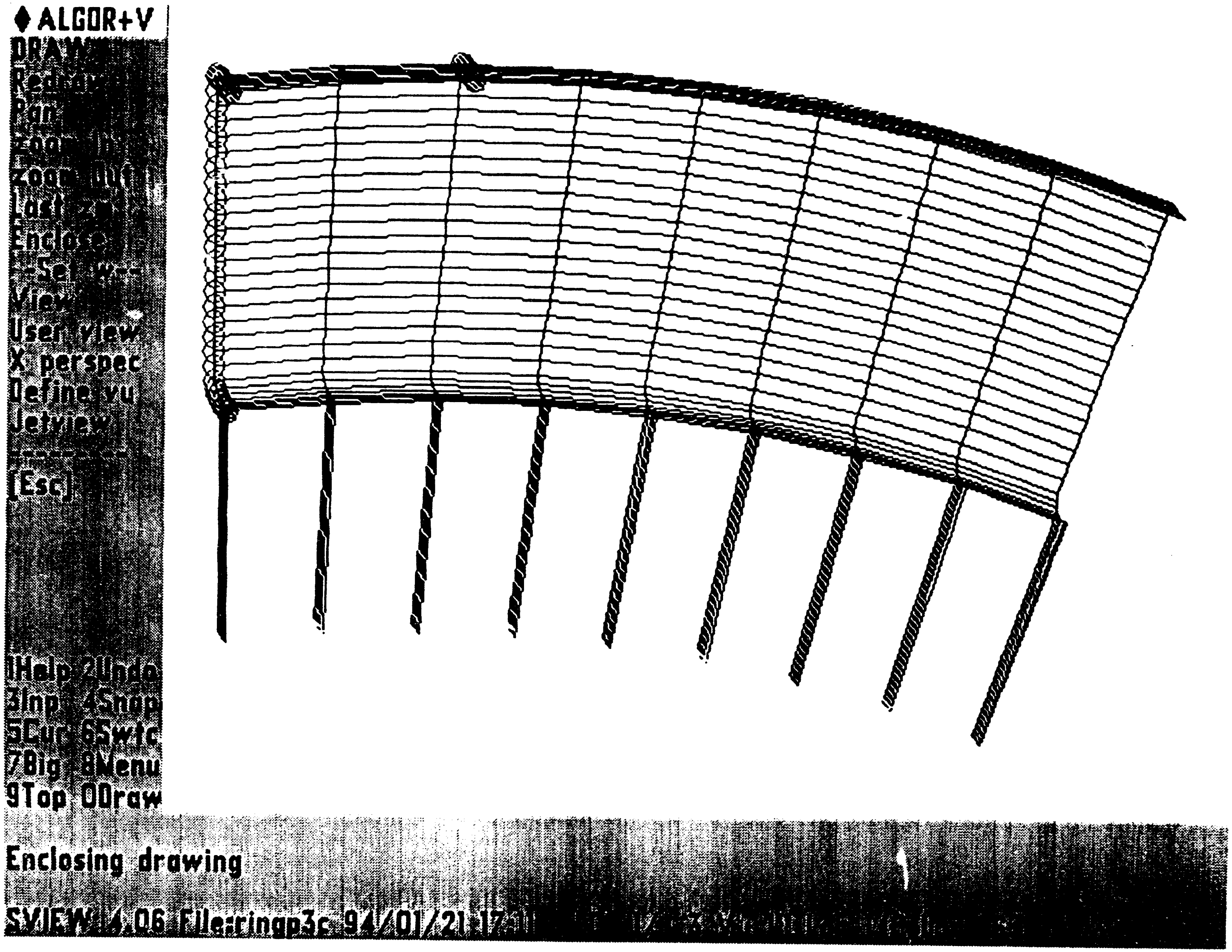

ALGOR+V
User view
X perspec
Define vu
Jetview
[Esc]
1Help 2Undo
3Inp 4Snap
5Cur 6Swtc
7Big 8Menu
9Top 0Draw
Enclosing drawing
SVIEW 4.06 File:ringp3c 94/01/21

Figure 15a

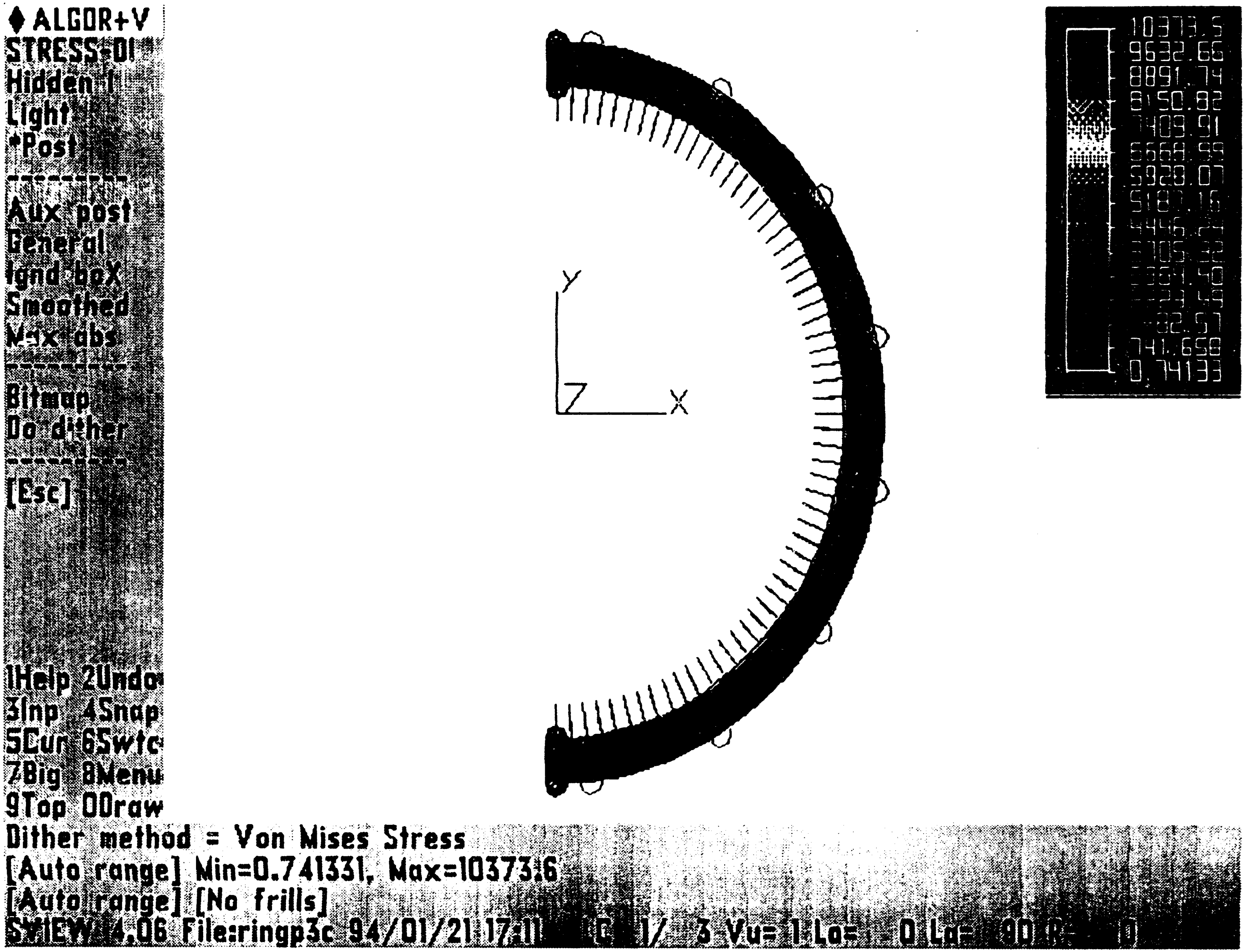

ALGOR+V
STRESS-DI
Hidden
Light
*Post
Aux post
General
lgnd boX
Smoothed
Bitmap
Do dither
[Esc]
1Help 2Undo
3Inp 4Snap
5Cur 6Swtc
7Big 8Menu
9Top 0Draw
Y
Z
X
10373.5
9632.66
8891.74
8150.82
7409.91
5928.07
741.658
0.74133
Dither method = Von Mises Stress
[Auto range] Min=0.741331, Max=10373.6
[Auto range] [No frills]

Figure 15b

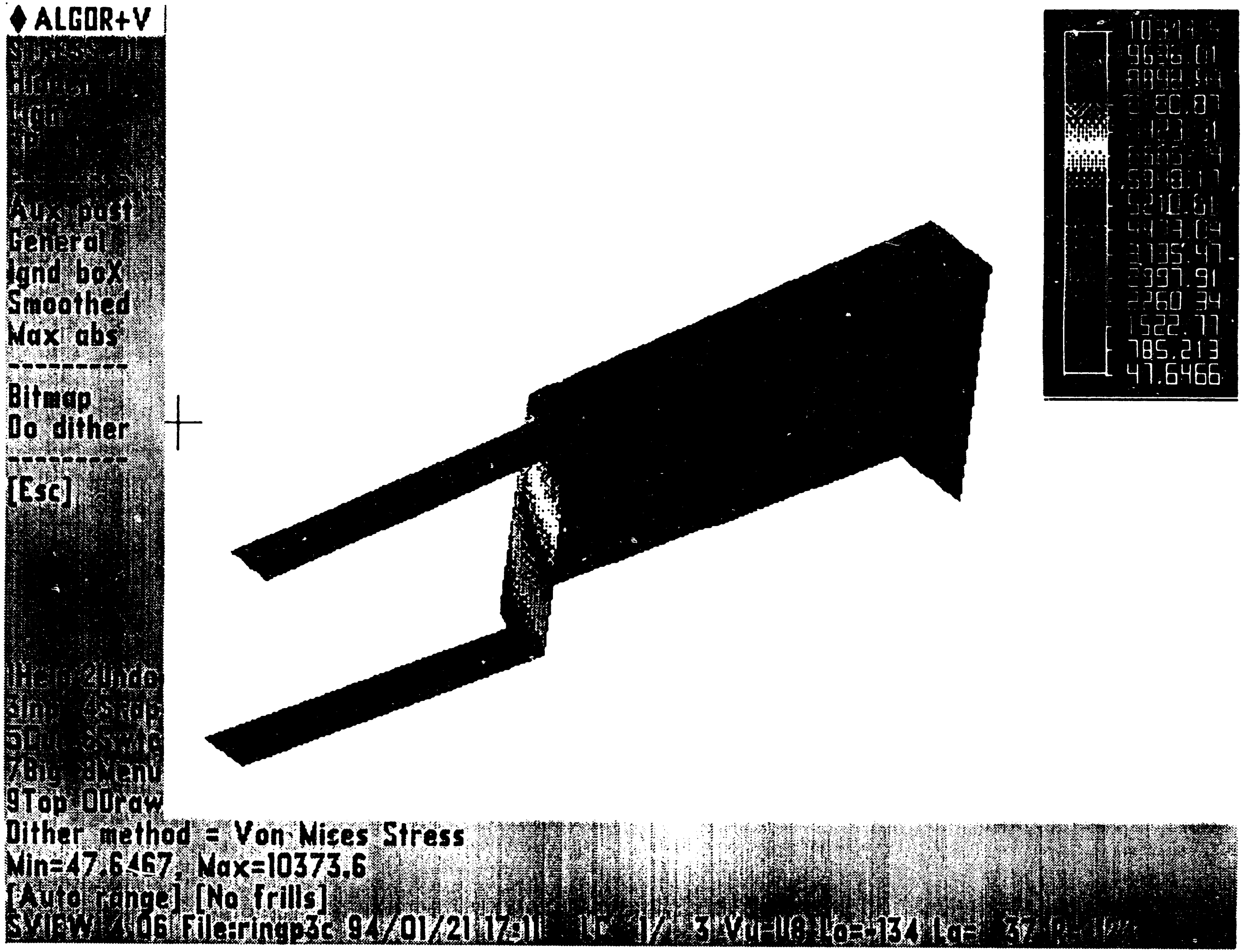

ALGOR+V
Aux post
General
lgnd boX
Smoothed
Max abs
Bitmap
Do dither
[Esc]
9Top 0Draw
Dither method = Von Mises Stress
Min=47.6467, Max=10373.6
[Auto range] [No frills]
9636.01
785.213
47.6466

Figure 15c

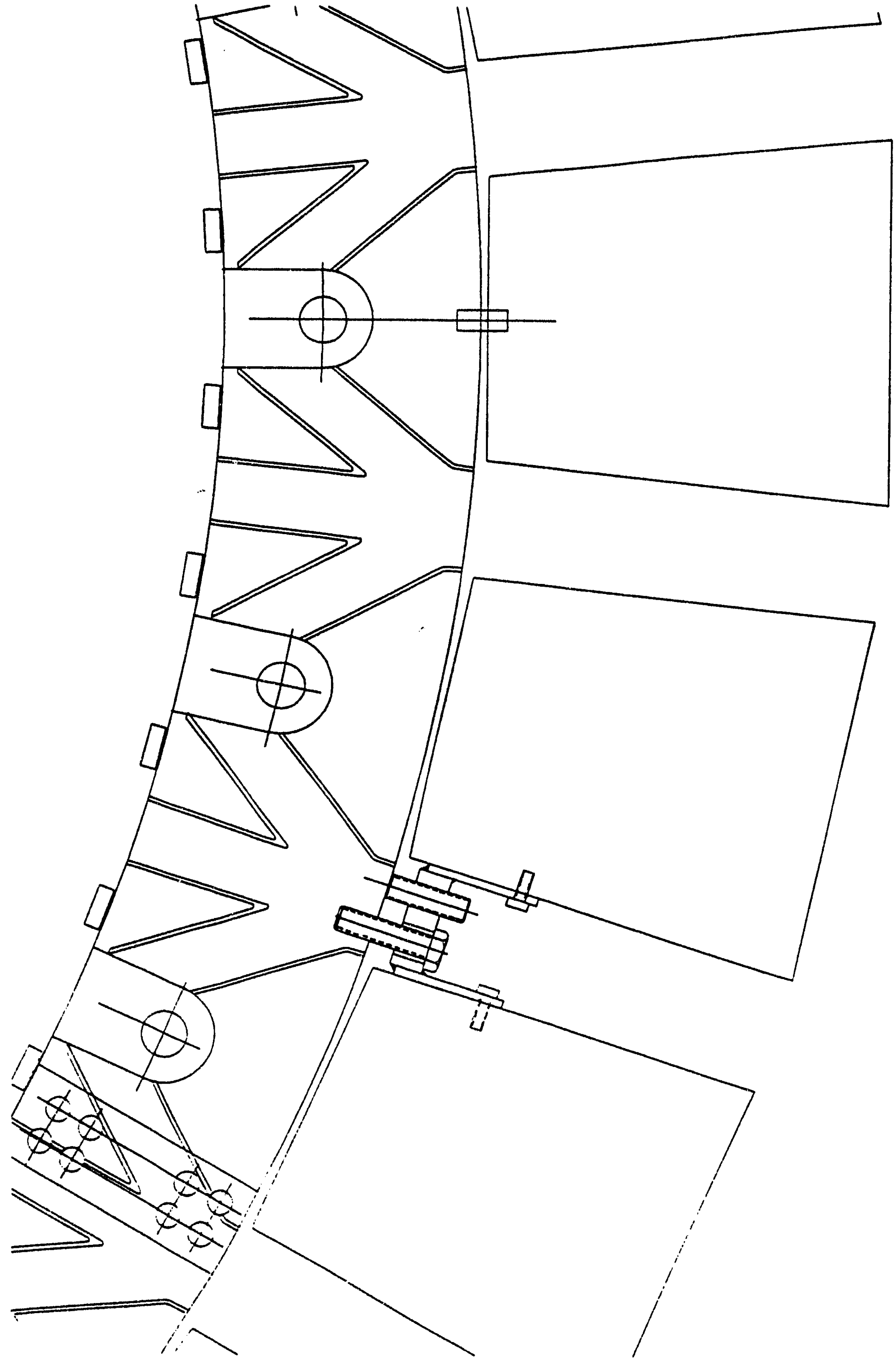


Figure 16

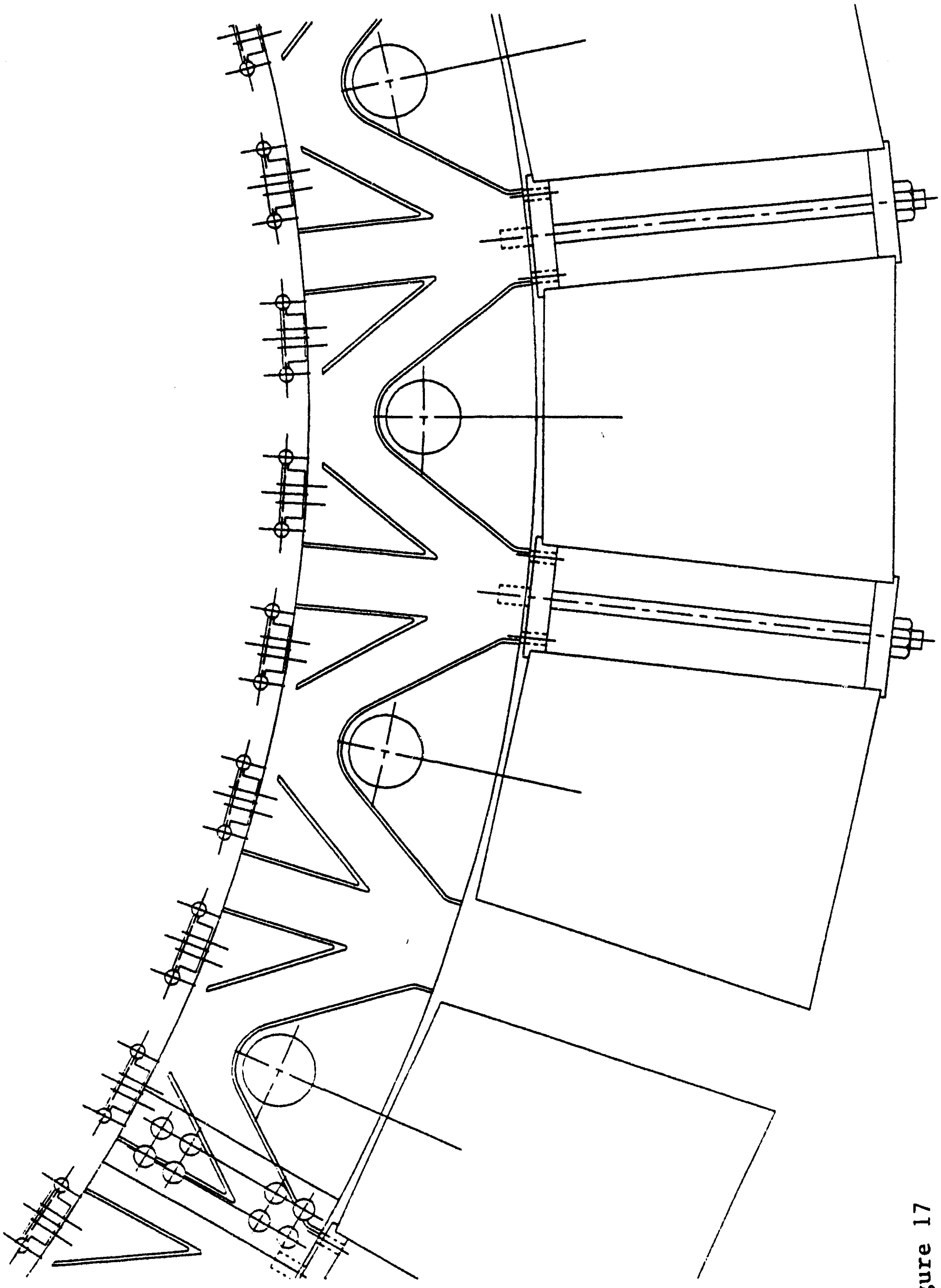
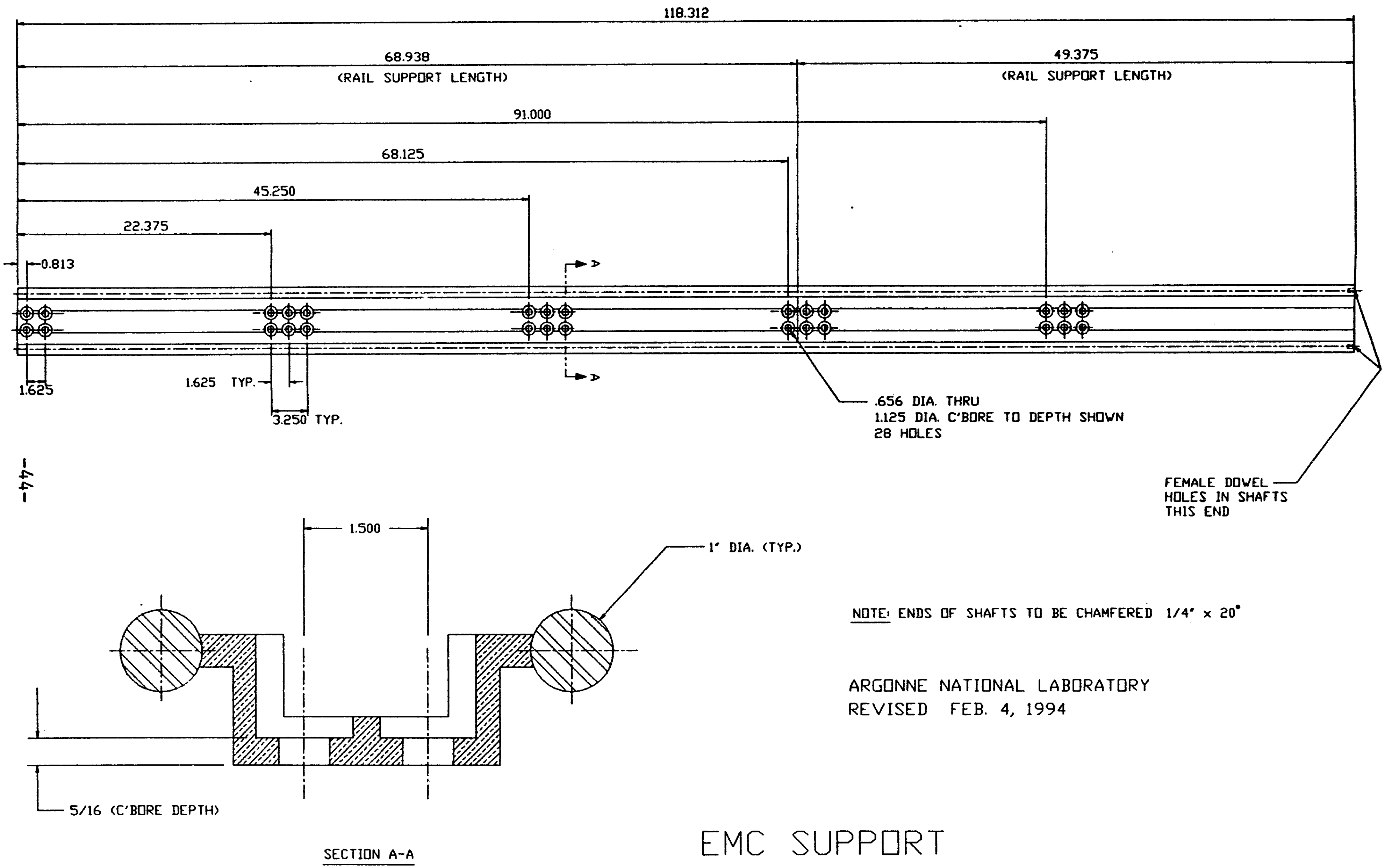


Figure 17



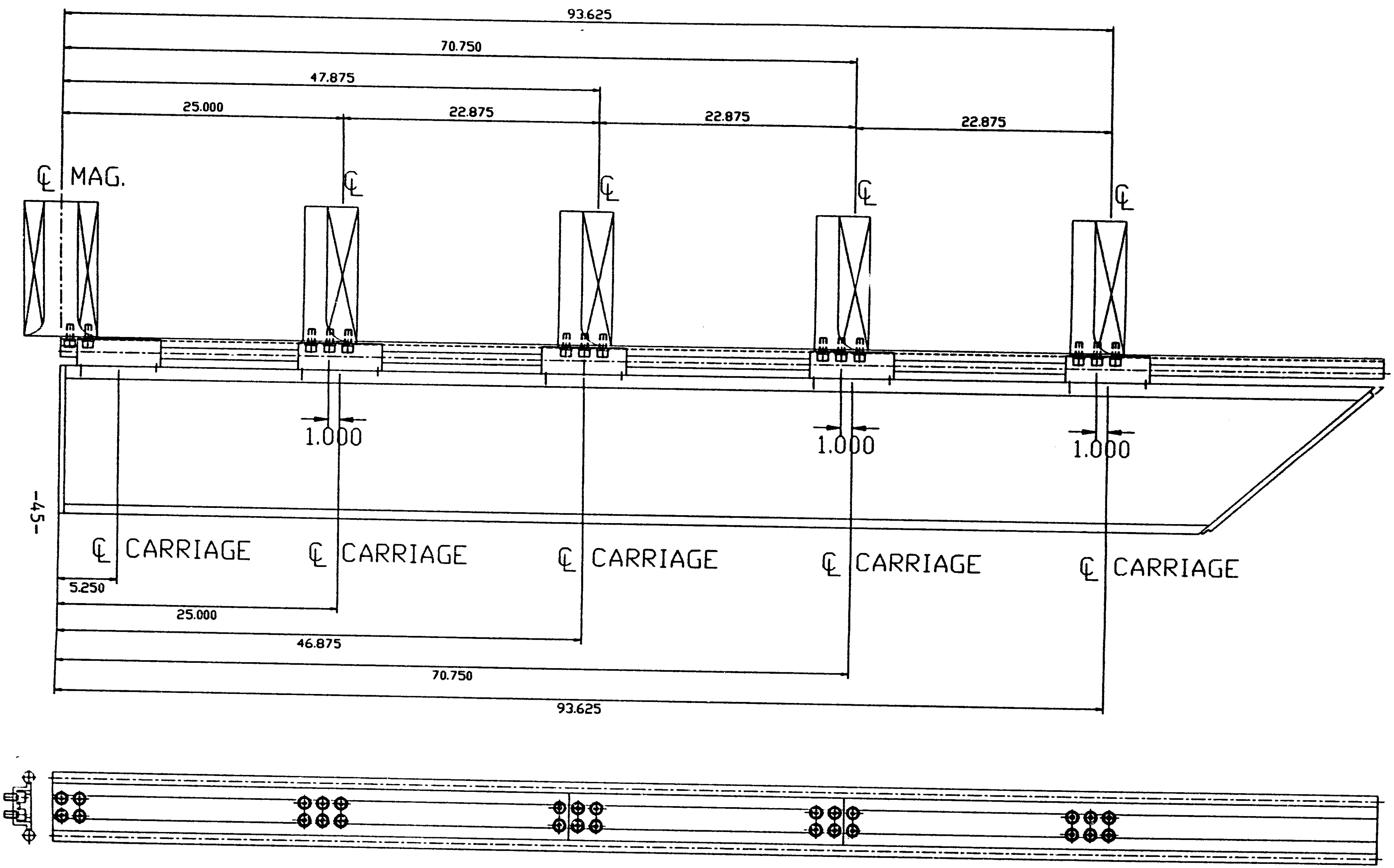
NOTE: ENDS OF SHAFTS TO BE CHAMFERED 1/4" x 20°

ARGONNE NATIONAL LABORATORY
REVISED FEB. 4, 1994

EMC SUPPORT
THOMSON QUICKSLIDE - MODIFIED

ANL SKETCH # HEP2DA-16-00B-MODIFIED

Figure 18



ARGONNE NATIONAL LABORATORY
12-3-93

EMC SUPPORT
ANL SKETCH # HEP1000

Figure 19

APPENDIX I

Installation Scenario - 12° Segments

1) Install base for the magnet. Base has centering pins for the lower return iron.

2) Install lower return iron pieces. Centering pins in base locate these pieces. Lower center return iron piece has centering pins for the end rings.

3) Install end rings. End rings have centering pins for the upper return iron pieces.

4) Install end coils with upper supports captive on coil spacers.

5) Install lower EMC supports. The return iron pieces have centering pins at all EMC support locations.

6) Continue this process until all coils and EMC supports are installed.

7) Install upper backleg steel pieces using centering pins on the end rings to locate them.

8) Fasten upper EMC supports to the upper return iron pieces using the centering pins in the return iron for centering.

9) Position survey equipment as required. Current scenario utilizes a central tube with end supports and bearings. The tube has an arm assembly which can slide along the central tube. The arm assembly has (one) (two) (three) arms (or complete ring without bearings on the central tube) with a fixture at the end of each arm which has slots for at least six adjacent ways. Initial setup consists of installing way spacers in the arm slots and positioning the arm assembly at each support in the "z" position. The arm assembly is then

rotated 360° to ensure that the supports are not positioned too close to the beam line in the radial direction. (Note: If a complete ring is used, rotation is not necessary.) After this is done, remove way spacers and move positioning arm assembly out of the magnet in the "z" direction.

10) Loosely attach the bottom ways to the EMC supports. (Note: All ways can be attached if a complete ring is used.)

11) Slide positioning arm assembly on the ways from the end. Locate and position ways at each "z" support location using positioning fixture. Mark machining patterns for the shims if necessary. Machine shims or use standard shims if available. Install shims. Tighten bolts holding ways to the supports. (Note: Positioning fixture should allow for tightening bolts without moving fixture.) Recheck way location and angle. Add minishims as necessary.

12) Repeat this procedure for all bottom ways. (Note: If a complete ring is used, all ways are positioned at each "z" location. Scaffolding then follows the assembly press in the "z" location.)

13) Attach the top ways and align and shim using the alignment fixture as done for the bottom ways. Scaffold as required.

14) As a final check, install dummy EMC alignment modules.

APPENDIX II

Installation Scenario - Pinned 60° Segments

1) Install base for the magnet.

2) Install lower return iron pieces. Lower return iron piece has centering holes for the aluminum rings. Side return iron pieces have centering pins to fit in slots in the rings.

3) Install end rings.

4) Coil and aluminum ring installation moves from the two ends to the center of the magnet. Alternately install coils and aluminum rings. Aluminum rings are supported by a stiffening spider which is also used for alignment.

5) Align aluminum rings and tighten ring support locking bolts.

6) Install upper backleg steel pieces.

7) Fasten aluminum rings to the upper return iron pieces, adjust alignment bolt and tighten support locking bolts.

8) Remove positioning and support spiders from the aluminum rings.

9) Loosely attach one bottom way to the aluminum rings.

10) Survey and align the bottom way.

11) Loosely attach all lower ways to the aluminum rings.

12) Slide the alignment fixture along the ways using the positioned bottom way for guidance. The alignment fixture has slot positions for at least six ways and a spacer on each end to maintain proper spacing from the ring.

13) Shim and tighten each way as required.

14) Repeat way alignment for all the bottom ways.

15) Install scaffolding to allow upper way installation and alignment.

16) Loosely attach all upper ways.

17) Slide alignment fixture along the last two aligned bottom ways and the first four loose top ways.

18) Shim and tighten each top way as required.

19) Repeat way alignment for all top ways.

20) As a final check, install dummy alignment EMC modules.

END

DATE FILMED

4/12/94