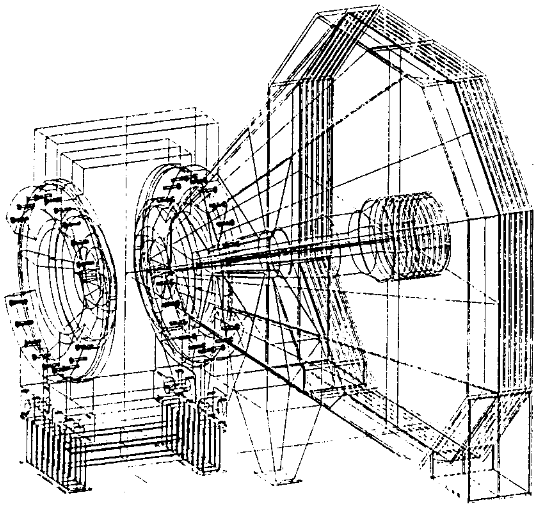
RHIC/PHENIX DETECTOR
Collaboration Meeting



PHENIX

Magnet Subsystem

Joel M. Bowers
Robert M. Yamamoto
representing the LLNL Design Team

Lawrence Livermore National Laboratory

October 14-20, 1992

R.M. Yamamoto

WBS Cost Comparison ($k)
10/10/92 - R. Yamamoto

WBS	**Element**	**Cost Version** 10/10	5/29	PCDR
5.1	**Magnet**	**5508.7**	**5276.0**	**4018.0**
5.1.1	**Central Mag**	**3077.8**	**2504.0**	**2262.0**
5.1.1.1	Central Coils	1411.0	1106.0	1106.0
5.1.1.1.1	EDIA	222.5	288.0	288.0
5.1.1.1.2	Fabrication	999.1	680.0	680.0
5.1.1.1.2.1	***Coils***	***(848.4)***	***(284.0)***	***(284.0)***
5.1.1.1.2.2	Power Supply	(150.7)	(396.0)	(396.0)
5.1.1.1.3	Assy/Installtion	95.4	80.0	80.0
5.1.1.1.4	Testing	94.0	58.0	58.0
5.1.1.2	***Magnet Steel***	***1666.8***	***1398.0***	***1156.0***
5.1.1.2.1	EDIA	269.3	310.0	
5.1.1.2.2	Fabrication	1109.0	973.0	
5.1.1.2.3	Assy/Installtion	265.5	92.0	
5.1.1.2.4	Testing	23.0	23.0	
5.1.2	**Muon Piston**	**2430.9**	**2772.0**	**1756.0**
5.1.2.1	Muon Piston Coils	575.1	456.0	456.0
5.1.2.1.1	EDIA	234.9	173.0	173.0
5.1.2.1.2	Fabrication	246.2	237.0	237.0
5.1.2.1.2.1	Coils	(210.9)	(102.0)	(102.0)
5.1.2.1.2.2	Power Supply	(35.3)	(135.0)	(135.0)
5.1.2.1.3	Assy/Installtion	34.5	29.0	29.0
5.1.2.1.4	Testing	59.5	17.0	17.0
5.1.2.2	***Muon Steel***	***1855.8***	***2316.0***	***1300.0***
5.1.2.2.1	EDIA	269.3	310.0	
5.1.2.2.2	Fabrication	1399.0	1891.0	
5.1.2.2.3	Assy/Installtion	164.5	92.0	
5.1.2.2.4	Testing	23.0	23.0	

Basis of Estimate

WBS: **5.1.1.1** Item: **PHENIX - Central Coils: Inner/Outer**

Date:October 9, 1992 Rev: 0C By: R. Yamamoto

Element Scope:

This element covers the entire cost of the engineering, design, fabrication, assembly, installation and testing of the inner (2) and outer (2) coils for the Central Magnet.

Technical design description:

Inner Coil:

The inner coils (2 required) are made up of 6 bifilar wound double pancake coils which are individually vacuum epoxy impregnated. Each double pancake subassembly is 50 mm in thickness but increases linearly in diameter in increments of 200 mm. As an example, the smallest double pancake has an inside diameter of 1100 mm and an outside diameter of 1587 mm and the largest double pancake has an inside diameter of 2100 mm and an outside diameter of 2587 mm. When installed, the 6 double pancakes are nested together side by side and rest on machined steps on the iron pole pieces.

The inner coils have a design value of 280,000 amp-turns. It utilizes a square, hollow, copper magnet conductor which is nominally 20.301 mm (0.7993 in) square with a 12.814 mm (0.5045 in) hole. The coil configuration is a 132 turn conductor package (22 turns per double pancake times 6 double pancakes). Total conductor length required is 734 meters (2510 ft) per coil resulting in a coil weight of 1945 kg (4278 lbs). 12 water circuits corresponding to 2 circuits per double pancake subassembly (bifilar wound) provide a pressure drop of 60 psig with a maximum water temperature rise of 41°C (inlet water temperature is 20°C). The copper conductor will be insulated with a "half-lap" of mylar tape enclosed in a continuous dacron sheath, wound on a coil winding form and epoxy impregnated under vacuum in a potting mold. Once completed, the coil will be electrically checked for shorts and hydrostatically pressure checked and flow checked through each of the 12 water circuits. Required water flow rate is approx. 63 gallons/minute per coil.

The inner coil requires 2122 amps @ 102 volts for a power supply requirement of 217 kwatts (280,000 amp-turns). The coil can theoretically achieve 461,800 amp-turns by allowing the outlet water temperature to rise to 80°C (vs. 41°C) and using a power supply of 619 kwatts.

Outer Coil:

The outer coils (2 required) are conceptually identical in design to the inner coils. They are also made up of 6 bifilar wound double pancake coils and have inside diameters ranging from 2990 mm to 3900 mm and outside diameters ranging from 3387 mm to 4387 mm.

The outer coils have a design value of 225,000 amp-turns and utilize the same size conductor and coil configuration as the inner coils. Total conductor length is 1511 meters (4858 ft) per coil resulting in a coil weight of 3840 kg (8448 lbs). Maximum outlet water temperature rise is 53°C with a required water flow rate of 42 gallons/minute per coil.

The outer coil requires 1705 amps @ 166 volts for a power supply requirement of 284 kwatts (225,000 amp-turns). The coil can theoretically achieve 296,000 amp-turns by allowing the outlet water temperature to rise to 80°C (vs. 53°C) and using a power supply of 509 kwatts.

Eng/Dsgn/Ins/Adm (mm): 15.15[1] Cost ($k):**222.5k** Dur: 11/92-11/94

5.1.1.1.1 Central Coils (both inner and outer):

This estimate for EDIA is based upon recent design experience resulting from design and specification of the GEM Magnet Subsystem. The manpower for this effort is divided into two categories: effort required for the engineering/design/analysis (Dsgn Phase) of the coil (11/92 through 2/93; 4 months) and effort required for the purchase/fabrication/assembly/installation/test (Fab Phase) of the coil (3/93 through 11/94; 21 months). The estimate is based upon actual LLNL charge rates for each individual and is estimated as follows:

Name	Type	Salary Category $/avg. mo	Dsgn. Phase man-months	Fab. Phase man-months	Total $ K's
Bob Yamamoto	Eng	14,529	0.9	4.0	71.2
Joel Bowers	Eng	11,923	0.5	0.0	7.3
Palmer House	Eng	14,529	0.5	0.0	5.4
Alan House	Eng	9,724	3.0	1.0	35.3
Dick Martin	Eng	10,800	3.0	1.0	35.3
Bon Highland	Des	9,724	0.5	3.0	37.8
Brigitte Gim	Des	10,800	0.5	3.0	37.8
Joe Ryland	Cord	8,837	0.75	1.0	15.5
			6.15	9.0	**$172.5k**

Travel: Estimate travel to coil/steel vendors and trips to BNL to be a total of 2 per month for the duration of the job for 25 months which equals 50 trips. Divide travel costs between each of the four magnet WBS items equally (Central Magnet Coils & Steel + Muon Piston Magnet Coil & Steel) which equates to 12.5 trips per WBS item. This travel includes potential foreign travel to Europe/Russia and Asia. Assume 2 people per trip @ $2k average cost per trip.

Total travel cost is: (12.5 trips) X (2 people) X ($2k/trip) = **$50k**

Total EDIA cost: $172.5k + $50k = **$222.5k**

[1]plus travel

Fabrication ($k): 848.4 + 150.7 = 999.1k Dur: 6/93-5/94

5.1.1.1.2 Central Coils (both inner and outer):

The fabrication of the Central Coils will be a build to print from LLNL provided drawings. The winding mandrel and the potting fixture will be specified by LLNL. The detail design of this support hardware will be the responsibility of the coil vendor with the design being approved by LLNL. Based on vendor estimates, it will take 4 months to procure the copper conductor and 8 months to fabricate the coils. The fabrication cost estimate is based on actual cost data from a similar type of epoxy impregnated coil built at LLNL (3/91). Some of the cost data has been modified (downward) due to recent vendor estimates on the cost of the conductor and economy of scale. The engineering supervision provided by LLNL for this task is included in 5.1.1.1.1, the EDIA for fabrication by a vendor. Historical single coil cost includes:

materials, fixtures, labor	$9.0k	
copper conductor	$1.8k	($4.00/lb for conductor + excess)
misc hardware, supplies	$1.2k	
water manifolds, supports	<u>$3.0k</u>	
Total:	$15.0k	per 450 lb complete coil assembly

Inner Coil total weight:	4278 lbs times 2 coils =	8,556 lbs
Outer coil total weight:	8448 lbs times 2 coils =	<u>16,896 lbs</u>
Total Central Coil weight:		25,452 lbs

<u>**5.1.1.1.2.1**</u> Coil fabrication cost:
25,452 lbs times $15k/450 lbs = <u>**$848.4k**</u>

<u>**5.1.1.1.2.2**</u> Power Supplies: (both inner and outer):

The power supplies specified are the nominal amount required to achieve the baseline operating field of the magnet system. Provided is the following table which reflects both baseline and maximum operating coil conditions (maximum coil operating set by limiting the exit cooling water temperature to 80°C):

<u>Coil type</u>	amp-turns <u>baseline</u>	reqd power supply <u>baseline</u>	amp-turns <u>maximum</u>	reqd power supply <u>maximum</u>
inner	280,000	217 kwatts	461,000	619 kwatts
outer	225,000	284 kwatts	296,000	509 kwatts

Power supply costs were based upon budgetary estimates received from two power supply companies. They gave the following cost information (+ or - 10%)

492 kw supply	$74k
650 kw supply	$78k
1214 kw supply	$135k

From these estimates, I have arrived at a cost estimate for our power supplies scaling with power (kw). To estimate costs, I've chosen the power supply which most closely matches our power requirement since there is a large fixed cost associated with the overall cost of a power supply.

Inner coil power supply costs:	217kw/492kw * $74k * 2 power supplies =	$65.3k
Outer coil power supply costs:	284kw/492kw * $74k * 2 power supplies =	<u>$85.4k</u>

5.1.1.1.2.2 Power supply cost: **$150.7k**

Assy/Installation (mm): 8.3 **Cost** ($k): 95.4k **Dur:** 8/94-10/94

5.1.1.1.3

This includes installing the four coils onto the pole pieces in the detector hall. It includes all of the electrical and LCW (low conductivity water) hook-ups and doing all system integration checkouts. Once completed, the magnet is ready for test operation. The engineering supervision for this task is included in 5.1.1.1.1, the EDIA for this portion of assy/installation.

The inner and outer coils have 6 double pancakes per coil or a total of 24 double pancakes total. I estimate it will take approx. 3 technicians 1/2 week to completely assemble and install a single double pancake coil onto the pole pieces. Total manpower required for the central magnet coils is 1440 man-hours (8.3 man-months). Use 1794 hours per man year (out of a total of 2080 hours in a year) which equates to 10.35 man-months per man year to account for items such as vacation, sick leave, holidays, etc.

Cost = 8.3 man-months/10.35 man-months * $119k/yr = **$95.4k**

Testing (mm): 6.0 **Cost** ($k): 94.0k[2] **Dur:** 10/94-11/94

5.1.1.1.4

This includes running the magnet coils (inner and outer) at full rated current, magnetically mapping the coils as required and checking all instrumentation and system performance. The engineering supervision for this task is included in 5.1.1.1.1, the EDIA for this testing.

It is estimated that it will take 3 technicians 1 month to test and map a coil pair (including reverse polarity). This equates to a total of 6 man-months to completely test the magnet subsystem.

Use 1794 hours per man year (out of a total of 2080 hours in a year) which equates to 10.35mm per man year to account for items such as vacation, sick leave, holidays, etc.

Cost = 6 man-months/10.35 man-months * $119/yr = **$69.0k**

[2]Estimated cost for the magnetic mapper, data acquisition system and misc hardware is $50.0k but cost is shared equally with the Muon Piston Coil so that total cost to the Central Magnet is **$25.0k**

Total cost is $69.0k + $25.0k = **$94.0k**

Unit type: ea **Number of units:** 4 (2 pairs)

Estimate Type: Bottoms Up (BU)

Risk Factors:

Technical:	4	Basis: New design based on established, well-proven technology
Cost:	4	Basis: Cost based on recent design and fabrication of similar coil.
Schedule:	4	Basis: Fabrication delay does not affect overall Detector completion.

Misc Comments:

Basis of Estimate

WBS: **5.1.1.2** Item: **PHENIX - Central Magnet Steel**

Date: October 9, 1992 Rev: 0B By: R. Yamamoto/J. Bowers

Element Scope:

This element covers the entire cost of the engineering, design, fabrication, assembly, installation and testing of the central magnet steel and its associated support structure for the Central Magnet.

Technical design description:

The basic magnet steel structure will consist of two pole pieces, two large flux returns, and a support structure. Each pole piece (LLNL drawing #AAA92-102744-00) will be cast or forged ASTM 1006 with an approximate weight of 105 tons. Both will have two machined circular grooves to accept the inner and outer coils, and will be separated by a nominal gap of 1.2 meters. The two facing poles will be magnetically and structurally tied together with two large flux return plates(3 M^2 cross section), attached to the top and bottom of the poles. The entire pole assembly will be supported on a rigid steel structure. This structure will be designed to allow the Central Magnet to translate a short distance along the beam axis (z direction) and then move horizontally transverse to the beam (x direction) several meters into the working area of the detector hall. A transporter consisting of Hilman rollers, hydraulic jacks, and steel plate is planned for this purpose.

Eng/Dsgn/Ins/Adm (mm): 19.05[1] Cost ($k): 269.3k Dur: 11/92-11/94

5.1.1.2.1 Central Magnet Steel:

This estimate for EDIA is based upon recent LLNL design experience resulting from the design and specification of a magnet subsytem for another large particle detector. The manpower for this effort is divided into two categories: effort required for the engineering/design/analysis (Dsgn Phase) of the coil (11/92 through 2/93; 4 months) and effort required for the purchase/fabrication/assembly/installation/test (Fab Phase) of the coil (3/93 through 11/94; 21 months). The estimate is based upon actual LLNL charge rates for each individual and is estimated as follows:

Name	Type	Salary Category $/avg. mo	Dsgn. Phase man-months	Fab. Phase man-months	Total $ K's
Bob Yamamoto	Eng	14,529	0.8	2.0	40.7
Joel Bowers	Eng	11,923	1.5	~~4.0~~	65.6
Palmer House	Eng	14,529	0.5	1.0	21.8
Alan House	Eng	9,724	2.0	0.0	19.5
Dick Martin	Eng	10,800	0.5	0.0	5.4
Bon Highland	Des	9,724	2.0	~~1.0~~	29.2
Brigitte Gim	Des	10,800	0.5	1.5	21.6
Joe Ryland	Cord	8,837	0.75	1.0	15.5
			8.55	~~10.5~~	**$219.3k**

Travel: Estimate travel to coil/steel vendors and trips to BNL to be a total of 2 per month for the duration of the job for 25 months which equals 50 trips. Divide travel costs between each of the four magnet WBS items equally (Central Magnet Coils & Steel + Muon Piston Magnet Coil & Steel) which equates to 12.5 trips per WBS item. This travel includes potential foreign travel to Europe/Russia and Asia. Assume 2 people per trip @ $2k average cost per trip.

Total travel cost is: (12.5 trips) X (2 people) X ($2k/trip) = **$50k**

Total EDIA cost: $219.3k + $50k = **$269.3k**

[1]plus travel

Fabrication ($k): **1109k** Dur: 6/93-8/94

5.1.1.2.2 Central Magnet Steel:

The fabrication of the Central Magnet steel and structure will be a build to print from LLNL provided drawings. The large pole pieces (approx. 105 tons each) will be either cast or forged due to its large size and weight. In addition, magnetic performance is enhanced (the fewer the joints the better) and assembly time minimized by making the poles in single units. Based on vendor estimates, it will take approx. 12 months to fabricate, machine and transport to BNL the two large pole pieces. The fabrication cost estimate for the poles is provided in the form of a vendor estimate made for budgetary purposes. The balance of the magnetic steel and steel support structure is based on current market prices for cast and plate steel and generally accepted fabrication practices. The engineering supervision provided by LLNL for this task is included in 5.1.1.2.1, the EDIA for fabrication by a vendor.

The vendor estimates received for the fabrication of the two pole pieces (LLNL drawing #AAA92-102744-00) ranged from a low value of $476k to a high value of $1500k. The low estimate however did not include the completion of all machining operations. For this reason, I am estimating the cost of the two pole pieces by using the second lowest estimate received.

Cost for the two pole pieces fully machined: **$690k**

Ring segments

Each pole piece is backed by two ring segments which serves as a structural and magnetic transition to the flux return plates. An upper segment connect the pole piece to the upper flux return plates, and a lower segment ties to lower return plates. The segments fastened to adjoining parts with bolts.

raw material cost = 4 ea x 32000 lb x $0.30/lb = $38.4k
Forging operation = 160 hours x $100/hour = $16k
machining and finishing = 160 hours x $100/hour = $16k
blasting and painting = $8k
transportation to site = $6k (two truck loads)

High strength bolts, 40 ea x $200 = $8k

total cost of ring segments = **$92k**

Flux Return Plates

Upper and lower flux return plates provide a magnetic return path for the Central Magnet assembly. The lower plates interface the support structure and the transport system. Machining details accept shear pins and mounting plates of the transport system. Blind tapped holes on the bottom mounting faces provide attachment points for the support structure.

raw material cost: top flux return
90000 lb x $0.30/lb = $27k
Blanchard grinding and machining = 200 hours x $100/hour = $20k
blasting and painting = $10k
transportation to site = $6k

raw material cost: bottom flux return
180000 lb x $0.30/lb = $54k
Blanchard grinding and machining = 500 hours x $100/hour = $50k
blasting and painting = $20k
transportation to site = $12k

total cost of flux return plates = $63k (top) $136K (bottom) = **$199k**

Support structure

The support structure for the central magnet is a closed section weldment constructed from low carbon steel rectangular structural tubing and flat plate. Two columns, located directly underneath each pole piece, provide torsional and lateral stability for both operation and transport of the magnet assembly. Each column consists of stacked rectangular tubes stitch welded together and stabilized with top and bottom mounting plates. The columns are tied together with a cross beam to provide lateral stiffness.

total weight of support structure assembly = 10 tons
raw material cost (A36 low carbon steel) = $0.30/lb x 20,000 lb = $6K

Finishing cost to remove mill scale = $1.5k

cutting and weld prep= 40 hours x $100/hour = $4k weld fixturing and alignment = 16 hours x $100/hour = $1.6k

weld material cost is included in welding cost
welding cost = 24 hours x $100/hour = $2.4k

machine interfaces = 16 hours x $100/hour = $1.6k

transportation to site = $3k

blasting and painting = $2k

total cost of support structure = **$22k**

Facility modifications to interface support structure

Two low carbon steel plates will need to be embedded in the floor beneath the support structure, to provide adequate anchorage for mounting studs. The floor will be chipped out to a depth of 4 inches, and holes will be further drilled in a pattern to accommodate stud anchors for the plate. Weld studs will be fastened to the bottom of the plate, which will be set in epoxy grout and leveled to the floor. Existing rebar in the concrete will be cut and welded to the anchor plate. Additional grout will be pressure injected into holes in the plate to completely fill the gap between the plate and the floor. Studs will then be screwed into the plate to level and hold the central magnet assembly.

anchor plate (A36 low carbon steel) = $0.30/lb x 4,000 lb = $1.2K
floor preparations = 100 man hours x $100/hour = $10k
installing anchor plate = 80 man hours x $100/hour = $8k

mounting hardware (studs, nuts, etc) = $1k

total cost of facility modifications = **$20k**

Transport system

Transportation hardware is required for lifting and moving the central magnet assembly during periodic maintenance and detector upgrades. Items needed include recipricating rollers, hydraulic jacks, removeable lifting fixtures, and a hydraulic system.

forged round bar, raw stock, 4ea x 2500 lb x $0.30/lb = $3k
plate stock, 4 ea x 2500 lb x $0.30/lb = $3k
Shear pins, 4 ea x 100 lb x $3/lb = $1.2k
machining = 120 hours x $100/hour = $12K
welding = 40 hours x $100/hour = $4K

hydraulic jacks, Templeton Kelly, R500-6, 4ea @ $8105 = $32K

miscellaneous hydraulic equipment = $5k (pump, oil, hoses, valves, etc)

Hilman rollers, 500XT, 4 ea @ 4983 = $20k (vendor quote)

100 feet of temporary track plate, 2" thick = 20,000 x $0.30/lb = $6k

total cost of transport system = **$86k**

5.1.1.2.2 Total steel fabrication cost:
$690k + $92k + $199k +$ 22k + $20k + $86k =**$1109k**

Assy/Installation (mm): 21.0 Cost ($k): 265.5k Dur: 9/94-10/94

5.1.1.2.3

This includes assembly and installation of the two pole pieces, all magnetic flux return steel and the entire steel support structure (including the Central Magnet transport system) in the detector hall. It includes all structural alignment and fit-up of the magnet and doing all subsystem integration checkouts. Assembly and installation of the inner and outer coils is included in WBS 5.1.1.1.3 and is not costed here. Once magnet assembly is complete, the magnet will be rolled into place and installed in its operating position on the RHIC beamline. The engineering supervision for this task is included in 5.1.1.2.1, the EDIA for this portion of assy/installation.

Magnet assembly will require 10 technicians 2 months to construct and assemble the magnet support structure, completely assemble the two pole pieces onto the support structure and align and mate all hardware. This work includes welders, riggers and general technicians as well as their own supervisory staff. This time includes the moving of the subassembly from the high bay area (where assembly is taking place) into the beamline itself. In addition, 2 alignment surveyors will be needed for 2 months. Their effort will be shared equally between the Muon Piston Magnet so the amount charged will be a total of 1 man-month. Total manpower required for the central magnet is 21 man-months. Use 1794 hours per man year (out of a total of 2080 hours in a year) which equates to 10.35 man-months per man year to account for items such as vacation, sick leave, holidays, etc.

Cost = 21.0 man-months/10.35 man-months * $119k/yr = **$241.4k**

Misc. hardware and supply costs is estimated at 10% of labor costs or **$24.1k**.

Total cost is: $241.4k + $24.1k = **$265.5k**

Testing (mm): 2.0 Cost ($k): 23.0k Dur: 9/94-10/94

5.1.1.2.4

The bulk of the testing will take place once the inner and outer coils are installed onto the two pole pieces. All electrical and magnetic tests are costed under WBS 5.1.1.1.4, coil testing. QA checking of the finished machined parts on-site at BNL (when it has not been done previously at the vendor fabrication site) and material certification (as required) is included in this section. The engineering supervision for this task is included in 5.1.1.2.1, the EDIA for this testing.

It is estimated that it will take 2 technicians 1 month to test perform these tests.

Use 1794 hours per man year (out of a total of 2080 hours in a year) which equates to 10.35mm per man year to account for items such as vacation, sick leave, holidays, etc.

Cost = 2 man-months/10.35 man-months * $119/yr = **$23.0k**

Unit type: ea **Number of units:** 1

Estimate Type: Bottoms Up (BU)

Risk Factors:

Technical: 8 Basis: Fabrication of large pole pieces is at industry limit.

Cost: 6 Basis: Cost based on several vendor budgetary estimates.

Schedule: 10 Basis: Fabrication delay affects overall Detector completion.

Misc Comments:

Basis of Estimate

WBS: **5.1.2.1** Item: **PHENIX - Muon Piston Mag Coil**

Date:October 9, 1992 Rev: 0B By: R. Yamamoto

Element Scope:

This element covers the entire cost of the engineering, design, fabrication, assembly, installation and testing of the single coil for the Muon Piston Magnet.

Technical design description:

Muon Piston Coil:
The muon piston coil (1 required) is a quadrafilar wound solenoidal coil (having two layers) which will be vacuum epoxy impregnated onto its epoxy-fiberglass winding form. The shape of the coil is a tapered cone having an overall length of 1.4 meters and a small end inside diameter of 1.624 meters (5.33 ft) and a large end inside diameter of 2.054 meters (6.74 ft).

The muon piston coil has a design value of 300,000 amp-turns. It utilizes a square, hollow, copper magnet conductor which is nominally 24.13 mm (0.95 in) square with a 15.49 mm (0.6098 in) hole. The coil configuration is a 105 turn conductor package comprised of two layers of solenoidal type windings. Total conductor length required is 630 meters (2068 ft) per coil resulting in a coil weight of 2226 kg (4897 lbs). Each quadrafilar wound conductor segment has its own individual water circuit in addition to each coil layer having its own parallel water supply giving rise to a total of 8 individual water circuits. The LCW system provides cooling water to achieve a pressure drop of 60 psig with a maximum water temperature rise of 35°C (inlet water temperature is 20°C). The copper conductor will be insulated with a "half-lap" of mylar tape enclosed in a continuous dacron sheath, wound on a coil winding form and epoxy impregnated under vacuum in a potting mold. Once completed, the coil will be electrically checked for shorts and hydrostatically pressure checked and flow checked through each of the 8 water circuits. Required water flow rate is approx. 64 gallons/minute for the entire coil.

The muon coil requires 2858 amps @ 82 volts for a power supply requirement of 235 kwatts (300,000 amp-turns). The coil can theoretically achieve 568,800 amp-turns by allowing the outlet water temperature to rise to 80°C (vs. 35°C) and using a power supply of 905 kwatts.

Eng/Dsgn/Ins/Adm (mm): 15.15[1] **Cost ($k):234.9k Dur: 11/92-11/94**

5.1.2.1.1 Muon Piston Coil:

This estimate for EDIA is based upon coils I have designed and built over the past several years. The manpower for this effort is divided into two categories: effort required for the engineering/design/analysis (Dsgn Phase) of the coil (11/92 through 1/93; 3 months) and effort required for the purchase/fabrication/assembly/installation/test (Fab Phase) of the coil (2/93 through 11/94; 22 months). The estimate is based upon actual LLNL charge rates for each individual and is estimated as follows:

Name	Type	Salary Category $/avg. mo	Dsgn. Phase man-months	Fab. Phase man-months	Total $ K's
Bob Yamamoto	Eng	14,529	0.9	4.0	71.2
Ross Schlueter	Eng	14,529	0.5	0.0	7.3
Art Harvey	Eng	10,800	0.5	0.0	5.4
Don Bubp	Des	11,923	3.0	1.0	47.7
Brigitte Gim	Des	10,800	0.5	3.0	37.8
Joe Ryland	Cord	8,837	0.75	1.0	15.5
			6.15	9.0	**$184.9k**

Travel: Estimate travel to coil/steel vendors and trips to BNL to be a total of 2 per month for the duration of the job for 25 months which equals 50 trips. Divide travel costs between each of the four magnet WBS items equally (Central Magnet Coils & Steel + Muon Piston Magnet Coil & Steel) which equates to 12.5 trips per WBS item. This travel includes potential foreign travel to Europe/Russia and Asia. Assume 2 people per trip @ $2k average cost per trip.

Total travel cost is: (12.5 trips) X (2 people) X ($2k/trip) = **$50k**

Total EDIA cost: $184.9k + $50k = **$234.9k**

[1]plus travel

Fabrication ($k): 210.9 + 35.3 = 246.2k Dur: 6/93-3/94

5.1.2.1.2 Muon Piston Coil:

The fabrication of the Muon Piston Coil will be a build to print from LLNL provided drawings. The winding mandrel and the potting fixture will be specified by LLNL. The detail design of this support hardware will be the responsibility of the coil vendor with the design being approved by LLNL. Based on vendor estimates, it will take 4 months to procure the copper conductor and 6months to fabricate the coil. The fabrication cost estimate is based on actual cost data from epoxy impregnated coils recently built at LLNL. Some of the cost data has been modified (downward) due to recent vendor estimates on the cost of the conductor. However, since the winding mandrel requires machining a epoxy-fiberglass lay-up on a 5-axis numerically controlled machine, the cost for fixturing and machining labor is quite high. The engineering supervision provided by LLNL for this task is included in 5.1.21.1, the EDIA for fabrication by a vendor. Historical single coil cost includes:

materials, fixtures, labor	$12.0k	
copper conductor	$1.8k	($4.00/lb for conductor + excess)
misc hardware, supplies	$1.2k	
water manifolds, supports	$3.0k	
Total:	$18.0k	per 450 lb complete coil assembly

Coil fabrication cost:
4897 lbs times $18k/450 lbs = **$195.9k**

The special handling fixture required to safely transport and install the muon coil onto the muon piston core will also be built from LLNL provided drawings. Estimated cost of this fixture is **$15k** (120 hrs fab times $100/hr + $3k for raw materials).

5.1.2.1.2.1 Total coil fabrication cost:
$195.9k + $15.0k = **$210.9k**

5.1.2.1.2.2 Power Supply:

The power supply specified is the nominal amount required to achieve the baseline operating field of the magnet system. Provided is the following table which reflects both baseline and maximum operating coil conditions (maximum coil operating set by limiting the exit cooling water temperature to 80°C):

Coil type	amp-turns baseline	reqd power supply baseline	amp-turns maximum	reqd power supply maximum
muon	300,000	235 kwatts	568,800	905 kwatts

Power supply costs were based upon budgetary estimates received from two power supply companies. They gave the following cost information (+ or - 10%)

492 kw supply	$74k
650 kw supply	$78k
1214 kw supply	$135k

From these estimates, I have arrived at a cost estimate for our power supplies scaling with power (kw). To estimate costs, I've chosen the power supply which most closely matches our power requirement since there is a large fixed cost associated with the overall cost of a power supply.

Muon coil power supply costs: 235kw/492kw * $74k = $35.3k

5.1.1.1.2.2 Power supply cost: **$35.3k**

Assy/Installation (mm): 3.0 Cost ($k): 34.5k Dur: 8/94-9/94

5.1.1.1.3

This includes installing the single coil onto the large piston pole in the detector hall. It includes all of the electrical and LCW (low conductivity water) hook-ups and doing all system integration checkouts. Once completed, the magnet is ready for test operation. The engineering supervision for this task is included in 5.1.2.1.1, the EDIA for this portion of assy/installation.

The muon piston coil will require special handling and installation fixturing to prevent possible damage to the coil. The cost of this fixture is included in the fabrication section above. I estimate it will take approx. 3 technicians 1 month to completely assemble and install the coil onto the pole piece. Total manpower required for the central magnet coils is 3 man-months. Use 1794 hours per man year (out of a total of 2080 hours in a year) which equates to 10.35 man-months per man year to account for items such as vacation, sick leave, holidays, etc.

Cost = 3.0 man-months/10.35 man-months * $119k/yr = **$34.5k**

Testing (mm): 3.0[2] **Cost ($k):** **59.5k**[2] **Dur:** 10/94-11/94

5.1.2.1.4

This includes running the magnet coil at full rated current, magnetically mapping the coils as required and checking all instrumentation and system performance. The engineering supervision for this task is included in 5.1.2.1.1, the EDIA for this testing.

It is estimated that it will take 3 technicians 1 month to test and map the coil. This equates to a total of 3 man-months to completely test the magnet subsystem.

Use 1794 hours per man year (out of a total of 2080 hours in a year) which equates to 10.35mm per man year to account for items such as vacation, sick leave, holidays, etc.

Cost = 3 man-months/10.35 man-months * $119/yr = **$34.5k**

[2]Estimated cost for the magnetic mapper, data acquisition system and misc hardware is $50.0k but cost is shared equally with the Central Coils so that total cost to the muon piston magnet is **$25.0k**

Total cost is: $34.5k + $25.0k = **$59.5k**

Unit type: ea **Number of units:** 1

Estimate Type: Bottoms Up (BU)

Risk Factors:

Technical: 4 Basis: New design based on established, well-proven technology

Cost: 4 Basis: Cost based on recent design and fabrication of large coils.

Schedule: 4 Basis: Fabrication delay does not affect overall Detector completion.

Misc Comments:

Basis of Estimate

WBS: **5.1.2.2** Item: **PHENIX - Muon Piston Magnet Steel**

Date: October 9, 1992 Rev: 0B By: R. Yamamoto/J. Bowers

Element Scope:

This element covers the entire cost of the engineering, design, fabrication, assembly, installation and testing of the magnet steel and its associated support structure for the Muon Piston Magnet.

Technical design description:

The basic magnet steel structure will consist of a large tapered iron core (LLNL drawing #AAA92-102745-00) bolted to a flux return end plate which is 30 cm (11.81 in) in thickness (LLNL drawing #AAA92-102747-00). Eight trapazoidal steel plates, 8 cm (3.15 in) in thickness, are arranged in an octogon pattern ("lampshade") around the iron core (LLNL drawing #AAA92-102746-00). These plates provide the return flux path for the muon piston magnet. The tapered iron core will be either cast or forged as a single piece and weigh approximately 75 tons. The end plate will be constructed from several plate sections welded together (approx. weight is 263 tons) and the "lampshade" flux return will be fabricated from plate steel (approx. weight is 176 tons total). All structural material will be ASTM 1006. The iron core and "lampshade" plate assemblies will be supported on a rigid steel structure. This structure will be designed to allow for access of the three sets of muon chambers that mount inside the open volume between the iron core and the "lampshade". The muon piston magnet assembly is a stationary structure and rests on metal shims during detector operation.

Eng/Dsgn/Ins/Adm (mm): 19.05[1] Cost ($k): 269.3k Dur: 11/92-11/94

5.1.2.2.1 Muon Piston Magnet Steel:

This estimate for EDIA is based upon recent LLNL design experience from the design and specification of a magnet subsystem for another large particle detector. The manpower for this effort is divided into two categories: effort required for the engineering/design/analysis (Dsgn Phase) of the coil (11/92 through 2/93; 4 months) and effort required for the purchase/fabrication/assembly/installation/test (Fab Phase) of the coil (3/93 through 11/94; 21 months). The estimate is based upon actual LLNL charge rates for each individual and is estimated as follows:

Name	Type	Salary Category $/avg. mo	Dsgn. Phase man-months	Fab. Phase man-months	Total $ K's
Bob Yamamoto	Eng	14,529	0.8	2.0	40.7
Joel Bowers	Eng	11,923	1.5	4.0	65.6
Palmer House	Eng	14,529	0.5	1.0	21.8
Alan House	Eng	9,724	2.0	0.0	19.5
Dick Martin	Eng	10,800	0.5	0.0	5.4
Bon Highland	Des	9,724	2.0	1.0	29.2
Brigitte Gim	Des	10,800	0.5	1.5	21.6
Joe Ryland	Cord	8,837	0.75	1.0	15.5
			8.55	10.5	**$219.3k**

Travel: Estimate travel to coil/steel vendors and trips to BNL to be a total of 2 per month for the duration of the job for 25 months which equals 50 trips. Divide travel costs between each of the four magnet WBS items equally (Central Magnet Coils & Steel + Muon Piston Magnet Coil & Steel) which equates to 12.5 trips per WBS item. This travel includes potential foreign travel to Europe/Russia and Asia. Assume 2 people per trip @ $2k average cost per trip.

Total travel cost is: (12.5 trips) X (2 people) X ($2k/trip) = **$50k**

Total EDIA cost: $219.3k + $50k = **$269.3k**

[1] plus travel

Fabrication ($k): **1399k** **Dur:** 6/93-8/94

5.1.2.2.2 Muon Piston Magnet Steel:

The fabrication of the Muon Piston Magnet steel and structure will be a build to print from LLNL provided drawings. The large iron core (approx. 75 tons) will be either cast or forged due to its large size and weight. In addition, magnetic performance is enhanced (the fewer the joints the better) and assembly time minimized by making the iron core as a single unit. Based on vendor estimates, it will take approx. 12 months to fabricate, machine and transport to BNL the iron core, which is the critical path fabrication item of the magnet subsystem. The fabrication cost estimate for the iron core, back plate and "lampshade" is provided in the form of a vendor estimate made for budgetary purposes. The balance of the magnetic steel and steel support structure is based on current market prices for cast and plate steel and generally accepted fabrication practices. The engineering supervision provided by LLNL for this task is included in 5.1.2.2.1, the EDIA for fabrication by a vendor.

The vendor estimates received for the fabrication of the iron core (LLNL drawing #AAA92-102745-00) ranged from a low value of $188k to a high value of $470k. The low estimate however did not include the completion of all machining operations. For this reason, I am estimating the cost of the iron core by using the second lowest estimate received.

Cost for the iron core fully machined: ~~**$370k**~~ 190K...

The vendor estimates received for the fabrication of the back plate (LLNL drawing #AAA92-102747-00) ranged from a low value of $515k to a high value of $2218k. The low estimate included the completion of all machining operations. For this reason, I am estimating the cost of the back plate by using the lowest estimate received.

Cost for the back plate fully machined: **$515k**

The vendor estimates received for the fabrication of the "lampshade" (LLNL drawing #AAA92-102746-00) ranged from a low value of $367k to a high value of $1103k. The low estimate included the completion of all machining operations. For this reason, I am estimating the cost of the "lampshade" by using the lowest estimate received.

Cost for the "lampshade" fully machined: **$367k**

Cost of bead blasting, primering, and painting the above items is painting= **$40k**

The support structure for the muon piston magnet will be constructed from A36 low carbon steel, and mounted to the floor with concrete epoxy anchors. Approximately 20 tons of steel will be used in fabrication. The forward support, located near the central magnet, will be a plate girder weldment, with a varying closed cross section designed to accommodate the unique geometry of the lampshade interface. The rear support, which is relatively short, will resemble outriggers underneath the magnet back plate. A nominal 2" clearance will be built into the design to allow for alignment.

raw material cost = 40,000 lb x $0.30/lb = $12k

Finishing cost to remove mill scale = $6k

cutting and weld prep= 160 hours x $100/hour = $16k

weld fixturing and alignment
80 man hours x $100/manhour = $8k

weld material cost is included in welding cost
welding cost = 2000 lb weld/ 5 lb/hour x $100/hour = $40k

machine interfaces 16 hours/face x 9 faces x $100/hr = $14.4k

blasting and painting = $5k

transportation to site = $6k (two tractor-trailer loads)

total fabrication cost of support structure = **107K**

5.1.1.2.2 Total steel fabrication cost:
$370k +$515k +$367k + $40k + $107k = **$1399k**

Assy/Installation (mm): 13.0 Cost ($k): 164.5k Dur: 10/94-11/94

5.1.2.2.3

This includes assembly and installation of the iron core, the back plate, the 8 steel plate assemblies that make up the "lampshade" flux return and the entire steel support structure required to support this assembly in the detector hall. It includes all structural alignment and fit-up of the magnet and doing all subsystem integration checkouts. Assembly and installation of the muon piston coil is included in WBS 5.1.2.1.3 and is not costed here. Once magnet assembly and installation is complete, the magnet will be in its operating position on the RHIC beamline and ready for final checkout and testing. The engineering supervision for this task is included in 5.1.2.2.1, the EDIA for this portion of assy/installation.

Magnet assembly and installation will require 6 technicians 2 months to construct and assemble the magnet support structure, completely assemble the iron core onto the back plate, assemble the "lampshade" plate elements and align and mate all hardware. This work includes welders, riggers and general technicians as well as their own supervisory staff. In addition, 2 alignment surveyors will be needed for 2 months. Their effort will be shared equally between the Central Magnet so the amount charged will be a total of 1 man-month. Total manpower required for the muon piston magnet is 13 man-months. Use 1794 hours per man year (out of a total of 2080 hours in a year) which equates to 10.35 man-months per man year to account for items such as vacation, sick leave, holidays, etc.

Cost = 13.0 man-months/10.35 man-months * $119k/yr = **$149.5k**

Misc. hardware and supply costs is estimated at 10% of labor costs or **$15.0k**.

Total cost is: $149.5k + $15.0k = **$164.5k**

Testing **(mm): 2.0** **Cost ($k): 23.0k** **Dur: 10/94-11/94**

5.1.2.2.4

The bulk of the testing will take place once the muon piston coil is installed onto the iron core and the magnet steel is completely assembled and installed in place. All electrical and magnetic tests are costed under WBS 5.1.2.1.4, coil testing. QA checking of the finished machined parts on-site at BNL (when it has not been done previously at the vendor fabrication site) and material certification (as required) is included in this section. The engineering supervision for this task is included in 5.1.2.2.1, the EDIA for this testing.

It is estimated that it will take 2 technicians 1 month to test perform these tests.

Use 1794 hours per man year (out of a total of 2080 hours in a year) which equates to 10.35mm per man year to account for items such as vacation, sick leave, holidays, etc.

Cost = 2 man-months/10.35 man-months * $119/yr = **$23.0k**

Unit type: ea **Number of units:** 1

Estimate Type: Bottoms Up (BU)

Risk Factors:

Technical: 8 Basis: Fabrication of large iron core is at industry limit.

Cost: 6 Basis: Cost based on several vendor budgetary estimates.

Schedule: 10 Basis: Fabrication delay affects overall Detector completion.

Misc Comments:

RHIC - PHENIX DETECTOR
MAGNET SUBSYSTEM - STEEL

Vendor Estimate Summary - Proprietary Information
October 1992
R. M. Yamamoto

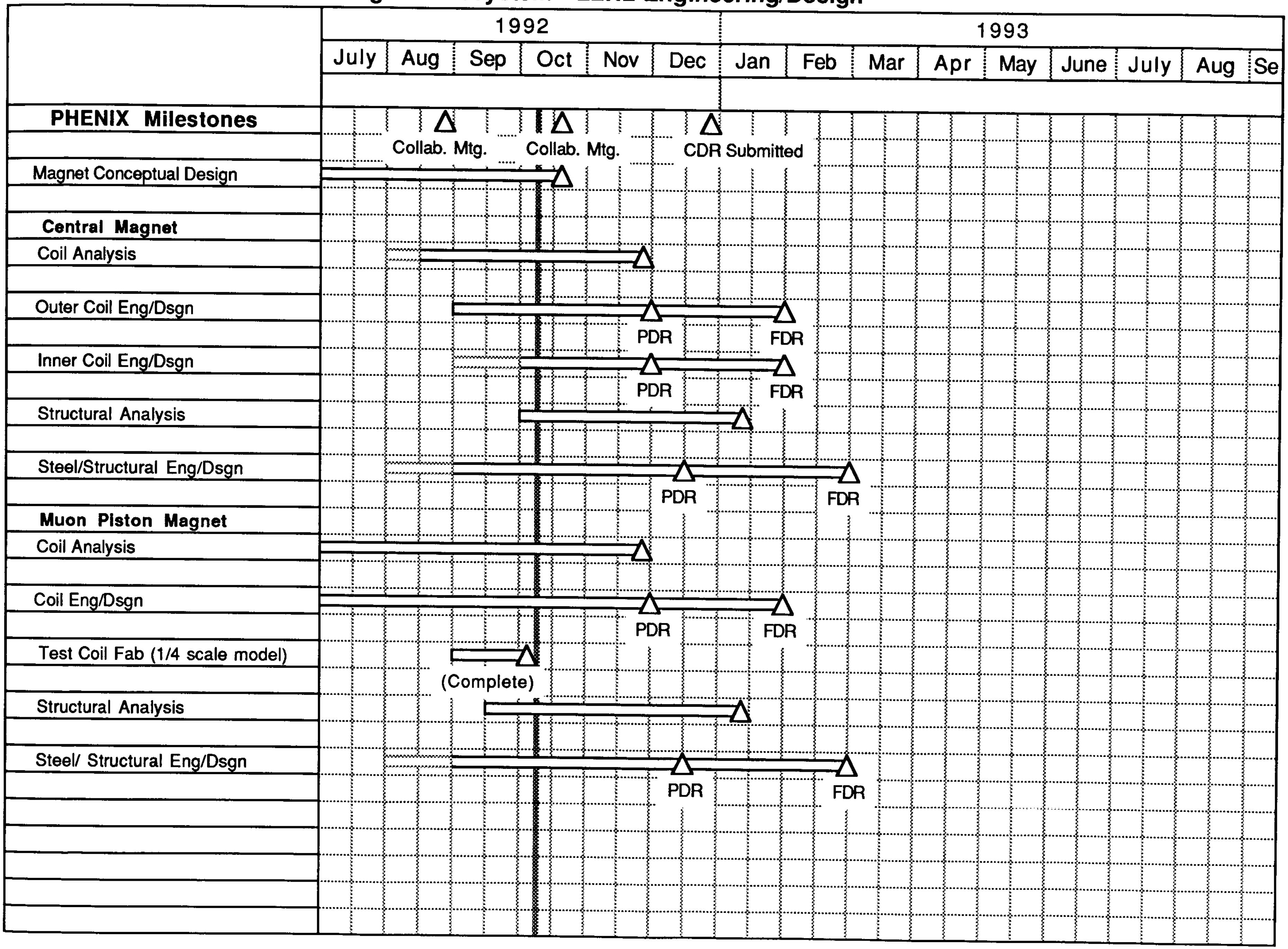
VENDOR	ITEM		TOTAL COST ($K)	COST / LB
A.C. Equipment	Pole Pieces (2)	210 tons	$ 1182	$2.80
West Allis, WI	Piston Core	78 tons	470	3.01
	Lampshade	176 tons	977	2.78
	Back Plate	263 tons	1400	2.66
Direct Machine	Pole Pieces (2)		$ 1500	$3.55
Tucson, AZ	Piston Core		463	2.97
	Lampshade		ø	ø
	Back Plate		2218	4.22
Canadian Steel	Pole Pieces (2)		476[1]	$2.27
Montreal, Quebec	Piston Core		188[1]	1.21
	Lampshade		**367**	**1.04**
	Back Plate		599	1.14
Bethlehem Steel	Pole Pieces (2)		1072	$5.10
Bethlehem, PA	Piston Core		190	1.22
	Lampshade		ø	ø
	Back Plate		ø	ø
CBI Services	Pole Pieces (2)		ø	ø
Cordova, AL	Piston Core		ø	ø
	Lampshade		376	$1.07
	Back Plate		762	1.45
Creusot-Marrel	**Pole Pieces (2)**		**690**	**$1.64**
France	**Piston Core**		**370**	**2.37**
	Lampshade		ø	ø
	Back Plate		**515**	**0.98**
Murdock, Inc.	Pole Pieces (2)		ø	ø
Compton, CA	Piston Core		ø	ø
	Lampshade		1103	$3.13
	Back Plate		1775	3.37

BOLD: used in cost estimate

[1] fabrication cost does not include the completion of all machining operations

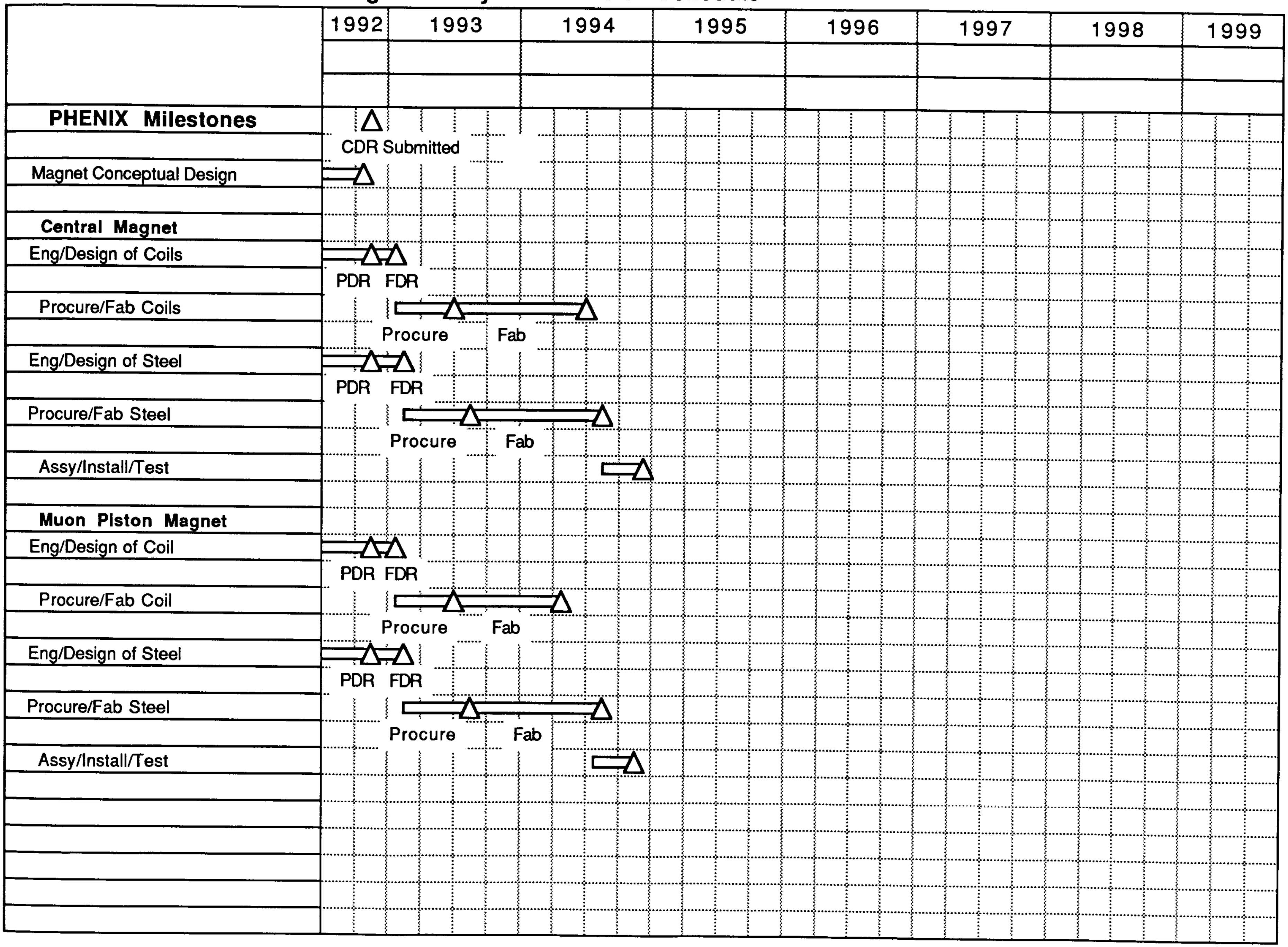
VENDOR	ITEM	TOTAL COST	COST / LB.
Lukens Steel Coatesville, PA	Pole Pieces (2) Piston Core Lampshade Back Plate	NO BID	
PDM Pittsburg, PA	Pole Pieces (2) Piston Core Lampshade Back Plate	NO BID	
Gary Steel Berkeley, CA	Pole Pieces (2) Piston Core Lampshade Back Plate	NO BID	
Steward Machine Birmingham, AL	Pole Pieces (2) Piston Core Lampshade Back Plate	NO BID	
Harbert Machine Birmingham, AL	Pole Pieces (2) Piston Core Lampshade Back Plate	NO BID	

PHENIX Magnet Subsystem - LLNL Engineering/Design



Saturday, October 10, 1992

PHENIX Magnet Subsystem - Overall Schedule



Saturday, October 10, 1992

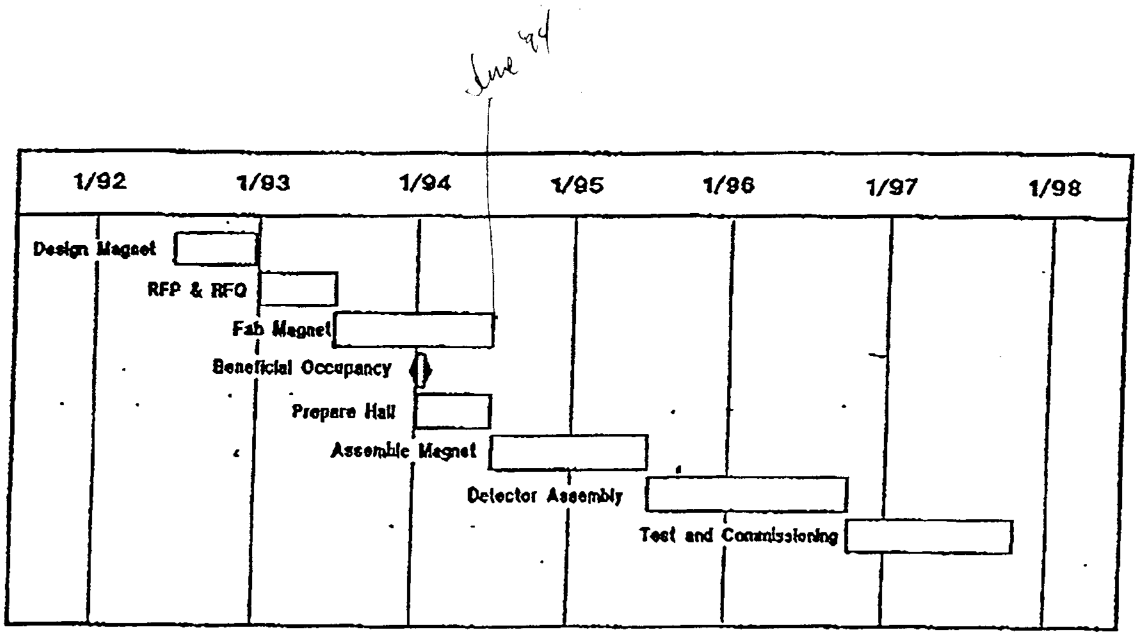


Figure 3.1: Construction schedule chart for the PHENIX central magnet.

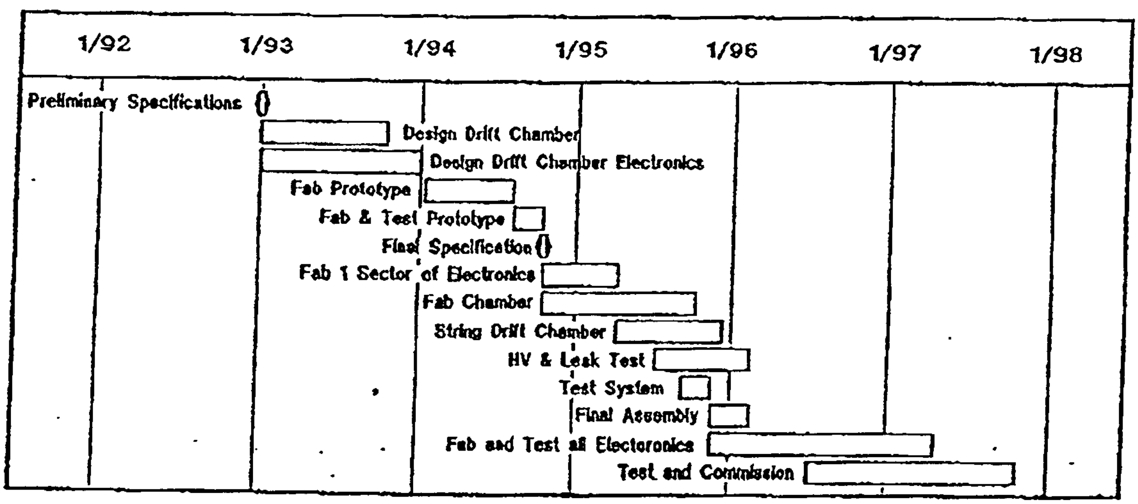


Figure 3.2: Construction schedule chart for the PHENIX tracking system drift chambers.

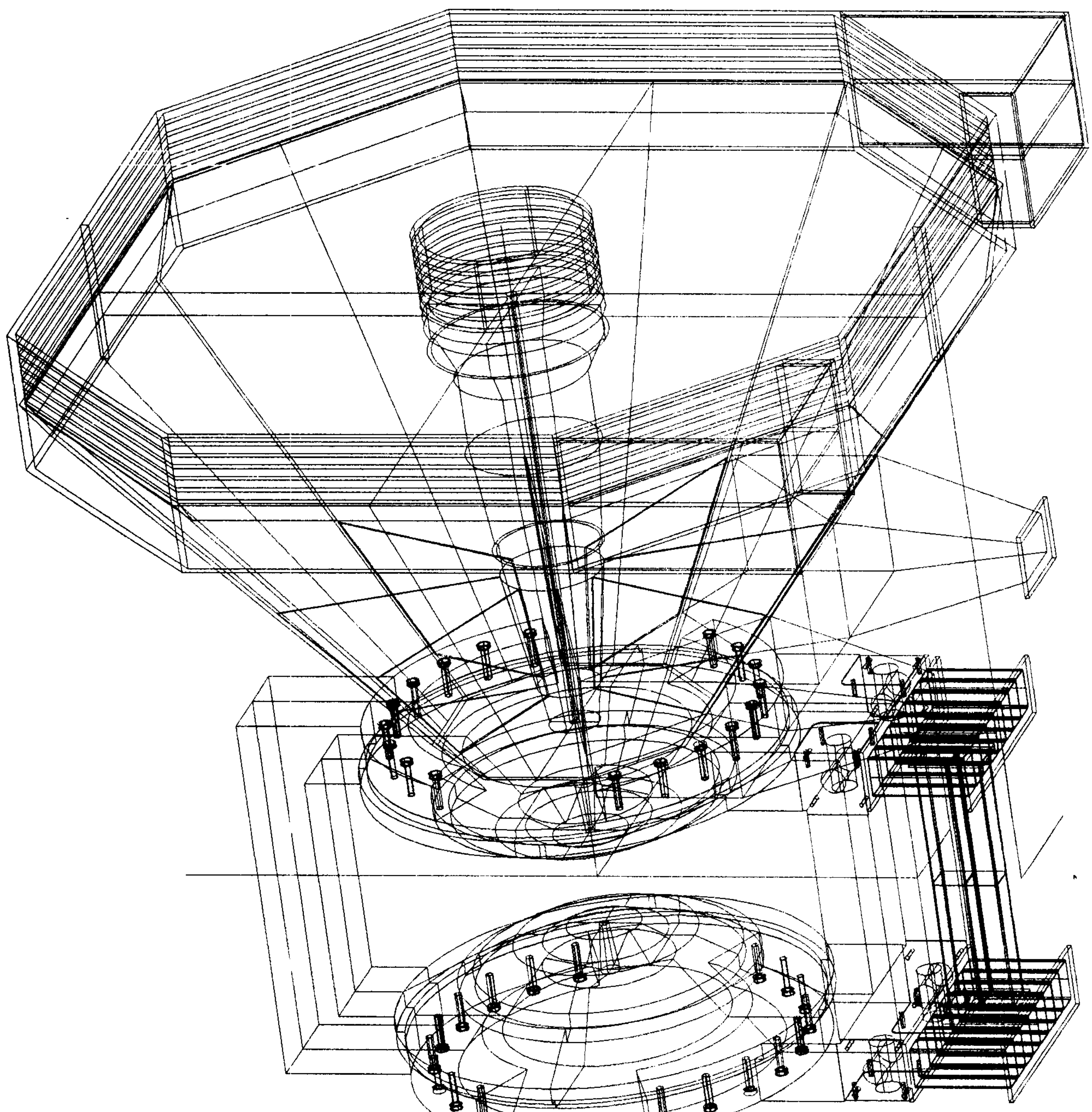
PHENIX Mag Subsystem - Procure/Fab Durations

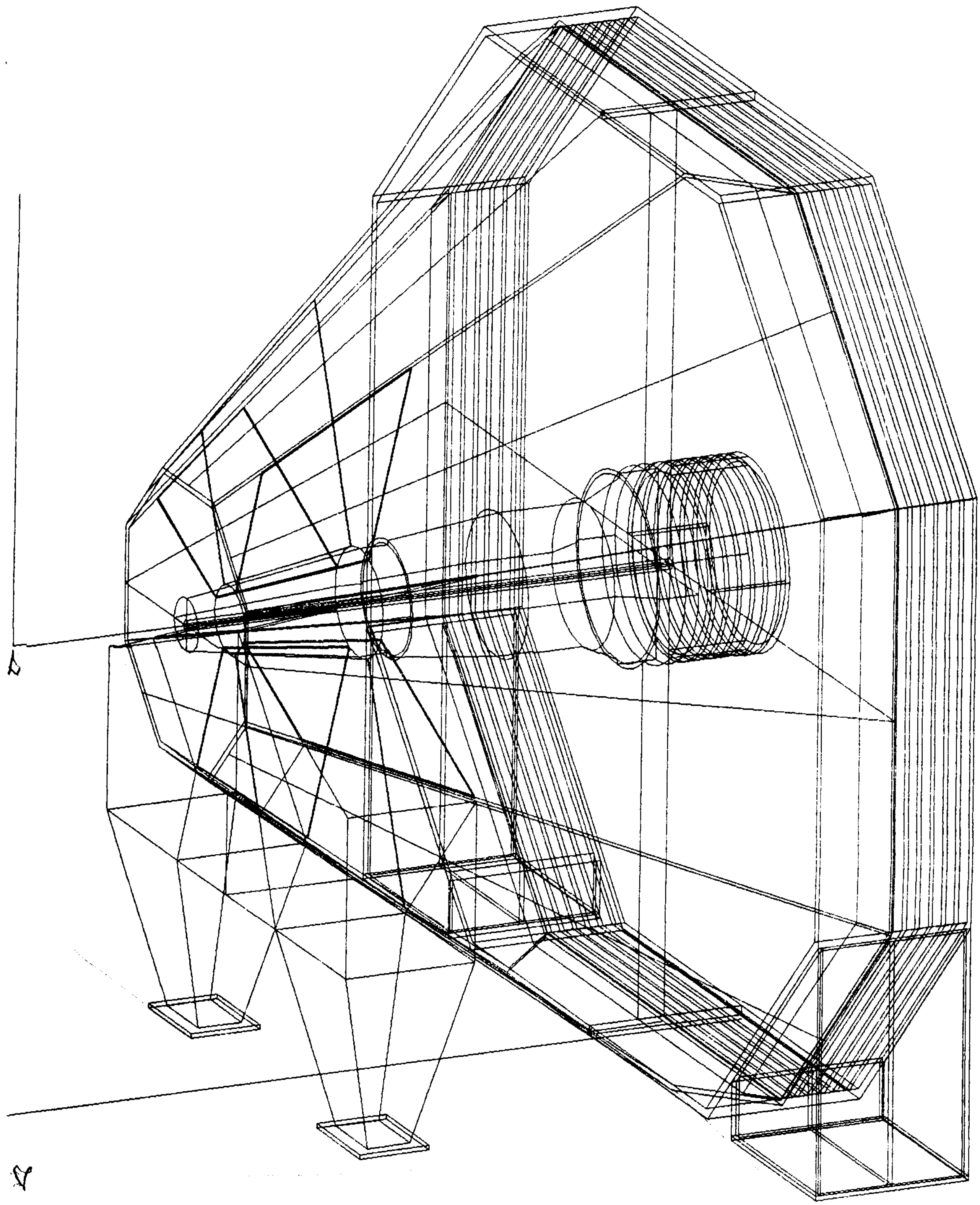
COILS:

- 4 months required to place purchase order
- fabrication lead time for copper conductor is 4 months
- fab time for central coils will take 8 months
- fab time for muon coil will take 6 months

STEEL:

- 6 months required to place purchase order for central magnet pole pieces (2) and muon iron core
- fab time for pole pieces + iron core is 1 year
  CRITICAL PATH ITEM !

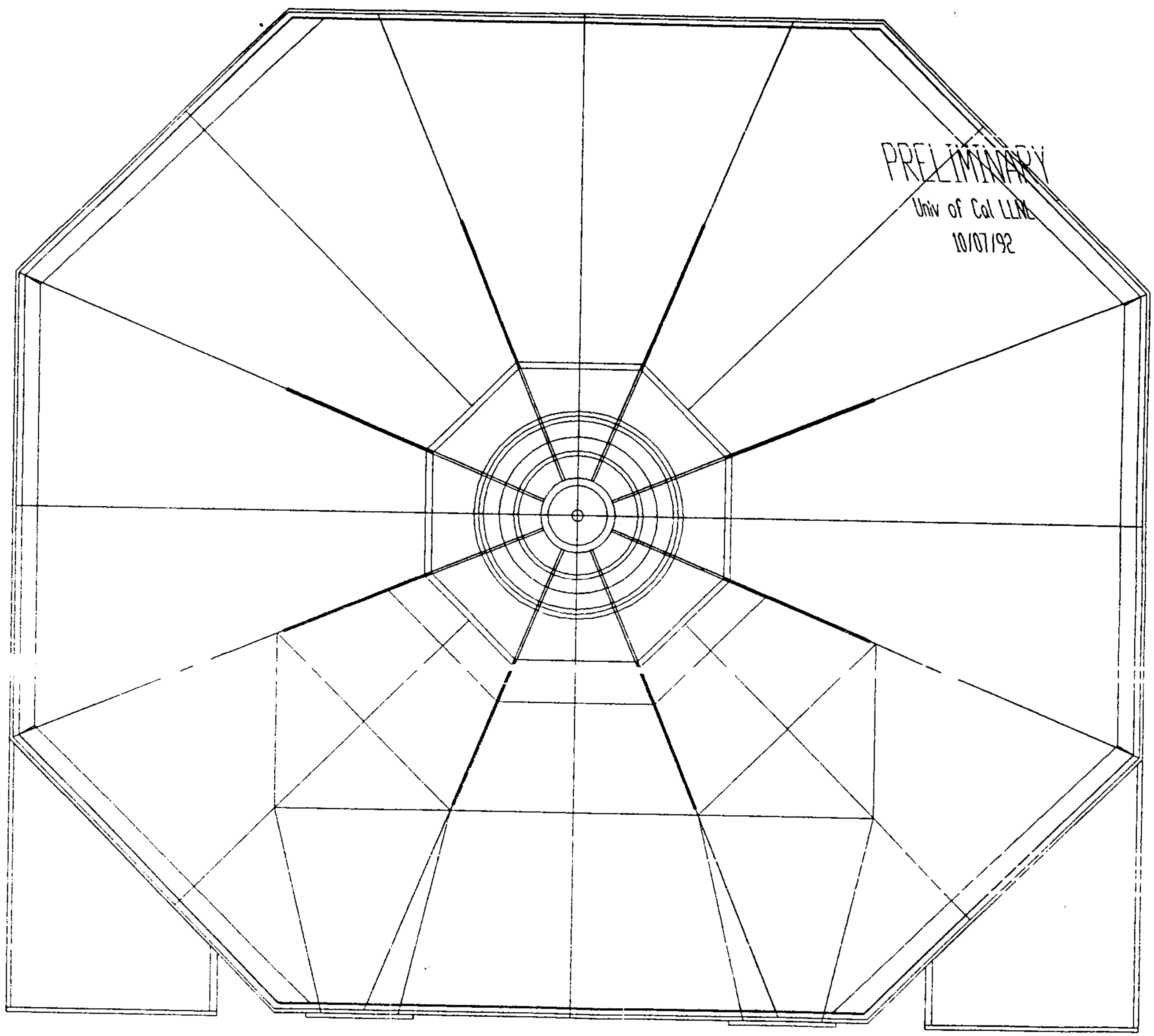


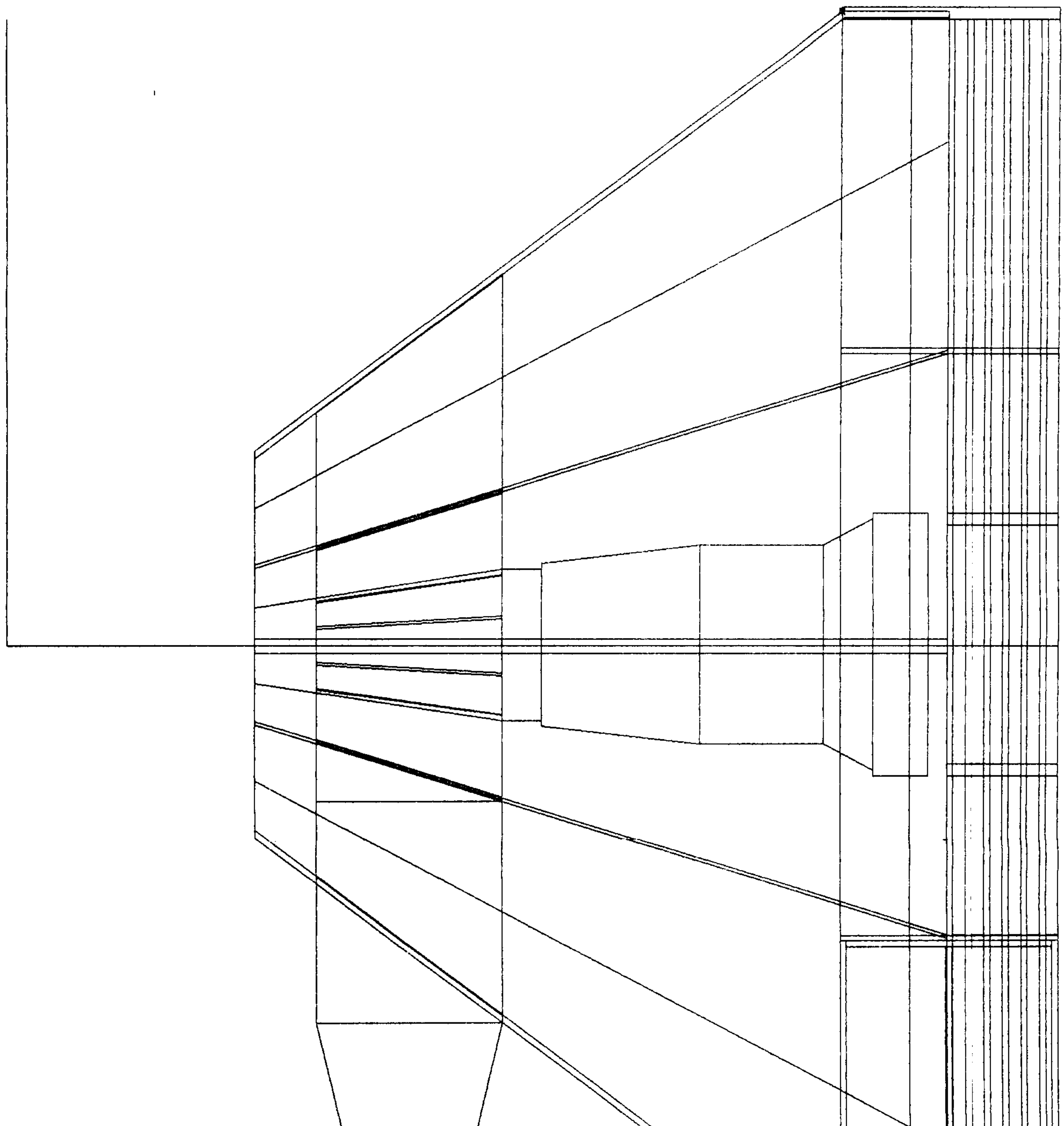


PREL

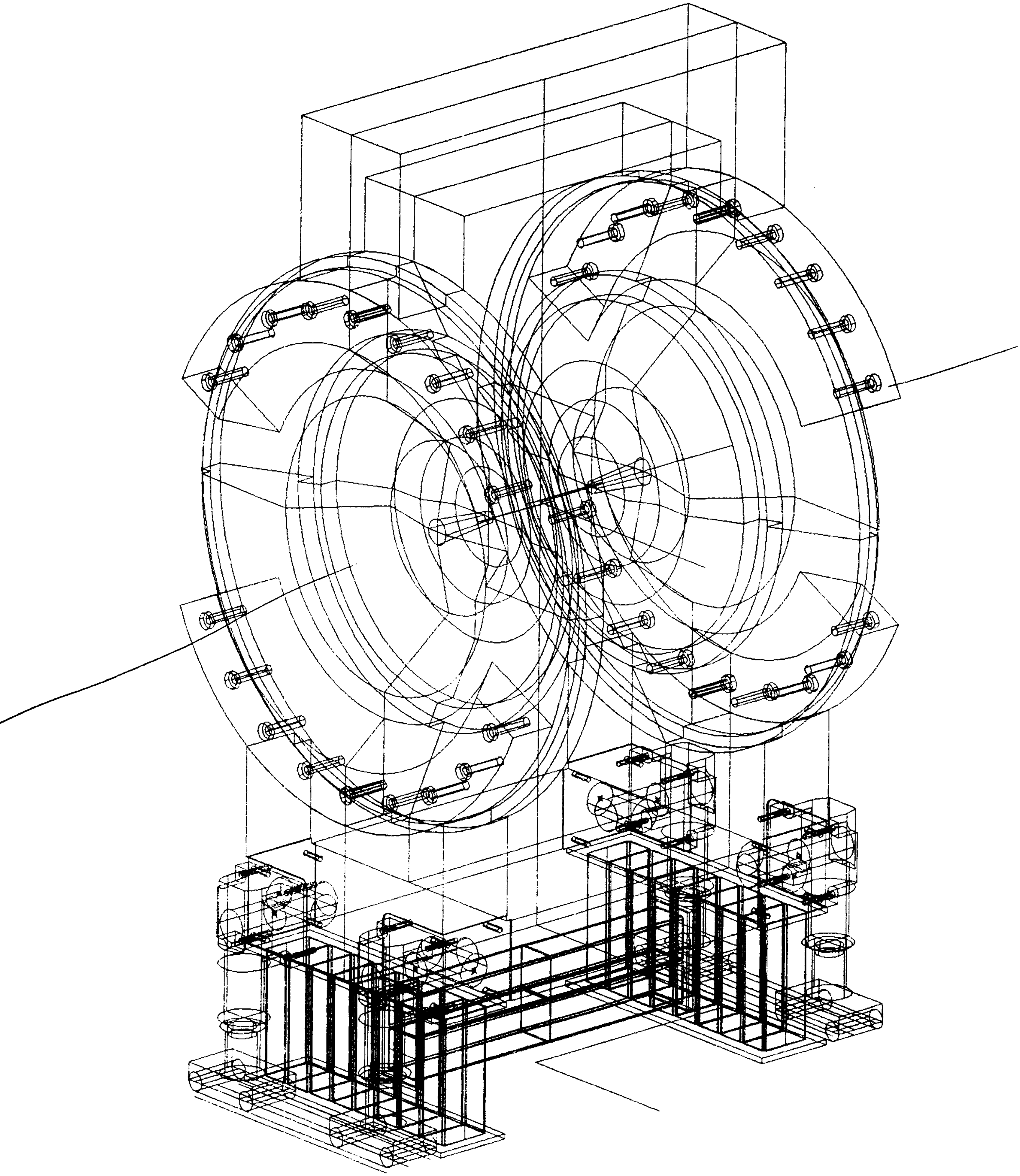
Univ o

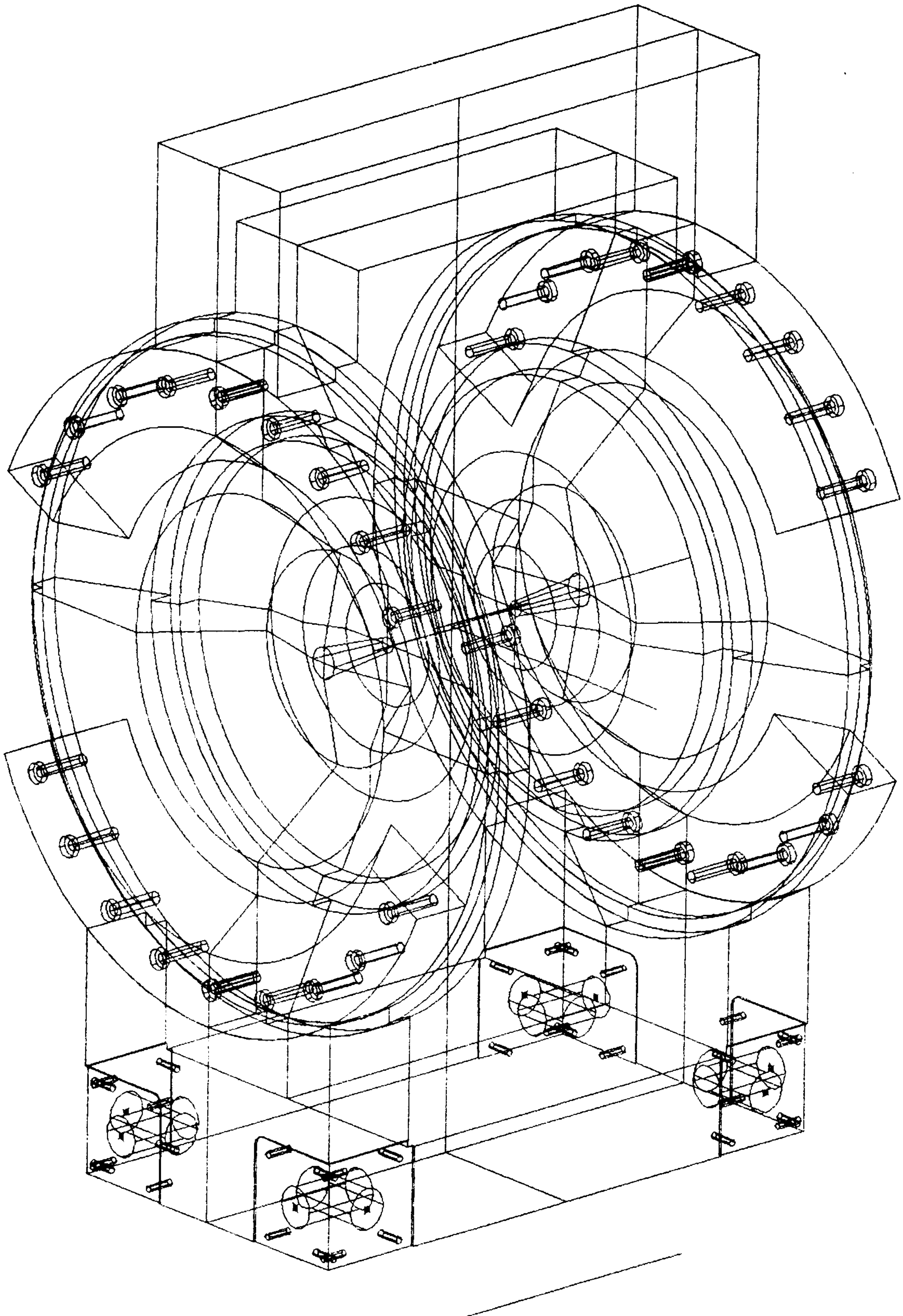
10,

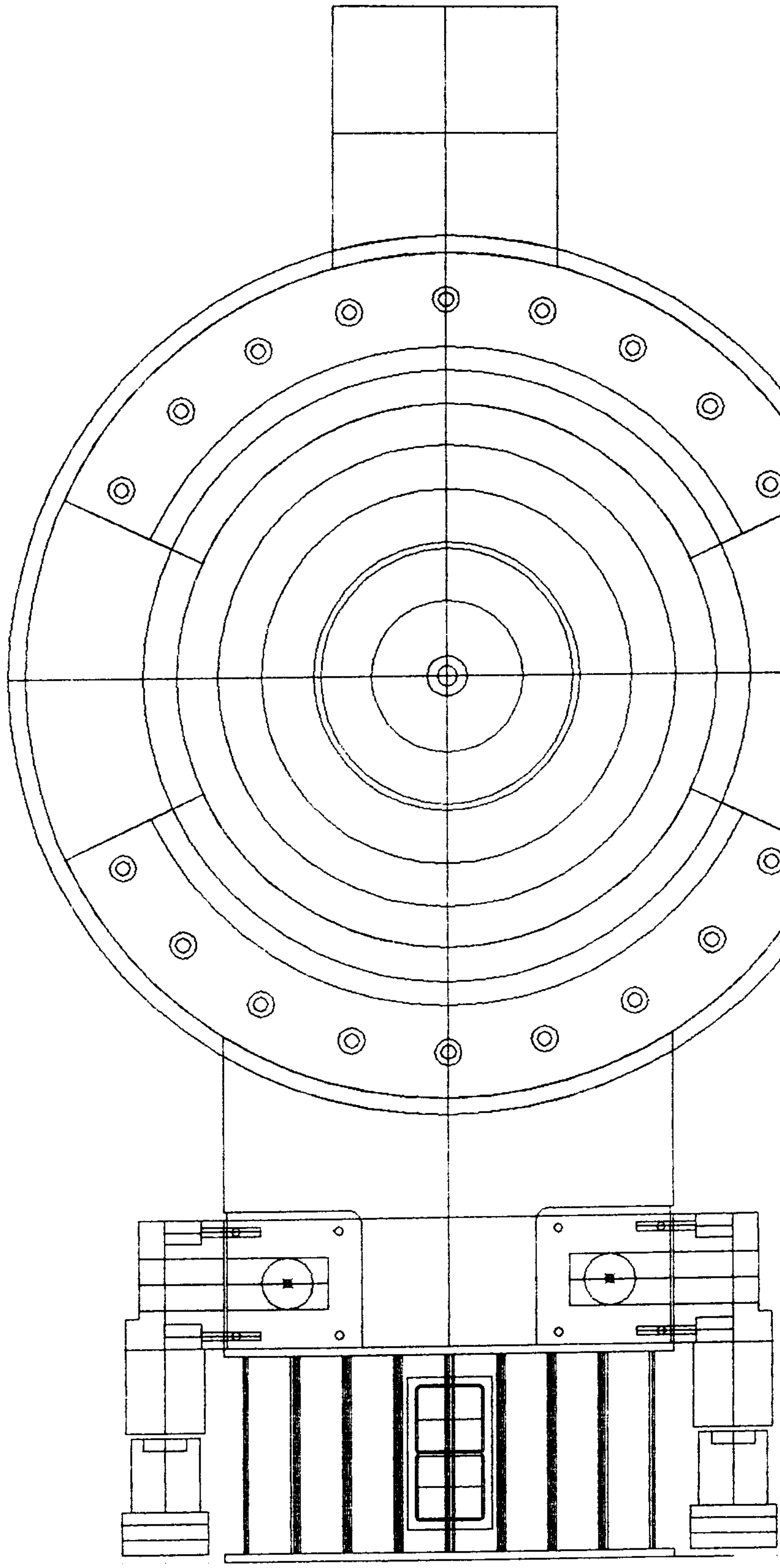

PRELIMINARY
Univ of Cal LLNL
10/07/92



F



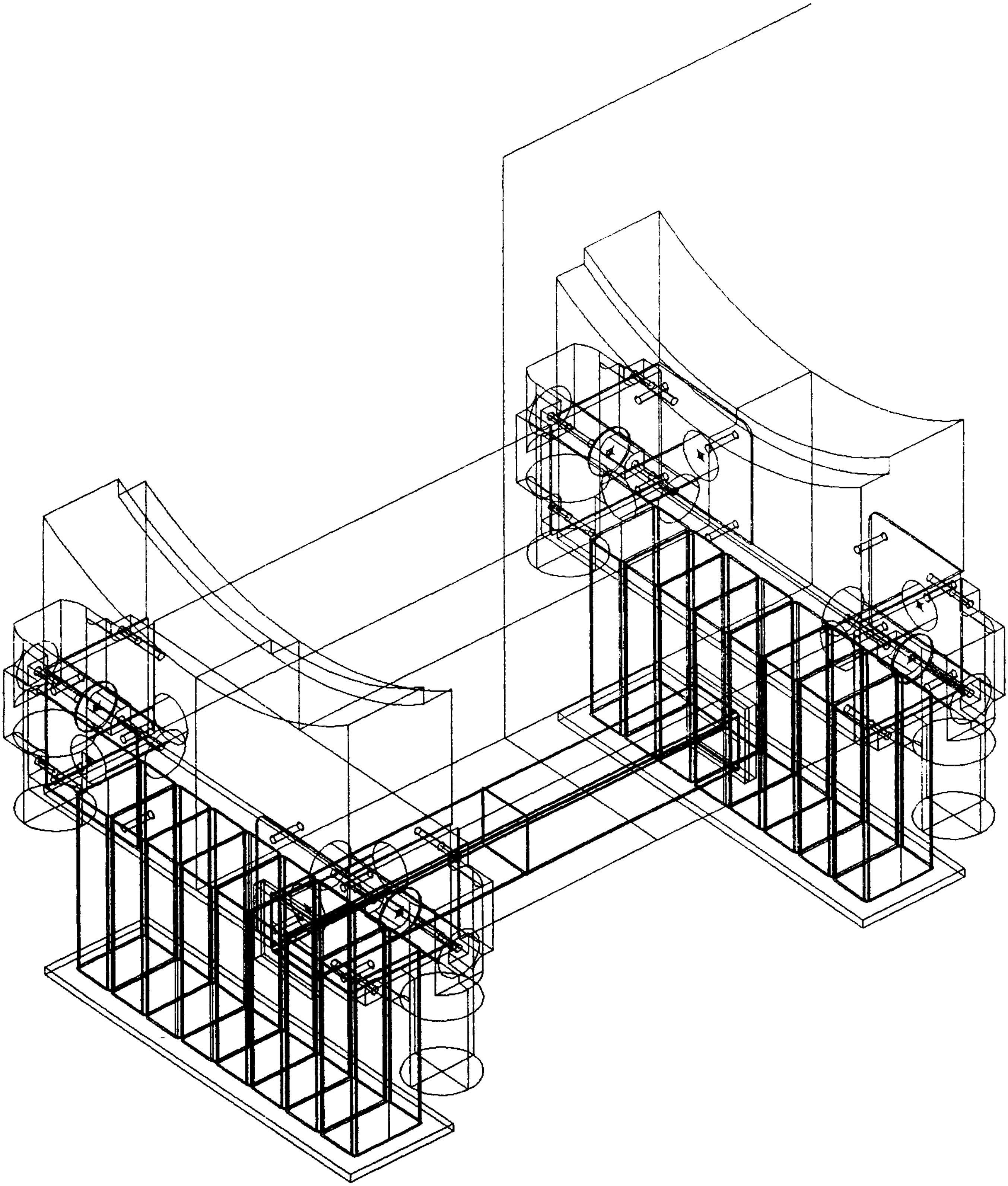


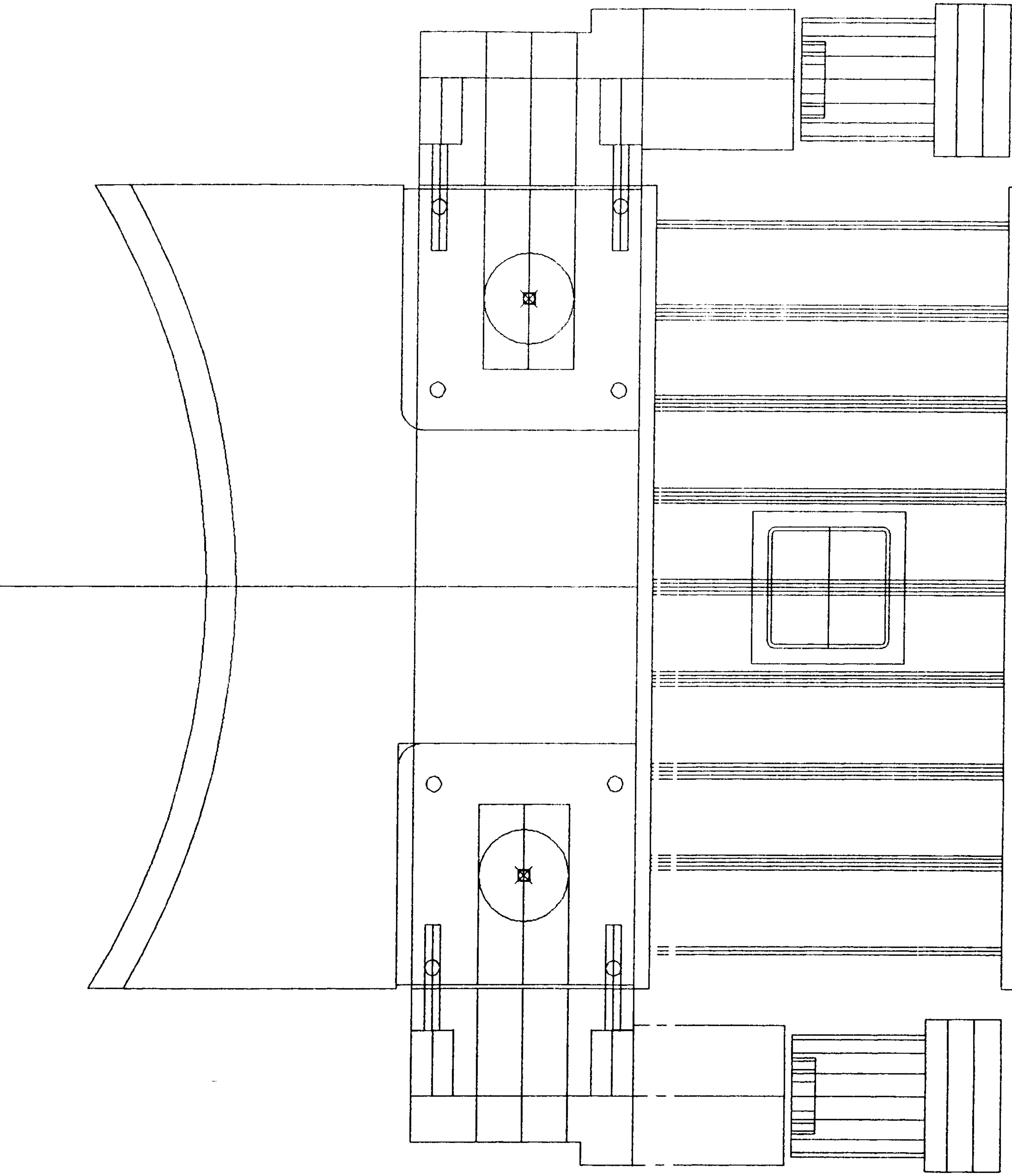


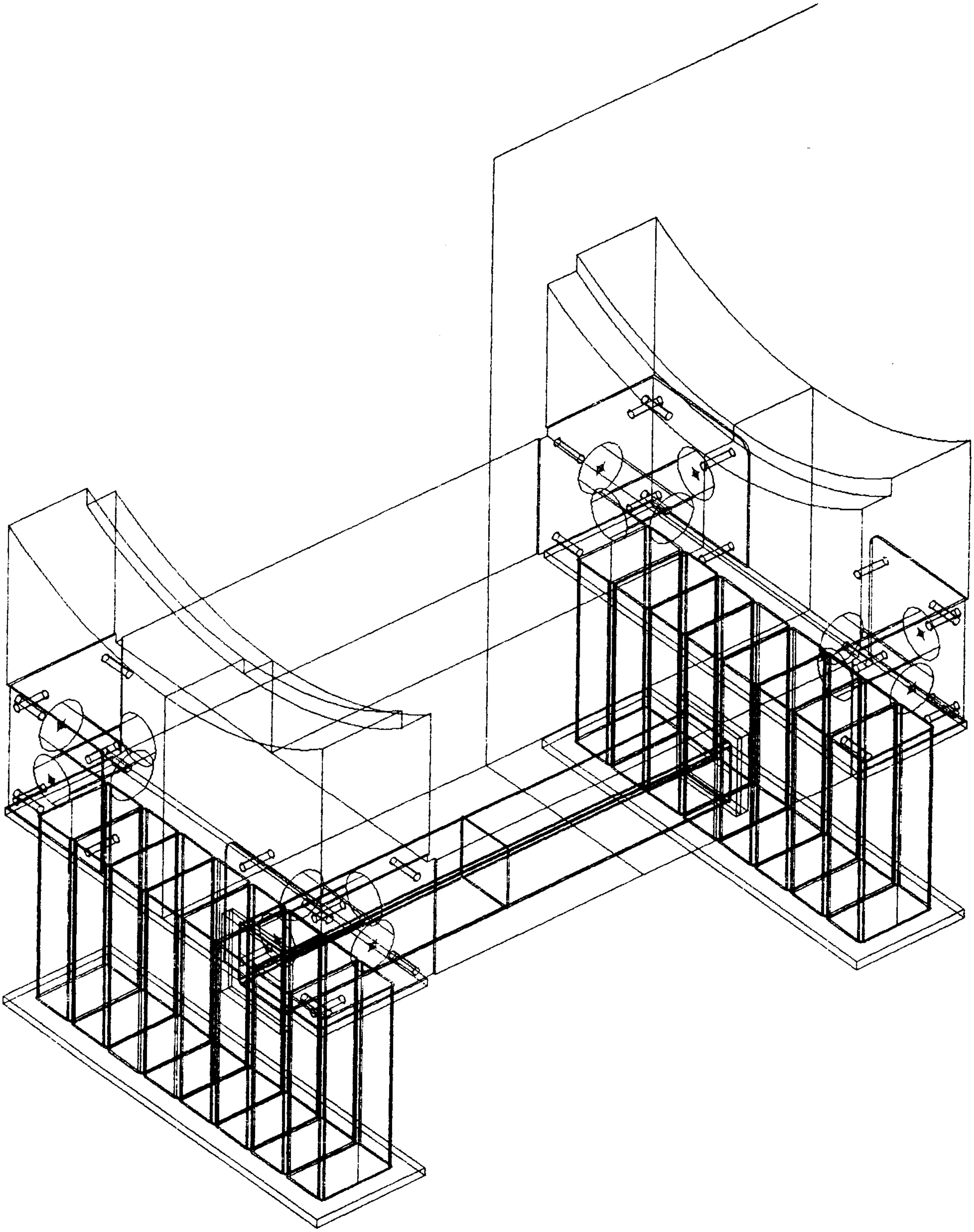
PRELIM

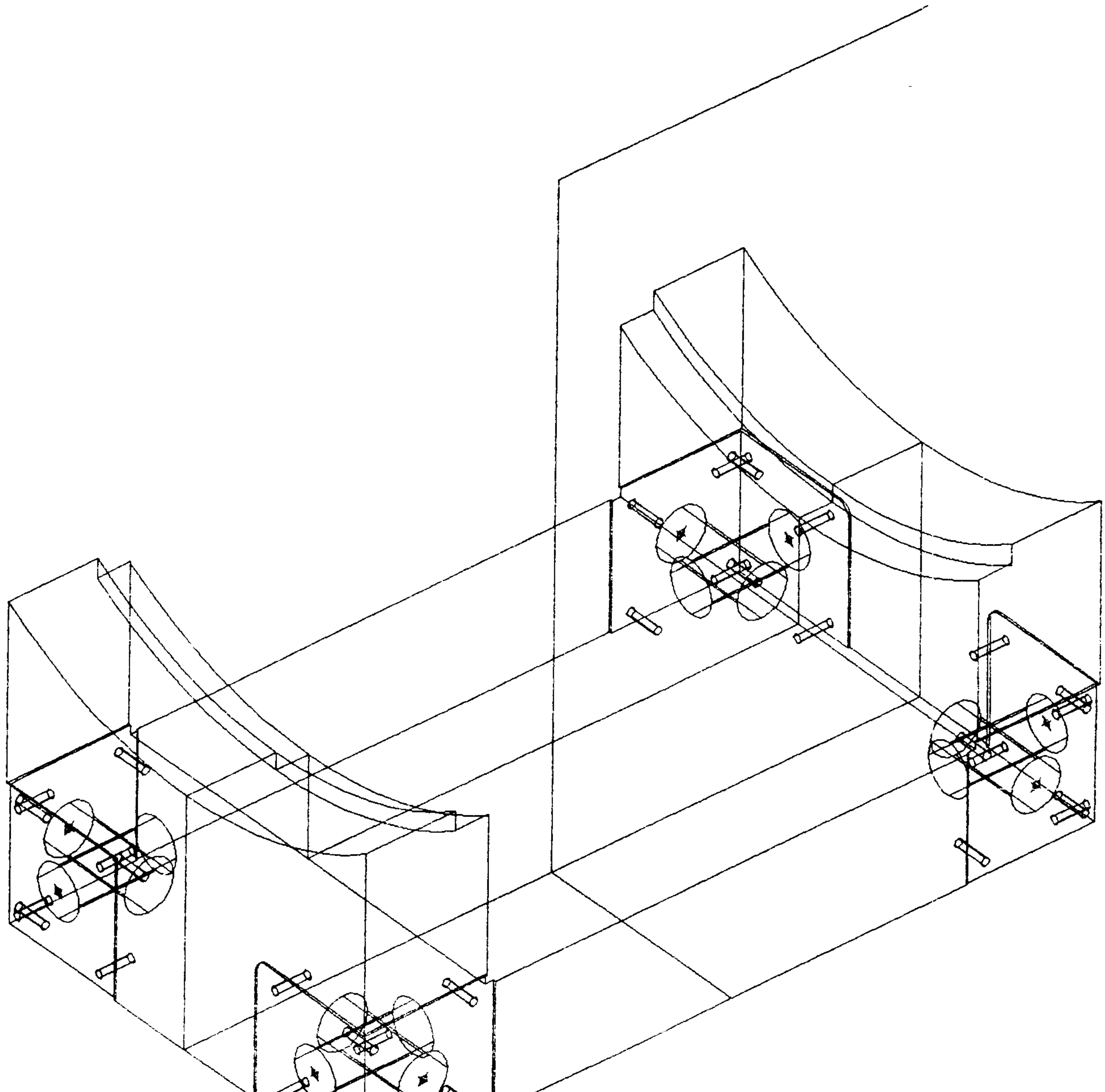
Univ of C

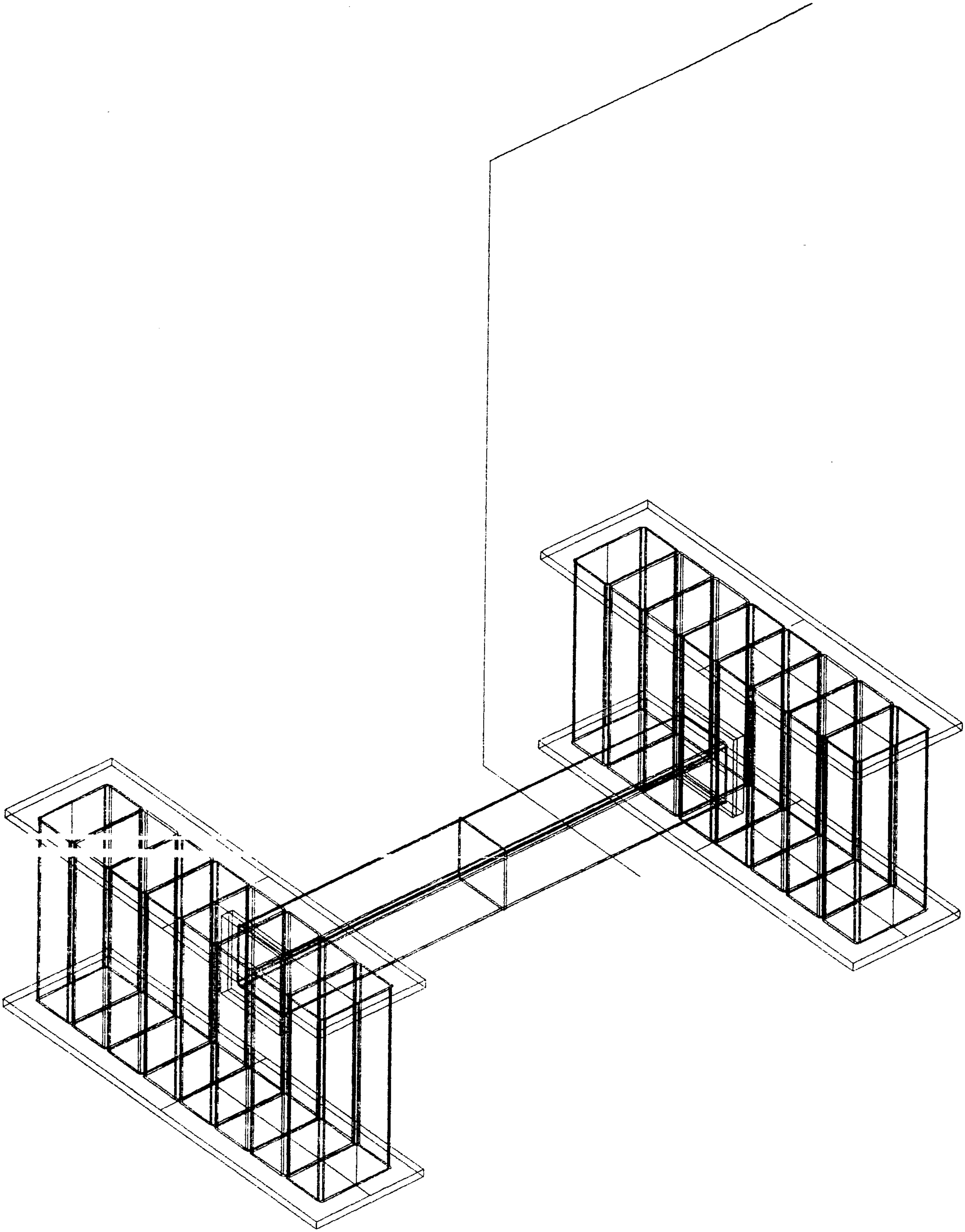
10/06/

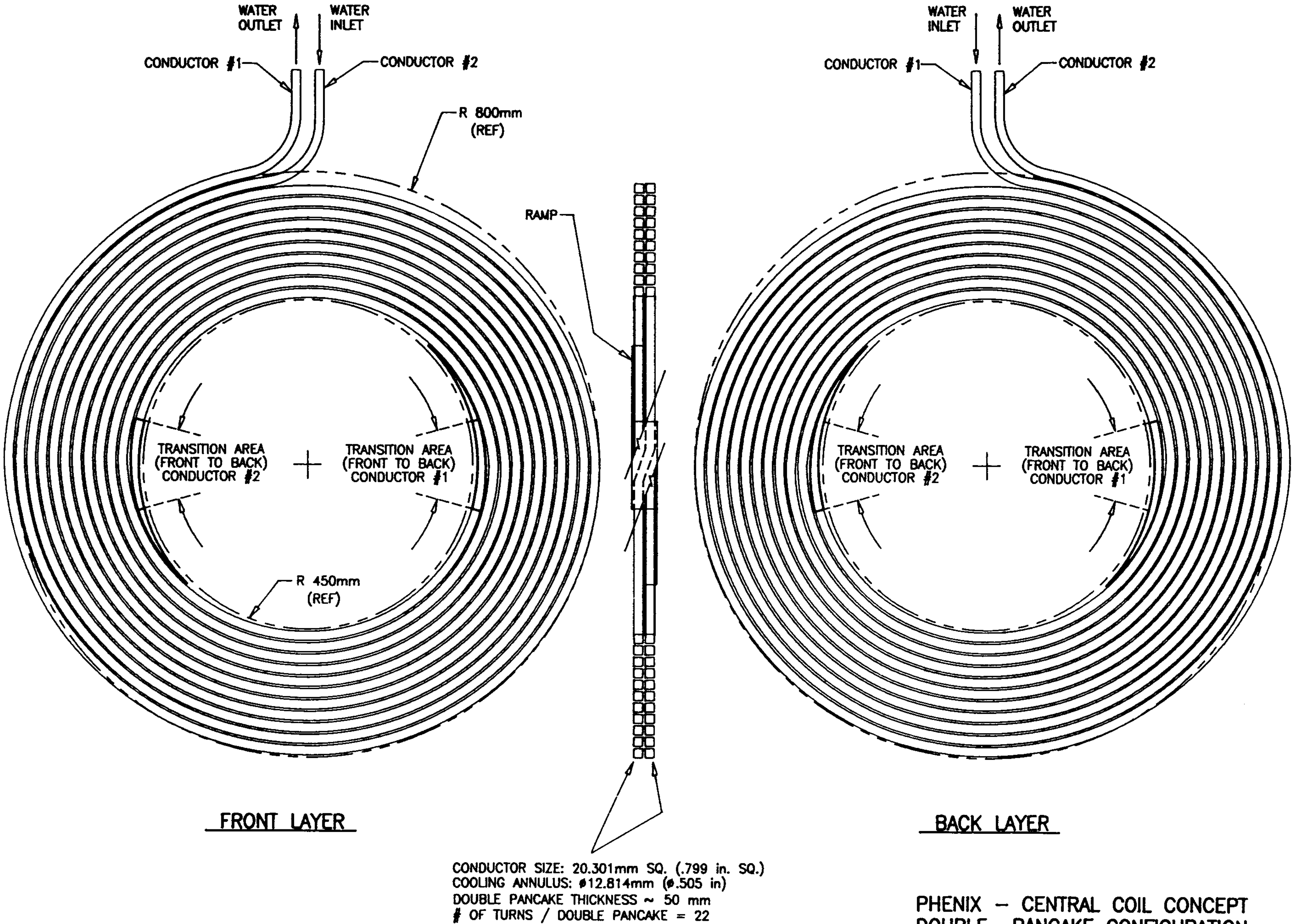




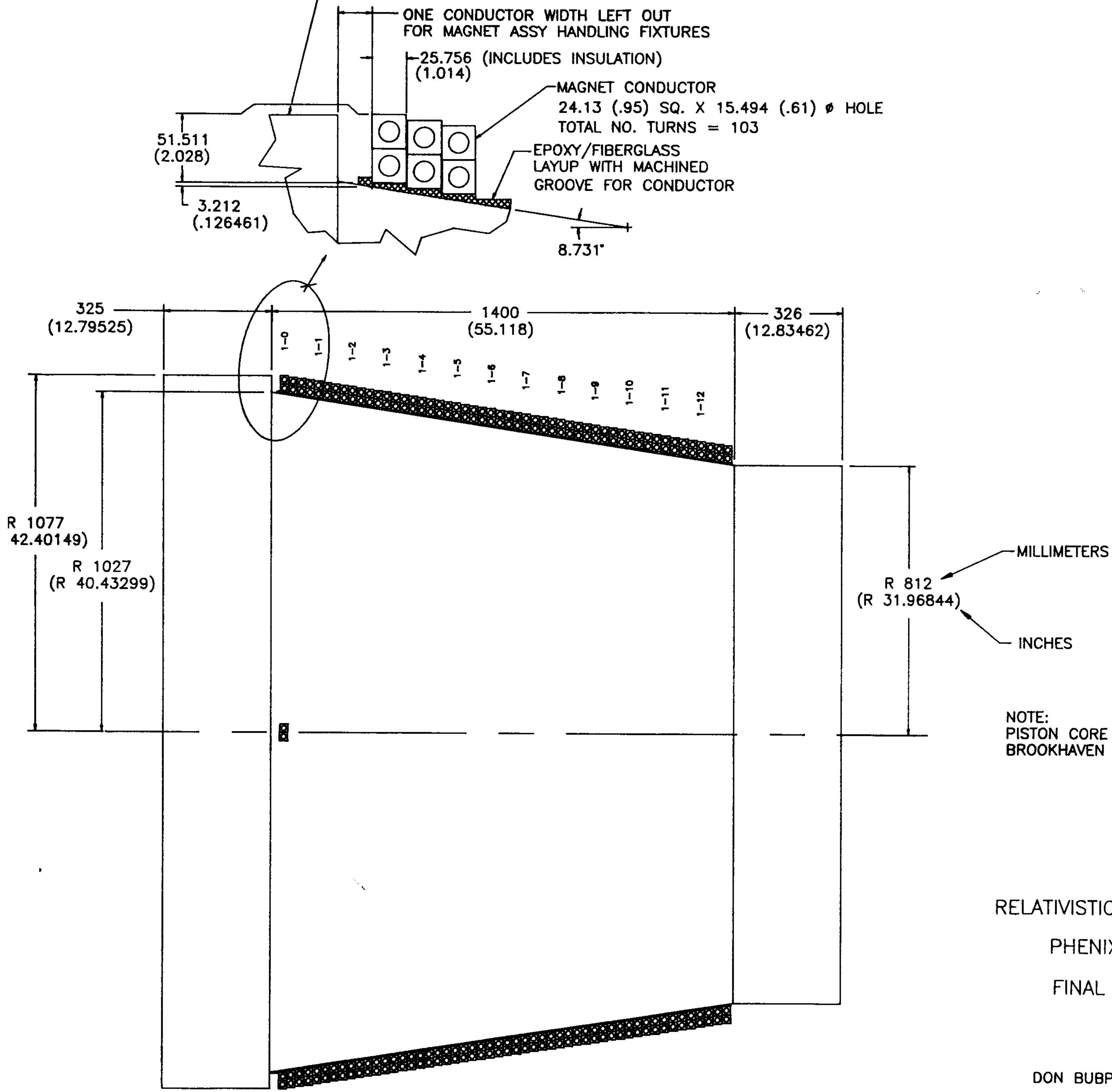








PHENIX – CENTRAL COIL CONCEPT
DOUBLE PANCAKE CONFIGURATION
(BIFILAR WOUND) 10/9/92



NOTE:
PISTON CORE STEEL DIMENSIONS PER
BROOKHAVEN FILE "PHENIX/MAGPROFI3, 08/25/92"

PHENIX

RELATIVISTIC HEAVY ION COLLIDER (RHIC)

PHENIX–MUON PISTON MAGNET

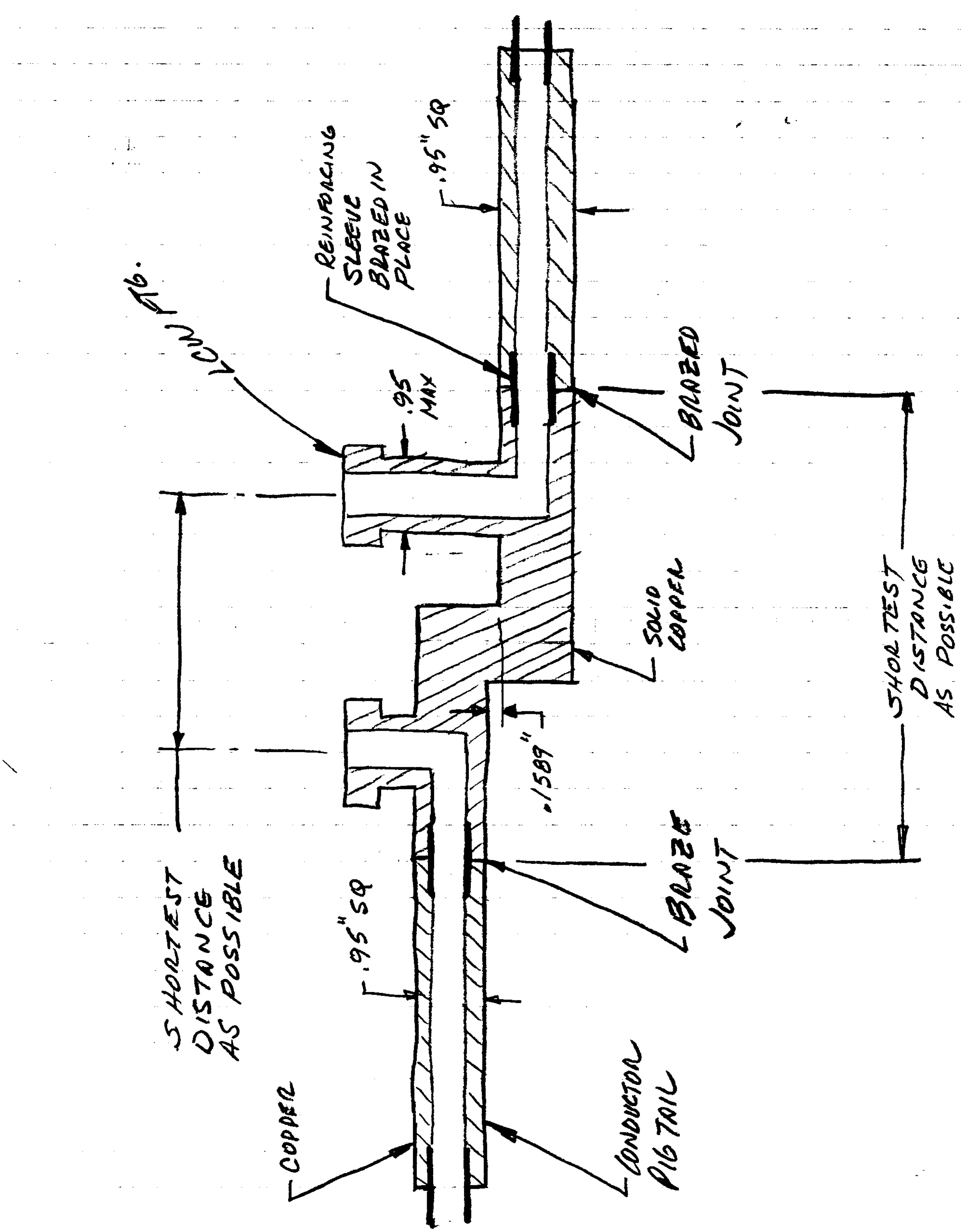
FINAL MAGNET DESIGN LAYOUT

DON BUBP 10/1/92 1/16"=1"

PISTON COIL / FINAL DESIGN

10-1-92

TRANSITION FROM 1ST LAYER TO 2ND LAYER



PISTON COIL / FINAL DESIGN

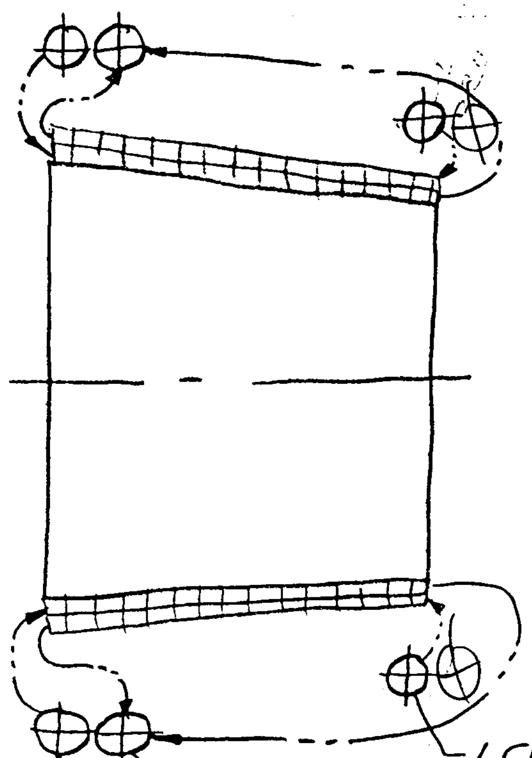
10-1-92
[illegible]

LCW COOLING MANIFOLDS
SCHEMATIC

MONITORS

- TEMP.
- ?? → LCW FLOW METERS ??

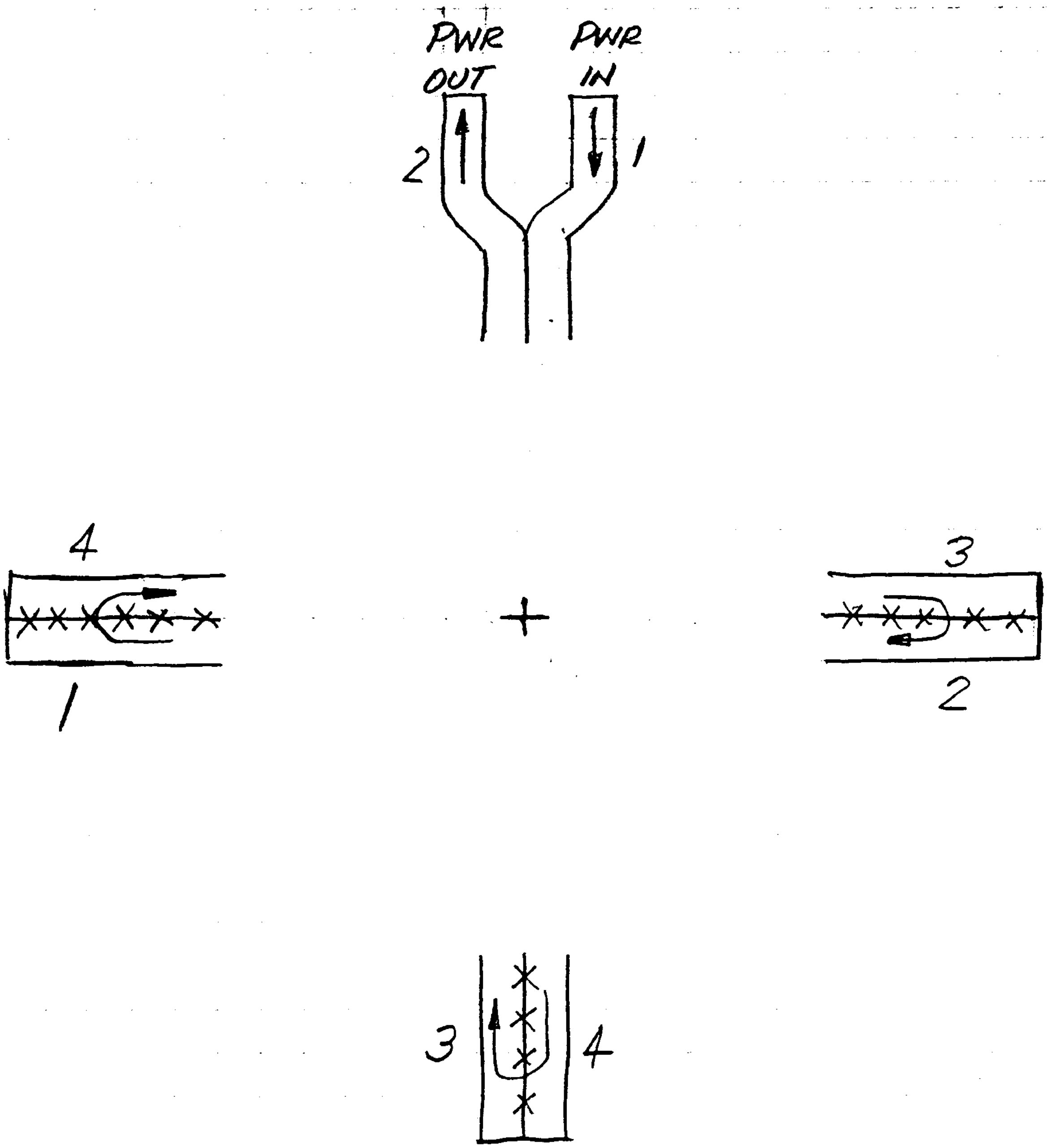
(OR BOTH FOR REDUNDANCY)

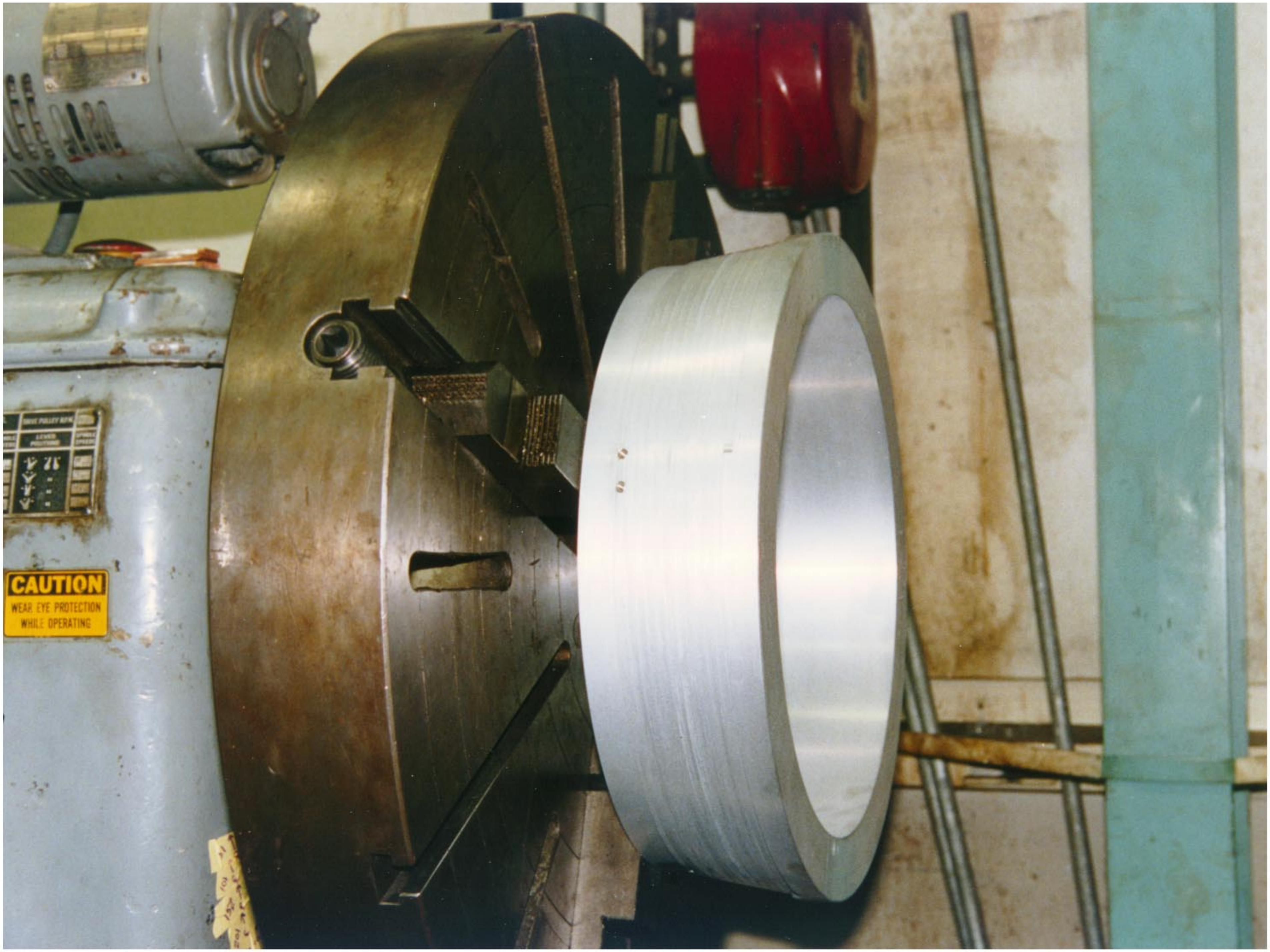


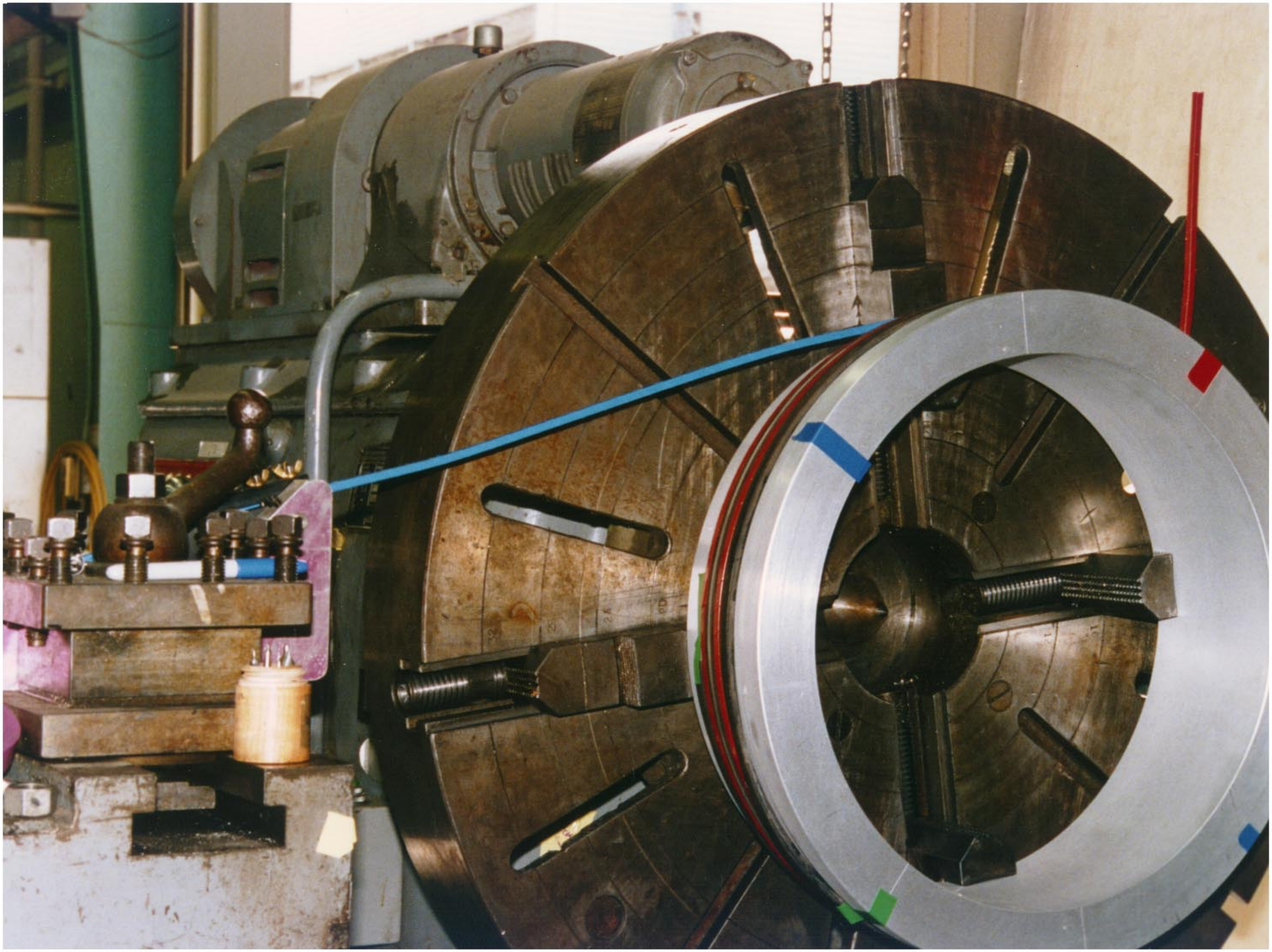
PISTON COIL / FINAL DESIGN 10-1-92

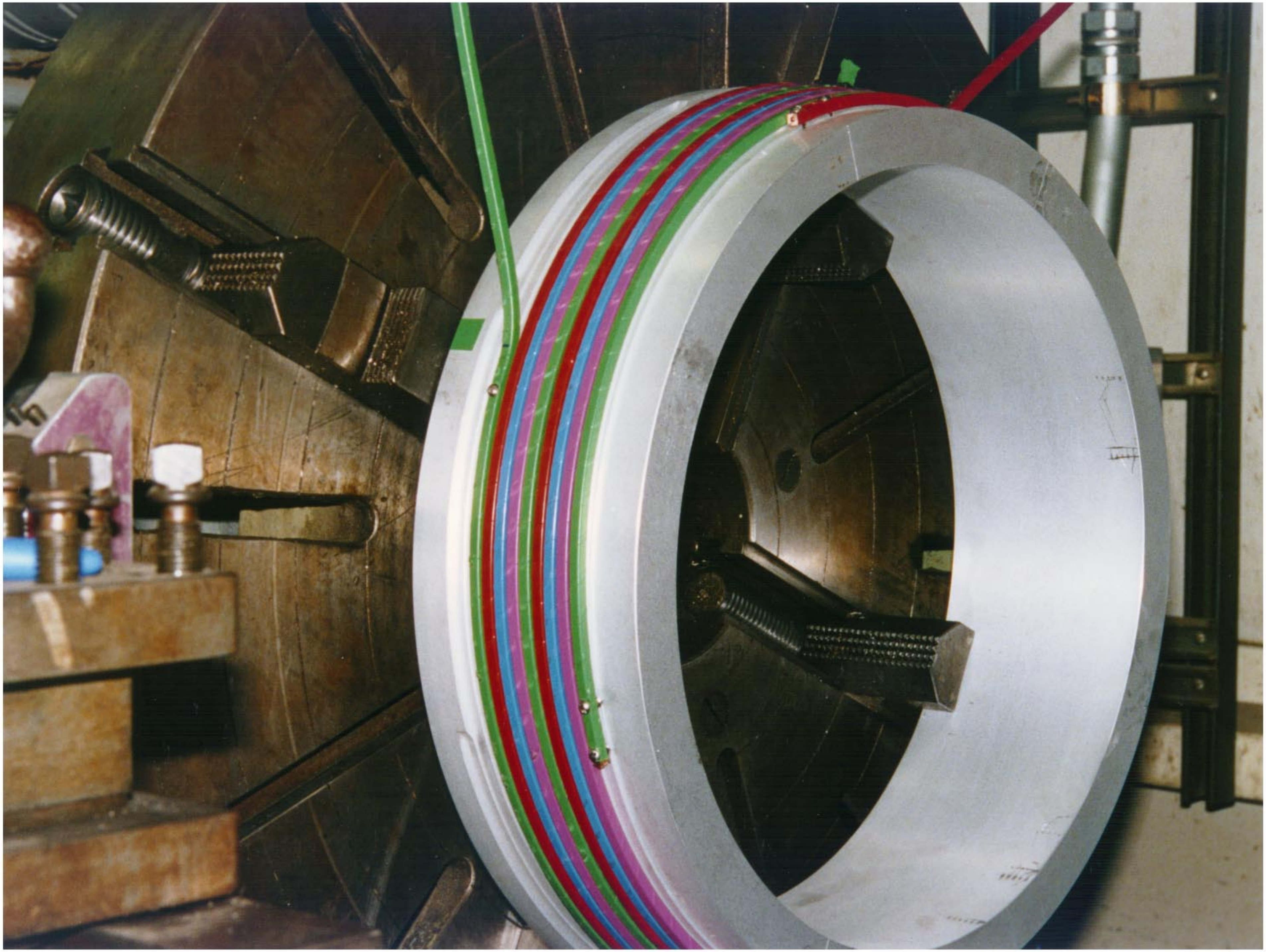
RLB

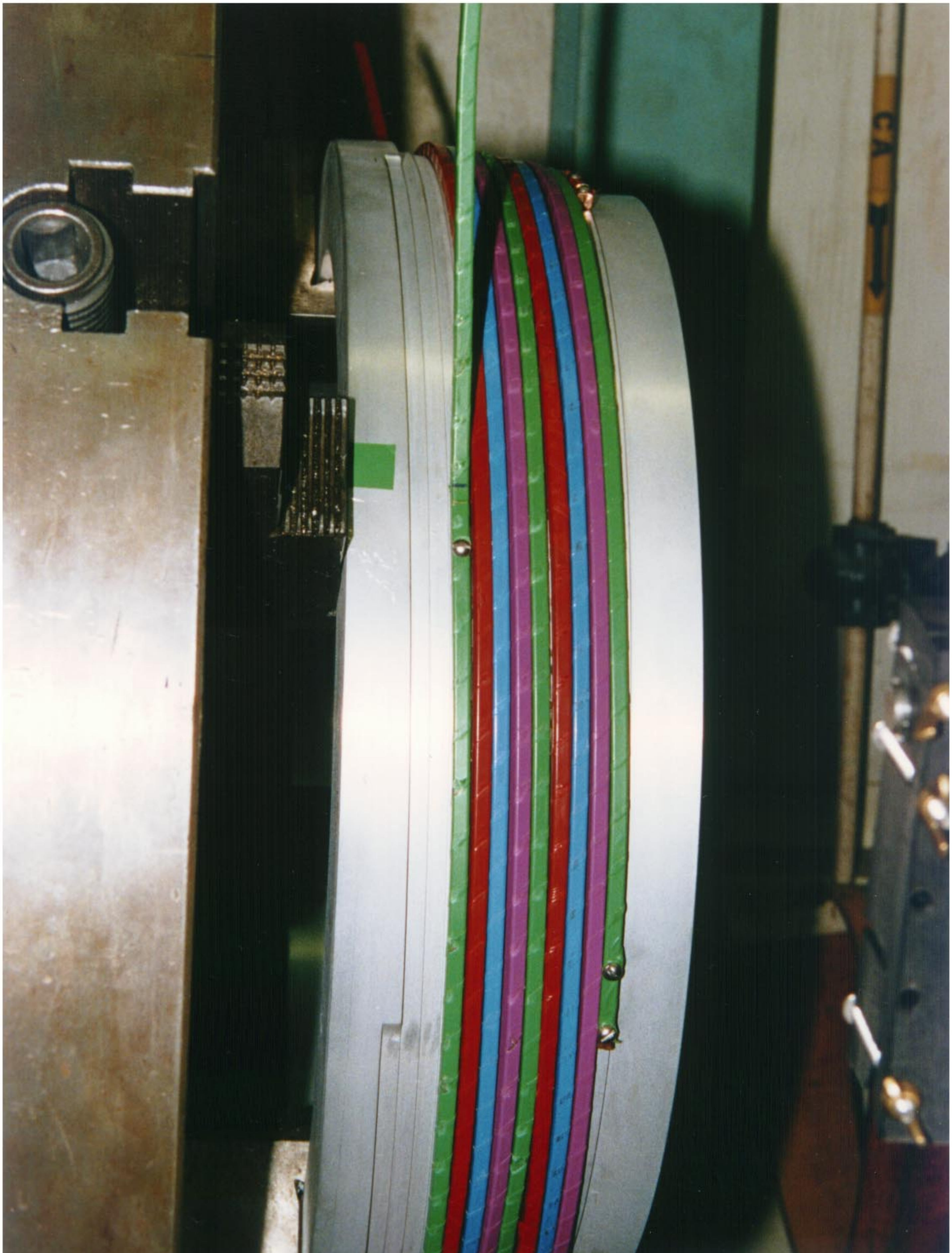
POWER SCHEMATIC

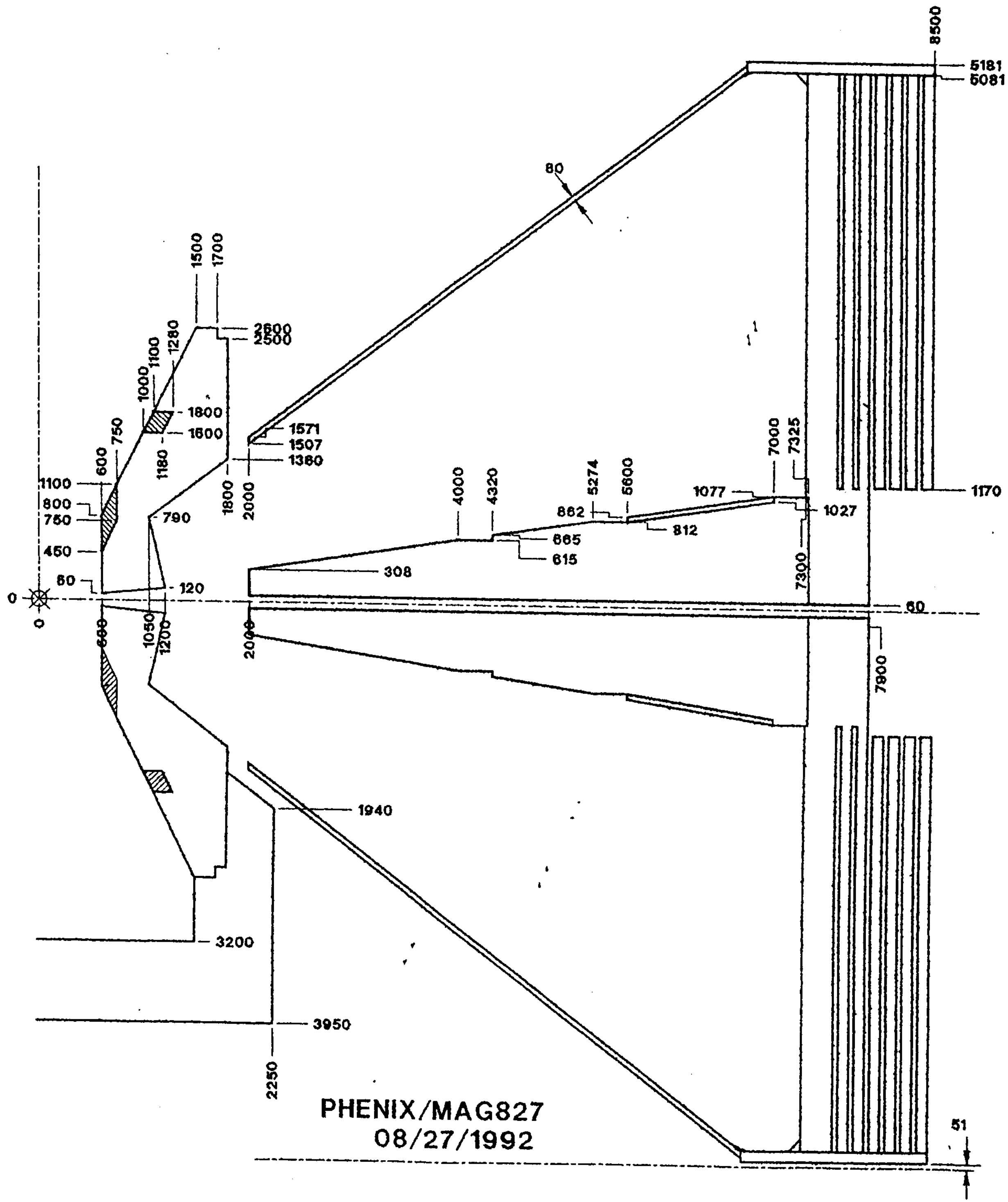



CAUTION
WEAR EYE PROTECTION
WHILE OPERATING









From Peter Kroon?

Dimensions
Bob - Latest version
(From mtg @ BNL 8/?)

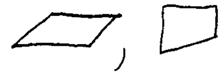
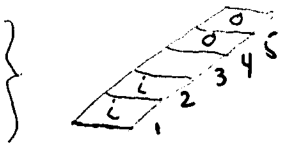
Ross

(not including
main coil dim.
modification)

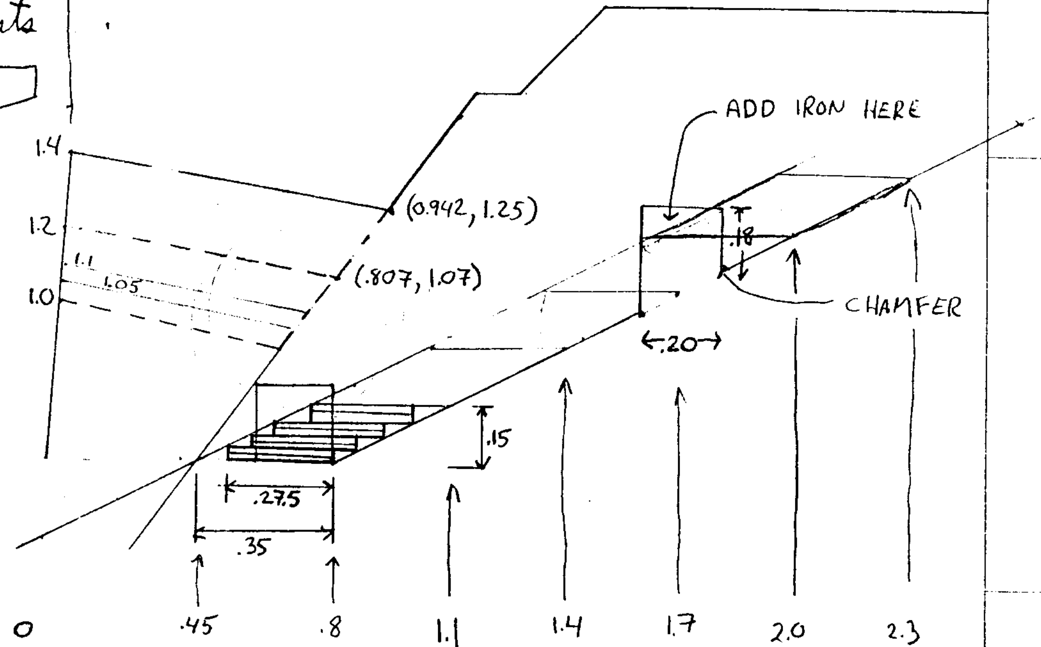
RDS

MAIN MAGNET COIL MAGNETICS

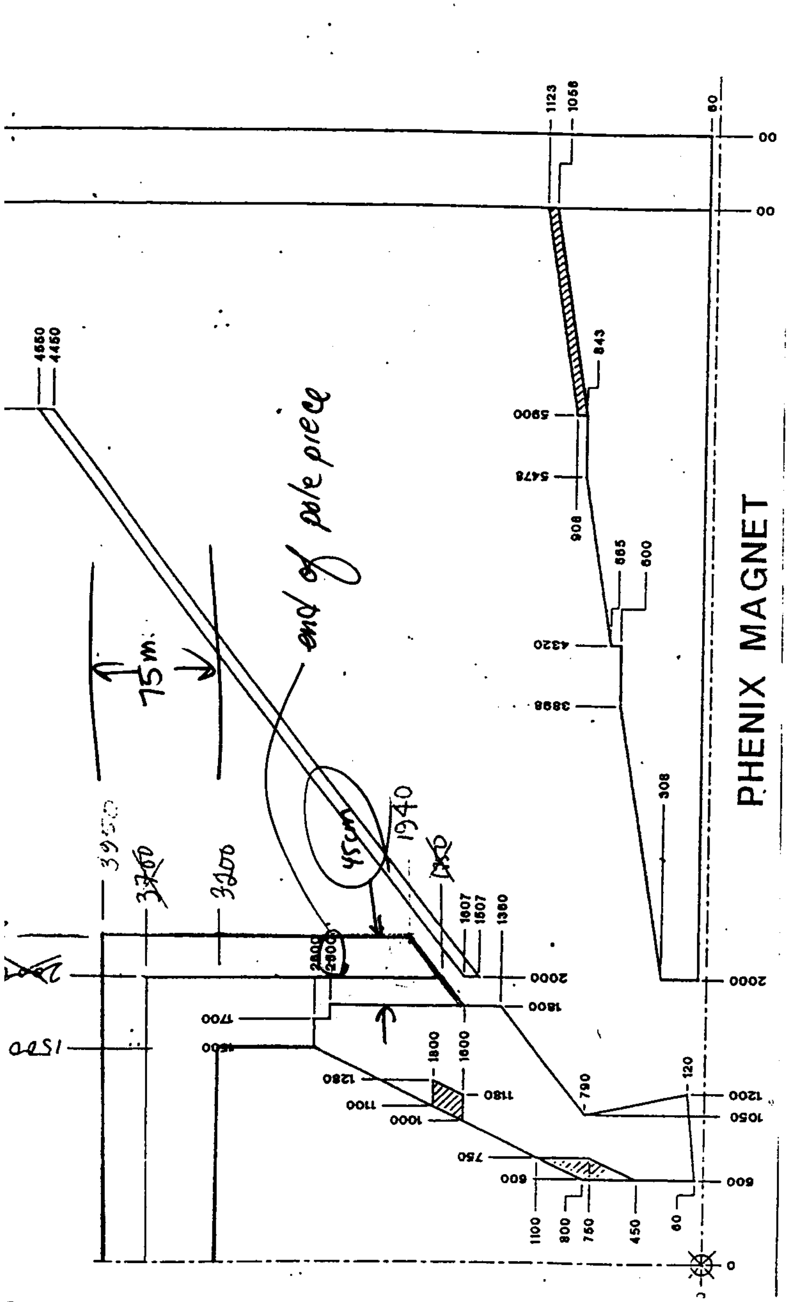
7/15/92
8/25/92

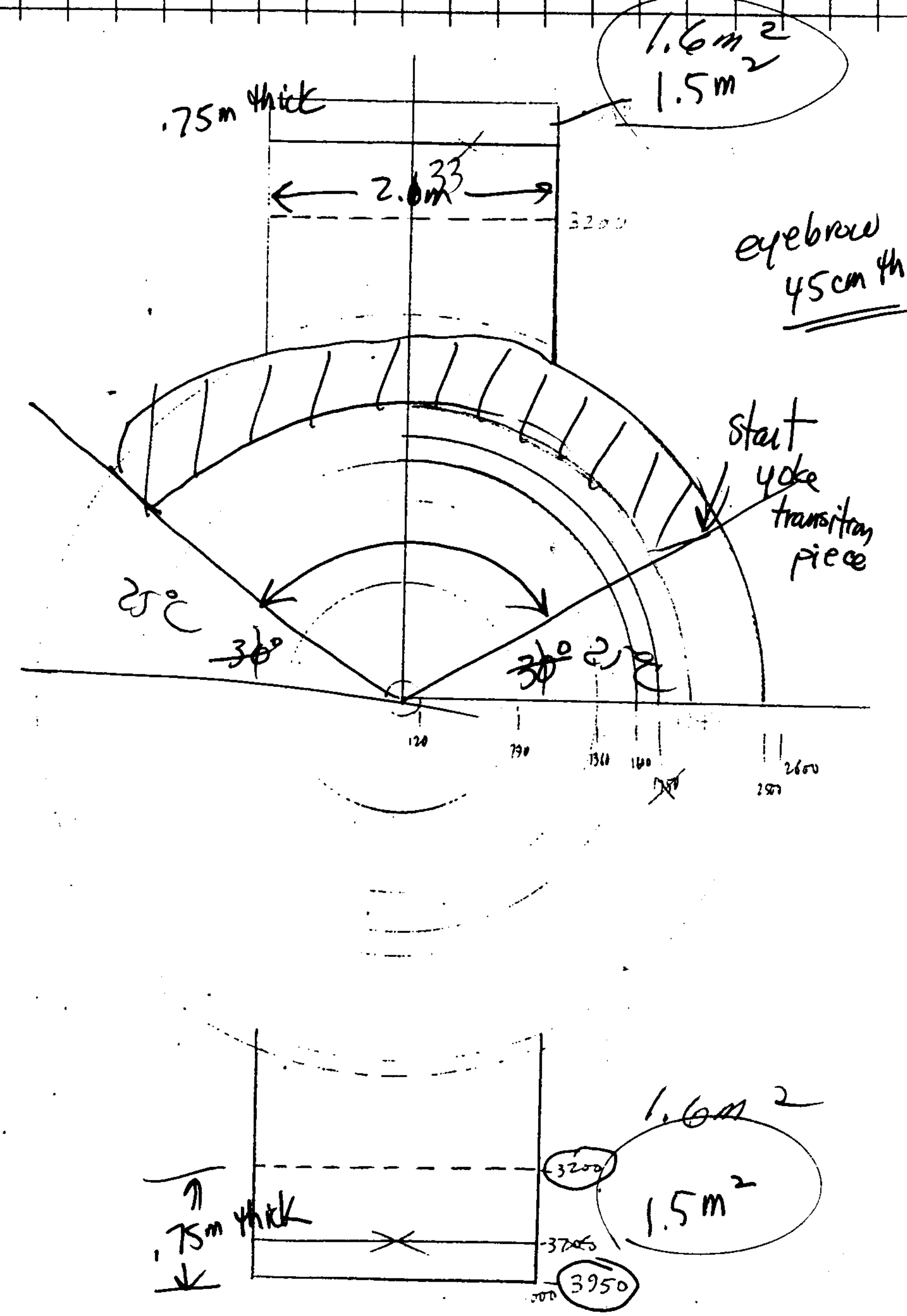
Run #	pole thick (m)	$\int_0^{2.6} B_z dr$ (KG-m)	B_{MAX} IRON @ INNER COIL (KG)	B_{MAX} IRON @ OUTER COIL (KG)	coils
42	1.2	10.5	15	14	line currents
43	1.2	10.1	17	21	
44	1.1	10.0	21.5	21	 "
45	1.05	9.9	22.5	20.5	 "
61 PP	1.2	10.44	22.3		
61 PM	1.2	2.23			

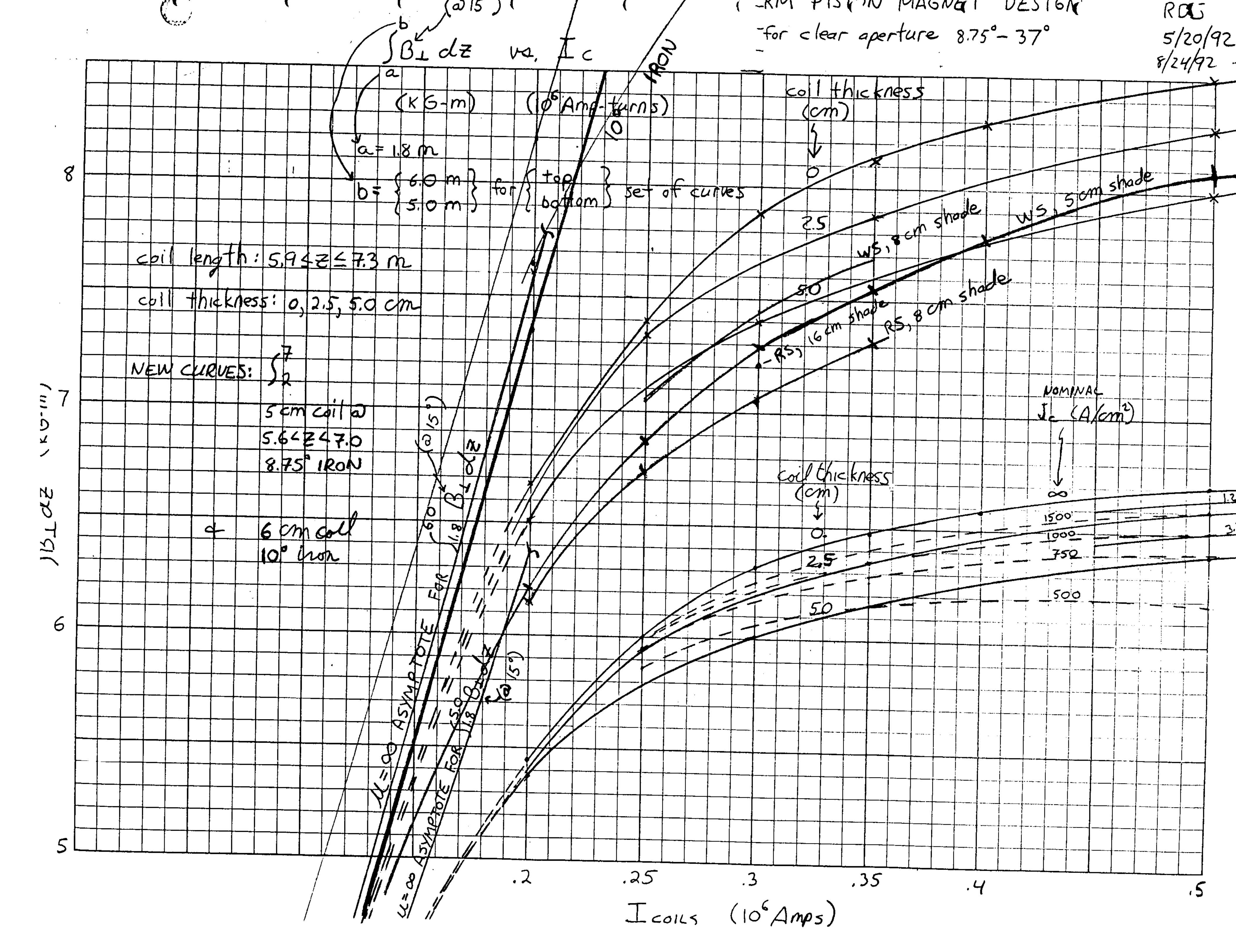
seq ① & ② inner coil
③ steel
④ & ⑤ outer coil



RE-RUN w/ ACTUAL B-H curve


PHENIX MAGNET
end of pole piece
.75m
45cm
1940
3950
3700
3200


.75m thick
1.6m²
1.5m²
2.0m 33
eyebrow
45cm thick
start
yoke
transition
piece
25°
30°
1.6m²
1.5m²
3200
3950
.75m thick



RM PISTON MAGNET DESIGN
for clear aperture 8.75° – 37°
RCJ
5/20/92
8/24/92
∫ₐᵇ B⊥ dz vs. Ic
(KG-m) (10⁶ Amp-turns)
a = 1.8 m
b = {6.0 m / 5.0 m} for {top / bottom} set of curves
coil length: 5.9 ≤ z ≤ 7.3 m
coil thickness: 0, 2.5, 5.0 cm
NEW CURVES: ∫₂⁷
5 cm coil @
5.6 < z < 7.0
8.75° IRON
& 6 cm coil
10° iron
0 IRON
coil thickness (cm)
0
2.5
5.0
WS, 8 cm shade
WS, 5 cm shade
RS, 16 cm shade
RS, 8 cm shade
μ = ∞ ASYMPTOTE FOR ∫₁.₈⁶·⁰ B⊥ dz (@15°)
μ = ∞ ASYMPTOTE FOR ∫₁.₈⁵·⁰ B⊥ dz (@15°)
NOMINAL Jc (A/cm²)
∞
1500
1000
750
500
coil thickness (cm)
0
2.5
5.0
∫B⊥ dz (KG-m)
5
6
7
8
.2
.25
.3
.35
.4
.5
I coils (10⁶ Amps)

Summary of Phenix Magnet Calculations

Run 4

```
phenix magnet heat transfer - 4
$
$ coils at 60 C, environment at 30 C
$ detector edges radiatively coupled
$ heat loss to environment by radiation only
$ emissivities:  steel=0.30, aluminum=0.10, coils=0.20
```

Run5

```
phenix magnet heat transfer - 5
$
$ coils at 60 C, environment at 30 C
$ detector edges in perfect thermal contact
$ heat loss to environment by radiation only
$ emissivities: steel=0.30, aluminum=0.10, coils=0.20
```

Run 6

```
phenix magnet heat transfer - 6
$
$ coils at 60 C, environment at 30 C
$ detector edges radiatively coupled
$ heat loss to environment by radiation and convection
$ emissivities:  steel=0.30, aluminum=0.10, coils=0.20
```

Run 7

```
phenix magnet heat transfer - 7
$
$ coils at 60 C, environment at 30 C
$ detector edges in perfect thermal contact
$ heat loss to environment by radiation and convection
$ emissivities: steel=0.30, aluminum=0.10, coils=0.20
```

Run 8

```
phenix magnet heat transfer - 8
$
$ coils at 60 C, environment at 30 C
$ detector edges radiatively coupled
$ heat loss to environment by radiation only
$ emissivities:  steel=0.50, aluminum=0.20, coils=0.50
```

Run 9

```
phenix magnet heat transfer - 9
$
$ coils at 60 C, environment at 30 C
$ detector edges in perfect thermal contact
$ heat loss to environment by radiation only
$ emissivities: steel=0.50, aluminum=0.20, coils=0.50
```

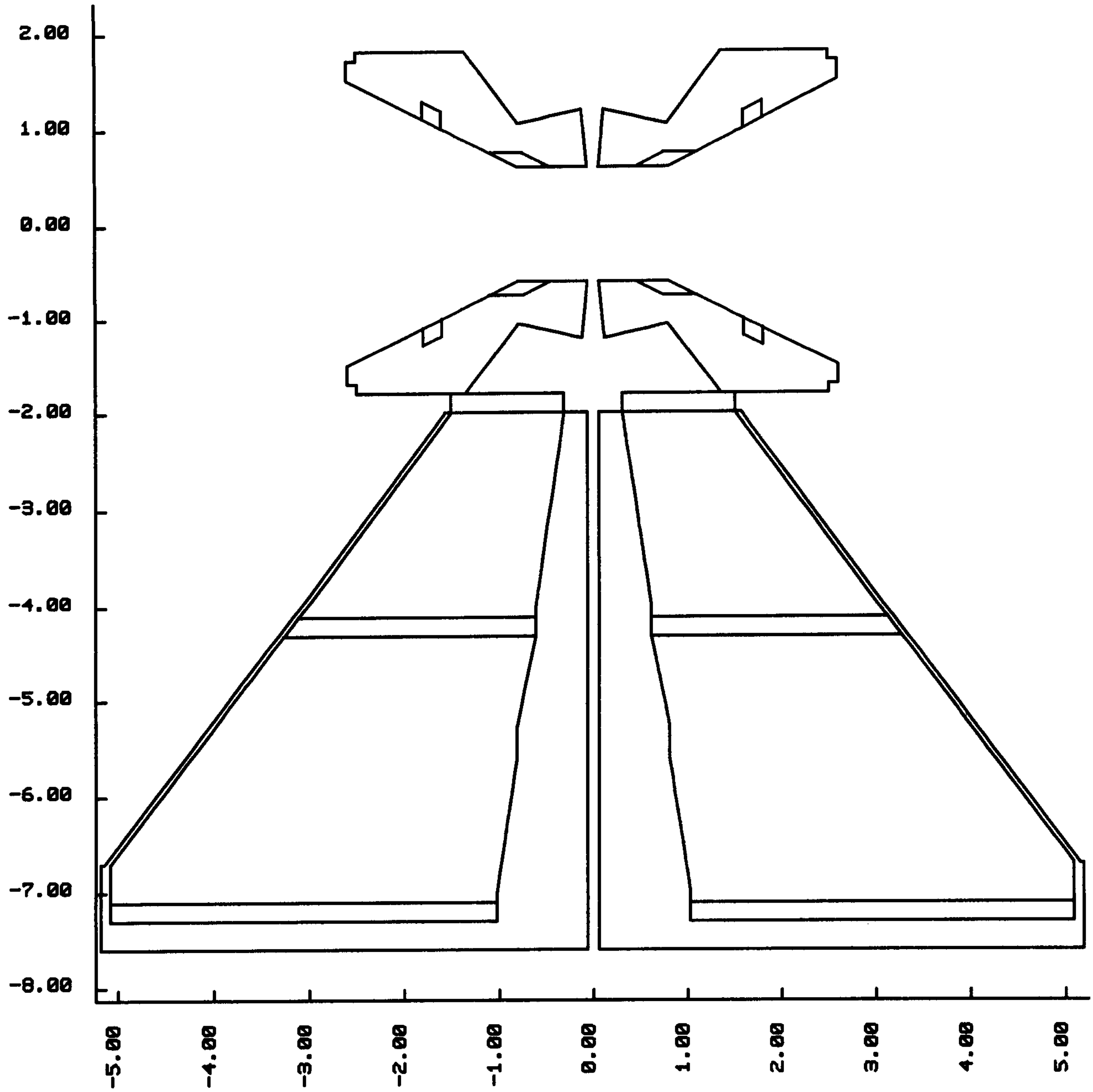
Run a

```
phenix magnet heat transfer-a
$
$ coils at 40 C, environment at 30 C
$ detector edges radiatively coupled
$ heat loss to environment by radiation only
$ emissivities:  steel=0.30, aluminum=0.10, coils=0.20
```

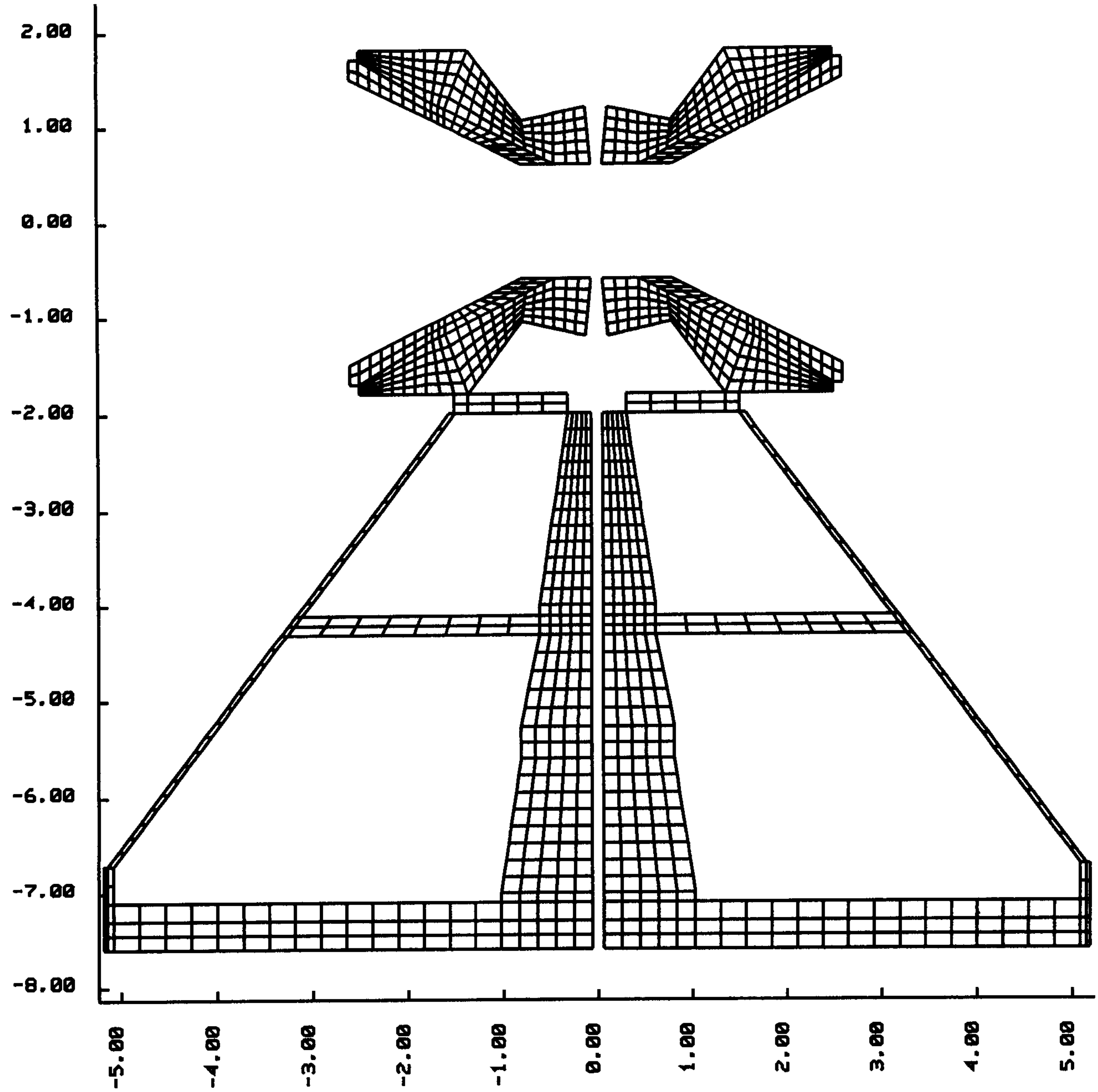
Run b

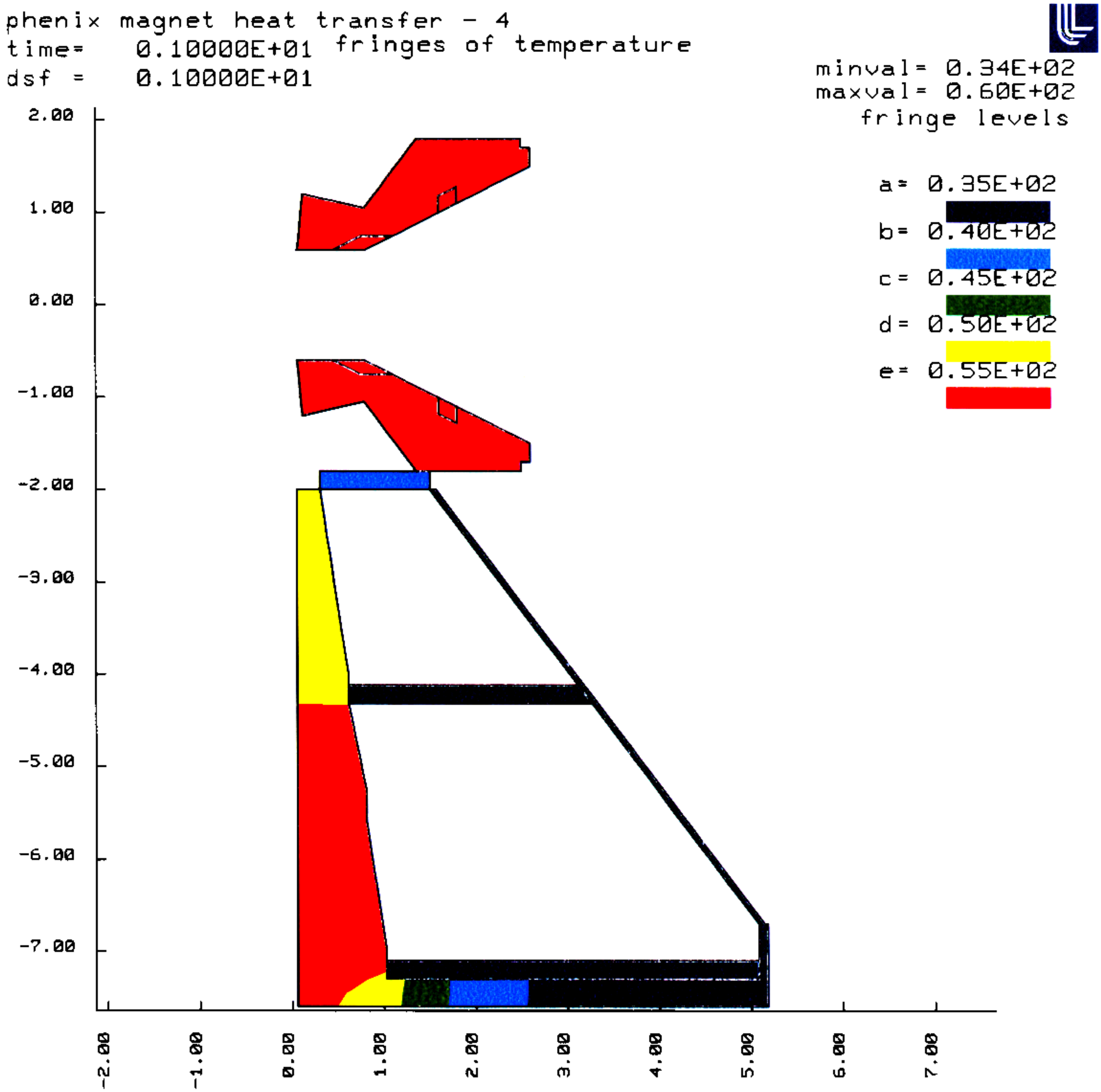
```
phenix magnet heat transfer - b
$
$ coils at 40 C, environment at 30 C
$ detector edges in perfect thermal contact
$ heat loss to environment by radiation only
$ emissivities: steel=0.30, aluminum=0.10, coils=0.20
```

phenix magnet heat transfer - 4
time=   0.00000E+00
dsf =   0.10000E+01

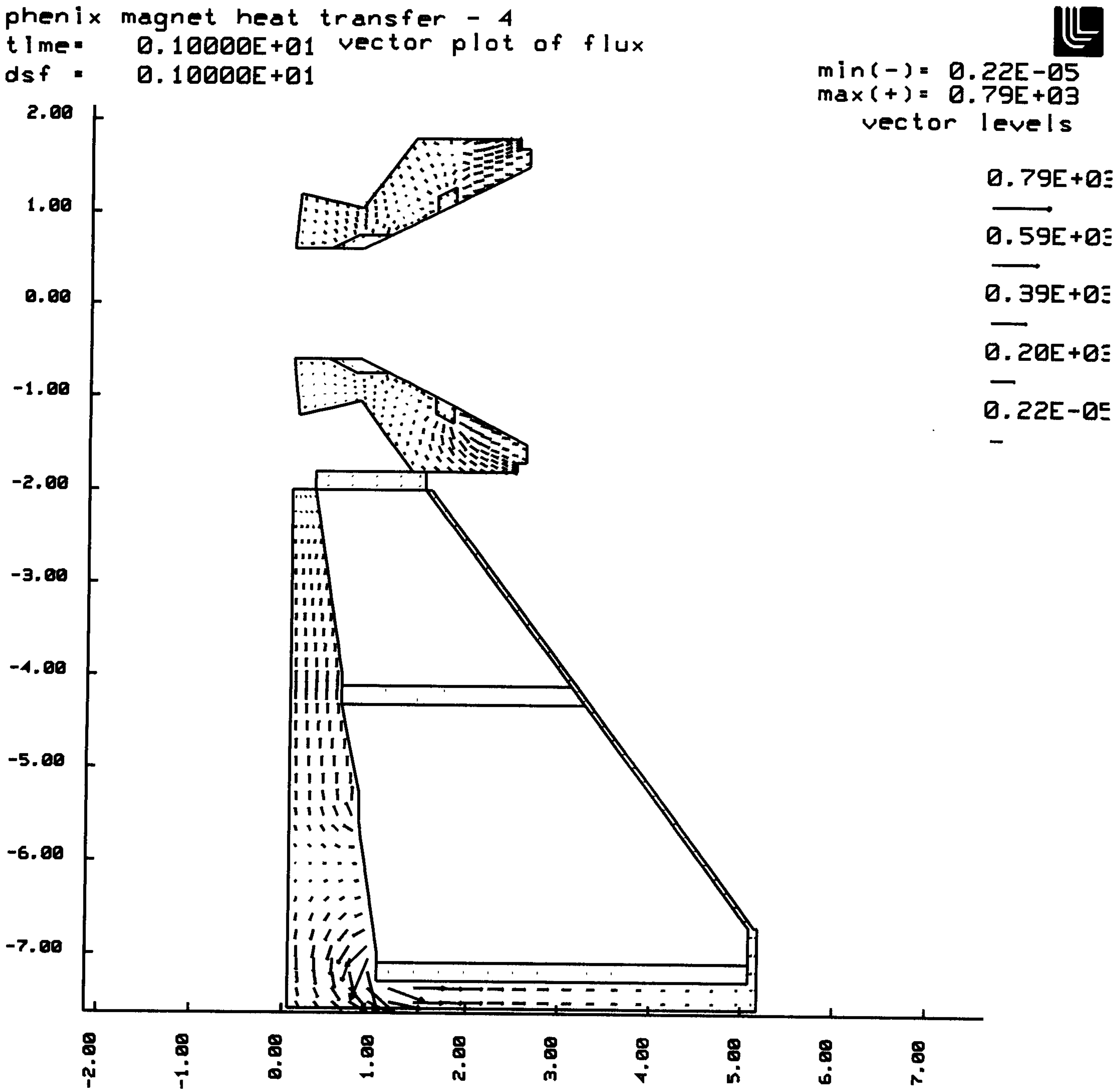


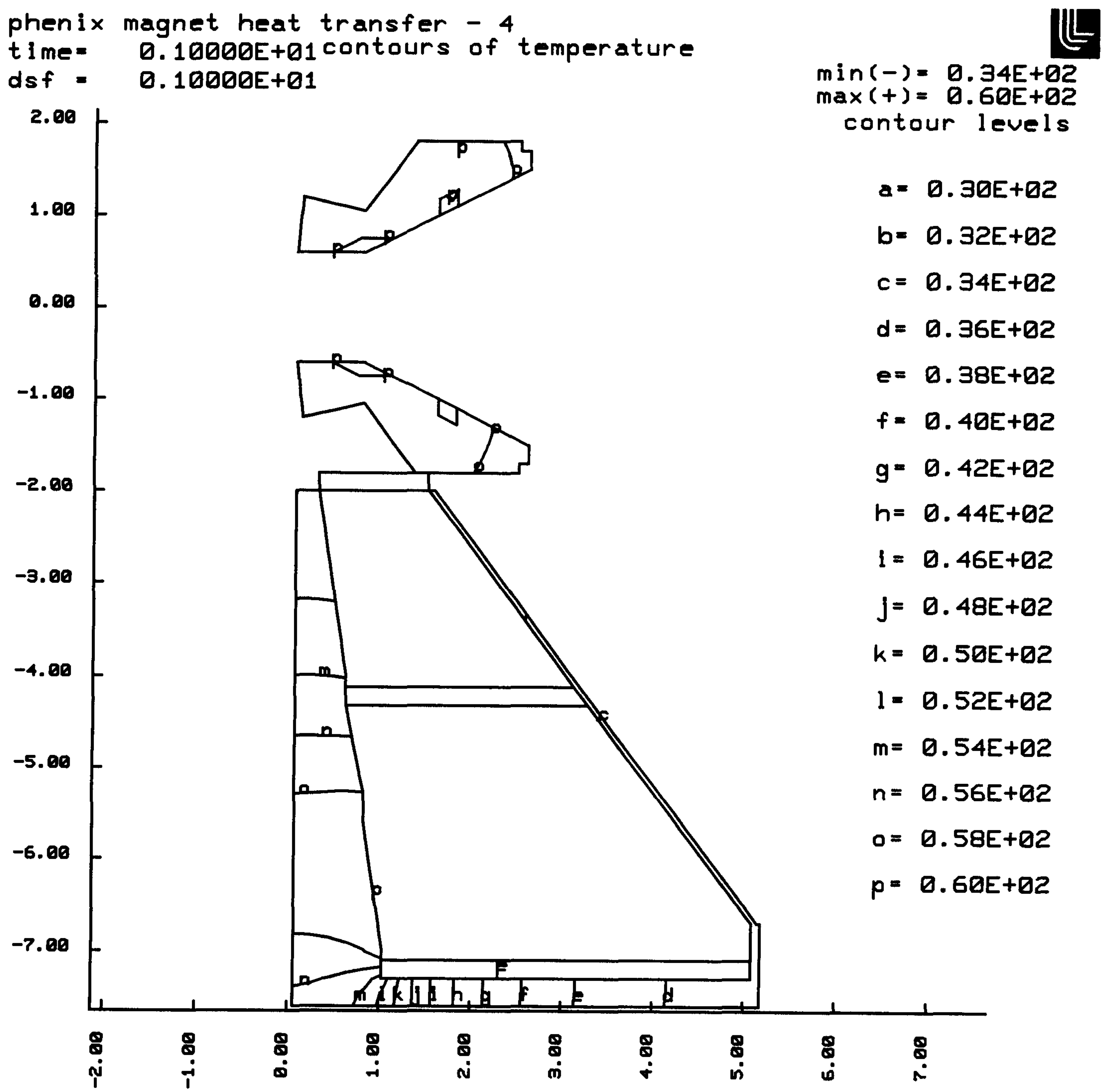
phenix magnet heat transfer - 4
dsf = 0.100E+01
time= 0.000E+00

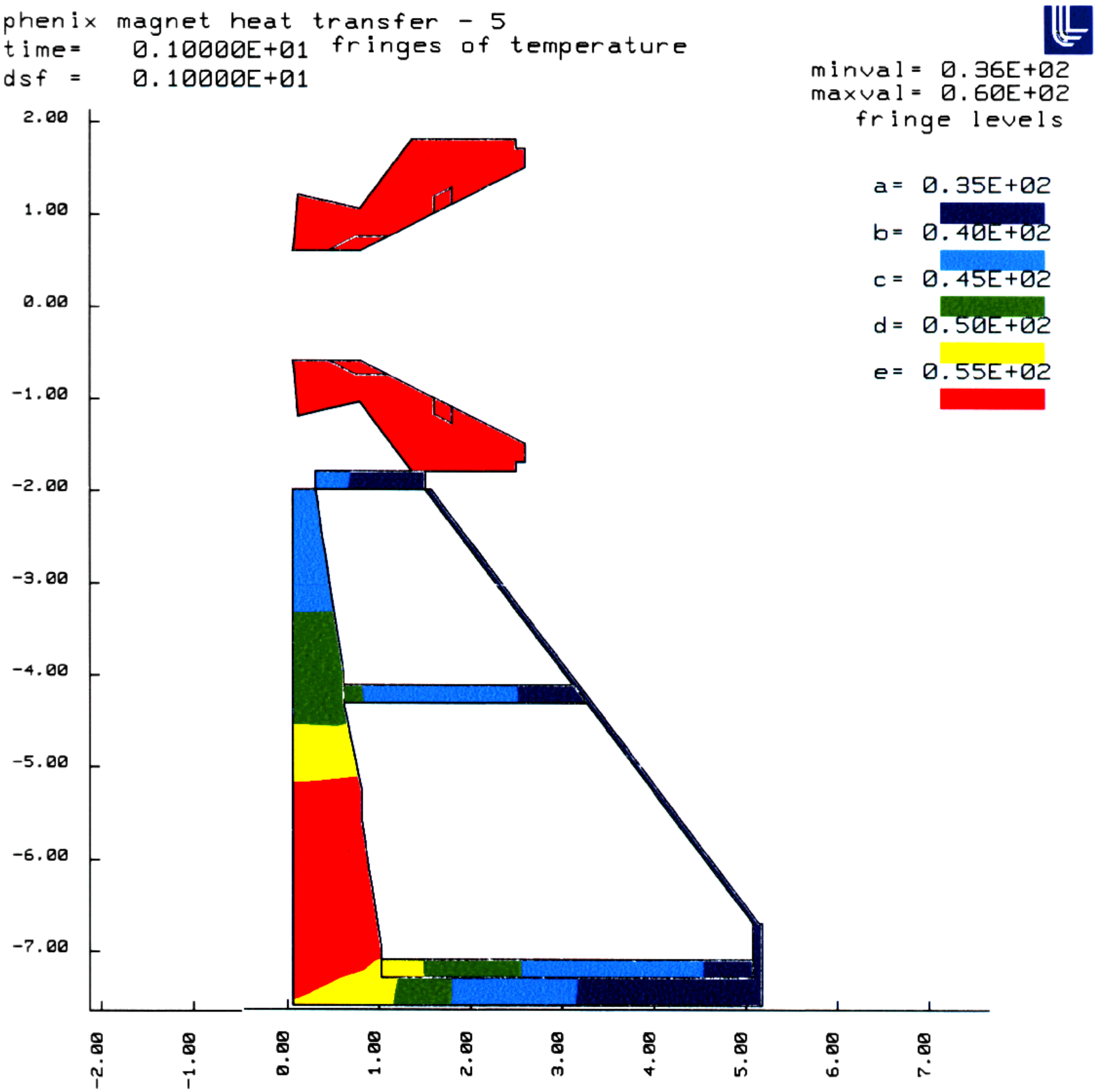


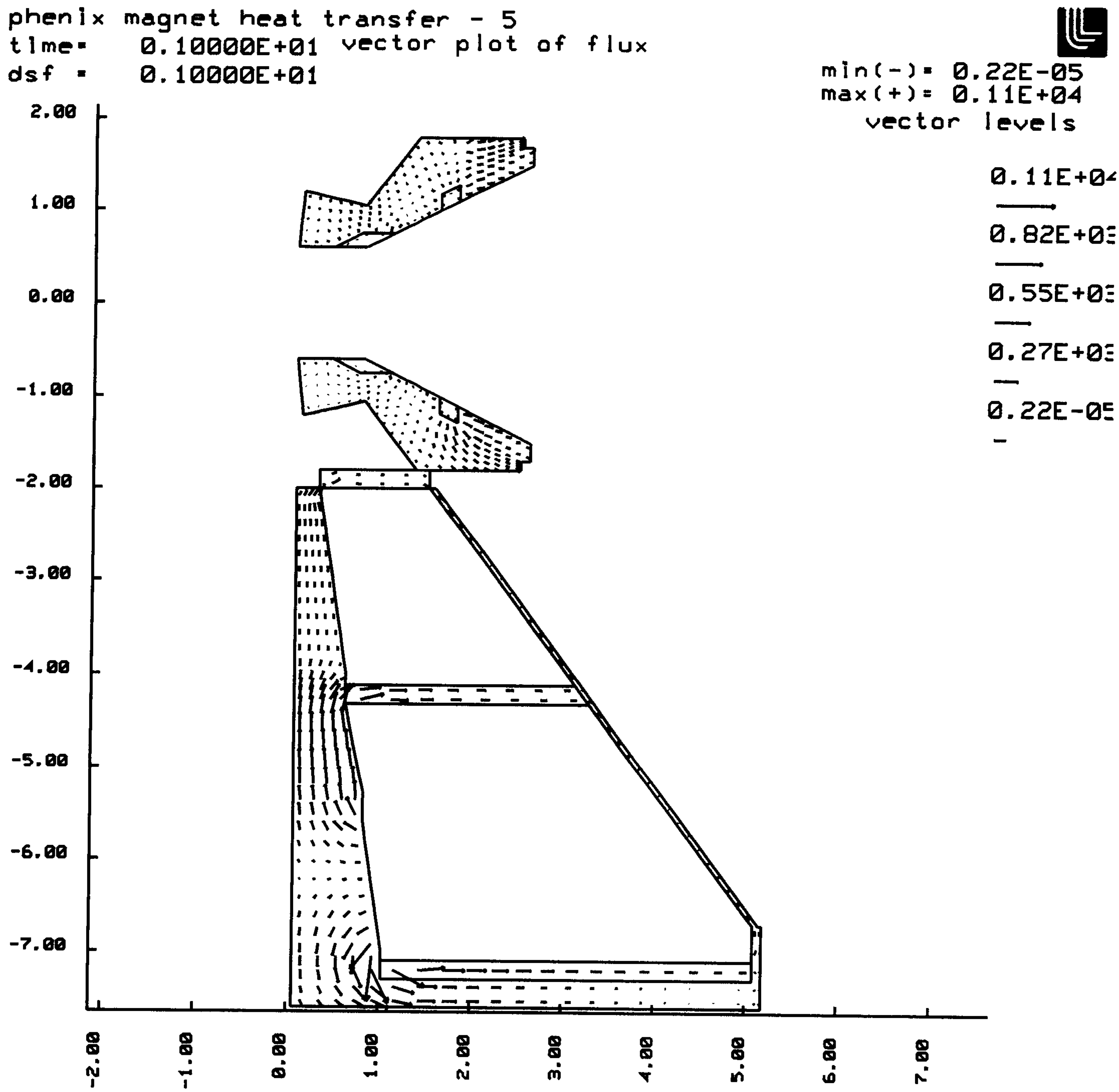


phenix magnet heat transfer - 4
time= 0.10000E+01 fringes of temperature
dsf = 0.10000E+01
minval= 0.34E+02
maxval= 0.60E+02
fringe levels
a= 0.35E+02
b= 0.40E+02
c= 0.45E+02
d= 0.50E+02
e= 0.55E+02
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
-7.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00

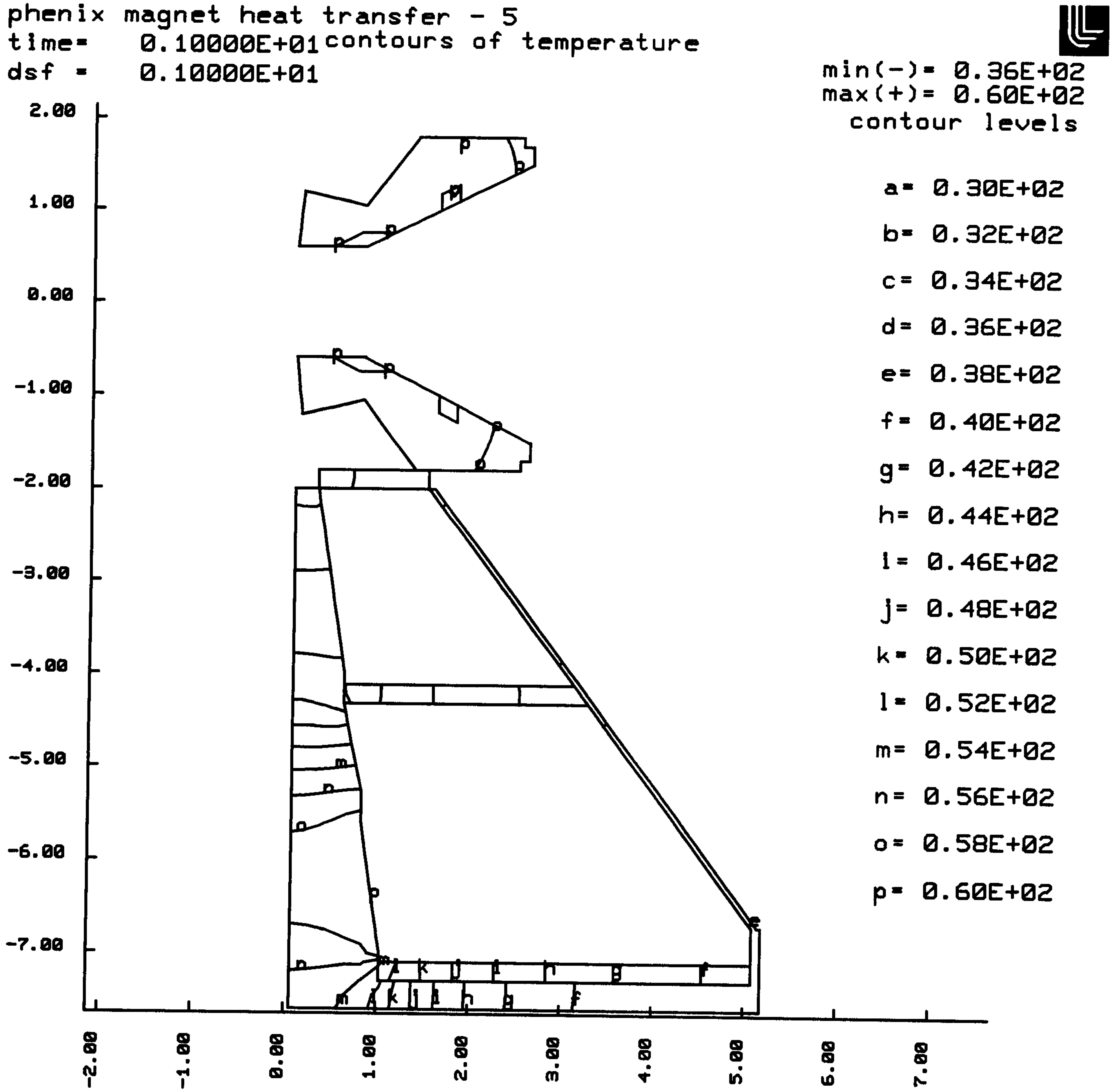

phenix magnet heat transfer - 4
time= 0.10000E+01 vector plot of flux
dsf = 0.10000E+01
min(-)= 0.22E-05
max(+)= 0.79E+03
vector levels
0.79E+03
0.59E+03
0.39E+03
0.20E+03
0.22E-05
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
-7.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00


phenix magnet heat transfer - 4
time= 0.10000E+01 contours of temperature
dsf = 0.10000E+01
min(-)= 0.34E+02
max(+)= 0.60E+02
contour levels
a= 0.30E+02
b= 0.32E+02
c= 0.34E+02
d= 0.36E+02
e= 0.38E+02
f= 0.40E+02
g= 0.42E+02
h= 0.44E+02
i= 0.46E+02
j= 0.48E+02
k= 0.50E+02
l= 0.52E+02
m= 0.54E+02
n= 0.56E+02
o= 0.58E+02
p= 0.60E+02
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
-7.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00

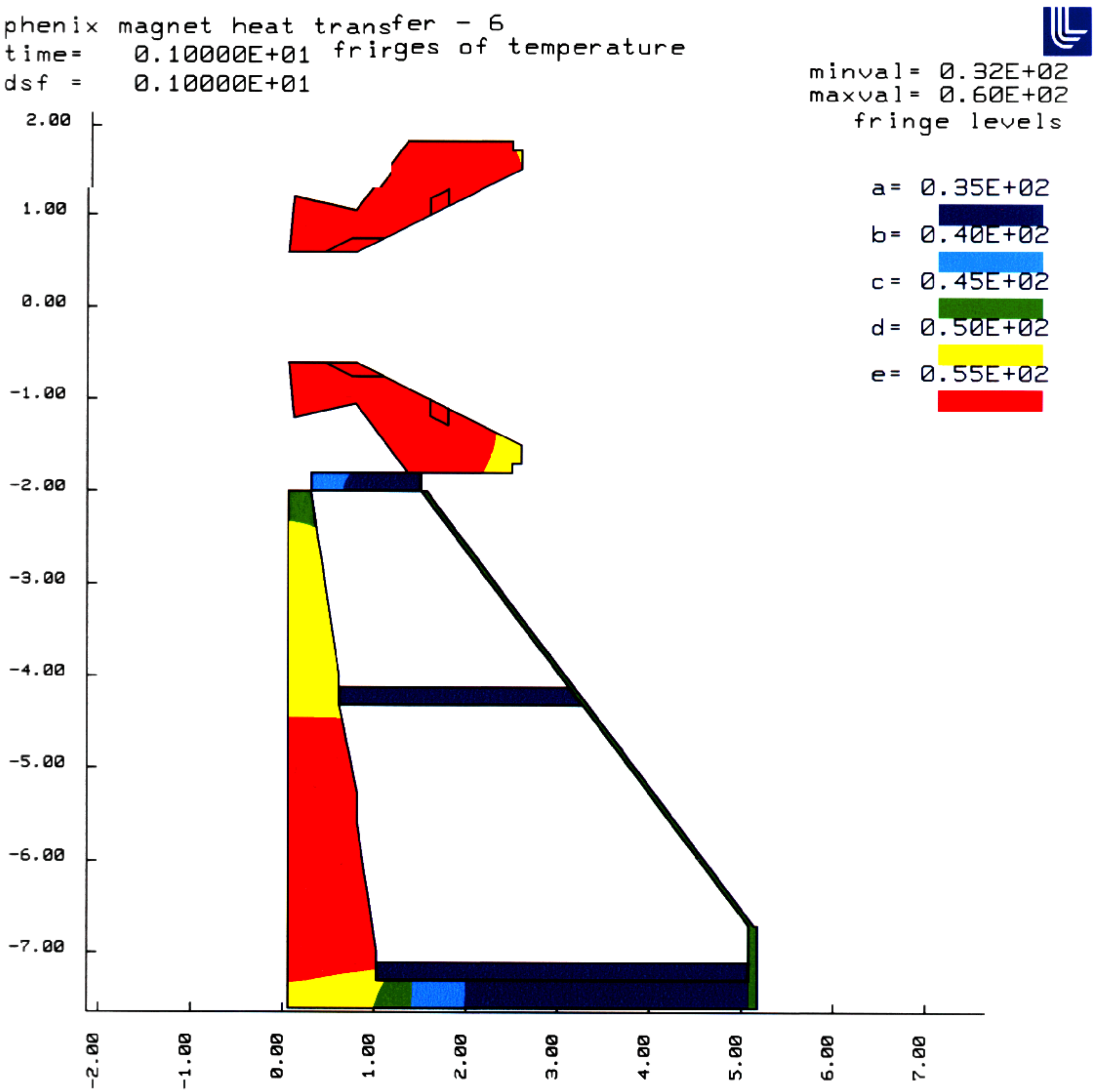

phenix magnet heat transfer - 5
time= 0.10000E+01
dsf = 0.10000E+01
fringes of temperature
minval= 0.36E+02
maxval= 0.60E+02
fringe levels
a= 0.35E+02
b= 0.40E+02
c= 0.45E+02
d= 0.50E+02
e= 0.55E+02
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
-7.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00

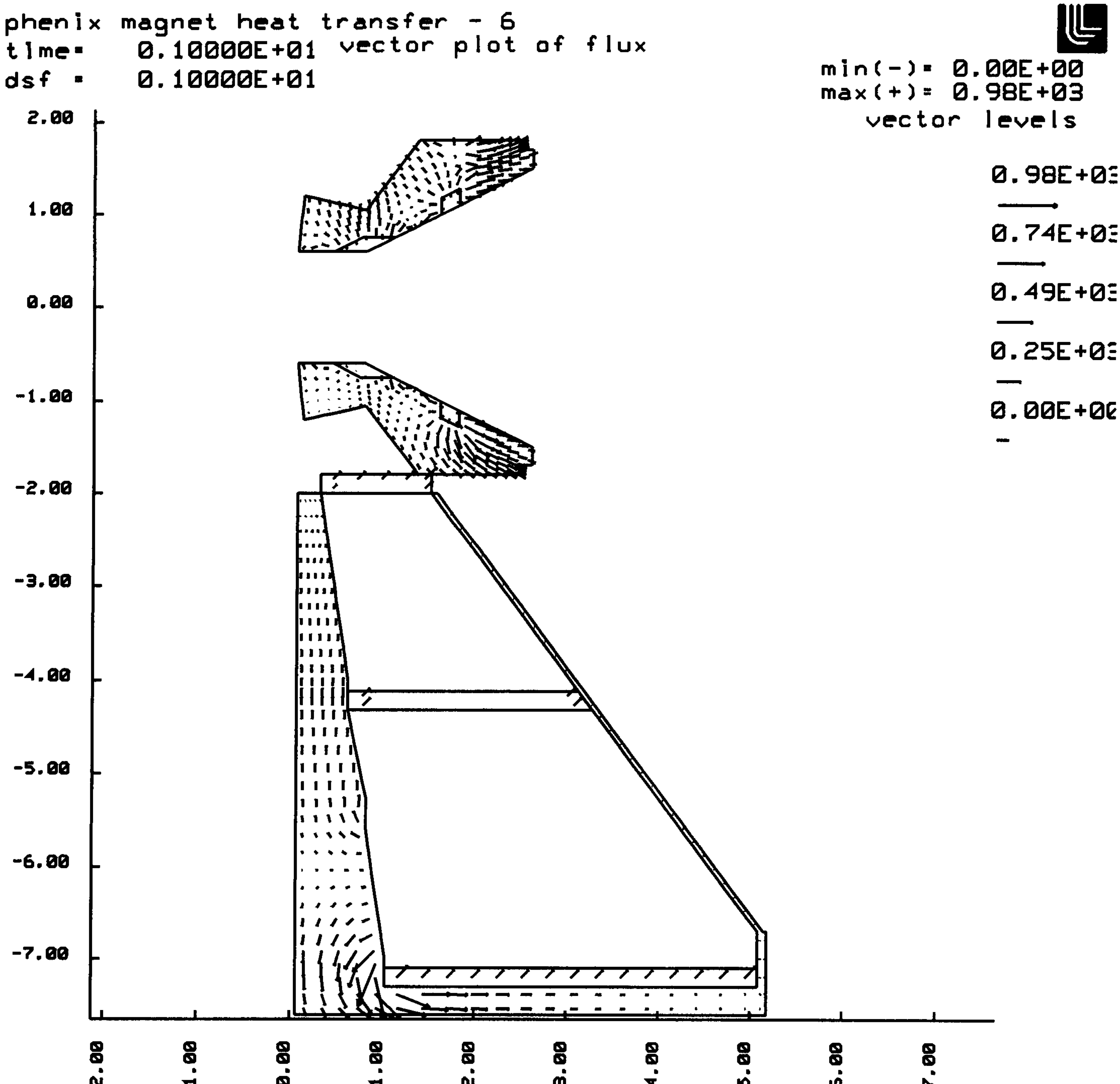


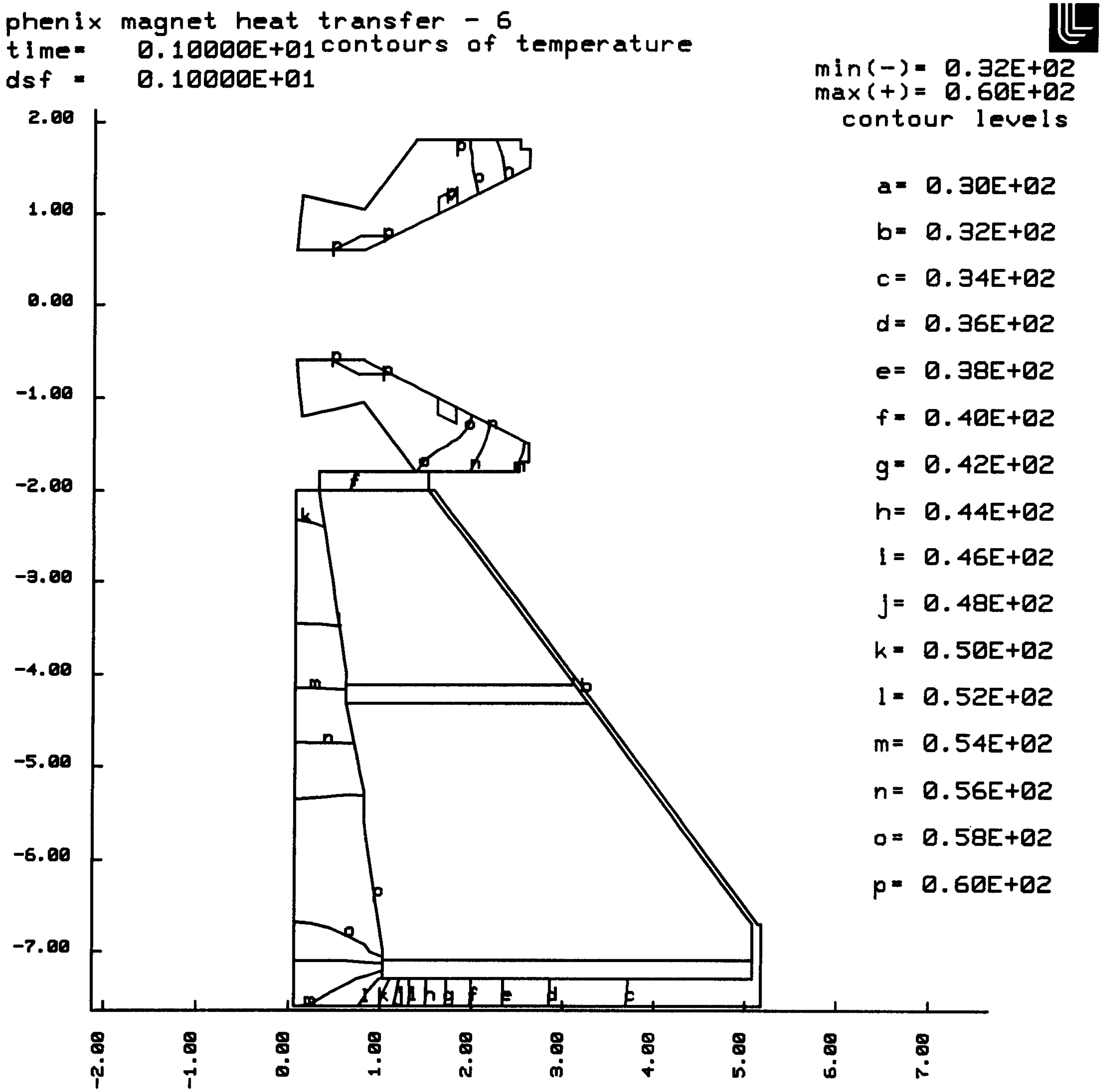
phenix magnet heat transfer - 5
time= 0.10000E+01 vector plot of flux
dsf = 0.10000E+01
min(-)= 0.22E-05
max(+)= 0.11E+04
vector levels
0.11E+04
0.82E+03
0.55E+03
0.27E+03
0.22E-05
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
-7.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00

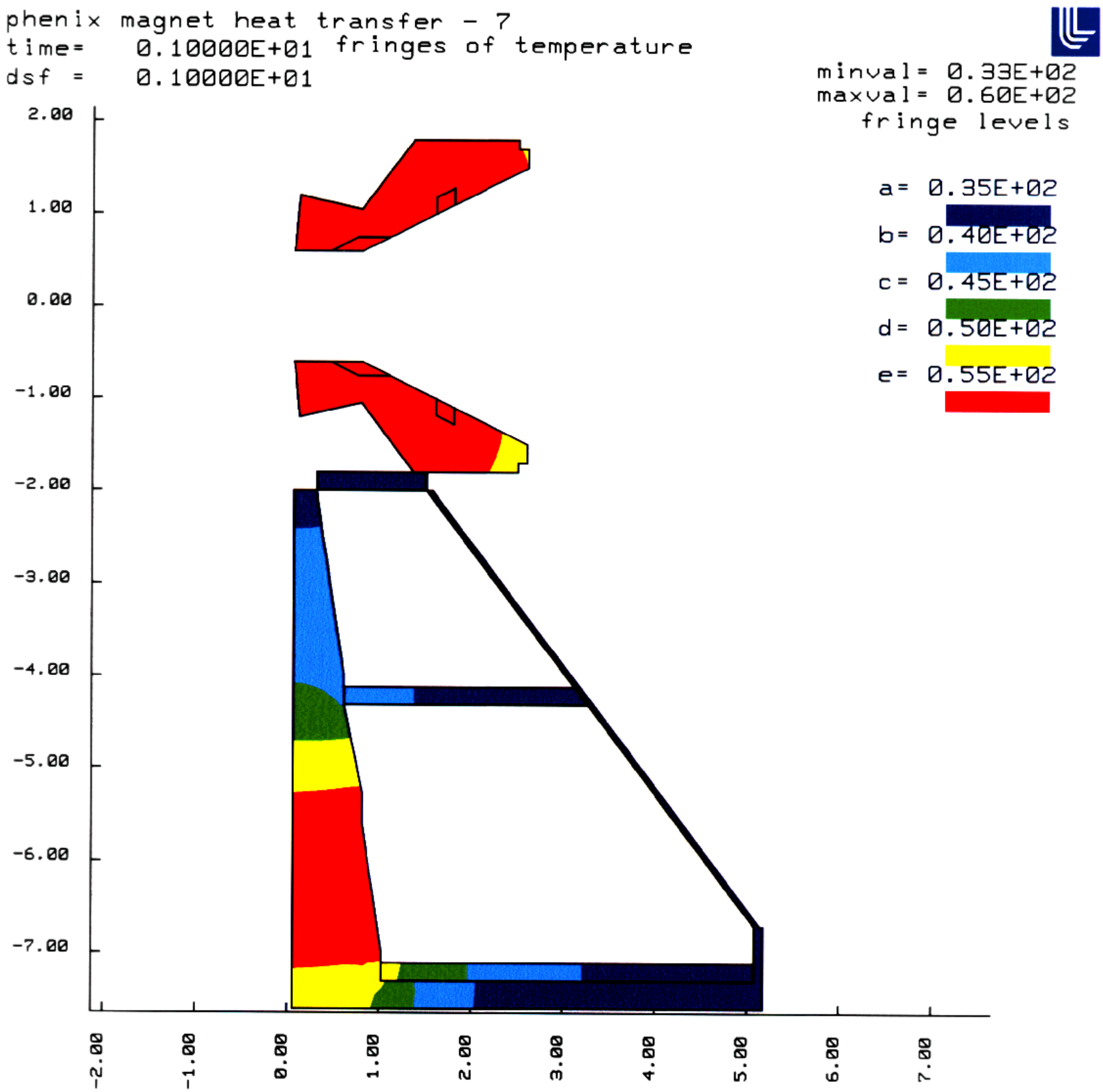


phenix magnet heat transfer - 5
time= 0.10000E+01 contours of temperature
dsf = 0.10000E+01
min(-)= 0.36E+02
max(+)= 0.60E+02
contour levels
a= 0.30E+02
b= 0.32E+02
c= 0.34E+02
d= 0.36E+02
e= 0.38E+02
f= 0.40E+02
g= 0.42E+02
h= 0.44E+02
i= 0.46E+02
j= 0.48E+02
k= 0.50E+02
l= 0.52E+02
m= 0.54E+02
n= 0.56E+02
o= 0.58E+02
p= 0.60E+02
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
-7.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00

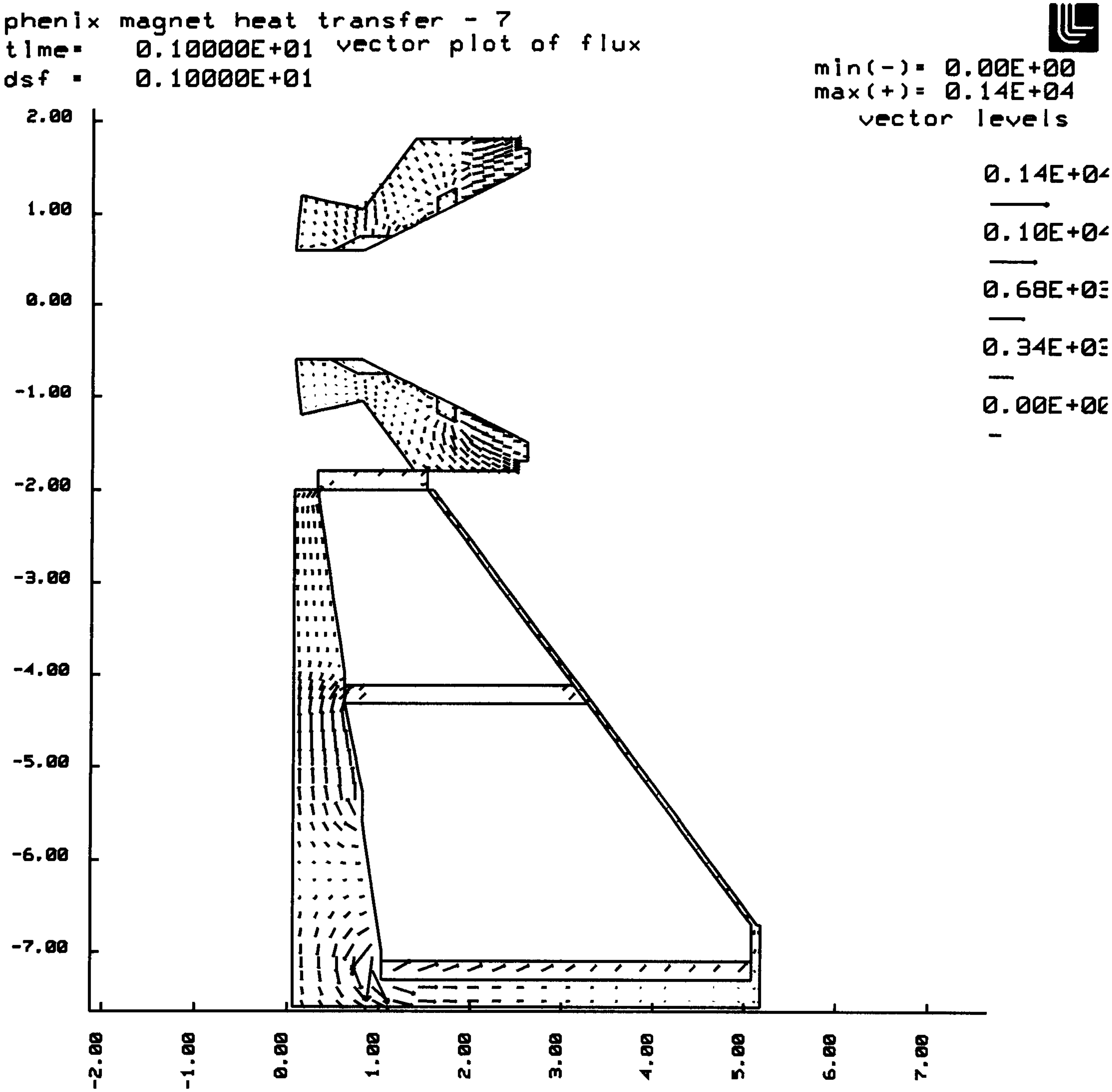

phenix magnet heat transfer - 6
time= 0.10000E+01 frirges of temperature
dsf = 0.10000E+01
minval= 0.32E+02
maxval= 0.60E+02
fringe levels
a= 0.35E+02
b= 0.40E+02
c= 0.45E+02
d= 0.50E+02
e= 0.55E+02
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
-7.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00

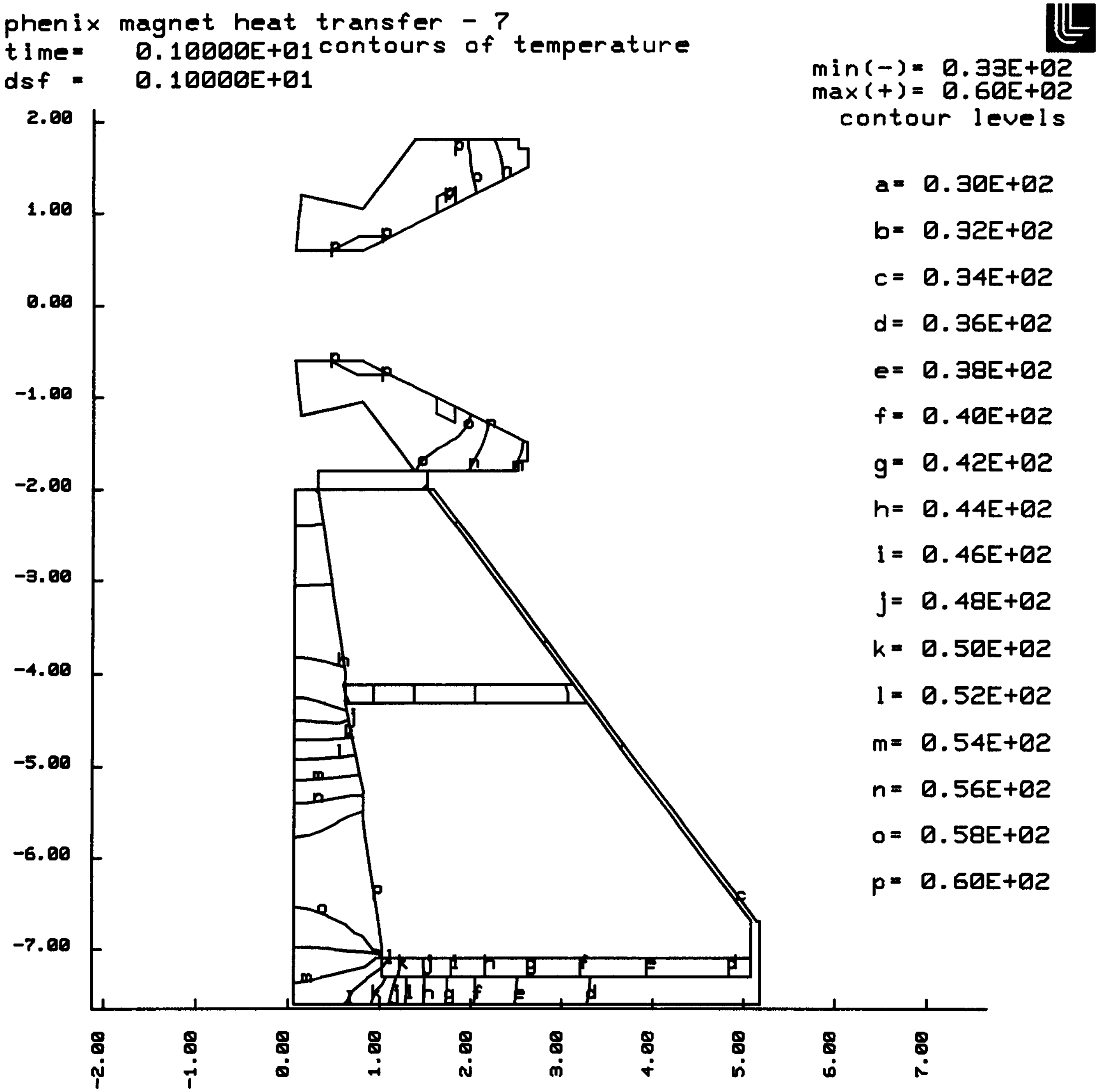

phenix magnet heat transfer - 6
time= 0.10000E+01 vector plot of flux
dsf = 0.10000E+01
min(-)= 0.00E+00
max(+)= 0.98E+03
vector levels
0.98E+03
0.74E+03
0.49E+03
0.25E+03
0.00E+00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
-7.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00

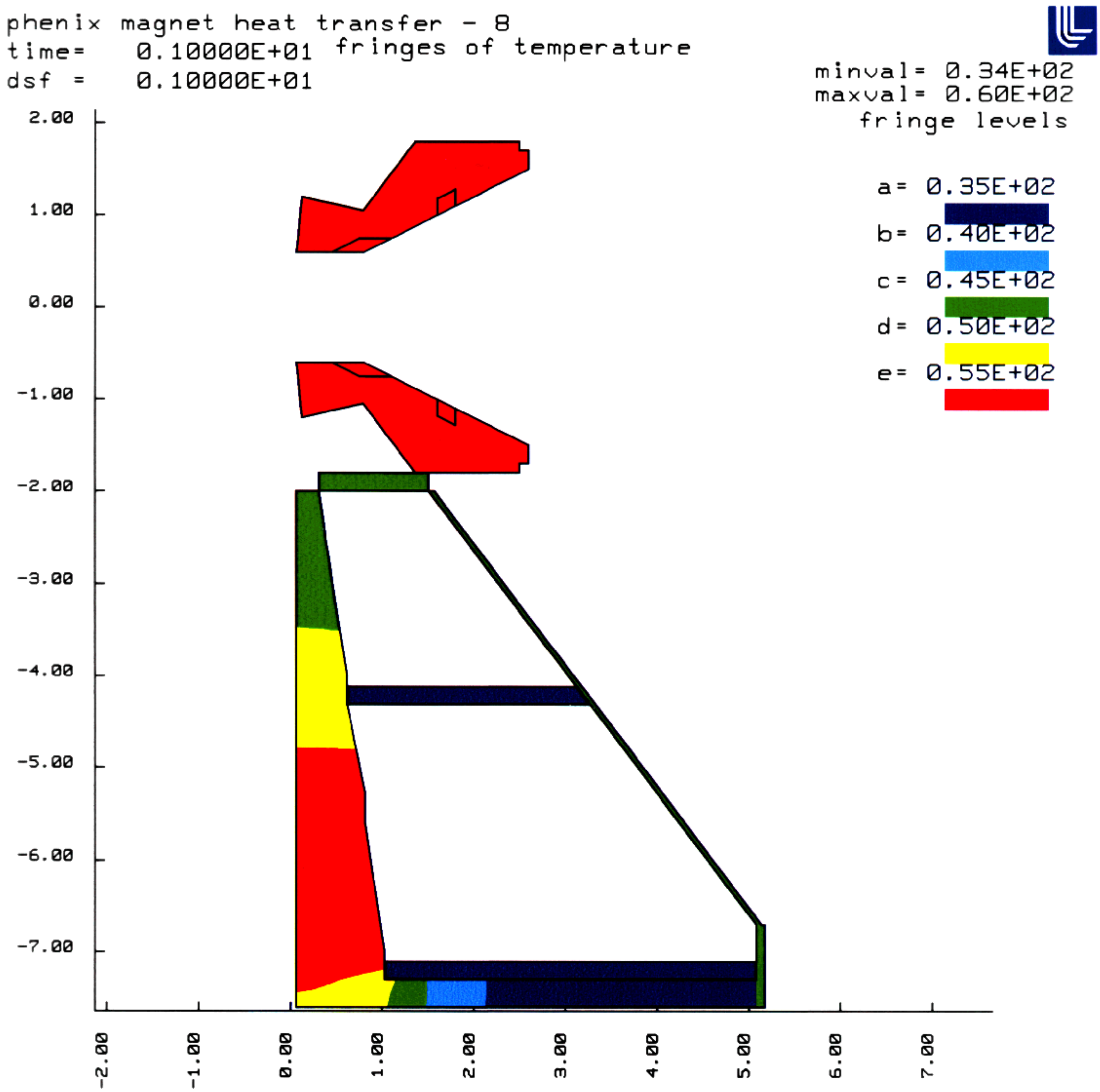

phenix magnet heat transfer - 6
time= 0.10000E+01 contours of temperature
dsf = 0.10000E+01
min(-)= 0.32E+02
max(+)= 0.60E+02
contour levels
a= 0.30E+02
b= 0.32E+02
c= 0.34E+02
d= 0.36E+02
e= 0.38E+02
f= 0.40E+02
g= 0.42E+02
h= 0.44E+02
i= 0.46E+02
j= 0.48E+02
k= 0.50E+02
l= 0.52E+02
m= 0.54E+02
n= 0.56E+02
o= 0.58E+02
p= 0.60E+02
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
-7.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00

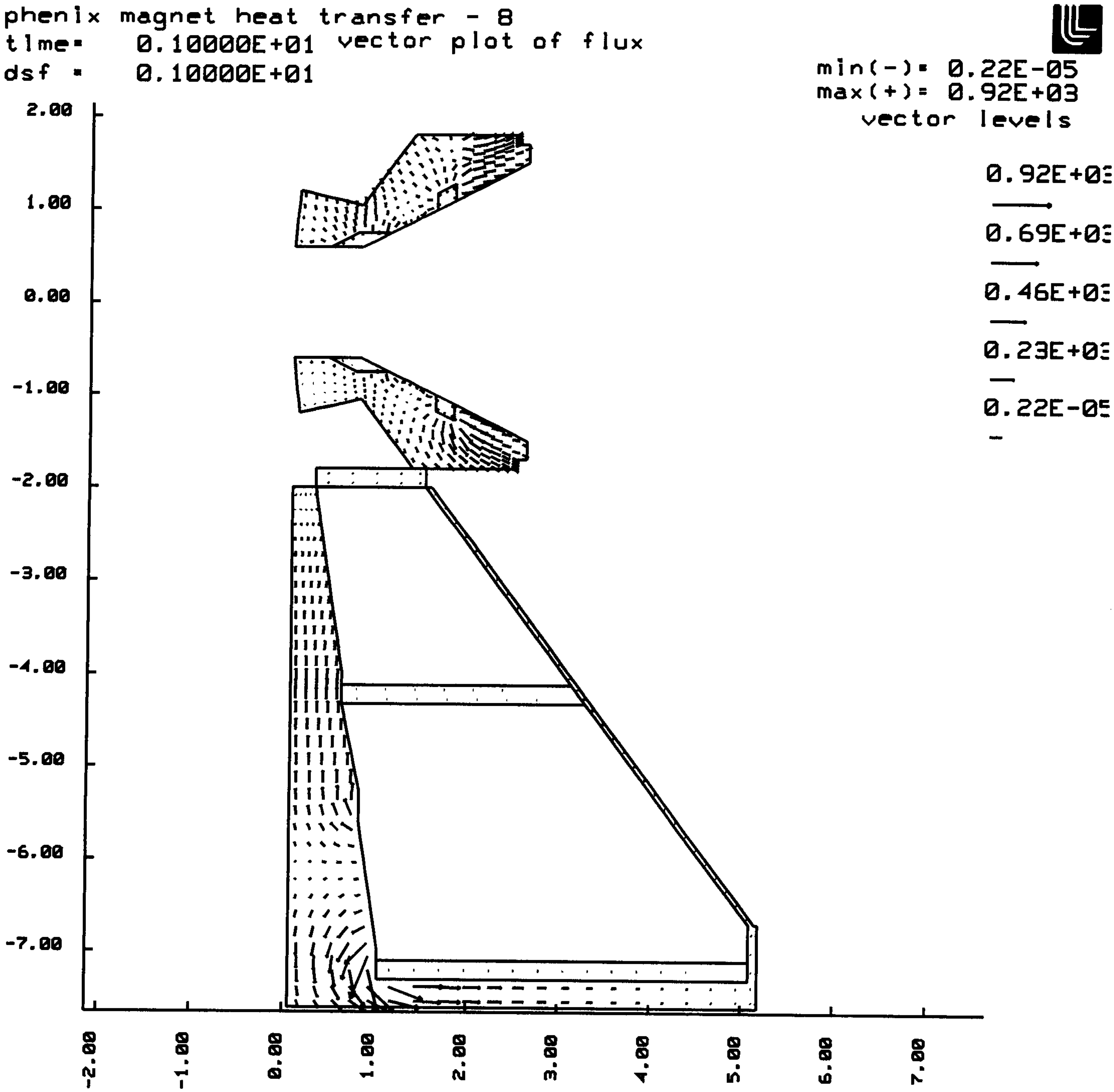


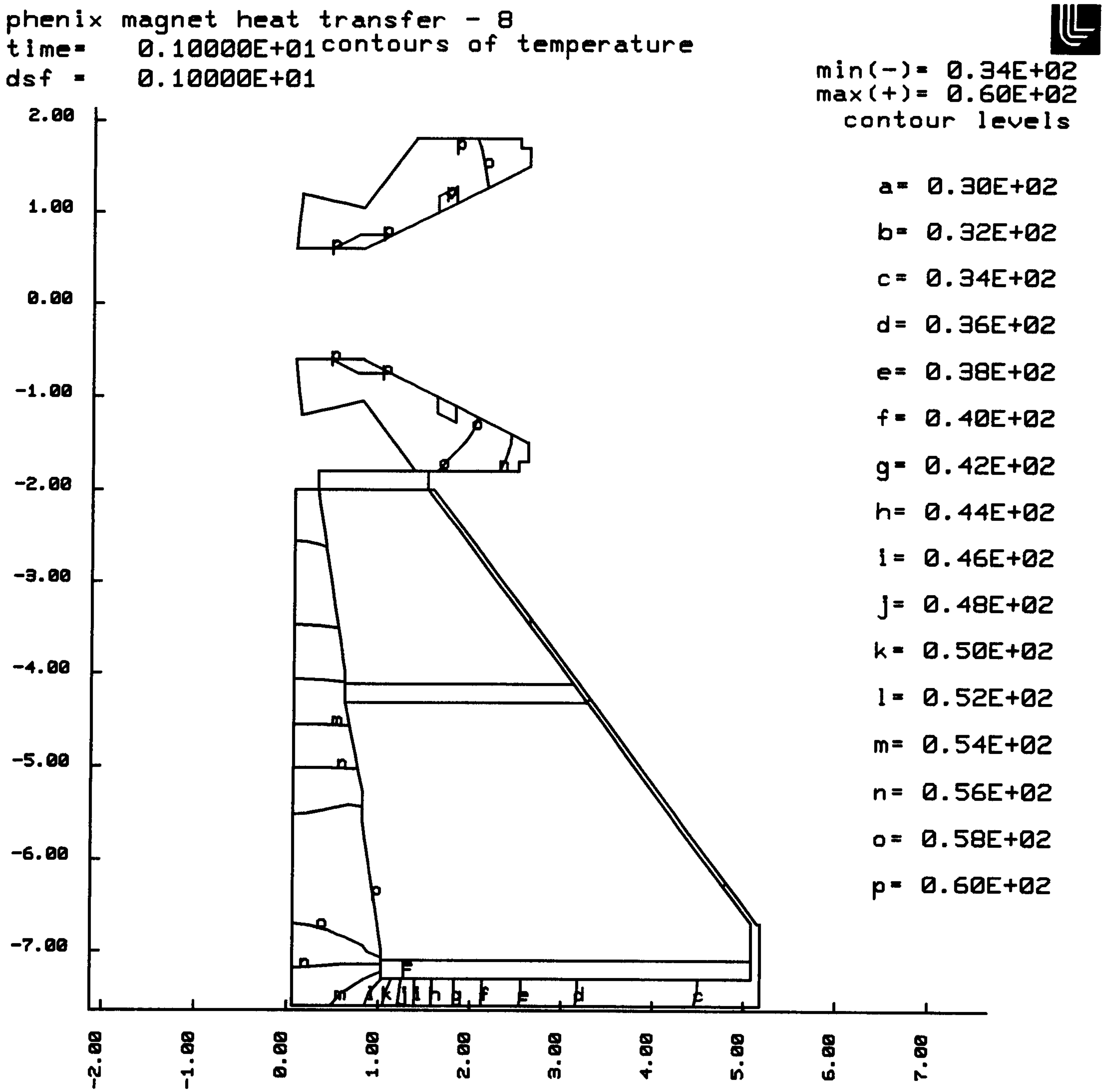
phenix magnet heat transfer - 7
time= 0.10000E+01 fringes of temperature
dsf = 0.10000E+01
minval= 0.33E+02
maxval= 0.60E+02
fringe levels
a= 0.35E+02
b= 0.40E+02
c= 0.45E+02
d= 0.50E+02
e= 0.55E+02
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
-7.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00

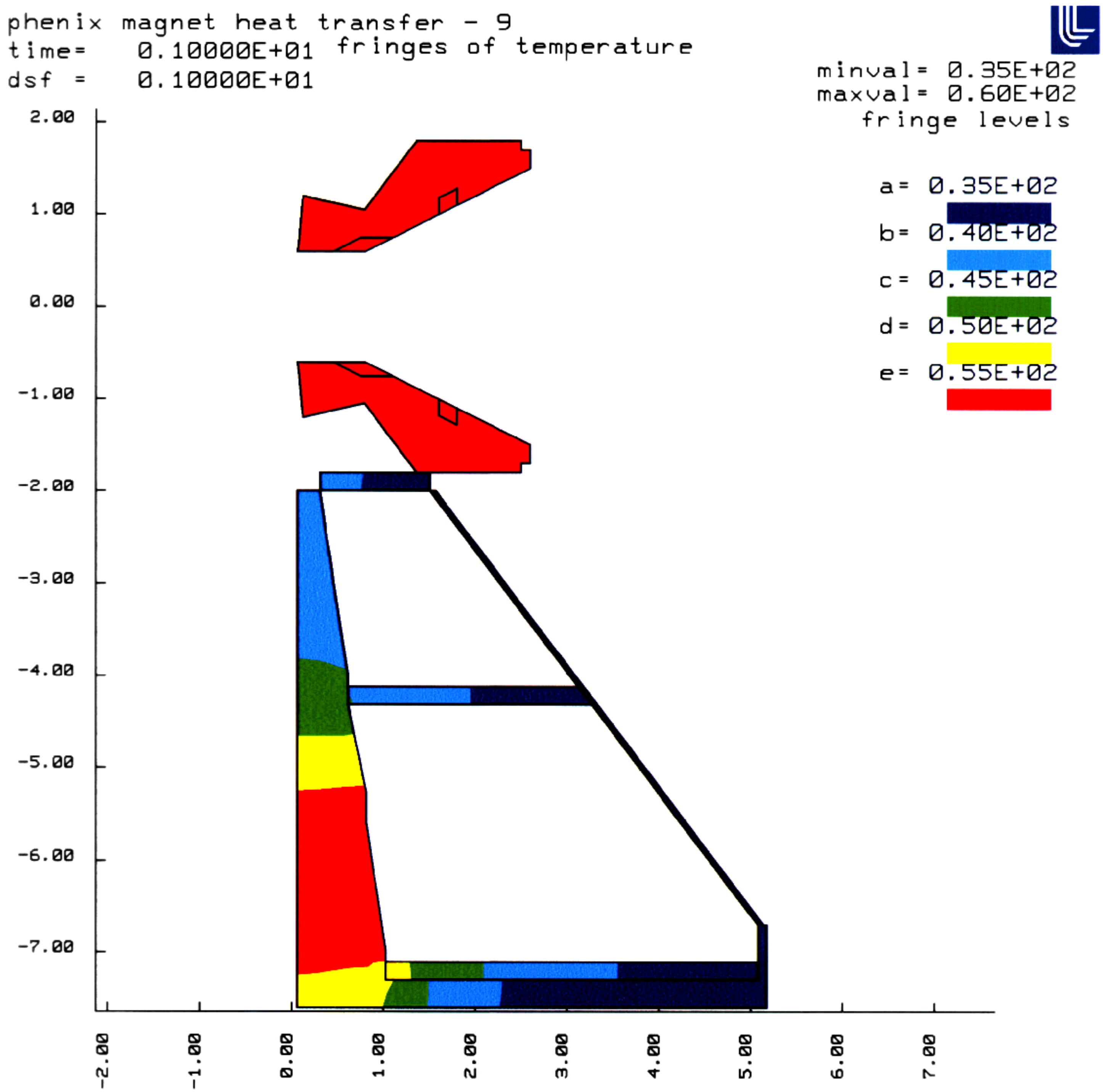

phenix magnet heat transfer - 7
time= 0.10000E+01 vector plot of flux
dsf = 0.10000E+01
min(-)= 0.00E+00
max(+)= 0.14E+04
vector levels
0.14E+04
0.10E+04
0.68E+03
0.34E+03
0.00E+00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
-7.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00


phenix magnet heat transfer - 7
time= 0.10000E+01 contours of temperature
dsf = 0.10000E+01
min(-)= 0.33E+02
max(+)= 0.60E+02
contour levels
a= 0.30E+02
b= 0.32E+02
c= 0.34E+02
d= 0.36E+02
e= 0.38E+02
f= 0.40E+02
g= 0.42E+02
h= 0.44E+02
i= 0.46E+02
j= 0.48E+02
k= 0.50E+02
l= 0.52E+02
m= 0.54E+02
n= 0.56E+02
o= 0.58E+02
p= 0.60E+02
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
-7.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00

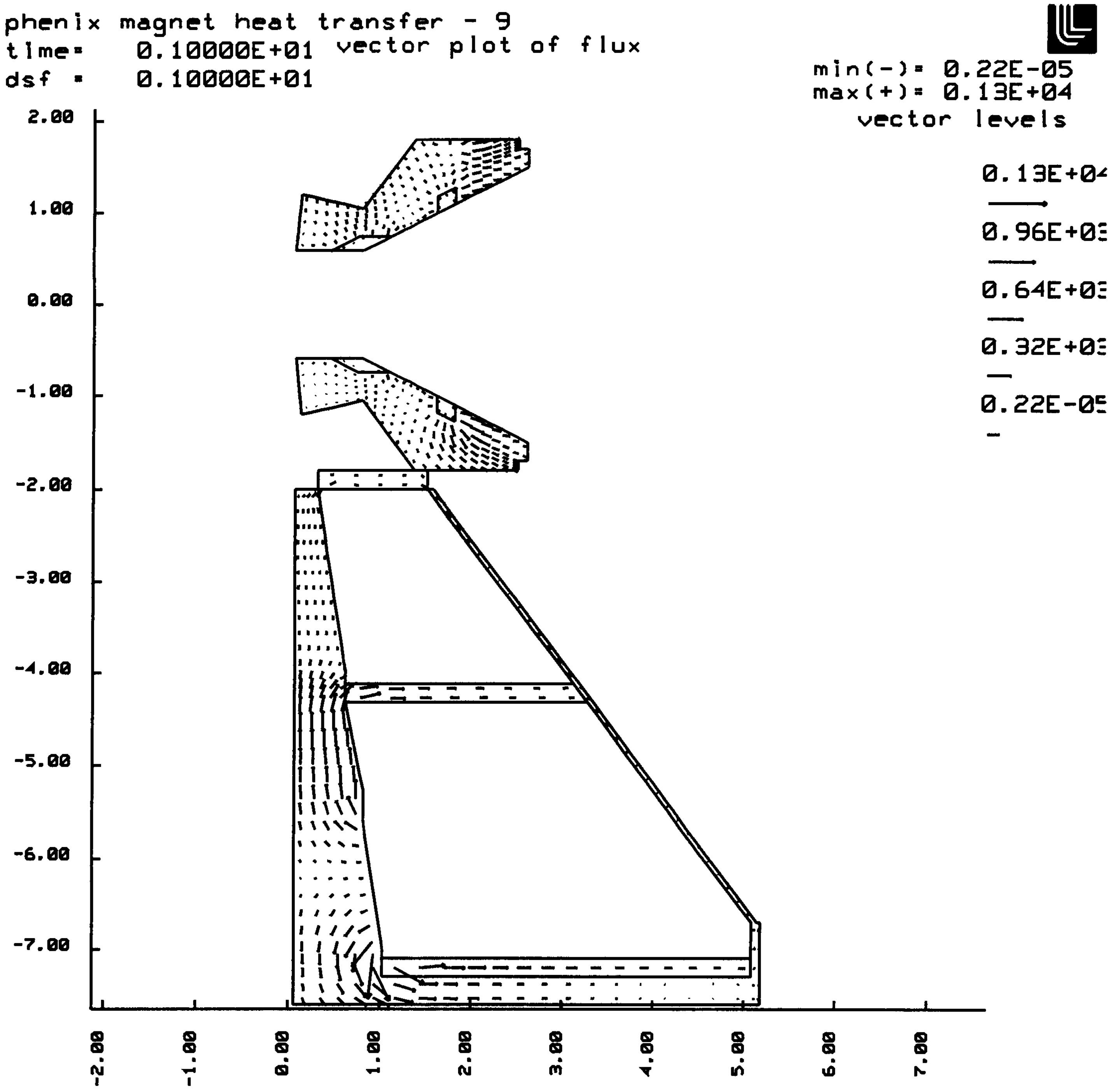

phenix magnet heat transfer - 8
time= 0.10000E+01 fringes of temperature
dsf = 0.10000E+01
minval= 0.34E+02
maxval= 0.60E+02
fringe levels
a= 0.35E+02
b= 0.40E+02
c= 0.45E+02
d= 0.50E+02
e= 0.55E+02
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
-7.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00


phenix magnet heat transfer - 8
time= 0.10000E+01 vector plot of flux
dsf = 0.10000E+01
min(-)= 0.22E-05
max(+)= 0.92E+03
vector levels
0.92E+03
0.69E+03
0.46E+03
0.23E+03
0.22E-05
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
-7.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00

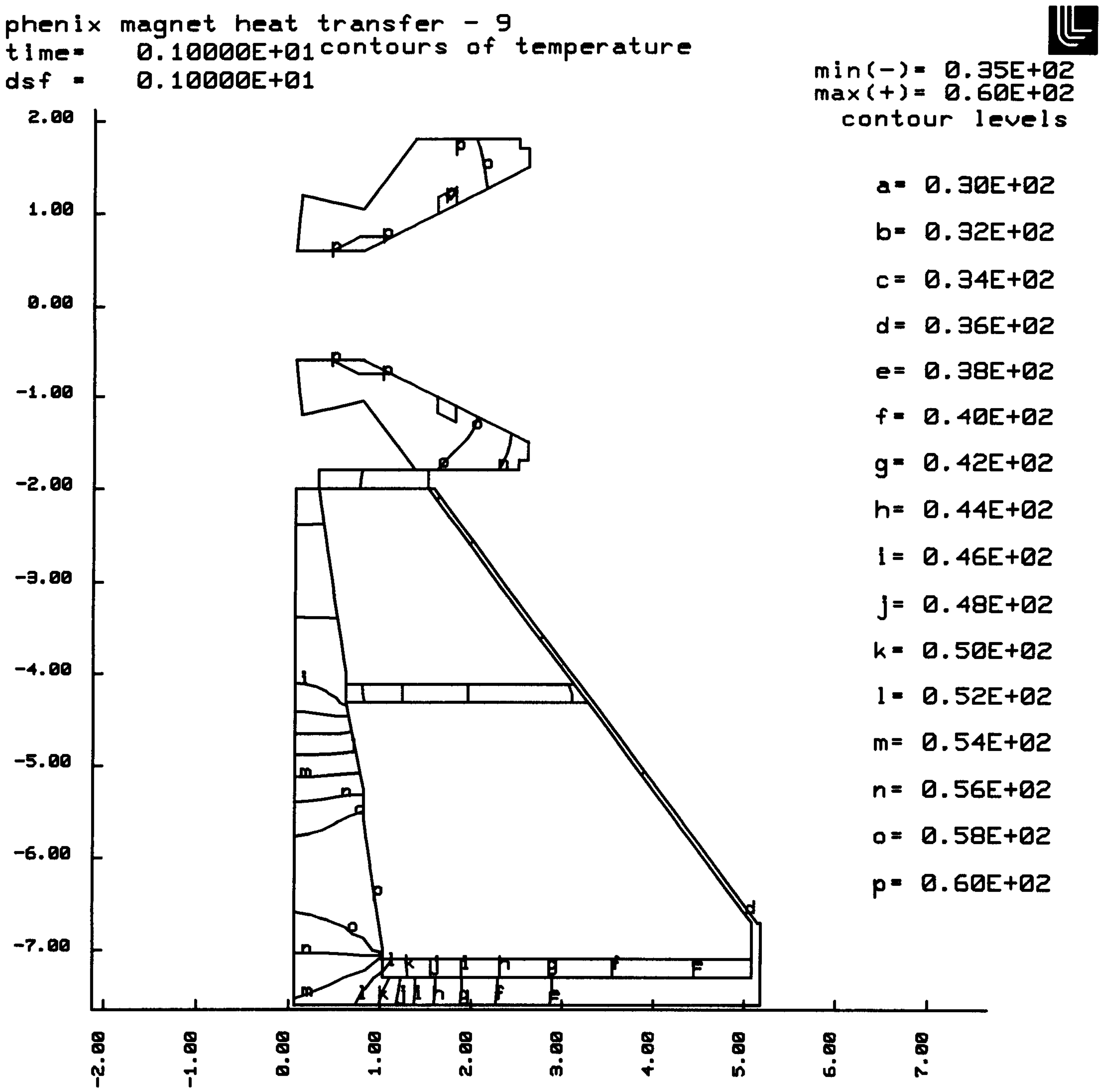

phenix magnet heat transfer - 8
time= 0.10000E+01 contours of temperature
dsf = 0.10000E+01
min(-)= 0.34E+02
max(+)= 0.60E+02
contour levels
a= 0.30E+02
b= 0.32E+02
c= 0.34E+02
d= 0.36E+02
e= 0.38E+02
f= 0.40E+02
g= 0.42E+02
h= 0.44E+02
i= 0.46E+02
j= 0.48E+02
k= 0.50E+02
l= 0.52E+02
m= 0.54E+02
n= 0.56E+02
o= 0.58E+02
p= 0.60E+02
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
-7.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00

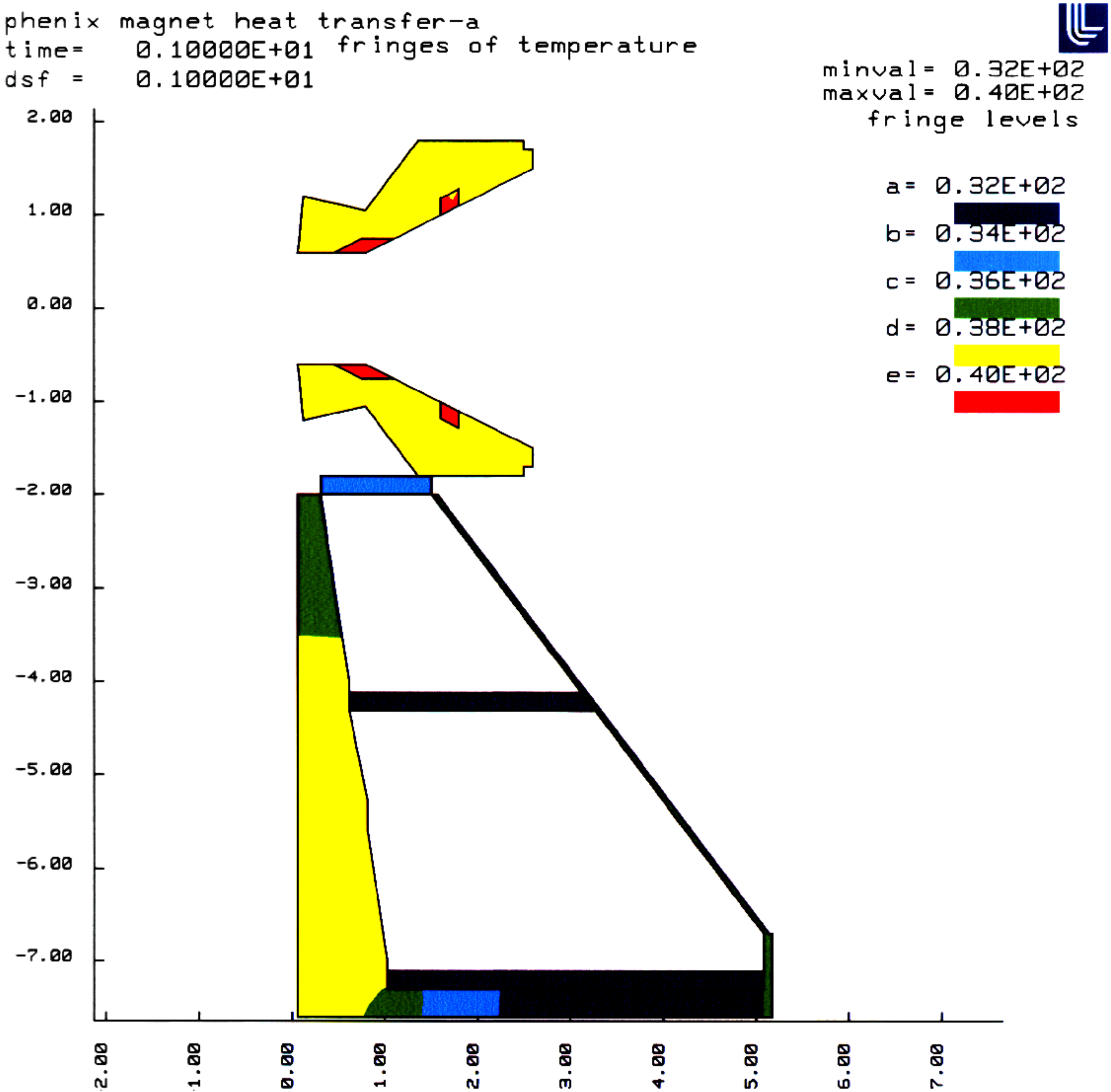


phenix magnet heat transfer - 9
time= 0.10000E+01 fringes of temperature
dsf = 0.10000E+01
minval= 0.35E+02
maxval= 0.60E+02
fringe levels
a= 0.35E+02
b= 0.40E+02
c= 0.45E+02
d= 0.50E+02
e= 0.55E+02
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
-7.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00

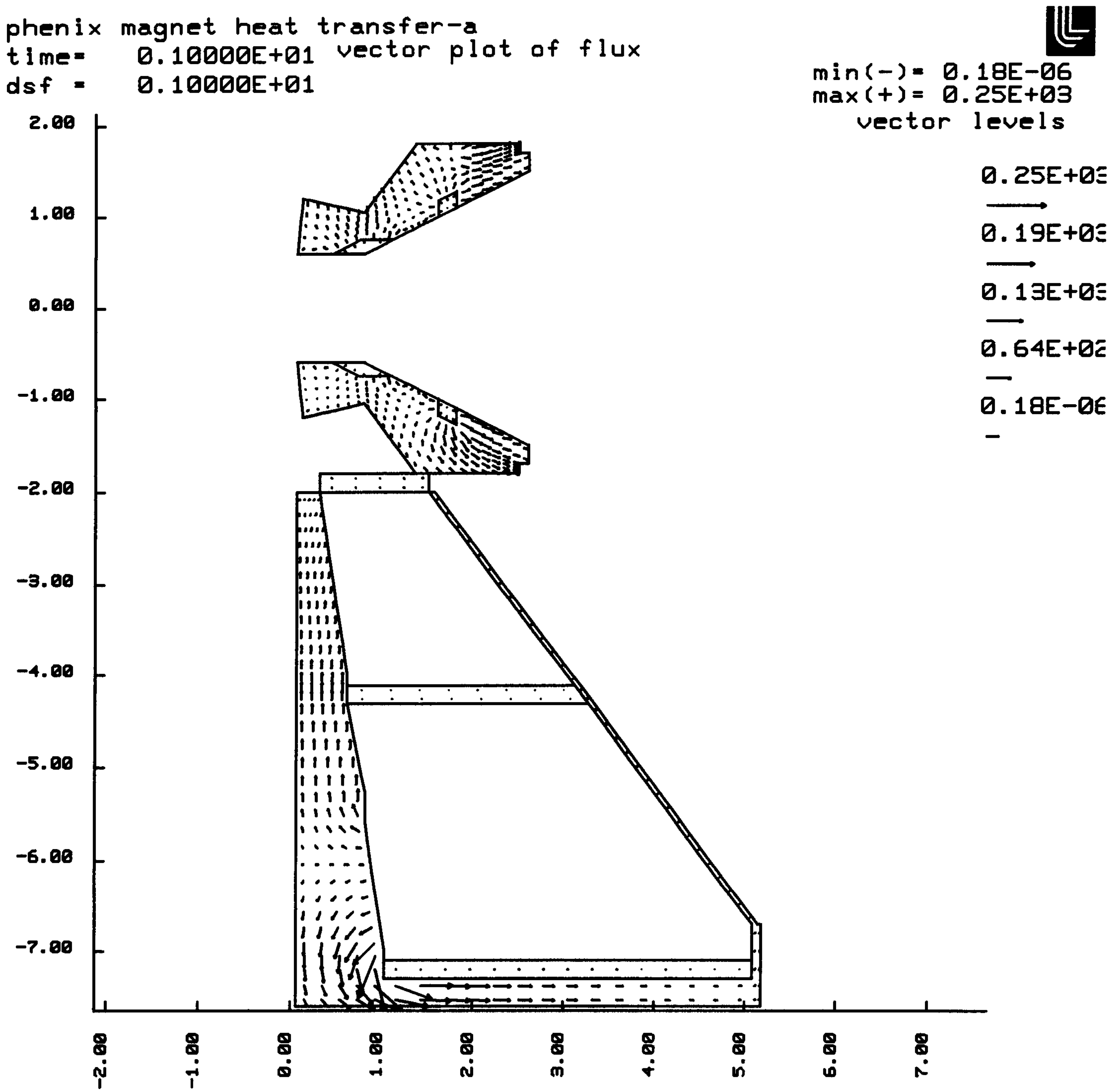


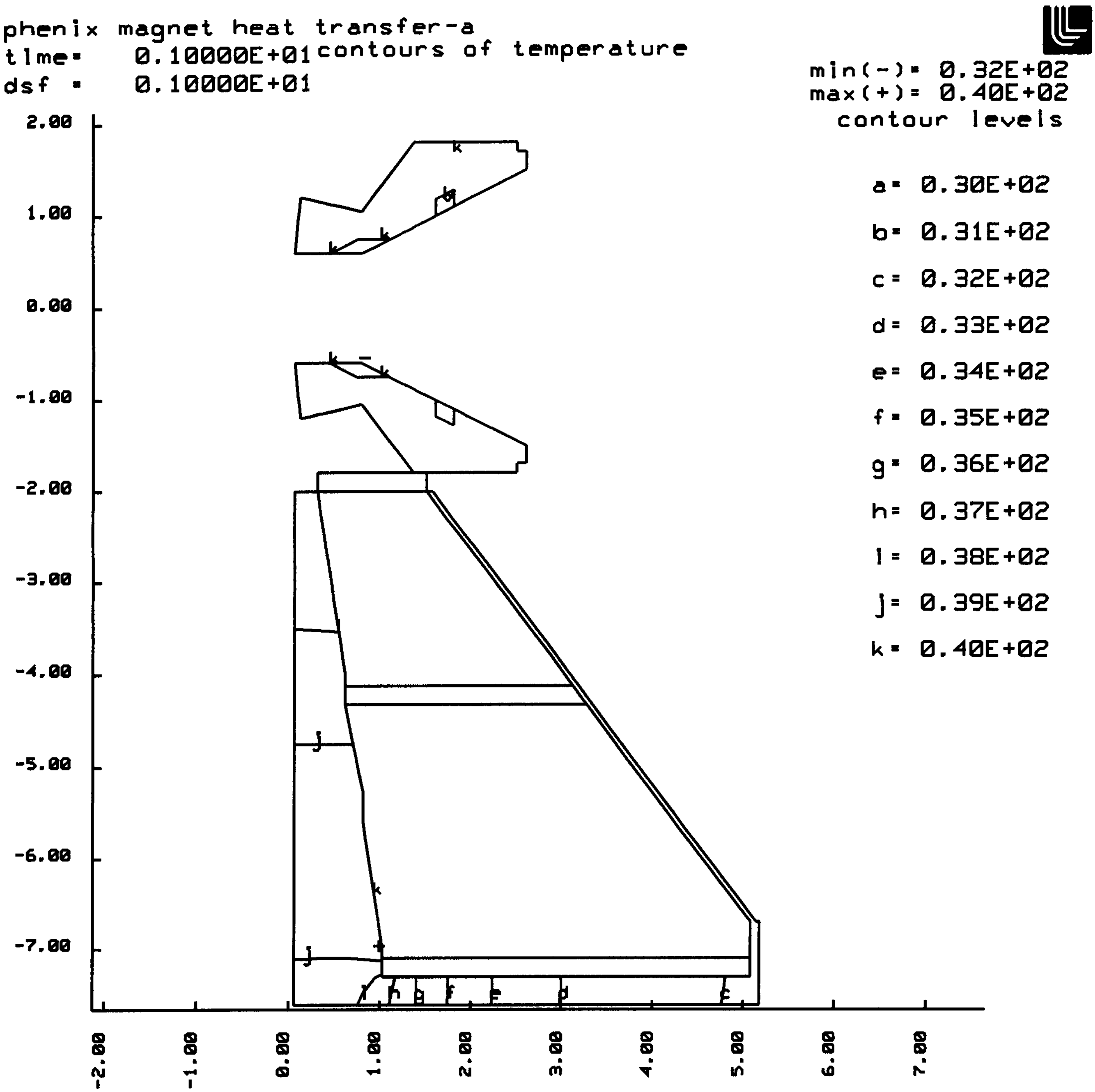
phenix magnet heat transfer - 9
time= 0.10000E+01 vector plot of flux
dsf = 0.10000E+01
min(-)= 0.22E-05
max(+)= 0.13E+04
vector levels
0.13E+04
0.96E+03
0.64E+03
0.32E+03
0.22E-05
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
-7.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00


phenix magnet heat transfer - 9
time= 0.10000E+01 contours of temperature
dsf = 0.10000E+01
min(-)= 0.35E+02
max(+)= 0.60E+02
contour levels
a= 0.30E+02
b= 0.32E+02
c= 0.34E+02
d= 0.36E+02
e= 0.38E+02
f= 0.40E+02
g= 0.42E+02
h= 0.44E+02
i= 0.46E+02
j= 0.48E+02
k= 0.50E+02
l= 0.52E+02
m= 0.54E+02
n= 0.56E+02
o= 0.58E+02
p= 0.60E+02
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
-7.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00

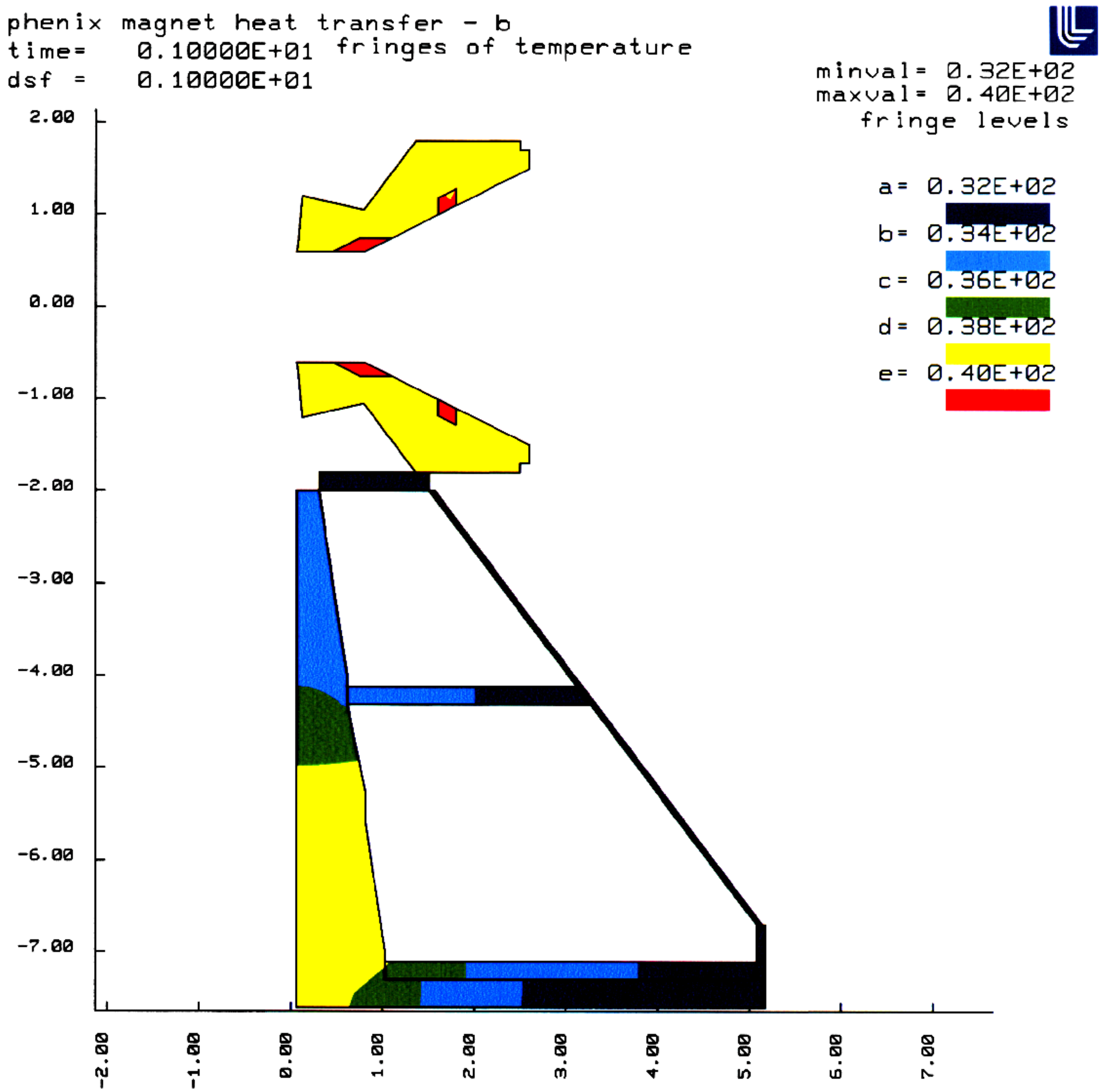


phenix magnet heat transfer-a
time= 0.10000E+01 fringes of temperature
dsf = 0.10000E+01
minval= 0.32E+02
maxval= 0.40E+02
fringe levels
a= 0.32E+02
b= 0.34E+02
c= 0.36E+02
d= 0.38E+02
e= 0.40E+02
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
-7.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00

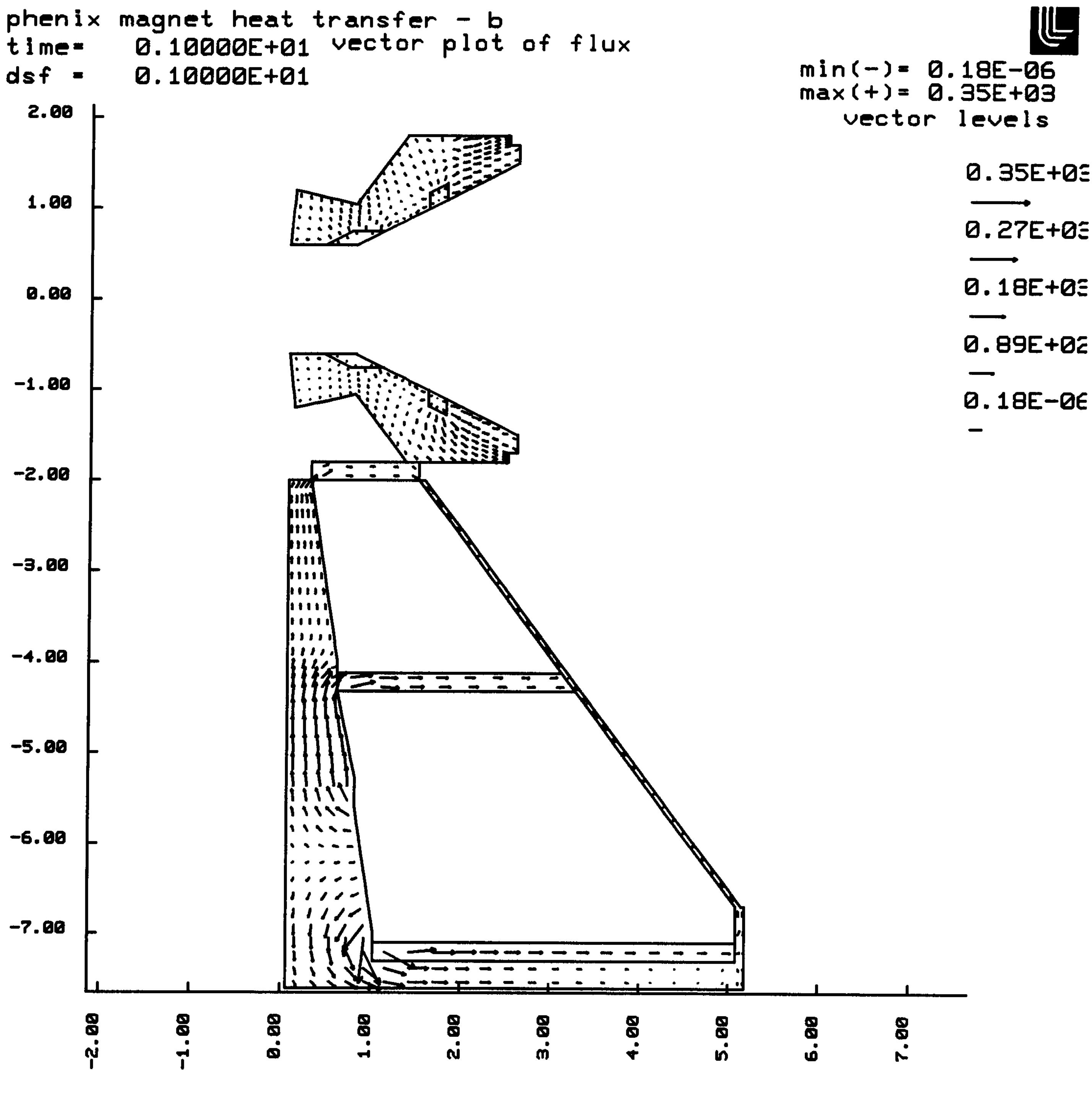

phenix magnet heat transfer-a
time= 0.10000E+01
dsf = 0.10000E+01
vector plot of flux
min(-)= 0.18E-06
max(+)= 0.25E+03
vector levels
0.25E+03
0.19E+03
0.13E+03
0.64E+02
0.18E-06
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
-7.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00



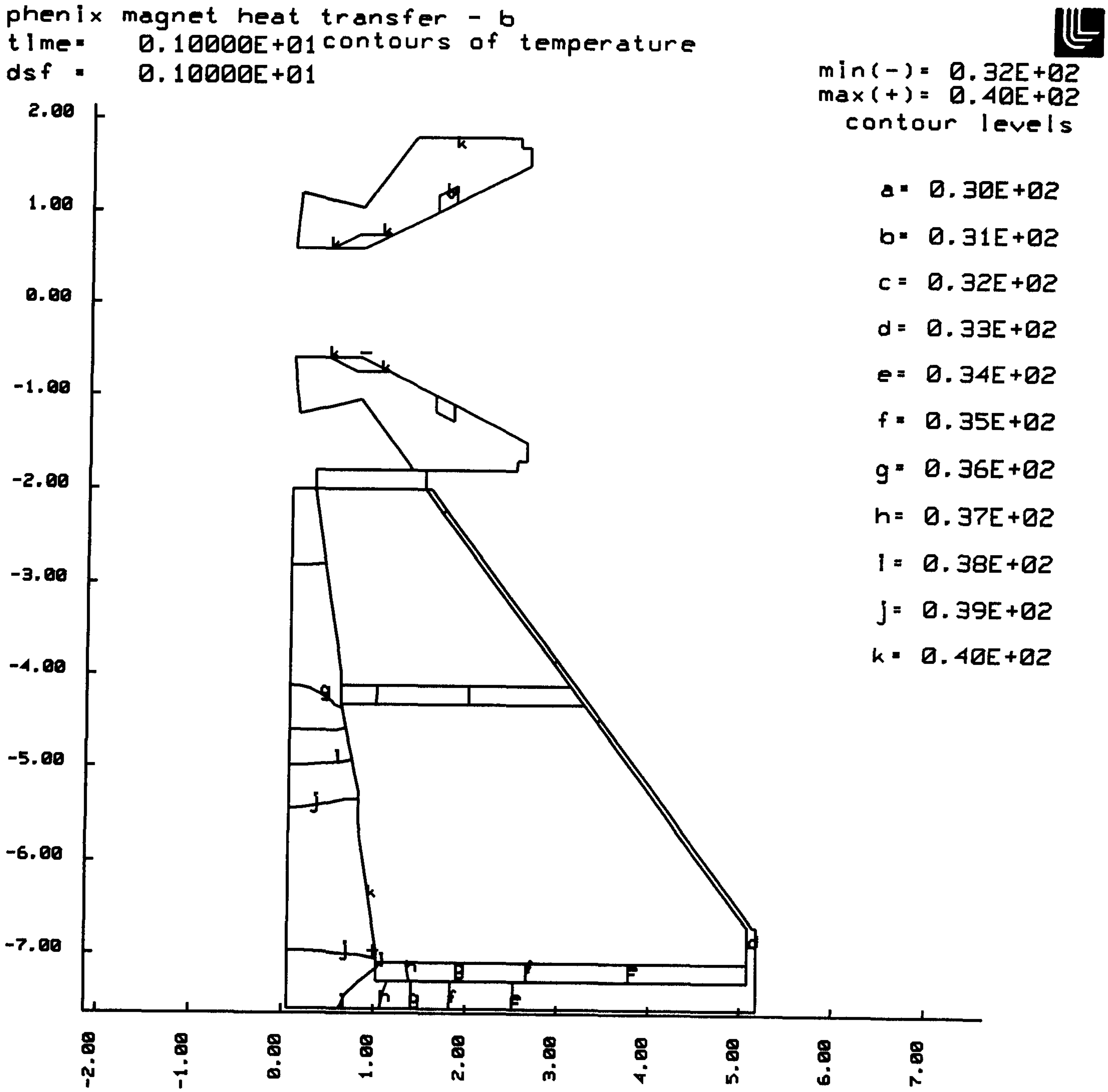
phenix magnet heat transfer-a
contours of temperature
time= 0.10000E+01
dsf = 0.10000E+01
min(-)= 0.32E+02
max(+)= 0.40E+02
contour levels
a= 0.30E+02
b= 0.31E+02
c= 0.32E+02
d= 0.33E+02
e= 0.34E+02
f= 0.35E+02
g= 0.36E+02
h= 0.37E+02
i= 0.38E+02
j= 0.39E+02
k= 0.40E+02
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
-7.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00



phenix magnet heat transfer - b
time= 0.10000E+01 fringes of temperature
dsf = 0.10000E+01
minval= 0.32E+02
maxval= 0.40E+02
fringe levels
a= 0.32E+02
b= 0.34E+02
c= 0.36E+02
d= 0.38E+02
e= 0.40E+02
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
-7.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00



phenix magnet heat transfer - b
time= 0.10000E+01 vector plot of flux
dsf = 0.10000E+01
min(-)= 0.18E-06
max(+)= 0.35E+03
vector levels
0.35E+03
0.27E+03
0.18E+03
0.89E+02
0.18E-06
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
-7.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00



phenix magnet heat transfer - b
time= 0.10000E+01 contours of temperature
dsf = 0.10000E+01
min(-)= 0.32E+02
max(+)= 0.40E+02
contour levels
a= 0.30E+02
b= 0.31E+02
c= 0.32E+02
d= 0.33E+02
e= 0.34E+02
f= 0.35E+02
g= 0.36E+02
h= 0.37E+02
i= 0.38E+02
j= 0.39E+02
k= 0.40E+02
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
-7.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00

PHENIX DETECTOR MAGNETS
CENTRAL INNER COIL   STAIRCASE OPTION A
A. R. HARVEY   SEPTEMBER 9, 15, 21, 1992

Six double pancake, bifilar wound, coils wound to fit entirely within a limiting parallelogram.

AMP_TURNS := 280000   MMtoIN := 0.03937 $INtoFT := \frac{1}{12}$

SLOPE := 2.00   INtoMM := 25.4

Parallelogram coordinates in mm.....(600,450), (600,800), (900,1400), (900,1050)

MAX_COIL_THK := 50 **mm**

COND_INS := 0.050·INtoMM   COND_INS = 1.27 **mm**

GROUND_INS := 0.125·INtoMM   GROUND_INS = 3.175 **mm**

INTERLAYER_INS := 0.020·INtoMM   INTERLAYER_INS = 0.508 **mm**

INS_COND := 0.5·(MAX_COIL_THK − 2·GROUND_INS − INTERLAYER_INS)

INS_COND = 21.571 **mm**   COIL_HT_LIMIT := 250 **mm**

MAX_COIL_BUILD := COIL_HT_LIMIT − 2·GROUND_INS

$NO\_RADIAL\_COND := \frac{MAX\_COIL\_BUILD}{INS\_COND}$ NO_RADIAL_COND = 11.295

NO_RADIAL_COND := 11

TURNS_PER_PAN := 2·NO_RADIAL_COND   TURNS_PER_PAN = 22

TOTAL_TURNS := 6·TURNS_PER_PAN   TOTAL_TURNS = 132

$AMPS := ceil\left(\frac{AMP\_TURNS}{TOTAL\_TURNS}\right)$ AMPS = 2122

Set parameters and settup equations to solve for flow rate and water temperature rise

WATER_IN_TEMP := 20 **deg C**   PRESSURE_DROP := 60 **psi**

$G(P,L,D) := 68.5\cdot\left(\frac{P}{L}\right)^{0.56}\cdot D^{2.76}$ $W(L,A) := ceil(3.88\cdot A\cdot L)$

$R(L,A) := 8.15\cdot 10^{-6}\cdot\frac{L}{A}$

$F(I,G,R) := \left(\frac{16.28}{I}\right)^{2}\cdot\frac{G}{R}$

$\theta(T,F) := \frac{0.00393\cdot T + 0.992}{F - 0.001965}$

Pancake 1 is the smallest diameter pancake coil. Pancake 6 is the largest. Pancake 6 has the longest fluid path, pancake 1, the shortest.

i := 1.. 6   BASE_IR := 450

PHENIX DETECTOR MAGNETS
CENTRAL INNER COIL   STAIRCASE OPTION A
A. R. HARVEY   SEPTEMBER 9, 15, 21, 1992

$COIL\_ID_i := 2\cdot(BASE\_IR + 100\cdot i)$

$COIL\_OD_i := COIL\_ID_i + 2\cdot(2\ GROUND\_INS + NO\_RADIAL\_COND\cdot INS\_COND)$

$MEAN\_DIA_i := 0.5\cdot(COIL\_ID_i + COIL\_OD_i)$

$PATH\_LENGTH_i := \pi\cdot MEAN\_DIA_i\cdot NO\_RADIAL\_COND$

$COND\_OD := INS\_COND - COND\_INS$ $COND\_OD = 20.301$ mm   (.80")

$COND\_BORE := INtoMM\cdot(0.7\cdot MMtoIN\cdot COND\_OD - 0.055)$ $COND\_BORE = 12.814$ mm   (.505" ⌀)

$P := PRESSURE\_DROP$ $L_i := PATH\_LENGTH_i\cdot MMtoIN\cdot INtoFT$

$D := COND\_BORE\cdot MMtoIN$ $A := (COND\_OD\cdot MMtoIN)^2 - 0.25\cdot\pi\cdot D^2$

$GPM_i := G(P, L_i, D)$

$RESIST_i := R(L_i, A)$

$TF_i := F(AMPS, GPM_i, RESIST_i)$

$WATER\_OUT\_TEMP_i := \theta(WATER\_IN\_TEMP, TF_i) + WATER\_IN\_TEMP$

$AVE\_TEMP_i := 0.5\cdot(WATER\_IN\_TEMP + WATER\_OUT\_TEMP_i)$

$OP\_RESIST_i := RESIST_i\cdot[1 + 0.00393\cdot(AVE\_TEMP_i - 20)]$

$TOTAL\_RESIST := 2\cdot\sum_i OP\_RESIST_i$ $TOTAL\_RESIST = 0.048$

$VOLTS := ceil(AMPS\cdot TOTAL\_RESIST)$ $VOLTS = 102$

$KWATTS := ceil(0.001\cdot AMPS\cdot VOLTS)$ $KWATTS = 217$ ✓

$CON\_LENGTH := 2\cdot ceil\left(\sum_i L_i\right)$ $CON\_LENGTH = 2510$ ~~mm~~
AH

$PAN\_NO_i := i$

$WEIGHT_i := 2\cdot W(L_i, A)$

double pancake

PHENIX DETECTOR MAGNETS
CENTRAL INNER COIL STAIRCASE OPTION A
A. R. HARVEY SEPTEMBER 9, 15, 21, 1992

PAN_NO_i	GPM_i	$WATER\_OUT\_TEMP_i$	AVE_TEMP_i	$WEIGHT_i$	$COIL\_ID_i$	$COIL\_OD_i$
1	6.151	28.495	24.248	520	1100	1587.262
2	5.691	30.589	25.294	598	1300	1787.262
3	5.315	32.857	26.429	674	1500	1987.262
4	5.002	35.297	27.649	752	1700	2187.262
5	4.735	37.906	28.953	828	1900	2387.262
6	4.504	40.68	30.34	906	2100	2587.262

*2 for total flow for coil ~ 63gpm/coil.

4278 lbs.

Weight is in pounds. Temperatures are degrees C. Coil ID and OD are in mm.

SUMMARY

CONDUCTOR

$COND\_OD = 20.301$ mm $COND\_BORE = 12.814$ mm

$TURNS\_PER\_PAN = 22$

ELECTRICAL

$AMPS = 2122$ $VOLTS = 102$ $KWATTS = 217$

OPERATING PARAMETERS

$PRESSURE\_DROP = 60$ psi $WATER\_IN\_TEMP = 20$ deg C

Solve for the maximum allowable current for a water outlet temperature of 80 degrees C.

Pancake coil 6 must satisfy this requirement. The remaining 5 pancake coils will have water outlet temperatures which are less.

$$CURRENT(G,\theta,R) := 16.28\cdot\sqrt{\frac{G\cdot\theta}{R}}$$

$WATER\_OUT\_TEMP_6 := 76.1$ deg C **(Reduced for roundoff adjustment)**

$$AVE\_TEMP_6 := 0.5\cdot(WATER\_IN\_TEMP + WATER\_OUT\_TEMP_6)$$

$$OP\_RESIST_6 := RESIST_6\cdot[1 + 0.00393\cdot(AVE\_TEMP_6 - 20)]$$

$$MAX\_AMPS := CURRENT(GPM_6, WATER\_OUT\_TEMP_6 - WATER\_IN\_TEMP, OP\_RESIST_6)$$

$AMPS := floor(MAX\_AMPS)$ $AMPS = 3496$

$$TF_i := F(AMPS, GPM_i, RESIST_i)$$

$$WATER\_OUT\_TEMP_i := \theta(WATER\_IN\_TEMP, TF_i) + WATER\_IN\_TEMP$$

$$AVE\_TEMP_i := 0.5\cdot(WATER\_IN\_TEMP + WATER\_OUT\_TEMP_i)$$

$OP\_RESIST_i := RESIST_i \cdot \left[1 + 0.00393 \cdot \left(AVE\_TEMP_i - 20 \right) \right]$

$TOTAL\_RESIST := 2 \cdot \left(\sum_i OP\_RESIST_i \right)$ $TOTAL\_RESIST = 0.051$ **Ohms**

$VOLTS := ceil(AMPS \cdot TOTAL\_RESIST)$ $VOLTS = 177$

$KWATTS := ceil(0.001 \cdot AMPS \cdot VOLTS)$ $KWATTS = 619$

$CON\_LENGTH := ceil\left(2 \cdot \sum_i L_i \right)$ $CON\_LENGTH = 2309$ ft

PAN_NO_i	$WATER\_OUT\_TEMP_i$	AVE_TEMP_i	$WEIGHT_i$	$COIL\_ID_i$	$COIL\_OD_i$
1	43.692	31.846	520	1100	1587.262
2	49.731	34.865	598	1300	1787.262
3	56.369	38.185	674	1500	1987.262
4	63.62	41.81	752	1700	2187.262
5	71.502	45.751	828	1900	2387.262
6	80.038	50.019	906	2100	2587.262

4278 lbs

Weight is in pounds. Temperatures are degrees C. Coil ID and OD are in mm.

SUMMARY

CONDUCTOR

$COND\_OD = 20.301$ **mm** $COND\_BORE = 12.814$ **mm**

$TURNS\_PER\_PAN = 22$ $TOTAL\_TURNS = 132$

ELECTRICAL

$AMPS = 3496$ $VOLTS = 177$ $KWATTS = 619$ ✓

$MAX\_AMP\_TURNS := AMPS \cdot TOTAL\_TURNS$ $MAX\_AMP\_TURNS = 4.615 \cdot 10^5$

OPERATING PARAMETERS

$PRESSURE\_DROP = 60$ **psi** $WATER\_IN\_TEMP = 20$ **deg C**

$MAX\_WATER\_OUT\_TEMP := floor\left(WATER\_OUT\_TEMP_6 \right)$

$MAX\_WATER\_OUT\_TEMP = 80$ **deg C**

PHENIX DETECTOR MAGNETS
CENTRAL INNER COIL STAIRCASE OPTION B
A. R. HARVEY SEPTEMBER 18, 1992

straddle option

Six double pancake, bifilar wound, coils wound to straddle the lower boundary but otherwise fit within a limiting parallelogram.

AMP_TURNS := 280000 MMtoIN := 0.03937 $INtoFT := \frac{1}{12}$

SLOPE := 2.00 INtoMM := 25.4

Parallelogram coordinates in mm.....(600,450), (600,800), (900,1400), (900,1050)

MAX_COIL_THK := 50 **mm**

COND_INS := 0.050·INtoMM COND_INS = 1.27 **mm**

GROUND_INS := 0.125·INtoMM GROUND_INS = 3.175 **mm**

INTERLAYER_INS := 0.020·INtoMM INTERLAYER_INS = 0.508 **mm**

INS_COND := 0.5·(MAX_COIL_THK − 2·GROUND_INS − INTERLAYER_INS)

INS_COND = 21.571 **mm** COIL_HT_LIMIT := 300 **mm**

MAX_COIL_BUILD := COIL_HT_LIMIT − 2·GROUND_INS

$NO\_RADIAL\_COND := \frac{MAX\_COIL\_BUILD}{INS\_COND}$ NO_RADIAL_COND = 13.613

NO_RADIAL_COND := 13

TURNS_PER_PAN := 2·NO_RADIAL_COND TURNS_PER_PAN = 26

TOTAL_TURNS := 6·TURNS_PER_PAN TOTAL_TURNS = 156

$AMPS := ceil\left(\frac{AMP\_TURNS}{TOTAL\_TURNS}\right)$ AMPS = 1795

Set parameters and settup equations to solve for flow rate and water temperature rise

WATER_IN_TEMP := 20 **deg C** PRESSURE_DROP := 60 **psi**

$G(P,L,D) := 68.5\cdot\left(\frac{P}{L}\right)^{0.56}\cdot D^{2.76}$ W(L, A) := ceil(3.88·A·L)

$R(L,A) := 8.15\cdot 10^{-6}\cdot\frac{L}{A}$

$F(I,G,R) := \left(\frac{16.28}{I}\right)^{2}\cdot\frac{G}{R}$

$\theta(T,F) := \frac{0.00393\cdot T + 0.992}{F - 0.001965}$

Pancake 1 is the smallest diameter pancake coil. Pancake 6 is the largest. Pancake 6 has the longest fluid path, pancake 1, the shortest.

i := 1.. 6 BASE_IR := 400 **mm**

$COIL\_ID_i := 2\cdot(BASE\_IR + 100\cdot i)$

$COIL\_OD_i := COIL\_ID_i + 2\cdot(2\ GROUND\_INS + NO\_RADIAL\_COND\cdot INS\_COND)$

$MEAN\_DIA_i := 0.5\cdot(COIL\_ID_i + COIL\_OD_i)$

$PATH\_LENGTH_i := \pi\cdot MEAN\_DIA_i\cdot NO\_RADIAL\_COND$

$COND\_OD := INS\_COND - COND\_INS$ $COND\_OD = 20.301$ **mm**

$COND\_BORE := INtoMM\cdot(0.7\cdot MMtoIN\cdot COND\_OD - 0.055)$ $COND\_BORE = 12.814$ **mm**

$P := PRESSURE\_DROP$ $L_i := PATH\_LENGTH_i\cdot MMtoIN\cdot INtoFT$

$D := COND\_BORE\cdot MMtoIN$ $A := (COND\_OD\cdot MMtoIN)^2 - 0.25\cdot\pi\cdot D^2$

$GPM_i := G(P, L_i, D)$

$RESIST_i := R(L_i, A)$

$TF_i := F(AMPS, GPM_i, RESIST_i)$

$WATER\_OUT\_TEMP_i := \theta(WATER\_IN\_TEMP, TF_i) + WATER\_IN\_TEMP$

$AVE\_TEMP_i := 0.5\cdot(WATER\_IN\_TEMP + WATER\_OUT\_TEMP_i)$

$OP\_RESIST_i := RESIST_i\cdot[1 + 0.00393\cdot(AVE\_TEMP_i - 20)]$

$TOTAL\_RESIST := 2\cdot\sum_i OP\_RESIST_i$ $TOTAL\_RESIST = 0.055$

$VOLTS := ceil(AMPS\cdot TOTAL\_RESIST)$ $VOLTS = 99$

$KWATTS := ceil(0.001\cdot AMPS\cdot VOLTS)$ $KWATTS = 178$

$CON\_LENGTH := ceil\left(\sum_i L_i\right)\cdot 2$ $CON\_LENGTH = 2874$

$PAN\_NO_i := i$

$WEIGHT_i := 2\cdot W(L_i, A)$

PHENIX DETECTOR MAGNETS
CENTRAL INNER COIL STAIRCASE OPTION B
A. R. HARVEY SEPTEMBER 18, 1992

PAN_NO_i	GPM_i	$WATER\_OUT\_TEMP_i$	AVE_TEMP_i	$WEIGHT_i$	$COIL\_ID_i$	$COIL\_OD_i$
1	5.739	27.359	23.679	588	1000	1573.546
2	5.293	29.251	24.625	680	1200	1773.546
3	4.931	31.306	25.653	770	1400	1973.546
4	4.632	33.519	26.759	862	1600	2173.546
5	4.377	35.887	27.943	954	1800	2373.546
6	4.159	38.407	29.204	1044	2000	2573.546

Weight is in pounds. Temperatures are degrees C. Coil ID and OD are in mm.

SUMMARY

CONDUCTOR

$COND\_OD = 20.301$ **mm** $COND\_BORE = 12.814$ **mm**

$TURNS\_PER\_PAN = 26$

ELECTRICAL

$AMPS = 1795$ $VOLTS = 99$ $KWATTS = 178$

OPERATING PARAMETERS

$PRESSURE\_DROP = 60$ **psi** $WATER\_IN\_TEMP = 20$ **deg C**

Solve for the maximum allowable current for a water outlet temperature of 80 degrees C.

Pancake coil 6 must satisfy this requirement. The remaining 5 pancake coils will have water outlet temperatures which are less.

$$CURRENT(G,\theta,R) := 16.28\cdot\sqrt{\frac{G\cdot\theta}{R}}$$

$WATER\_OUT\_TEMP_6 := 76.1$ **deg C** **(Reduced for roundoff adjustment)**

$$AVE\_TEMP_6 := 0.5\cdot\left(WATER\_IN\_TEMP + WATER\_OUT\_TEMP_6\right)$$

$$OP\_RESIST_6 := RESIST_6\cdot\left[1 + 0.00393\cdot\left(AVE\_TEMP_6 - 20\right)\right]$$

$$MAX\_AMPS := CURRENT\left(GPM_6, WATER\_OUT\_TEMP_6 - WATER\_IN\_TEMP, OP\_RESIST_6\right)$$

$AMPS := floor(MAX\_AMPS)$ $AMPS = 3128$

$$TF_i := F\left(AMPS, GPM_i, RESIST_i\right)$$

$$WATER\_OUT\_TEMP_i := \theta\left(WATER\_IN\_TEMP, TF_i\right) + WATER\_IN\_TEMP$$

$$AVE\_TEMP_i := 0.5\cdot\left(WATER\_IN\_TEMP + WATER\_OUT\_TEMP_i\right)$$

$OP\_RESIST_i := RESIST_i \cdot \left[1 + 0.00393 \cdot (AVE\_TEMP_i - 20) \right]$

$TOTAL\_RESIST := 2 \cdot \left(\sum_i OP\_RESIST_i \right)$ $TOTAL\_RESIST = 0.058$ **Ohms**

$VOLTS := ceil(AMPS \cdot TOTAL\_RESIST)$ $VOLTS = 181$

$KWATTS := ceil(0.001 \cdot AMPS \cdot VOLTS)$ $KWATTS = 567$

$CON\_LENGTH := ceil\left(2 \cdot \sum_i L_i \right)$ $CON\_LENGTH = 2873$ **ft**

PAN_NO_i	$WATER\_OUT\_TEMP_i$	AVE_TEMP_i	$WEIGHT_i$	$COIL\_ID_i$	$COIL\_OD_i$
1	42.979	31.49	588	1000	1573.546
2	49.098	34.549	680	1200	1773.546
3	55.847	37.924	770	1400	1973.546
4	63.238	41.619	862	1600	2173.546
5	71.289	45.645	954	1800	2373.546
6	80.028	50.014	1044	2000	2573.546

Weight is in pounds. Temperatures are degrees C. Coil ID and OD are in mm.

SUMMARY

CONDUCTOR

$COND\_OD = 20.301$ **mm** $COND\_BORE = 12.814$ **mm**

$TURNS\_PER\_PAN = 26$ $TOTAL\_TURNS = 156$

ELECTRICAL

$AMPS = 3128$ $VOLTS = 181$ $KWATTS = 567$

$MAX\_AMP\_TURNS := AMPS \cdot TOTAL\_TURNS$ $MAX\_AMP\_TURNS = 4.88 \cdot 10^5$

OPERATING PARAMETERS

$PRESSURE\_DROP = 60$ **psi** $WATER\_IN\_TEMP = 20$ **deg C**

$MAX\_WATER\_OUT\_TEMP := floor(WATER\_OUT\_TEMP_6)$

$MAX\_WATER\_OUT\_TEMP = 80$ **deg C**

PHENIX DETECTOR MAGNETS
CENTRAL INNER COIL   STAIRCASE OPTION C
A. R. HARVEY   SEPTEMBER 18, 1992

Six double pancake, bifilar wound, coils wound to straddle the upper and lower boundaries but otherwise fit within a limiting parallelogram.

$AMP\_TURNS := 280000$ $MMtoIN := 0.03937$ $INtoFT := \frac{1}{12}$

$SLOPE := 2.00$ $INtoMM := 25.4$

Parallelogram coordinates in mm.....(600,450), (600,800), (900,1400), (900,1050)

$MAX\_COIL\_THK := 50$ **mm**

$COND\_INS := 0.050 \cdot INtoMM$ $COND\_INS = 1.27$ **mm**

$GROUND\_INS := 0.125 \cdot INtoMM$ $GROUND\_INS = 3.175$ **mm**

$INTERLAYER\_INS := 0.020 \cdot INtoMM$ $INTERLAYER\_INS = 0.508$ **mm**

$INS\_COND := 0.5 \cdot (MAX\_COIL\_THK - 2 \cdot GROUND\_INS - INTERLAYER\_INS)$

$INS\_COND = 21.571$ **mm** $COIL\_HT\_LIMIT := 350$ **mm**

$MAX\_COIL\_BUILD := COIL\_HT\_LIMIT - 2 \cdot GROUND\_INS$

$NO\_RADIAL\_COND := \frac{MAX\_COIL\_BUILD}{INS\_COND}$ $NO\_RADIAL\_COND = 15.931$

$NO\_RADIAL\_COND := 16$

$TURNS\_PER\_PAN := 2 \cdot NO\_RADIAL\_COND$ $TURNS\_PER\_PAN = 32$

$TOTAL\_TURNS := 6 \cdot TURNS\_PER\_PAN$ $TOTAL\_TURNS = 192$

$AMPS := ceil\left(\frac{AMP\_TURNS}{TOTAL\_TURNS}\right)$ $AMPS = 1459$

Set parameters and settup equations to solve for flow rate and water temperature rise

$WATER\_IN\_TEMP := 20$ **deg C** $PRESSURE\_DROP := 60$ **psi**

$G(P,L,D) := 68.5 \cdot \left(\frac{P}{L}\right)^{0.56} \cdot D^{2.76}$ $W(L,A) := ceil(3.88 \cdot A \cdot L)$

$R(L,A) := 8.15 \cdot 10^{-6} \cdot \frac{L}{A}$

$F(I,G,R) := \left(\frac{16.28}{I}\right)^{2} \cdot \frac{G}{R}$

$\theta(T,F) := \frac{0.00393 \cdot T + 0.992}{F - 0.001965}$

Pancake 1 is the smallest diameter pancake coil. Pancake 6 is the largest. Pancake 6 has the longest fluid path, pancake 1, the shortest.

$i := 1..6$ $BASE\_IR := 400$ **mm**

$COIL\_ID_i := 2 \cdot (BASE\_IR + 100 \cdot i)$

$COIL\_OD_i := COIL\_ID_i + 2 \cdot (2\ GROUND\_INS + NO\_RADIAL\_COND \cdot INS\_COND)$

$MEAN\_DIA_i := 0.5 \cdot \left(COIL\_ID_i + COIL\_OD_i\right)$

$PATH\_LENGTH_i := \pi \cdot MEAN\_DIA_i \cdot NO\_RADIAL\_COND$

$COND\_OD := INS\_COND - COND\_INS$ $COND\_OD = 20.301$ mm

$COND\_BORE := INtoMM \cdot (0.7 \cdot MMtoIN \cdot COND\_OD - 0.055)$ $COND\_BORE = 12.814$ mm

$P := PRESSURE\_DROP$ $L_i := PATH\_LENGTH_i \cdot MMtoIN \cdot INtoFT$

$D := COND\_BORE \cdot MMtoIN$ $A := (COND\_OD \cdot MMtoIN)^2 - 0.25 \cdot \pi \cdot D^2$

$GPM_i := G\left(P, L_i, D\right)$

$RESIST_i := R\left(L_i, A\right)$

$TF_i := F\left(AMPS, GPM_i, RESIST_i\right)$

$WATER\_OUT\_TEMP_i := \theta\left(WATER\_IN\_TEMP, TF_i\right) + WATER\_IN\_TEMP$

$AVE\_TEMP_i := 0.5 \cdot \left(WATER\_IN\_TEMP + WATER\_OUT\_TEMP_i\right)$

$OP\_RESIST_i := RESIST_i \cdot \left[1 + 0.00393 \cdot \left(AVE\_TEMP_i - 20\right)\right]$

$TOTAL\_RESIST := 2 \cdot \sum_i OP\_RESIST_i$ $TOTAL\_RESIST = 0.07$

$VOLTS := ceil(AMPS \cdot TOTAL\_RESIST)$ $VOLTS = 102$

$KWATTS := ceil(0.001 \cdot AMPS \cdot VOLTS)$ $KWATTS = 149$

$CON\_LENGTH := ceil\left(\sum_i L_i\right) \cdot 2$ $CON\_LENGTH = 3666$

$PAN\_NO_i := i$

$WEIGHT_i := 2 \cdot W\left(L_i, A\right)$

PAN_NO_i	GPM_i	$WATER\_OUT\_TEMP_i$	AVE_TEMP_i	$WEIGHT_i$	$COIL\_ID_i$	$COIL\_OD_i$
1	4.97	27.255	23.627	760	1000	1702.972
2	4.601	29.027	24.513	872	1200	1902.972
3	4.299	30.944	25.472	984	1400	2102.972
4	4.046	33.003	26.501	1098	1600	2302.972
5	3.831	35.2	27.6	1210	1800	2502.972
6	3.645	37.534	28.767	1322	2000	2702.972

Weight is in pounds. Temperatures are degrees C. Coil ID and OD are in mm.

SUMMARY

CONDUCTOR

COND_OD = 20.301 **mm** COND_BORE = 12.814 **mm**

TURNS_PER_PAN = 32

ELECTRICAL

AMPS = 1459 VOLTS = 102 KWATTS = 149

OPERATING PARAMETERS

PRESSURE_DROP = 60 **psi** WATER_IN_TEMP = 20 **deg C**

Solve for the maximum allowable current for a water outlet temperature of 80 degrees C.

Pancake coil 6 must satisfy this requirement. The remaining 5 pancake coils will have water outlet temperatures which are less.

$$CURRENT(G,\theta,R) := 16.28\cdot\sqrt{\frac{G\cdot\theta}{R}}$$

$WATER\_OUT\_TEMP_6 := 76.1$ **deg C** **(Reduced for roundoff adjustment)**

$$AVE\_TEMP_6 := 0.5\cdot\left(WATER\_IN\_TEMP + WATER\_OUT\_TEMP_6\right)$$

$$OP\_RESIST_6 := RESIST_6\cdot\left[1 + 0.00393\cdot\left(AVE\_TEMP_6 - 20\right)\right]$$

$$MAX\_AMPS := CURRENT\left(GPM_6, WATER\_OUT\_TEMP_6 - WATER\_IN\_TEMP, OP\_RESIST_6\right)$$

$AMPS := floor(MAX\_AMPS)$ AMPS = 2603

$$TF_i := F\left(AMPS, GPM_i, RESIST_i\right)$$

$$WATER\_OUT\_TEMP_i := \theta\left(WATER\_IN\_TEMP, TF_i\right) + WATER\_IN\_TEMP$$

$$AVE\_TEMP_i := 0.5\cdot\left(WATER\_IN\_TEMP + WATER\_OUT\_TEMP_i\right)$$

$OP\_RESIST_i := RESIST_i \cdot [1 + 0.00393 \cdot (AVE\_TEMP_i - 20)]$

$TOTAL\_RESIST := 2 \cdot \left(\sum_i OP\_RESIST_i\right)$ $TOTAL\_RESIST = 0.074$ **Ohms**

$VOLTS := ceil(AMPS \cdot TOTAL\_RESIST)$ $VOLTS = 193$

$KWATTS := ceil(0.001 \cdot AMPS \cdot VOLTS)$ $KWATTS = 503$

$CON\_LENGTH := ceil\left(2 \cdot \sum_i L_i\right)$ $CON\_LENGTH = 3665$ **ft**

PAN_NO_i	$WATER\_OUT\_TEMP_i$	AVE_TEMP_i	$WEIGHT_i$	$COIL\_ID_i$	$COIL\_OD_i$
1	43.784	31.892	760	1000	1702.972
2	49.81	34.905	872	1200	1902.972
3	56.432	38.216	984	1400	2102.972
4	63.663	41.831	1098	1600	2302.972
5	71.52	45.76	1210	1800	2502.972
6	80.027	50.014	1322	2000	2702.972

Weight is in pounds. Temperatures are degrees C. Coil ID and OD are in mm.

SUMMARY

CONDUCTOR

$COND\_OD = 20.301$ **mm** $COND\_BORE = 12.814$ **mm**

$TURNS\_PER\_PAN = 32$ $TOTAL\_TURNS = 192$

ELECTRICAL

$AMPS = 2603$ $VOLTS = 193$ $KWATTS = 503$

$MAX\_AMP\_TURNS := AMPS \cdot TOTAL\_TURNS$ $MAX\_AMP\_TURNS = 4.998 \cdot 10^5$

OPERATING PARAMETERS

$PRESSURE\_DROP = 60$ **psi** $WATER\_IN\_TEMP = 20$ **deg C**

$MAX\_WATER\_OUT\_TEMP := floor(WATER\_OUT\_TEMP_6)$

$MAX\_WATER\_OUT\_TEMP = 80$ **deg C**

PHENIX DETECTOR MAGNETS
CENTRAL OUTER COIL   STAIRCASE OPTION A
A. R. HARVEY   SEPTEMBER 9, 15, 21, 1992

Six double pancake, bifilar wound, coils wound to fit entirely within a limiting parallelogram.

AMP_TURNS := 225000   MMtoIN := 0.03937 $INtoFT := \frac{1}{12}$

SLOPE := 2.00   INtoMM := 25.4

Parallelogram coordinates in mm.....(1050,1350), (1050,1700), (1350,2300), (1350,1950)

MAX_COIL_THK := 50 **mm**

COND_INS := 0.050·INtoMM   COND_INS = 1.27 **mm**

GROUND_INS := 0.125·INtoMM   GROUND_INS = 3.175 **mm**

INTERLAYER_INS := 0.020·INtoMM   INTERLAYER_INS = 0.508 **mm**

INS_COND := 0.5·(MAX_COIL_THK – 2·GROUND_INS – INTERLAYER_INS)

INS_COND = 21.571 **mm**   COIL_HT_LIMIT := 250 **mm**

MAX_COIL_BUILD := COIL_HT_LIMIT – 2·GROUND_INS

$$NO\_RADIAL\_COND := \frac{MAX\_COIL\_BUILD}{INS\_COND}$$ NO_RADIAL_COND = 11.295

NO_RADIAL_COND := 11

TURNS_PER_PAN := 2·NO_RADIAL_COND   TURNS_PER_PAN = 22

TOTAL_TURNS := 6·TURNS_PER_PAN   TOTAL_TURNS = 132

$$AMPS := ceil\left(\frac{AMP\_TURNS}{TOTAL\_TURNS}\right)$$ AMPS = 1705

Set parameters and settup equations to solve for flow rate and water temperature rise

WATER_IN_TEMP := 20 **deg C**   PRESSURE_DROP := 60 **psi**

$$G(P,L,D) := 68.5\cdot\left(\frac{P}{L}\right)^{0.56}\cdot D^{2.76}$$ $W(L,A) := ceil(3.88\cdot A\cdot L)$

$$R(L,A) := 8.15\cdot 10^{-6}\cdot\frac{L}{A}$$

$$F(I,G,R) := \left(\frac{16.28}{I}\right)^{2}\cdot\frac{G}{R}$$

$$\theta(T,F) := \frac{0.00393\cdot T + 0.992}{F - 0.001965}$$

Pancake 1 is the smallest diameter pancake coil. Pancake 6 is the largest. Pancake 6 has the longest fluid path, pancake 1, the shortest.

i := 1.. 6   BASE_IR := 1350 **mm**

$COIL\_ID_i := 2\cdot(BASE\_IR + 100\cdot i)$

$COIL\_OD_i := COIL\_ID_i + 2\cdot(2\ GROUND\_INS + NO\_RADIAL\_COND\cdot INS\_COND)$

$MEAN\_DIA_i := 0.5\cdot(COIL\_ID_i + COIL\_OD_i)$

$PATH\_LENGTH_i := \pi\cdot MEAN\_DIA_i\cdot NO\_RADIAL\_COND$

$COND\_OD := INS\_COND - COND\_INS$ $COND\_OD = 20.301$ mm

$COND\_BORE := INtoMM\cdot(0.7\cdot MMtoIN\cdot COND\_OD - 0.055)$ $COND\_BORE = 12.814$ mm

$P := PRESSURE\_DROP$ $L_i := PATH\_LENGTH_i\cdot MMtoIN\cdot INtoFT$

$D := COND\_BORE\cdot MMtoIN$ $A := (COND\_OD\cdot MMtoIN)^2 - 0.25\cdot\pi\cdot D^2$

$GPM_i := G(P, L_i, D)$

$RESIST_i := R(L_i, A)$

$TF_i := F(AMPS, GPM_i, RESIST_i)$

$WATER\_OUT\_TEMP_i := \theta(WATER\_IN\_TEMP, TF_i) + WATER\_IN\_TEMP$

$AVE\_TEMP_i := 0.5\cdot(WATER\_IN\_TEMP + WATER\_OUT\_TEMP_i)$

$OP\_RESIST_i := RESIST_i\cdot[1 + 0.00393\cdot(AVE\_TEMP_i - 20)]$

$TOTAL\_RESIST := 2\cdot\sum_i OP\_RESIST_i$ $TOTAL\_RESIST = 0.097$

$VOLTS := ceil(AMPS\cdot TOTAL\_RESIST)$ $VOLTS = 166$

$KWATTS := ceil(0.001\cdot AMPS\cdot VOLTS)$ $KWATTS = 284$

$CON\_LENGTH := ceil\left(2\cdot\sum_i L_i\right)$ $CON\_LENGTH = 4958$ ft

1511m

$PAN\_NO_i := i$

$WEIGHT_i := 2\cdot W(L_i, A)$

PHENIX DETECTOR MAGNETS
CENTRAL OUTER COIL   STAIRCASE OPTION A
A. R. HARVEY   SEPTEMBER 9, 15, 21, 1992

PAN_NO_i	GPM_i	$WATER\_OUT\_TEMP_i$	AVE_TEMP_i	$WEIGHT_i$	$COIL\_ID_i$	$COIL\_OD_i$
1	3.821	41.126	30.563	1214	2900	3387.262
2	3.691	43.352	31.676	1292	3100	3587.262
3	3.573	45.671	32.836	1370	3300	3787.262
4	3.465	48.085	34.043	1446	3500	3987.262
5	3.366	50.594	35.297	1524	3700	4187.262
6	3.274	53.198	36.599	1602	3900	4387.262

21.19 x 2 = 42.38 gpm   8448 lbs (3840 kg)

Weight is in pounds. Temperatures are degrees C. Coil ID and OD are in mm.

SUMMARY

CONDUCTOR

$COND\_OD = 20.301$ mm $COND\_BORE = 12.814$ mm

$TURNS\_PER\_PAN = 22$

ELECTRICAL

$AMPS = 1705$ $VOLTS = 166$ $KWATTS = 284$

OPERATING PARAMETERS

$PRESSURE\_DROP = 60$ psi $WATER\_IN\_TEMP = 20$ deg C

Solve for the maximum allowable current for a water outlet temperature of 80 degrees C.

Pancake coil 6 must satisfy this requirement. The remaining 5 pancake coils will have water outlet temperatures which are less.

$$CURRENT(G,\theta,R) := 16.28\cdot\sqrt{\frac{G\cdot\theta}{R}}$$

$WATER\_OUT\_TEMP_6 := 76.1$ deg C   (Reduced for roundoff adjustment)

$$AVE\_TEMP_6 := 0.5\cdot\left(WATER\_IN\_TEMP + WATER\_OUT\_TEMP_6\right)$$

$$OP\_RESIST_6 := RESIST_6\cdot\left[1 + 0.00393\cdot\left(AVE\_TEMP_6 - 20\right)\right]$$

$$MAX\_AMPS := CURRENT\left(GPM_6, WATER\_OUT\_TEMP_6 - WATER\_IN\_TEMP, OP\_RESIST_6\right)$$

$AMPS := floor(MAX\_AMPS)$ $AMPS = 2241$

$$TF_i := F\left(AMPS, GPM_i, RESIST_i\right)$$

$$WATER\_OUT\_TEMP_i := \theta\left(WATER\_IN\_TEMP, TF_i\right) + WATER\_IN\_TEMP$$

$$AVE\_TEMP_i := 0.5\cdot\left(WATER\_IN\_TEMP + WATER\_OUT\_TEMP_i\right)$$

$OP\_RESIST_i := RESIST_i \cdot \left[1 + 0.00393 \cdot \left(AVE\_TEMP_i - 20 \right) \right]$

$TOTAL\_RESIST := 2 \cdot \sum_i OP\_RESIST_i$ $TOTAL\_RESIST = 0.101$ **Ohms**

$VOLTS := ceil(AMPS \cdot TOTAL\_RESIST)$ $VOLTS = 227$

$KWATTS := ceil(0.001 \cdot AMPS \cdot VOLTS)$ $KWATTS = 509$

$CON\_LENGTH := ceil\left(2 \cdot \sum_i L_i \right)$ $CON\_LENGTH = 4958$

PAN_NO_i	$WATER\_OUT\_TEMP_i$	AVE_TEMP_i	$WEIGHT_i$	$COIL\_ID_i$	$COIL\_OD_i$
1	57.557	38.778	1214	2900	3387.262
2	61.64	40.82	1292	3100	3587.262
3	65.923	42.961	1370	3300	3787.262
4	70.409	45.205	1446	3500	3987.262
5	75.104	47.552	1524	3700	4187.262
6	80.012	50.006	1602	3900	4387.262

Weight is in pounds. Temperatures are degrees C. Coil ID and OD are in mm.

SUMMARY

CONDUCTOR

$COND\_OD = 20.301$ **mm** $COND\_BORE = 12.814$ **mm**

$TURNS\_PER\_PAN = 22$ $TOTAL\_TURNS = 132$

ELECTRICAL

$AMPS = 2241$ $VOLTS = 227$ $KWATTS = 509$

$MAX\_AMP\_TURNS := AMPS \cdot TOTAL\_TURNS$ $MAX\_AMP\_TURNS = 2.958 \cdot 10^5$

OPERATING PARAMETERS

$PRESSURE\_DROP = 60$ **psi** $WATER\_IN\_TEMP = 20$ **deg C**

$MAX\_WATER\_OUT\_TEMP := floor\left(WATER\_OUT\_TEMP_6 \right)$

$MAX\_WATER\_OUT\_TEMP = 80$ **deg C**

PHENIX DETECTOR MAGNETS
CENTRAL OUTER COIL STAIRCASE OPTION B
A. R. HARVEY SEPTEMBER 21, 1992

Six double pancake, bifilar wound, coils wound to straddle the lower boundary but otherwise fit within a limiting parallelogram.

$AMP\_TURNS := 225000$ $MMtoIN := 0.03937$ $INtoFT := \frac{1}{12}$

$SLOPE := 2.00$ $INtoMM := 25.4$

Parallelogram coordinates in mm.....(1050,1350), (1050,1700), (1350,2300), (1350,1950)

$MAX\_COIL\_THK := 50$ **mm**

$COND\_INS := 0.050 \cdot INtoMM$ $COND\_INS = 1.27$ **mm**

$GROUND\_INS := 0.125 \cdot INtoMM$ $GROUND\_INS = 3.175$ **mm**

$INTERLAYER\_INS := 0.020 \cdot INtoMM$ $INTERLAYER\_INS = 0.508$ **mm**

$INS\_COND := 0.5 \cdot (MAX\_COIL\_THK - 2 \cdot GROUND\_INS - INTERLAYER\_INS)$

$INS\_COND = 21.571$ **mm** $COIL\_HT\_LIMIT := 300$ **mm**

$MAX\_COIL\_BUILD := COIL\_HT\_LIMIT - 2 \cdot GROUND\_INS$

$NO\_RADIAL\_COND := \frac{MAX\_COIL\_BUILD}{INS\_COND}$ $NO\_RADIAL\_COND = 13.613$

$NO\_RADIAL\_COND := 13$

$TURNS\_PER\_PAN := 2 \cdot NO\_RADIAL\_COND$ $TURNS\_PER\_PAN = 26$

$TOTAL\_TURNS := 6 \cdot TURNS\_PER\_PAN$ $TOTAL\_TURNS = 156$

$AMPS := ceil\left(\frac{AMP\_TURNS}{TOTAL\_TURNS}\right)$ $AMPS = 1443$

Set parameters and settup equations to solve for flow rate and water temperature rise

$WATER\_IN\_TEMP := 20$ **deg C** $PRESSURE\_DROP := 60$ **psi**

$G(P,L,D) := 68.5 \cdot \left(\frac{P}{L}\right)^{0.56} \cdot D^{2.76}$ $W(L,A) := ceil(3.88 \cdot A \cdot L)$

$R(L,A) := 8.15 \cdot 10^{-6} \cdot \frac{L}{A}$

$F(I,G,R) := \left(\frac{16.28}{I}\right)^2 \cdot \frac{G}{R}$

$\theta(T,F) := \frac{0.00393 \cdot T + 0.992}{F - 0.001965}$

Pancake 1 is the smallest diameter pancake coil. Pancake 6 is the largest. Pancake 6 has the longest fluid path, pancake 1, the shortest.

$i := 1..6$ $BASE\_IR := 1350$ **mm**

$COIL\_ID_i := 2\cdot(BASE\_IR + 100\cdot i)$

$COIL\_OD_i := COIL\_ID_i + 2\cdot(2\ GROUND\_INS + NO\_RADIAL\_COND\cdot INS\_COND)$

$MEAN\_DIA_i := 0.5\cdot\left(COIL\_ID_i + COIL\_OD_i\right)$

$PATH\_LENGTH_i := \pi\cdot MEAN\_DIA_i\cdot NO\_RADIAL\_COND$

$COND\_OD := INS\_COND - COND\_INS$ $COND\_OD = 20.301$ mm

$COND\_BORE := INtoMM\cdot(0.7\cdot MMtoIN\cdot COND\_OD - 0.055)$ $COND\_BORE = 12.814$ mm

$P := PRESSURE\_DROP$ $L_i := PATH\_LENGTH_i\cdot MMtoIN\cdot INtoFT$

$D := COND\_BORE\cdot MMtoIN$ $A := (COND\_OD\cdot MMtoIN)^2 - 0.25\cdot\pi\cdot D^2$

$GPM_i := G\left(P, L_i, D\right)$

$RESIST_i := R\left(L_i, A\right)$

$TF_i := F\left(AMPS, GPM_i, RESIST_i\right)$

$WATER\_OUT\_TEMP_i := \theta\left(WATER\_IN\_TEMP, TF_i\right) + WATER\_IN\_TEMP$

$AVE\_TEMP_i := 0.5\cdot\left(WATER\_IN\_TEMP + WATER\_OUT\_TEMP_i\right)$

$OP\_RESIST_i := RESIST_i\cdot\left[1 + 0.00393\cdot\left(AVE\_TEMP_i - 20\right)\right]$

$TOTAL\_RESIST := 2\cdot\sum_i OP\_RESIST_i$ $TOTAL\_RESIST = 0.116$

$VOLTS := ceil(AMPS\cdot TOTAL\_RESIST)$ $VOLTS = 167$

$KWATTS := ceil(0.001\cdot AMPS\cdot VOLTS)$ $KWATTS = 241$

$CON\_LENGTH := ceil\left(\sum_i L_i\right)\cdot 2$ $CON\_LENGTH = 5928$

$PAN\_NO_i := i$

$WEIGHT_i := 2\cdot W\left(L_i, A\right)$

PHENIX DETECTOR MAGNETS
CENTRAL OUTER COIL STAIRCASE OPTION B
A. R. HARVEY SEPTEMBER 21, 1992

PAN_NO_i	GPM_i	$WATER\_OUT\_TEMP_i$	AVE_TEMP_i	$WEIGHT_i$	$COIL\_ID_i$	$COIL\_OD_i$
1	3.453	40.02	30.01	1456	2900	3473.546
2	3.338	42.095	31.048	1546	3100	3673.546
3	3.232	44.256	32.128	1638	3300	3873.546
4	3.135	46.503	33.252	1730	3500	4073.546
5	3.046	48.836	34.418	1820	3700	4273.546
6	2.964	51.256	35.628	1912	3900	4473.546

Weight is in pounds. Temperatures are degrees C. Coil ID and OD are in mm.

SUMMARY

CONDUCTOR

$COND\_OD = 20.301$ **mm** $COND\_BORE = 12.814$ **mm**

$TURNS\_PER\_PAN = 26$

ELECTRICAL

$AMPS = 1443$ $VOLTS = 167$ $KWATTS = 241$

OPERATING PARAMETERS

$PRESSURE\_DROP = 60$ **psi** $WATER\_IN\_TEMP = 20$ **deg C**

Solve for the maximum allowable current for a water outlet temperature of 80 degrees C.

Pancake coil 6 must satisfy this requirement. The remaining 5 pancake coils will have water outlet temperatures which are less.

$$CURRENT(G,\theta,R) := 16.28\cdot\sqrt{\frac{G\cdot\theta}{R}}$$

$WATER\_OUT\_TEMP_6 := 76.1$ **deg C** **(Reduced for roundoff adjustment)**

$$AVE\_TEMP_6 := 0.5\cdot\left(WATER\_IN\_TEMP + WATER\_OUT\_TEMP_6\right)$$

$$OP\_RESIST_6 := RESIST_6\cdot\left[1 + 0.00393\cdot\left(AVE\_TEMP_6 - 20\right)\right]$$

$$MAX\_AMPS := CURRENT\left(GPM_6, WATER\_OUT\_TEMP_6 - WATER\_IN\_TEMP, OP\_RESIST_6\right)$$

$AMPS := floor(MAX\_AMPS)$ $AMPS = 1952$

$$TF_i := F\left(AMPS, GPM_i, RESIST_i\right)$$

$$WATER\_OUT\_TEMP_i := \theta\left(WATER\_IN\_TEMP, TF_i\right) + WATER\_IN\_TEMP$$

$$AVE\_TEMP_i := 0.5\cdot\left(WATER\_IN\_TEMP + WATER\_OUT\_TEMP_i\right)$$

$OP\_RESIST_i := RESIST_i \cdot \left[1 + 0.00393 \cdot (AVE\_TEMP_i - 20) \right]$

$TOTAL\_RESIST := 2 \cdot \left(\sum_i OP\_RESIST_i \right)$ $TOTAL\_RESIST = 0.121$ **Ohms**

$VOLTS := ceil(AMPS \cdot TOTAL\_RESIST)$ $VOLTS = 236$

$KWATTS := ceil(0.001 \cdot AMPS \cdot VOLTS)$ $KWATTS = 461$

$CON\_LENGTH := ceil\left(2 \cdot \sum_i L_i \right)$ $CON\_LENGTH = 5928$ **ft**

PAN_NO_i	$WATER\_OUT\_TEMP_i$	AVE_TEMP_i	$WEIGHT_i$	$COIL\_ID_i$	$COIL\_OD_i$
1	57.788	38.894	1456	2900	3473.546
2	61.841	40.92	1546	3100	3673.546
3	66.09	43.045	1638	3300	3873.546
4	70.539	45.269	1730	3500	4073.546
5	75.192	47.596	1820	3700	4273.546
6	80.054	50.027	1912	3900	4473.546

Weight is in pounds. Temperatures are degrees C. Coil ID and OD are in mm.

SUMMARY

CONDUCTOR

$COND\_OD = 20.301$ **mm** $COND\_BORE = 12.814$ **mm**

$TURNS\_PER\_PAN = 26$ $TOTAL\_TURNS = 156$

ELECTRICAL

$AMPS = 1952$ $VOLTS = 236$ $KWATTS = 461$

$MAX\_AMP\_TURNS := AMPS \cdot TOTAL\_TURNS$ $MAX\_AMP\_TURNS = 3.045 \cdot 10^5$

OPERATING PARAMETERS

$PRESSURE\_DROP = 60$ **psi** $WATER\_IN\_TEMP = 20$ **deg C**

$MAX\_WATER\_OUT\_TEMP := floor(WATER\_OUT\_TEMP_6)$

$MAX\_WATER\_OUT\_TEMP = 80$ **deg C**

PHENIX DETECTOR MAGNETS
CENTRAL OUTER COIL   STAIRCASE OPTION C
A. R. HARVEY   SEPTEMBER 21, 1992

Six double pancake, bifilar wound, coils wound to straddle the upper and lower boundaries but otherwise fit within a limiting parallelogram.

AMP_TURNS := 280000   MMtoIN := 0.03937 $INtoFT := \frac{1}{12}$

SLOPE := 2.00   INtoMM := 25.4

Parallelogram coordinates in mm.....(1050,1350), (1050,1700), (1350,2300), (1350,1950)

MAX_COIL_THK := 50 **mm**

COND_INS := 0.050·INtoMM   COND_INS = 1.27 **mm**

GROUND_INS := 0.125·INtoMM   GROUND_INS = 3.175 **mm**

INTERLAYER_INS := 0.020·INtoMM   INTERLAYER_INS = 0.508 **mm**

INS_COND := 0.5·(MAX_COIL_THK − 2·GROUND_INS − INTERLAYER_INS)

INS_COND = 21.571 **mm**   COIL_HT_LIMIT := 350 **mm**

MAX_COIL_BUILD := COIL_HT_LIMIT − 2·GROUND_INS

$$NO\_RADIAL\_COND := \frac{MAX\_COIL\_BUILD}{INS\_COND}$$ NO_RADIAL_COND = 15.931

NO_RADIAL_COND := 16

TURNS_PER_PAN := 2·NO_RADIAL_COND   TURNS_PER_PAN = 32

TOTAL_TURNS := 6·TURNS_PER_PAN   TOTAL_TURNS = 192

$$AMPS := ceil\left(\frac{AMP\_TURNS}{TOTAL\_TURNS}\right)$$ AMPS = 1459

Set parameters and settup equations to solve for flow rate and water temperature rise

WATER_IN_TEMP := 20 **deg C**   PRESSURE_DROP := 60 **psi**

$$G(P,L,D) := 68.5\cdot\left(\frac{P}{L}\right)^{0.56}\cdot D^{2.76}$$ $W(L,A) := ceil(3.88\cdot A\cdot L)$

$$R(L,A) := 8.15\cdot 10^{-6}\cdot\frac{L}{A}$$

$$F(I,G,R) := \left(\frac{16.28}{I}\right)^{2}\cdot\frac{G}{R}$$

$$\theta(T,F) := \frac{0.00393\cdot T + 0.992}{F - 0.001965}$$

Pancake 1 is the smallest diameter pancake coil. Pancake 6 is the largest. Pancake 6 has the longest fluid path, pancake 1, the shortest.

i := 1.. 6   BASE_IR := 1350 **mm**

$COIL\_ID_i := 2 \cdot (BASE\_IR + 100 \cdot i)$

$COIL\_OD_i := COIL\_ID_i + 2 \cdot (2\ GROUND\_INS + NO\_RADIAL\_COND \cdot INS\_COND)$

$MEAN\_DIA_i := 0.5 \cdot (COIL\_ID_i + COIL\_OD_i)$

$PATH\_LENGTH_i := \pi \cdot MEAN\_DIA_i \cdot NO\_RADIAL\_COND$

$COND\_OD := INS\_COND - COND\_INS$ $COND\_OD = 20.301$ mm

$COND\_BORE := INtoMM \cdot (0.7 \cdot MMtoIN \cdot COND\_OD - 0.055)$ $COND\_BORE = 12.814$ mm

$P := PRESSURE\_DROP$ $L_i := PATH\_LENGTH_i \cdot MMtoIN \cdot INtoFT$

$D := COND\_BORE \cdot MMtoIN$ $A := (COND\_OD \cdot MMtoIN)^2 - 0.25 \cdot \pi \cdot D^2$

$GPM_i := G(P, L_i, D)$

$RESIST_i := R(L_i, A)$

$TF_i := F(AMPS, GPM_i, RESIST_i)$

$WATER\_OUT\_TEMP_i := \theta(WATER\_IN\_TEMP, TF_i) + WATER\_IN\_TEMP$

$AVE\_TEMP_i := 0.5 \cdot (WATER\_IN\_TEMP + WATER\_OUT\_TEMP_i)$

$OP\_RESIST_i := RESIST_i \cdot [1 + 0.00393 \cdot (AVE\_TEMP_i - 20)]$

$TOTAL\_RESIST := 2 \cdot \sum_i OP\_RESIST_i$ $TOTAL\_RESIST = 0.148$

$VOLTS := ceil(AMPS \cdot TOTAL\_RESIST)$ $VOLTS = 217$

$KWATTS := ceil(0.001 \cdot AMPS \cdot VOLTS)$ $KWATTS = 317$

$CON\_LENGTH := ceil\left(\sum_i L_i\right) \cdot 2$ $CON\_LENGTH = 7426$

$PAN\_NO_i := i$

$WEIGHT_i := 2 \cdot W(L_i, A)$

PHENIX DETECTOR MAGNETS
CENTRAL OUTER COIL STAIRCASE OPTION C
A. R. HARVEY SEPTEMBER 21, 1992

PAN_NO_i	GPM_i	$WATER\_OUT\_TEMP_i$	AVE_TEMP_i	$WEIGHT_i$	$COIL\_ID_i$	$COIL\_OD_i$
1	3.04	49.698	34.849	1828	2900	3602.972
2	2.94	52.77	36.385	1940	3100	3802.972
3	2.849	55.979	37.99	2052	3300	4002.972
4	2.765	59.325	39.663	2164	3500	4202.972
5	2.688	62.811	41.405	2276	3700	4402.972
6	2.616	66.438	43.219	2390	3900	4602.972

Weight is in pounds. Temperatures are degrees C. Coil ID and OD are in mm.

SUMMARY

CONDUCTOR

$COND\_OD = 20.301$ **mm** $COND\_BORE = 12.814$ **mm**

$TURNS\_PER\_PAN = 32$

ELECTRICAL

$AMPS = 1459$ $VOLTS = 217$ $KWATTS = 317$

OPERATING PARAMETERS

$PRESSURE\_DROP = 60$ **psi** $WATER\_IN\_TEMP = 20$ **deg C**

Solve for the maximum allowable current for a water outlet temperature of 80 degrees C.

Pancake coil 6 must satisfy this requirement. The remaining 5 pancake coils will have water outlet temperatures which are less.

$$CURRENT(G,\theta,R) := 16.28\cdot\sqrt{\frac{G\cdot\theta}{R}}$$

$WATER\_OUT\_TEMP_6 := 76.1$ **deg C** **(Reduced for roundoff adjustment)**

$$AVE\_TEMP_6 := 0.5\cdot\left(WATER\_IN\_TEMP + WATER\_OUT\_TEMP_6\right)$$

$$OP\_RESIST_6 := RESIST_6\cdot\left[1 + 0.00393\cdot\left(AVE\_TEMP_6 - 20\right)\right]$$

$$MAX\_AMPS := CURRENT\left(GPM_6, WATER\_OUT\_TEMP_6 - WATER\_IN\_TEMP, OP\_RESIST_6\right)$$

$AMPS := floor(MAX\_AMPS)$ $AMPS = 1640$

$$TF_i := F\left(AMPS, GPM_i, RESIST_i\right)$$

$$WATER\_OUT\_TEMP_i := \theta\left(WATER\_IN\_TEMP, TF_i\right) + WATER\_IN\_TEMP$$

$$AVE\_TEMP_i := 0.5\cdot\left(WATER\_IN\_TEMP + WATER\_OUT\_TEMP_i\right)$$

$OP\_RESIST_i := RESIST_i \cdot \left[1 + 0.00393 \cdot \left(AVE\_TEMP_i - 20 \right) \right]$

$TOTAL\_RESIST := 2 \cdot \left(\sum_i OP\_RESIST_i \right)$ $TOTAL\_RESIST = 0.151$ **Ohms**

$VOLTS := ceil(AMPS \cdot TOTAL\_RESIST)$ $VOLTS = 249$

$KWATTS := ceil(0.001 \cdot AMPS \cdot VOLTS)$ $KWATTS = 409$

$CON\_LENGTH := ceil\left(2 \cdot \sum_i L_i \right)$ $CON\_LENGTH = 7425$ **ft**

PAN_NO_i	$WATER\_OUT\_TEMP_i$	AVE_TEMP_i	$WEIGHT_i$	$COIL\_ID_i$	$COIL\_OD_i$
1	58.07	39.035	1828	2900	3602.972
2	62.072	41.036	1940	3100	3802.972
3	66.265	43.132	2052	3300	4002.972
4	70.651	45.326	2164	3500	4202.972
5	75.235	47.618	2276	3700	4402.972
6	80.022	50.011	2390	3900	4602.972

Weight is in pounds. Temperatures are degrees C. Coil ID and OD are in mm.

SUMMARY

CONDUCTOR

$COND\_OD = 20.301$ **mm** $COND\_BORE = 12.814$ **mm**

$TURNS\_PER\_PAN = 32$ $TOTAL\_TURNS = 192$

ELECTRICAL

$AMPS = 1640$ $VOLTS = 249$ $KWATTS = 409$

$MAX\_AMP\_TURNS := AMPS \cdot TOTAL\_TURNS$ $MAX\_AMP\_TURNS = 3.149 \cdot 10^5$

OPERATING PARAMETERS

$PRESSURE\_DROP = 60$ **psi** $WATER\_IN\_TEMP = 20$ **deg C**

$MAX\_WATER\_OUT\_TEMP := floor\left(WATER\_OUT\_TEMP_6 \right)$

$MAX\_WATER\_OUT\_TEMP = 80$ **deg C**

PHENIX DETECTOR MAGNET
MUON PISTON COIL 8 WATER CIRCUIT OPTION
A. R. HARVEY SEPTEMBER 28, OCTOBER 5, 1992

INPUT PARAMETERS

AMP_TURNS := 300000 WATER_IN_TEMP := 20 **degree C**

PRESSURE_DROP := 60 **psi** MAX_WATER_OUT_TEMP := 80 **degree C**

COND_OD := 0.95 **inch** COND_BORE := 0.610 **inch**

LEFT_END_IR := 812 **mm** RIGHT_END_IR := 1027 **mm**

AX_REF_LEFT := 5600 **mm** AX_REF_RIGHT := 7000 **mm**

GROUND_INS := 0.125 **inch** COND_INS := 0.050 **inch**

COND_TOL := 0.020 **inch** INTERLAYER_INS := 0.020 **inch**

OVERWRAP := 0.125 **inch** GAP_ALLOWANCE := 0.062 **inch**

CONVERSION FACTORS

MMtoIN := 0.03937 INtoMM := 25.4 INtoFT := 0.08333

FUNCTIONS AND EQUATIONS

$$G(P,L,D) := 68.5 \cdot \left(\frac{P}{L}\right)^{0.56} \cdot D^{2.76} \qquad W(L,A) := \text{ceil}(3.88 \cdot A \cdot L)$$

$$R(L,A) := 8.15 \cdot 10^{-6} \cdot \frac{L}{A} \qquad F(I,G,R) := \left(\frac{16.28}{I}\right)^{2} \cdot \frac{G}{R}$$

$$TEMP(T,F) := \frac{0.00393 \cdot T + 0.992}{F - 0.001965}$$

Set up coil dimensions

INS_COND := COND_OD + COND_INS COND_LAND := INS_COND + COND_TOL

MAX_COIL_LGT := AX_REF_RIGHT − AX_REF_LEFT COND_LAND = 1.02 **inch**

$$MAX\_NO\_LANDS := \frac{MAX\_COIL\_LGT \cdot MMtoIN}{COND\_LAND} \qquad MAX\_NO\_LANDS = 54.037$$

NO_LANDS := 54 TOTAL_TURNS := 2·NO_LANDS − 3 TOTAL_TURNS = 105

$$TURNS\_PER\_CIRCUIT := \frac{TOTAL\_TURNS}{8} \qquad TURNS\_PER\_CIRCUIT = 13.125$$

$$SLOPE := \frac{RIGHT\_END\_IR - LEFT\_END\_IR}{MAX\_COIL\_LGT} \qquad SLOPE = 0.154$$

COIL_RT_IR := RIGHT_END_IR + INtoMM·(GROUND_INS + GAP_ALLOWANCE)

COIL_RT_IR = 1031.75 **mm**

$COIL\_RT\_MR1 := COIL\_RT\_IR + 0.5 \cdot (INS\_COND + COND\_TOL) \cdot INtoMM$

$COIL\_RT\_MR2 := COIL\_RT\_MR1 + (INS\_COND + INTERLAYER\_INS) \cdot INtoMM$

$PITCH := 4 \cdot COND\_LAND \cdot INtoMM$ $\Delta R := PITCH \cdot SLOPE$

$\theta_{total} := 2 \cdot \pi \cdot TURNS\_PER\_CIRCUIT$ $NO\_INCS := 300$

$\Delta\theta := \frac{\theta_{total}}{NO\_INCS}$ $PITCH\_SUM := PITCH \cdot TURNS\_PER\_CIRCUIT$

$\Delta PITCH := \frac{PITCH\_SUM}{NO\_INCS}$ $i := 1 .. NO\_INCS$

$\theta_i := i \cdot \Delta\theta$ $MR1_i := COIL\_RT\_MR1 - \frac{0.5 \cdot \theta_i \cdot \Delta R}{\pi}$

$MR2_i := COIL\_RT\_MR2 - \frac{0.5 \cdot \theta_i \cdot \Delta R}{\pi}$ $\Delta CIRC1_i := MR1_i \cdot \Delta\theta$

$\Delta CIRC2_i := MR2_i \cdot \Delta\theta$ $\Delta LEN1_i := \sqrt{\Delta PITCH^2 + (\Delta CIRC1_i)^2}$

$\Delta LEN2_i := \sqrt{\Delta PITCH^2 + (\Delta CIRC2_i)^2}$

$CON\_LENGTH1 := ceil\left(MMtoIN \cdot INtoFT \cdot \sum_i \Delta LEN1_i\right)$ $CON\_LENGTH1 = 255$ ft

$CON\_LENGTH2 := ceil\left(MMtoIN \cdot INtoFT \cdot \sum_i \Delta LEN2_i\right)$ $CON\_LENGTH2 = 262$ ft

Compute water flow rates, temperature rises, current, etc. for specified Ampere-turns.

$AMPS := ceil\left(\frac{AMP\_TURNS}{TOTAL\_TURNS}\right)$ $AMPS = 2.858 \cdot 10^3$

$GPM1 := G(PRESSURE\_DROP, CON\_LENGTH1, COND\_BORE)$ $GPM1 = 7.786$

$GPM2 := G(PRESSURE\_DROP, CON\_LENGTH2, COND\_BORE)$ $GPM2 = 7.669$

$COND\_AREA := COND\_OD^2 - 0.25 \cdot \pi \cdot COND\_BORE^2$

$RESIST1 := R(CON\_LENGTH1, COND\_AREA)$ $RESIST2 := R(CON\_LENGTH2, COND\_AREA)$

$TF1 := F(AMPS, GPM1, RESIST1)$ $TF2 := F(AMPS, GPM2, RESIST2)$

$WATER\_OUT\_TEMP1 := TEMP(WATER\_IN\_TEMP, TF1) + WATER\_IN\_TEMP$

$WATER\_OUT\_TEMP1 = 34.825$ **deg C**

$WATER\_OUT\_TEMP2 := TEMP(WATER\_IN\_TEMP, TF2) + WATER\_IN\_TEMP$

WATER_OUT_TEMP2 = 35.483 **deg C**

AVE_TEMP1 := 0.5·(WATER_IN_TEMP + WATER_OUT_TEMP1) AVE_TEMP1 = 27.412 **deg C**

AVE_TEMP2 := 0.5·(WATER_IN_TEMP + WATER_OUT_TEMP2) AVE_TEMP2 = 27.741 **deg C**

OP_RESIST := 4·RESIST1·(1 + 0.00393·(AVE_TEMP1 − 20))

OP_RESIST := OP_RESIST + 4·RESIST2·(1 + 0.00393·(AVE_TEMP2 − 20)) OP_RESIST = 0.028

VOLTS := ceil(AMPS·OP_RESIST) VOLTS = 82

KWATTS := ceil(0.001·AMPS·VOLTS) KWATTS = 235

TOT_CON_LENGTH := 4·(CON_LENGTH1 + CON_LENGTH2TOT_CON_LENGTH = $2.068 \cdot 10^3$ **ft**

WEIGHT := W(TOT_CON_LENGTH, COND_AREA) WEIGHT = $4.897 \cdot 10^3$ **lbs**

SUMMARY I

CONDUCTOR

COND_OD = 0.95 **in** CON_OD := COND_OD·INtoMM CON_OD = 24.13 **mm**

COND_BORE = 0.61 **in** CON_BORE := COND_BORE·INtoMM CON_BORE = 15.494 **mm**

TOT_CON_LENGTH = 2068 **ft** WEIGHT = 4897 **lbs**

630 meters. 2226 Kg's

ELECTRICAL

AMPS = 2858 VOLTS = 82 KWATTS = 235

OPERATING PARAMETERS

PRESSURE_DROP = 60 **psi** WATER_IN_TEMP = 20 **deg C**

WATER_OUT_TEMP1 = 34.825 **deg C** WATER_OUT_TEMP2 = 35.483 **deg C**

AVE_TEMP1 = 27.412 **deg C** AVE_TEMP2 = 27.741 **deg C**

TOTAL_GPM := ceil(GPM1 + GPM2)·4 TOTAL_GPM = 64

COIL PARAMETERS

TURNS_PER_CIRCUIT = 13.125 TOTAL_TURNS = 105

105

PHENIX DETECTOR MAGNET

MUON PISTON COIL 8 WATER CIRCUIT OPTION

A. R. HARVEY SEPTEMBER 28, OCTOBER 5, 8, 1992

INPUT PARAMETERS

AMP_TURNS := 300000

WATER_IN_TEMP := 20 degree C

PRESSURE_DROP := 60 psi

MAX_WATER_OUT_TEMP := 80 degree C

COND_OD := 0.95 inch

COND_BORE := 0.610 inch

LEFT_END_IR := 812 mm

RIGHT_END_IR := 1027 mm

AX_REF_LEFT := 5600 mm

AX_REF_RIGHT := 7000 mm

GROUND_INS := 0.125 inch

COND_INS := 0.050 inch

COND_TOL := 0.020 inch

INTERLAYER_INS := 0.020 inch

OVERWRAP := 0.125 inch

GAP_ALLOWANCE := 0.062 inch

CONVERSION FACTORS

MMtoIN := 0.03937 INtoMM := 25.4 INtoFT := 0.08333

FUNCTIONS AND EQUATIONS

$$G(P,L,D) := 68.5\cdot\left(\frac{P}{L}\right)^{0.56}\cdot D^{2.76}$$

$$W(L,A) := ceil(3.88\cdot A\cdot L)$$

$$R(L,A) := 8.15\cdot 10^{-6}\cdot\frac{L}{A}$$

$$F(I,G,R) := \left(\frac{16.28}{I}\right)^{2}\cdot\frac{G}{R}$$

$$TEMP(T,F) := \frac{0.00393\cdot T + 0.992}{F - 0.001965}$$

$$CURRENT(G,DT,R) := 16.28\cdot\sqrt{\frac{G\cdot DT}{R}}$$

Set up coil dimensions

INS_COND := COND_OD + COND_INS

COND_LAND := INS_COND + COND_TOL

MAX_COIL_LGT := AX_REF_RIGHT – AX_REF_LEFT

COND_LAND = 1.02 inch

$$MAX\_NO\_LANDS := \frac{MAX\_COIL\_LGT\cdot MMtoIN}{COND\_LAND}$$

MAX_NO_LANDS = 54.037

NO_LANDS := 54 TOTAL_TURNS := 2·NO_LANDS – 3 TOTAL_TURNS = 105

$$TURNS\_PER\_CIRCUIT := \frac{TOTAL\_TURNS}{8}$$

TURNS_PER_CIRCUIT = 13.125

$$SLOPE := \frac{RIGHT\_END\_IR - LEFT\_END\_IR}{MAX\_COIL\_LGT}$$

SLOPE = 0.154

COIL_RT_IR := RIGHT_END_IR + INtoMM·(GROUND_INS + GAP_ALLOWANCE)

COIL_RT_IR = 1031.75 mm

PHENIX DETECTOR MAGNET
MUON PISTON COIL 8 WATER CIRCUIT OPTION
A. R. HARVEY SEPTEMBER 28, OCTOBER 5, 8, 1992

$COIL\_RT\_MR1 := COIL\_RT\_IR + 0.5\cdot(INS\_COND + COND\_TOL)\cdot INtoMM$

$COIL\_RT\_MR2 := COIL\_RT\_MR1 + (INS\_COND + INTERLAYER\_INS)\cdot INtoMM$

$PITCH := 4\cdot COND\_LAND\cdot INtoMM$ $\Delta R := PITCH\cdot SLOPE$

$\theta_{total} := 2\cdot\pi\cdot TURNS\_PER\_CIRCUIT$ $NO\_INCS := 300$

$\Delta\theta := \dfrac{\theta_{total}}{NO\_INCS}$ $PITCH\_SUM := PITCH\cdot TURNS\_PER\_CIRCUIT$

$\Delta PITCH := \dfrac{PITCH\_SUM}{NO\_INCS}$ $i := 1..NO\_INCS$

$\theta_i := i\cdot\Delta\theta$ $MR1_i := COIL\_RT\_MR1 - \dfrac{0.5\cdot\theta_i\cdot\Delta R}{\pi}$

$MR2_i := COIL\_RT\_MR2 - \dfrac{0.5\cdot\theta_i\cdot\Delta R}{\pi}$ $\Delta CIRC1_i := MR1_i\cdot\Delta\theta$

$\Delta CIRC2_i := MR2_i\cdot\Delta\theta$ $\Delta LEN1_i := \sqrt{\Delta PITCH^2 + \left(\Delta CIRC1_i\right)^2}$

$\Delta LEN2_i := \sqrt{\Delta PITCH^2 + \left(\Delta CIRC2_i\right)^2}$

$CON\_LENGTH1 := ceil\left(MMtoIN\cdot INtoFT\cdot\sum_i \Delta LEN1_i\right)$ $CON\_LENGTH1 = 255$ ft

$CON\_LENGTH2 := ceil\left(MMtoIN\cdot INtoFT\cdot\sum_i \Delta LEN2_i\right)$ $CON\_LENGTH2 = 262$ ft

Compute water flow rates, temperature rises, current, etc. for specified Ampere-turns.

$AMPS := ceil\left(\dfrac{AMP\_TURNS}{TOTAL\_TURNS}\right)$ $AMPS = 2.858\cdot 10^3$

$GPM1 := G(PRESSURE\_DROP, CON\_LENGTH1, COND\_BORE)$ $GPM1 = 7.786$

$GPM2 := G(PRESSURE\_DROP, CON\_LENGTH2, COND\_BORE)$ $GPM2 = 7.669$

$COND\_AREA := COND\_OD^2 - 0.25\cdot\pi\cdot COND\_BORE^2$

$RESIST1 := R(CON\_LENGTH1, COND\_AREA)$ $RESIST2 := R(CON\_LENGTH2, COND\_AREA)$

$TF1 := F(AMPS, GPM1, RESIST1)$ $TF2 := F(AMPS, GPM2, RESIST2)$

$WATER\_OUT\_TEMP1 := TEMP(WATER\_IN\_TEMP, TF1) + WATER\_IN\_TEMP$

$WATER\_OUT\_TEMP1 = 34.825$ **deg C**

$WATER\_OUT\_TEMP2 := TEMP(WATER\_IN\_TEMP, TF2) + WATER\_IN\_TEMP$

WATER_OUT_TEMP2 =35.483 **deg C**

AVE_TEMP1 := 0.5·(WATER_IN_TEMP + WATER_OUT_TEMP1) AVE_TEMP1 = 27.412 **deg C**

AVE_TEMP2 := 0.5·(WATER_IN_TEMP + WATER_OUT_TEMP2) AVE_TEMP2 = 27.741 **deg C**

OP_RESIST := 4·RESIST1·(1 + 0.00393·(AVE_TEMP1 – 20))

OP_RESIST := OP_RESIST + 4·RESIST2·(1 + 0.00393·(AVE_TEMP2 – 20)) OP_RESIST = 0.028

VOLTS := ceil(AMPS·OP_RESIST)   VOLTS = 82

KWATTS := ceil(0.001·AMPS·VOLTS)   KWATTS = 235

TOT_CON_LENGTH := 4·(CON_LENGTH1 + CON_LENGTH2TOT_CON_LENGTH = $2.068 \cdot 10^3$ **ft**

WEIGHT := W(TOT_CON_LENGTH, COND_AREA)   WEIGHT = $4.897 \cdot 10^3$ **lbs**

SUMMARY I

CONDUCTOR

COND_OD = 0.95 **in**   CON_OD := COND_OD·INtoMM   CON_OD = 24.13 **mm**

COND_BORE = 0.61 **in**   CON_BORE := COND_BORE·INtoMM   CON_BORE = 15.494 **mm**

TOT_CON_LENGTH = 2068 **ft**   WEIGHT = 4897 **lbs**

ELECTRICAL

AMPS = 2858   VOLTS = 82   KWATTS = 235

OPERATING PARAMETERS

PRESSURE_DROP = 60 **psi**   WATER_IN_TEMP = 20 **deg C**

WATER_OUT_TEMP1 = 34.825 **deg C**   WATER_OUT_TEMP2 = 35.483 **deg C**

AVE_TEMP1 = 27.412 **deg C**   AVE_TEMP2 = 27.741 **deg C**

TOTAL_GPM := ceil(GPM1 + GPM2)·4   TOTAL_GPM = 64

COIL PARAMETERS

TURNS_PER_CIRCUIT = 13.125   TOTAL_TURNS = 105

AMP_TURNS = 300000

COMPUTE MAXIMUM ALLOWABLE AMPERE TURNS FOR A MAXIMUM ALLOWABLE WATER OUTLET TEMPERATURE OF 80 DEGREES C.

WATER_OUT_TEMP2 := 76.1 **deg C** **(Reduced for roundoff adjustment)**

AVE_TEMP2 := 0.5·(WATER_IN_TEMP + WATER_OUT_TEMP2)

OP_RESIST2 := RESIST2·(1 + 0.00393·(AVE_TEMP2 − 20))

TEMP_RISE2 := WATER_OUT_TEMP2 − WATER_IN_TEMP

MAX_AMPS := CURRENT(GPM2, TEMP_RISE2, OP_RESIST2)

AMPS := floor(MAX_AMPS) AMPS = 5417

TF2 := F(AMPS, GPM2, RESIST2)

WATER_OUT_TEMP2 := TEMP(WATER_IN_TEMP, TF2) + WATER_IN_TEMP

WATER_OUT_TEMP2 = 80.044 **deg C**

TF1 := F(AMPS, GPM1, RESIST1)

WATER_OUT_TEMP1 := TEMP(WATER_IN_TEMP, TF1) + WATER_IN_TEMP

WATER_OUT_TEMP1 = 77.299 **deg C**

AVE_TEMP1 := 0.5·(WATER_IN_TEMP + WATER_OUT_TEMP1)

AVE_TEMP2 := 0.5·(WATER_IN_TEMP + WATER_OUT_TEMP2)

AVE_TEMP1 = 48.65 **deg C** AVE_TEMP2 = 50.022 **deg C**

OP_RESIST1 := 4·RESIST1·(1 + 0.00393·(AVE_TEMP1 − 20))

OP_RESIST := OP_RESIST1 + 4·RESIST2·(1 + 0.00393·(AVE_TEMP2 − 20))

OP_RESIST = 0.031 **Ohms**

VOLTS := ceil(AMPS·OP_RESIST)

KWATTS := ceil(0.001·AMPS·VOLTS)

MAX_AMP_TURNS := AMPS·TOTAL_TURNS

SUMMARY II

CONDUCTOR

COND_OD = 0.95 **in** CON_OD = 24.13 **mm**

COND_BORE = 0.61 **in** CON_BORE = 15.494 **mm**

TOT_CON_LENGTH = 2068 **ft** WEIGHT = 4897 **lbs**

ELECTRICAL

AMPS = 5417 VOLTS = 167 KWATTS = 905

OPERATING PARAMETERS

PRESSURE_DROP = 60 **psi** WATER_IN_TEMP = 20 **deg C**

WATER_OUT_TEMP1 = 77.299 **degC** WATER_OUT_TEMP2 = 80.044 **deg C**

AVE_TEMP1 = 48.65 **deg C** AVE_TEMP2 = 50.022 **deg C**

GPM1 = 7.786 GPM2 = 7.669

TOTAL_GPM := 4·ceil(GPM1 + GPM2) TOTAL_GPM = 64

COIL PARAMETERS

TURNS_PER_CIRCUIT = 13.125 TOTAL_TURNS = 105

MAX_AMP_TURNS = $5.688 \cdot 10^5$

PHENIX DETECTOR MAGNET

MUON PISTON COIL 8 WATER CIRCUIT OPTION (53 LAND)

A. R. HARVEY OCTOBER 8, 1992

INPUT PARAMETERS

AMP_TURNS := 300000

WATER_IN_TEMP := 20 degree C

PRESSURE_DROP := 60 psi

MAX_WATER_OUT_TEMP := 80 degree C

COND_OD := 0.95 inch

COND_BORE := 0.610 inch

LEFT_END_IR := 812 mm

RIGHT_END_IR := 1027 mm

AX_REF_LEFT := 5600 mm

AX_REF_RIGHT := 7000 mm

GROUND_INS := 0.125 inch

COND_INS := 0.050 inch

COND_TOL := 0.020 inch

INTERLAYER_INS := 0.020 inch

OVERWRAP := 0.125 inch

GAP_ALLOWANCE := 0.062 inch

CONVERSION FACTORS

MMtoIN := 0.03937

INtoMM := 25.4

INtoFT := 0.08333

FUNCTIONS AND EQUATIONS

$$G(P,L,D) := 68.5 \cdot \left(\frac{P}{L}\right)^{0.56} \cdot D^{2.76}$$

$$W(L,A) := \mathrm{ceil}(3.88 \cdot A \cdot L)$$

$$R(L,A) := 8.15 \cdot 10^{-6} \cdot \frac{L}{A}$$

$$F(I,G,R) := \left(\frac{16.28}{I}\right)^2 \cdot \frac{G}{R}$$

$$TEMP(T,F) := \frac{0.00393 \cdot T + 0.992}{F - 0.001965}$$

$$CURRENT(G,DT,R) := 16.28 \cdot \sqrt{\frac{G \cdot DT}{R}}$$

Set up coil dimensions

INS_COND := COND_OD + COND_INS

COND_LAND := INS_COND + COND_TOL

MAX_COIL_LGT := AX_REF_RIGHT − AX_REF_LEFT

COND_LAND = 1.02 inch

$$MAX\_NO\_LANDS := \frac{MAX\_COIL\_LGT \cdot MMtoIN}{COND\_LAND}$$

MAX_NO_LANDS = 54.037

NO_LANDS := 53

TOTAL_TURNS := 2·NO_LANDS − 3

TOTAL_TURNS = 103

$$TURNS\_PER\_CIRCUIT := \frac{TOTAL\_TURNS}{8}$$

TURNS_PER_CIRCUIT = 12.875

$$SLOPE := \frac{RIGHT\_END\_IR - LEFT\_END\_IR}{MAX\_COIL\_LGT}$$

SLOPE = 0.154

COIL_RT_IR := RIGHT_END_IR + INtoMM·(GROUND_INS + GAP_ALLOWANCE)

COIL_RT_IR = 1031.75 mm

PHENIX DETECTOR MAGNET
MUON PISTON COIL 8 WATER CIRCUIT OPTION (53 LAND)
A. R. HARVEY OCTOBER 8, 1992

$COIL\_RT\_MR1 := COIL\_RT\_IR + 0.5\cdot(INS\_COND + COND\_TOL)\cdot INtoMM - COND\_LAND\cdot SLOPE\cdot INtoMM$

$COIL\_RT\_MR2 := COIL\_RT\_MR1 + (INS\_COND + INTERLAYER\_INS)\cdot INtoMM$

$PITCH := 4\cdot COND\_LAND\cdot INtoMM$ $\Delta R := PITCH\cdot SLOPE$

$\theta_{total} := 2\cdot\pi\cdot TURNS\_PER\_CIRCUIT$ $NO\_INCS := 300$

$\Delta\theta := \dfrac{\theta_{total}}{NO\_INCS}$ $PITCH\_SUM := PITCH\cdot TURNS\_PER\_CIRCUIT$

$\Delta PITCH := \dfrac{PITCH\_SUM}{NO\_INCS}$ $i := 1 .. NO\_INCS$

$\theta_i := i\cdot\Delta\theta$ $MR1_i := COIL\_RT\_MR1 - \dfrac{0.5\cdot\theta_i\cdot\Delta R}{\pi}$

$MR2_i := COIL\_RT\_MR2 - \dfrac{0.5\cdot\theta_i\cdot\Delta R}{\pi}$ $\Delta CIRC1_i := MR1_i\cdot\Delta\theta$

$\Delta CIRC2_i := MR2_i\cdot\Delta\theta$ $\Delta LEN1_i := \sqrt{\Delta PITCH^2 + (\Delta CIRC1_i)^2}$

$\Delta LEN2_i := \sqrt{\Delta PITCH^2 + (\Delta CIRC2_i)^2}$

$CON\_LENGTH1 := ceil\left(MMtoIN\cdot INtoFT\cdot\sum_i \Delta LEN1_i\right)$ $CON\_LENGTH1 = 249$ ft

$CON\_LENGTH2 := ceil\left(MMtoIN\cdot INtoFT\cdot\sum_i \Delta LEN2_i\right)$ $CON\_LENGTH2 = 256$ ft

Compute water flow rates, temperature rises, current, etc. for specified Ampere-turns.

$AMPS := ceil\left(\dfrac{AMP\_TURNS}{TOTAL\_TURNS}\right)$ $AMPS = 2.913\cdot 10^3$

$GPM1 := G(PRESSURE\_DROP, CON\_LENGTH1, COND\_BORE)$ $GPM1 = 7.89$

$GPM2 := G(PRESSURE\_DROP, CON\_LENGTH2, COND\_BORE)$ $GPM2 = 7.769$

$COND\_AREA := COND\_OD^2 - 0.25\cdot\pi\cdot COND\_BORE^2$

$RESIST1 := R(CON\_LENGTH1, COND\_AREA)$ $RESIST2 := R(CON\_LENGTH2, COND\_AREA)$

$TF1 := F(AMPS, GPM1, RESIST1)$ $TF2 := F(AMPS, GPM2, RESIST2)$

$WATER\_OUT\_TEMP1 := TEMP(WATER\_IN\_TEMP, TF1) + WATER\_IN\_TEMP$

$WATER\_OUT\_TEMP1 = 34.84$ **deg C**

$WATER\_OUT\_TEMP2 := TEMP(WATER\_IN\_TEMP, TF2) + WATER\_IN\_TEMP$

WATER_OUT_TEMP2 =35.514 deg C

AVE_TEMP1 := 0.5·(WATER_IN_TEMP + WATER_OUT_TEMP1) AVE_TEMP1 = 27.42 deg C

AVE_TEMP2 := 0.5·(WATER_IN_TEMP + WATER_OUT_TEMP2) AVE_TEMP2 = 27.757 deg C

OP_RESIST := 4·RESIST1·(1 + 0.00393·(AVE_TEMP1 − 20))

OP_RESIST := OP_RESIST + 4·RESIST2·(1 + 0.00393·(AVE_TEMP2 − 20)) OP_RESIST = 0.028

VOLTS := ceil(AMPS·OP_RESIST)   VOLTS = 81

KWATTS := ceil(0.001·AMPS·VOLTS)   KWATTS = 236

TOT_CON_LENGTH := 4·(CON_LENGTH1 + CON_LENGTH2TOT_CON_LENGTH = $2.02 \cdot 10^3$ ft

WEIGHT := W(TOT_CON_LENGTH, COND_AREA)   WEIGHT = $4.783 \cdot 10^3$ lbs

SUMMARY I

CONDUCTOR

COND_OD = 0.95 in   CON_OD := COND_OD·INtoMM   CON_OD = 24.13 mm

COND_BORE = 0.61 in   CON_BORE := COND_BORE·INtoMM   CON_BORE = 15.494 mm

TOT_CON_LENGTH = 2020 ft   WEIGHT = 4783 lbs

ELECTRICAL

AMPS = 2913   VOLTS = 81   KWATTS = 236

OPERATING PARAMETERS

PRESSURE_DROP = 60 psi   WATER_IN_TEMP = 20 deg C

WATER_OUT_TEMP1 = 34.84 deg C   WATER_OUT_TEMP2 = 35.514 deg C

AVE_TEMP1 = 27.42 deg C   AVE_TEMP2 = 27.757 deg C

TOTAL_GPM := ceil(GPM1 + GPM2)·4   TOTAL_GPM = 64

COIL PARAMETERS

TURNS_PER_CIRCUIT = 12.875   TOTAL_TURNS = 103

AMP_TURNS = 300000

COMPUTE MAXIMUM ALLOWABLE AMPERE TURNS FOR A MAXIMUM ALLOWABLE WATER OUTLET TEMPERATURE OF 80 DEGREES C.

WATER_OUT_TEMP2 := 76.1 **deg C** **(Reduced for roundoff adjustment)**

AVE_TEMP2 := 0.5·(WATER_IN_TEMP + WATER_OUT_TEMP2)

OP_RESIST2 := RESIST2·(1 + 0.00393·(AVE_TEMP2 − 20))

TEMP_RISE2 := WATER_OUT_TEMP2 − WATER_IN_TEMP

MAX_AMPS := CURRENT(GPM2, TEMP_RISE2, OP_RESIST2)

AMPS := floor(MAX_AMPS) AMPS = 5516

TF2 := F(AMPS, GPM2, RESIST2)

WATER_OUT_TEMP2 := TEMP(WATER_IN_TEMP, TF2) + WATER_IN_TEMP

WATER_OUT_TEMP2 = 80.05 **deg C**

TF1 := F(AMPS, GPM1, RESIST1)

WATER_OUT_TEMP1 := TEMP(WATER_IN_TEMP, TF1) + WATER_IN_TEMP

WATER_OUT_TEMP1 = 77.241 **deg C**

AVE_TEMP1 := 0.5·(WATER_IN_TEMP + WATER_OUT_TEMP1)

AVE_TEMP2 := 0.5·(WATER_IN_TEMP + WATER_OUT_TEMP2)

AVE_TEMP1 = 48.62 **deg C** AVE_TEMP2 = 50.025 **deg C**

OP_RESIST1 := 4·RESIST1·(1 + 0.00393·(AVE_TEMP1 − 20))

OP_RESIST := OP_RESIST1 + 4·RESIST2·(1 + 0.00393·(AVE_TEMP2 − 20))

OP_RESIST = 0.03 **Ohms**

VOLTS := ceil(AMPS·OP_RESIST)

KWATTS := ceil(0.001·AMPS·VOLTS)

MAX_AMP_TURNS := AMPS·TOTAL_TURNS

SUMMARY II

CONDUCTOR

COND_OD = 0.95 in

CON_OD = 24.13 mm

COND_BORE = 0.61 in

CON_BORE = 15.494 mm

TOT_CON_LENGTH = 2020 ft

WEIGHT = 4783 lbs

ELECTRICAL

AMPS = 5516

VOLTS = 166

KWATTS = 916

OPERATING PARAMETERS

PRESSURE_DROP = 60 psi

WATER_IN_TEMP = 20 deg C

WATER_OUT_TEMP1 = 77.241 degC

WATER_OUT_TEMP2 = 80.05 deg C

AVE_TEMP1 = 48.62 deg C

AVE_TEMP2 = 50.025 deg C

GPM1 = 7.89

GPM2 = 7.769

TOTAL_GPM := 4·ceil(GPM1 + GPM2)

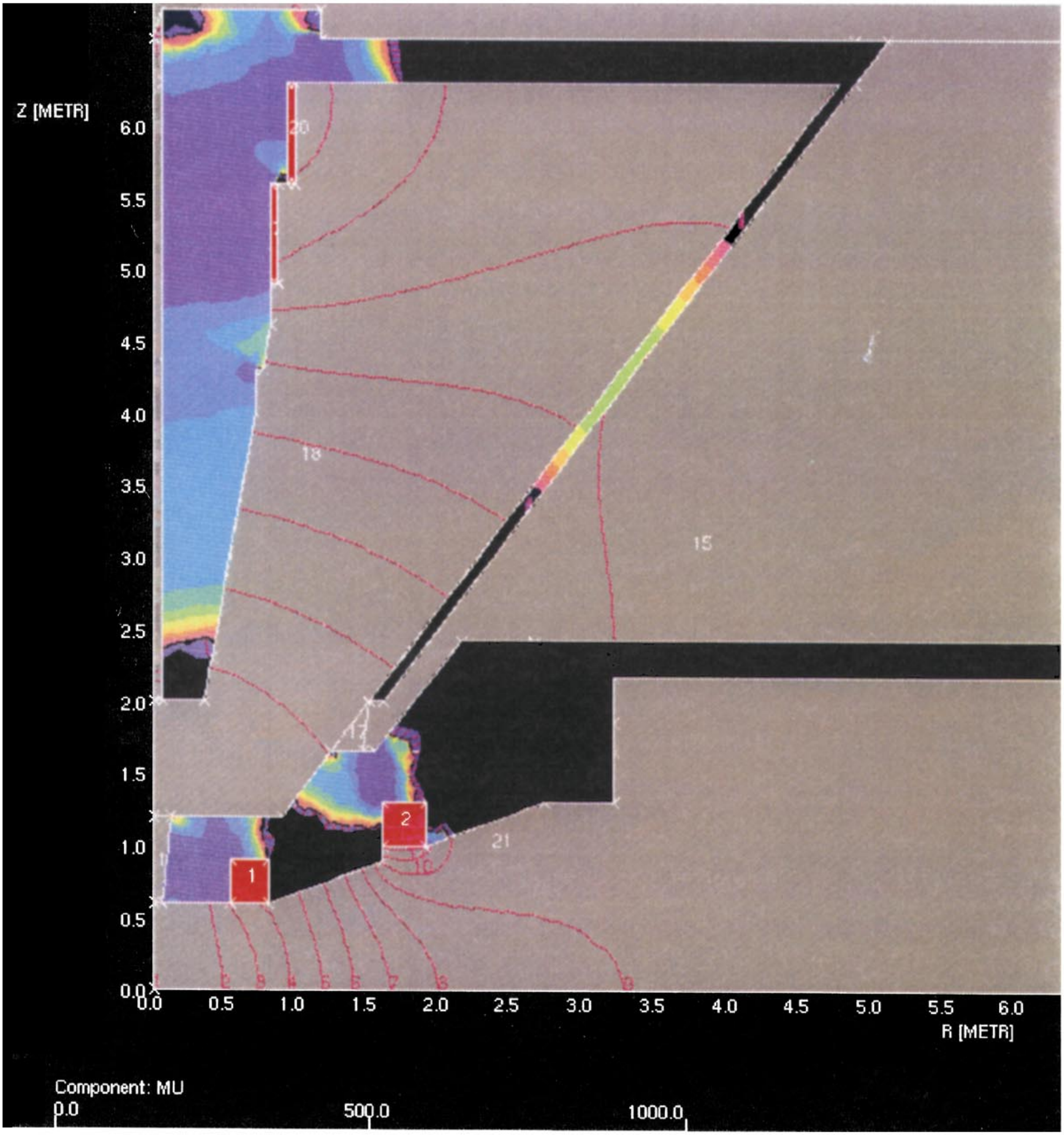
TOTAL_GPM = 64

COIL PARAMETERS

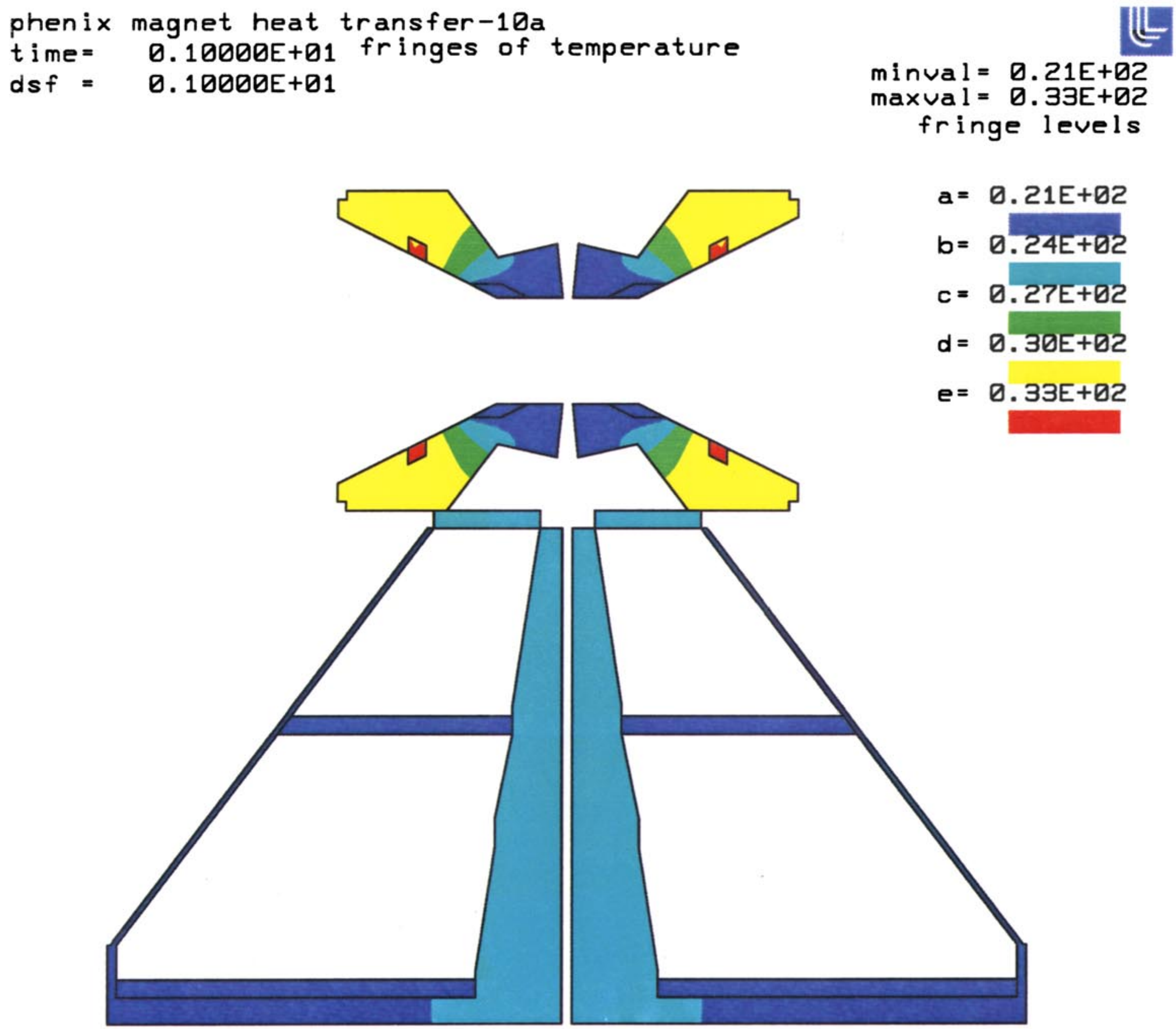
TURNS_PER_CIRCUIT = 12.875

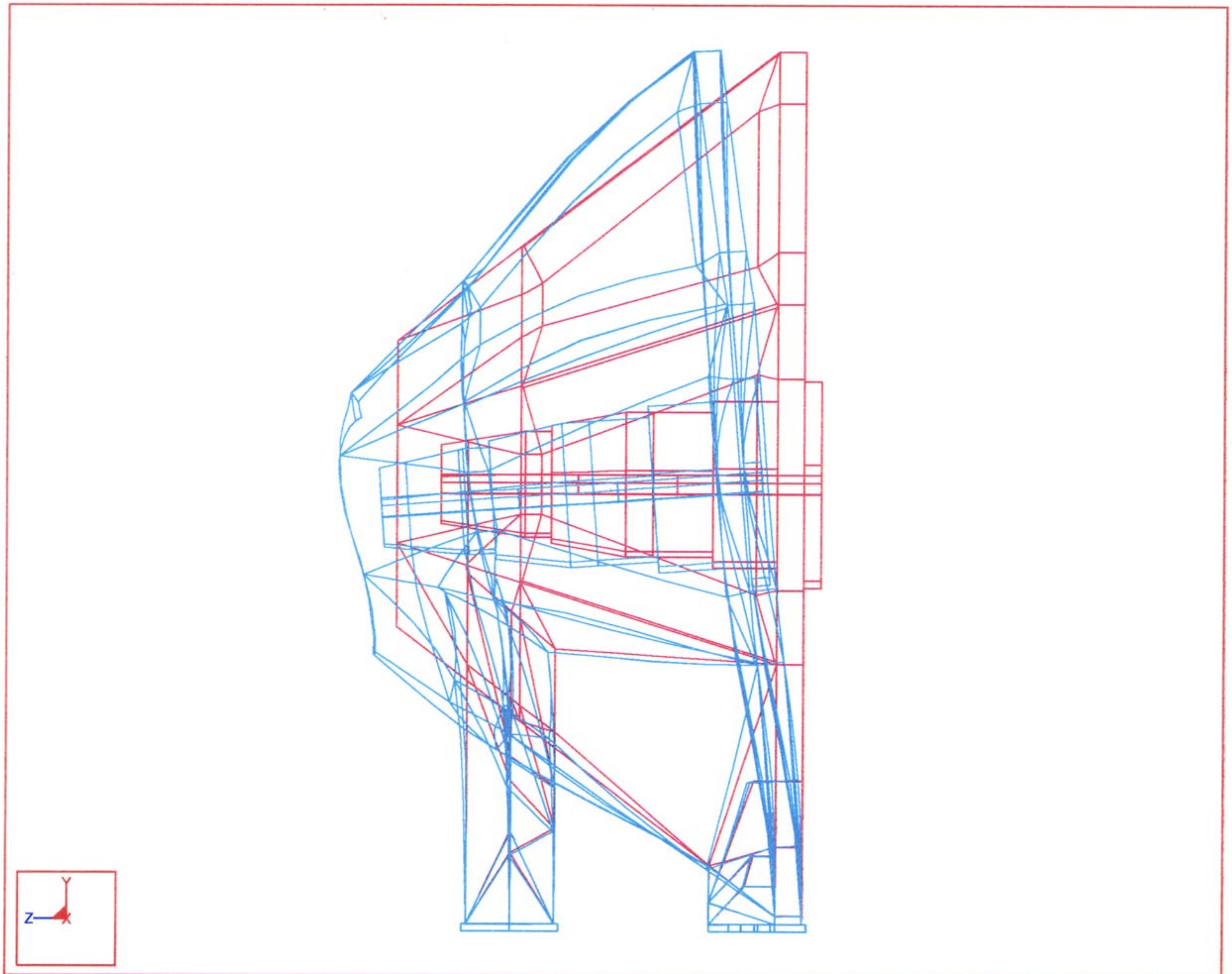
TOTAL_TURNS = 103

MAX_AMP_TURNS = $5.681 \cdot 10^5$



Z [METR]
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
R [METR]
20
18
17
15
21
1
2
Component: MU
0.0
500.0
1000.0


phenix magnet heat transfer-10a
time= 0.10000E+01 fringes of temperature
dsf = 0.10000E+01
minval= 0.21E+02
maxval= 0.33E+02
fringe levels
a= 0.21E+02
b= 0.24E+02
c= 0.27E+02
d= 0.30E+02
e= 0.33E+02



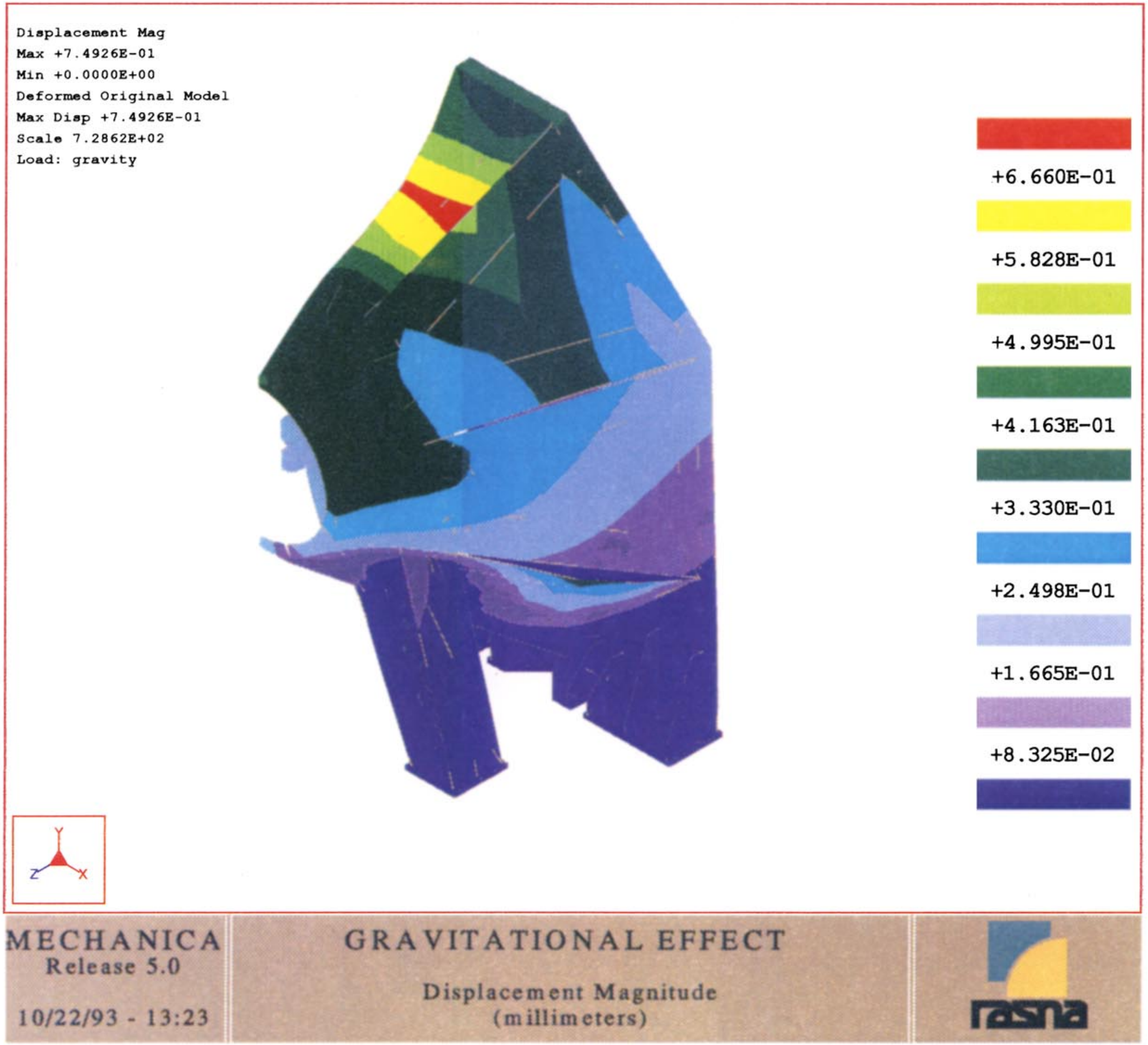
MECHANICA
Release 5.0

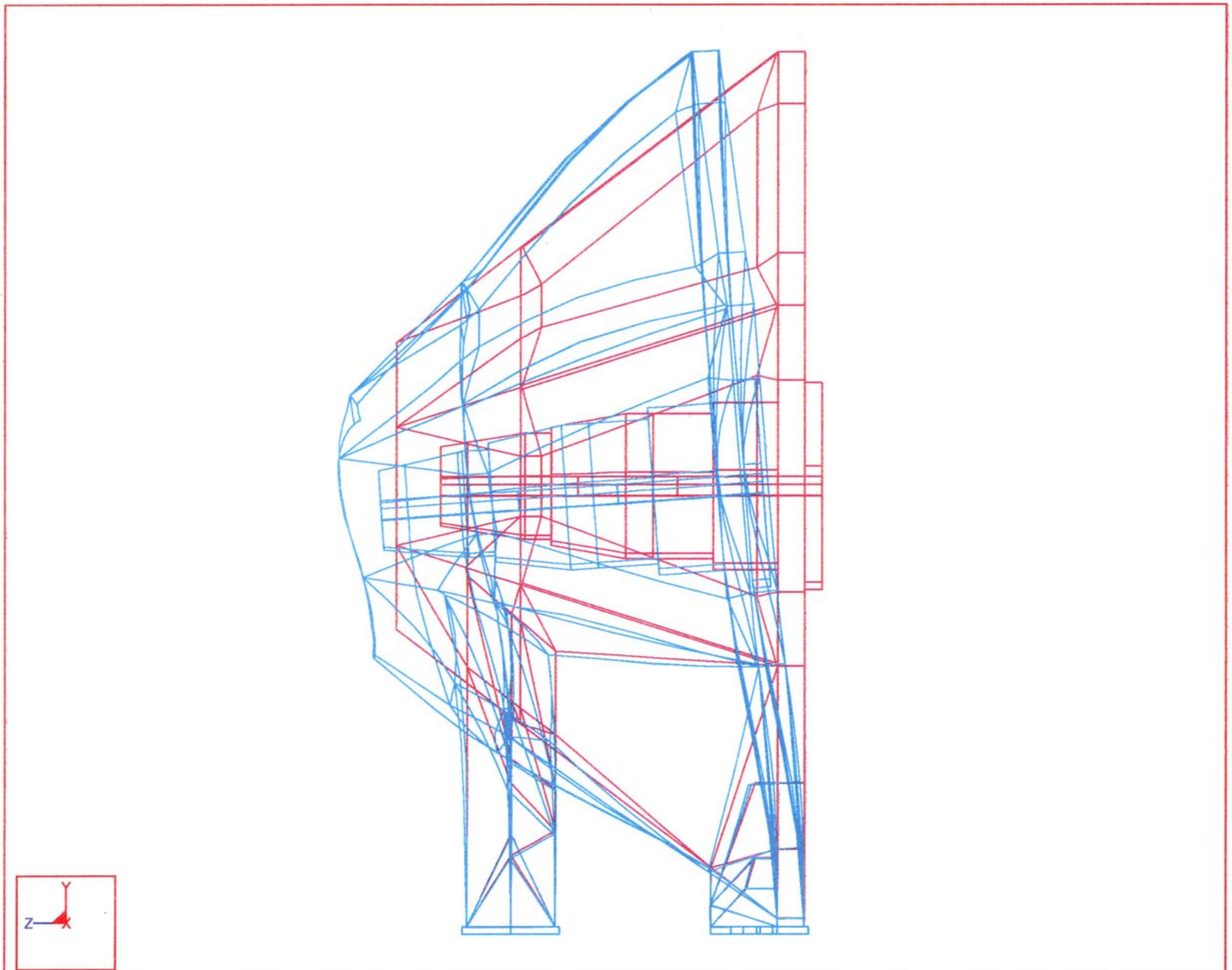
10/22/93 - 14:03

First Mode

10.4 Hz

rasna

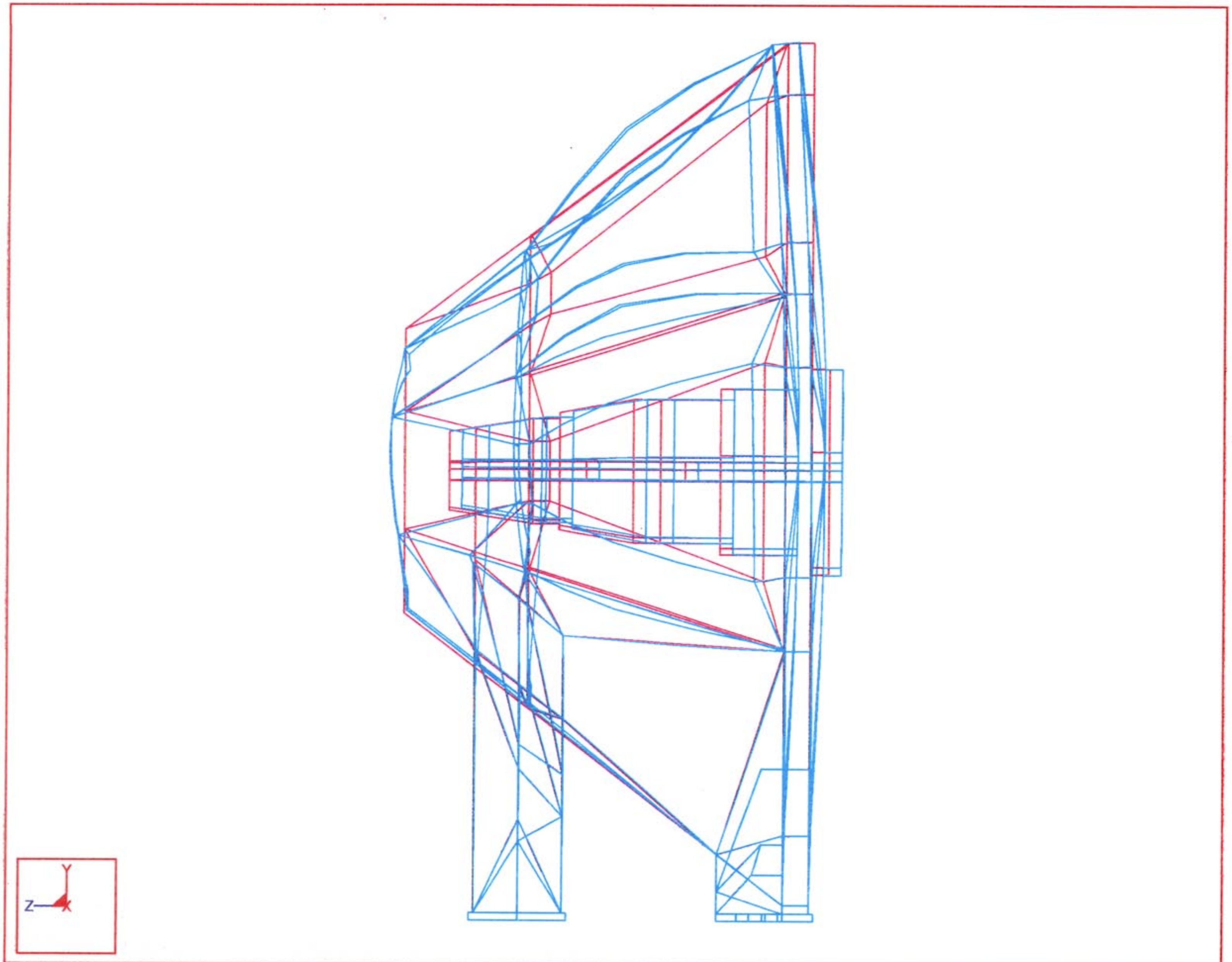

Displacement Mag
Max +7.4926E-01
Min +0.0000E+00
Deformed Original Model
Max Disp +7.4926E-01
Scale 7.2862E+02
Load: gravity
+6.660E-01
+5.828E-01
+4.995E-01
+4.163E-01
+3.330E-01
+2.498E-01
+1.665E-01
+8.325E-02
Y
Z
X
MECHANICA
Release 5.0
10/22/93 - 13:23
GRAVITATIONAL EFFECT
Displacement Magnitude
(millimeters)
rasna



MECHANICA
Release 5.0
10/22/93 - 14:03

First Mode
10.4 Hz

rasna



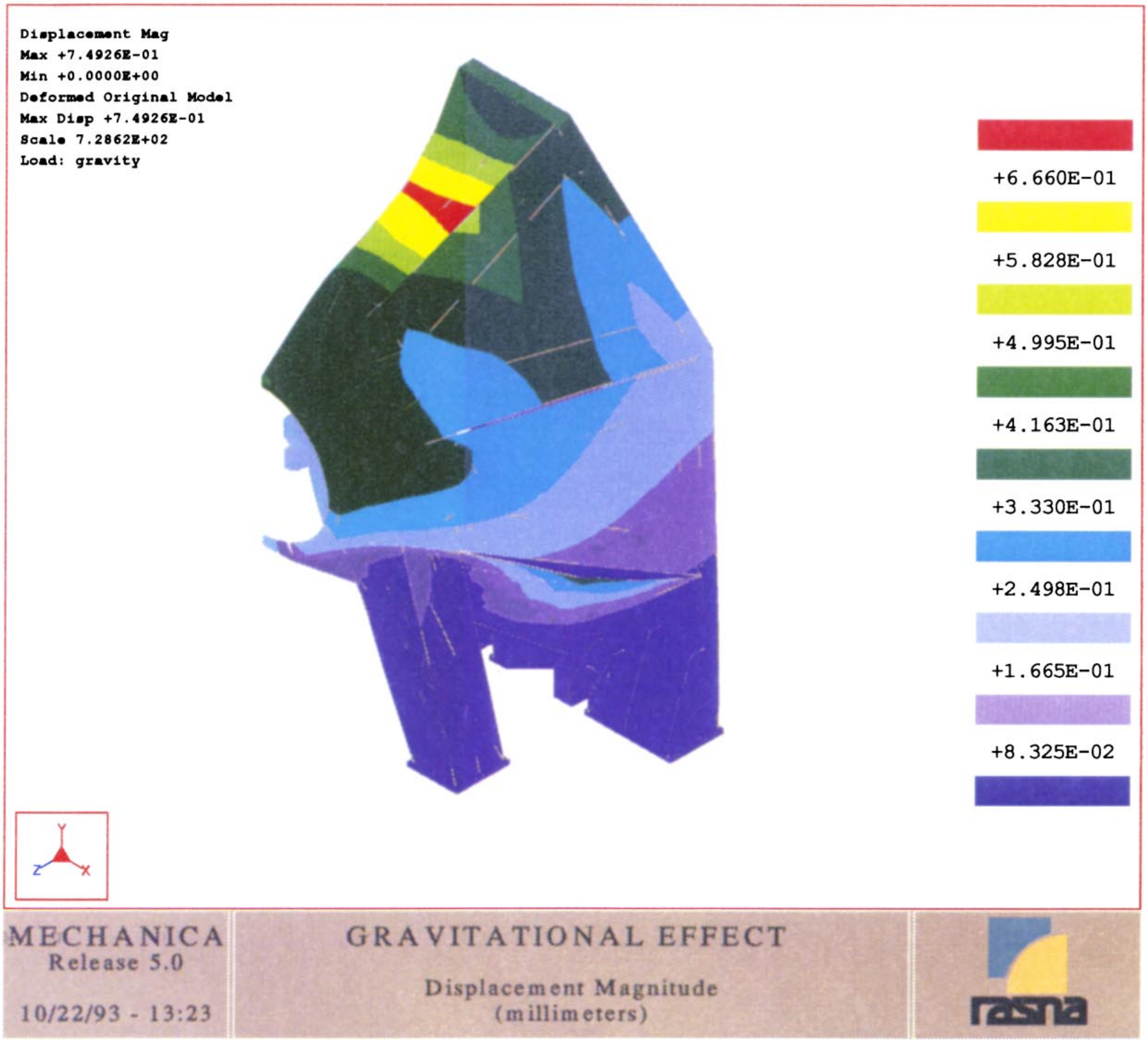
MECHANICA
Release 5.0

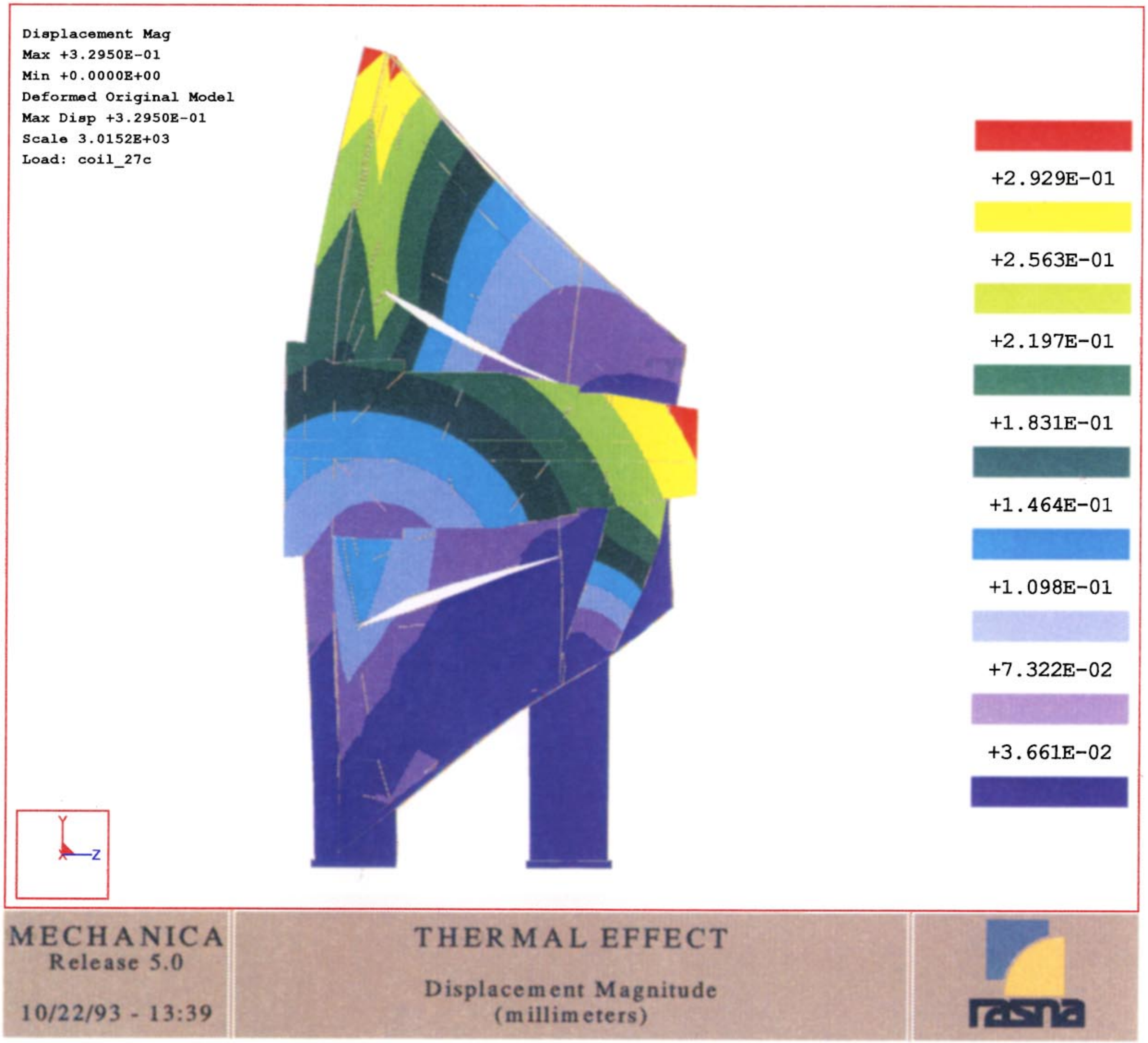
10/22/93 - 14:01

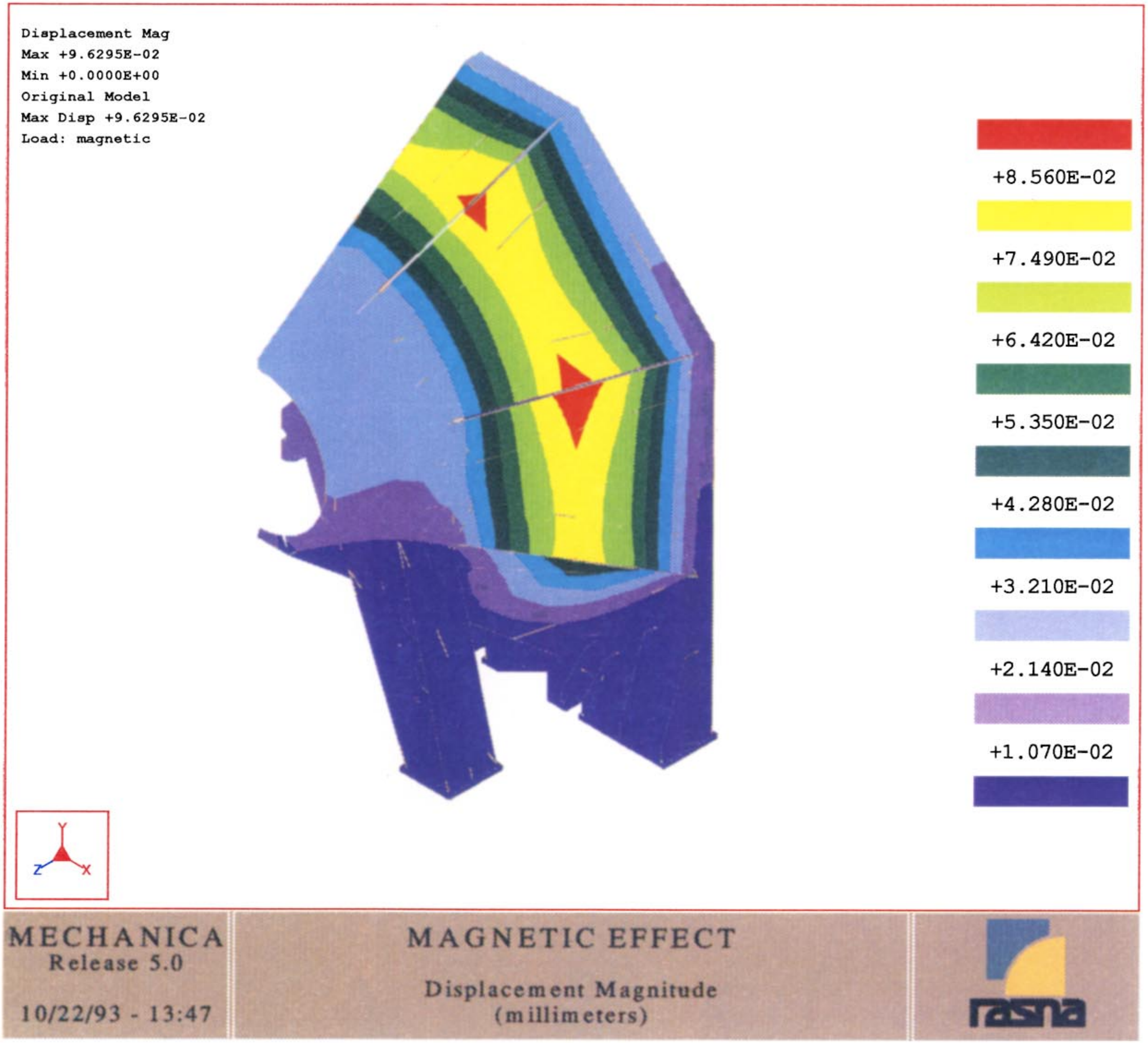
Second Mode

19.0 Hz

rasna


Displacement Mag
Max +7.4926E-01
Min +0.0000E+00
Deformed Original Model
Max Disp +7.4926E-01
Scale 7.2862E+02
Load: gravity
+6.660E-01
+5.828E-01
+4.995E-01
+4.163E-01
+3.330E-01
+2.498E-01
+1.665E-01
+8.325E-02
Y
Z
X
MECHANICA
Release 5.0
10/22/93 - 13:23
GRAVITATIONAL EFFECT
Displacement Magnitude
(millimeters)
rasna


Displacement Mag
Max +3.2950E-01
Min +0.0000E+00
Deformed Original Model
Max Disp +3.2950E-01
Scale 3.0152E+03
Load: coil_27c
+2.929E-01
+2.563E-01
+2.197E-01
+1.831E-01
+1.464E-01
+1.098E-01
+7.322E-02
+3.661E-02
Y
Z
X
MECHANICA
Release 5.0
10/22/93 - 13:39
THERMAL EFFECT
Displacement Magnitude
(millimeters)
rasna


Displacement Mag
Max +9.6295E-02
Min +0.0000E+00
Original Model
Max Disp +9.6295E-02
Load: magnetic
+8.560E-02
+7.490E-02
+6.420E-02
+5.350E-02
+4.280E-02
+3.210E-02
+2.140E-02
+1.070E-02
Y
Z
X
MECHANICA
Release 5.0
10/22/93 - 13:47
MAGNETIC EFFECT
Displacement Magnitude
(millimeters)
rasna