Serial No. OSU79-00143

FINAL REPORT
March 31, 1980

RESEARCH AND DEVELOPMENT STUDIES FOR ANECHOIC EMC TEST FACILITIES

(PHASE II)

BY
T. Pavlasek
Department of Electrical Engineering
Engineering Faculty, McGill University
Montreal Quebec

FOR
Department of Communications
Department of Supply and Services Contract
McGill Reference No. 236-45
Covering the period August 1, 1979 - March 31, 1980

Serial No. OSU79-00143

FINAL REPORT
② March 31, 1980

(RESEARCH AND DEVELOPMENT STUDIES FOR ANECHOIC EMC TEST FACILITIES : final report/

(PHASE II)

BY
(T. Pavlasek)
Department of Electrical Engineering
Engineering Faculty, McGill University
Montreal Quebec

FOR
Department of Communications
Department of Supply and Services Contract
McGill Reference No. 236-45
Covering the period August 1, 1979 - March 31, 1980

TABLE OF CONTENTS

Final Report: "RESEARCH AND DEVELOPMENT STUDIES FOR ANECHOIC E.M.C. TEST FACILITIES (PHASE II)"

1. Introductory Statement

This report is a summary of work done for the Department of Communications, under DSS Contract OSU 79-00143, under the direction of T. J. F. Pavlasek at McGill University. The remunerated staff engaged in this work consisted of Mr. Shantnu Mishra, Research Associate on a part-time basis and casual clerical staff. This report covers the period August 1, 1979 to March 31, 1980. This was the second stage of a project which was first started under Contract OSU 78-00148 and was carried out from August 1, 1978 to March 31, 1979.

.1 Review of Phase I (1978-9)

The first phase of the project consisted of

i. An extensive literature survey of the state of art of anechoic rooms and other types of test chambers and measurement techniques. The results of this survey were reported verbally, in writing and a detailed bibliography was provided.

ii. A study of existing e.m. absorber materials was carried out, including an extensive survey of the industry supplying such products. The e.m. properties of the available materials were compiled into tabulations and graphs useful for the choice of materials when designing anechoic chambers.

iii. An experimental program of measurements, using a specialized scale model anechoic chamber, was initiated to determine the detailed behaviour of chambers under a wide range of conditions. Some preliminary measurements were obtained, which indicated that it might be possible to design chambers with absorber lining for ems measurement at reduced cost.

The Phase I results were reported on in several verbal presentations and in a Progress Report, December 1, 1978 (1) and a 'Final Report', March 31, 1979 (2).

.2 The Second Phase of the Report

The second phase consisted of an extensive set of measurements and their analysis. The progress of this work was reported in verbal presentations, by a Progress Report, November 30, 1979 (3) and is described in detail in this Final Report.

This Final Report contains:

i. A review of the problem which gave rise to the two-phase project.

ii. A report of the results of measurements in the form of an atlas of maps and profiles and an analysis of the results.

iii. A presentation of design considerations for the construction of Absorber Lined Chambers (ALC's).

The original objective was to examine the possibility of designing and building 'anechoic'-like chambers (henceforth called ALC's - Absorber Lined Chambers) which would be both economical and useable over a frequency range from 20 MHz to 10 GHz, this range being suggested in the original contract documents. The results of the research indicate that such ALC's may be possible and guidelines are suggested for their design and use.

The results are nevertheless preliminary and it is evident that the stage has been reached at which operational 'medium size' ALC's should be built on an experimental basis and their characteristics studied in detail. Further work on small scale models is also recommended to obtain further information regarding the possibility of Compact ALC's for susceptibility measurements for use in testing of mass-produced consumer items.

2. Review of the Problem

.1 Introduction

It is approximately a hundred years since Hertz's first experiments with e.m. waves (1888) (Private correspondence Heinrich Hertz to H. Von Helmholtz, November 30, 1888) and about eighty years since Marconi's first transatlantic coded radio transmissions (1901) and Fessenden's voice and music transmissions (1900). Since that time use of the e.m. (radio) spectrum has grown virtually exponentially not only in the utilization of the frequency spectrum itself, but also in the ensuing buildup of ambient e.m. field levels.

This growth has stimulated, and been accompanied by, the development of electronic devices, which were originally evolved mainly for communication use but have now become all-pervasive in the modern technological environment.

Now, electronic devices and systems are used not only for communication purposes but are used intensively in the control, instrumentation, power areas and, with the more recent advent of digital technology, they are the basis of the current explosive growth of the computer era.

This simultaneous growth of ambient field levels and the proliferation of sensitive electronic devices gives rise to concern about the ability of such devices to continue reliable operation and to protect themselves from becoming 'victims' of their own environment. The evolution of the e.m. environment is illustrated qualitatively in Fig. 2.1 which suggests the growth of ambient e.m. levels in urban areas over the past eight decades. Initially only the natural cosmic and geophysical e.m. activity was present. Now however,

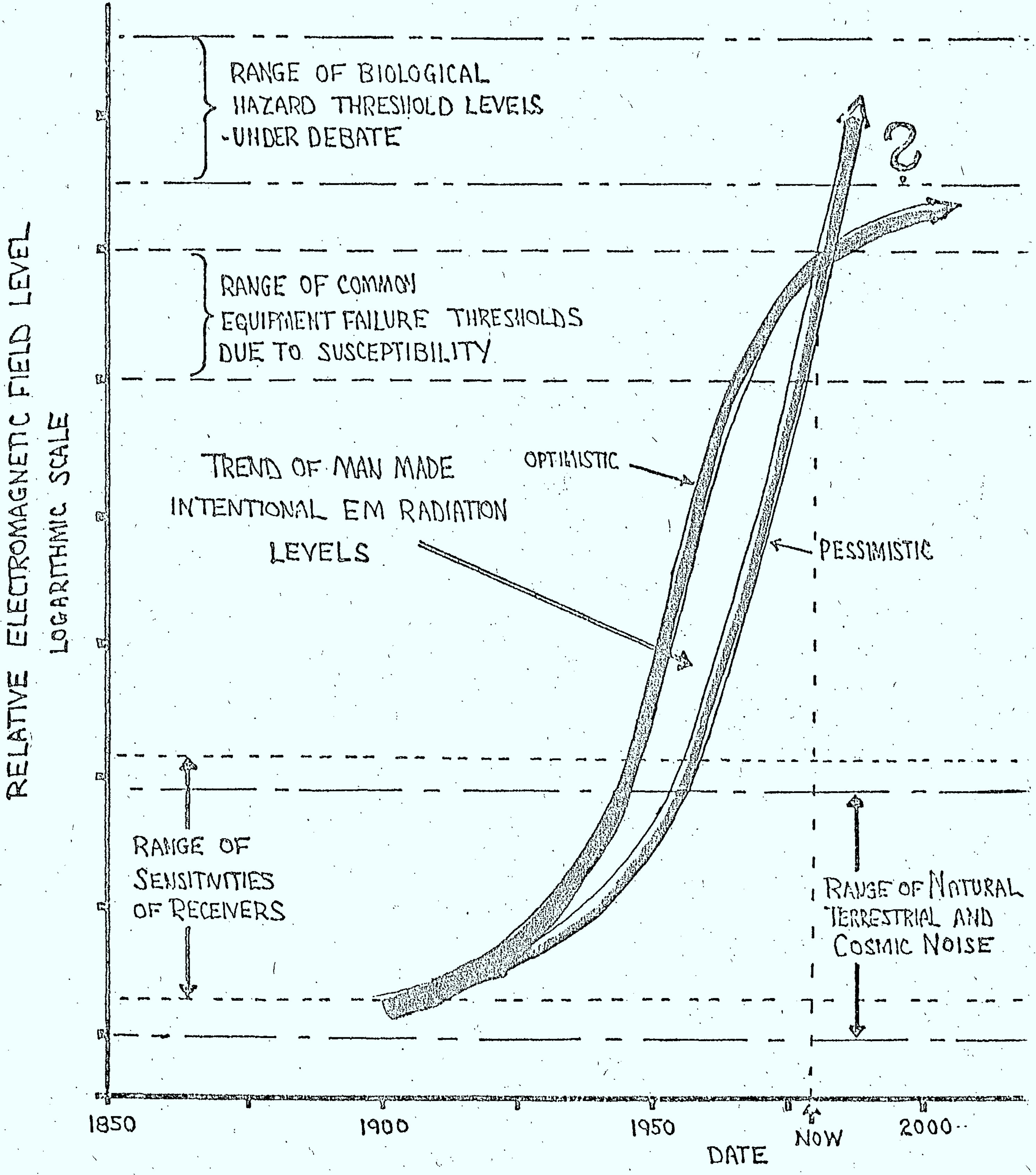


FIG. 2.1 GROWTH TREND OF THE INTENTIONAL MAN-MADE E.M. ENVIRONMENT

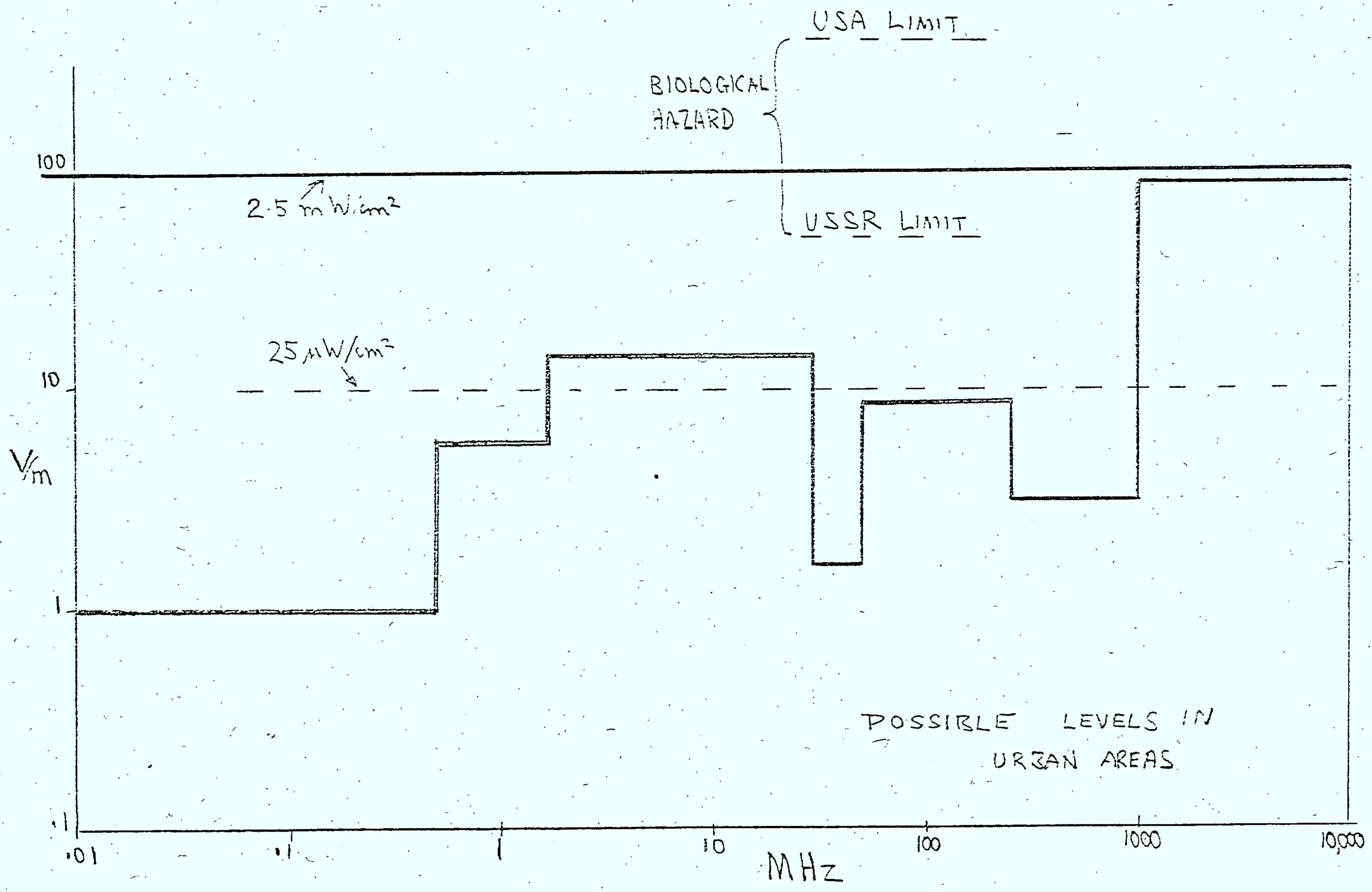


Fig. 2.2 Possible Levels of Ambient E.M. Fields in Urban Areas

the man-made intentional or incidental e.m. field sources mask the natural ambient levels by several orders of magnitude and are beginning to produce degraded erratic behaviour, and sometimes complete failure of sensitive electronic systems. Beyond this, in some specific locations, the ambient levels are growing towards those which may be biologically hazardous.

If a quantitative analysis is made of the "possible" (not necessarily probable) levels of ambient e.m. fields in urban areas, which may exist as a result of duly authorized radiating sources, the graph of field strength levels vs frequency shown in Fig. 2.2 results (4). This figure has received some attention since its publication in 1978 by the DOC in Canada and has been widely distributed in the USA by the FCC (5) as well.

It is apparent that these levels are becoming serious enough to affect the operation of many devices, ranging from relatively non-critical entertainment equipment to potentially critical measuring and computing systems.

This section of the report reviews some aspects of the above problems which are generally described by the acronyms e.m.c. (electromagnetic compatibility), e.m.i. (electromagnetic interference) and e.m.s. (electromagnetic susceptibility).

.2 The Nature of the E.M. Environment Sources - the "Active" Devices

The sources of e.m. radiation which contribute to the e.m. environment fall into two distinct categories, namely intentional and unintentional radiators.

.2.1 "Intentional" radiators, in legalistic terms, are devices such as transmitters for am, fm, tv broadcasting, for point to point and mobile communications, for navigational and remote sensing systems. Radiators of this category operate with due approval of national and international regulatory bodies. Such radiators are specifically authorized to operate at particular frequencies, at specified power levels and in specific geographical locations or areas. Certain other devices which unavoidably generate substantial radiation and are also controlled by regulation include industrial, scientific and medical equipment, such as dielectric heating devices and medical diathermy units. It is devices of this type, whose existence is authorized and known, which are included in the calculations which led to the information presented in Fig. 2.2.

.2.2 In addition to the above are the "unintentional" radiators which also contribute to the e.m. environment but whose radiation is not accounted for in Fig. 2.2 so that the possible levels could be higher than indicated. "Unintentional" radiators are devices which radiate at some frequency and power at which they are not authorized to do so or, are not even designed to do so. Some of these devices are deliberate (and illegal) but most are incidental and may not even be known to radiate. Some of these sources include automobile ignition, power and high voltage equipment, and generally all electronic systems particularly those using transient, switching and short pulse (digital) techniques. While some of these may not individually produce large amounts of radiated power, the aggregate field levels which result may be significant and can produce significant effects on other equipment.

.3 The 'Response' to the E.M. Environment by Receptors or 'Victims' (The Passive Devices)

The devices which respond to the e.m. environment may again be divided into two categories, those which are intended to receive signals or in some way act as 'deliberate field acceptors' and those which are subjected to the fields and become 'unintentional acceptors' or 'victims'.

.3.1 The 'deliberate acceptors' include in particular radio signal receivers for communications and entertainment. Such receivers are characterized by a limited range of operating frequency and by deliberately high sensitivity. Sensitive measuring, control, navigational and remote sensing instrumentation also falls in this category.

.3.2 An 'unintentional acceptor' or 'victim' is any device which responds to the ambient e.m. field environment in an undesired manner which may affect, degrade or prevent its desired operation. The 'victim' may even become permanently damaged and inoperational. 'Deliberate acceptors', because of their inherent high sensitivity are prime candidates for becoming 'victims' to <u>other</u> fields not intended for their operation. Other electronic equipment which is intended to operate in a 'closed universe' of its own may also become a victim of the e.m. surroundings. Equipment which operates internally at inherently low signal levels is particularly <u>susceptible</u>.

.3.3 <u>Examples of 'Victims'</u>

A very commonly observed case of a victim is that of the automobile a.m. radio failure to operate in the neighbourhood of power lines. Another is the influence some pocket calculators or desk top computers can produce on an adjacent a.m. receiver (an experiment which can be tried in the home). The failure of television receivers to operate in urban areas is also widespread while many a high-quality tape recorder has <u>inadvertently</u> detected and recorded the signal from nearby a.m. and f.m. transmitters. More worrisome are the implications to security systems in general, of rumours about garage doors opening apparently because of high power mobile transmitters passing by. Of greater concern yet are reports of malfunctioning of control systems and of error signals or stoppages in the operation of microprocessor based vehicular, industrial and commercial data and digital control systems (6).

.4 'Countermeasures'

.4.1 Agencies and Societies Involved in E.M.C.

The problem of e.m. compatibility, interference and susceptibility is not new but its extent is reaching levels which warrant urgent consideration and action. Research in e.m.c. is growing in importance and has been active especially in the military field for some time. However, in the civilian sector the matter is only now beginning to receive increased attention. At present the data collected is essentially in the form of 'complaints' which arise sporadically and are only a random sampling of the problem. Systematic data gathering and scientific analysis of the actual environment (along the classical lines of measurement and scientific studies which e.m. propagation has received in the past eighty years, is only now being envisaged. Extensive, structured monitoring and surveillance has yet to be developed and put into effect.

The agencies and societies involved in this work are national, regional and international. In Canada, the prime responsibility and activity is in the DOC while that in the USA is the FCC. In Europe, activity is being concerted by CISPER.

Scientific societies such as the IEEE's EMC Society have been publishing journals and organising international symposia for some time of which the following are major examples

- IEEE-EMC Transactions & Newsletter
- Biennial Symposia on EMC in Europe
- Annual EMC Symposia in USA

Nevertheless work in this area in relation to civilian needs is only just evolving. Three general areas of activity which need to be developed can be identified:

a. that dealing with measurement, analysis and control of activities in the environment itself,

b. the laboratory simulation of the environment and development of measuring techniques with the objective of evolving equipment design and evaluation criteria.

c. the theoretical analysis and modelling of e.m.c. problems.

The areas of simulating the environment in the laboratory or on the factory production floor and of theoretical analysis and modelling are the crucial ones to be investigated.

The following sections of this report describe some aspects of the laboratory simulation problems involved, with emphasis on research and development in the design of enclosures or chambers for laboratory simulation of the environment.

The facilities evolved are intended to be used for the evaluation of the susceptibility of equipment as possible 'victims' or conversely as unwanted emitters. The long range intent would be to establish guidelines for standards leading to eventual environmental regulatory control procedures.

.4.2 The Problems of Laboratory Measurements

The two parameters which need to be determined in the case of any equipment are:

a. its susceptibility to external e.m. sources

b. its own behaviour as a possible emitter.

Furthermore, in either case, the mechanism involved may be that of

a. field radiation

b. by conductive current.

There thus exist four possible combinations which are designated:

RS - radiated susceptibility

CS - conducted susceptibility

RE - radiation emission

CE - conduction emission.

The 'susceptibility' of equipment is a measure of the degradation of its performance under the influence of radiated or conducted e.m. energy. The converse term 'immunity' is also used as designation of performance.

The quantification of 'degradation' is a major difficulty because it is largely subjective and to a considerable extent arbitrary in some equipment.

Emission is the amount of unwanted e.m. energy produced by a device and is characterized by the frequency and the power emitted. These quantities are more easily quantifiable (though not necessarily easily measured).

Considerable literature and practice have developed regarding e.m.c., e.m.i., and e.m.s. in relation to military equipment. Certain standards and test procedures are openly published and well known (7). However, their direct application to civilian use may be only partly relevant because the criteria on which they are based, especially in the judgemental area of quantifying degradation of performance, may be fundamentally different.

.4.3 General Susceptibility

To measure the susceptibility of any device it is necessary to have:

1. A known, calibrated, controllable source of e.m. energy operable over a wide range of frequencies.
2. A volume of space in which a known field is produced.
3. Measuring equipment to monitor the amount of field the equipment under test (e.u.t.) is immersed in.
4. Equipment to measure the 'degradation' of performance of the e.u.t.
5. Data processing facilities.

An 'open field' site could be a possible choice of 'space' but practical considerations such as isolation and power requirements do not make this easily useable and feasible. The alternative then, is to have the test field generated in a constrained volume - shielded to avoid disturbance from and to the outside world. Because of the wide range of frequencies at which tests are required (from DC to 10's of GHz) a universal controlled environment enclosure is very difficult to realize. A considerable amount of research work has been done in the past few years to develop measurement techniques and environment simulation.

The remainder of this report is concerned with the development of enclosures for the simulation of the e.m. environment needed for emission measurements.

3. Statement of Phase II Objective

The objective of the Phase II (1979-80) project was as a continuation of the Phase I (1978-79) project whose objective was:

Phase I Objectives

It is intended to establish the technical design parameters and cost factors of an Electromagnetic Compatibility (EMC) Test Facility for the Department of Communications. Such an EMC Test Facility is intended to be operable over a range from not more than 20 MHz to not less than 10,000 MHz. The Facility is to be appropriate for the accommodation of electrical, electronic equipment and systems for the purpose of defining EMS (electromagnetic susceptibility) conditions, establishing standards and measurement methodology for same.

The sub-objectives and milestones are to be generally in accordance with those indicated in the Project Submission Document FY 78/79, outlining expected results and mutually agreed upon modifications arising from information and knowledge evolving from the research study as it progresses.

In sum, the first stage of the study is to consist of 1) data gathering 2) existing anechoic room material evaluation 3) investigation of new material opportunities and chamber configurations and 4) determination of relative costs of materials. The second stage would be concerned with scale modelling of chambers with appropriate materials to demonstrate the feasibility of possible designs.

The specific statement of objectives for Phase II was:

Phase II Objectives:

The results of the first year's activities in this project provide the basis for continuing and extending the study of the development of an anechoic test facility for EMC measurements. The facility is intended to be operable over a range from not more than 20 MHz to not less than 10 GHz. Also, the facility is to be appropriate for the accommodation of electrical, electronic equipment and systems for the purpose of defining EMC conditions, establishing standards and measurement methodology for the same.

The sub-objectives and milestones are to be generally in accordance with those indicated in the Project Submission Document FY 78/79 outlining the expected results and bearing the same title, dated 32/10/77 subject to mutually agreed upon modifications arising from information and knowledge evolving from the research study as it progresses.

In sum, this, the second stage of the study is to consist of: 1. Making measurements in scale modelled anechoic configurations with appropriate materials and models of EUT's to demonstrate the feasibility of possible designs. 2. Developing and testing new material configurations and investigating the scale modelling of an anechoic enclosure using such materials.

These objectives were approached through an extensive program of measurements whose results are presented in the following. It need be noted that at an early stage of the program a mutual decision was made <u>not</u> to pursue the development of new materials (see part 2 above) since it became apparent that the prime objectives might be achieved using existing materials. The concept of ALC's (absorber-lined chambers) was thus evolved.

4. Methodology

The behaviour of an ALC was studied by making detailed measurements of the field structure (amplitude and phase) over sectional planes spanning the interior of the ALC. The measurement techniques, the data processing and map drawing process are described in Final Report (Stage 1) and elsewhere (8).

The ALC used was a frequency scaled model chamber capable of a variety of modes of operation, as described previously (2,3). The program of measurements was designed to determine ALC behaviour over a wide frequency range and for a variety of wall lining conditions.

The model room (a $(1\ \mathrm{m})^3$ internal dimensions enclosure) was measured at frequencies ranging from 0.6 to 23.5 GHz. The sectional planes were those containing the central axis and lying parallel or perpendicular to the E-field polarization. Measurements were made with the ALC: fully lined, partially lined and for some cases with and without an EUT model inside the chamber.

Table 5.1 in the following section lists all the conditions which were examined.

5. Measurements and Results

.5.1 Method of Measurement

The measurements were made at 23.5 GHz, 1 GHz and 0.6 GHz. These were carried out in an existing 'large' anechoic room within which was placed a small scale model chamber.

The 'model' anechoic room consists of a frame of unique design, made entirely of wood bonded by resin cement. The frame is in sections held together by 'nylotron' screw fasteners. Movable portions allow the mounting of absorber of different thicknesses, while maintaining the inner dimensions at a predetermined value. The absorber panels can be easily mounted and changed through the use of velcro fasteners. The frame of the 'model' chamber thus causes a minimum perturbation of a test field since it consists exclusively of dielectric materials whose dielectric constant is relatively low.

The room has inner dimensions of 1.2 x 1.2 x 1.0 m and was completely lined by Emerson Cuming CV4 material for the fully lined chamber measurements. For measurements with partial lining, either a side wall or the floor were replaced by aluminum foil.

The illumination sources used were:

i. Open ended waveguide for 23.5 GHz

ii. Half-wave dipoles cut for 0.6 and 1 GHz respectively.

These were placed in or close to the centre of an end-wall. The geometry of the arrangement is shown in Fig. 5.1

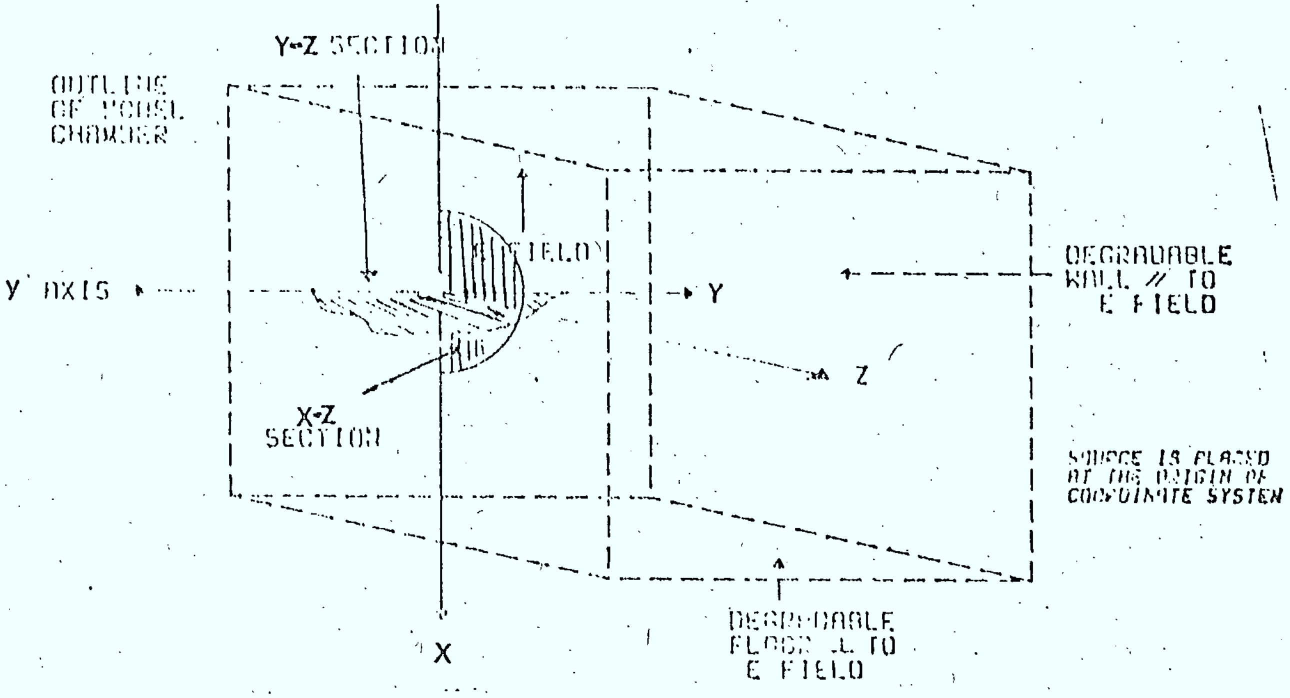


Figure 5.1

The measuring equipment consists of

i. Amplitude and phase measuring system
    - A homodyne technique based apparatus at 23.5 GHz
    - Vector Voltmeter at 0.6 and 1 GHz

ii. A probe positioning system permitting the positioning of a probe anywhere within model chamber

iii. The probes were electrically small dipoles

iv. The data acquisition system is a Motorola 6800 based microcomputer with appropriate AD and control interfacing and with floppy disk storage. The data acquisition system is interfaced to the University's large, high speed AMDAHL VM10 computer which is used for bulk data processing and map plotting. In addition, the graphical facilities of a VAX computer graphics and an Autotrol Computer Drafting system were used. The measuring and data acquisition processing system are shown diagramatically in Appendix A.

.5.2 Program of Measurements

Measurements were made at 23.5 GHz, 1 GHz and 0.6 GHz, thus representing various frequency scaling possibilities, as indicated in Fig. 2 of Progress Report (see also Appendix B). The absorber used thus allows an interpretation that a 1 m cube room would represent a 30 m cube room and the 0.6 GHz measurements correspond to 20 MHz in such a full scale room.

Measurements were made with:

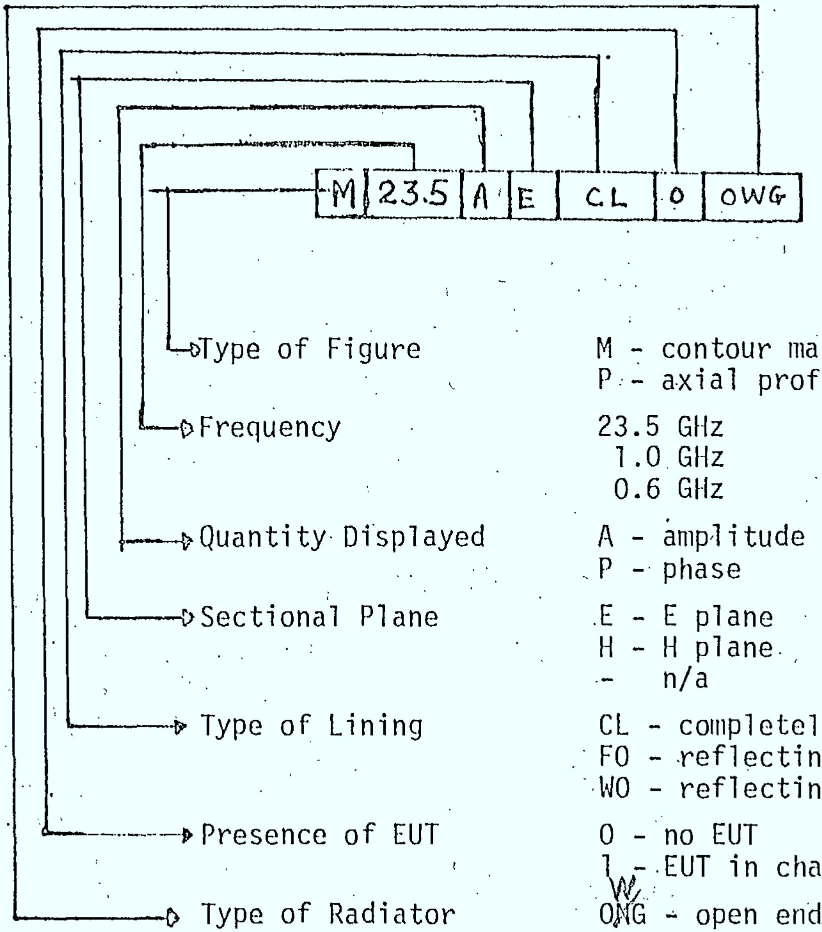
1. i. a fully lined room
   ii. with the floor replaced by a reflecting surface
   iii. with a side wall replaced by a reflecting surface.
2. i. the room empty
   ii. with a scale model E.U.T. in various locations.

In all cases relative amplitude and phase were measured and in the majority of cases these were made in the X-Z plane (vertical plane ‖ to E-field) and the Y-Z plane (horizontal plane ⊥ to E-field). Both planes contain the central axis.

Table 5.1 below is a cross-reference listing of all the maps produced by the abovementioned measurements. The identification coding enables locating the maps within the 'Atlas' which follows.

In addition to the maps, axial profiles along the central optical axis are presented for the fully lined case at 23.5 and 1 GHz and for all three cases at 0.6 GHz.

The maps or profiles also have a coding which is according to the following scheme and this serves as a descriptive identifying caption. The Atlas is paginated as ATLAS PAGE 1 etc.



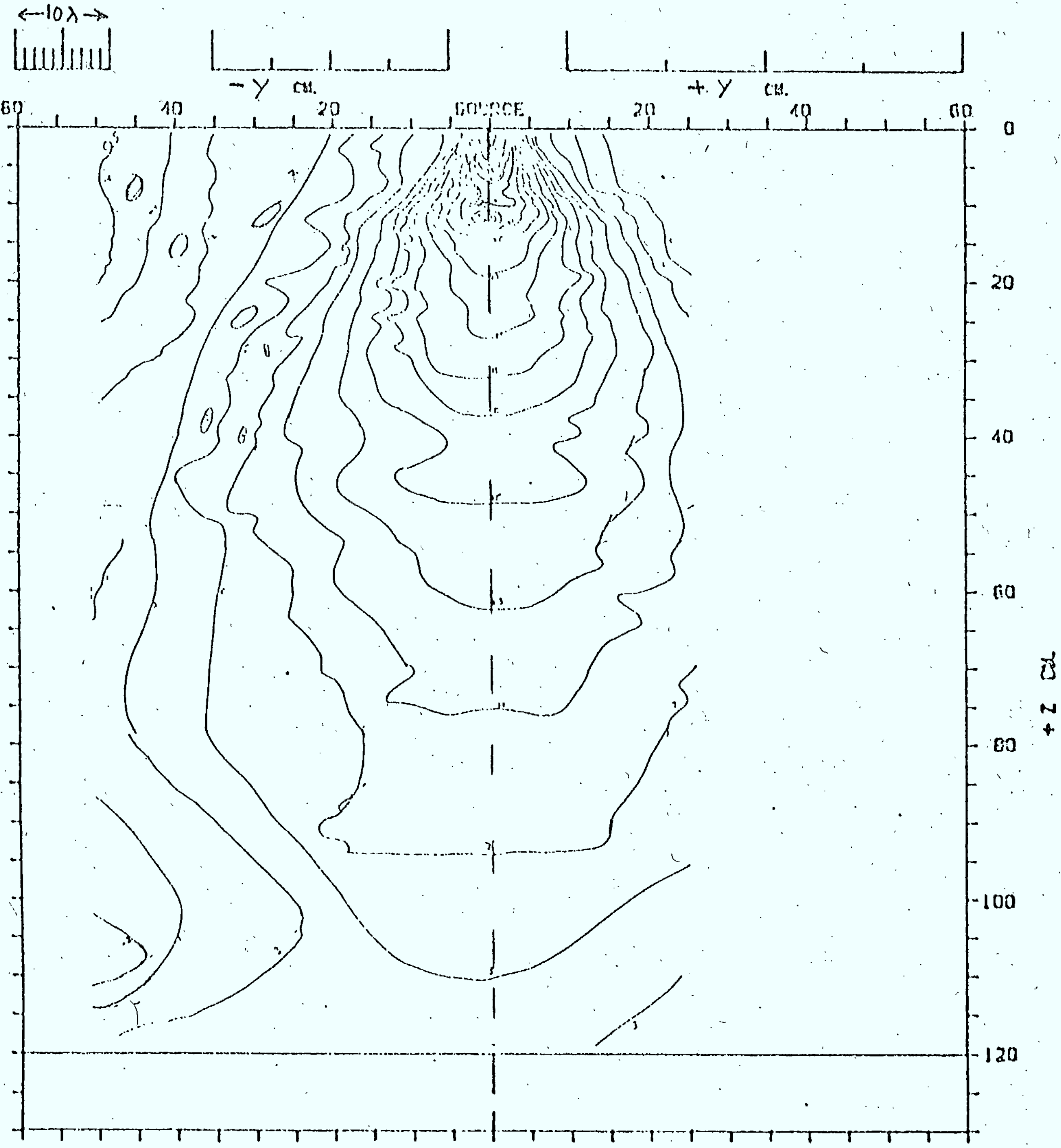
Type of Figure	M - contour map P - axial profile
Frequency	23.5 GHz 1.0 GHz 0.6 GHz
Quantity Displayed	A - amplitude P - phase
Sectional Plane	E - E plane H - H plane - n/a
Type of Lining	CL - completely lined FO - reflecting floor WO - reflecting wall
Presence of EUT	O - no EUT 1 - EUT in chamber
Type of Radiator	O~~N~~WG - open ended waveguide HWD - λ/2 dipole

TABLE 5.1

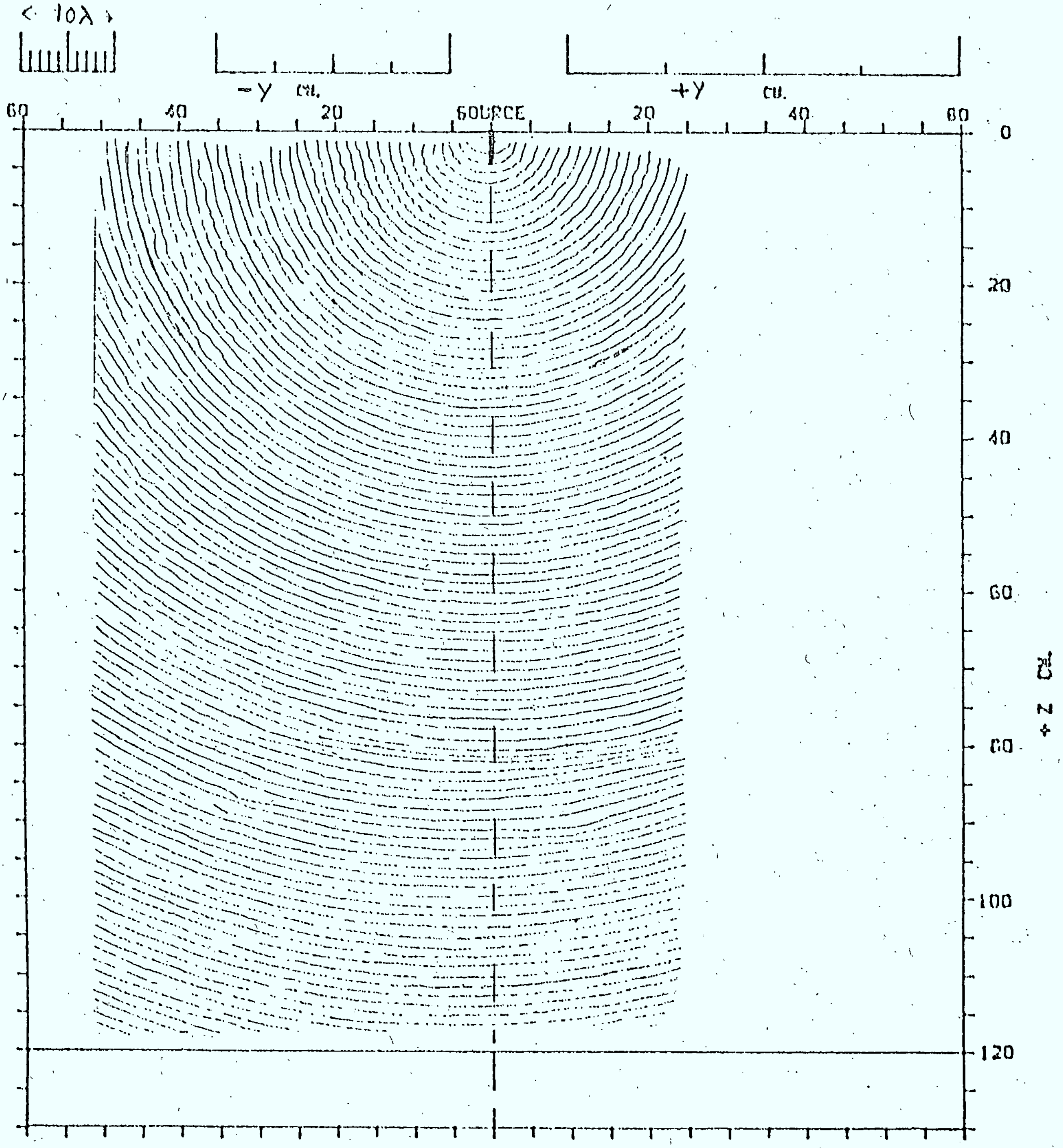
ATLAS MAP AND PROFILE INDEX

DETAILS OF SETUP				Sectional Plane	Freq. (GHz)	23.5	1.0	0.6	
						ATLAS Page Number			
Empty Chamber	Completely Lined Chamber			H	Amplitude	1	6	11	
					Phase	2	7	12	
				E	A	3	8	13	
					P	4	9	14	
				Centre Profile	A	5	10	15	
					P	-	-	16	
	Partly Lined Chamber	Case A Reflecting Floor		H	A	17	21	25	
					P	18	22	26	Missing
				E	A	19	23	27	
					P	20	24	28	
				Centre Profile	A	-	-	29	
					P	-	-	30	
		Case B Reflecting Wall		H	A	31	35	40	
					P	32	36	41	
				E	A	33	37	42	
					P	34	38	43	
				Centre Profile	A	-	39	44	
					P	-	-	45	
	Details in E.U.T. Region			H	A		50, 56	60	
					P		51, 57	61	
E.U.T. In The Chamber	Completely Lined	E.U.T. Location	Near Max.	H	A		52	-	
					P		53	-	
			Near Min.	H	A		54	-	
					P		55	-	
			Arbitrary	H	A	46	58	62	
					P	47	59	63	
	Partly Lined	E.U.T. In Central Region	Case A	H	A	-	-	-	
					P	-	-	-	
			Case B	H	A	48	-	-	
					P	49	-	-	

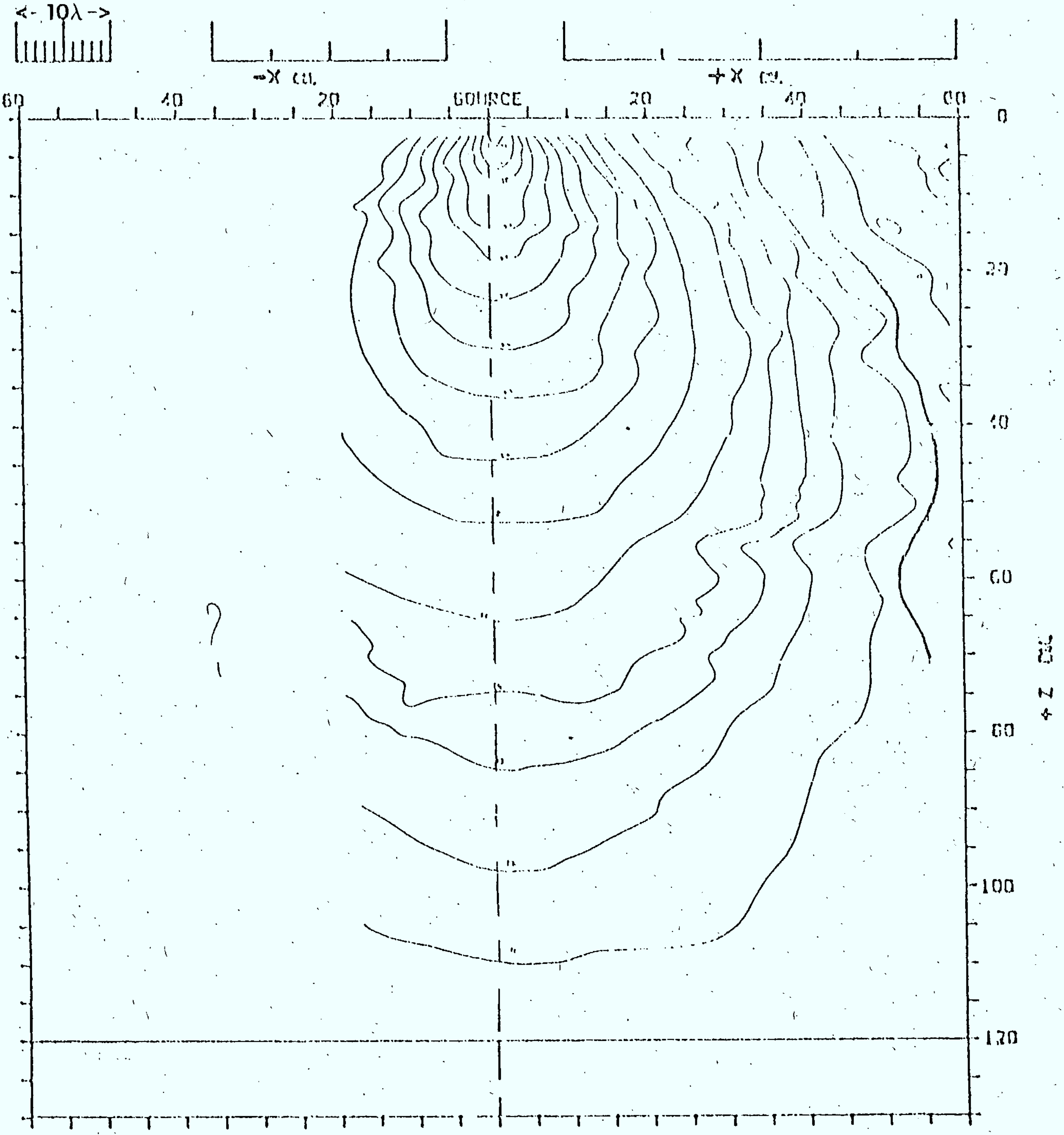
M	23.5	A	H	CL	0	OWG



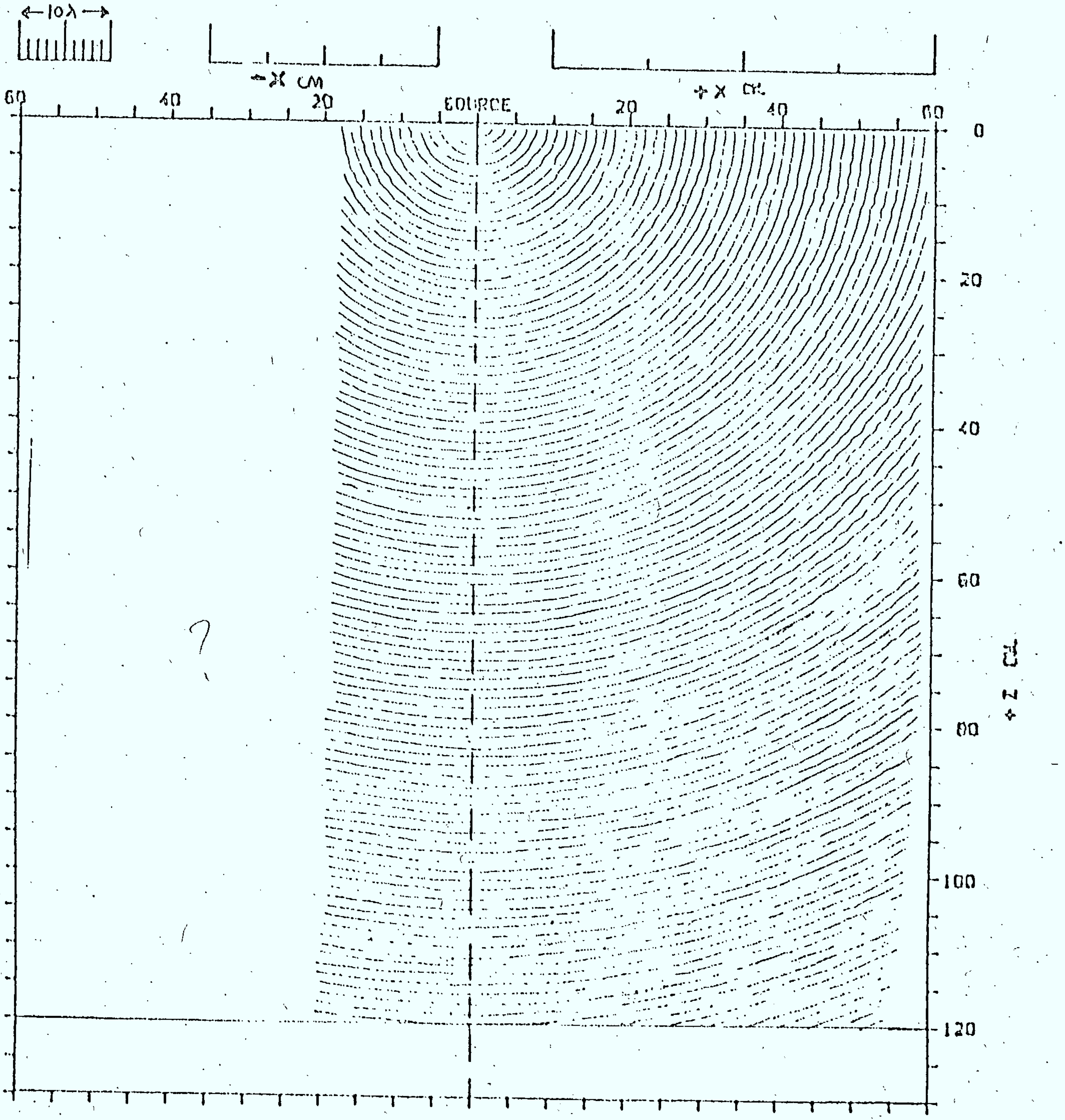
M	23.5	P	H	CL	0	OWG



M	23.5	A	E	CL	0	OWG

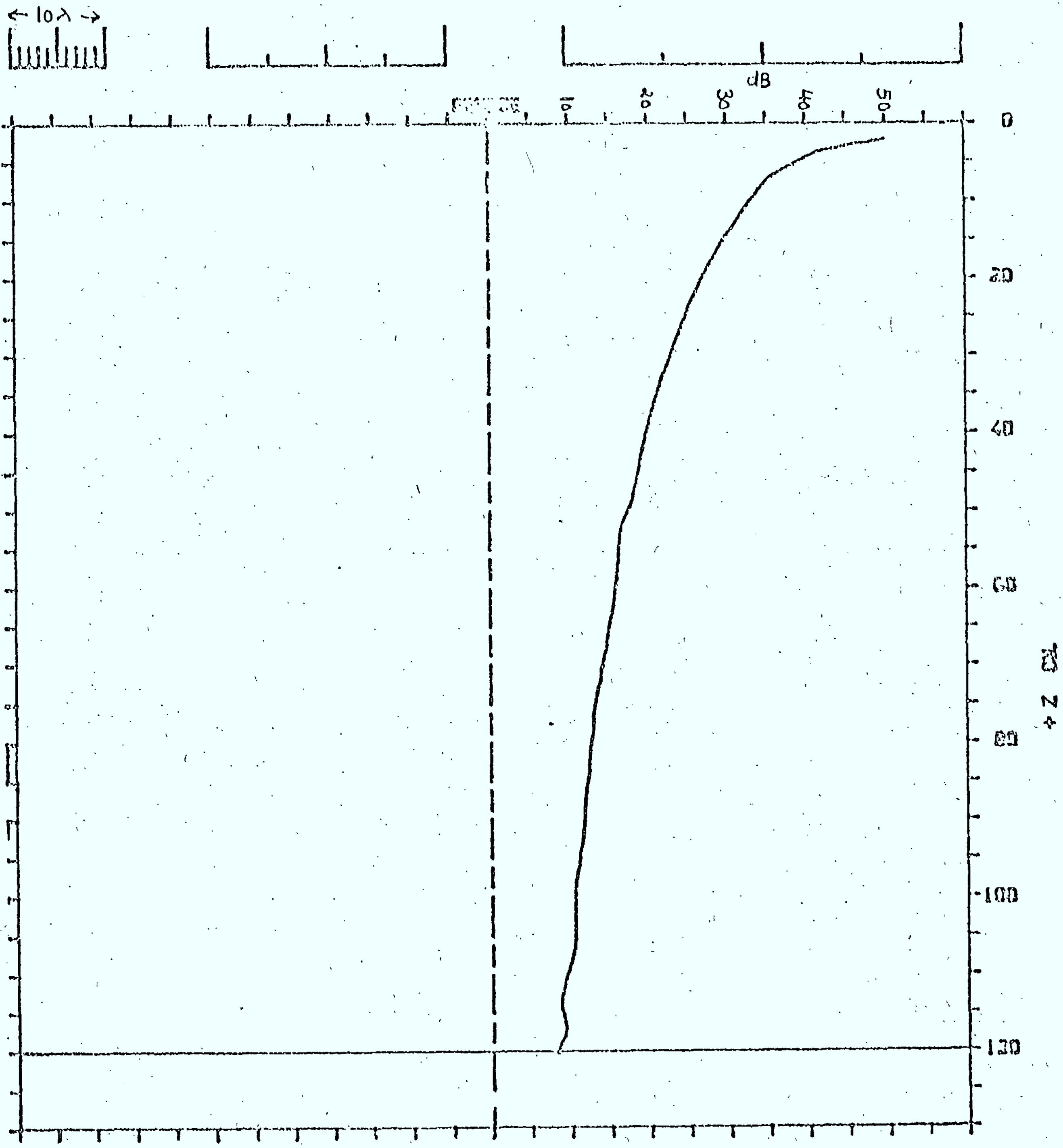


II	23.5	P	E	CL	0	OWG

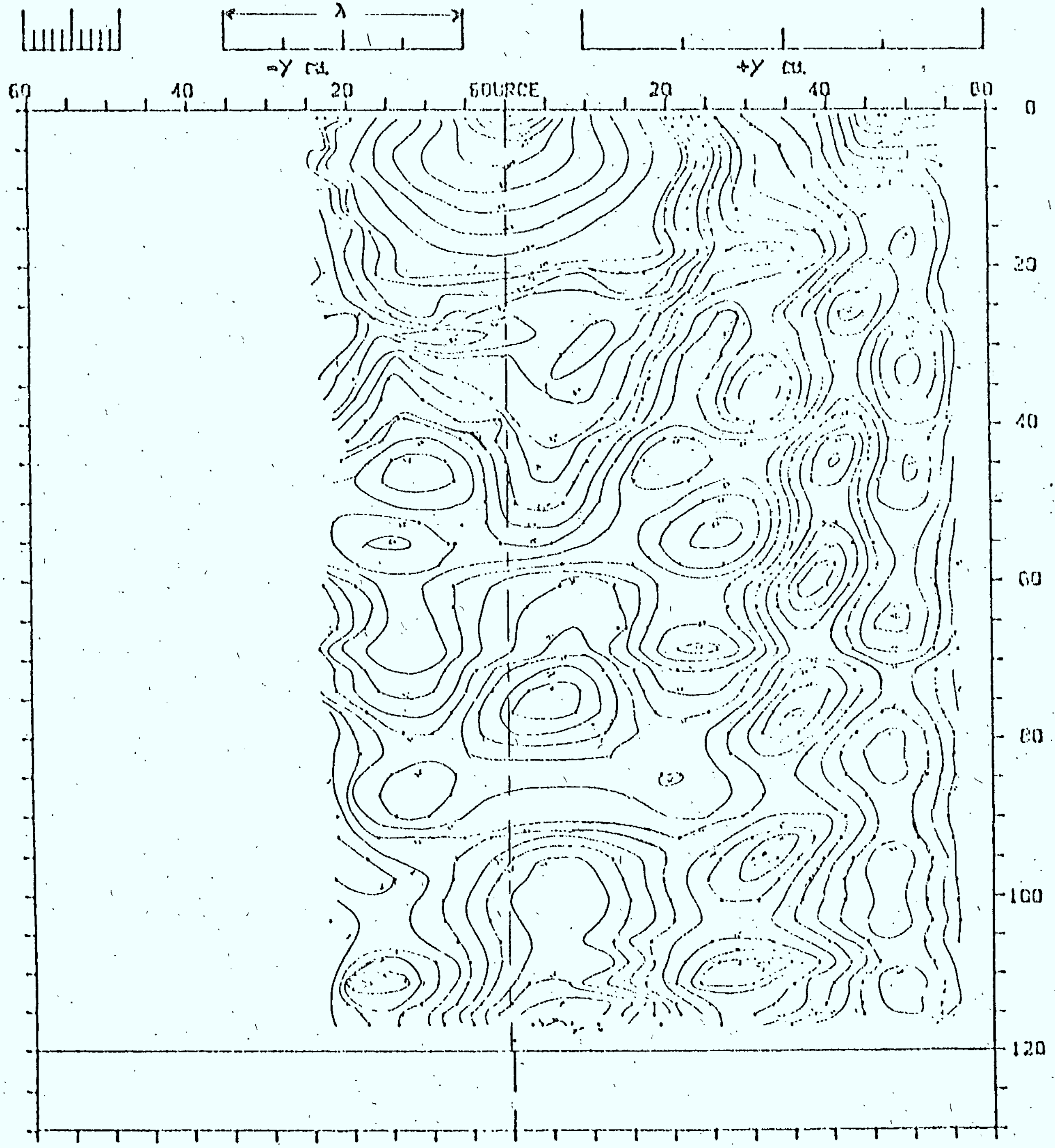


MCGILL 79-00 DOC OSU 79-00143 SRU/TP

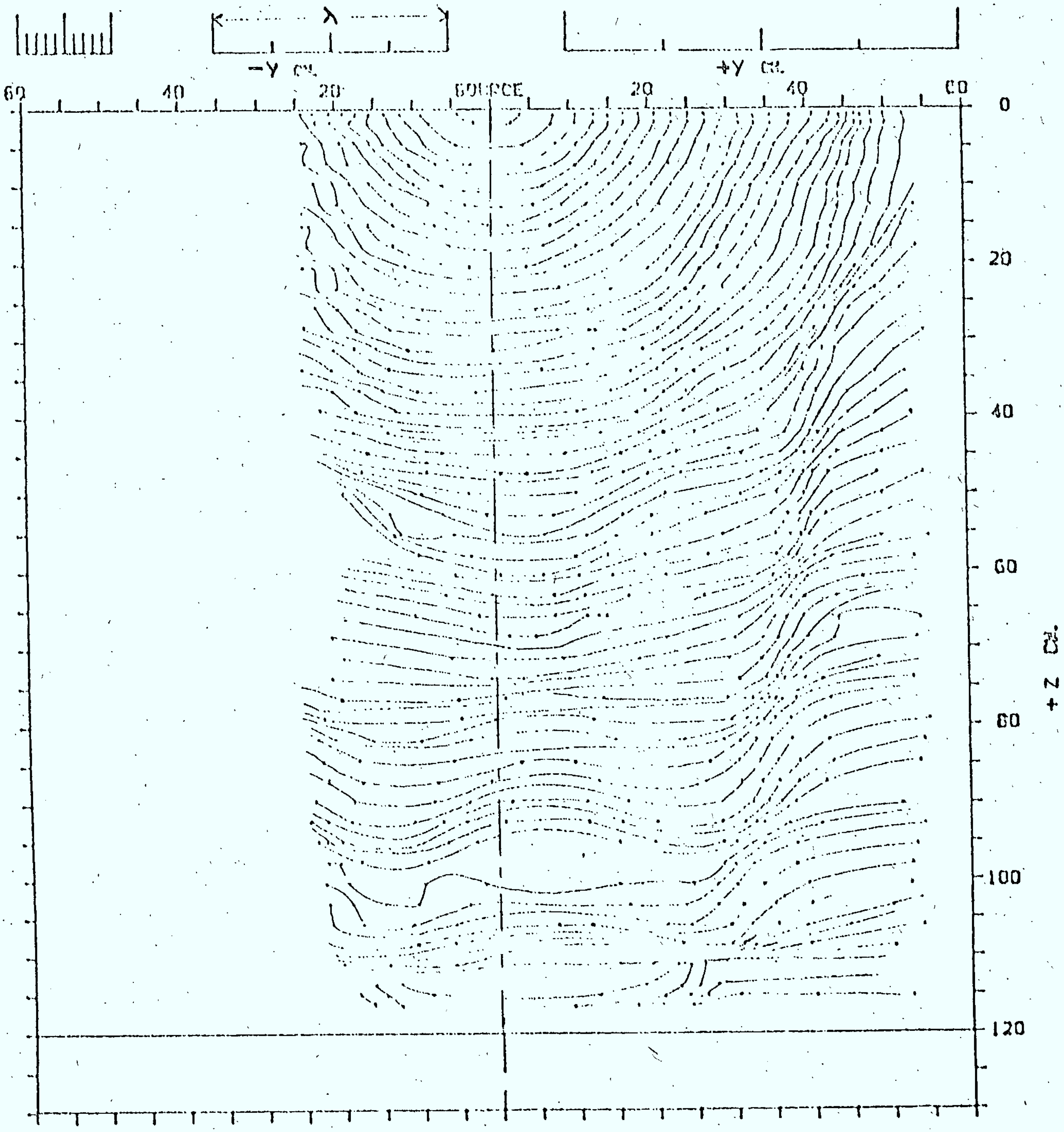
P 23.5 A - CL B OWG



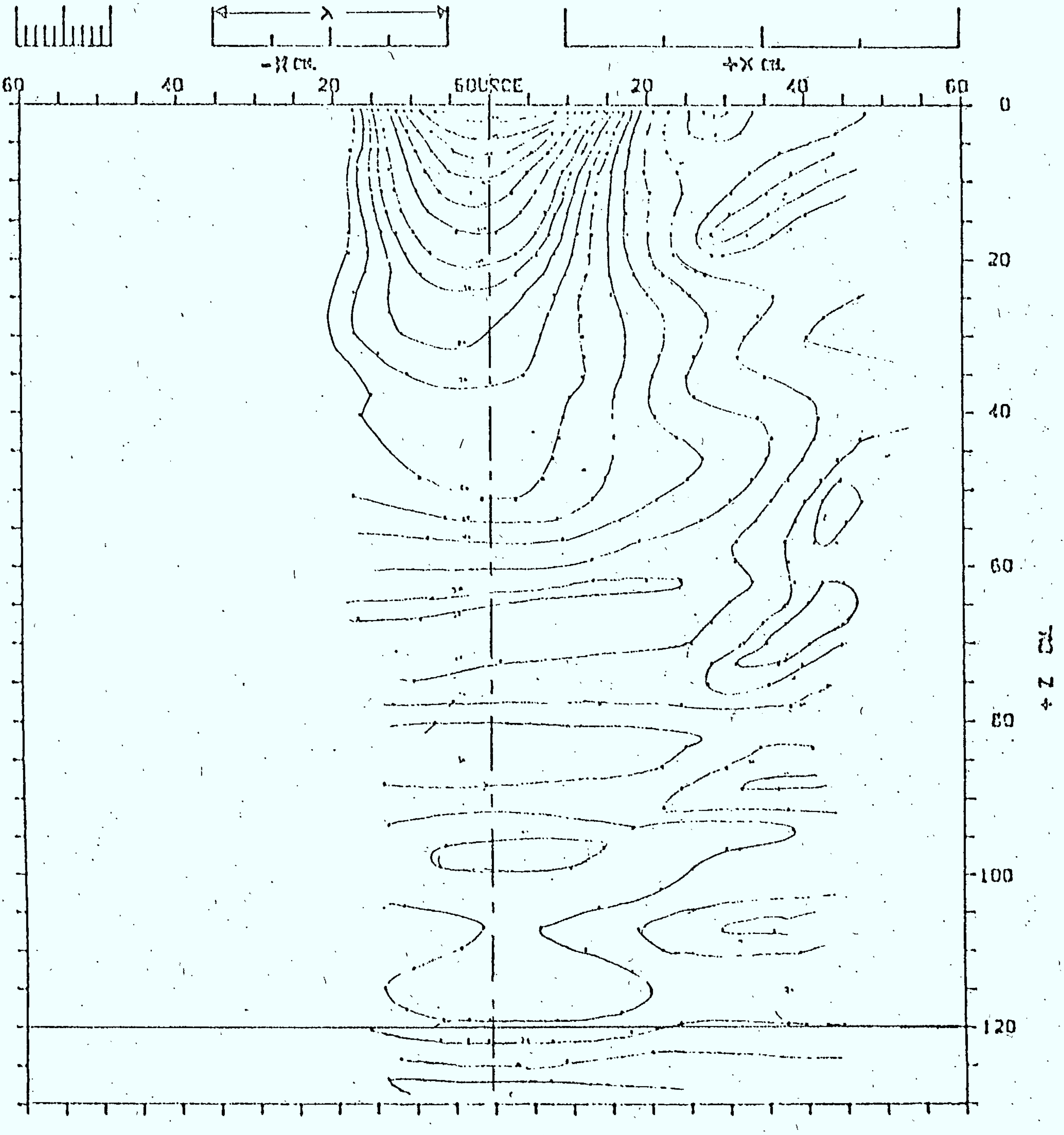
M	1.0	A	H	C.L	0	HWD



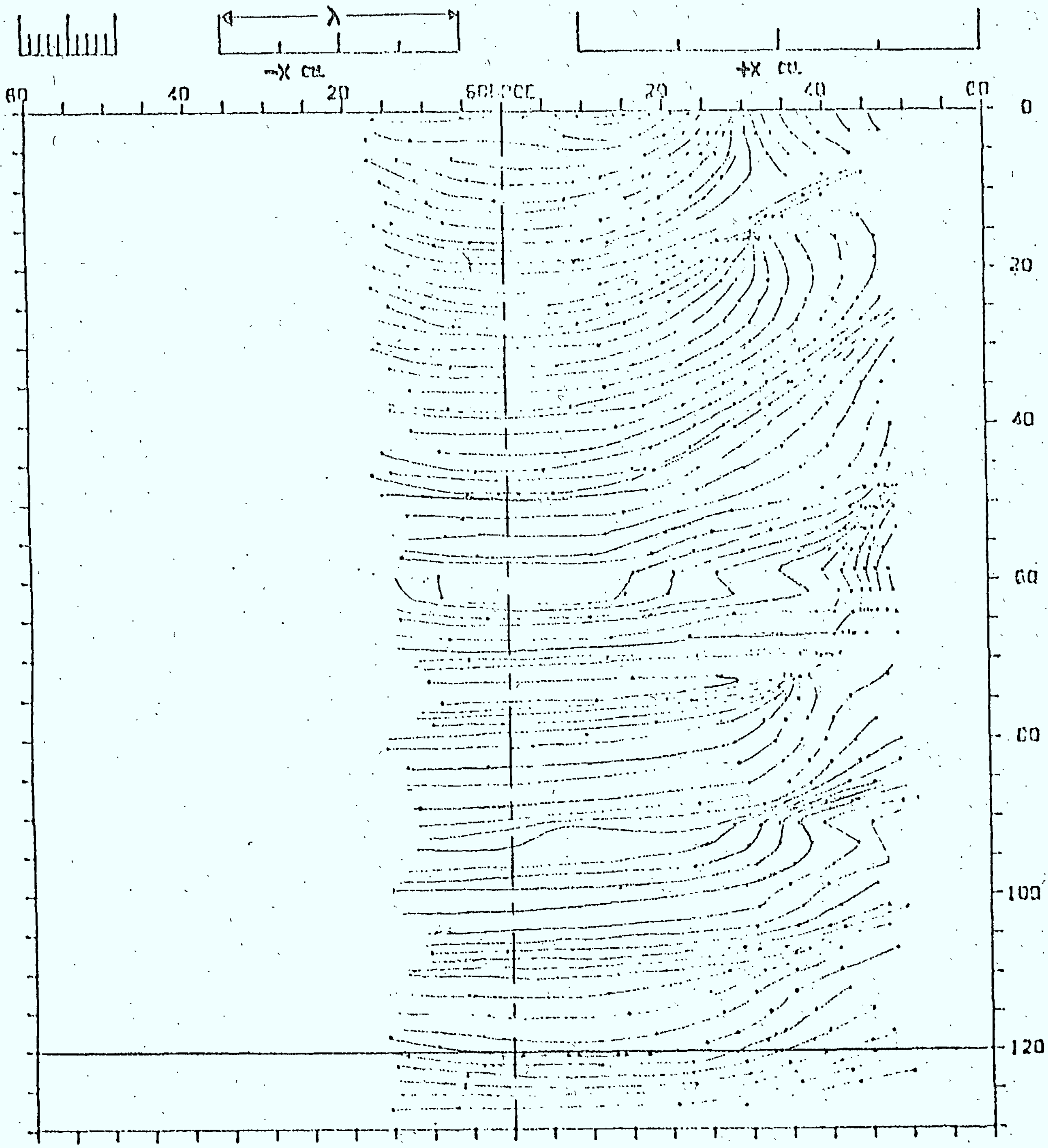
H	1.0	P	H	CL	0	HWD



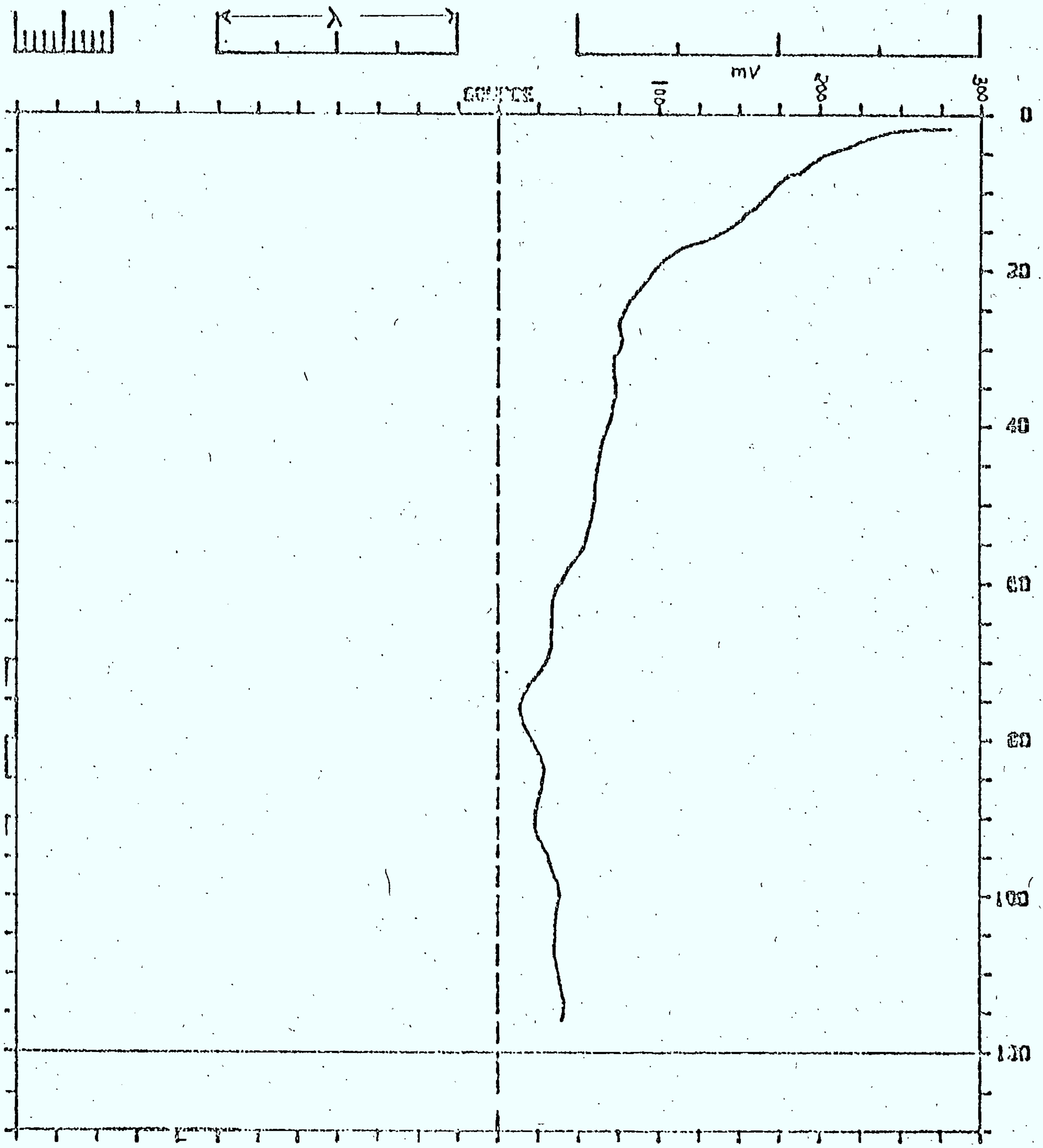
N | 1.0 | A | E | CL | 0 | HWD



H	1.0	P	E	CL	0	HWD

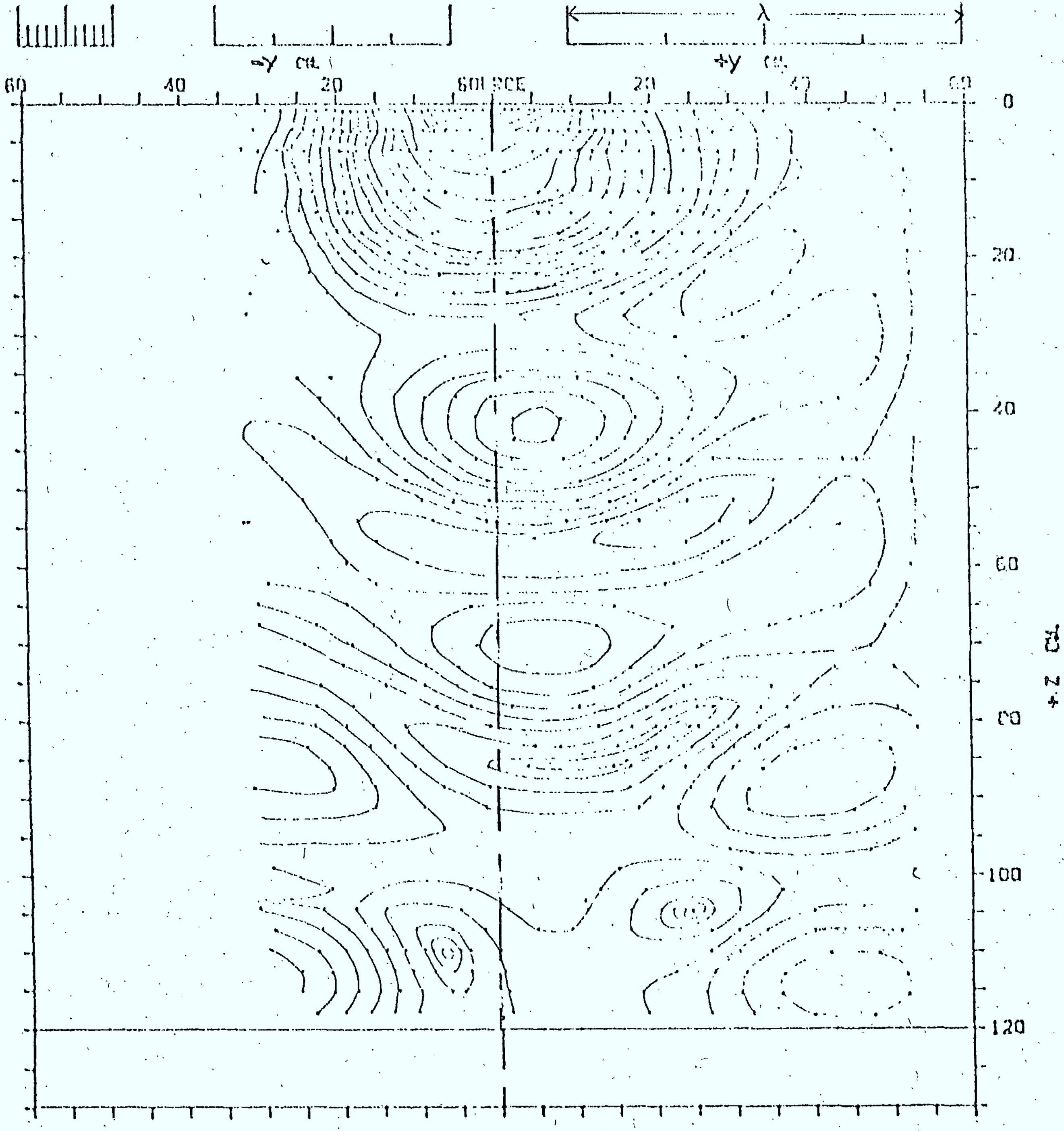


P	1.0	A	-	CL	0	HWD

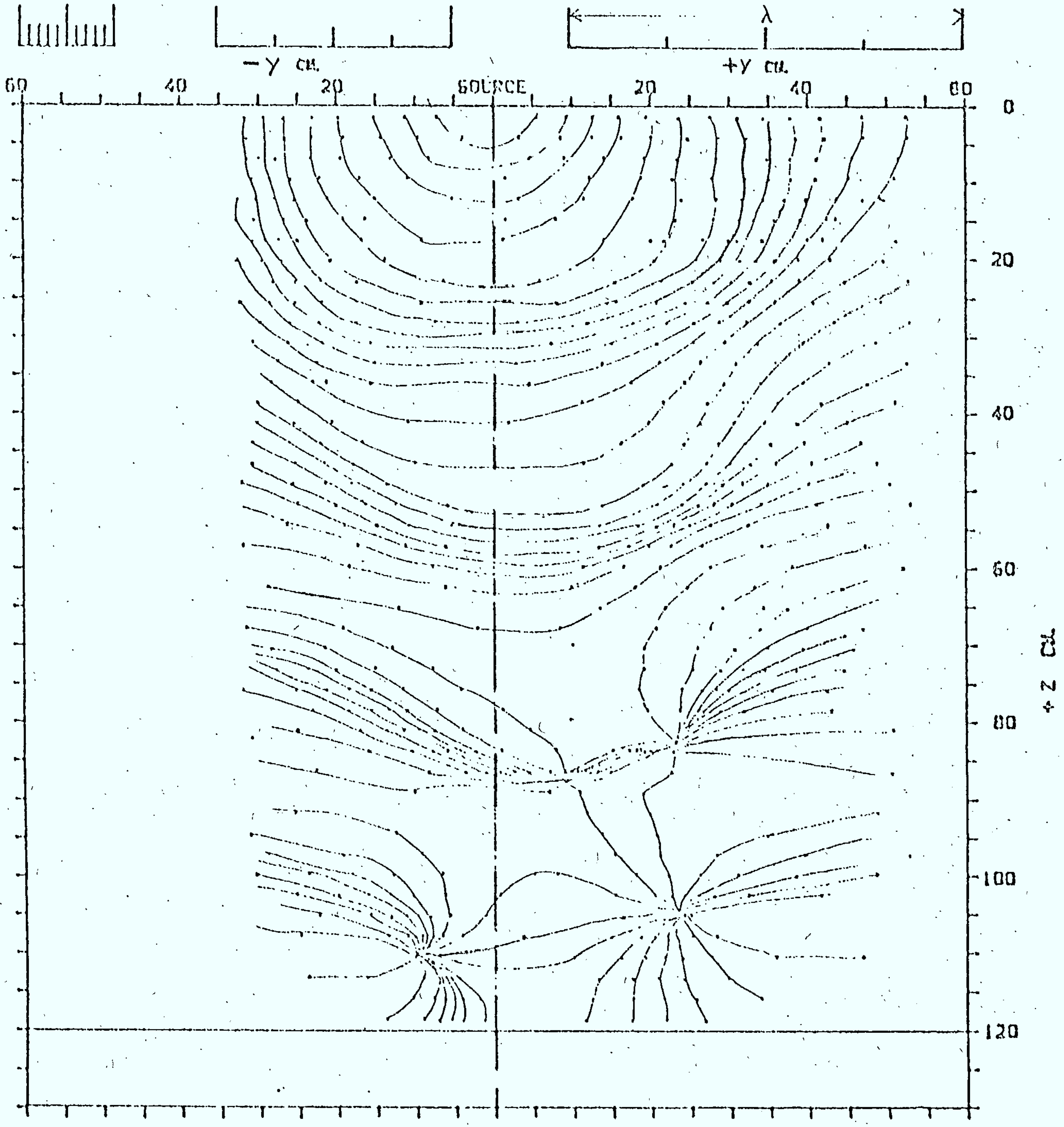


MCGILL 79-80   BOC OGU 79-00149   SRU/TP

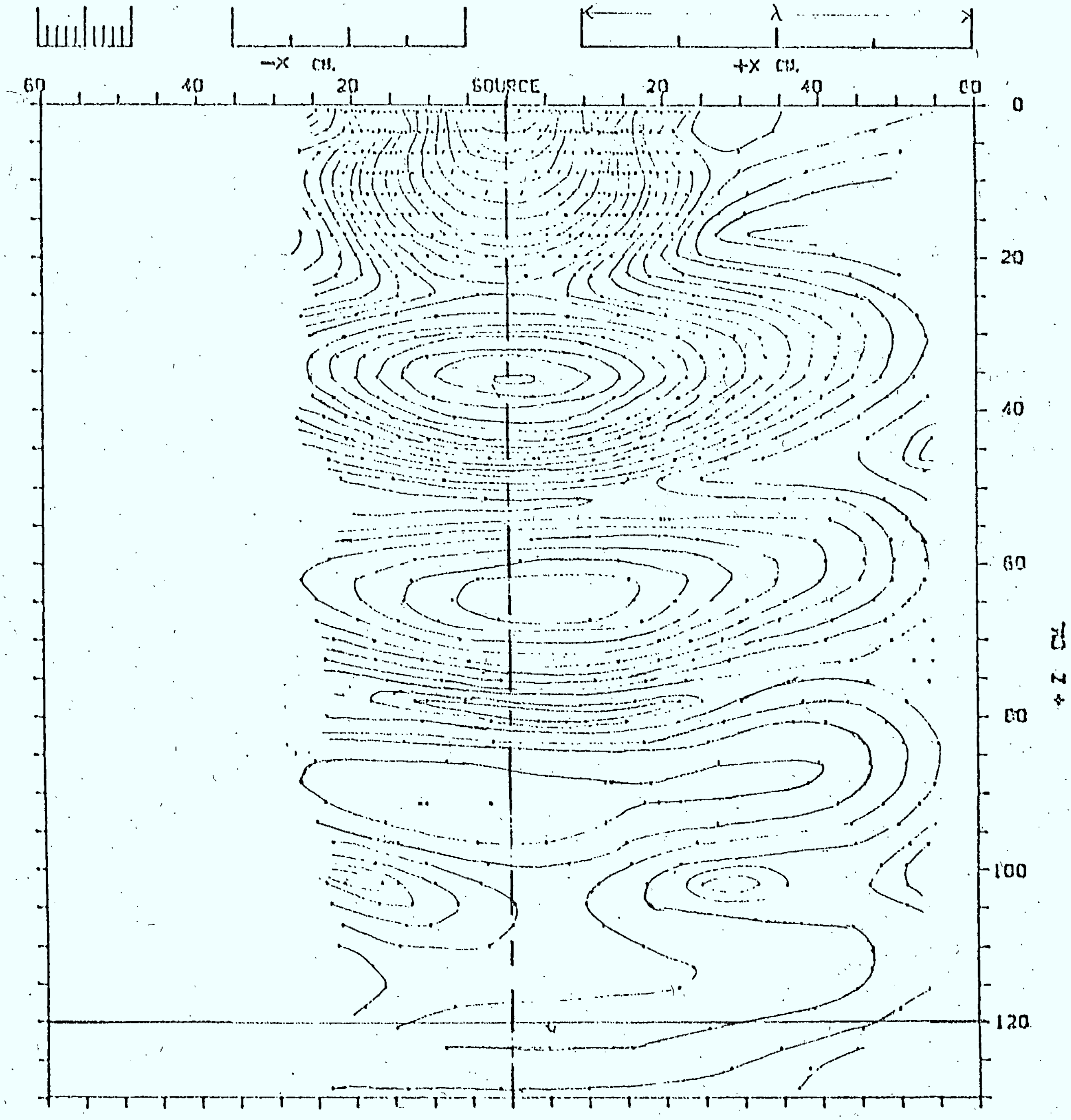
H	0.6	A	H	CL	0	HWD



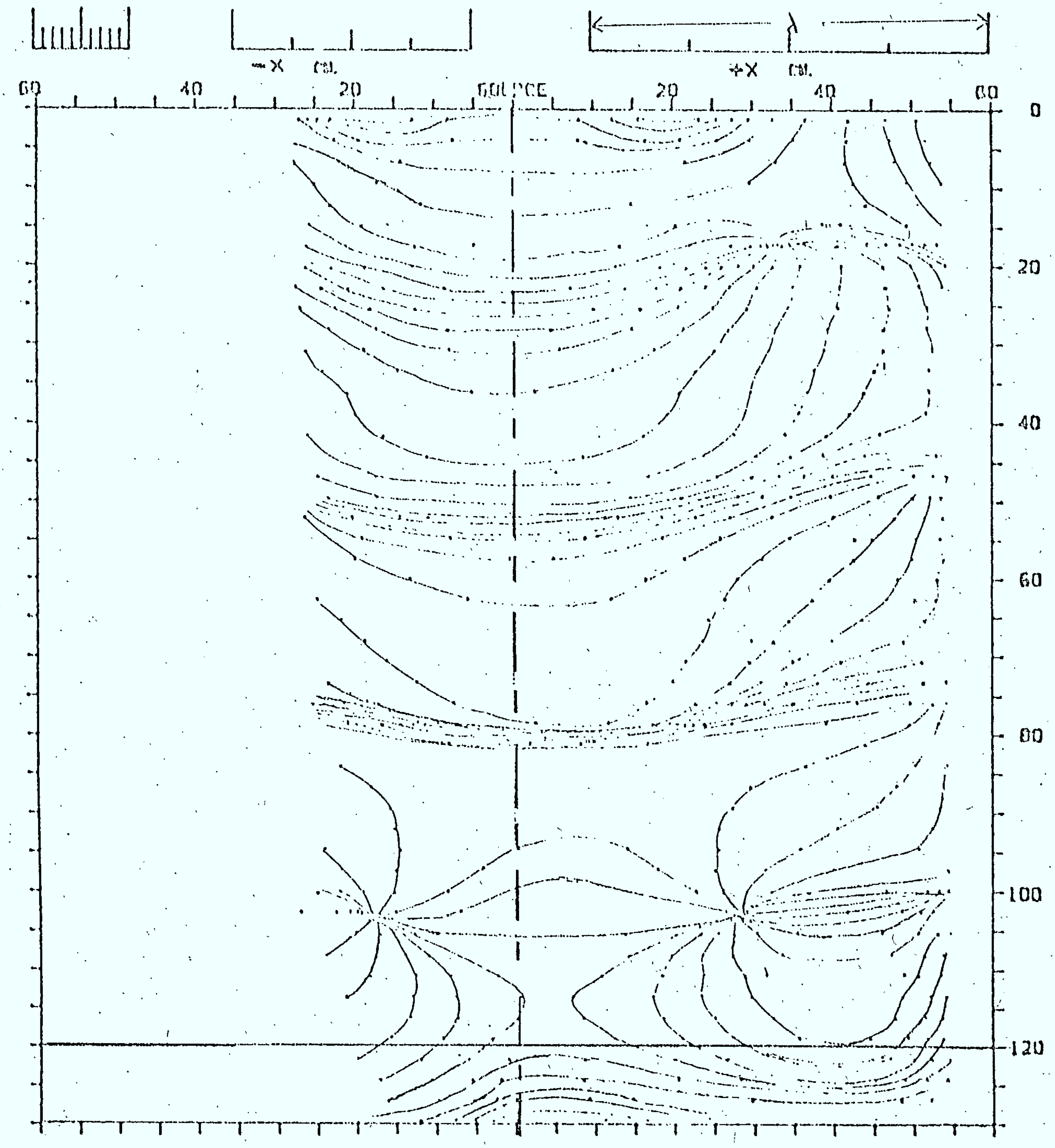
W	0.6	P	H	CL	0	HWD



W	0.6	A	E	CL	0	HWD

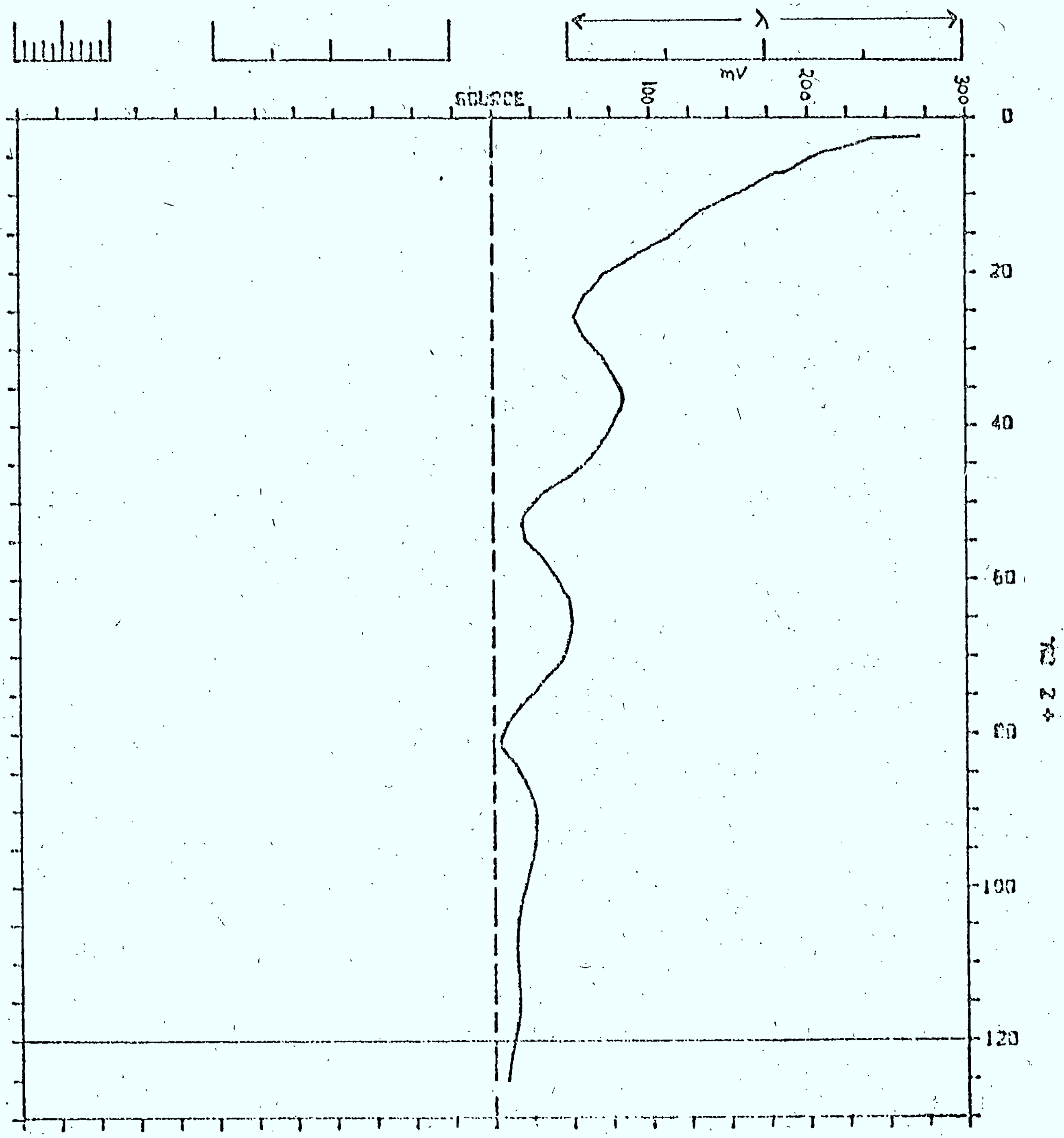


M | 0.6 | P | E | CL | 0 | HWD

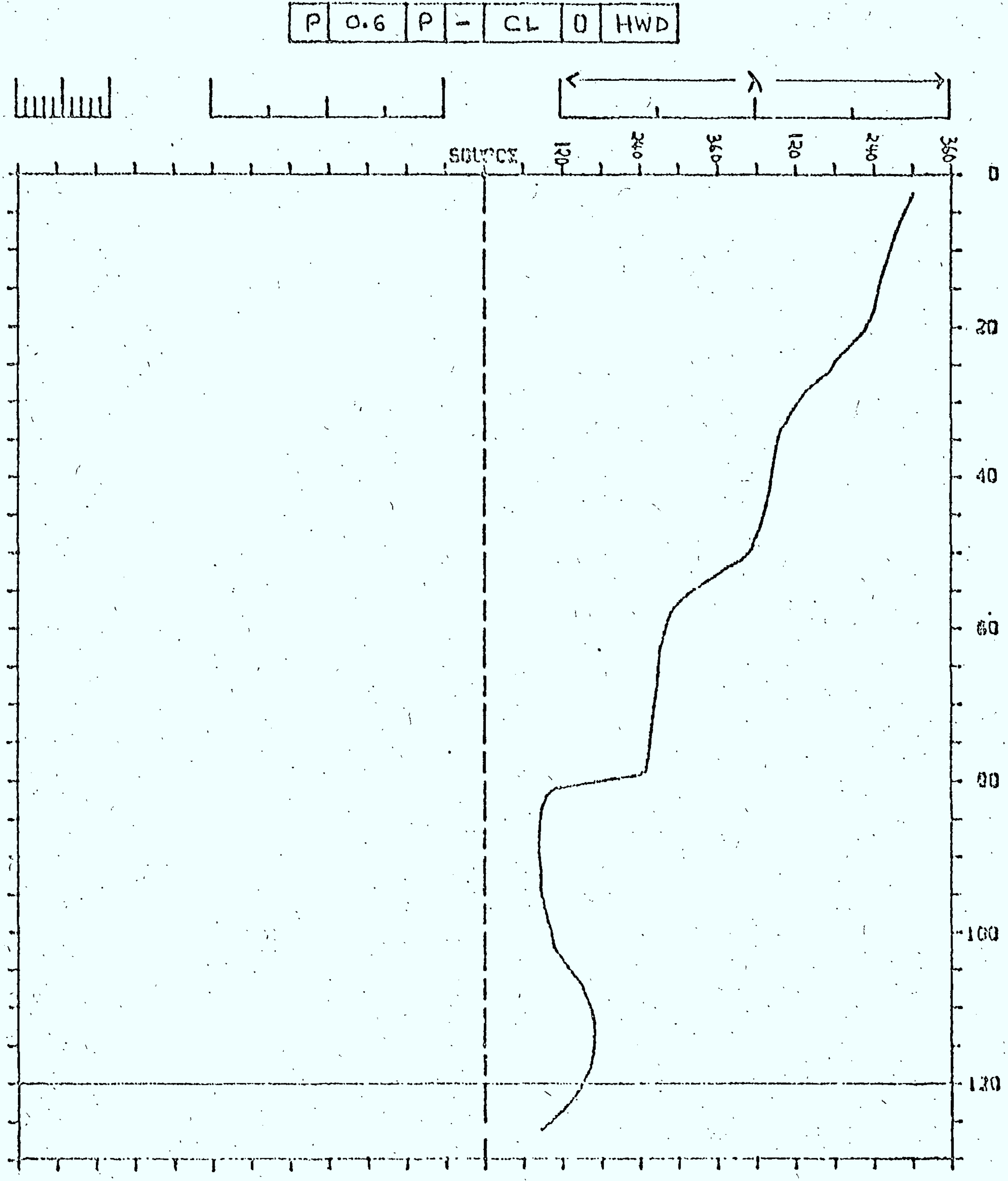


ATLAS PAGE 15

P	0.6	A	-	CL	D	HWD

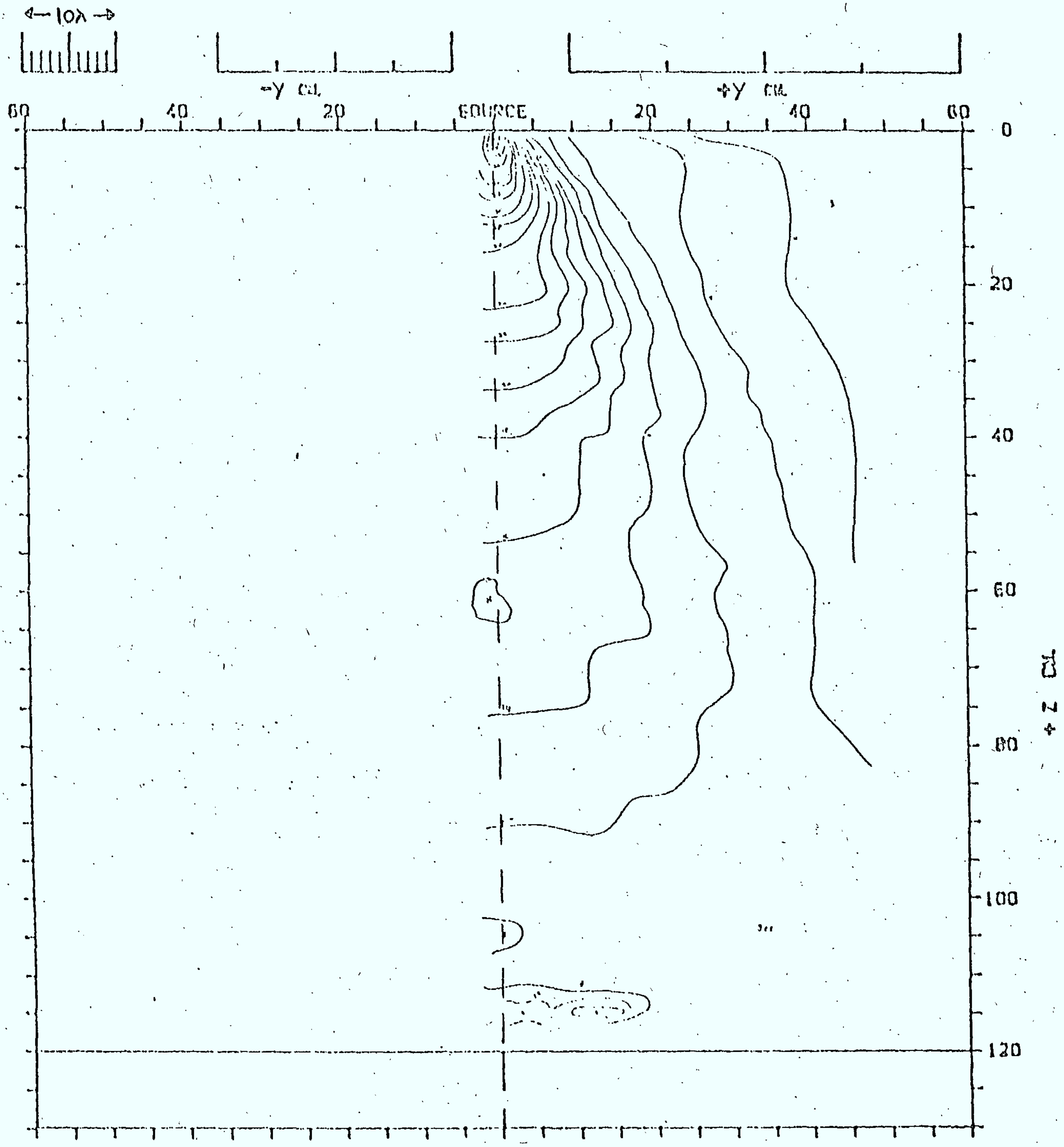


MCGILL 79-80   DCC CSB 79-[illegible]   [illegible]/TP

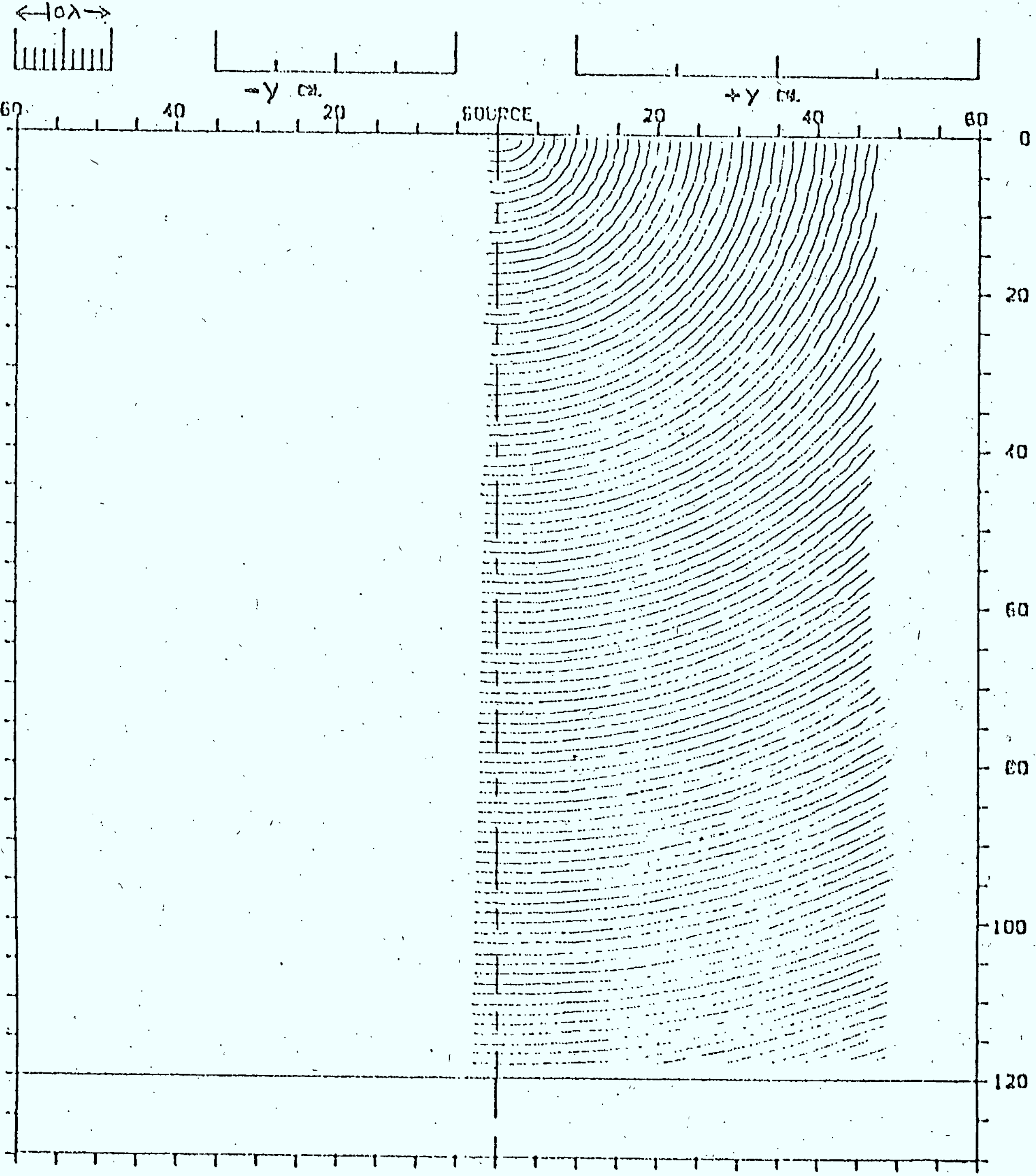


MCGILL 79-80   DRC OSU 79-00149   SPM/TP

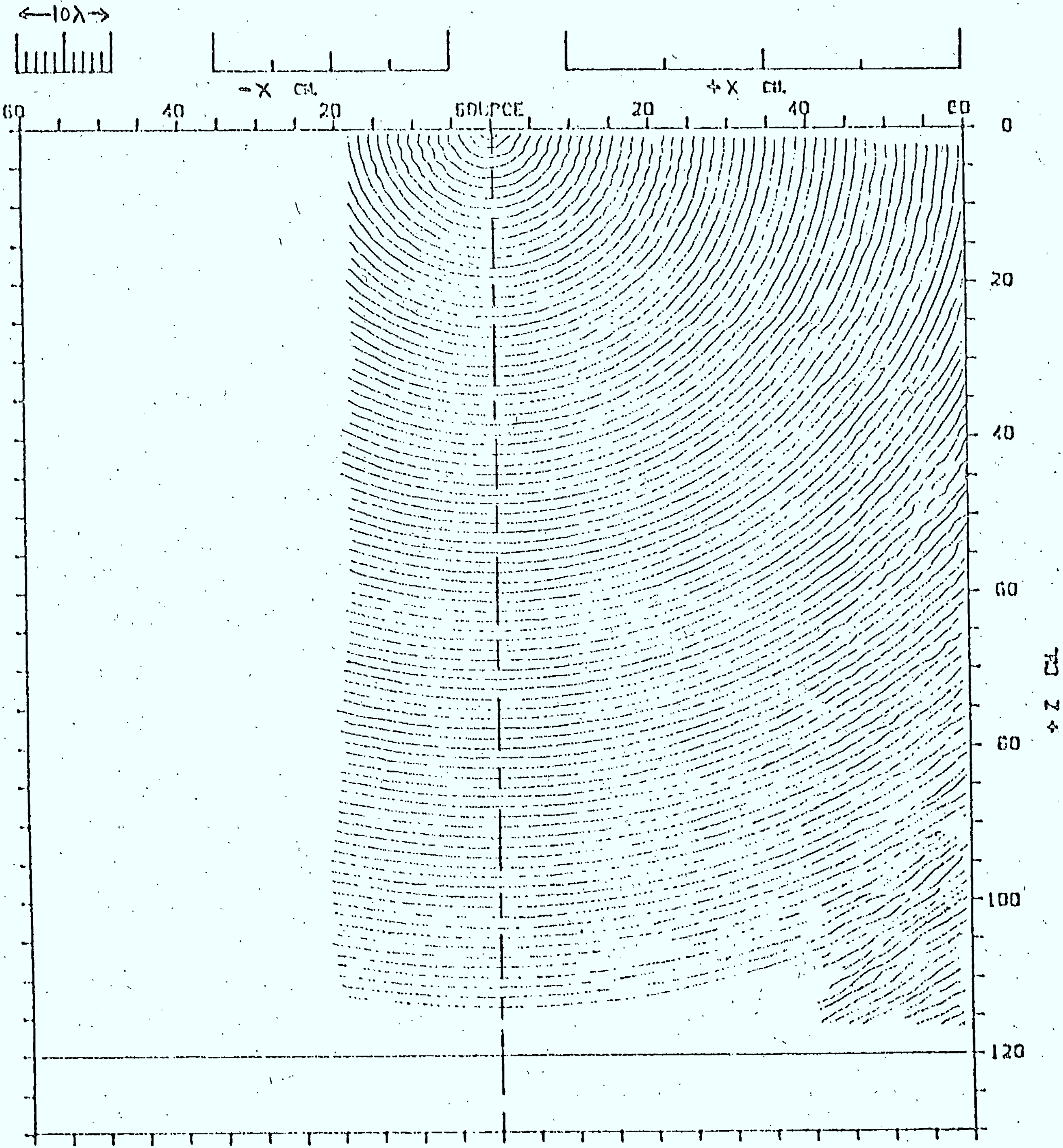
11	23.5	A	H	FO	0	OWG



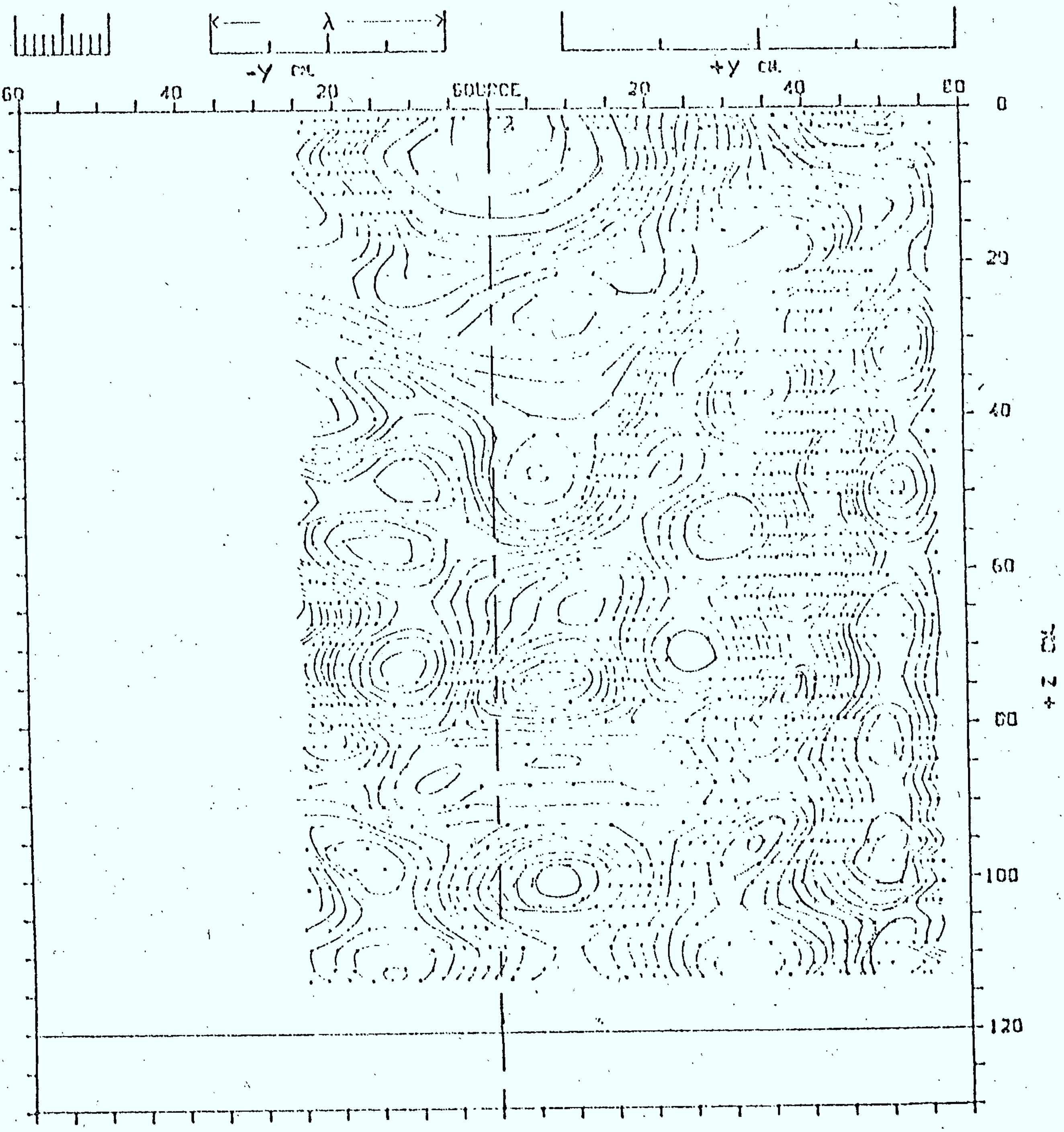
M	23.5	P	H	F0	0	OWG



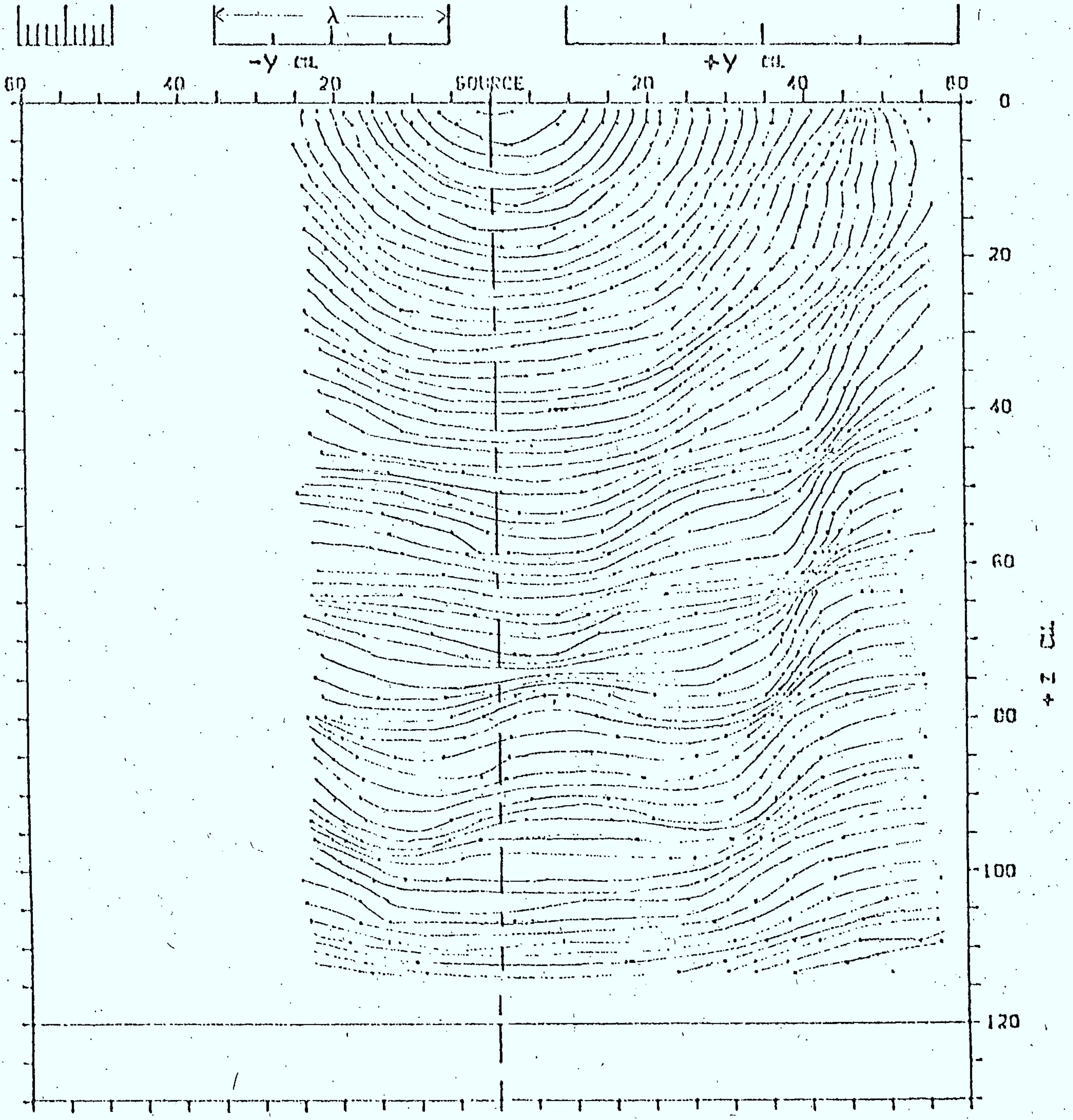
M	23.5	P	E	FO	0	OWG



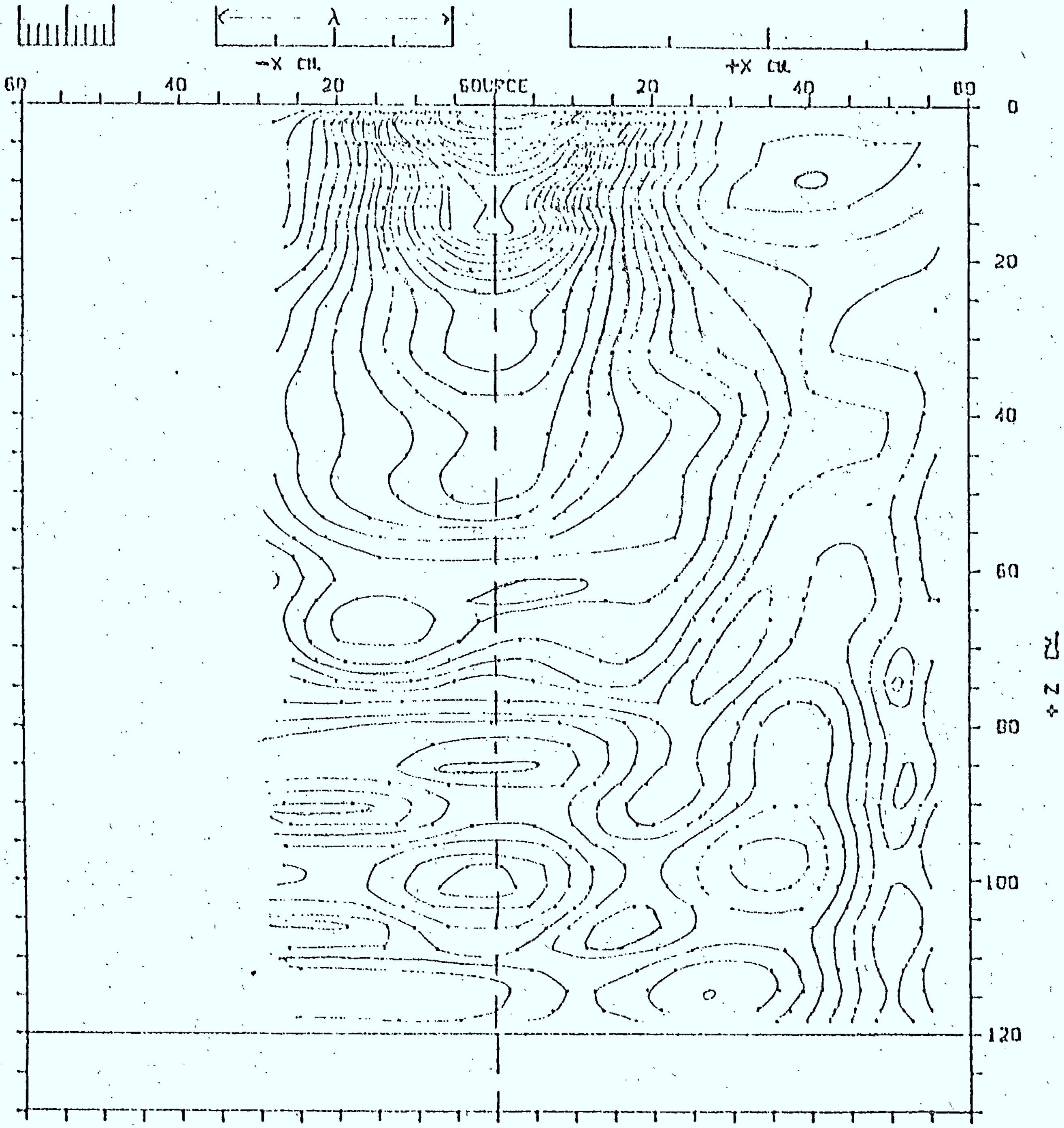
H	1.0	A	H	FO	0	HWD



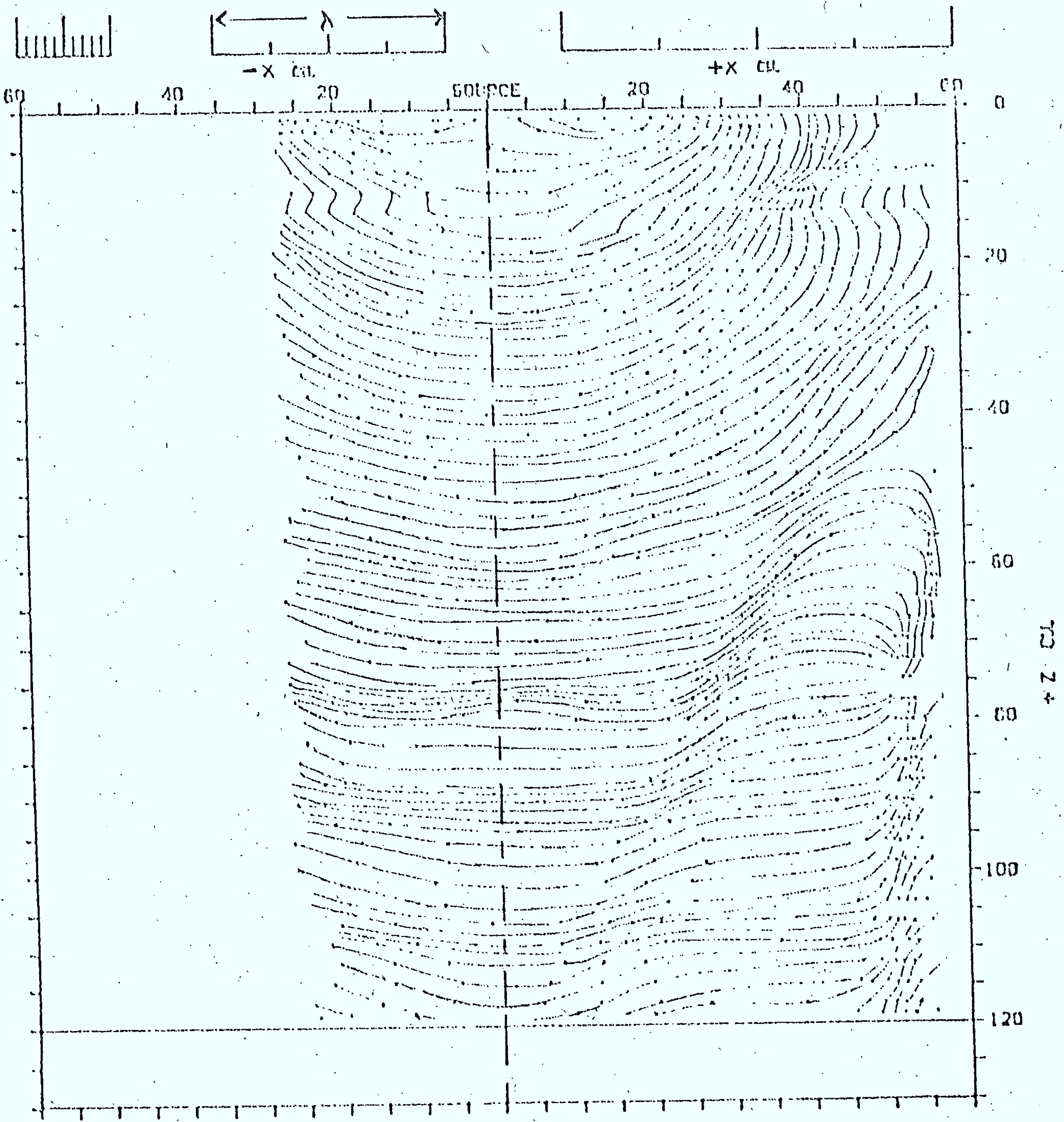
N	1.0	P	H	FO	0	HWD



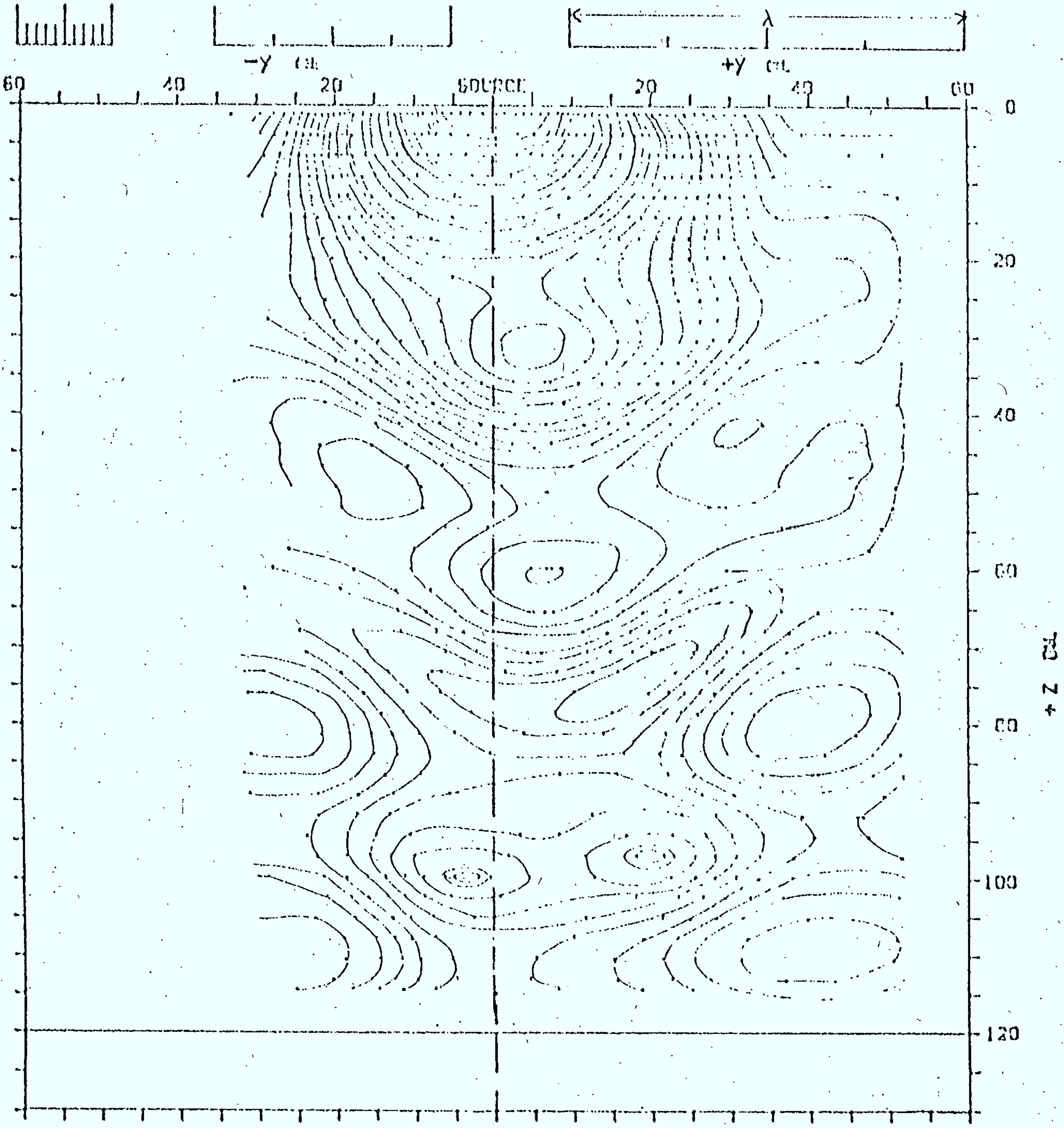
M	1.0	A	E	F0	0	HWD



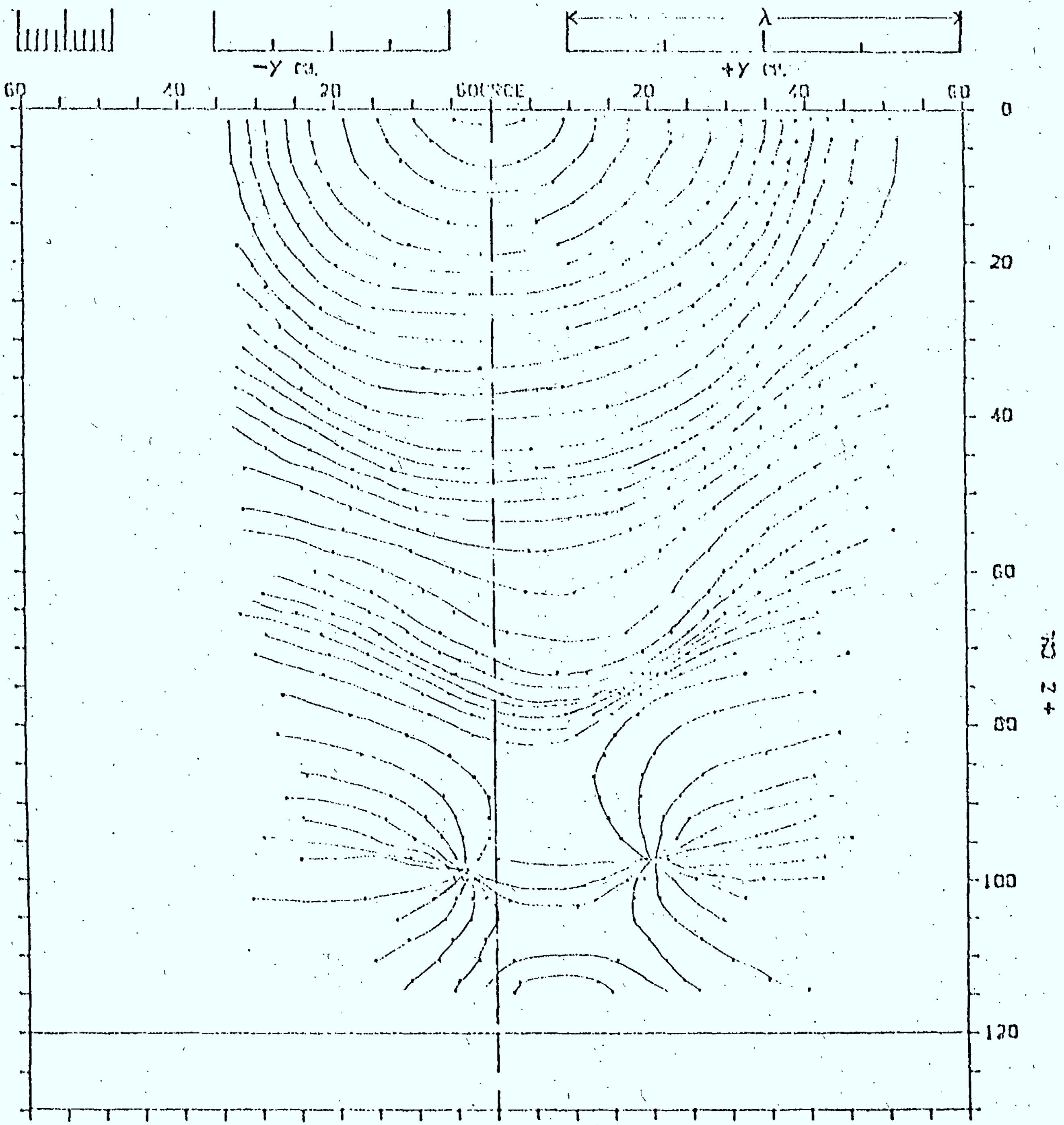
M	1.0	P	E	FO	0	HWD



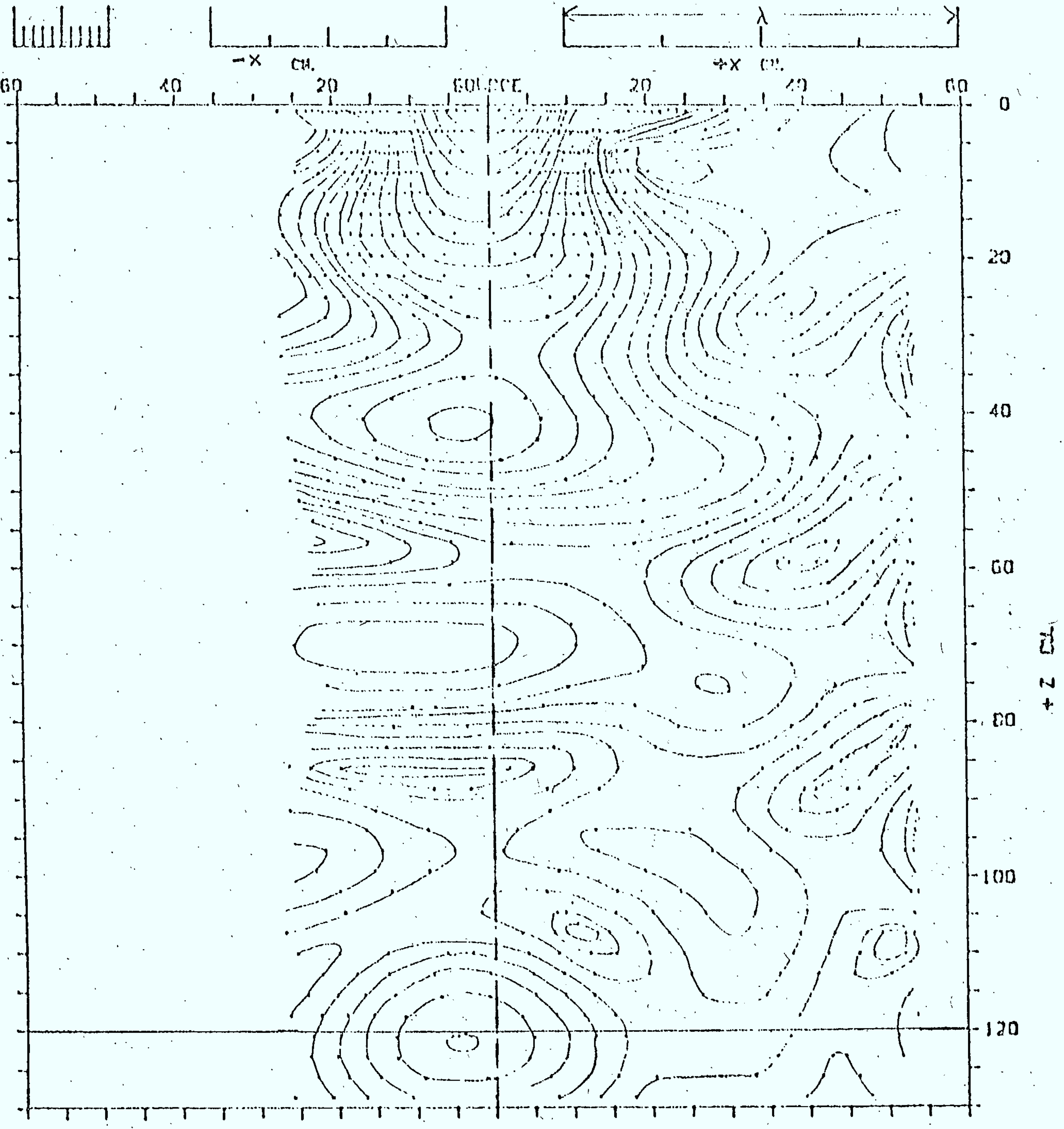
H	0.6	A	H	FO	0	HWD



II	0.6	P	H	FO	0	HWD



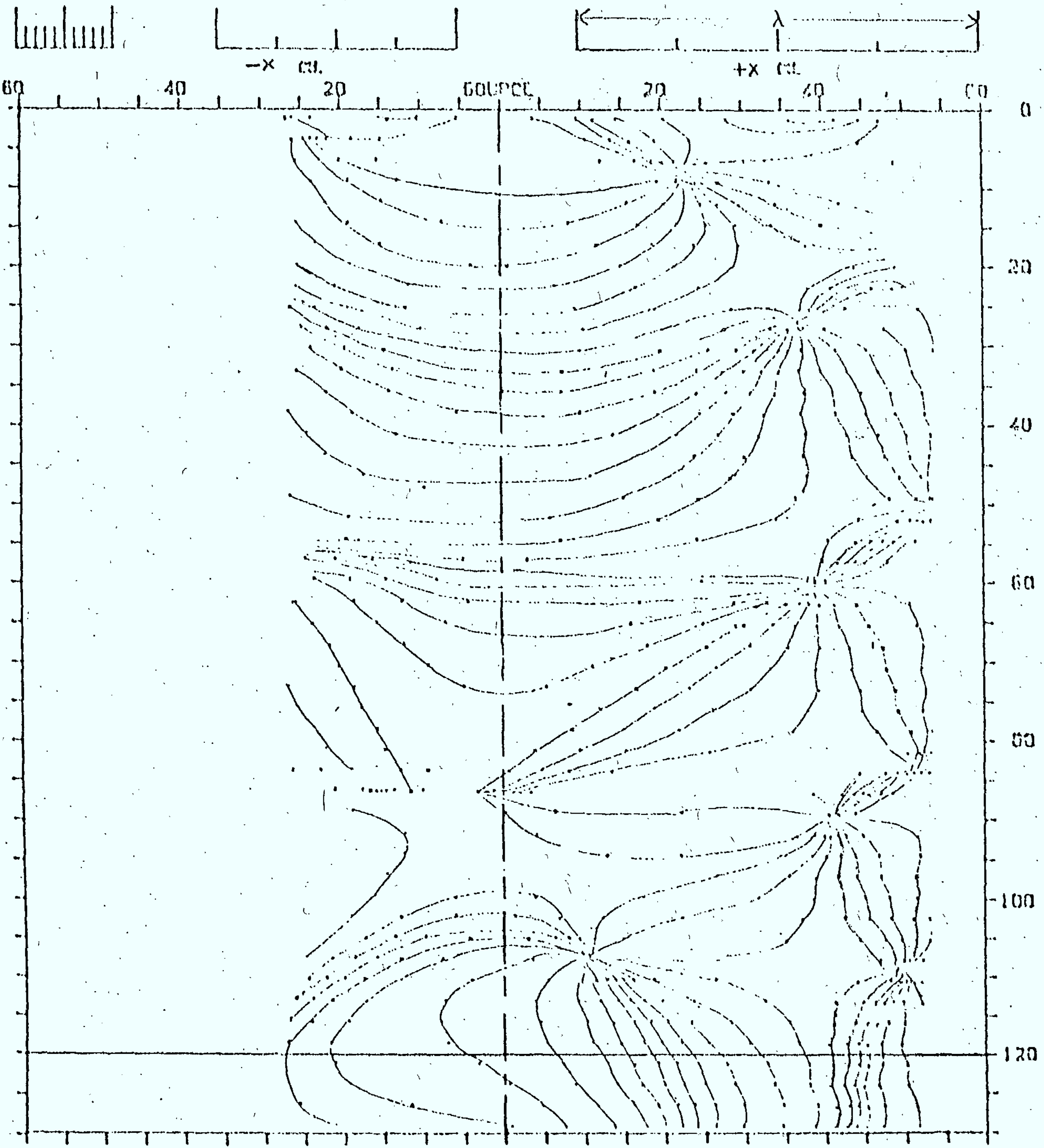
H	0.6	A	E	F0	0	HWD



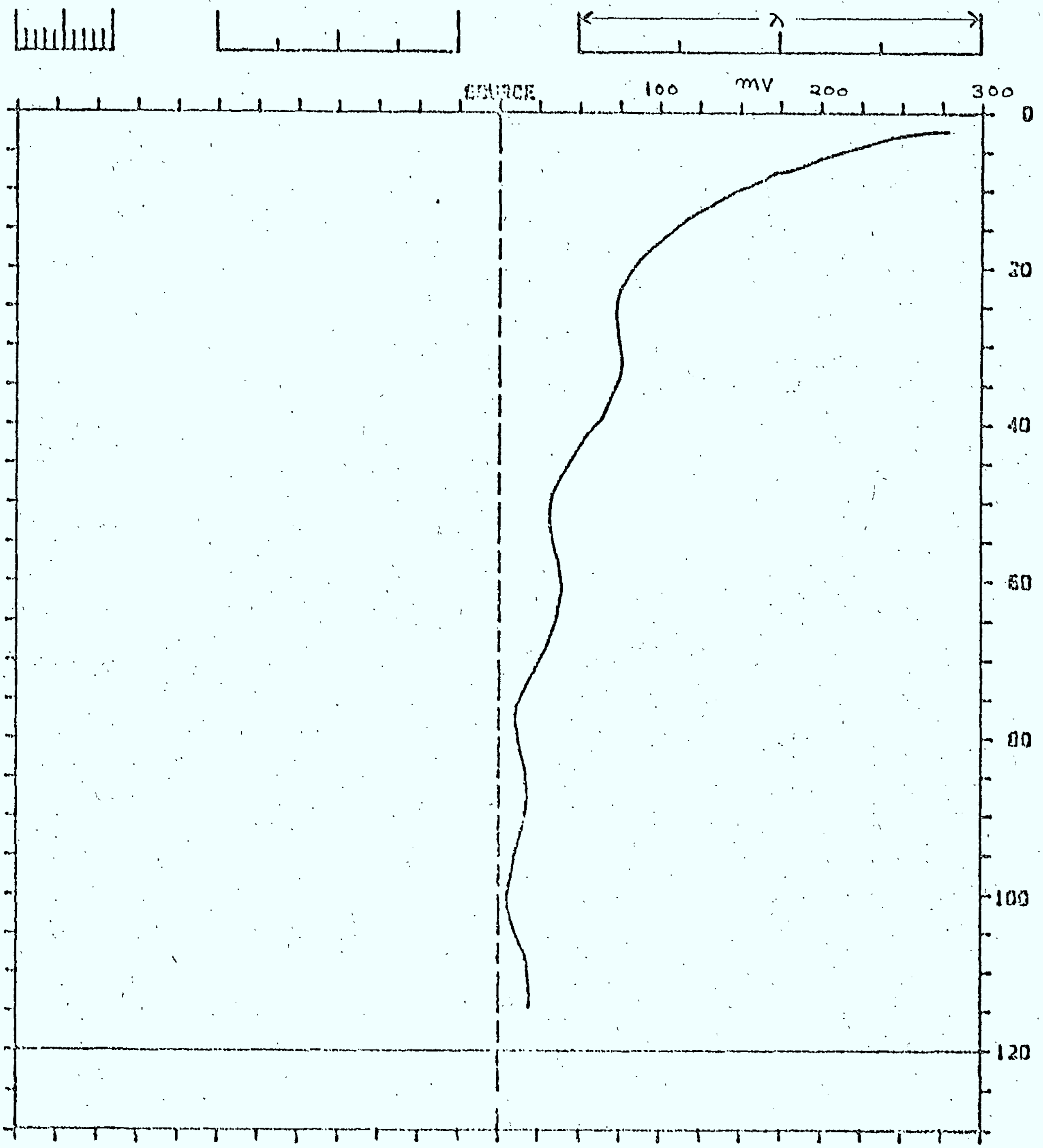
MCGILL 79-80 DOC OSU 79-00143 SRU/TP

112 P

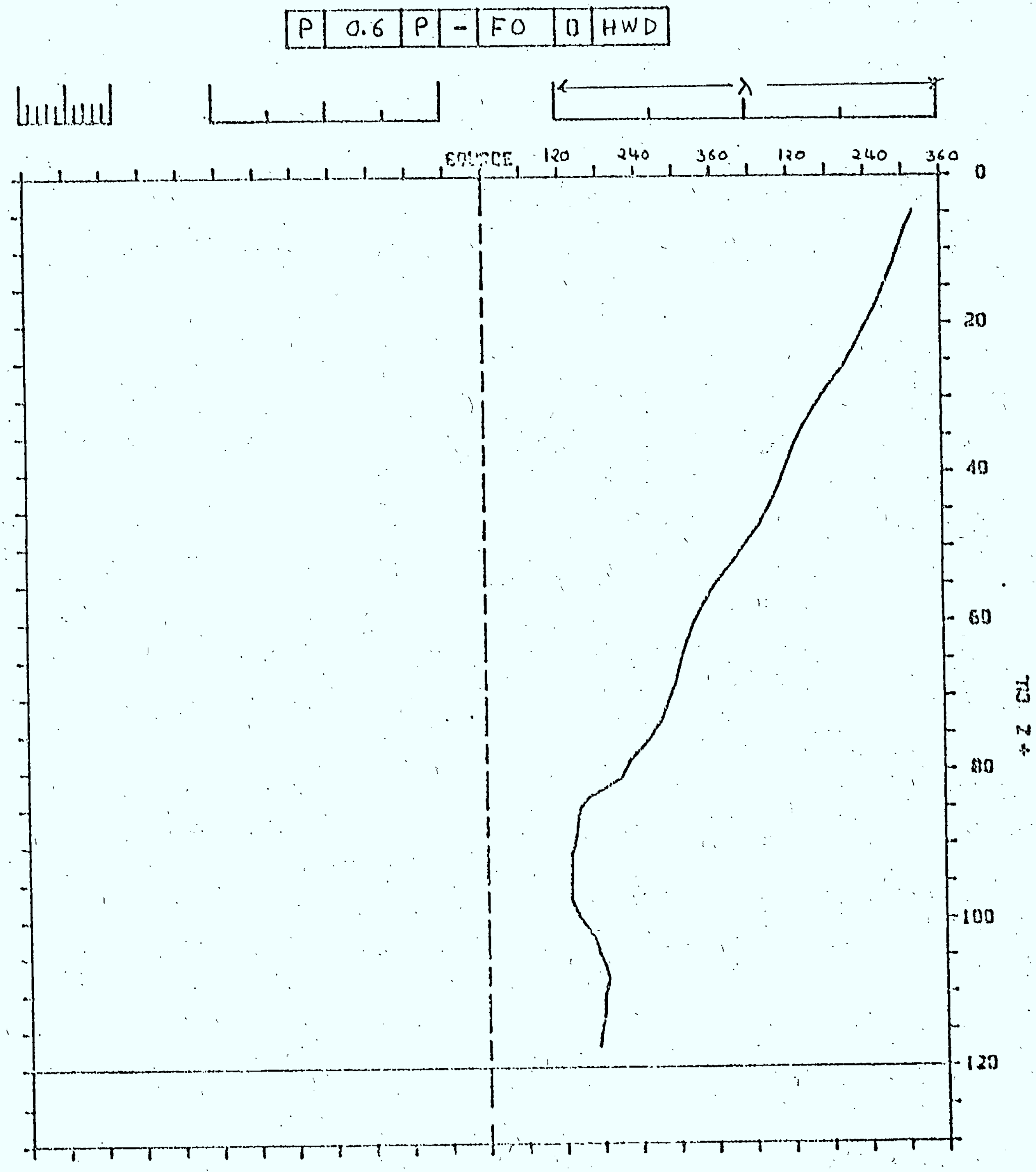
M	0.6	P	E	FO	0	HWD



P	0.6	A	-	FO	0	HWD

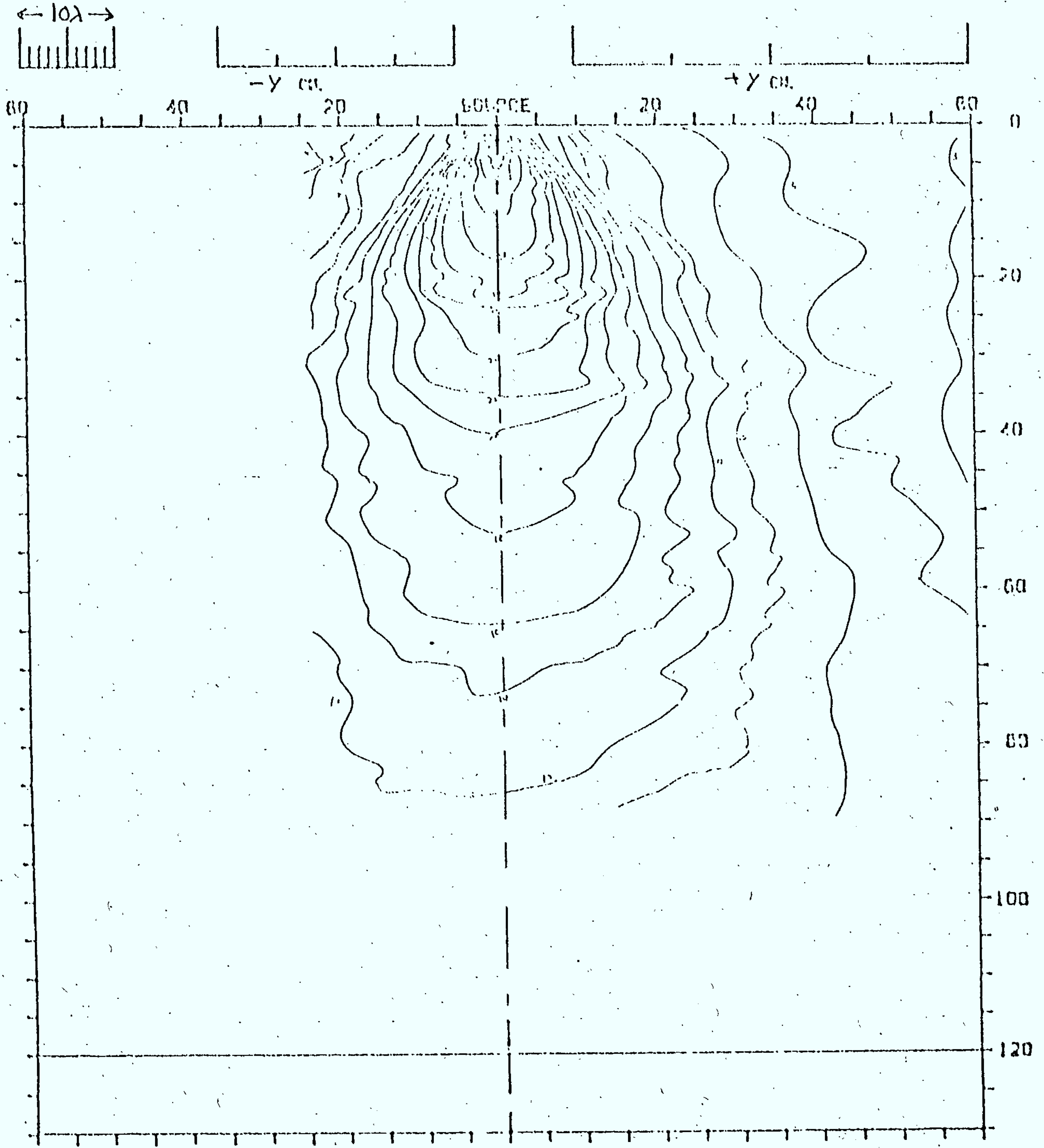


MCGILL 79-80   DOC OSU 79-00143   SRU/TP



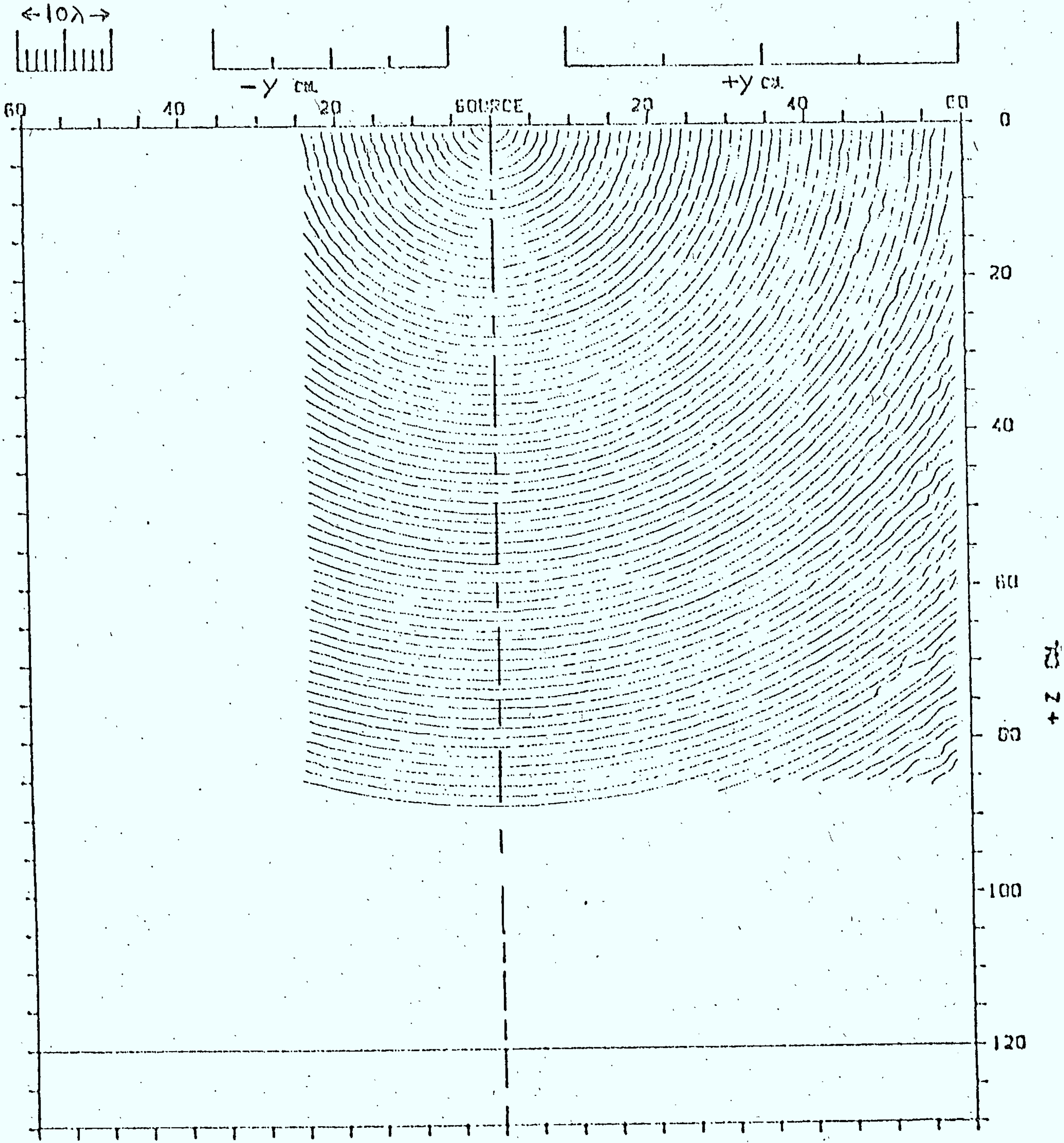
MCGILL 79-80 DOC OSU 79-00149 SRU/TP

| H | 23.5 | A | H | WO | 0 | OWG |

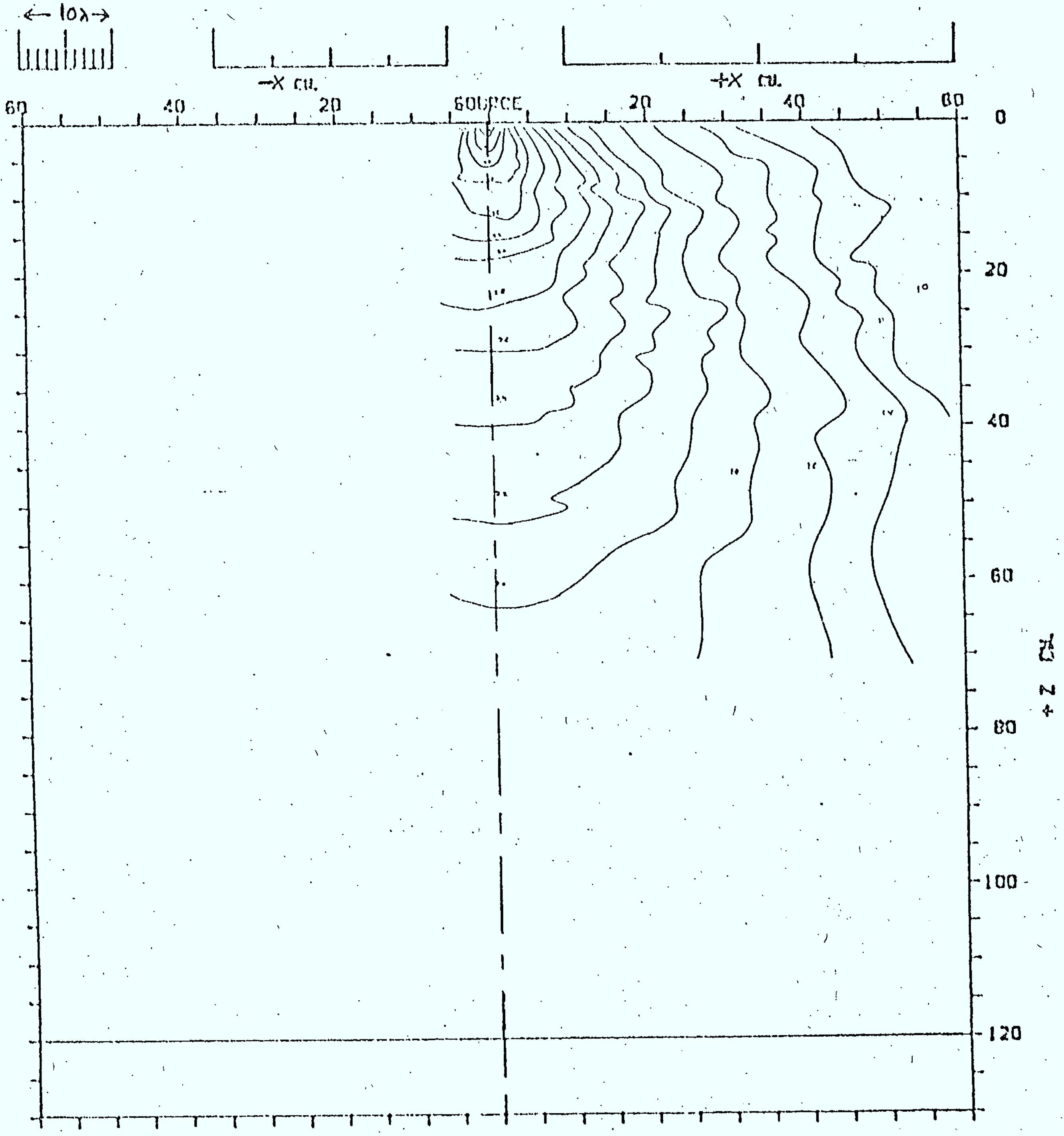


MCGILL 79-80 DOC OSU 79-00143 SRU/TP

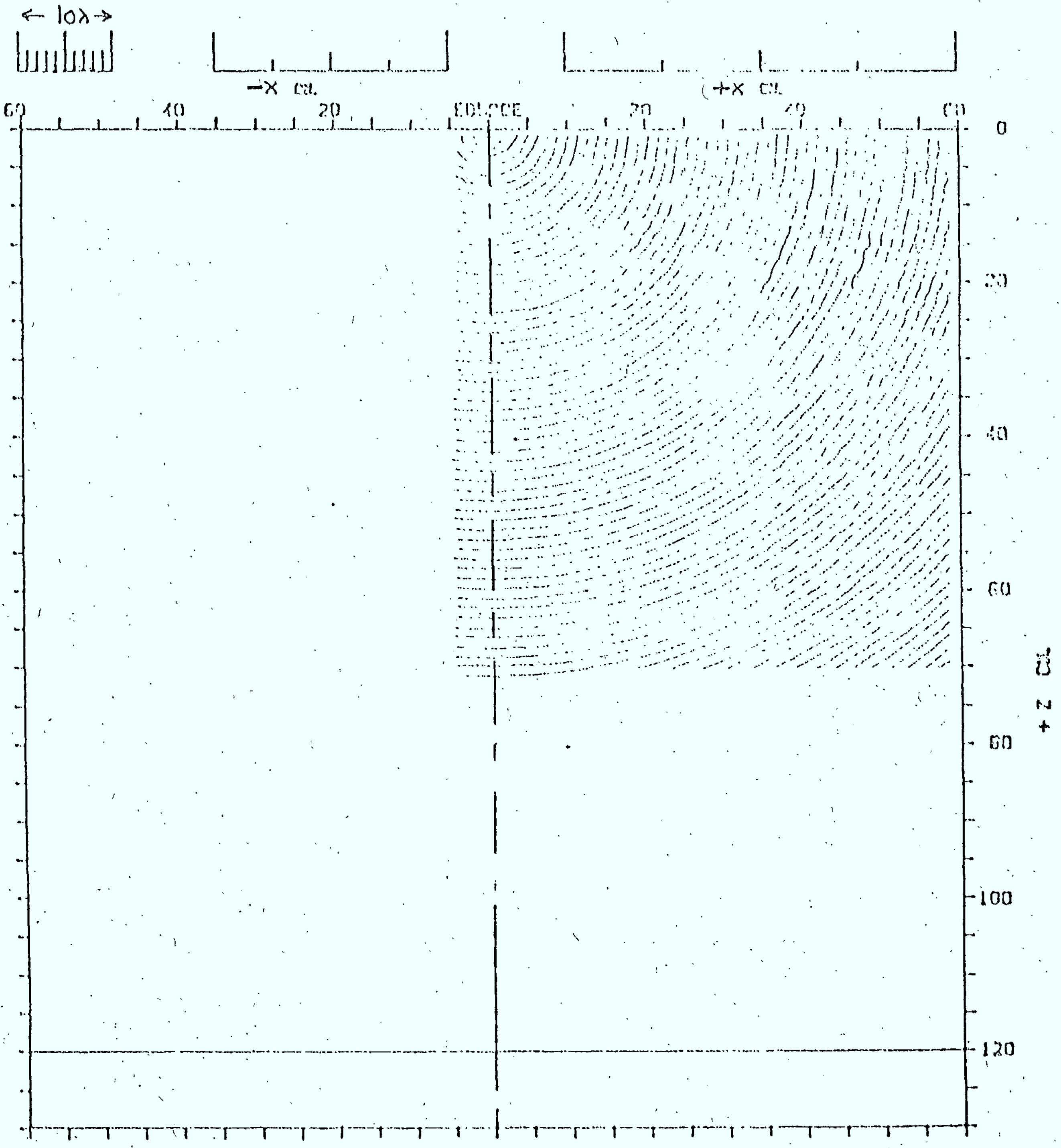
M | 23.5 | P | H | WO | 0 | OWG



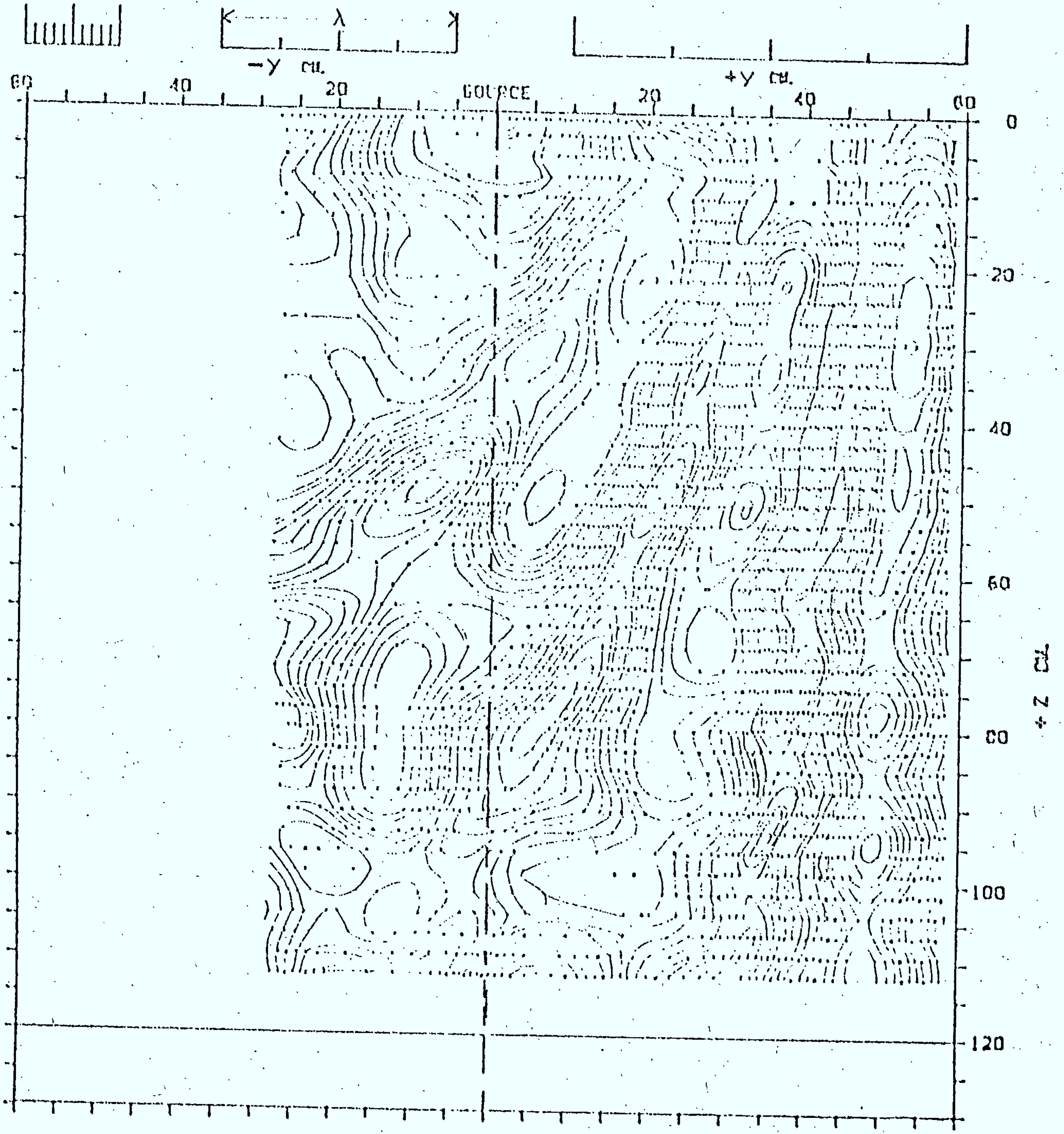
M 23.5 A E Wo 0 HWD



H | 23.5 | P | E | WO | 0 | OWG

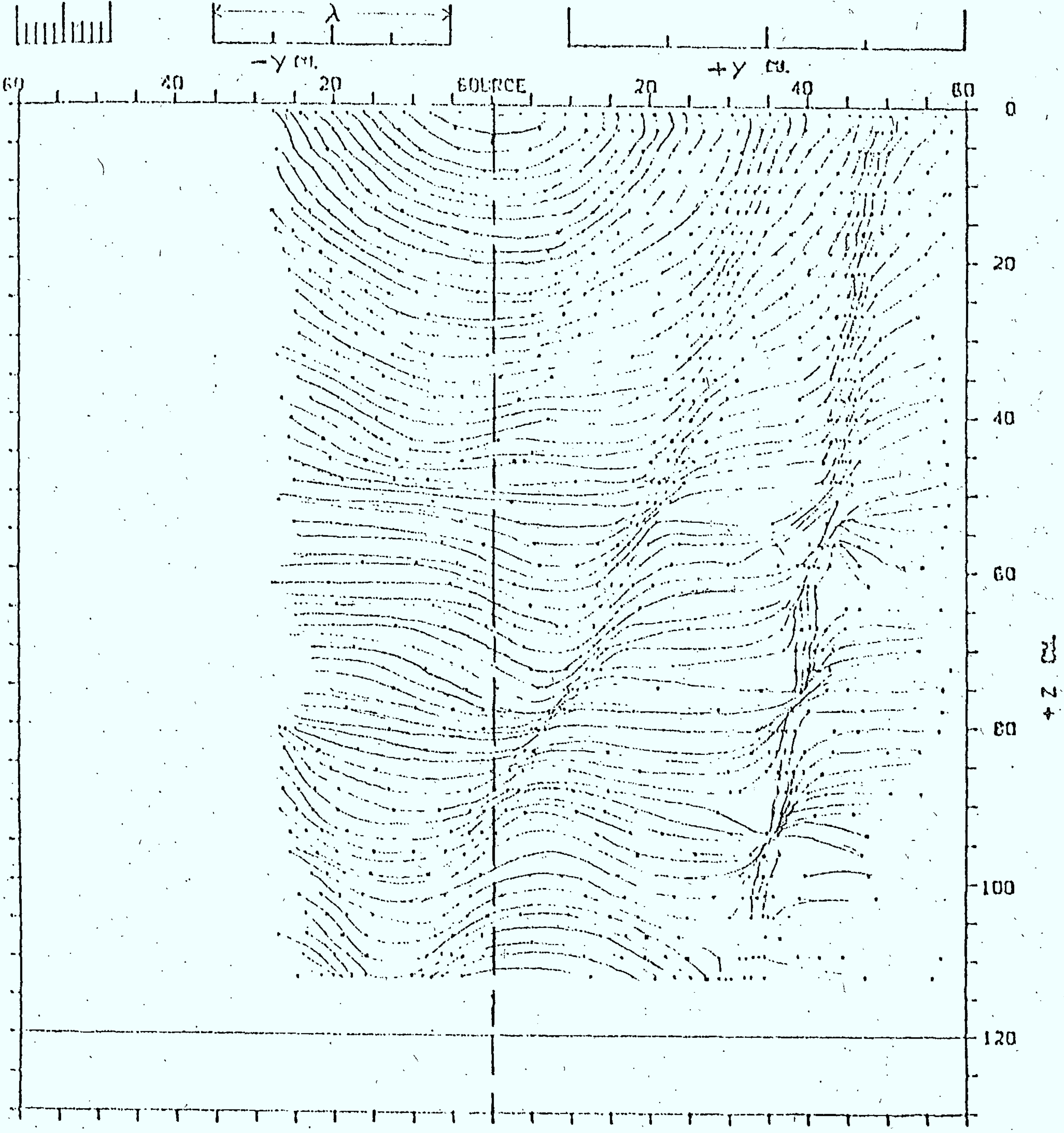


M | 1.0 | A | H | WO | 0 | HWD

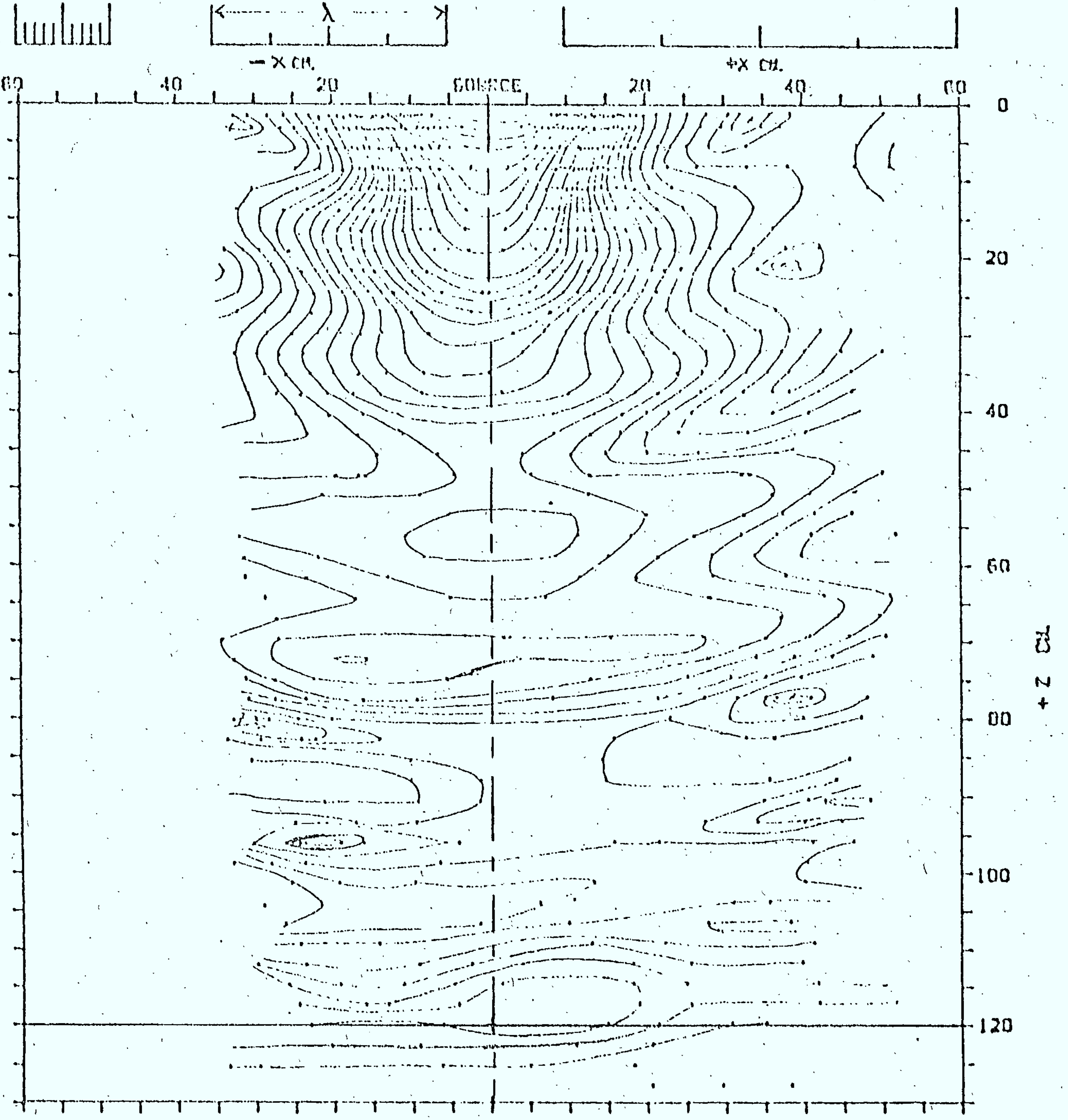


MCGILL 79-80 DOC OSU 79-00143 SRW/TP

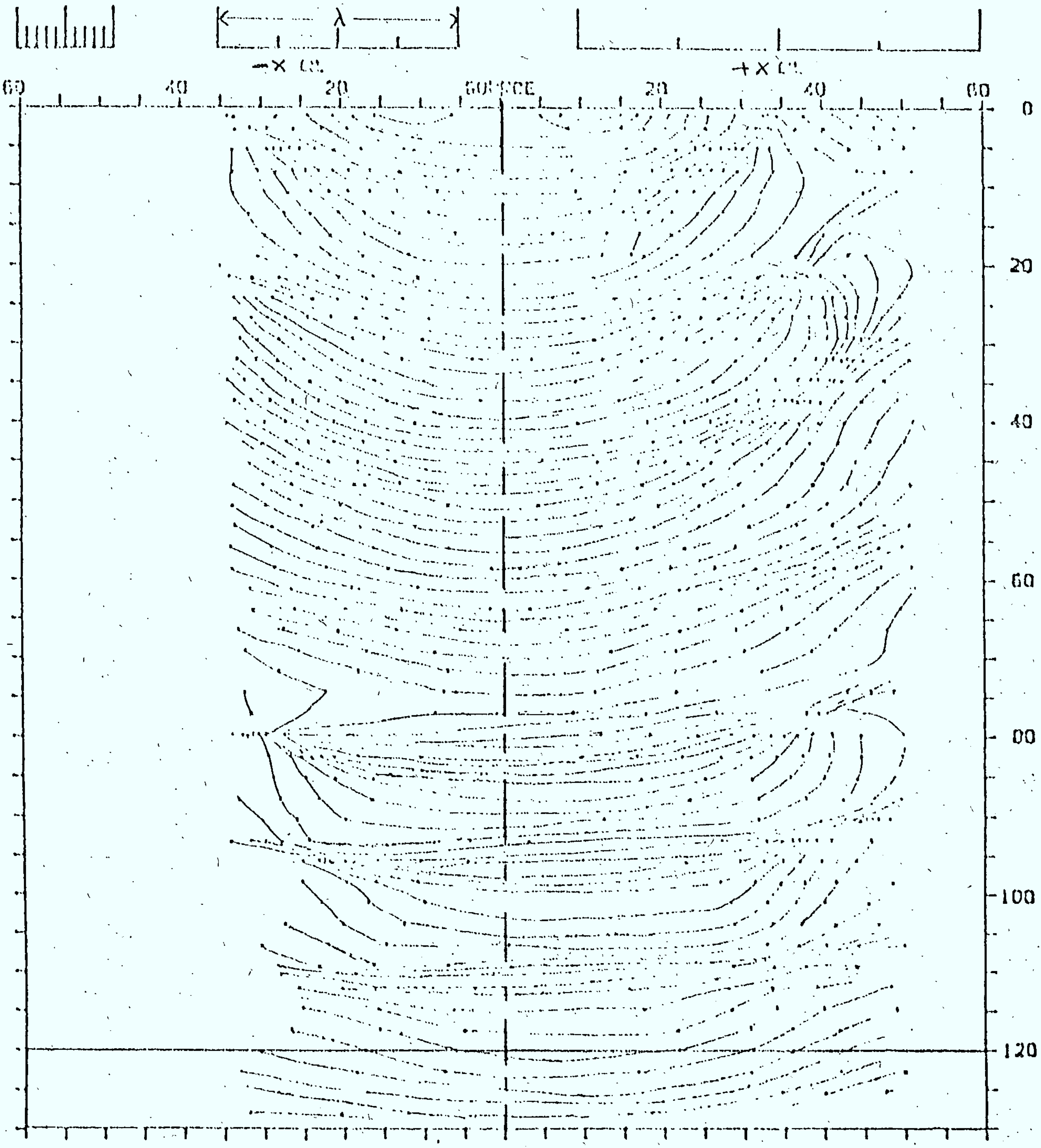
M	1.0	P	H	WO	0	HWD



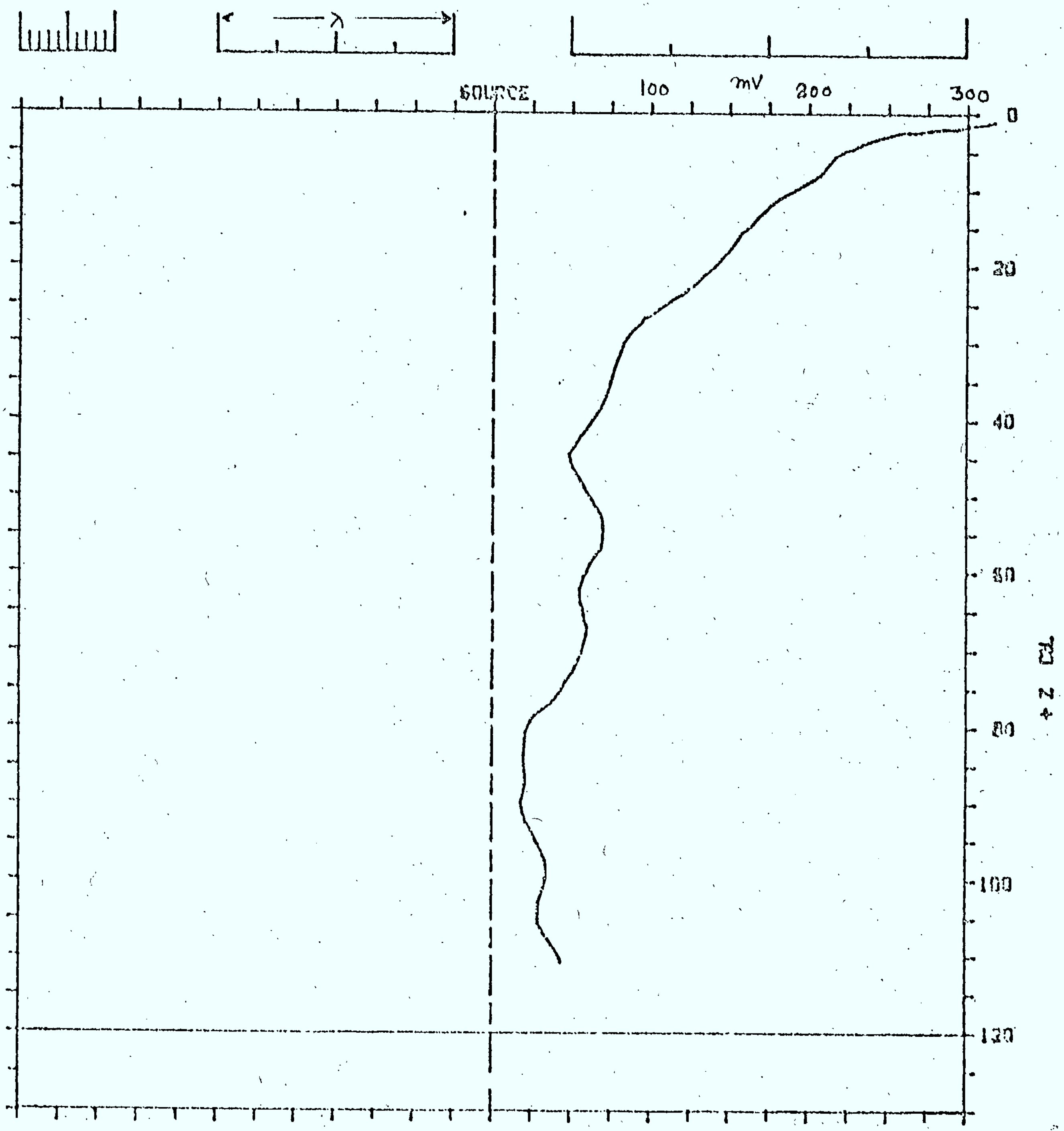
M	1.0	A	E	WO	0	HWD



II	1.0	P	E	WO	0	HWD

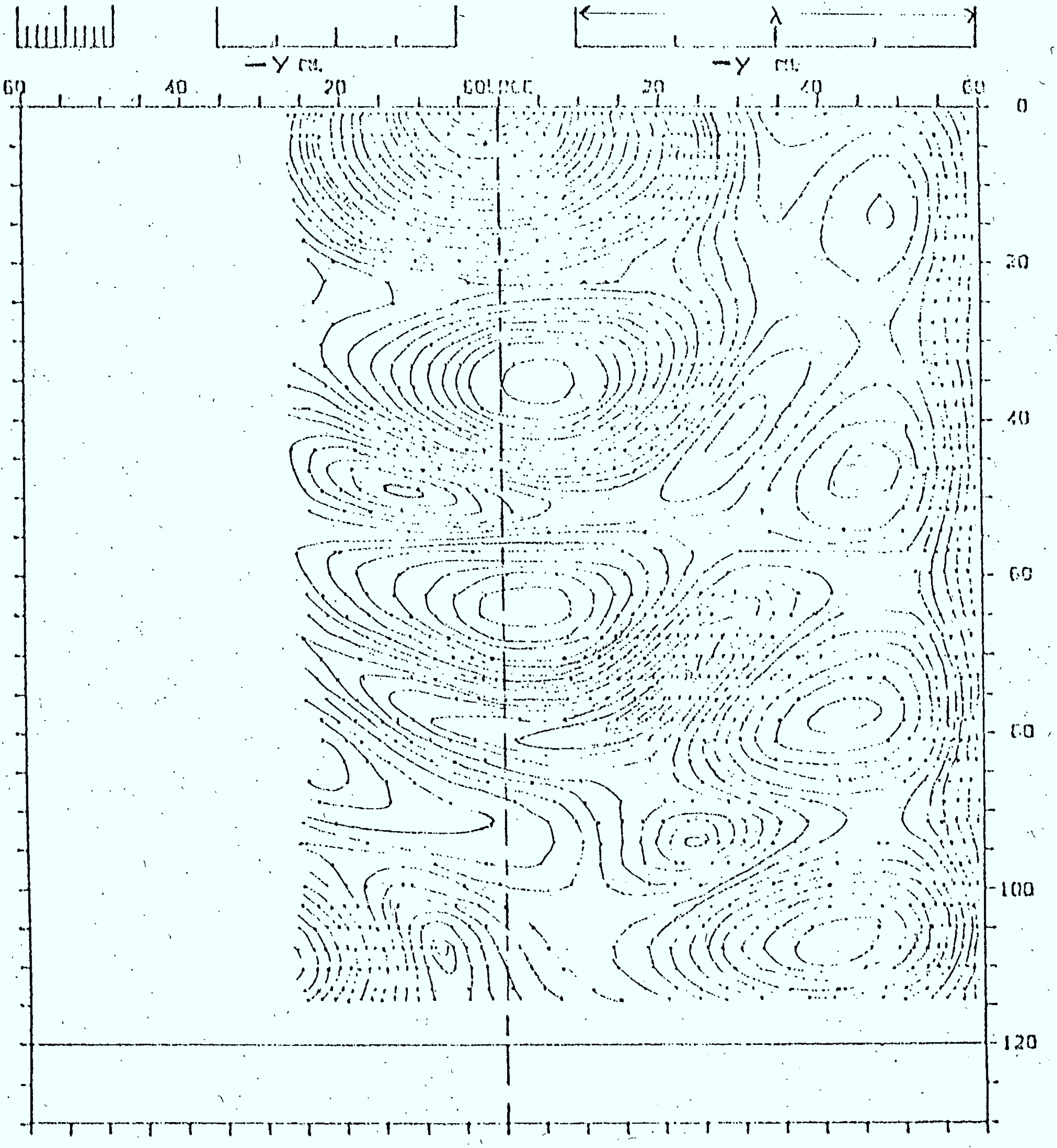


P	1.0	A	–	WO	0	HWD

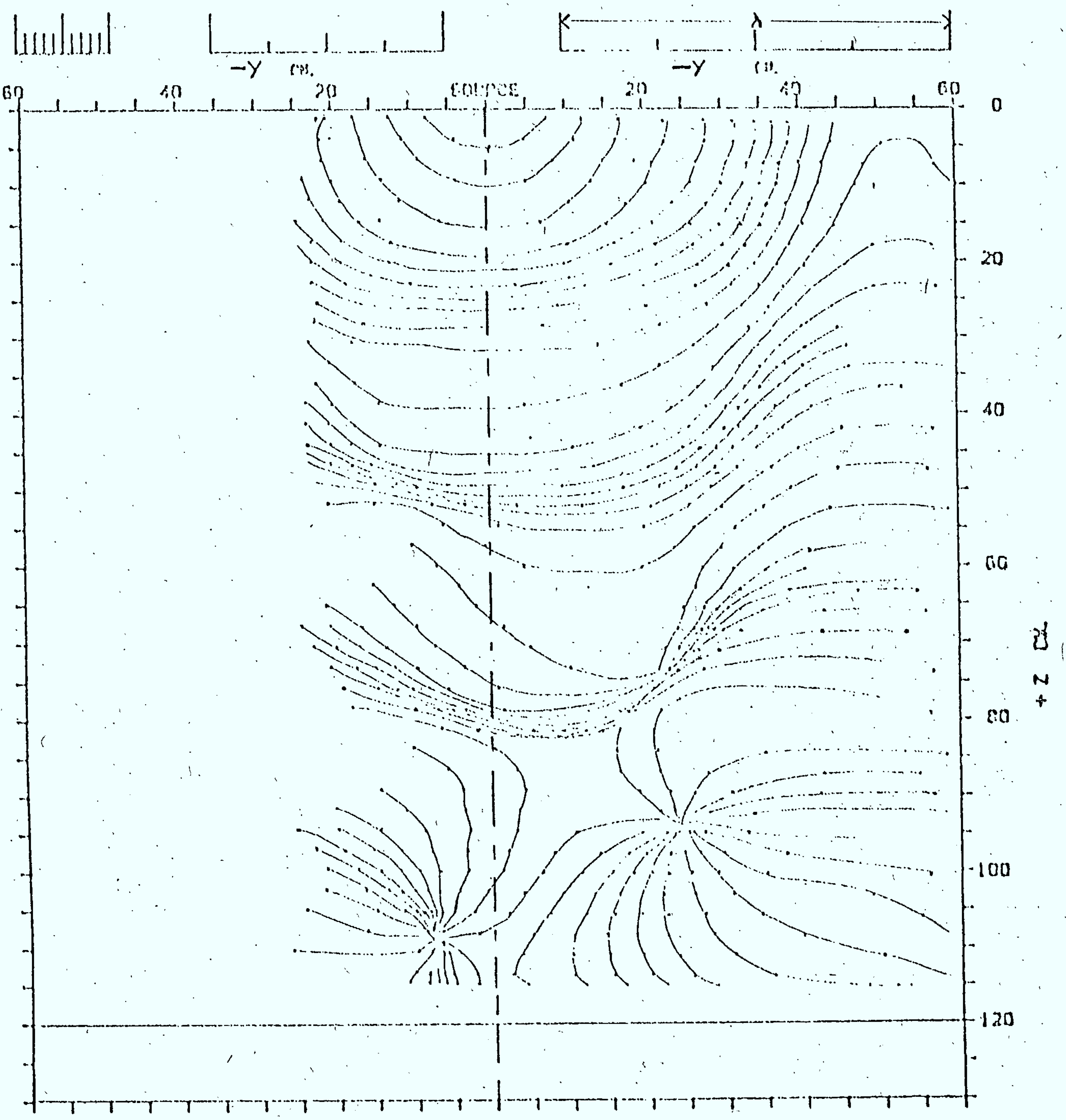


MCGILL 79-80 DOC OSU 79-00143 SRM/TP

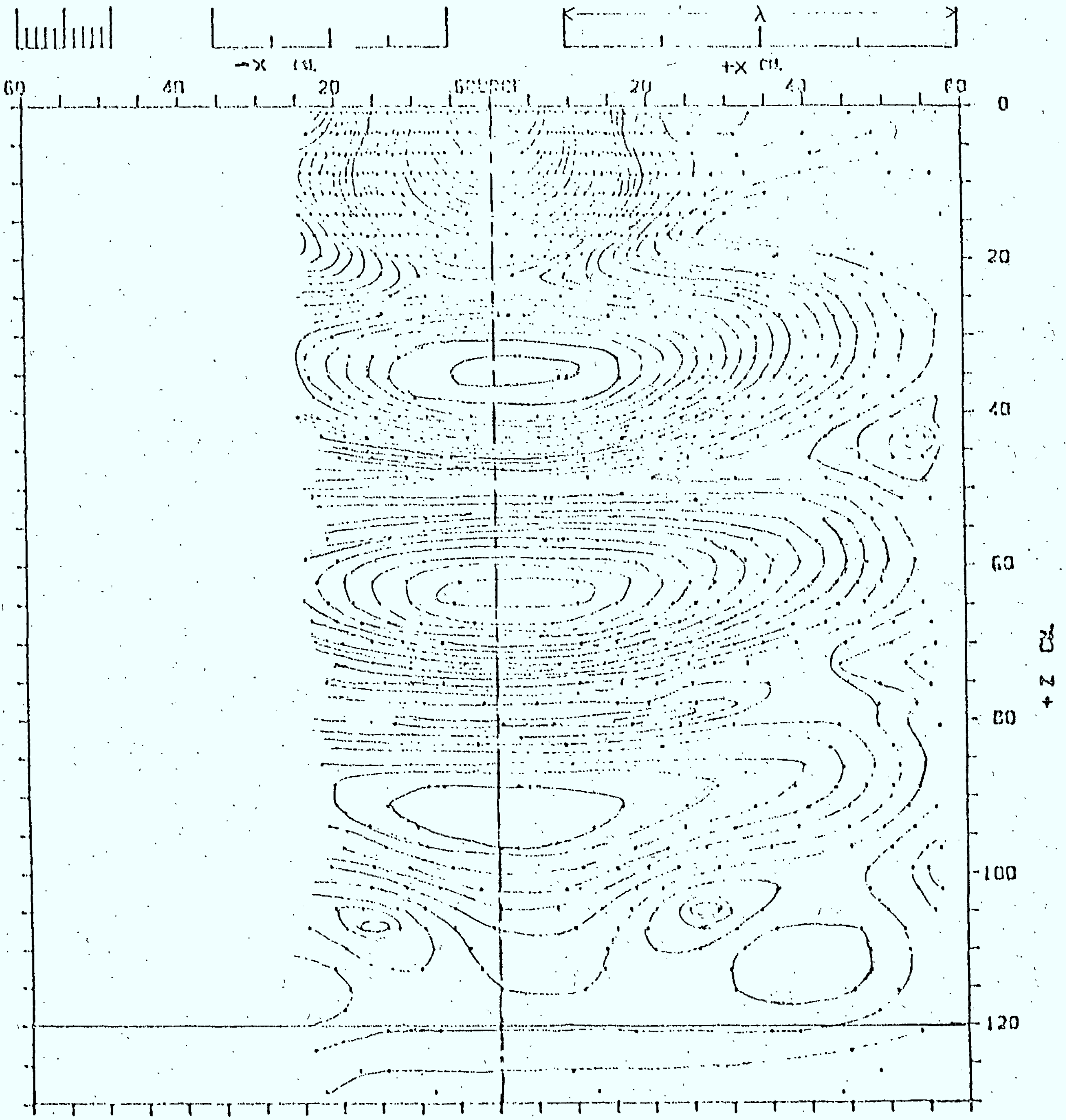
M | 0.6 | A | H | WO | 0 | HWD



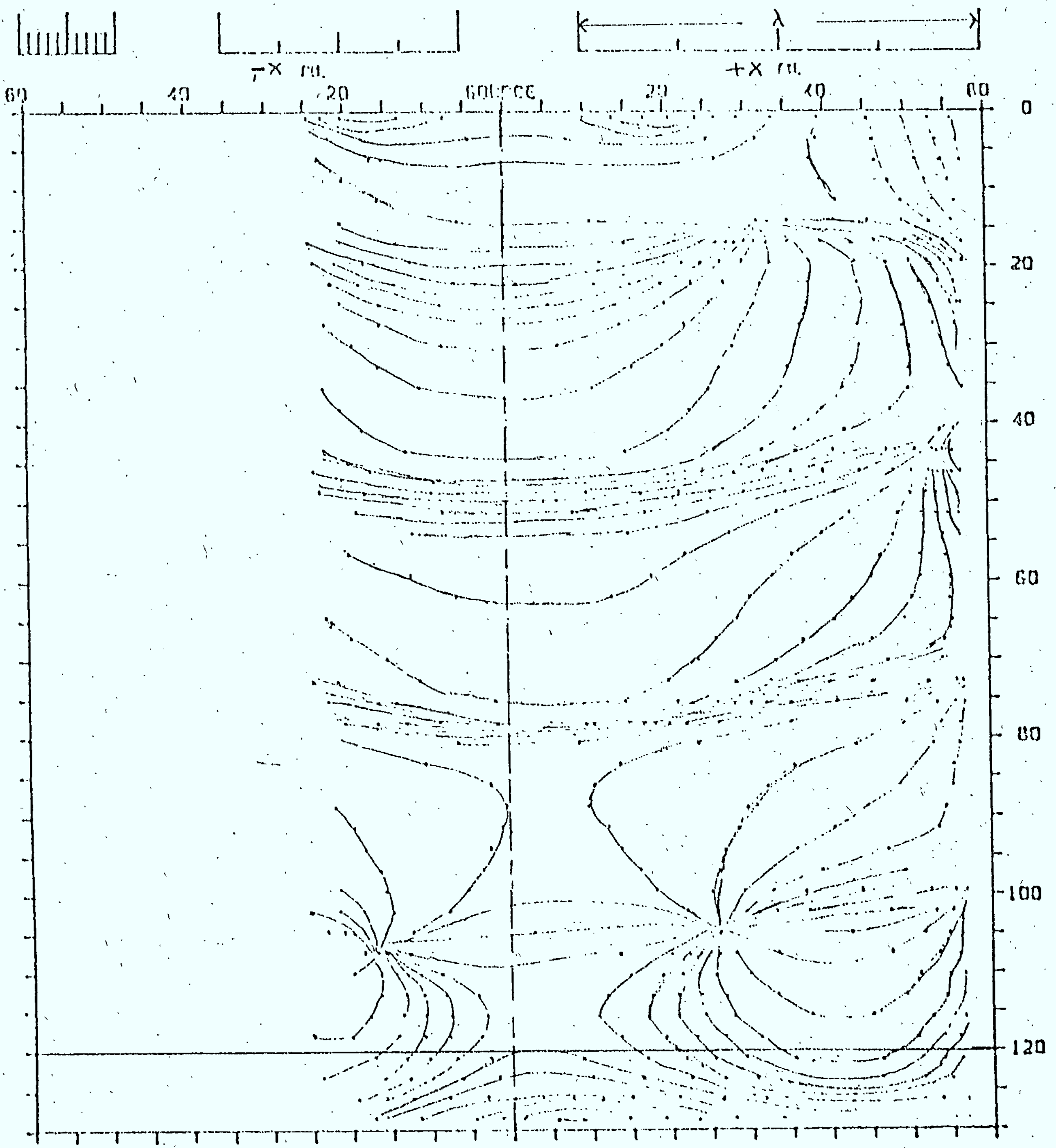
H | 0.6 | P | H | WO | 0 | HWD



M	0.6	A	E	WO	0	HWD

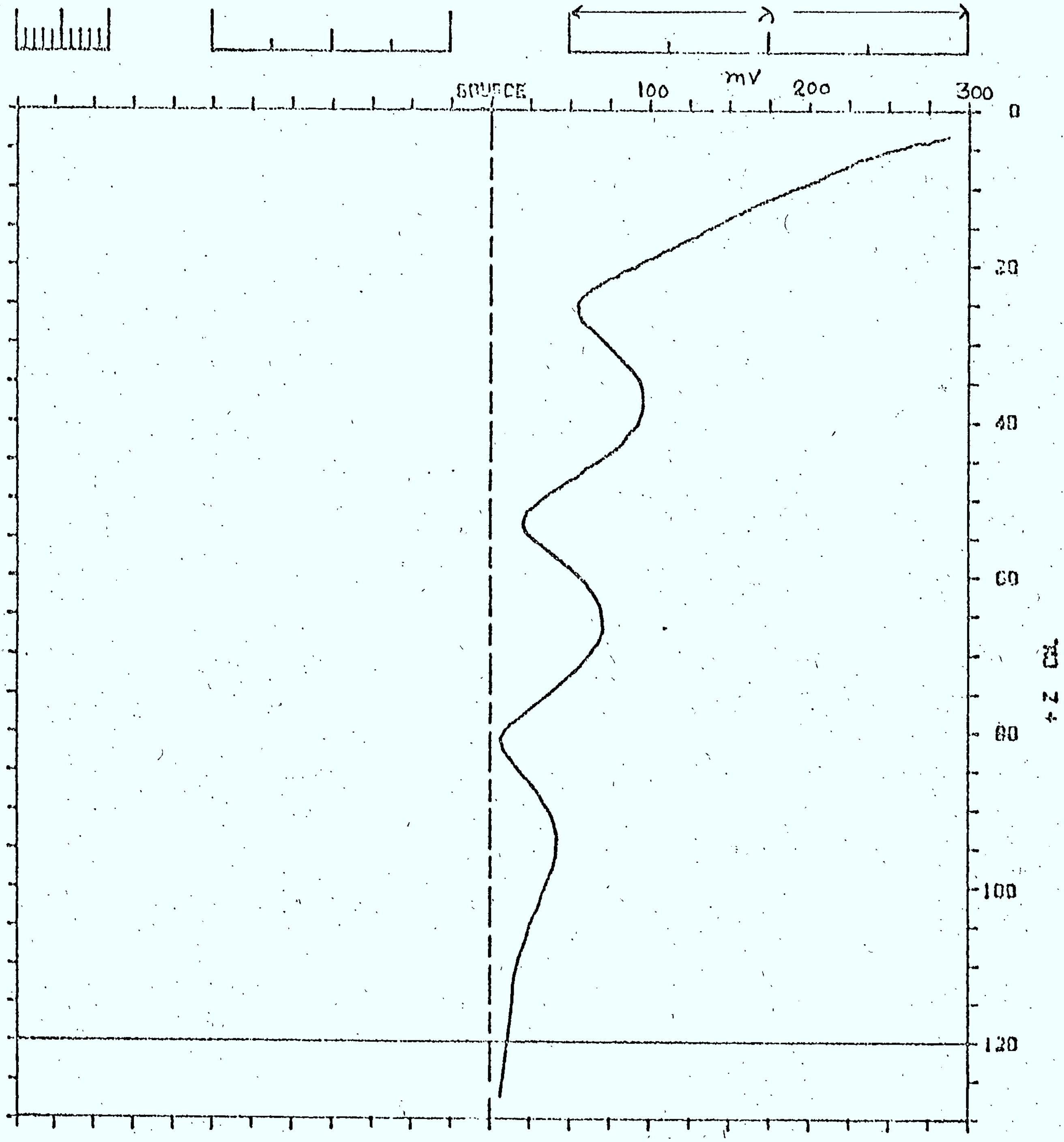


M 0.6 P E WO 0 HWD



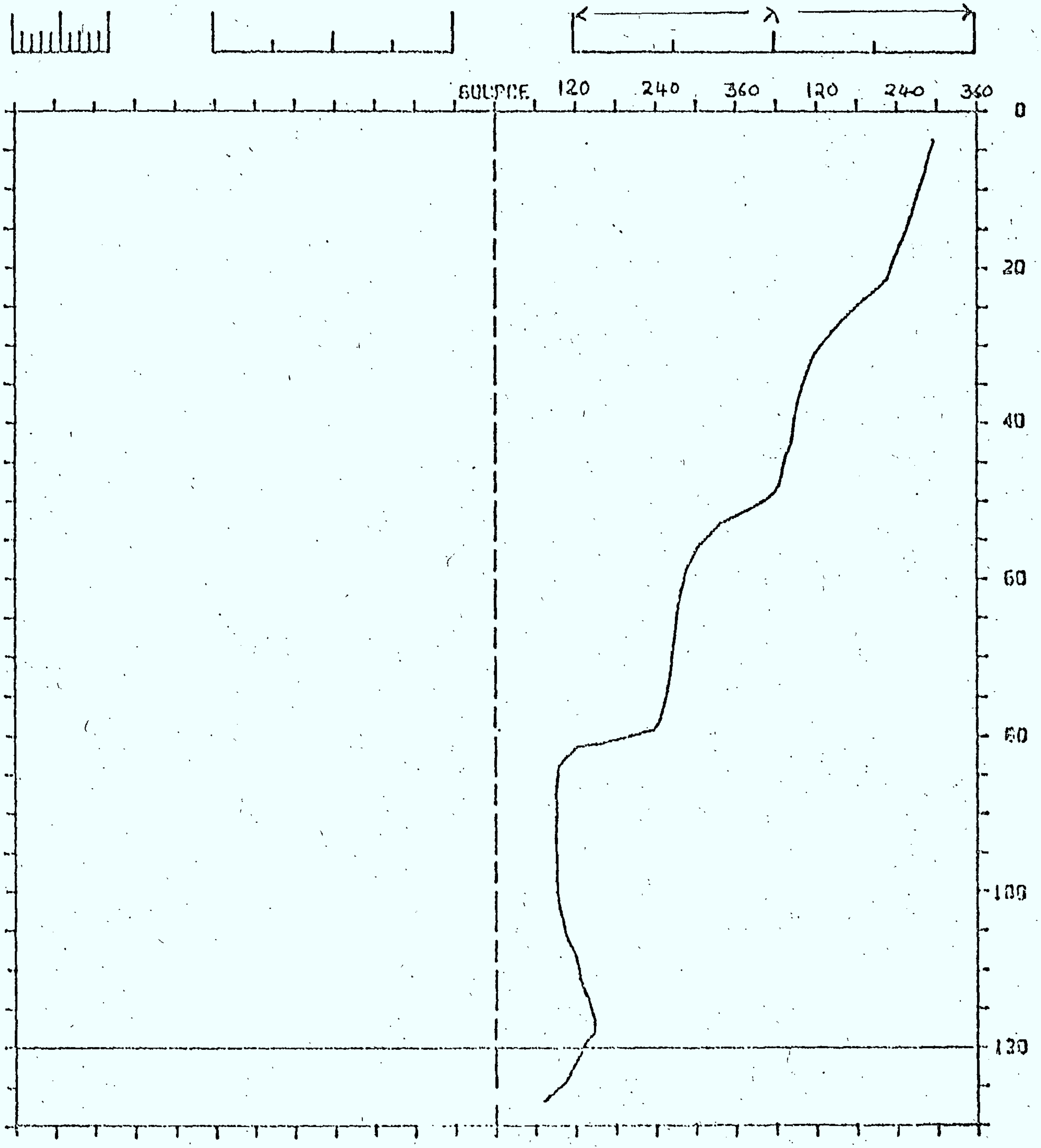
ATLAS PAGE 44

P	0.6	A	-	WO	U	HWD

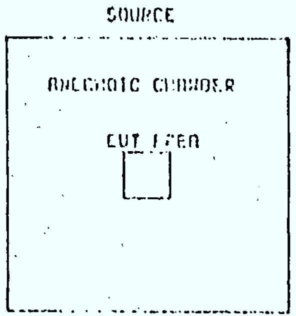


MCGILL 79-80 DOC OSU 79-00143 GRW/TP

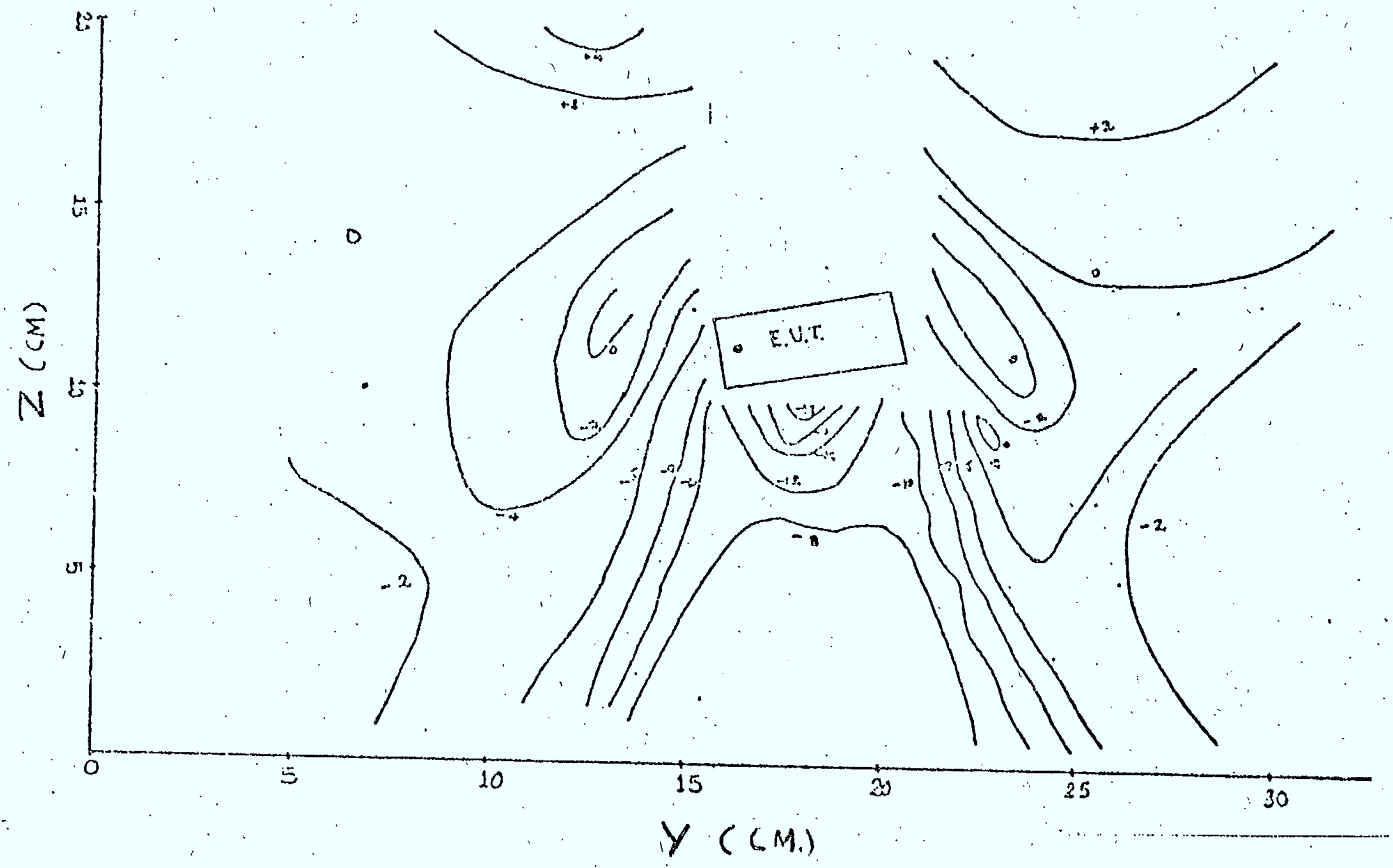
P	0.6	P	-	WO	0	HWD

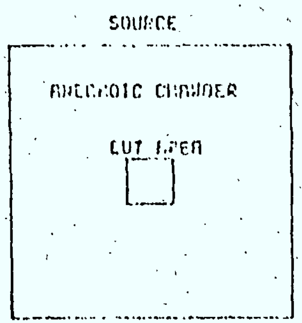


MCGILL 79-00 DOC OSU 79-00143 SRU/TP

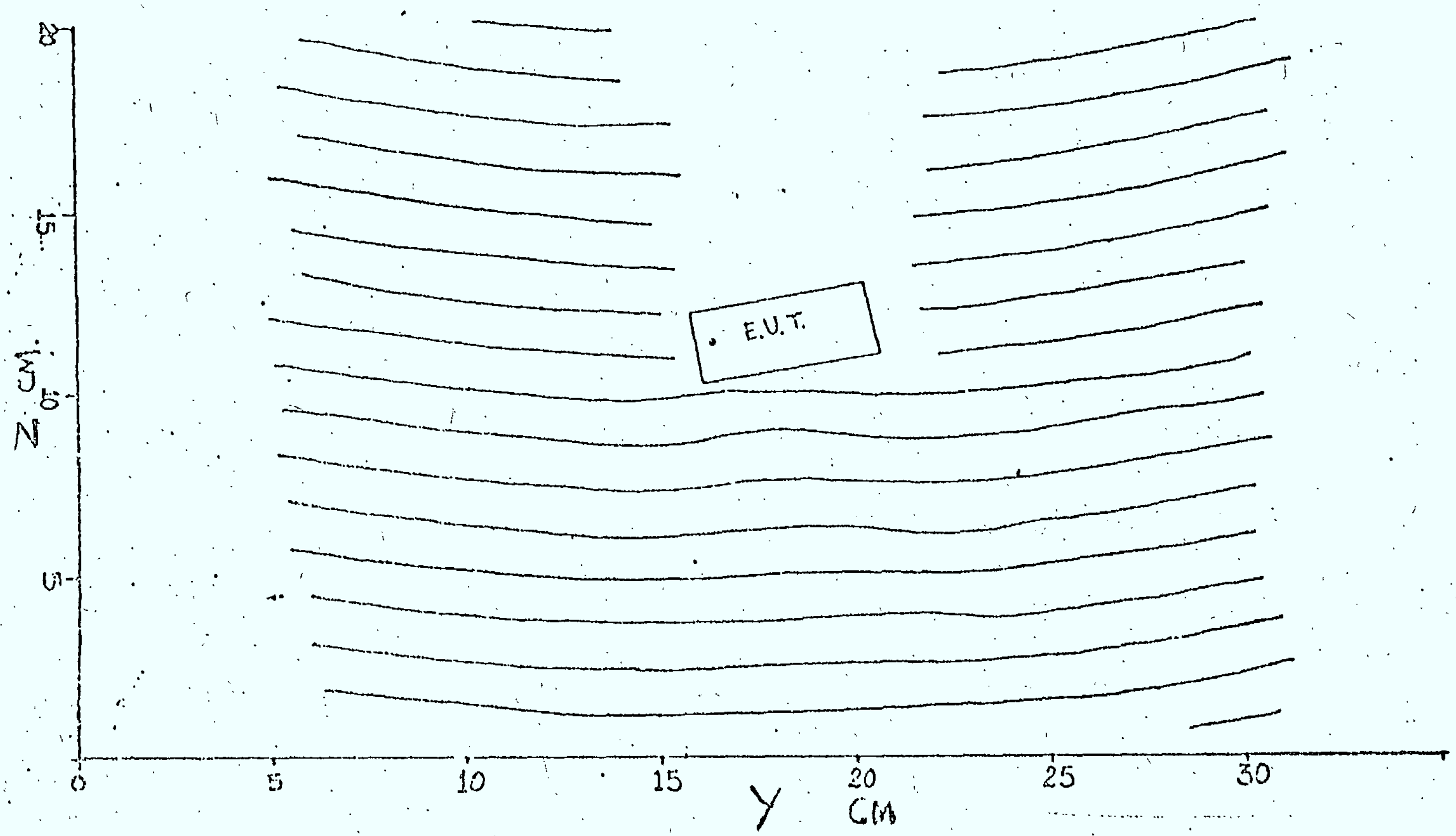


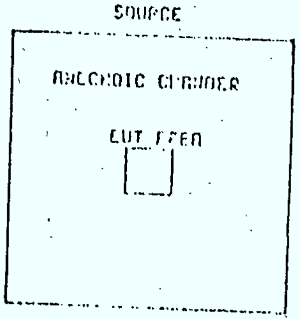
M	23.5	A	H	CL	I	OWG





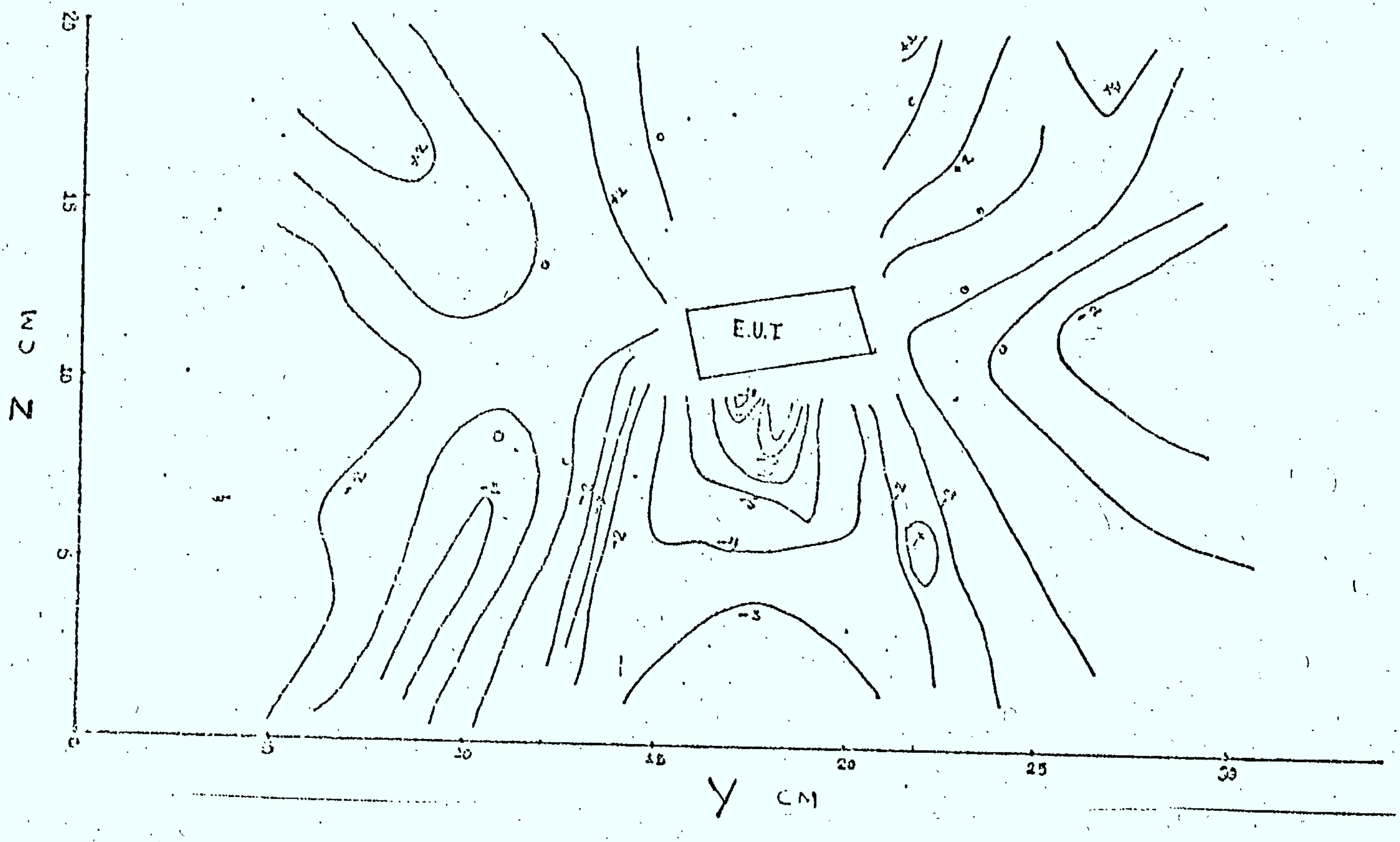
M	23.5	P	H	CL	I	OWG



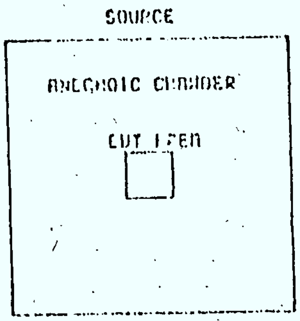


M	23.5	A	H	WO	I	OWG

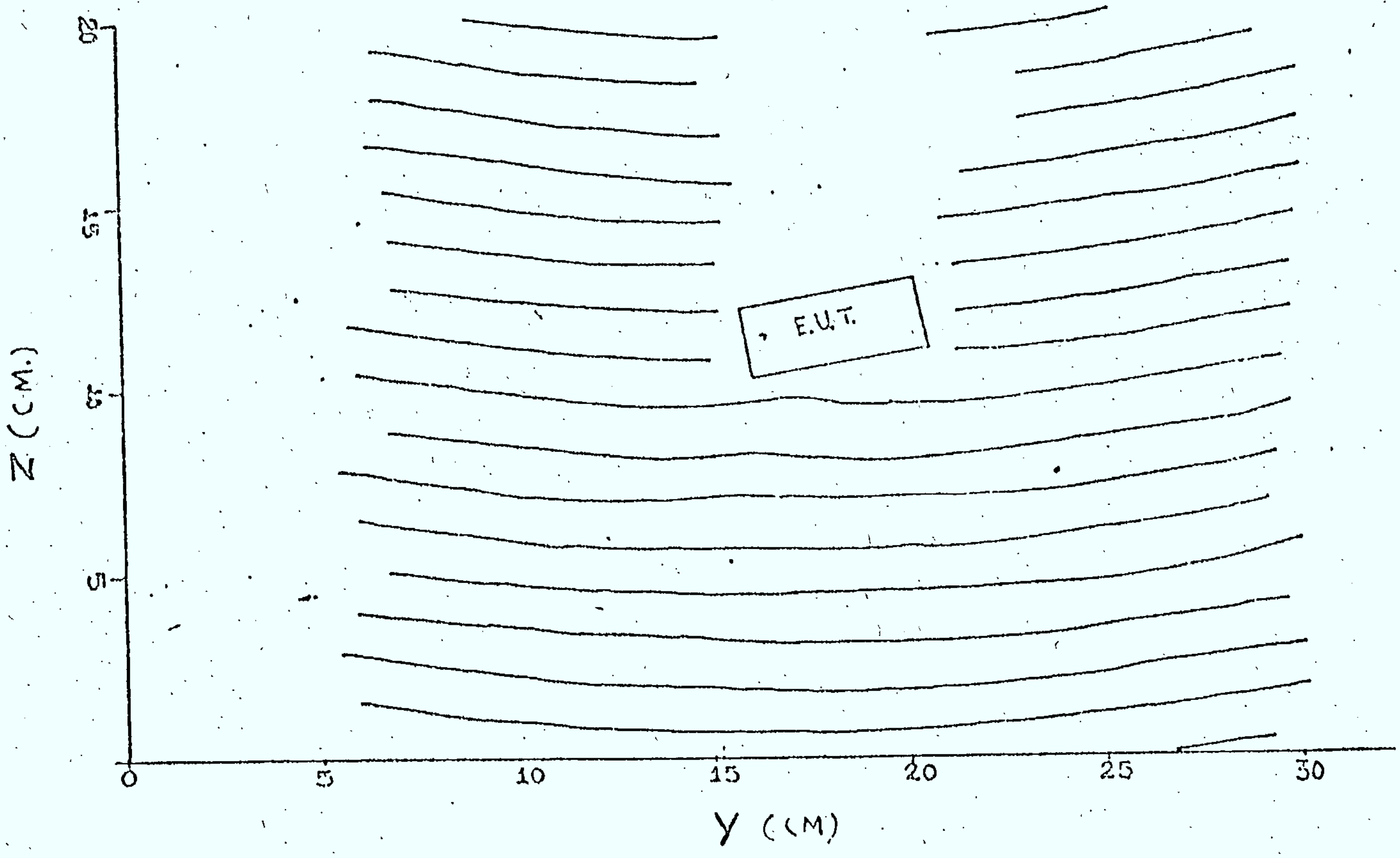
ATLAS PAGE 48

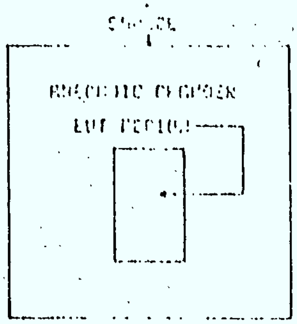


[illegible] [illegible] [illegible]

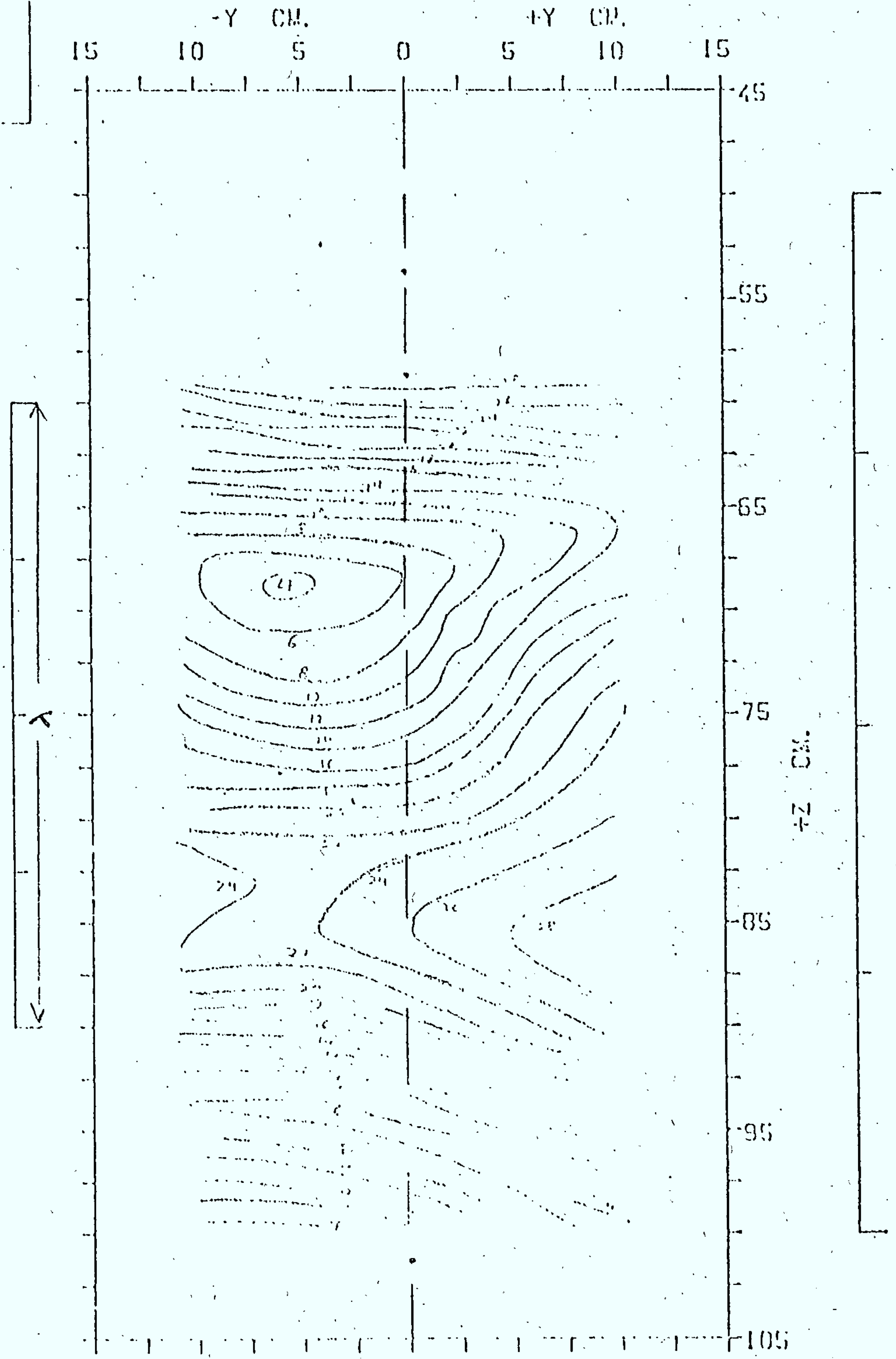


M	23.5	P	H	WO	1	OWG

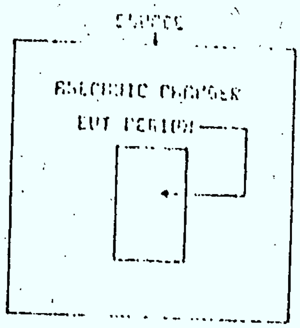


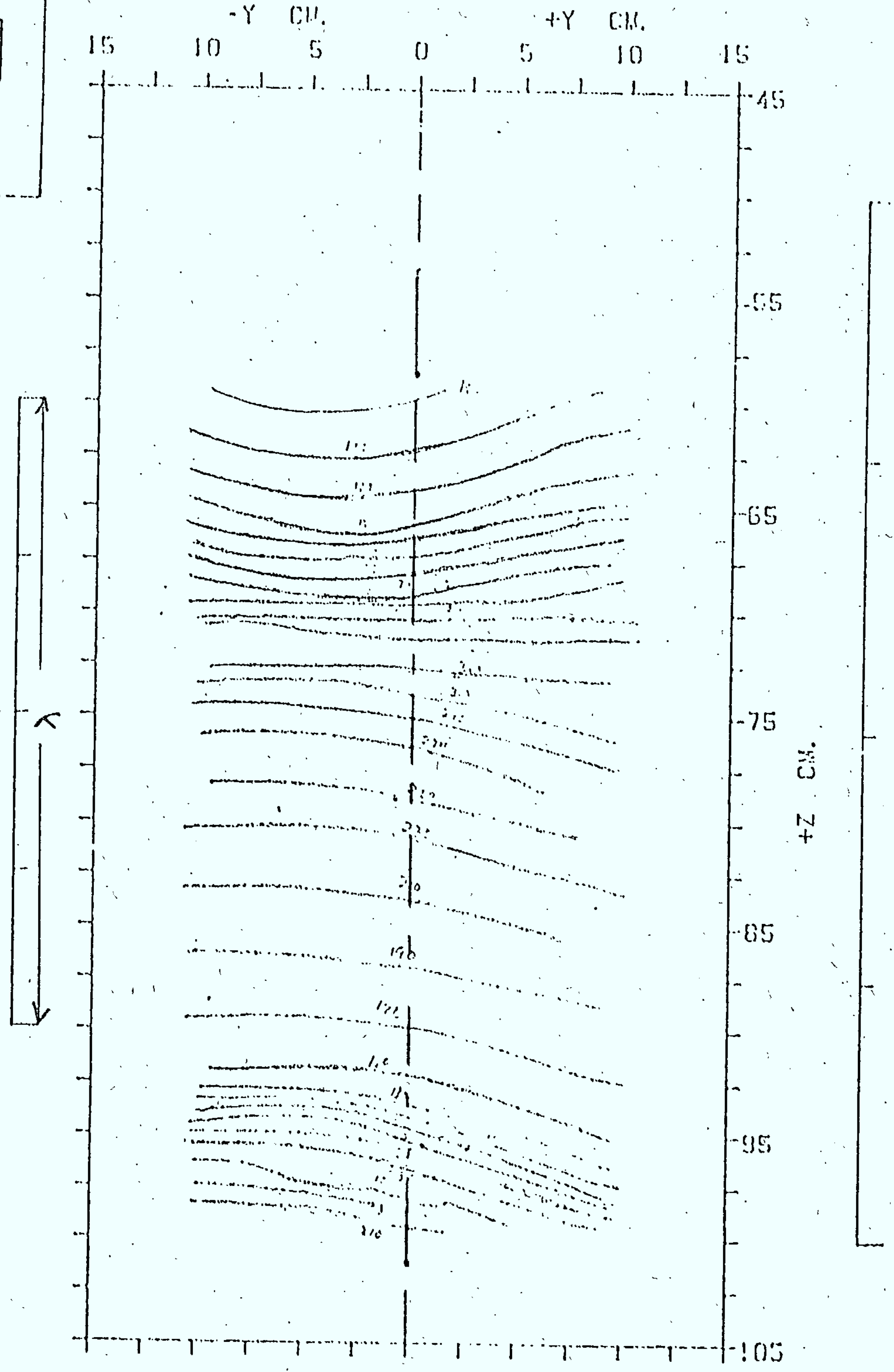


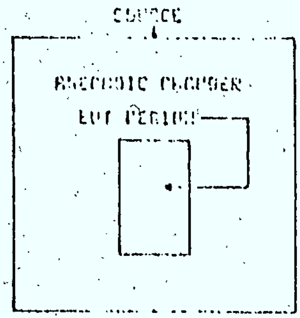
M	1.0	A	H	CL	O	HWD

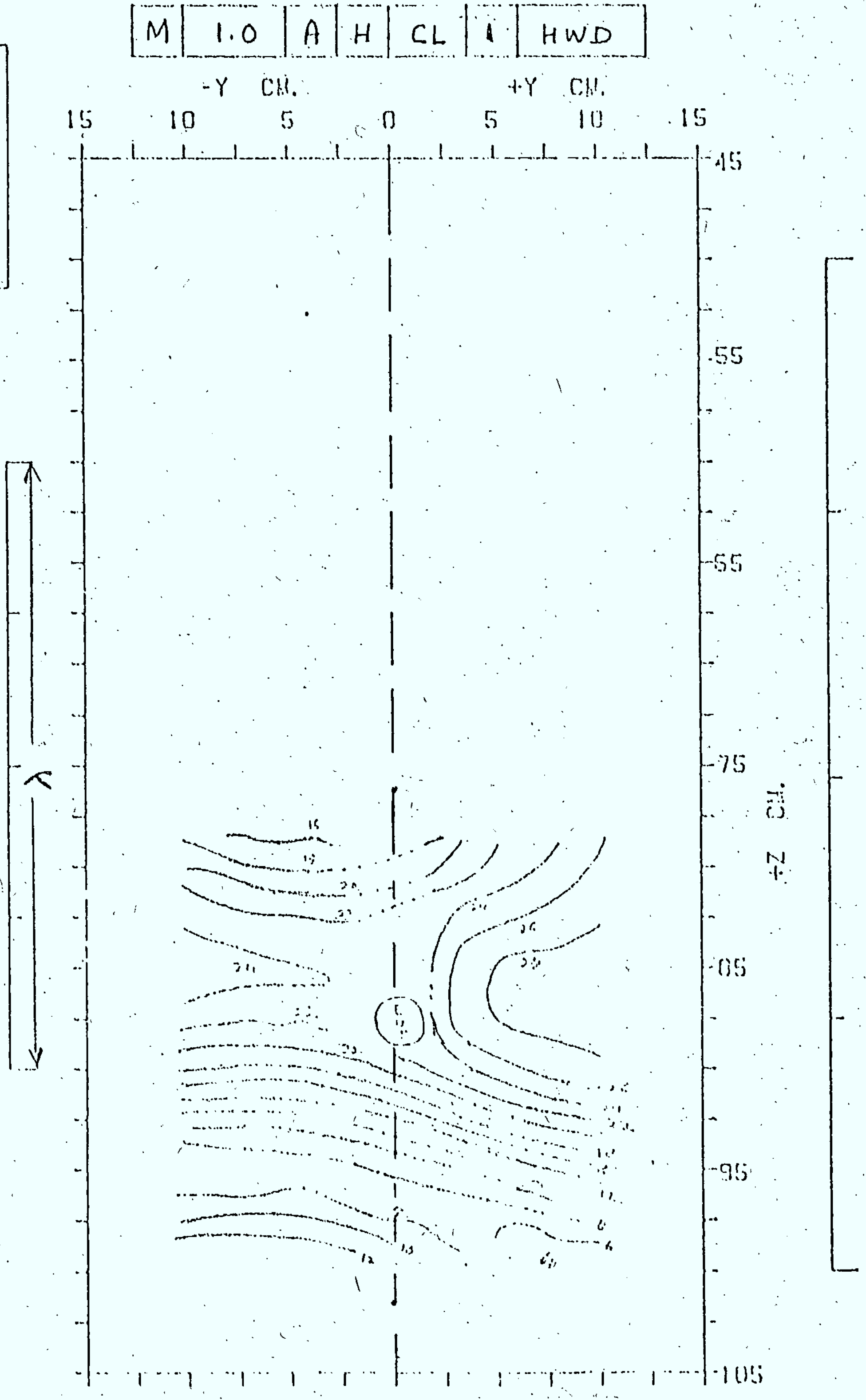


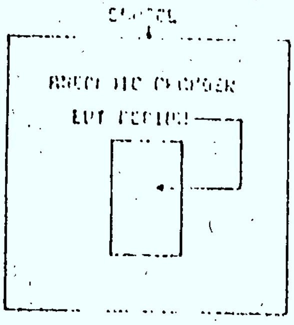
M	1.0	P	H	CL	O	HWD



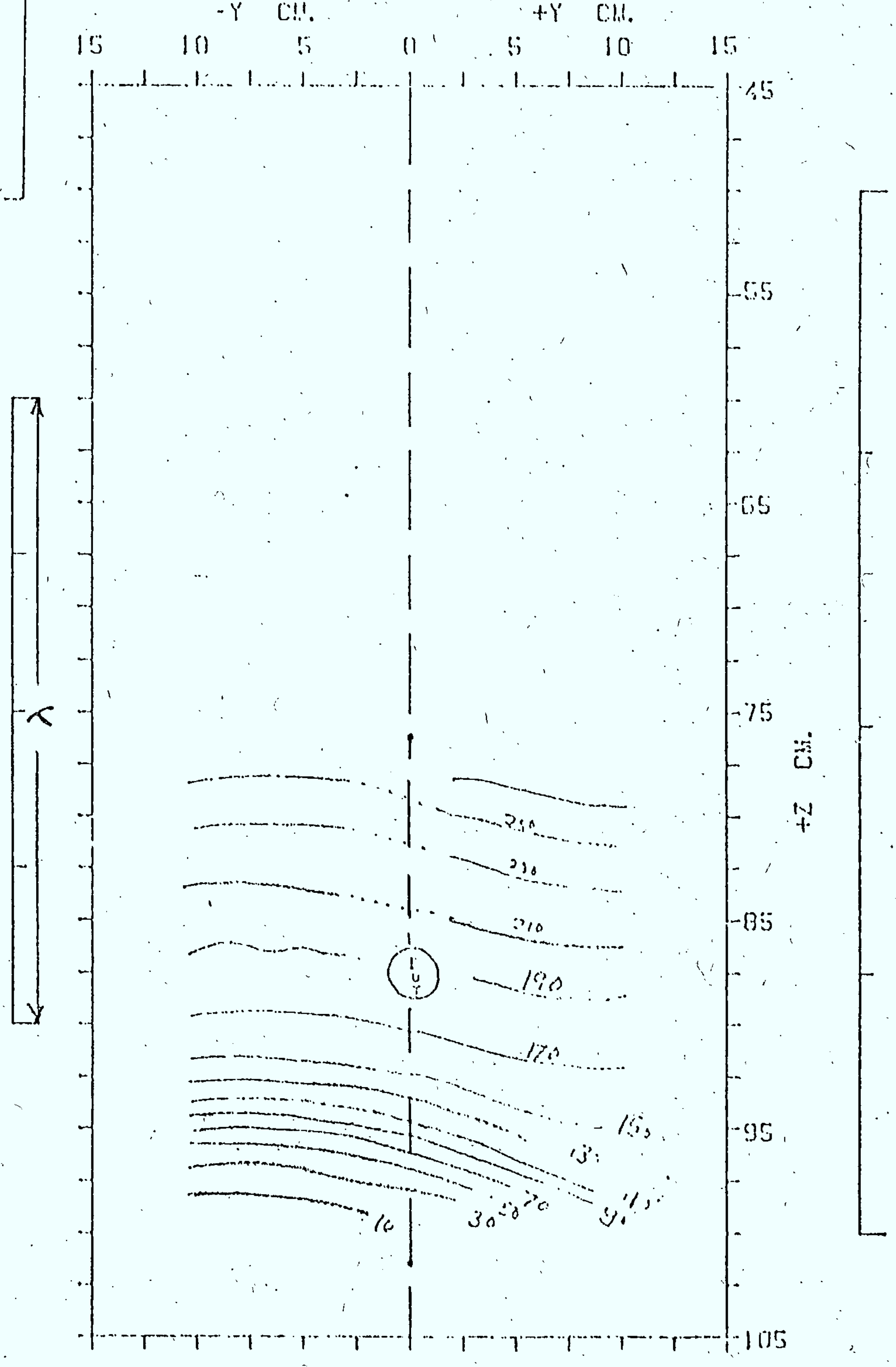



SOURCE
ANECHOIC CHAMBER
EUT PERIOD

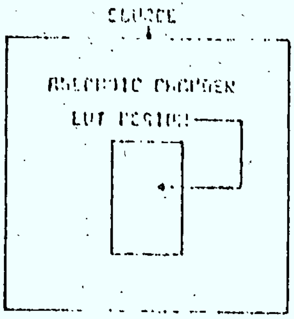

M
1.0
A
H
CL
1
HWD
-Y CM.
+Y CM.
15
10
5
0
5
10
15
-45
-55
-65
-75
-85
-95
-105
+Z CM.
λ

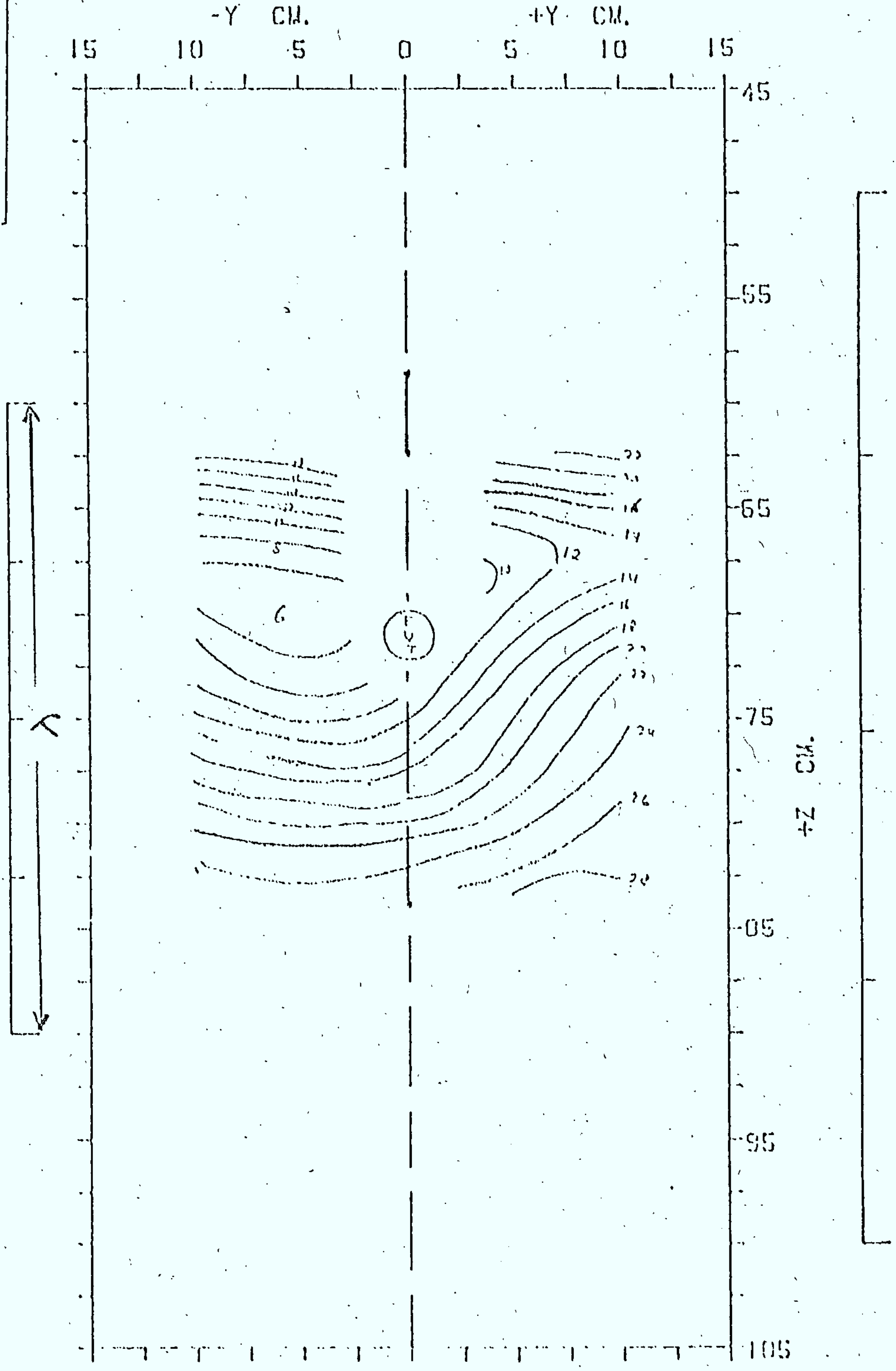


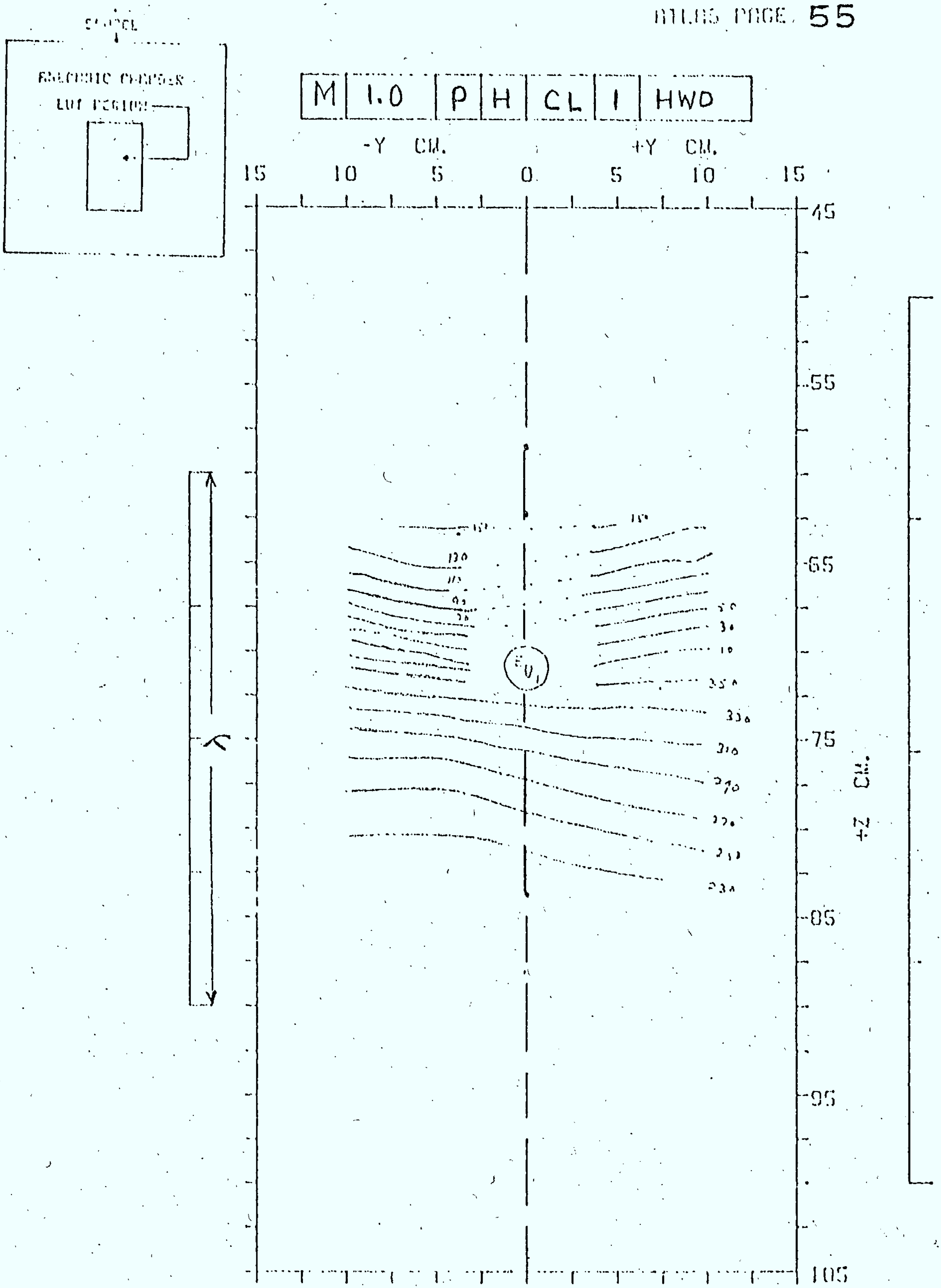
M | 1.0 | P | H | CL | I | HWD

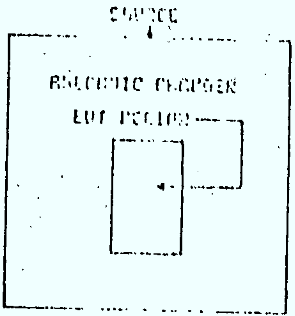


M	1.0	A	H	CL	I	HWD

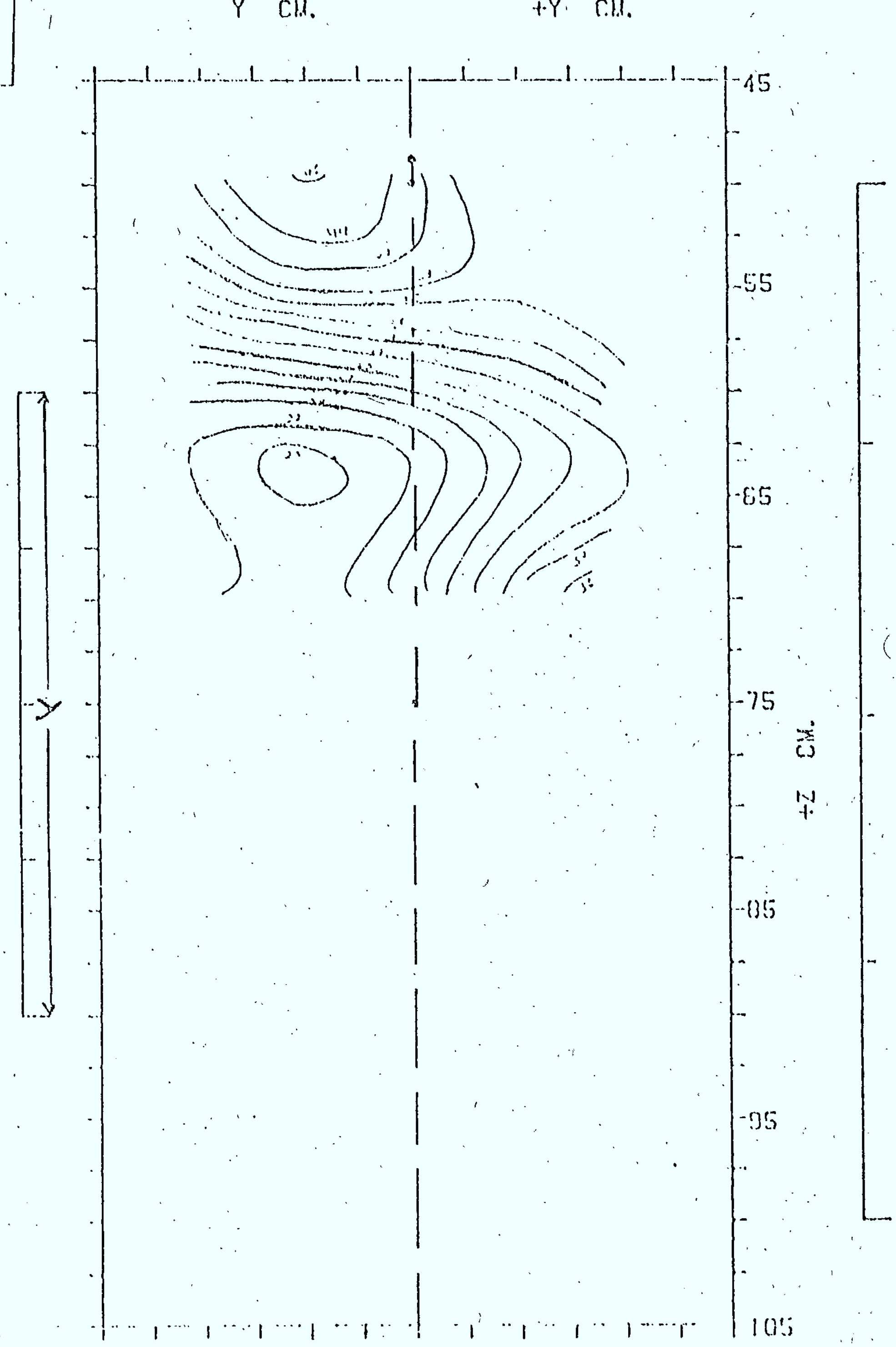




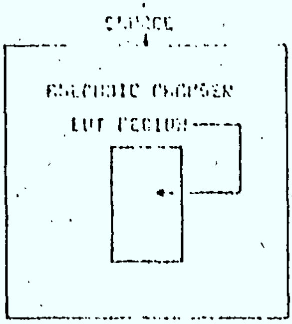

CHANNEL
MAGNETIC CHAMBER
CUT REGION
M
1.0
P
H
CL
I
HWD
-Y CM.
+Y CM.
15
10
5
0
5
10
15
45
55
65
75
85
95
105
+Z CM.
λ
EU1
130
115
95
75
150
150
50
30
10
350
330
310
290
270
250
230

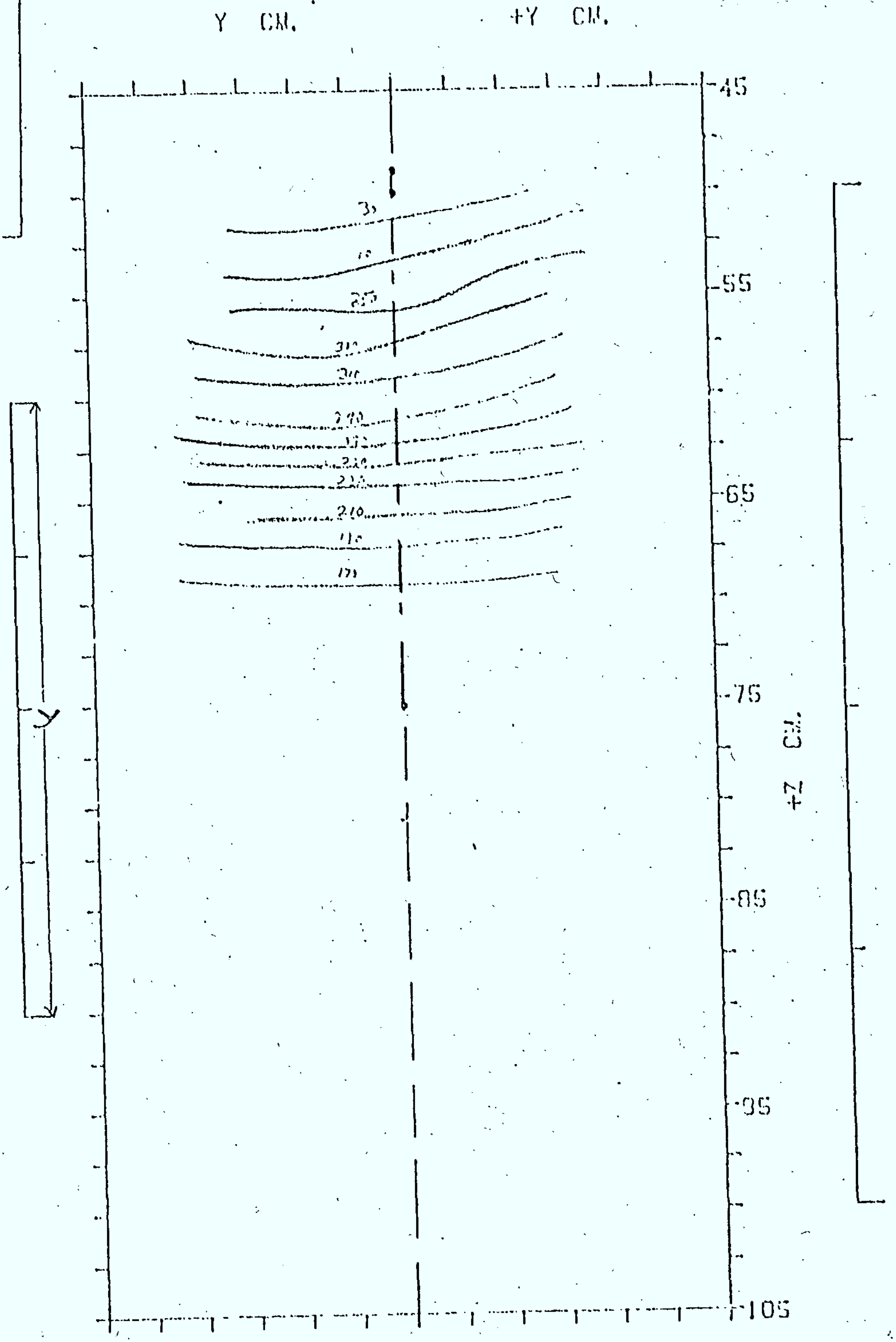


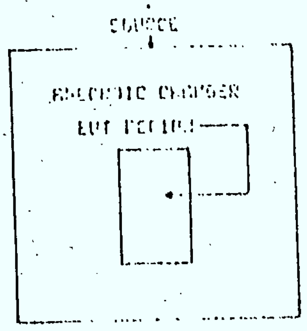
M	1.0	A	H	CL	D	HWD



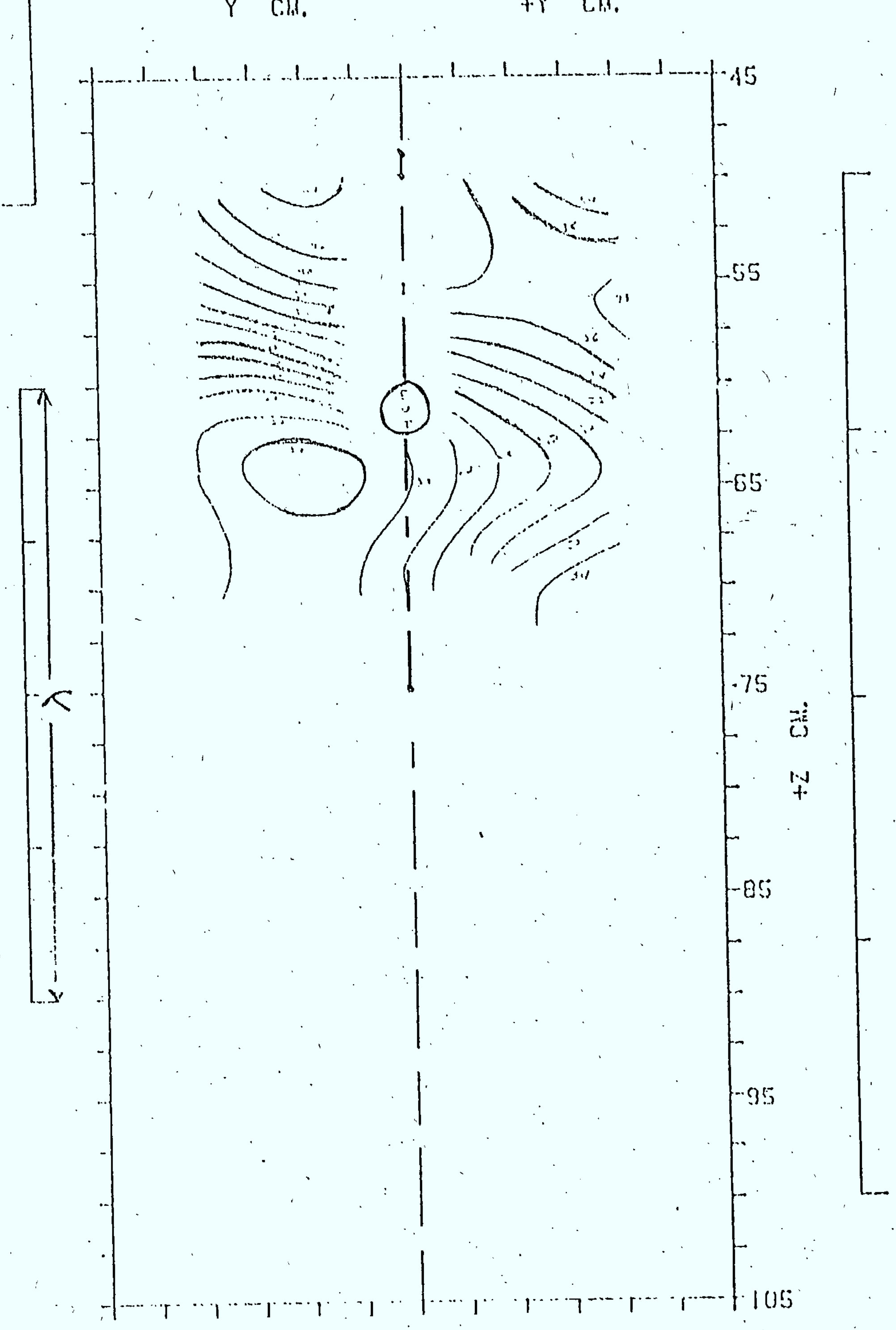
M	1.0	P	H	CL	0	HWD



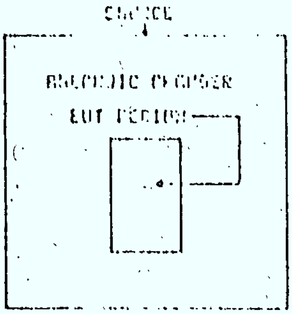


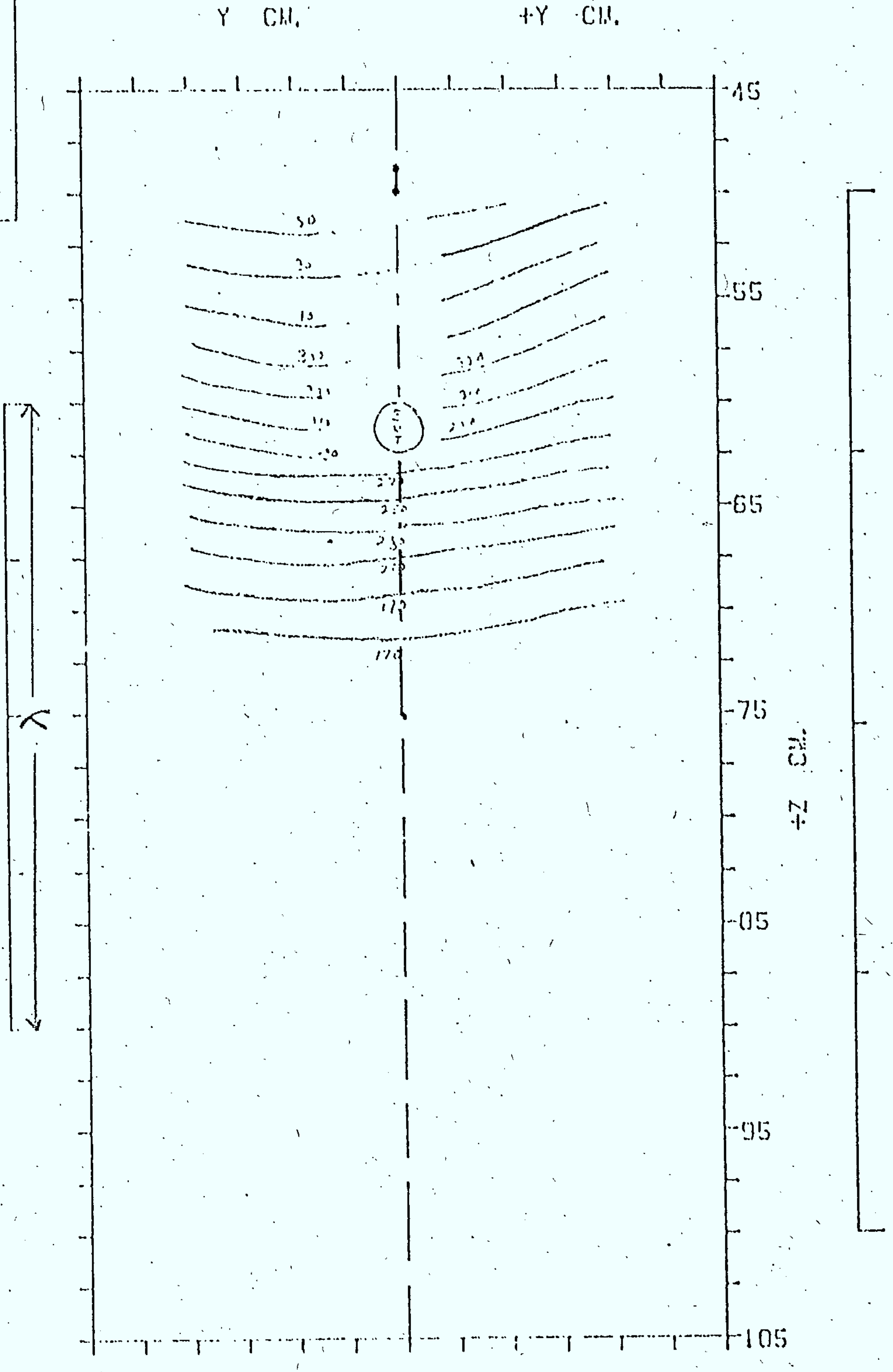


M	1.0	A	H	CL	1	HWP

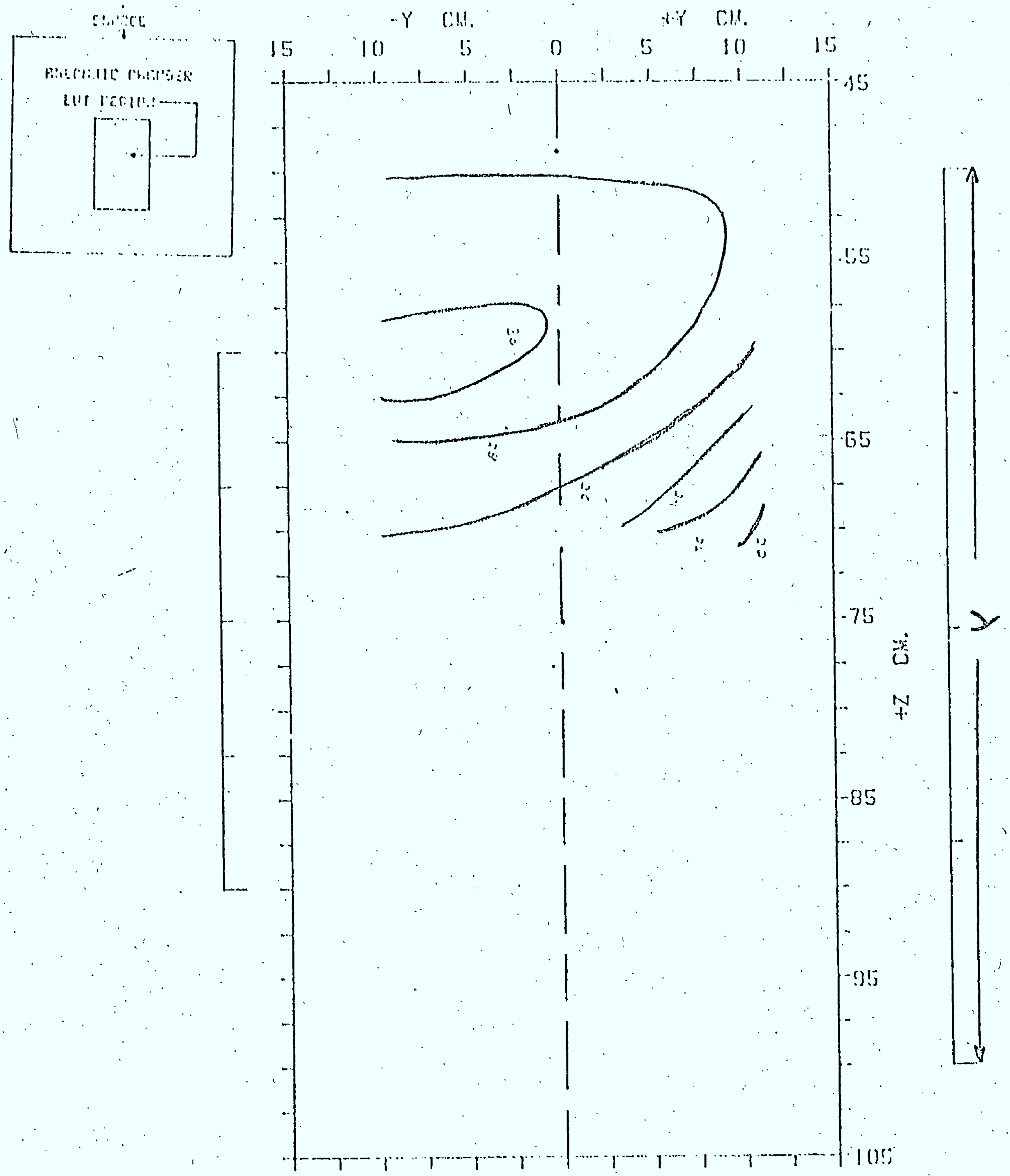


M	1.0	P	H	CL	1	HWD

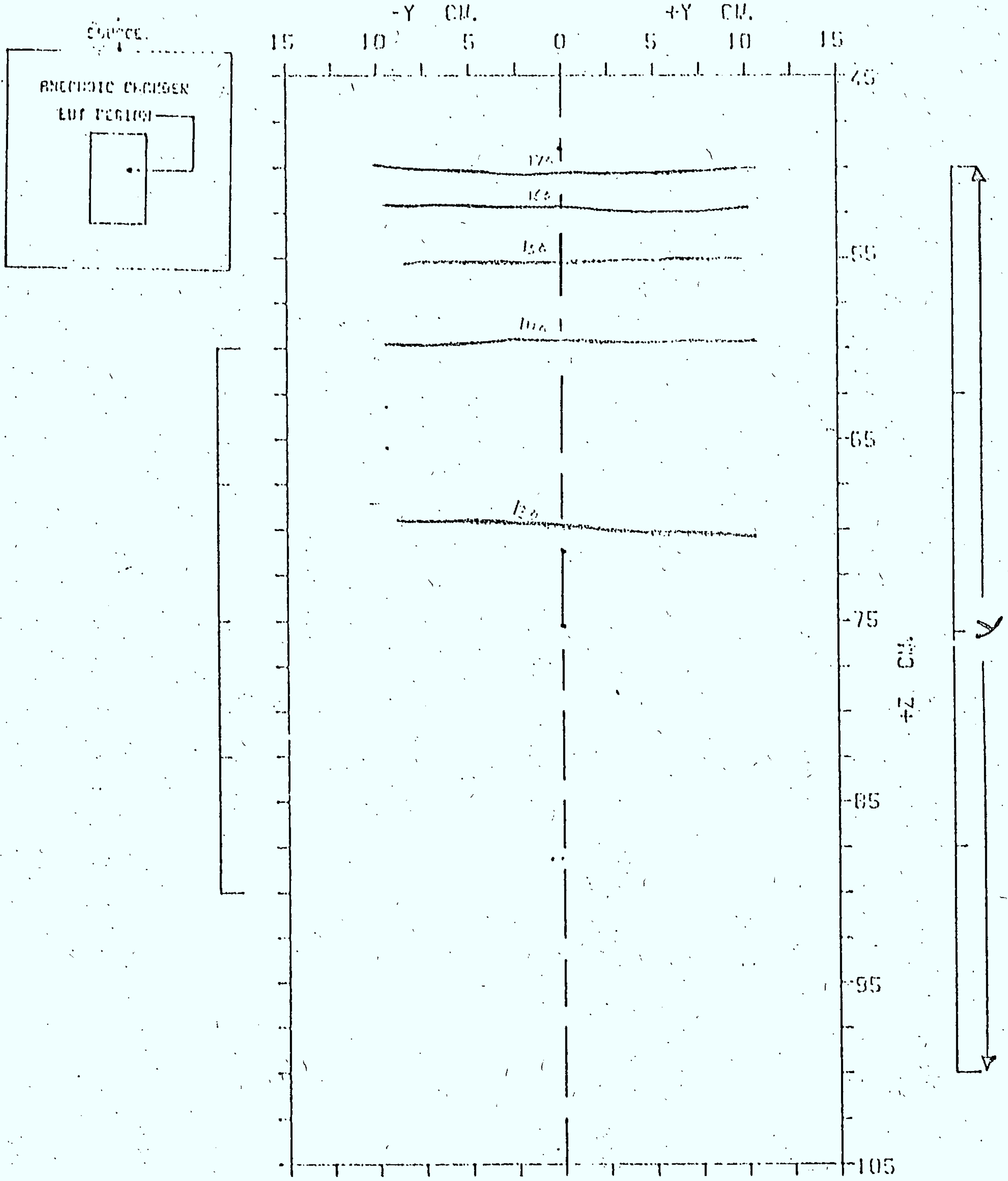




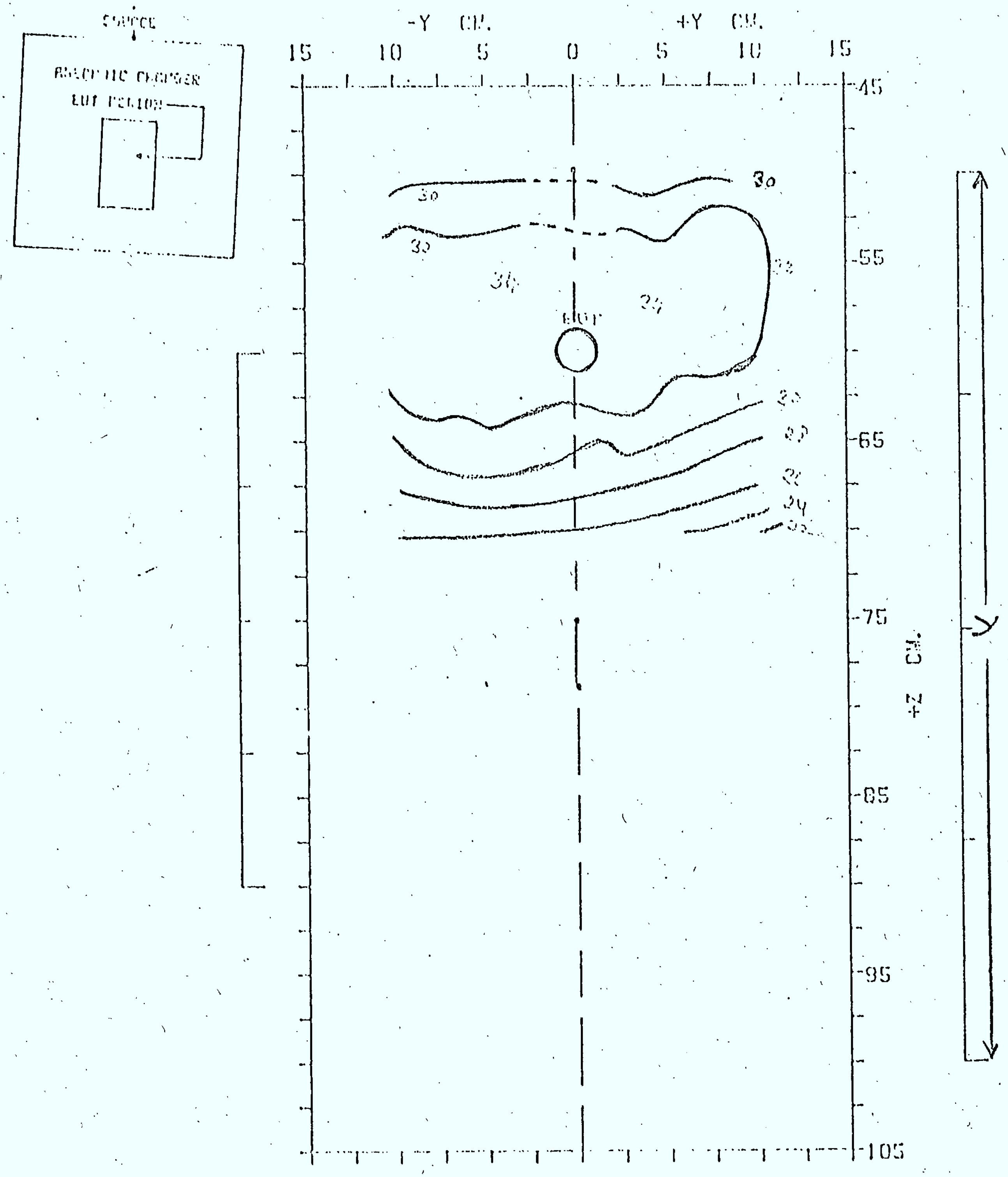
M	0.6	A	H	CL	O	HWD



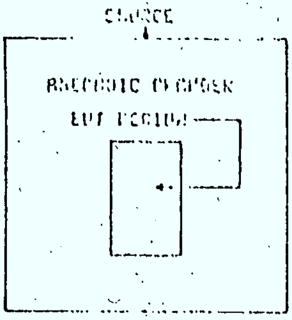
M | 0.6 | P | H | CL | O | HWD

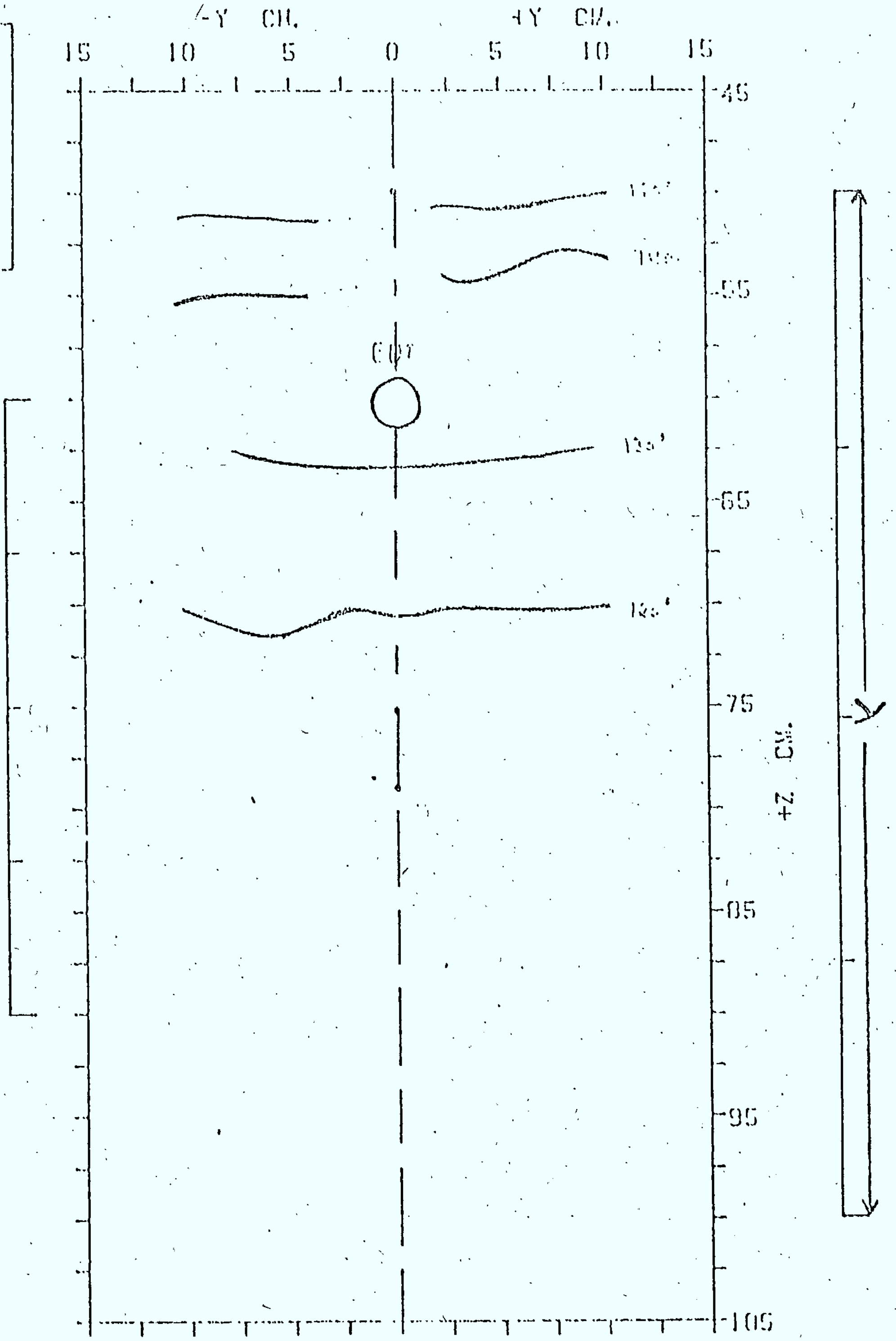


M	0.6	A	H	CL	1	HWD



M	0.6	P	H	CL	I	HWD





.5.4 Observations and Conclusions

The analysis and study of the maps and profiles leads to a number of salient observations of which the principal ones are enumerated below along with conclusions which may be drawn from them:

OBSERVATIONS	CONCLUSIONS OR COMMENTS
.1 The fully lined chamber At 23.5 GHz the field (both amplitude and phase) within the chamber is essentially that of the source itself and no major influence of the chamber's walls is noticeable. The amplitude profile along the central axis is essentially a 1/r function, the phase profile is linear and the phase contours are essentially spherical. There is no major modal structure evident which could be attributed to reflections from the walls, (e.g. there is little evidence of an interference pattern). A comparison of the E and H plane maps does not indicate any major differences except for those inherent in the field of an open-ended waveguide. At 1 GHz and 0.6 GHz the absorbent wall lining has substantial reflectivity because the material is being used at a frequency more than an order of magnitude below its intended operating range. The amplitude and phase maps now exhibit a modal pattern of a kind which may be anticipated as a result of multiple wave interference. An important diagnostic indicator is the behaviour of the phase (9, 10). In a region of absolute nulls the phase contours exhibit a multi-valuedness characteristic of a 'singularity'. This behaviour is clearly seen in the case of both the E and H plane maps at 0.6 GHz near the far walls of the chamber thus indicating	.1 It is evident that in chambers of restricted size it is inappropriate to attempt achieving plane waves. EMS measurements should therefore be predicated on spherical wave fields. - The development of a test facility must consider the choice of illuminating source at the same time as the choice of a chamber is made since these form an integrated system. - The results show that at some upper frequency the chamber may be considered to be truly 'anechoic'. As the frequency is reduced there is a gradual transformation until at the lower frequency end the chamber behaves as a lossy (Low Q) cavity. Nevertheless even at the low frequency end there exists a central region of the field which appears to be useable. The local apparent SWR at low frequencies is sufficiently small that placement of an EUT in such a region can still be possible provided the EUT occupies only a small fraction of the chamber.

the presence of absolute nulls. Despite this, the central region of the room is relatively 'smooth' in amplitude and the phase contours continue to be essentially spherical.

In the case of the 1 GHz condition the field appears to be much more 'structured' for the H-plane though relatively monotonic in the E-plane. The phase structure however does not indicate the presence of any nulls ('singularities'). Because of the shorter wavelength the spacing between successive maxima and minima is smaller and is indeed of the order of $\lambda/2$. Comparing the 0.6 and 1 GHz profiles again indicates that the 1 GHz case is more structured even in the central region. However, the 'mean SWR' is much lower. In fact, in the central region the field is remarkably uniform over a distance of the order of a wavelength.

In examining the field structure particularly in the H-plane, the 'interference pattern' exists mainly in the vicinity of the walls (side and back). Nevertheless even in the .6 GHz case there exists a 'central' region within which the field is relatively 'smooth' although the size of such a region is reduced substantially with the reduction of frequency.

.2 <u>Partially lined chamber</u> (side wall or floor of reflecting material)

In comparing the partially lined chamber maps with the fully lined case it is observed that the general trends as a function of frequency are preserved. At 23.5 GHz the fields are not fundamentally different from those of the fully lined room. Any differences that exist are essentially in the vicinity of the reflecting walls only. As the frequency is lowered the fields become increasingly structured until at 0.6 GHz a number of null (singularity) points become fully developed as witnessed vividly

.2 It is apparent that at the higher frequency end the replacement of a single wall or a floor does not affect the central region field structure dramatically or even noticeably.

At the lower frequency end the entire field structure is distorted somewhat, compared to the fully lined case, but nevertheless preserves the modal characteristics already present. The effect is most pronounced with the reflecting wall parallel to the E-field by the phase structure. A relatively central 'smooth' region still exists but is further reduced in size.

In comparing the cases for the reflecting floor as compared to a reflecting wall it is clearly evident that the deterioration is most significant when the side wall is reflecting. This is to be expected since in this case the reflecting wall is parallel to the E-field and therefore a null field region is produced along the wall. On the other hand the floor is essentially perpendicular to the E-field and the boundary conditions permit wave propagation tangentially to the floor with minimal reflection, so that the field structure is not affected substantially except at the lowest frequency.

In comparing the central axis amplitude profiles for the fully lined and the two partially lined cases it is useful to estimate an 'effective' max/min ratio in the 'central' region. Although the identification of such a 'central' region is in some degree arbitrary, such a comparison can be usefully made and results in the following table:

freq. GHz Condition	23.5	1	.6
Fully lined	1dB	1dB	3dB
Floor Reflecting	1dB	3dB	3dB
Side Wall Reflecting	1dB	4dB	5dB

.3 Field in the Vicinity of an E.U.T.

The maps of fields in the vicinity of EUT were made with models of EUT's (metallic box or cans) whose dimensions were chosen to scale such that in full size these would correspond to large domestic electronic equipment (e.g. large TV and Stereo equipment, small Direct Broadcast Satellite antenna, desk-type personal computer or computer terminal etc.).

polarization and under this condition the use of the chamber may be questionable. However, when the floor is reflecting the local apparent SWR is quite tolerable in the central region, and in fact does not differ from the fully lined case. Thus if the chamber is useable at such a frequency when fully lined, the replacement of a floor by a fully reflecting surface may still be tolerable.

.3 The insertion of an EUT does not appear to disturb the general structure of the field of the chamber except in the immediate vicinity of the EUT, as would be expected from the boundary conditions on the EUT itself.

It must be noted, however, that the EUT size chosen was very much less than the basic linear dimension of the chamber

As noted above, field deterioration is most noticeable in the H-plane and therefore the fields in the vicinity of the EUT were measured in that plane only. These measurements were made at 23.5, 1 and .6 GHz. In addition to this, more detailed (larger scale) maps are made without the EUT (at 1 and .6 GHz) in the region of placement of the EUT to allow more detailed comparison of the field structure with and without the EUT. At 1 GHz the position of the EUT was also varied to determine what effect this might have.

In comparing the 'empty' field with the 'EUT present' field there appear to be no major dramatic differences in the field structure (except on and at the EUT itself). It may be concluded that the insertion of the EUT does not alter the overall field structure in the room at these EUT sizes. ($L_{eut} < L_{room}$.)

In particular the phase structure, which is normally a sensitive indicator of a distortion of the field, remains essentially unaltered.

In the 23.5 GHz case a comparison was made also when the EUT was present in a fully lined and in a reflecting side wall room. No substantial difference is noticeable for these two cases at this wavelength, except that the field in the immediate shadow of the EUT becomes partly filled in.

At 1 GHz the EUT was placed in three different locations, two on the central axis, one at a field maximum and one at a field minimum. The third location was off-central axis in an arbitrary location. An examination of these three conditions and their comparison with the 'empty field' show again very little disturbance of the field and also that there is little difference among the three cases themselves.

(about 2%). On the other hand, in practice at EUT is not necessarily completely metallic but is a composite of different materials.

It also needs to be noted that at the low frequency end an EUT is much smaller electrically than the wavelength so that the disturbance to the field is inherently small, while greater local disturbance is to be expected at the high frequency range when the EUT size is greater than the wavelength.

The positioning of the EUT does not appear to be critical as long as it is in the central region.

6. Design Considerations for ALC's

Based on the measurements detailed in section 5 and in previous reports, it is evident that reduced cost enclosures can be designed for susceptibility measurements to operate over a wide range of frequencies. Such absorber lined chambers (ALC's), though not fully anechoic over their entire range of operation can nevertheless be used for e.m.s. measurements.

Salient design considerations for such ALC's are the subject of this section.

ALC's may be classified in two categories:

a. Fully lined chambers
b. Partially lined chambers

a. Fully lined chambers are antenna quality chambers from a certain frequency f_{AQ} and upwards. However, their range of operation is extendable downwards to as low as .05 f_{AQ} for susceptibility measurements. Such chambers therefore offer the possibility of dual purpose use namely, for antenna grade measurements from f_{AQ} upwards and for susceptibility measurements from 0.05 f_{AQ} and upwards. As the frequency of operation decreases below f_{AQ} a cavity-like modal field structure gradually emerges but is characterized by the persistent presence of a relatively smooth central region which remains available for the placement of an e.u.t. for e.m.s. measurements.

The primary design specification therefore is the choice of f_{AQ}. This choice determines the material to be used for the wall absorber lining. This choice is aided by graphs which were presented in (2) along with tables indicating cost of lining various sized rooms with various absorbers. The absorber selection curves are presented in Appendix (B).

The room size is primarily dependent on the e.u.t. size, the form of the illuminating source and the frequency of operation. The results indicate that at the lowest operating frequency $(.05f_{AQ})$ a chamber of linear dimensions of the order of 2λ is satisfactorily useable and that larger (but costlier) chambers would thus be correspondingly useable. The extent to which the chamber size might be reduced significantly below 2λ remains open to further investigation. However, the experience gained suggests intuitively that a 15 to 20% reduction in size would not have serious consequences.

The shape of the chamber used was a cube. The results, however, indicate a number of possibilities for different shapes with a view for further size reduction. A primary consideration is the nature of the radiating source used.

Certain regions of the room are not significantly illuminated by the radiator, constitute an unused region and may therefore be eliminated. Corners of the room on the wall at which the source is placed, fall in this category. The polarization of the source also offers a reduction in size by using a rectangular rather than square cross section such that the ceiling and floor are closer together than the side walls, in the case of vertical E-field polarization. Further study is required to identify other opportunities in room shape change leading to eventual further cost reduction.

b. Partially lined chambers using reflecting materials in certain sectors represent an extremal form of absorber performance degradation. Such chambers would result in further substantial cost reduction, however, they would no longer serve a dual purpose but would be intended for e.m.s. type measurements exclusively.

The same considerations of choice of f_{AQ}, size and shape apply in general as in the fully lined case.

The implication of the results are that replacement of a floor (or ceiling) perpendicular to the E-field is tolerable. This not only has capital cost advantages, but should have major operational cost and convenience advantages in placing and handling the e.u.t.

Replacement of an absorbing wall parallel to the E-field by a reflecting wall in its entirety is not recommended. However, a gradation in quality of material, strategically placed may be a useful approach. The source radiation characteristics would be a guiding factor, for example, reflection away from the central zone might be tolerable.

A cost optimization opportunity thus exists for balancing reduced cost of lining in unimportant regions against increased cost of lining using higher performance absorber in critical locations. In a different form this is a known approach in anechoic room design.

7. Concluding Remarks and Recommendations

.1 Project Evaluation

In conclusion it is apparent that the objectives of the project have been achieved to the extent that it has been demonstrated that it is feasible to use chambers for e.m.s. measurements over a very wide range of frequencies (e.g. 20 MHz to 10 GHz). A direct consequence has been the 'definition' of a test enclosure designated as ALC - absorber-lined chamber - for use in this application. The basic criteria and some guidelines for the design of ALC enclosures have been identified and described.

As a consequence of this work, further areas of development have been identified which require additional detailed examination. These include further studies regarding:

a.) Optimization of enclosure shape

b.) Minimization of enclosure size

c.) Design of appropriate illumination sources

d.) Use of ALC's for emission (rather than susceptibility) measurements

e.) More theoretical analysis of ALC enclosures with the possibility of evolving computer based design techniques.

It is recommended that the above studies be carried out as an extension of the project.

.2 Assessment of the General Problem

The general problem as described in Section 3 of this report involves broader issues of which the design of e.m.s. test facilities forms but a part. Furthermore, in the case of the test facilities themselves the design of enclosures is only a part of the problem. The following comments suggest further work which needs to be undertaken in the general area of e.m.c., e.m.s., e.m.i.

.2.1 EMC, EMS, EMI Facilities

The design and use of emc/ems facilities needs to be approached on a total system basis. As has been pointed out in verbal presentations during the work of the project, the operating problems and costs may be as great or greater than the facility design and capital problems and costs. On the capital cost side, the instrumentation and data processing costs may be as great or greater than those of the enclosure, the sources and the radiators. Some of these topics are indicated in a listing presented previously (Appendix C).

.2.2 Pilot Facilities

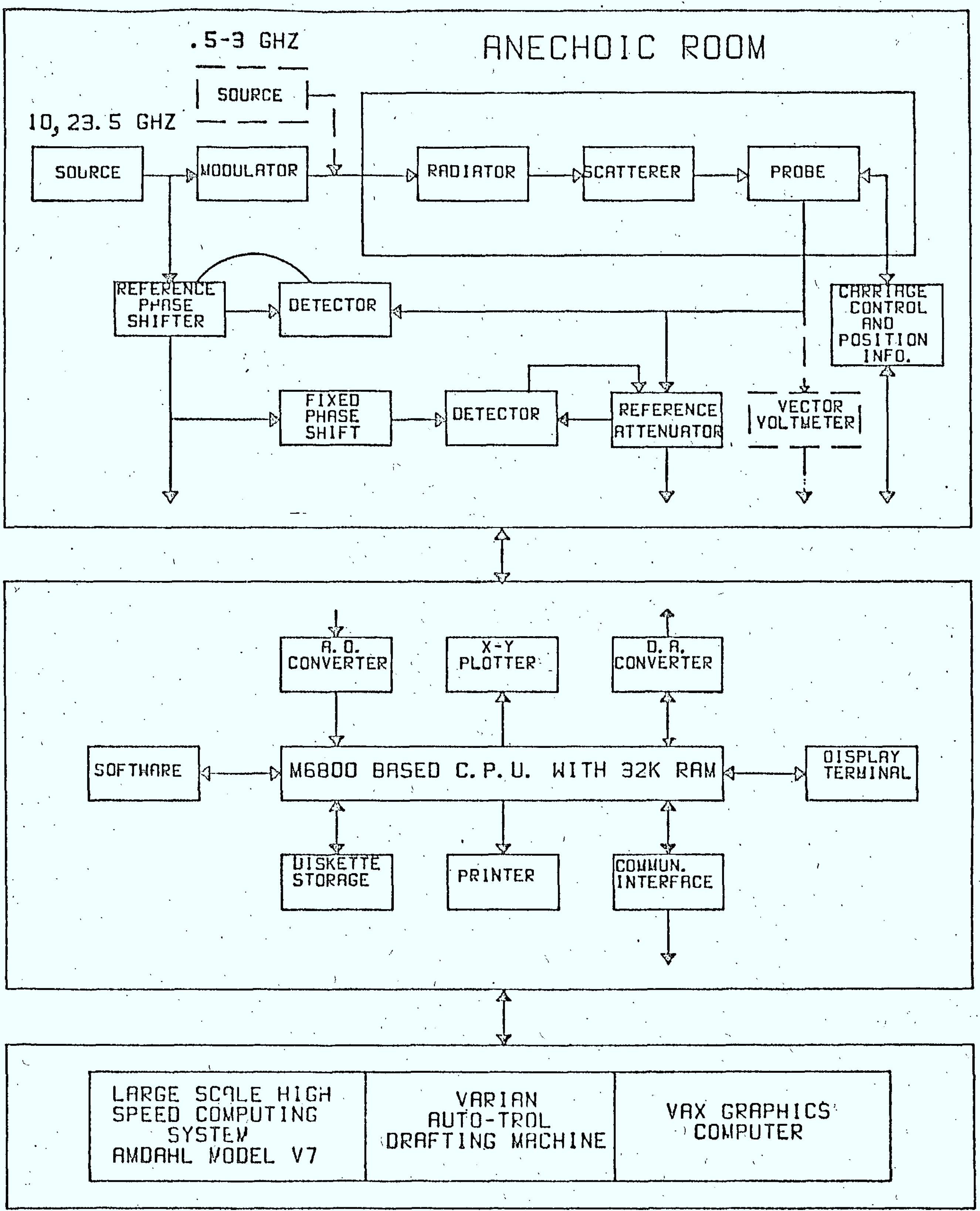
It appears appropriate now to follow up this project by establishing a medium size developmental facility as a means of acquiring operational experience. In addition to further examination of the behaviour of the enclosure, systematic attention should be given to sources, radiators, instrumentation, data acquisition and management techniques. Above all, attention can now be given to the fundamental, crucial problem, which has not yet begun, namely the development of methodology for measuring the susceptibility effects themselves!

.2.3 The Electronic Environment

As mentioned in section 2, a separate major area of study which needs to be initiated is an evaluation of the state of the electromagnetic environment in a systematic and ongoing manner. To date, the condition of the e.m. environment is not known in any detail, except perhaps in some specific local instances. Interference and high field conditions are not known except as a result of complaints which, in themselves, are not presented in a quantifiable manner except on a statistical basis in terms of frequency of occurrence. The techniques of extensive, rapid field surveying which would be the basis for ongoing surveillance and controls, have yet to be developed as does the methodology for managing the large amounts of data which this would involve. If, as appears to be the case, the situation is indeed serious, then it is essential that such detailed evaluations of the e.m. environment, particularly in densely populated regions, be undertaken before critical conditions become evident.

APPENDIX A

BLOCK DIAGRAM OF THE MEASURING SYSTEM



APPENDIX B

GUIDE FOR SELECTION OF ABSORBER MATERIAL

A worst case analysis was made to calculate the resident s.w.r. in the chamber. It was assumed that the wall material has a specified minimum reflectivity for the oncoming radiation. All the different walls are then assumed to produce the worst situation such that the energy at the point under consideration would be either in phase or out of phase. Based on this total summation, the worst case s.w.r. as a function of reflectivity of the material was calculated. This is illustrated in Graph A-1.

When considered inversely this graph can be used to calculate what the wall reflectivity should be if a certain minimum s.w.r. in the chamber is specified. Also drawn on the same curve is an averaged curve which fits very well with manufacturer supplied data for most of the free space foam pyramid type of absorbing materials.

This curve can be used to calculate the thickness of absorbing material required for a specified reflectivity of the material. Using these two curves in conjunction with each other, it is possible to estimate the specifications regarding material thickness for a given worst case s.w.r. A few results of such calculations are shown in the table.

FREQ. MHz	WORST CASE S.W.R.	WALL REFLECTIVITY	REQUIRED MATERIAL THICKNESS
30 MHz	1 dB	23.5 dB	3.5 m
30 MHz	3 dB	15 dB	1.2 m
30 MHz	6 dB	10 dB	.60 m
300 MHz	1 dB	23.5 dB	.35 m
300 MHz	3 dB	15.0 dB	.12 m
300 MHz	6 dB	10.0 dB	.06 m

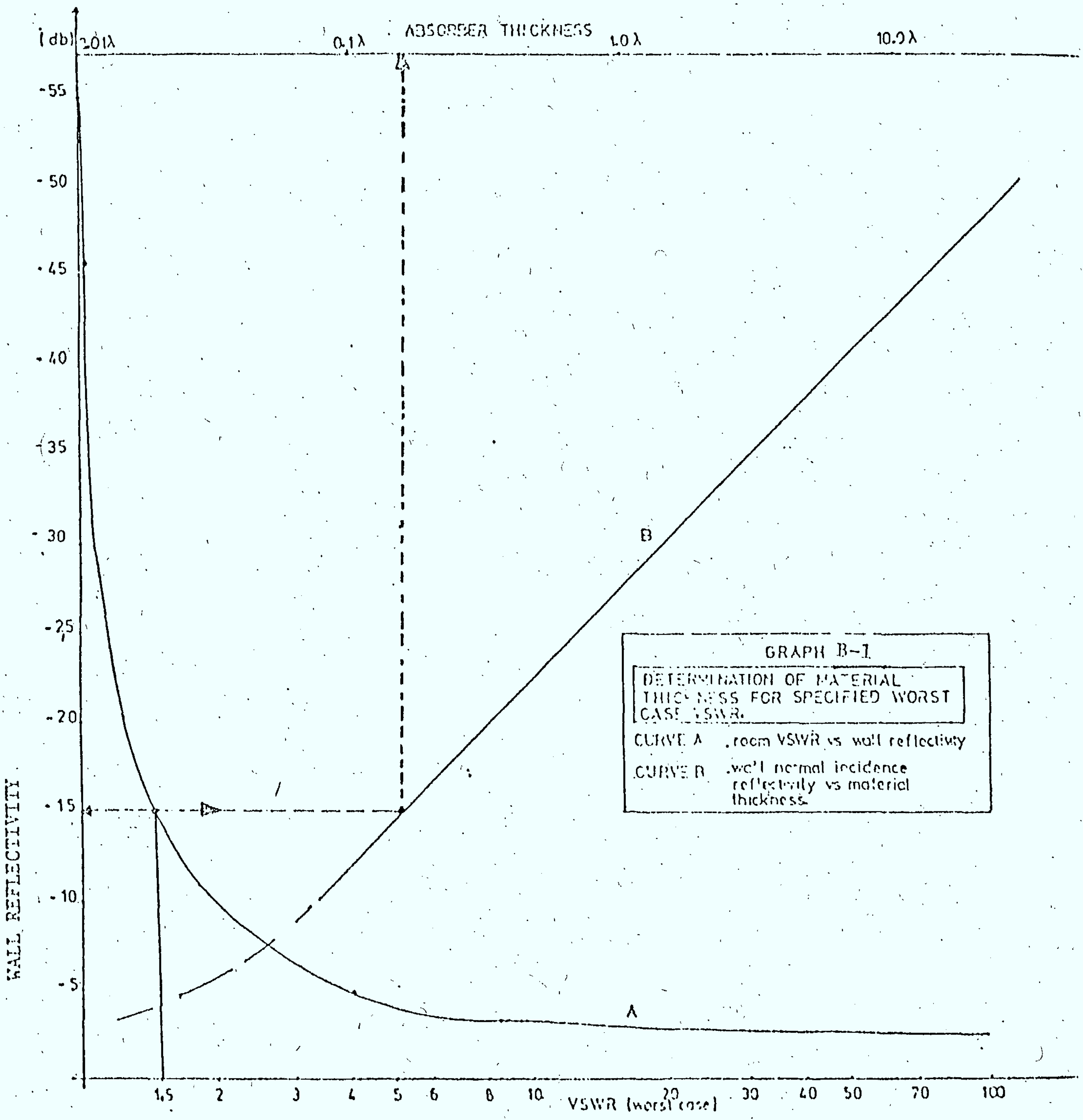

(db)
.01λ
0.1λ
ABSORBER THICKNESS
1.0λ
10.0λ
-55
-50
-45
-40
-35
-30
-25
-20
-15
-10
-5
WALL REFLECTIVITY
B
A
1.5
2
3
4
5
6
8
10
20
30
40
50
70
100
VSWR (worst case)
GRAPH B-1
DETERMINATION OF MATERIAL THICKNESS FOR SPECIFIED WORST CASE VSWR.
CURVE A . room VSWR vs wall reflectivity
CURVE B . wall normal incidence reflectivity vs material thickness.

Fig. B-1

For a sample calculation, see the dotted line on Fig. A-1. A s.w.r. = 1.5 gives reflectivity of -15 dB (curve A). Reflectivity -15 dB gives material thickness .2λ = 2.0 m for a frequency of 30 MHz.

Effect of Angular Dependence of Material Reflectivity

It may be noted that the calculations in A-1 are based on material performance at normal incidence. The commonly used materials are fabricated to give best performance at normal incidence, but their performance degrades as the angle of incidence is changed from normal (90°). The variation is non-linear and is also a function of the normal reflectivity. The slope is minimum at normal incidence but increases very rapidly beyond an incidence angle of about 50°. This explains why it is advised not to use a room configuration where an angle of incidence goes below 60° at any wall. A family of curves showing the available reflectivity as a function of normal reflectivity for different angles of incidence is presented in Fig. A-2. This graph has been derived from the family of curves given in Fig. A-3, which show the absorber performance data as obtained from information published by the makers. Fig. A-2 can be used in combination with Fig. A-3 to find a correction factor for the required normal wall reflectivity based on minimum angles of incidence. An estimate of the degradation of room performance can thus be made as a consequence of the departure from normal incidence. Thus more oblique incidence configurations may require higher performance and higher cost materials but this may be counterbalanced by reduced cross-sectional size of the chamber.

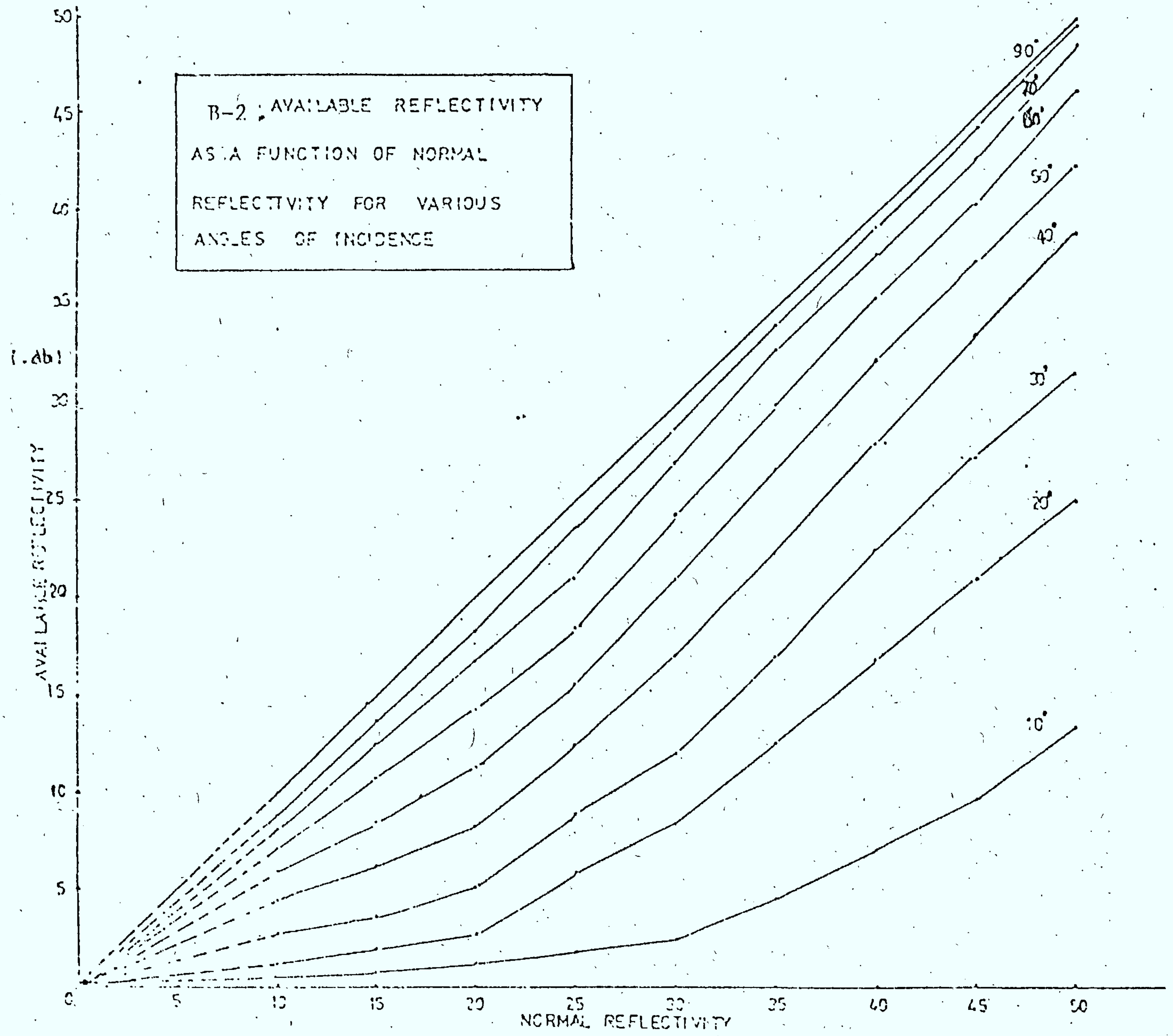

B-2 : AVAILABLE REFLECTIVITY
AS A FUNCTION OF NORMAL
REFLECTIVITY FOR VARIOUS
ANGLES OF INCIDENCE
(.db)
AVAILABLE REFLECTIVITY
50
45
40
35
30
25
20
15
10
5
0
5
10
15
20
25
30
35
40
45
50
NORMAL REFLECTIVITY
90°
70°
60°
50°
40°
30°
20°
10°

Fig. B-2

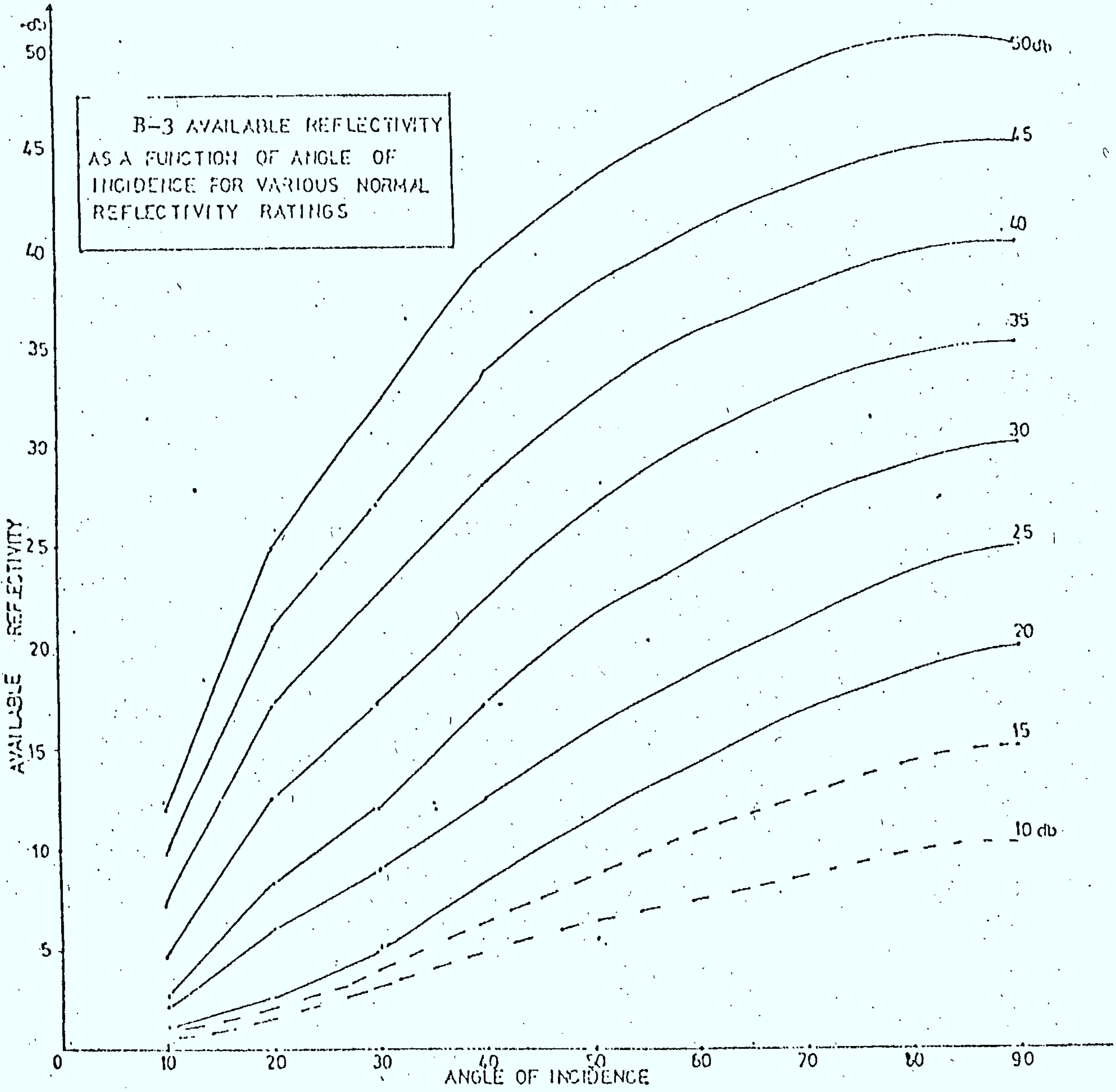

B-3 AVAILABLE REFLECTIVITY AS A FUNCTION OF ANGLE OF INCIDENCE FOR VARIOUS NORMAL REFLECTIVITY RATINGS
db
50
45
40
35
30
25
20
15
10
5
0
AVAILABLE REFLECTIVITY
10
20
30
40
50
60
70
80
90
ANGLE OF INCIDENCE
50db
45
40
35
30
25
20
15
10 db

Fig. B-3

Appendix C Cost Factors for Test Facilities

COSTS

CAPITAL

SITE
- ACCESS
- GEOGRAPHICAL LOCATION
- E.M. LOCATION

CIVIL COSTS
- SIZE AND GEOMETRY
- LIFE EXPECTANCY
- SPECIAL SERVICES AND REQUIREMENTS

ENCLOSURE
- WALL LINING
- SHIELDING
- STRUCTURE

MEASURING EQUIPMENT

	EMISSION		SUSCEPTIBILITY	
	C	R	C	R
SOURCES				
DETECTORS FIELD PERFORMANCE				
DATA -ACQUISITION -PROCESSING				
SERVICE REQUIREMENTS				

OPERATING

PERSONNEL
- SKILLED
- SUPPORT STAFF

OPERATING COST OF MEASUREMENTS
- SET UP TIME
- CALIBRATION
- MEASUREMENT
- DATA REDUCTION
- EQUIPMENT MAINTENANCE

BUILDING SERVICES
- INCREMENTAL COST DUE TO SPECIAL NEEDS OF EQUIPMENT

BUILDING MAINTENANCE
- INCREMENTAL COST DUE TO SPECIAL NEEDS OF EQUIPMENT

9. REFERENCES

(1) T. Pavlasek, "Research and Development Studies for Anechoic E.M.C. Test Facilities Stage I", Progress Report for D.O.C., Serial No. OSU78-00148, December 1, 1978.

(2) T. Pavlasek, "Research and Development Studies for Anechoic E.M.C. Test Facilities Stage I", Final Report for D.O.C., Serial No. OSU78-00148, March 31, 1979.

(3) T. Pavlasek, "Research and Development Studies for Anechoic E.M.C. Test Facilities Phase II", Progress Report for D.O.C. Serial No. OSU79-00143, November 30, 1979.

(4) Electromagnetic Compatibility Advisory Bulletin EMCAB 1, September 1, 1977, D.O.C., Canada.

(5) Notice of Inquiry or Radio Frequency (R.F.) Interference to Electronic Equipment", No. FCC78-801, November 1978, F.C.C. U.S.A.

(6) "Microwaves in Detroit?", Microwave Systems News, Vol. 10, No. 3, March 1980, pp 25-26.

(7) MIL-STD-461A "EMI Characteristics, Requirement for Equipment and MIL-STD-462B "EMI Characteristics, Measurement of", Department of Defence U.S.A., 1967, 1968 and their subsequent revisions from time to time.

(8) B. Howarth & T. Pavlasek, "Analysis of Automatic Homodyne Method: Amplitude and Phase Measurements", Trans. IEEE on Microwave Theory and Techniques, Vol. MTT-20, No. 9, September 1972, pp. 623-626.

(9) W. Braunbek and G. Laukien, Optik, 9, 1952, p. 174.

(10) Y. Lum and T. Pavlasek, "Influence of Aberrations and Aperture Inclinations on the Phase and Intensity Structure in the Image Region of a Lens", IEEE Trans. on Antenna and Propagation, Vol AP 12, No. 6, December 1964.