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A DISCUSSION OF HEAT MIRROR FILM: PERFORMANCE, PRODUCTION PROCESS, AND COST ESTIMATES

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Energy and Environment Division

A Discussion Of Heat Mirror Film: Performance, Production Process, And Cost Estimates

B. P. Levin and P. E. Schumacher

October 4, 1977

Lawrence Berkeley Laboratory University of California/Berkeley

Prepared for the U.S. Department of Energy under Contract No. W-7405-ENG-48

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A DISCUSSION OF HEAT MIRROR FILM:

Performance,
Production Process,
and Cost Estimates

Prepared for Lawrence Berkeley Laboratories of the

Department of Energy, under

LBL Purchase Order No. 3258902

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October 4, 1977

CONTENTS

Figures

INTRODUCTION

A unique, transparent, electrically conductive plastic film is produced in commercial quantities by the Sierracin Corporation. This film is designated by the trade name Intrex^{R} and has been commercially available for several years. It was originally developed as a component in electrically heatable, transparent products such as de-icing windshields for aircraft, locomotives, and the like.

The electrical conductivity is imparted to the plastic film by the vacuum deposition of a thin film of gold onto one surface. This gold film exhibits typical luminous transmittance of 80% and sheet resistivity of 10 ohms per square. The free electron concentration in the gold film that permits such high electrical conductivity is also responsible for very high reflectance and low emittance of electromagnetic radiation in the near and middle infrared spectral regions. For this reason the Intrex film can be regarded as a "heat mirror" with possible application as a glazing cover interior to a conventional window where it serves to reflect low temperature, long wavelength radiation back into the interior of the heated space or prevent its radiation outward. Since the chief utility of such a heat mirror film is during the heating season, a high luminous transmittance, or more precisely a high solar transmittance, is essential to ensure the benefits of solar heat gain. Sierracin's Intrex film appears to exhibit a very favorable combination of infrared reflectance and solar transmittance and is therefore the subject of the inquiry by the Lawrence Berkeley Laboratories of the Department of Energy as to further related technical and economic factors, which constitute the substance of this report.

TASK I, Item 1

INTREX VISIBLE AND IR PERFORMANCE

We present here spectral transmittance and reflectance date for several types of Sierracin's Intrex^R film. The data were taken on Beckman spectrophotometers; the visible (VIS) and near infrared (NIR) data on the Model DK-2A and the infrared (IR) data on the IR-10. Transmittance measurements were made at normal incidence using air as a reference in these double beam spectrophotometers. Reflectance measurements were made with special attachments with 10° and 30° incidence respectively; freshly deposited silver was as the reference for the visible and near IR and freshly deposited gold was the reference in the infrared. Data are also included for the PET substrate material.

Data for the various samples are presented in the following sequence:

Spectral transmittance and reflectance for the visible/NIR and transmittance and reflectance for the IR. The sequence of Intrex film samples is in order of decreasing thickness of the gold coating. Both antireflected and bare gold coating data are presented. Reflectance data from both the coated and uncoated sides of the substrate are presented.

Table 1 lists the Intrex coatings and several of their characteristics for the following figures.

TABLE 1

Figures	Substrate	Coating	Type	Additional Coatings	Luminous Transmittance (%)	Sheet Resistance (ohm/sq.
1-4	PET	-	-	-	88.0	∞
5-8	PET	Intrex	T-42*	FX-43*	78.1	26.6
9-12	PET	Intrex	T-42	-	71.1	26.6
13-14	PET	Intrex	T-28	FX-43	79.6	16
15-16	PET	Intrex	T-28	-	72.0	16
17-20	PET	Intrex	T-18	FX-43	79.5	10
21-22	PET	Intrex	T-18	-	65.1	10

* Throughout this report we use nomenclature peculiar to Sierracin to denote several of the coatings discussed. With reference to Intrex film, the designation T-xy, where x and y are numbers, is related to the thickness of the gold coating. FX-43 and FX-54 refer to chemically applied coatings. The former is a titanium oxide; the latter is an organo-silicate polymer.

HEAT MIRROR PERFORMANCE

The benefits of a two-layer-with-air-gap window construction in reducing heat loss from a heated building interior to a cold exterior are well known. The air space between the two transparent layers can be chosen to minimize the convective and conductive losses through the window. However, with the typical transparent materials used for such constructions, low temperature thermal radiation from the interior is absorbed in the interior layer and the majority of this absorbed energy is ultimately transferred to the outside. This component of heat loss can be reduced by the use of a heat reflective layer or heat mirror, such as the Intrex film discussed here.

The spectral characteristics of room temperature thermal radiation are well known with its peak energy at 10 microns and 80% of the total energy falling between 7.5 and 32 microns. The high reflectivity of Intrex film in this portion of the spectrum, coupled with its relatively high transmittance in the visible and solar portion of the spectrum, make it an ideal candidate for a heat mirror/transparent window component. While detailed heat transfer calculations to determine the reduction of heat loss obtainable using Intrex film as the second transparent layer are beyond the scope of this work, preliminary estimates were made to determine the effectiveness of the film in this context. To this end, low temperature thermal radiation optical characteristics for two of the coatings were determined. These are given in Table 2.

TABLE 2

Substrate	Coating	Type	Incident Radiation Side	Optical Properties For Room Temperature Thermal Radiation		
				T (%)	R (%)	A (%)
PET	-	-	-	16.5	4.6	78.9
PET	Intrex	T-42,FX-43	Coated	0.85	71.7	27.4
PET	Intrex	T-42,FX-43	Uncoated	0.85	9.55	89.6
PET	Intrex	T-18,FX-43	Coated	0.0	86.6	13.4

In estimating the efficacy of the Intrex film in reducing heat loss, we assumed that Type 18 film was used and that its emissivity was equal to its absorptance.

The heat loss through any window depends strongly on the environmental conditions. For purposes of this exercise we assumed an interior temperature of $70^{O}F$, an exterior temperature of $28^{O}F$ with a wind velocity of 12 miles per hour. The latter is typical of winter conditions in many areas of the U.S., Ref. 1. Natural convection was assumed at the interior of the window. A one inch spacing between the glass and the Intrex film was used with no infiltration. Although the results do not depend strongly on size, a window 2 meters high by 1 meter wide was assumed here.

The results of several window configurations are given in Table 3.

TABLE 3

Window Construction	U Factor $\left(\frac{w}{m^2C}\right)$	U/U (Single Pane) (%)
Single glass pane	6.48	100
Glass + uncoated PET	3.07	47.4
Glass + T-18 coated Intrex, coating toward interior	2.21	34.1
Glass + T-18 coated Intrex, coating toward exterior	1.76	27.2
Glass + T-18 coated Intrex, both sides	1.31	20.2

The somewhat greater reduction of heat loss with the Intrex film coating toward the exterior is due to the fact that the convective conductance from the film to the room, which is in parallel with the radiative conductance, is greater than the convective conductance to the glass pane. Thus, the same IR reflectivity and low emissivity has a relatively smaller effect. This clearly has implications for the durability of the coated film to be expected in a typical building environment. This aspect of window construction will be discussed in a later section.

PROCESS DESCRIPTION

Intrex film is produced by a two-step process comprising first a continuous vacuum evaporation of a gold metallic deposit on polyethylene terephthalate (polyester or PET) film, followed by the deposition, by chemical means, of a less than quarter-wave thick deposit of titanium oxide which serves as both an anti-reflecting layer to increase the luminous transmittance and as a means to impart an important measure of mechanical protection, particularly abrasion resistance.

The metallizing is performed in a large self-contained vacuum chamber enclosing a reel-to-reel film transport device (Figure 23). This transport device accepts a maximum width roll of 36" in a horizontal position. The film threading provides a downward, vertical section from the supply roll, leading to a horizontal section where the metallization takes place, and an upward vertical section leading to the take-up roll. The vacuum metallization must be preceded by conventional glow discharge treatment of the entire length of substrate film in order to clean and condition the substrate surface. This is accomplished during transport of the film in one direction, and the metallization is accomplished during transport in the reverse direction; thus the film transport apparatus must operate with full tracking and tension control in both directions. The film transport rate is typically 20 feet/minute.

Vacuum System

The vacuum system consists of a 72 inch diameter 70 inch long movable chamber, a 72 inch diameter 39 inch long fixed chamber, two 32 inch diffusion pumps, a holding pump, and a roughing pump. The roughing pump is actually two pumps; a Roots 6 inch high vacuum booster pump with a Stokes 300 CFM mechanical backing pump. The fixed chamber is provided with four 12 inch diameter flanged feed through ports. All electrical and water connections are made through these ports. The movable chamber contains several 4 inch diameter sight glasses which provide a view of the critical components of the deposition system. All rotary and linear motion feed-throughs are on the baseplate to which the film drive and tension motors are mounted.

An ionization gage and one thermocouple gage are provided in the manifold to measure pressure in the chamber. Four additional thermocouple gages are located in the roughing backing lines.

All gages, valves and pumps are controlled from a center control panel. (Figures 24,25).

Film Transport

The film transport system consists of a bi-directional mechanical means to unwind a supply reel of substrate film, transport it across an aperture and rewind it onto a take-up reel, all at constant speed and tension, (Figure 26).

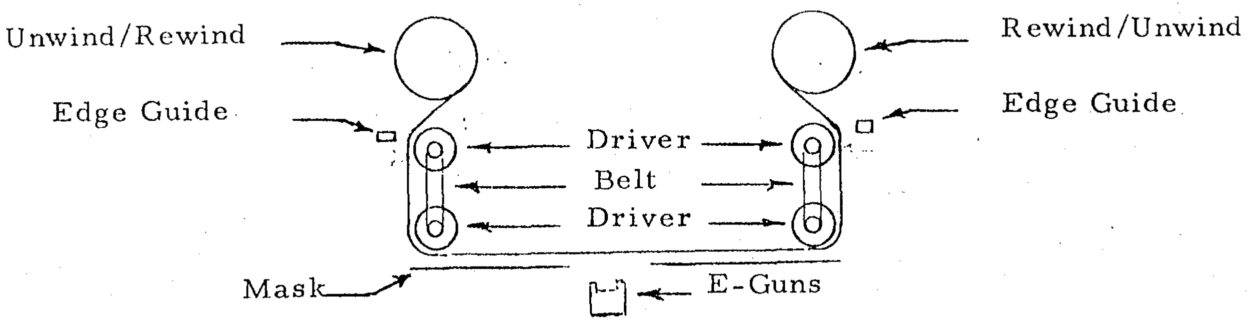
The rotating members of the system are: supply reel, two upper driver rollers, two lower driven rollers and the rewind reel. When the film direction is reversed the unwind becomes the rewind reel and vice versa, (Figure 27).

The lower pair or rollers is mounted in a sub frame which pivots in a horizontal plane, the motion of which guides the film evenly onto the rewind reel. The sub frame is actuated hydraulically; the hydraulic system is controlled by a pair of electro-optical film edge guides.

The transport system structure is a water cooled, welded assembly of square tubular members which are inter-connected by copper tubing.

Transport Drive and Control System

Because of the system requirement for film direction reversibility with constant film tension, the transport control is more complex than the usual industrial web transport. An end view schematic of the film path is shown in the figure below.



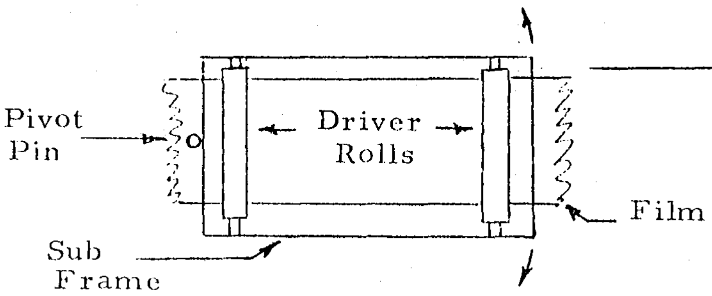
The driver rollers are shaft-connected to individual motor/eddy current clutch units outside of the chamber (Figure 28). These rollers are polished steel. Two rubber covered rollers are driven by cog belts connected to the driver rollers. All four are 6.00 inch diameter.

The winding rolls are also shaft-connected to motor/clutch units.

The four motor/clutch units each consist of: 1/2 hp constant speed induction motor, an eddy current clutch, a tachometer (either self contained or separate belt driven), and a co-axial, reduction gear box. Output shaft speed and/or torque is controlled by a D.C. voltage applied to the clutch field coil.

The driver rollers remain parallel to the winding rolls while the driven rollers pivot about a vertical axis running through one or the other rolls, depending on film direction, although the driven rollers ramain parallel to each other at all times.

A plan view of this action is shown below.



Film Direction - in the opposite direction the frame pivots about a pin on the right side of the frame (not shown) while the left pin, shown here, is no longer constrained.

The available angular motion of the sub-frame is sufficient to correct for ± one inch of uneven film on the unwind reel.

The film position is sensed by a lamp-detector adjacent to the rewind reel, the signal from which is electronically processed and used to control a solenoid hydraulic valve. The sub frame is moved by an external (to the chamber) double hydraulic cylinder acting through a push/pull rod and bell crank linkage.

The actual deposition is accomplished by evaporating 24K (99.99% pure) gold in a series of electron-beam guns arranged equidistant in a line transverse to the film transport direction and located beneath the horizontal section of the film, (Figure 26).

The glow discharge is accomplished by applying high alternating voltage of approximately 2000 volts to aluminum electrodes facing both surfaces of the film and located at both vertical sections of the transport, (Figure 26). Of course the glow discharge is performed at a pressure of a few microns Hg, whereas the metal deposition takes place at about 10^{-5} Torr.

The system as presently operated includes the elaborate servo-control devices described above for regulating film transport tracking and tension as well as conductivity of the deposited coating. These control systems are absolutely essential for achieving and maintaining conductivity for electrical heating purposes. For passive applications such as the heat mirror function these controls can be relaxed but not eliminated altogether. The servo-control system which governs the coating conductivity can be readily adapted to operate about a desired transmittance, rather than electrical conductivity, of the film, thus still providing carefully controlled deposition for the heat mirror application.

Chemical Deposition

The deposition of the anti-reflecting titanium oxide layer is accomplished by a proprietary "wet chemistry" process in which the metallized film is continuously coated by a dip roller apparatus, (Figure 29). The coating solution is applied in the desired thickness by adjusting the concentration of the solution and the rate of transport of the film past the dip roller, (Figure 30). This is performed in a specially designed and constructed web converter machine equipped with a film transport system with automatic edge guide, luminous transmittance photometers, infra-red heaters for final process cure, and film wind-up reel, (Figure 31). Typical coating thickness produced in this apparatus is 460 Angstroms. The luminous transmittance is increased approximately 10% by the application of this coating to the gold; it also provides a significant improvement in resistance to handling and physical damage.

TASK I, Item 2

MODIFICATIONS TO ENHANCE PERFORMANCE AS A HEAT MIRROR

Besides the possibility of Intrex coatings on both sides of the polyester substrate, the heat mirror effectiveness might be enhanced by increasing the thickness of gold film and hence, increasing its IR reflectivity. Clearly there is a tradeoff between improved heat reflection and decreased luminous and solar tramsittance. In order not to sacrifice the latter, improved anti-reflection of the gold coating would be necessary. While the existing, chemically applied anti-reflection coating does indeed enhance these latter transmittances as is seen in the luminous transmittance values in Table 1 and in the spectral transmittance curves, it is possible by the use of higher refractive index anti-reflecting layers to further improve those transmittances for a given thickness of gold. If suitable materials were chosen they would have little effect on the infrared reflectance, just as the present FX-43 layer has little effect.

Materials such as zinc sulfide or a more highly oxidized state of titanium oxide would be suitable candidates for these anti-reflection layers. Others might be tantalum oxide and zinc sulfide which are discussed in a later section. Such materials are most readily deposited by evaporation, either thermally or by electron beam, or by sputtering. The latter may be accomplished using inert gas sputtering of the material itself or by reactively sputtering the appropriate metal. Further improvement could be made by incorporating such anti-reflection layers on both sides of the gold film. Note that the present FX-43 anti-reflective layer is deposited only on the air side of the gold film. In addition it is possible to use multilayer dielectrics of different indices for even higher luminous transmittances at the expense of increased complexity and cost.

Vacuum deposition processes for these anti-reflection materials could readily be incorporated in a process similar to that currently used for the evaporation of the Intrex gold film. This could be achieved most expeditiously by adding more deposition stations in the vacuum coater so that one would deposit sequentially during a single pass of the PET substrate, an anti-reflecting layer, a gold layer, and another anti-reflecting layer. An alternate possibility would be to coat the successive layers during multiple passes of the polyester film, much as is done now with the glow discharge preparation of the PET and deposition of the gold film.

The additional costs incurred by incorporating vacuum deposited anti-reflecting layers would be primarily those associated with the increased deposition equipment since the materials cost is low compared to that of the gold. Of course, additional vacuum deposition process time would be involved, although in the case of successive deposition stations, this would be compensated for by the elimination of the second process step used to apply the FX-43 layer.

PRODUCTION EQUIPMENT CHANGES

The most straightforward approach to higher volume production is to extend the existing vacuum coater design concept to a larger scale, both in width and length of the coated film. In a previous design exercise we determined that the cantilever transport concept embodied in the present equipment could be extended to a 62 inch width, permitting 60 inches of usable coated width. The length of continuously coated film is likewise extended to 4800 feet, thus each roll contains 24,000 square feet of coated film.

On a two-shift, 5-day week basis a vacuum coater of this configuration can produce 250 rolls per year or 6,000,000 square feet per year, thus satisfying metallization of the first two production quantity increments of interest in this task. Of course to support each of these production rates with the 60 inch width vacuum coater, there is a corresponding need for a 60 inch width dip roll coater machine for application of the anti-reflection coating. This latter machine would be merely an upscaled version of the existing 3 foot coater, with identical transport and heat curing system, and can, on a two-shift, 5-day week basis, keep pace with the 6,000,000 square feet per year. A three-shift basis permits one such vacuum coater/dip coater combination to produce 12,000,000 square feet per year; thus the most economical means for achieving a production of 25,000,000 square feet per year is to utilize two complete coating systems, each comprising a vacuum coater and a dip roll coater.

The major direct costs for these production rates are as follows:

	1,000,000 sq.ft./yr.	5,000,000 sq.ft./yr.	25,000,000 sq.ft./yr.
Labor	$.038/sq.ft.	$.028/sq.ft.	$.021/sq.ft.
Materials	$.12/sq.ft.	$.12/sq.ft.	$.12/sq.ft.

The materials costs scale linearly with the quantities. The only major material cost which exhibits a cost reduction potential with large volume purchases is the base polyester film, but this is achieved only at volumes far greater than 25,000,000 sq. ft. per year. The materials costs cited above do, however, include an improvement in the recovery efficiency for the evaporated gold to about 65%.

Of the major indirect costs for these production rates, the most significant are depreciation and occupancy, reflecting the cost of design, construction, installation, and operation of the new 60 inch machines. An analysis of the chief cost items for the 60 inch vacuum coater is given in Figure 33. This information includes vendor identification and is updated to 1977 assuming a 10% inflation factor per year, compounded. The total costs for the vacuum coater hardware is seen to be $519,000. To this must be added $100,000 for Engineering and $75,000 for the dip roll coating maching. Thus, the aggregate cost for a 60 inch coating system is $694,000, while the aggregate cost for two such systems is $1,258,000. This is less than twice the cost of a single system because of economies in common engineering and design.

For a ten year straight line depreciation, the annual depreciation costs for the system equipment is $69,400 for a single system (1 and 5 million sq. ft./year). The corresponding occupancy costs are $20,000 and $40,000 respectively. These are 1977 figures and can be expected to rise sharply with the increase in energy and steel prices.

The major indirect costs for these production rates are tabulated below:

	1,000,000 sq.ft./yr.	5,000,000 sq.ft./yr.	25,000,000 sq.ft.yr.
Employee benefits (25%)	9,500	35,000	131,500
Operating Supplies	6,700	23,000	90,000
Maintenance and Repairs	15,000	20,000	45,000
Depreciation (10 yr. st. line)	69,400	69,400	125,800
Occupancy	20,000	20,000	40,000
Total	120,600	167,400	432,300
	$.121/sq.ft.	$.033/sq.ft.	$.017/sq.ft.

From these unit costs it can readily be seen that there is virtually no cost advantage in constructing a 60 inch system for the 1,000,000 and, probably, 5,000,000 sq. ft. annual production requirements. It must be noted, however, that the 36 inch limitation on width producible with the presently existing machine is very likely a serious impediment to widespread use of the film; hence, there is a product advantage in a 60 inch machine quite independent of unit cost. Of course, for 25,000,000 sq. ft. annual production the 60 inch system is essential.

The principal conclusion from these cost data is the dominant role of the gold evaporant cost. This again reflects the fundamental, electrically conductive (and moreover, electrically powerable) property of the coating.

TASK II

RELATED HEAT MIRROR ACTIVITIES

Metal-Dielectric Stacks

It is well known that the spectral transmittance of semi-transparent metallic films can be enhanced at a particular wavelength or over a band of wavelengths by means of suitable anti-reflection techniques. The optimum transmittance obtainable by this technique, the induced transmission, is remarkably high since the dominant loss in transmittance is by reflection. To obtain such high transmittances it is necessary to resort to multilayer dielectric stacks with the concomitant disadvantage that the spectral band of high transmittance is very narrow. However, even single dielectric layers will yield substantial improvement and can be made effective over broader spectral bands such as the visible.

Sierracin has extensive experience in such simple anti-reflected systems. In particular, high conductivity layers of gold and silver have been anti-reflected with zinc sulfide and tantalum oxide. The purpose of this work was to produce luminous transmittance values approaching 80% for metallic films with sheet resistances as low as 5 ohms/square. The infrared reflectance of these systems is similar to that of the metal film itself, since there is little absorption in the dielectric layers and their thickness is such that interference affects are negligible in the long wavelength region.

All films in these coatings were deposited by vacuum evaporation using both resistively heated and electron beam sources. Typical results obtained are summarized in Table 4.

TABLE 4

Metal	Dielectric	Sheet Resistance (ohms/sq.)	Luminous Transmittance (%)
Gold	Tantalum Oxide	4	75.5
		7	79.0
		10	80.7
		14	82.5
Gold	Zinc Sulfide	7	77.7
		10	80.0
		14	81.7
		20	82.5
Silver	Tantalum Oxide	7	82.6
		10	84.7
		14	85.3
		20	85.3
Silver	Zinc Sulfide	7	77.9
		10	79.2
		14	80.9
		20	83.2

The above data are for laminates incorporating the anti-reflected metallic layer between glass layers. However, the luminous transmittance data are expected to be similar to that of the same thin-film assembly on a glass substrate. We have not measured the infrared reflectance of these films but the values are expected to be similar to those of the Intrex films of comparable sheet resistance as listed in Table 1. The infrared reflectance of the silver films is expected to be similar to that of the gold films although their optical properties in the visible spectrum differ considerably.

Deposition of these multilayer films could readily be carried out in the manner described in Task I on enhanced/performance heat mirrors.

Semiconductor Heat Mirrors

Sierracin has extensive experience in the vacuum deposition of semiconducting oxides of the indium and tin oxide types on polymeric films. These films typically have been of higher resistivity than the previously discussed metallic films since they are designed for applications other than powerability, as was Intrex film. The latter application usually demands a low sheet resistance. The semiconducting films have very high luminous and solar transmittances; typically there is a transmittance loss of only several percent from that of the substrate. Such high sheet resistance films have relatively low infrared reflectance. However, it is possible to deposit these films with lower sheet resistance which results in increased infrared reflectance; they then become candidates for transparent heat mirrors. Spectral data for two such films are presented in Figures 34 through 41. Again, transmittance and reflectance in both the visible, near IR and infrared are given. Table 5 gives pertinent coating data.

TABLE 5

Figure	Substrate	Coating	Type	Luminous Transmittance (%)	Sheet Resistance
34-37	PET	Conductive Oxide	VTA	80.3	71.6
38-41	PET	Conductive Oxide	IVE	81.2	140

The optical characteristics of type VTA conductive oxide coated film for low-temperature, thermal radiation have been determined to be: transmittance 5.2%, reflectance 33.4%, and absorptance 61.4%. Comparison with the corresponding values for Intrex film in Table 1 indicate that the reflectance is considerably lower than that of the Intrex film. Note, however, the higher sheet resistance of the oxide coating. Were that sheet resistance reduced to values comparable to those of the Intrex film, increased infrared reflectance would result.

Sierracin has deposited these conducting oxides by sputtering. Both inert-gas sputtering from the oxide and reactive sputtering from the metal have been used. Several vacuum stations have been used for this work. Figure 42 shows the system used for development of new coating materials and processes. Figure 43 depicts a deposition system in which these processes are adapted to web coating. Figures 44 and 45 are photographs of a sputtering system currently being used for coating PET webs in widths to 13 inches. A study has been conducted to determine the cost of scaling this process to the present Intrex film coater with 36 inch web-width capability.

Alternate Metals

Because of the cost and color associated with thin gold films, alternate metals have been considered at various times. Most metals have optical characteristics such that even as thin films, they have high reflectance in the low-temperature thermal radiation portion of the spectrum. However, their optical characteristics in the visible and solar spectra are not so similar. At the latter wavelengths, for comparable thicknesses and infrared reflectivity, gold has the highest transmittance, followed by silver and copper. By comparison such metals as chromium and aluminum have far lower luminous transmittance. Stated another way, for equivalent luminous transmittances, thin gold films have the highest infrared reflectance, followed in turn by silver, copper, and chromium and aluminum, in that order.

Another factor to be considered when discussing alternate metals is their stability with time. Since all of these materials would be used in very thin film form for visible transparency reasons, they are clearly susceptible to corrosion. Of the materials listed here, only gold can be considered inert. However, the time for degradation by corrosion of some other materials may, with anti-reflection/protection layers, be long enough for the application discussed here. Sierracin's experience with silver anti-reflected with titanium oxide, zinc sulfide, and tantalum oxide indicates that significant deterioration of optical performance does occur within a period of a year.

A method of protecting a transparent copper coating on a surface is claimed in U.S. Patent 3,577,273 in which the evaporated copper is treated with a tin fluoride solution. It is claimed that this gives long term stability to the resistance of the copper film and presumably, therefore, to its optical properties. It is not reported whether the treatment affects the infrared optical properties.

Alternate Methods of Preparing Conductive Oxide, Transparent Films

In addition to direct deposition of the oxides by sputtering and evaporation, various metals have been deposited on substrates and subsequently oxidized to form a conductive oxide. For example, U.S. Patent 3,580,738 discloses a process in which indium is evaporated onto a substrate, subsequently exposed to air at a somewhat elevated temperature, and then treated with various acids. These processes are said to convert the metallic indium to an indium oxide which is both transparent and conductive.

Multilayer Polymeric Films

Several years ago the Dow Chemical Company introduced an interesting product consisting of hundreds of layers of thin plastic films produced by co-extrusion. Two polymers of different refractive index were alternated in thicknesses which produced optical interference effects in a manner similar to that of evaporated, multilayer dielectric stacks. Although the range of indices available with plastic materials is severely limited, a very large number of layers makes it possible to obtain appreciable reflectance in selected wavelength bands of the visible spectrum. Figures 46 and 47 show the transmittance and reflectance of two such structures having 231 and 462 individual layers. The 462 layer film has a strong reflectance peak in the blue end of the visible spectrum while the 231 layer film has a moderately high reflectance band at 0.8 microns.

In principle, this same technique could be adapted to provide reflectance in the infrared to act as a heat mirror. The difficulty arises in finding polymeric materials with low absorption in this portion of the spectrum. Most polymers have rather strong absorption bands in this region. This absorption precludes obtaining high reflectance with such a multilayer. However, such materials as polyethylene are relatively free of absorption bands and it is conceivable that a suitable combination of polyethylene and another absorption-free material with significantly different index could be designed to give the desired heat reflectance characteristics.

As outlined by Alfrey, et al, Reference 2, to obtain broad band reflectance, a graded-thickness multilayer stack is required. Uniform optical thickness multilayers lead to narrow band optical characteristics as shown in the preceding figures.

The film produced by Dow as illustrated in these figures was pronouncedly iridescent. Colors varied drastically over small distances. Such an effect would be objectionable in most window applications. However, with the increased layer thickness needed for infrared reflectances and the graded thicknesses necessary for broad band characteristics, this iridescence may be greated reduced.

TASK III

ABRASION-CORROSION RESISTANT COATINGS

Thin metal films are susceptible to damage by abrasion. As discussed earlier, Sierracin's Intrex film incorporates a titanium oxide overcoating of the gold film not only to anti-reflect and hence, increase the luminous transmittance of the film, but to afford a degree of mechanical protection. However, the oxide layer is itself a very thin film and affords only limited protection. Thus, the composite film is still susceptible to damage in any but the most benign environment. Thicker coatings of resinous material are regularly used by Sierracin to protect gold films in various products; these give excellent protection. The difficulty with this approach is that these thicker films include significant absorption in the thermal radiation portion of the spectrum. Such absorption can substantially negate the high infrared reflectivity of the gold film.

We investigated a particular Sierracin coating which has excellent abrasion resistance and which we hoped would have little absorption in the infrared. The coating is an organo-silicate polymer, Sierracin designated FX-54. It is a variant of Owens-Illinois Type 650 glass-resin coating. Deposition techniques similar to those used for Sierracin's FX-43 anti-reflecting coating can be used to apply this coating. It has excellent adhesion and superior abrasion resistance.

The infrared optical characteristics of such a film are shown in Figure 48, which shows the transmittance of the film on a polyethylene substrate with uncoated polyethylene as a reference. We see that there is significant absorption in the 10 micrometer region. This will have an appreciable effect on the infrared reflectance of the underlying gold layer. To determine this reduction in reflectance, the film was deposited on Type T-26 Intrex film with an FX-43 layer. Visible and infrared spectral data for this overcoated film are given in Figures 49 and 51. The channel spectra seen in Figure 49 are due to interference effects in the relatively thick FX-54 layer. The initial optical and electrical characteristics of the Type T-26 film are nearly identical to those of the T-28 film listed in Table 1. After overcoating with the FX-54 layer, the luminous transmittance decreased negligibly to 78.2%. However, the reflectance for room temperature thermal radiation decreased to 31.8% from an expected value of 80% for the non-overcoated Intrex film. Thus, as expected from the absorption characteristics of the FX-54, there is a severe decrease in the heat mirror qualities of this film.

A search for other abrasion resistant coatings which have low absorption in this portion of the spectrum is beyond the scope of this work. However, it is possible that such films can be found and adapted to this application.

We note once again as in Task I that the reduction of heat transfer through a window by using Intrex film as a heat mirror is fully as effective when that heat reflecting layer faces the exterior as when it faces the interior. In the former configuration the relatively fragile Intrex coating is not exposed to the incidental abrasion and abuse it might receive with the opposite orientation. With the exterior orientation, its effectiveness as a heat mirror is expected to be stable with time.

TASK IV

SINGLE LAYER CHEMICAL COATING

In Task I there is discussed an anti-reflection coating which is deposited by proprietary "wet chemistry" techniques over the vacuum-deposited gold. The anti-reflection coating is approximately 460Å thick titanium oxide and exhibits a refractive index of at least 1.7 at visible wavelengths.

This use of this material has led to the speculation that it might serve as a single layer, low cost heat mirror coating by virtue of enhanced Fresnel reflectance. To investigate this, a sample of polyethylene terephthalate film was coated on one surface; the infrared spectral reflectance of the uncoated surface was measured in a Beckman IR-10 spectrophotometer at 30° angle of incidence, then the same measurement was performed on the coated surface. The results are shown in Figure 52 of the section dealing with Task III, with the higher curve indicating the reflectance of the coated side.

From the figure it is evident that the reflectance of the coated side is negligibly greater (about 1%) than that of uncoated PET film and is probably within the experimental error for this measurement.

The result of this measurement is that the titania anti-reflection layer, as presently deposited, offers no heat mirror performance characteristics. One might speculate further on modifications to the present process or materials or, even, deposition of altogether different classes of materials by wet chemistry techniques to form low cost, single layer, heat mirror coatings, but inquiries into these matters are beyond the scope of this report, to the extent they are not covered in the discussion of Task II.

Since the subject coating fails to provide the required heat mirror benefits, there is no purpose served by a discussion of optimized production costs, and this Task is, accordingly, completed.

CONCLUSIONS

Sierracin's Intrex film has been shown to have optical properties which make it suitable for heat mirror window applications when used as the interior component of double layer glazing. The cost of the film in various quantities has been demonstrated to be low enough to make such heat mirrors economical. Possible modifications of Intrex films to improve heat mirror performance have been discussed. Several alternate approaches for lower cost heat mirror windows have been explored, including other metals, semiconducting oxides and multilayer polymers. Abrasion-corrosion resistant coatings for Intrex and their effect on heat mirror performance have also been discussed.

REFERENCES

1. AIP Conference Proceedings No. 25, Part 3, p. 258, S.M. Berman and S. D. Silverstein, eds., American Institute of Physics, N.Y. 1975.

2. Polymer Engineering and Science, 9, 6, p. 400 (Nov. 1969)

LIST OF FIGURES

CAPTION

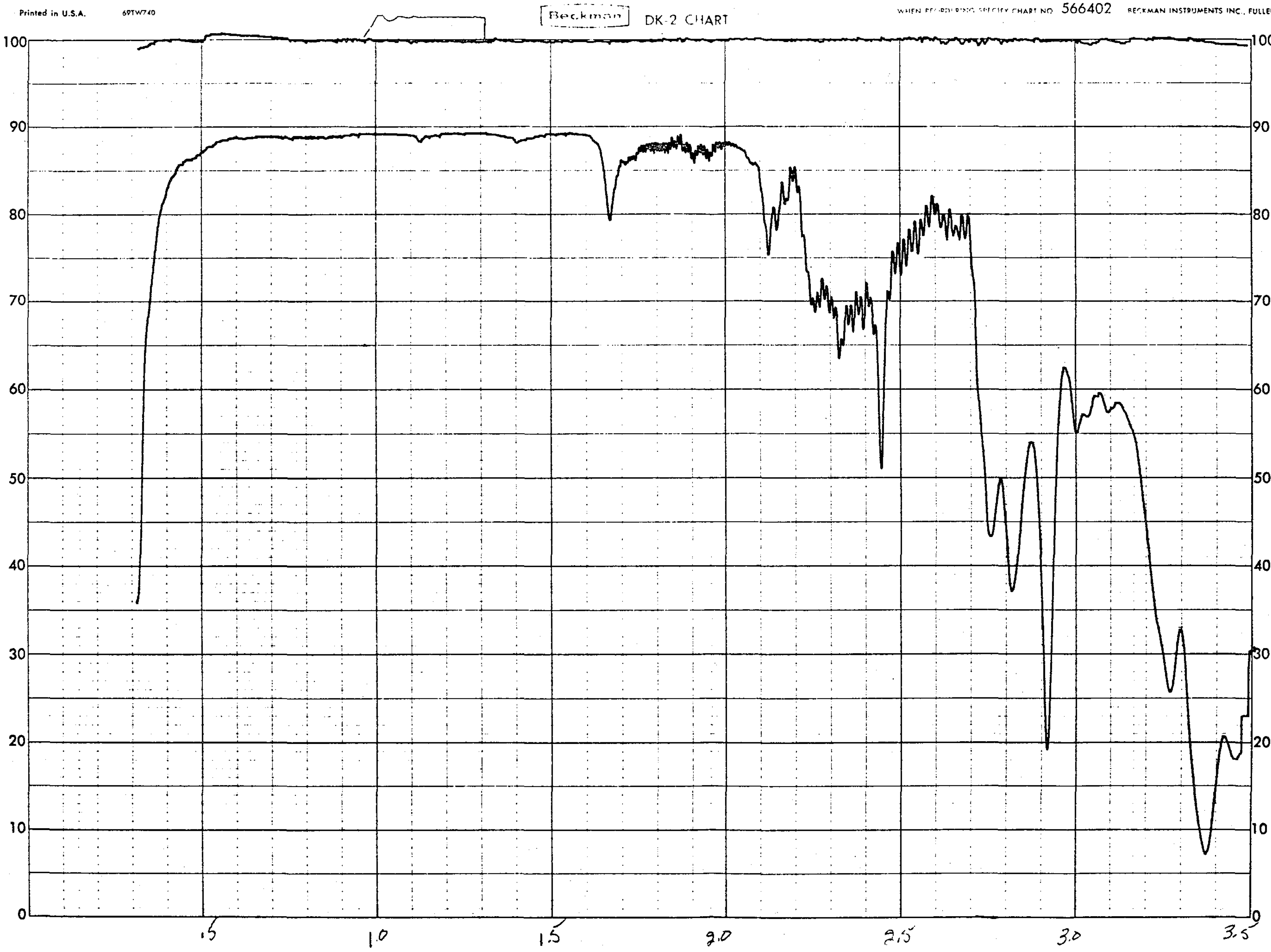
LIST OF FIGURES (CONTINUED)

CAPTION

Printed in U.S.A. 69TW740

Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.



T

1

SAMPLE 1C1

5 Mil
Uncoated

PATH________cm

ORIGIN________

SOLVENT________

REF Air

λ SPEED:________ nm/min

SCALE 0-100

SENS 70

PERIOD________

SOURCE: W x

H_2________

D_2________

DETECTOR: PM________

PbS X

ANALYST BRT

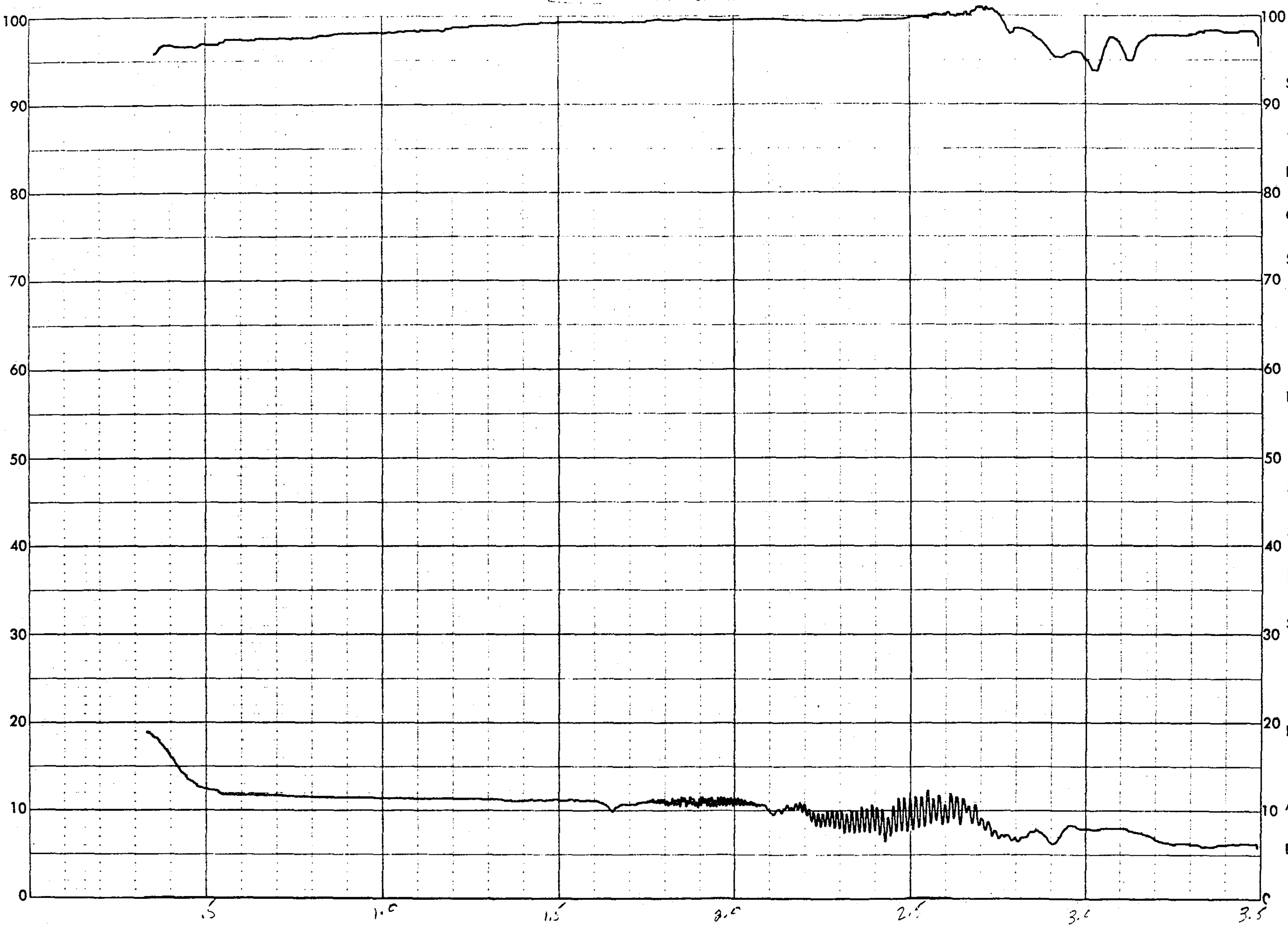
DATE 9-14-77

Fig. 1

Printed in U.S.A. A9TW740

Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.



R
2

SAMPLE 1C1
5 Mil
Clear

PATH ______ cm

ORIGIN ______

SOLVENT ______

Refl

REF Ag

λ SPEED: ______ nm/min

SCALE 0-100

SENS 70

PERIOD ______

SOURCE: W X
H₂ ______
D₂ ______

DETECTOR: PM ______
PbS X

ANALYST BRT

DATE 9-14-77

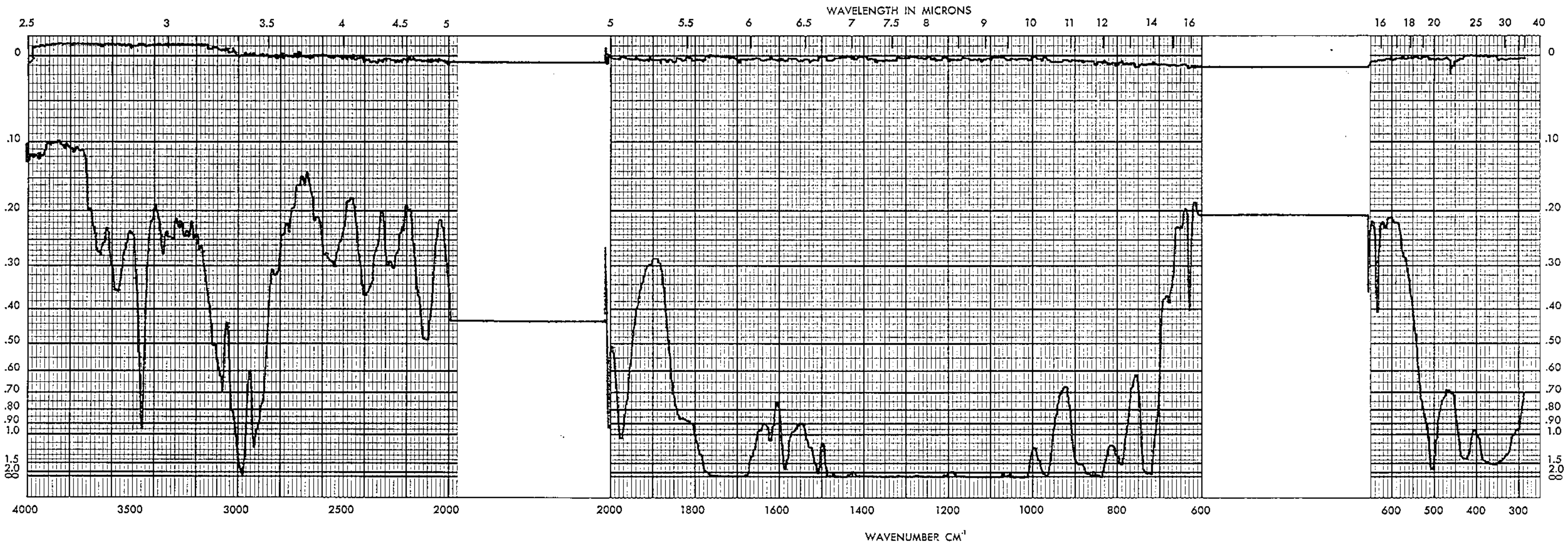
Fig. 2

T

3

PRINTED IN U.S.A.

WHEN REORDERING SPECIFY CHART NO. 101509 BECKMAN INSTRUMENTS, INC., FULLERTON, CA



SPECTRUM NO.

DATE

SAMPLE 1C1 5 Mil Virgin Film

Transmission

SOURCE

STRUCTURE

PATH mm

SOLVENT

CONCENTRATION

PHASE

COMMENTS

ANALYST

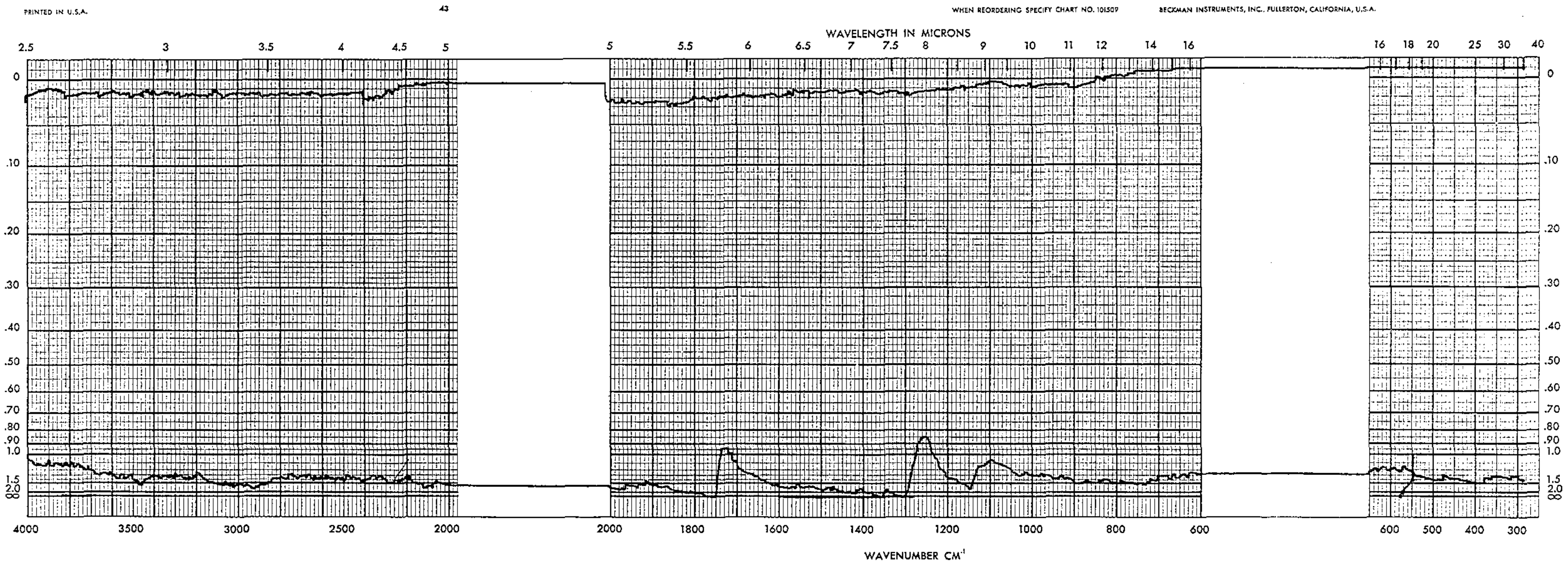
Beckman®

INFRARED

SPECTROPHOTOMETER

Fig. 3

R
4



SPECTRUM NO.
DATE
SAMPLE 1C1 5 Mil
Uncoated
No fx
SOURCE
STRUCTURE

PATH mm
SOLVENT
CONCENTRATION
PHASE
COMMENTS

ANALYST

Beckman®

INFRARED
SPECTROPHOTOMETER

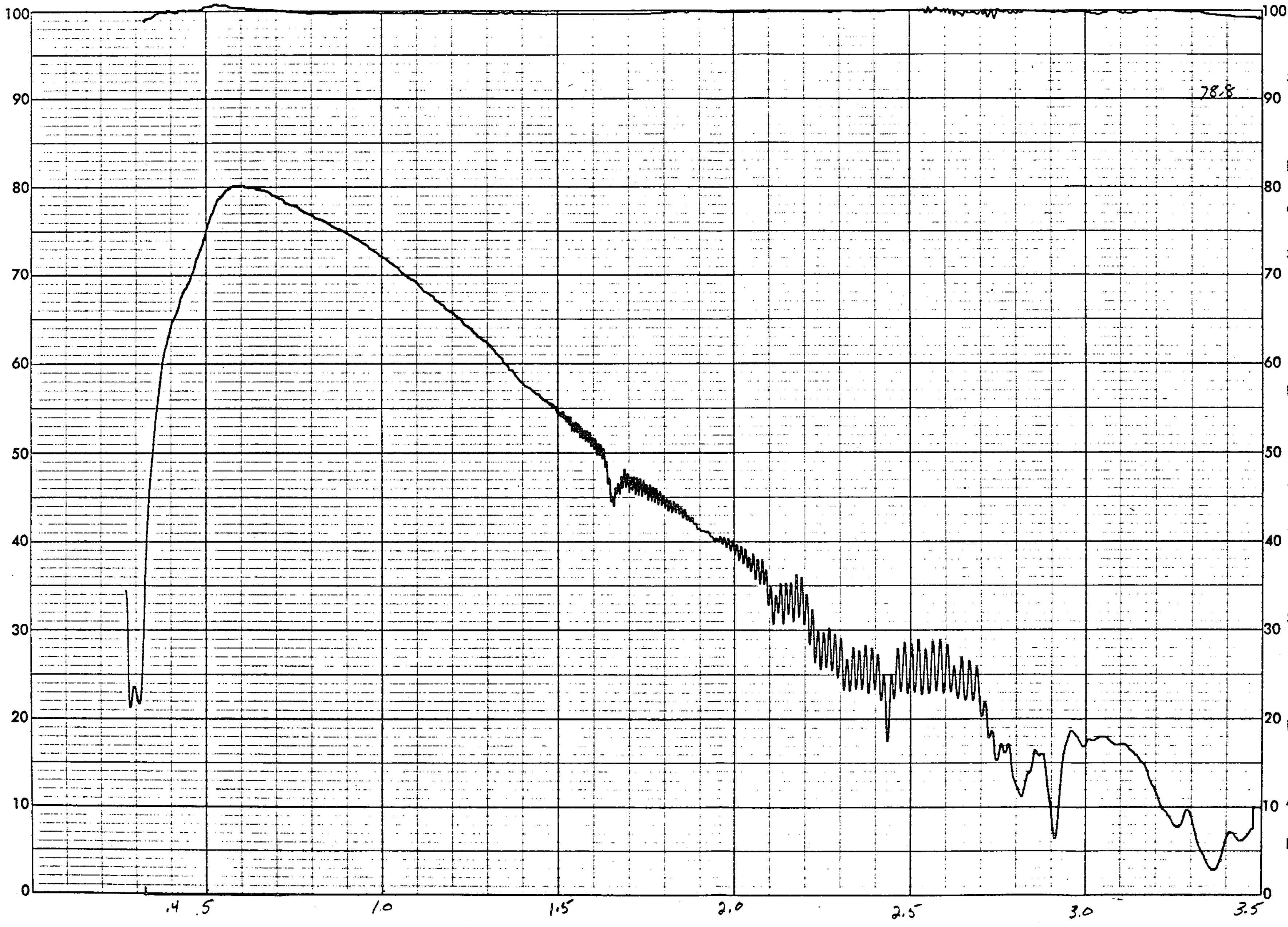
Fig. 4

Printed in U.S.A. 69TW740

Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.

T
—
5



SAMPLE Type
42 W/fx
4 Mil

PATH ______ cm

ORIGIN ______

SOLVENT ______

REF Air

λ SPEED: ______ nm/min

SCALE: 0-100

SENS 70

PERIOD ______

SOURCE: W x

H$_2$ ______

D$_2$ ______

DETECTOR: PM ______

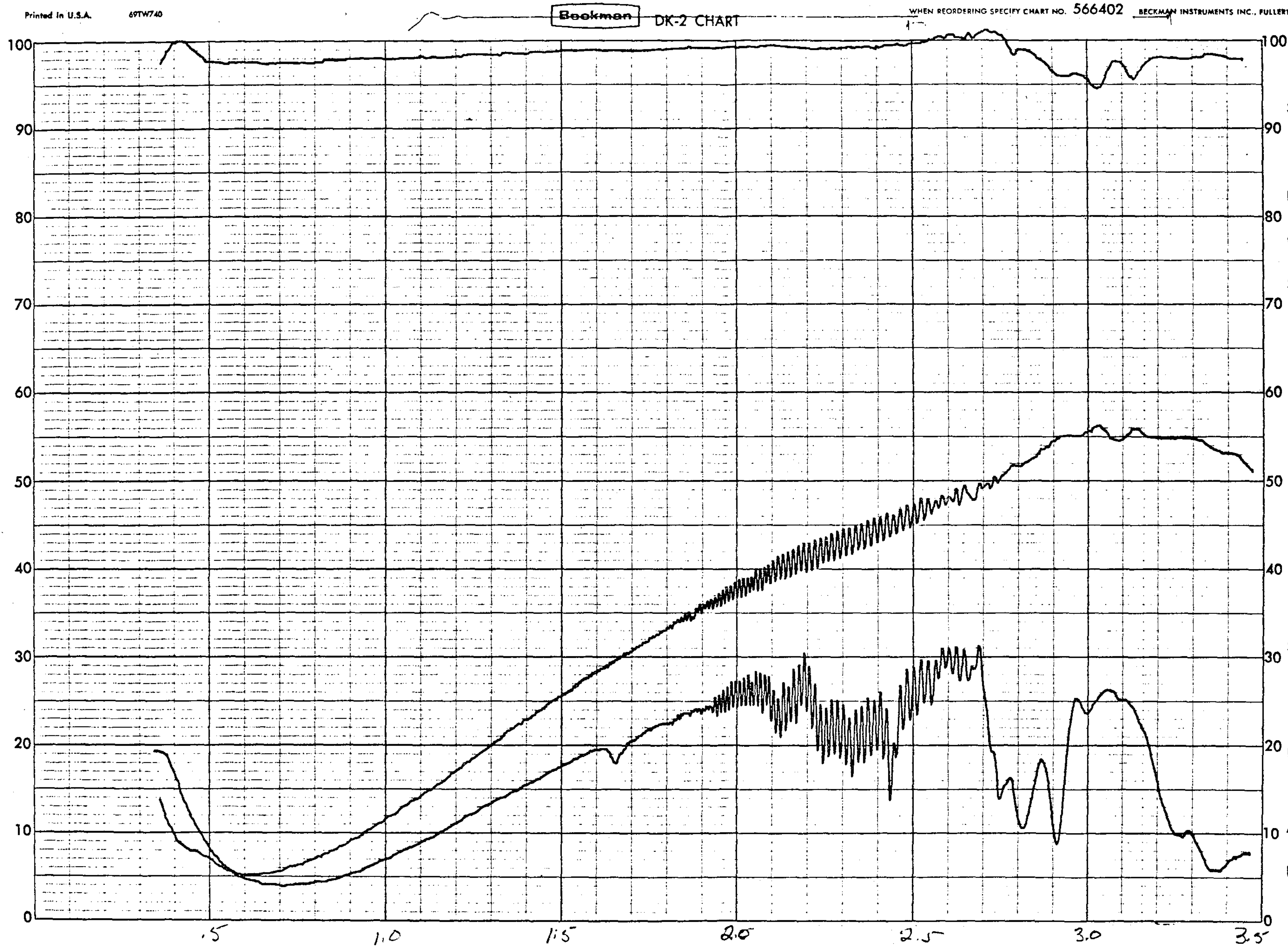
PbS ______

ANALYST BRT

DATE 9-13-77

Fig. 5

R
6



SAMPLE T42
W/Fx

PATH ________ cm

ORIGIN ________

SOLVENT ________

REF Ag

λ SPEED: ________ nm/min

SCALE 0-100

SENS 70

PERIOD ________

SOURCE: W X

H₂ ________

D₂ ________

DETECTOR: PM ________

PbS ________

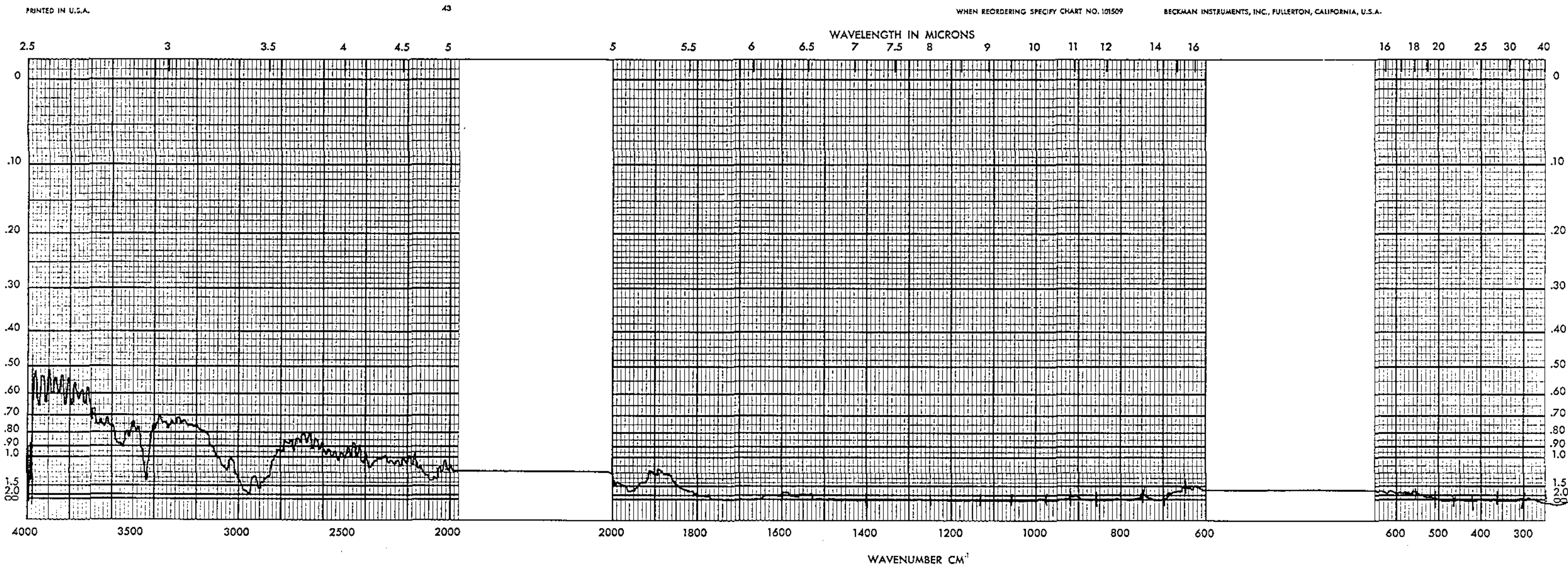
ANALYST BRT

DATE 9-13-77

Fig. 6

T

7



SPECTRUM NO.

DATE 9-13-77

SAMPLE T 42 W/EX

SOURCE STRUCTURE

PATH mm

SOLVENT

CONCENTRATION

PHASE

COMMENTS

ANALYST

Beckman®

INFRARED SPECTROPHOTOMETER

Fig. 7

R

8

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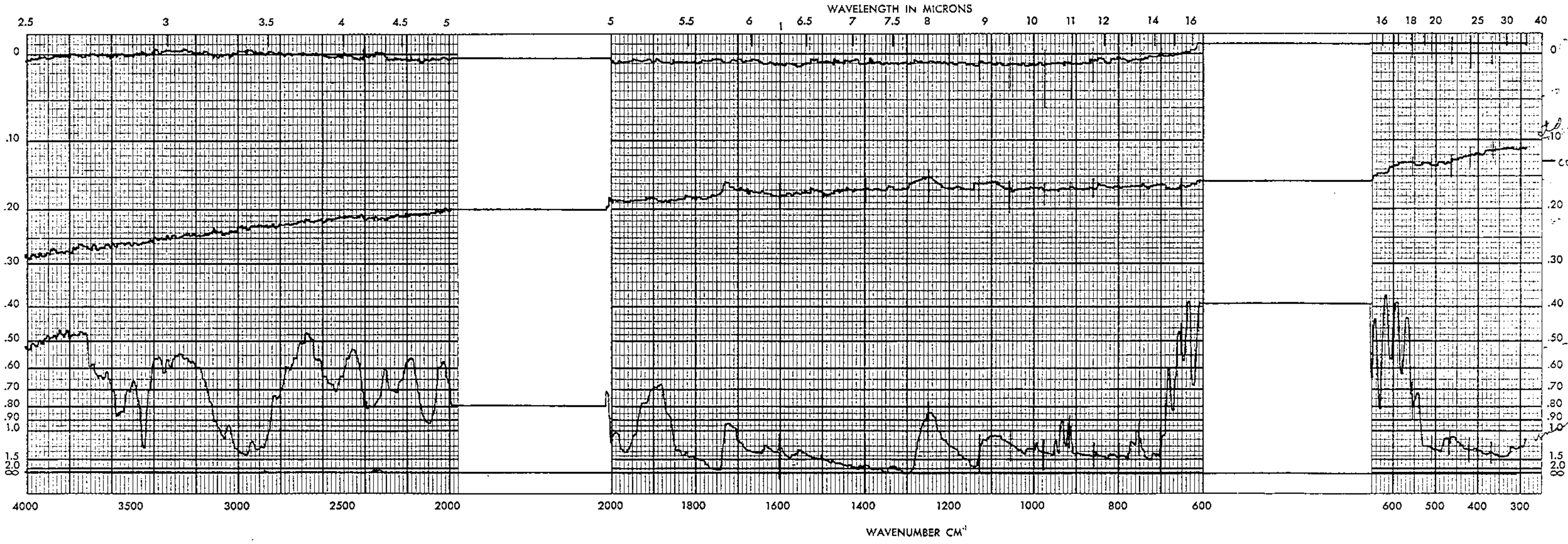
43

WHEN REORDERING SPECIFY CHART NO. 101509

BECKMAN INSTRUMENTS, INC., FULLERTON, CALIFORNIA, U.S.A.



SPECTRUM NO.

DATE

SAMPLE

T-42

W/Fx

SOURCE

STRUCTURE

PATH mm

SOLVENT

CONCENTRATION

PHASE

COMMENTS

ANALYST

Beckman®

INFRARED SPECTROPHOTOMETER

Fig. 8

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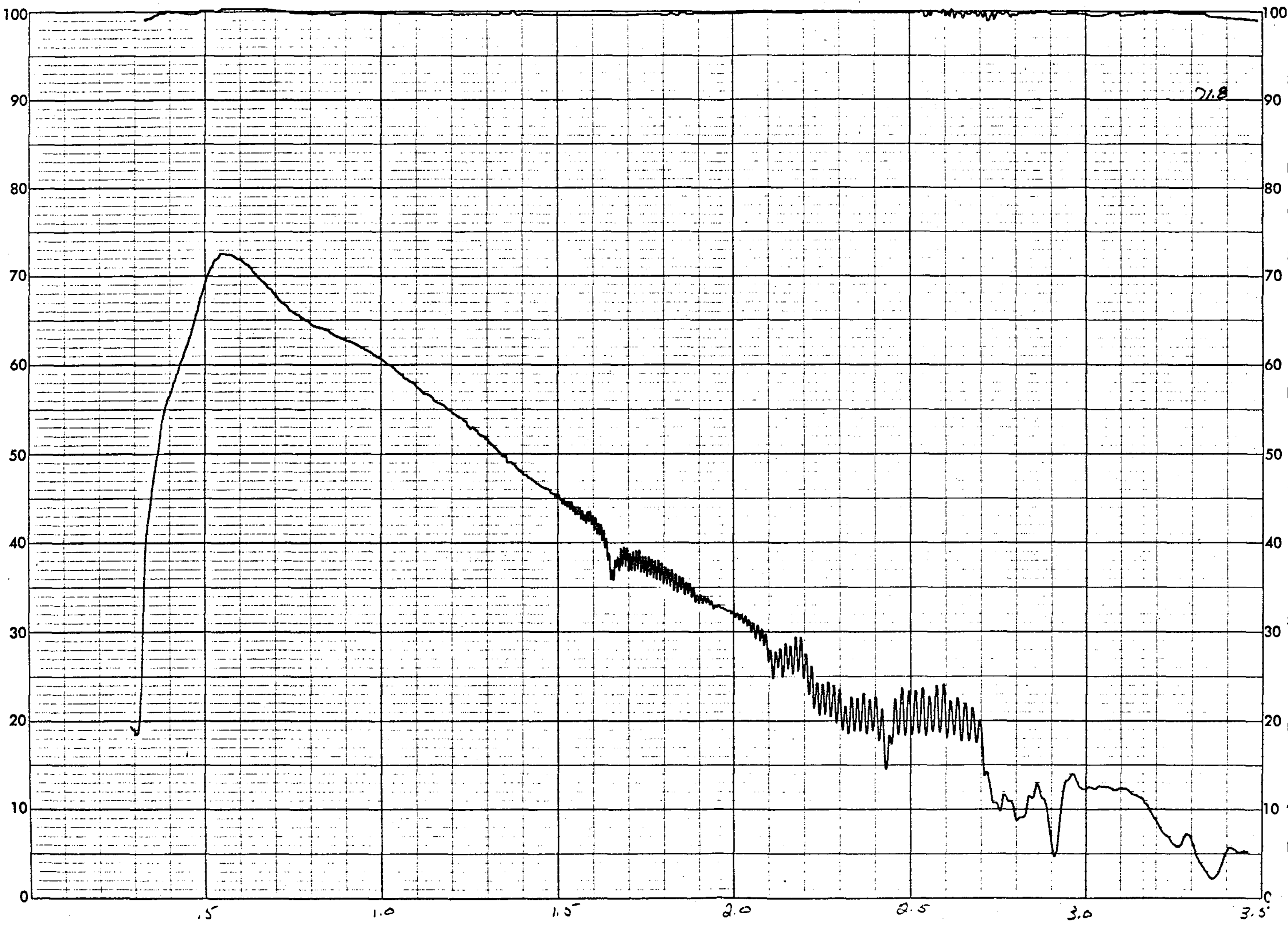
Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.

T
9



SAMPLE Type 42
W/O Fx
4 Mil

PATH ______ cm

ORIGIN ______

SOLVENT ______

REF Air

λ SPEED: ______ nm/min

SCALE 0-100

SENS 70

PERIOD ______

SOURCE: W x
H₂ ______
D₂ ______

DETECTOR: PM ______
PbS ______

ANALYST BRT

DATE 9-13-77

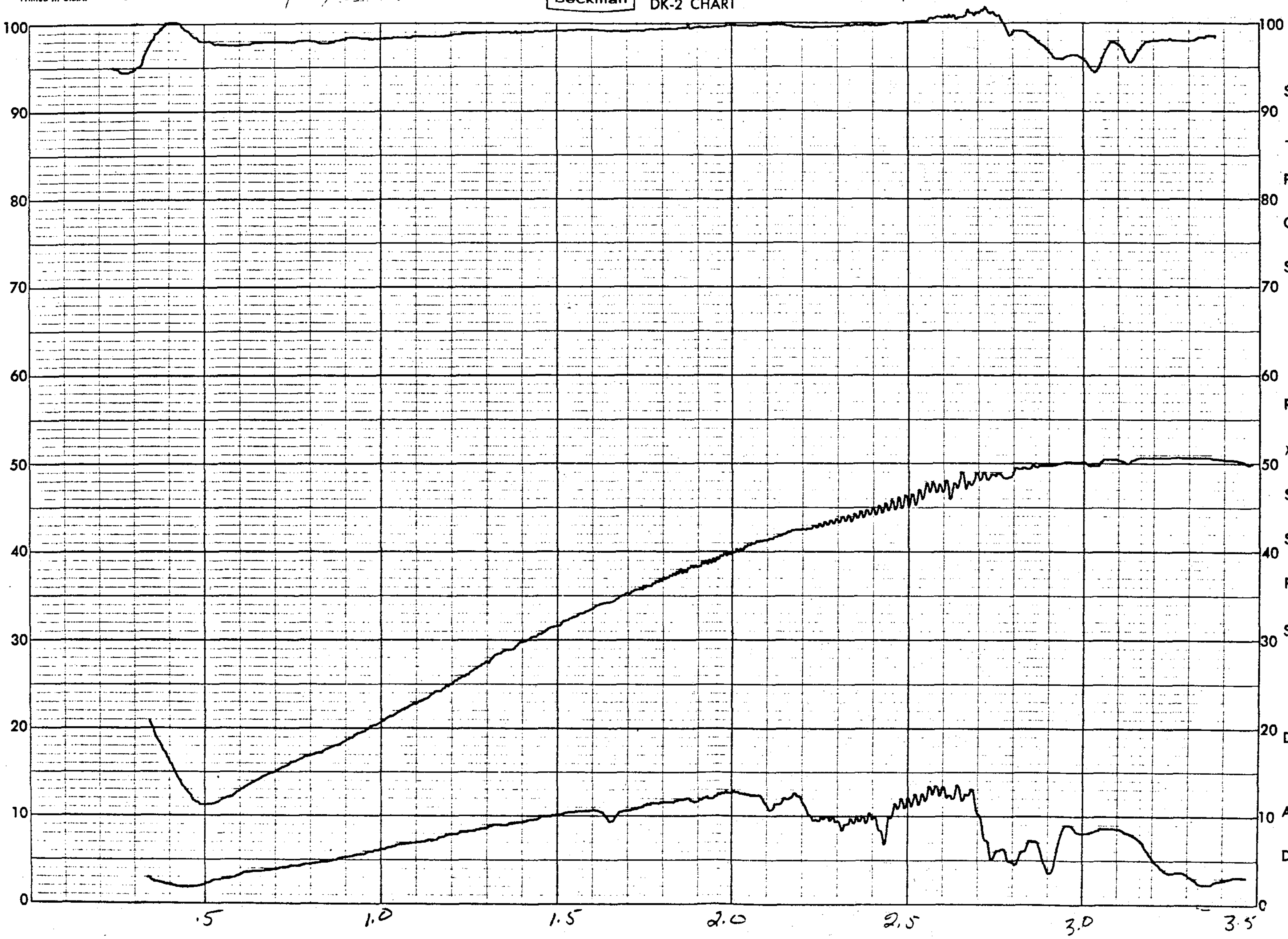
Fig. 9

Printed in U.S.A. 69TW740

Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.

R
10



SAMPLE T-42
W/O Fx

PATH ______ cm

ORIGIN ______

SOLVENT ______

REF Ag

λ SPEED: ______ nm/min

SCALE 0-100

SENS 70

PERIOD ______

SOURCE: W X

H₂ ______

D₂ ______

DETECTOR: PM ______

PbS ______

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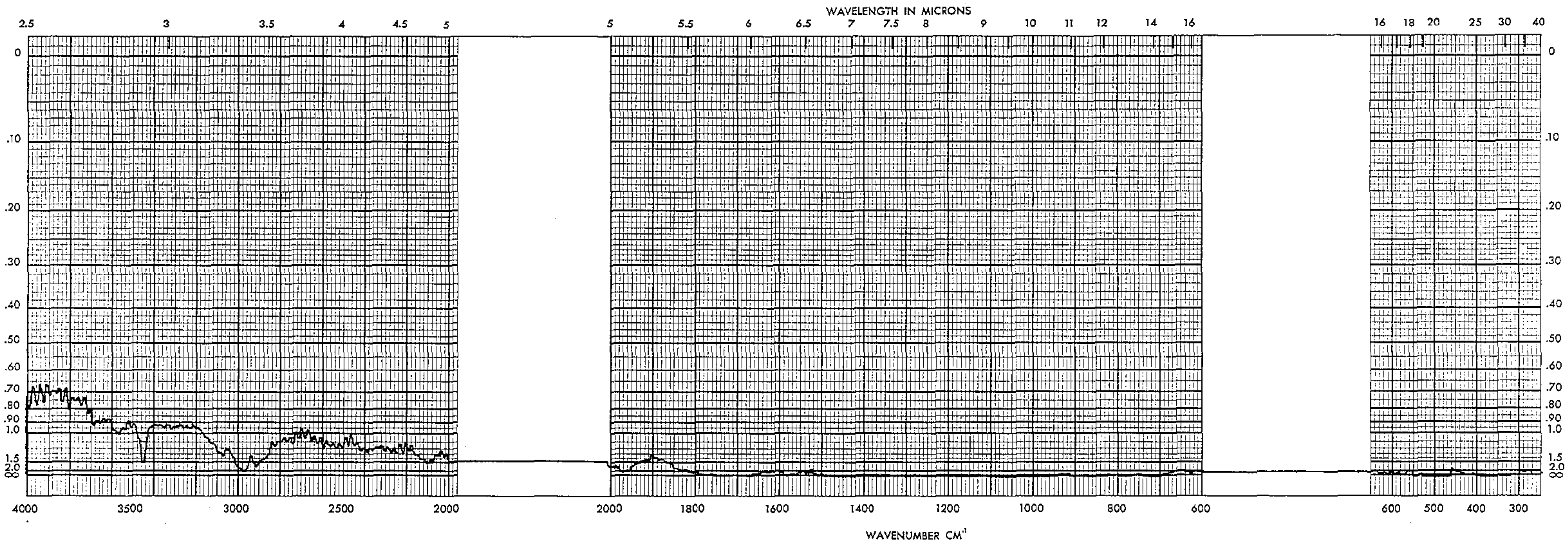
Fig. 10

T
II

PRINTED IN U.S.A. 43 WHEN REORDERING SPECIFY CHART NO. 101509 BECKMAN INSTRUMENTS, INC., FULLERTON, CALIFORNIA, U.S.A.



SPECTRUM NO.

DATE 9-13-77

SAMPLE T-42 W/O Fx

SOURCE
STRUCTURE

PATH mm

SOLVENT

CONCENTRATION

PHASE

COMMENTS

ANALYST

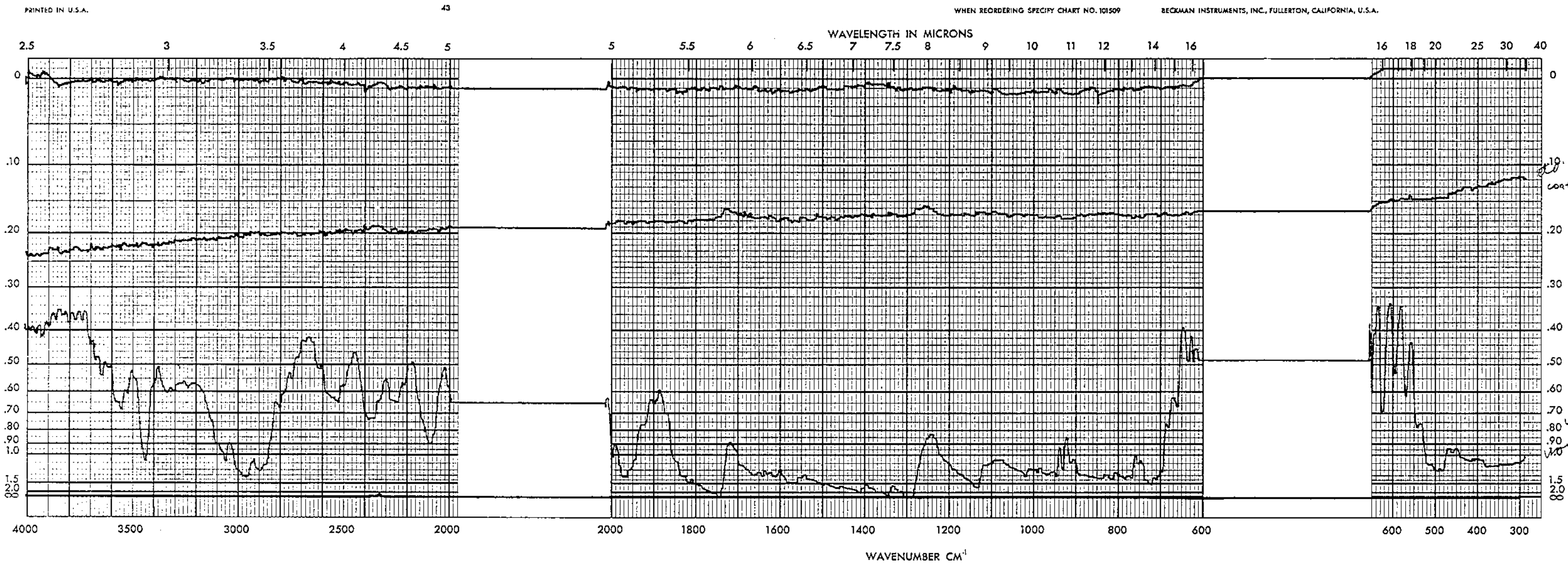
Beckman®

INFRARED
SPECTROPHOTOMETER

Fig. 11

R

12



SPECTRUM NO.

DATE

SAMPLE T-42

W/O Ex

SOURCE

STRUCTURE

PATH mm

SOLVENT

CONCENTRATION

PHASE

COMMENTS

ANALYST

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INFRARED

SPECTROPHOTOMETER

Fig. 12

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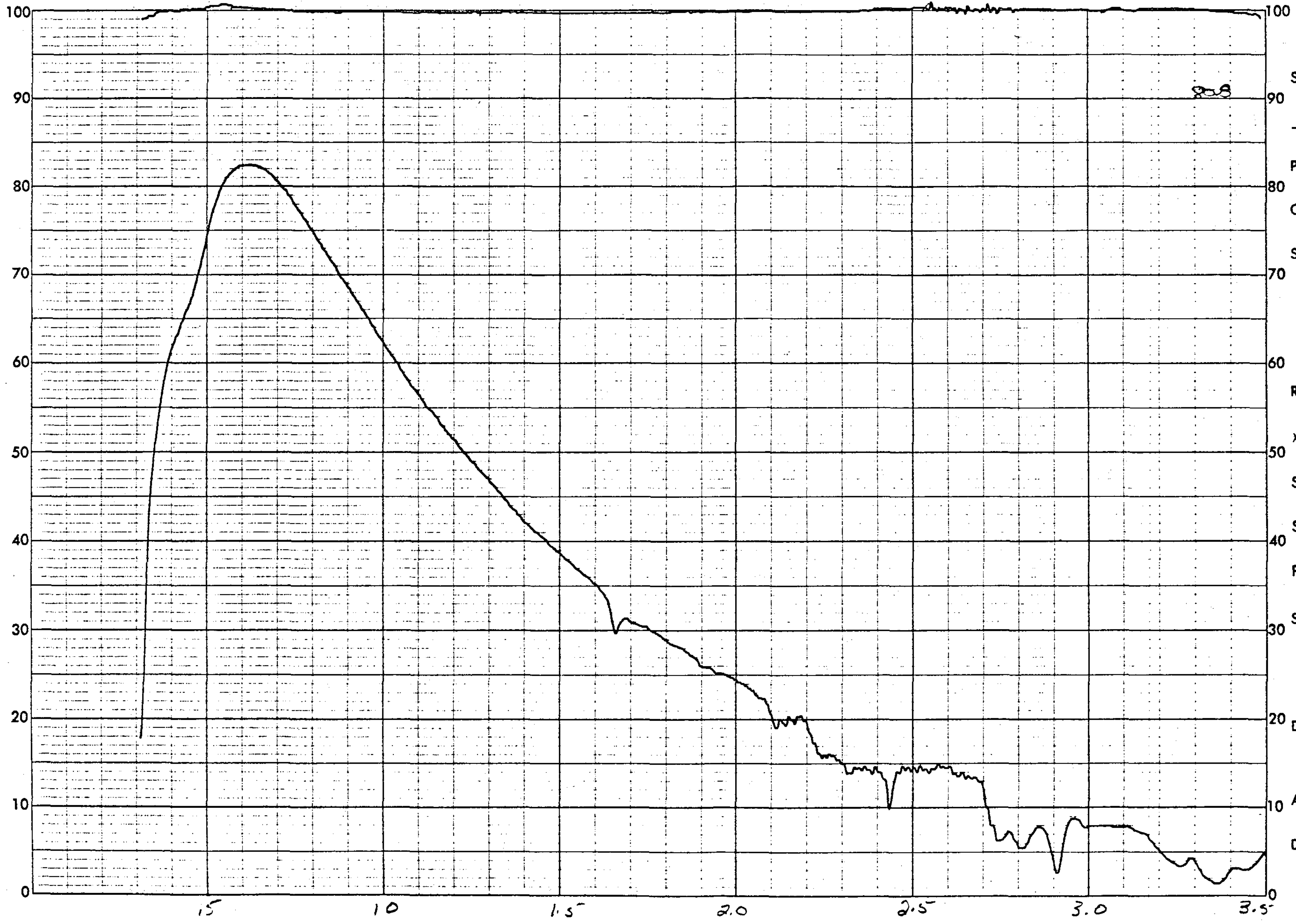
Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.

T
13



SAMPLE Type 28

W/Fx

PATH ____ cm

ORIGIN ____

SOLVENT ____

REF Air

λ SPEED: ____ nm/min

SCALE 0-100

SENS 70

PERIOD ____

SOURCE: W X

H_2 ____

D_2 ____

DETECTOR: PM ____

PbS ____

ANALYST BRT

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Fig. 13

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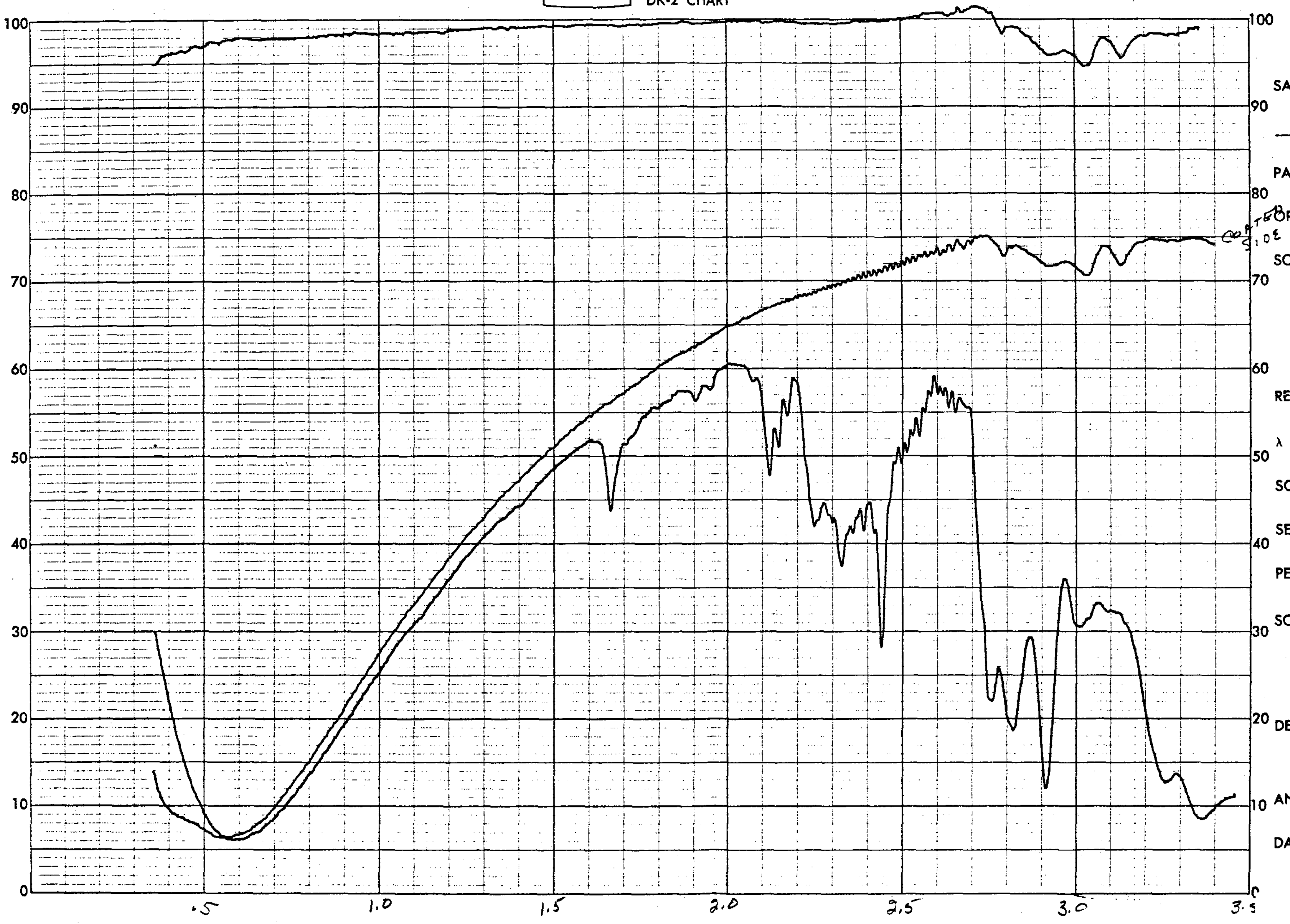
Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.

R

14



SAMPLE T-28

W/Fx

PATH ______ cm

ORIGIN ______

SOLVENT ______

REF Ag

λ SPEED: ______ nm/min

SCALE 0-100

SENS 70

PERIOD ______

SOURCE: W x

H₂ ______

D₂ ______

DETECTOR: PM ______

PbS ______

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Fig. 14

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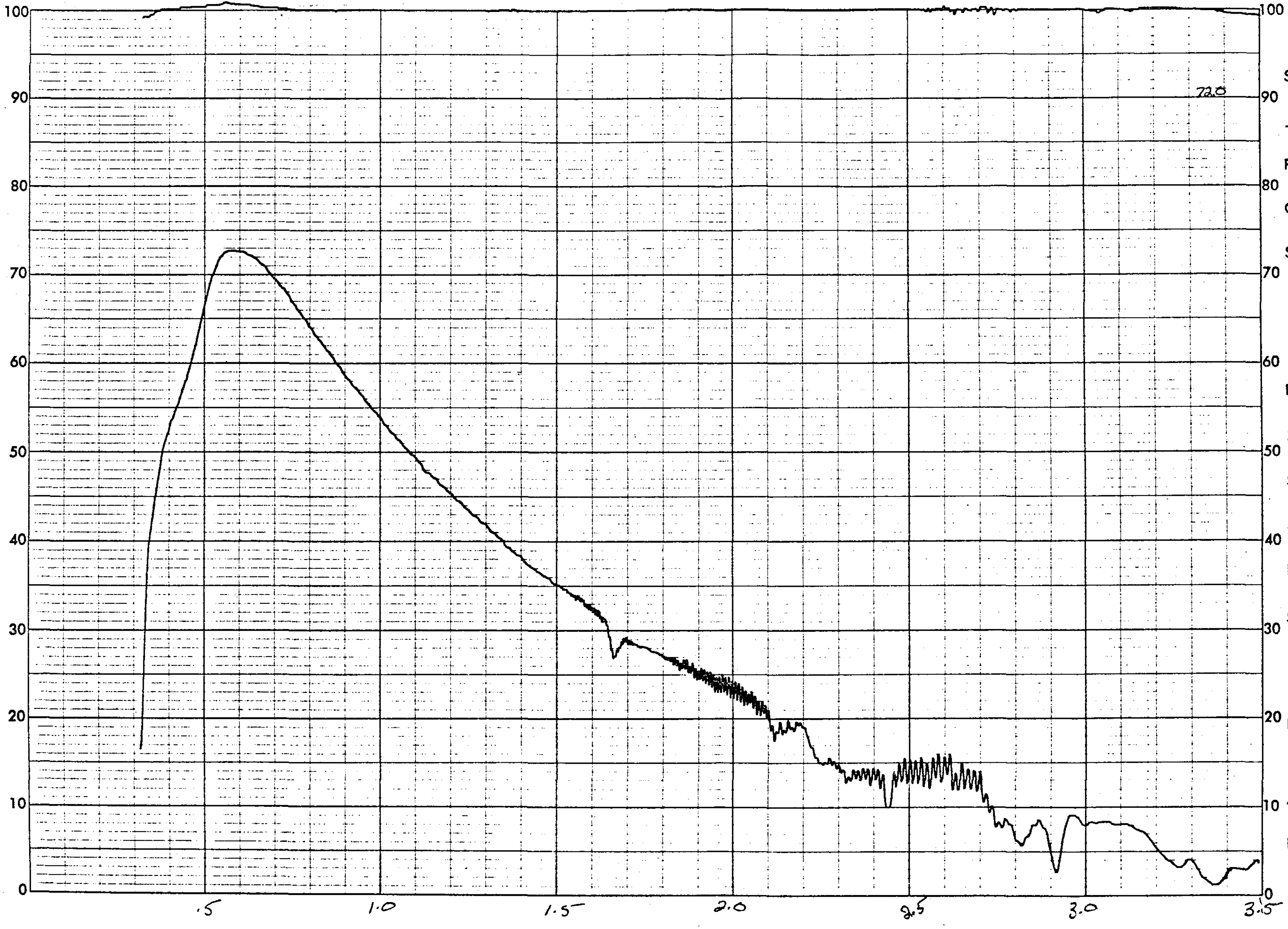
Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.



T

15

SAMPLE Type 28
W/O Fx

PATH ____ cm

ORIGIN

SOLVENT

REF Air

λ SPEED: ____ nm/min

SCALE 0-100

SENS 70

PERIOD

SOURCE: W X
H_2
D_2

DETECTOR: PM
PbS

ANALYST BRT

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Fig. 15

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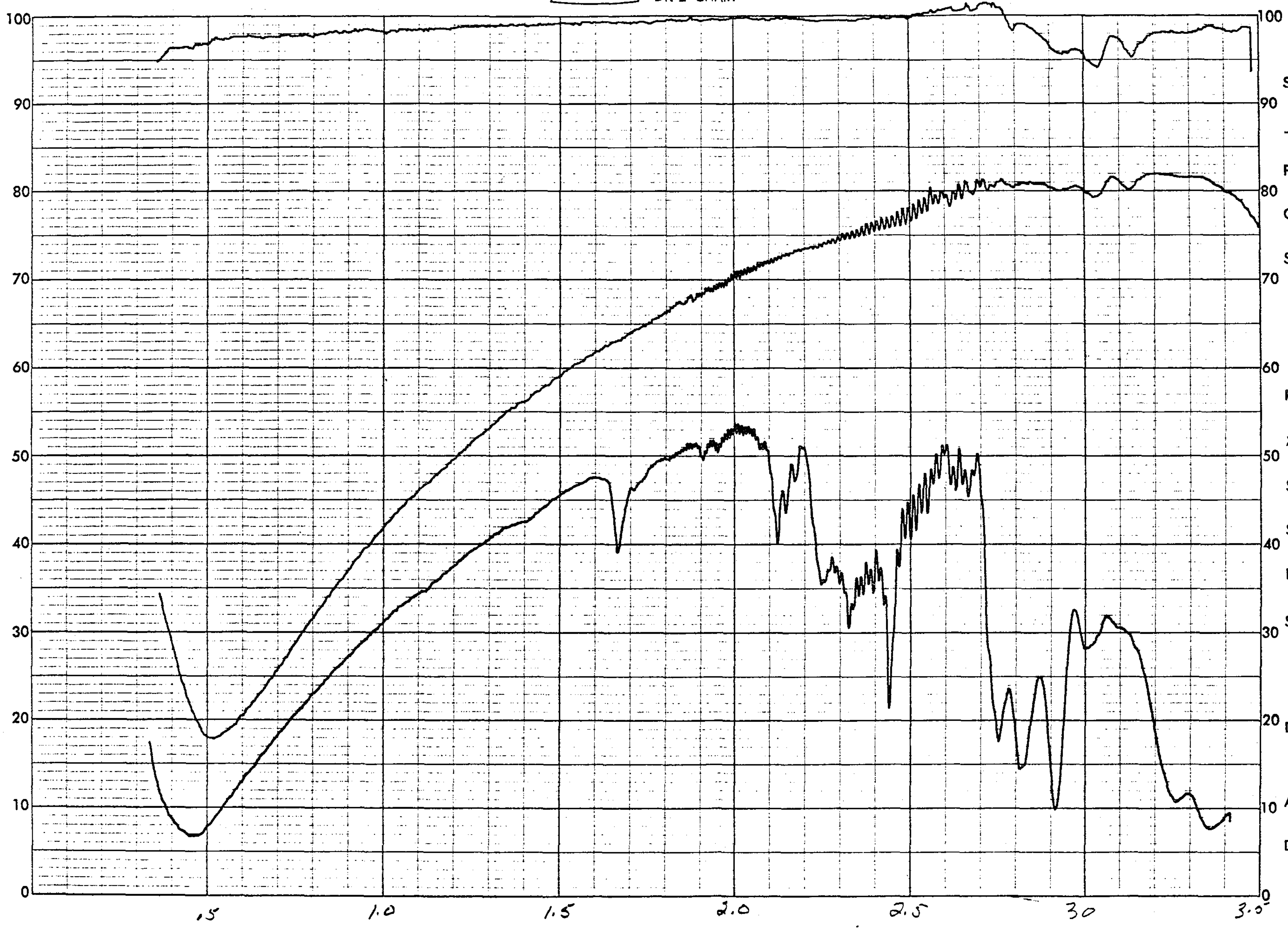
Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.

R

16



SAMPLE T-28
W/O Fx

PATH ______ cm

ORIGIN ______

SOLVENT ______

REF Ag

λ SPEED: ______ nm/min

SCALE 0-100

SENS 70

PERIOD ______

SOURCE: W x
H₂ ______
D₂ ______

DETECTOR: PM ______
PbS ______

ANALYST BRT

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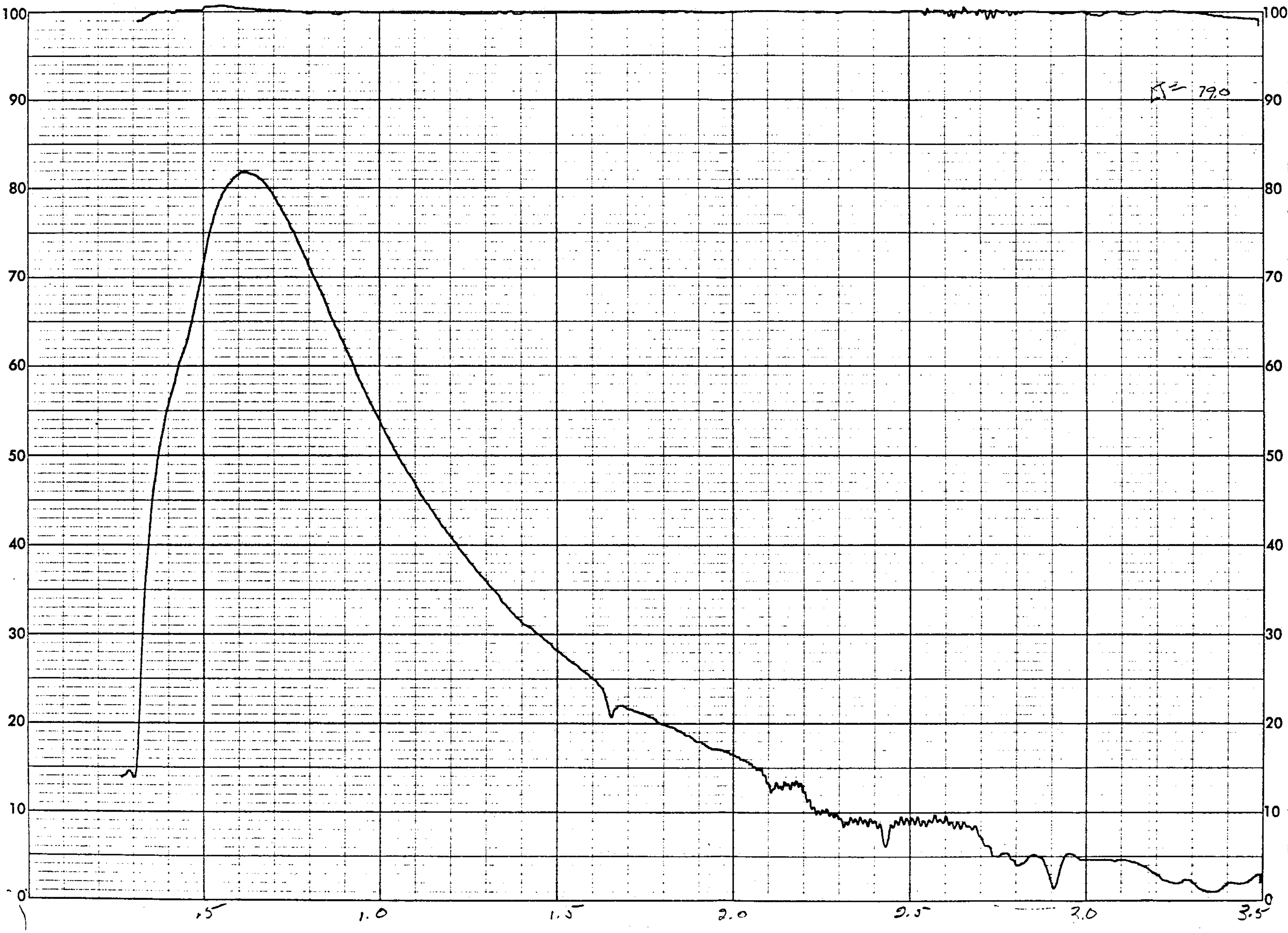
Fig. 16

Printed in U.S.A. 69TW740 **Beckman** DK-2 CHART WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.

T
17



SAMPLE Type 18
W/Fx

PATH ____ cm

ORIGIN ____

SOLVENT ____

REF Air

λ SPEED: ____ nm/min

SCALE 0-100

SENS 70

PERIOD ____

SOURCE: W X
H₂ ____
D₂ ____

DETECTOR: PM ____
PbS ____

ANALYST BET

DATE 9-13-77

Fig. 17

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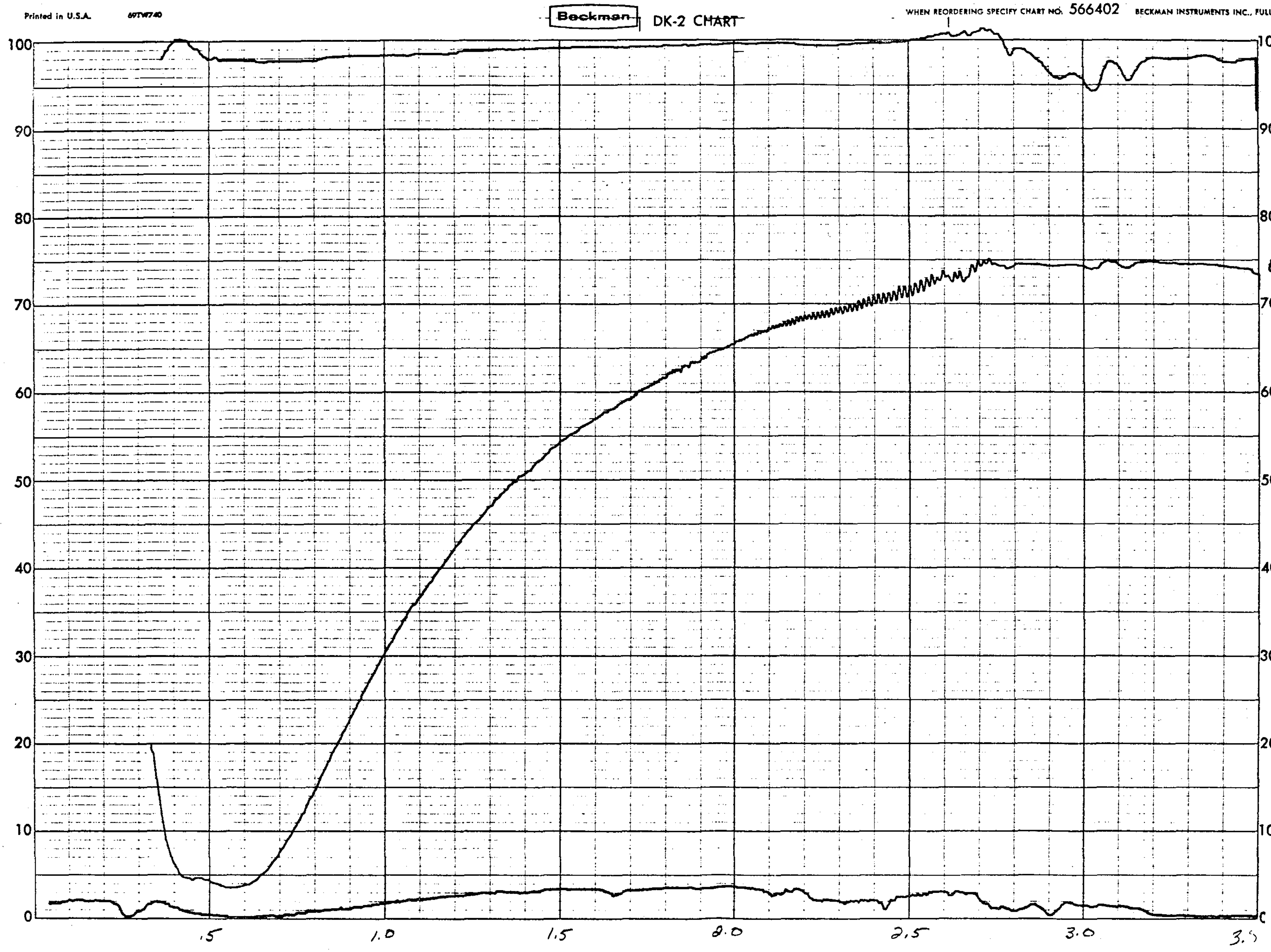
Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.



R
18

SAMPLE T-18
W/Fx

PATH ______ cm

ORIGIN Side
COATED

SOLVENT ______

Refl.

REF Ag

λ SPEED: ______ nm/min

SCALE 0-100

SENS 70

PERIOD ______

SOURCE: W X
H₂ ______
D₂ ______

DETECTOR: PM ______
PbS X

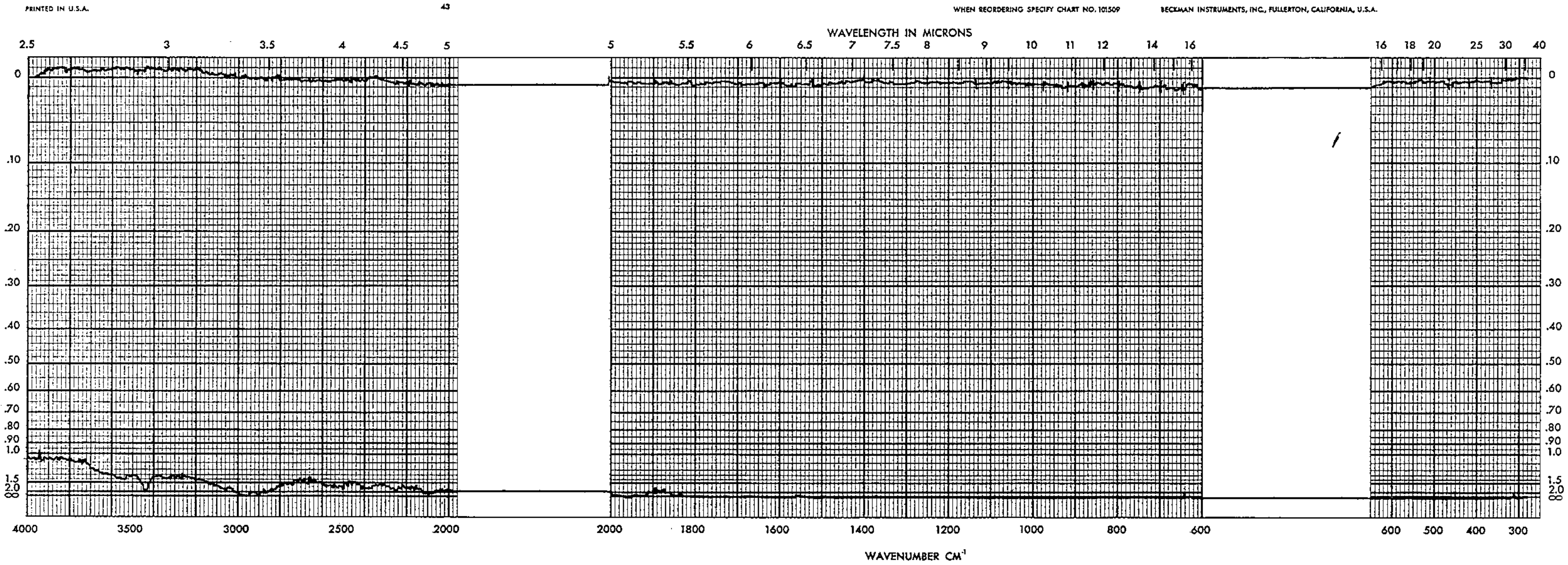
ANALYST BRT

DATE 9-13-77

Fig. 18

T

19



SPECTRUM NO.

DATE 9-13-77

SAMPLE T-18 W/Fx

Trans

SOURCE

STRUCTURE

PATH mm

SOLVENT

CONCENTRATION

PHASE

COMMENTS

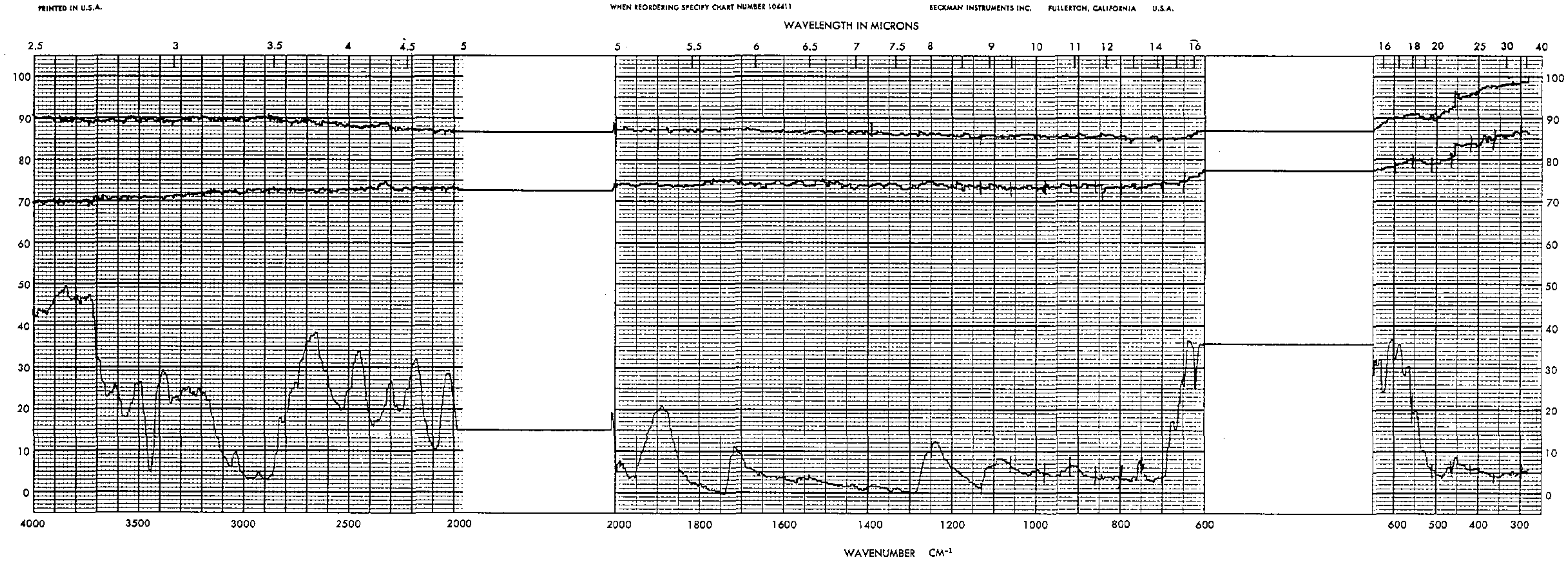
ANALYST

Beckman®

INFRARED

SPECTROPHOTOMETER

Fig. 19



SPECTRUM NO. ______
DATE 9-13-77
SAMPLE T-18 W/Fx

SOURCE ______
STRUCTURE

PATH ______ mm ______
SOLVENT ______
CONCENTRATION ______
PHASE ______
COMMENTS ______

ANALYST ______

BECKMAN®

INFRARED
SPECTROPHOTOMETER

Fig. 20

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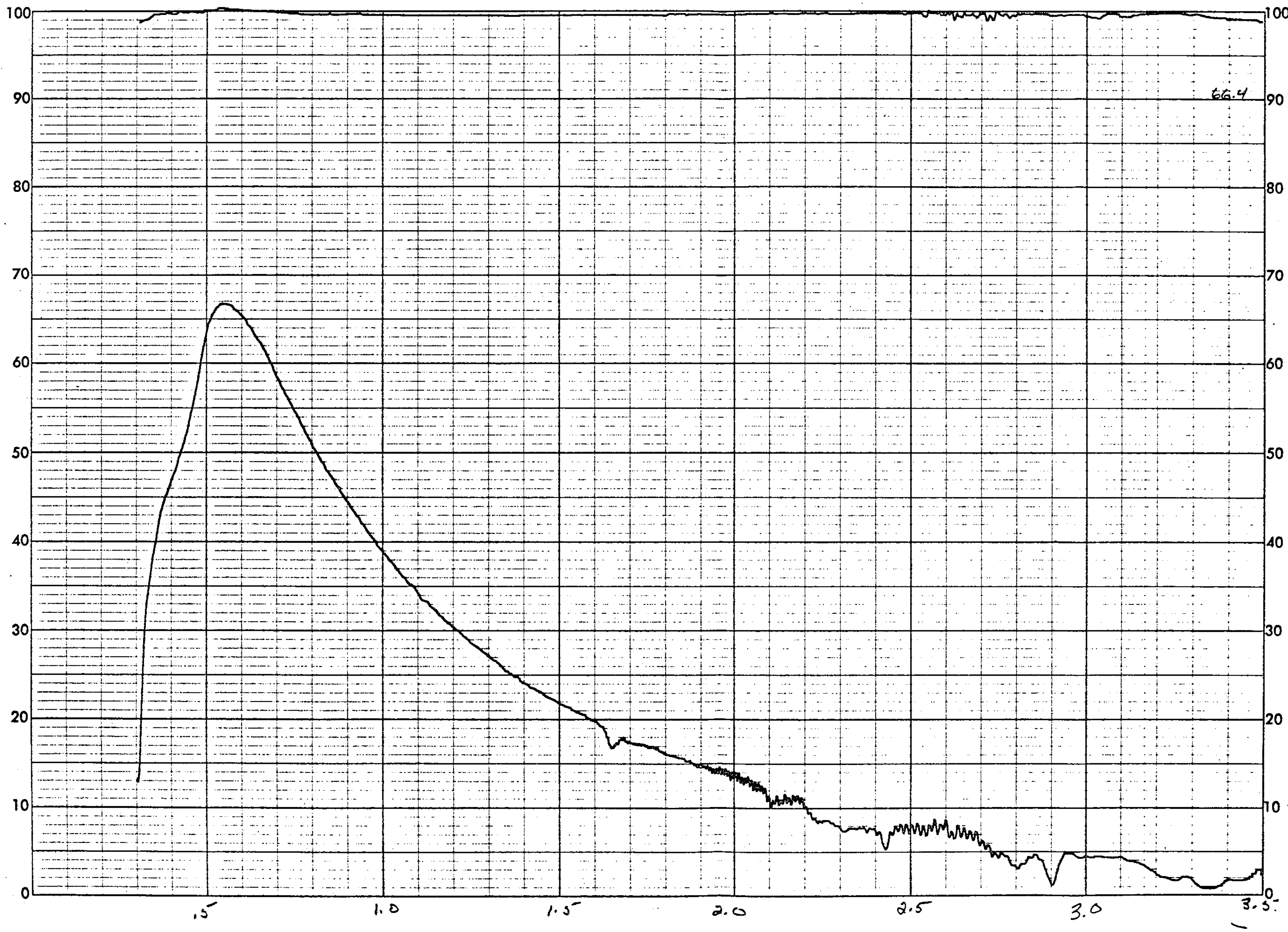
Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.

T
21



SAMPLE Type 18
W/O Fx

PATH ______ cm

ORIGIN ______

SOLVENT ______

REF Air

λ SPEED: ______ nm/min

SCALE 0-100

SENS 70

PERIOD ______

SOURCE: W X

H₂ ______

D₂ ______

DETECTOR: PM ______

PbS X

ANALYST BRT

DATE 9-13-77

Fig. 21

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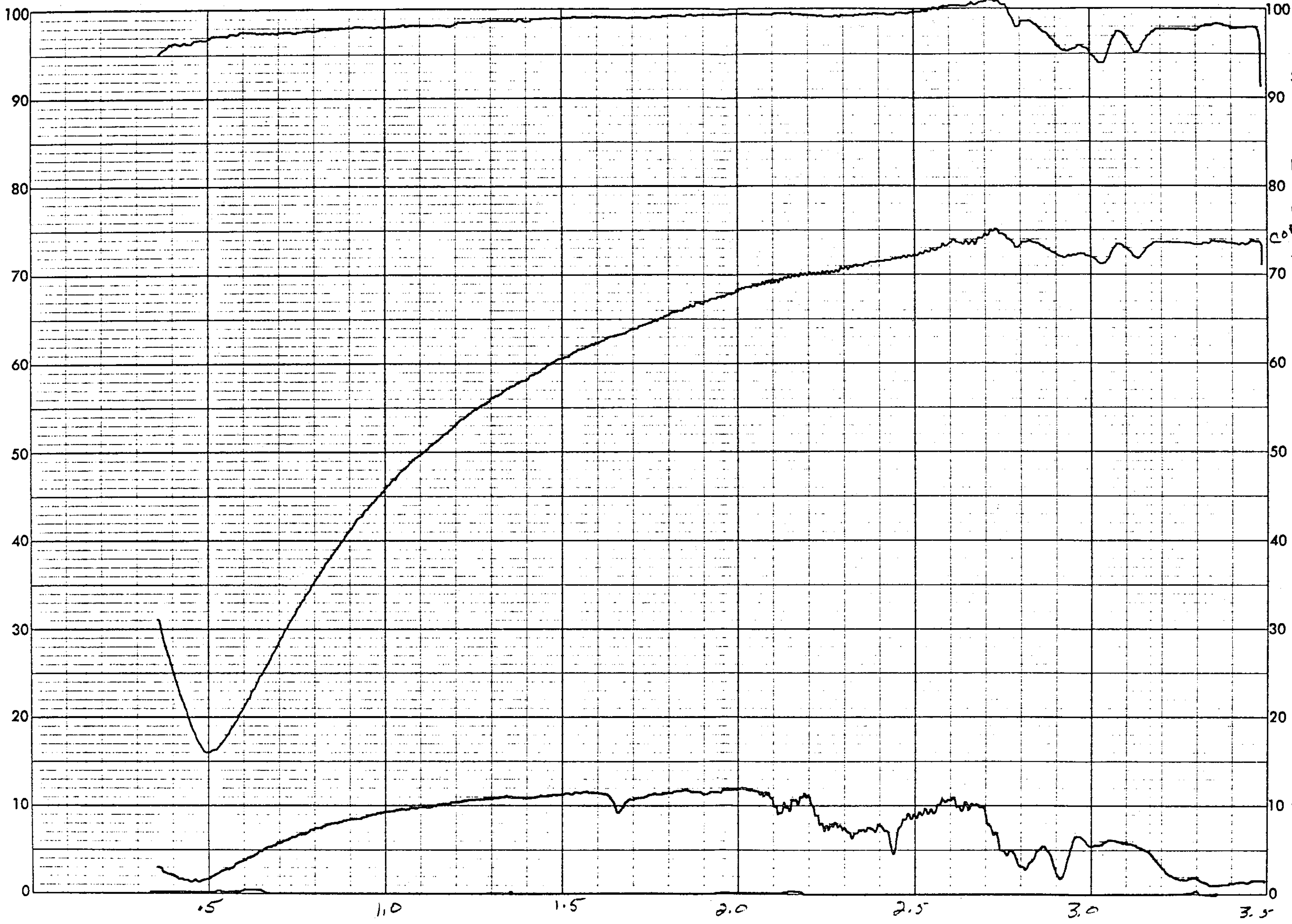
Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.

R

22



SAMPLE T-18

W/O Fx

PATH ______ cm

ORIGIN ______

COATED SIDE

SOLVENT ______

REF Ag

λ SPEED: ______ nm/min

SCALE 0-100

SENS 70

PERIOD ______

SOURCE: W X

H₂ ______

D₂ ______

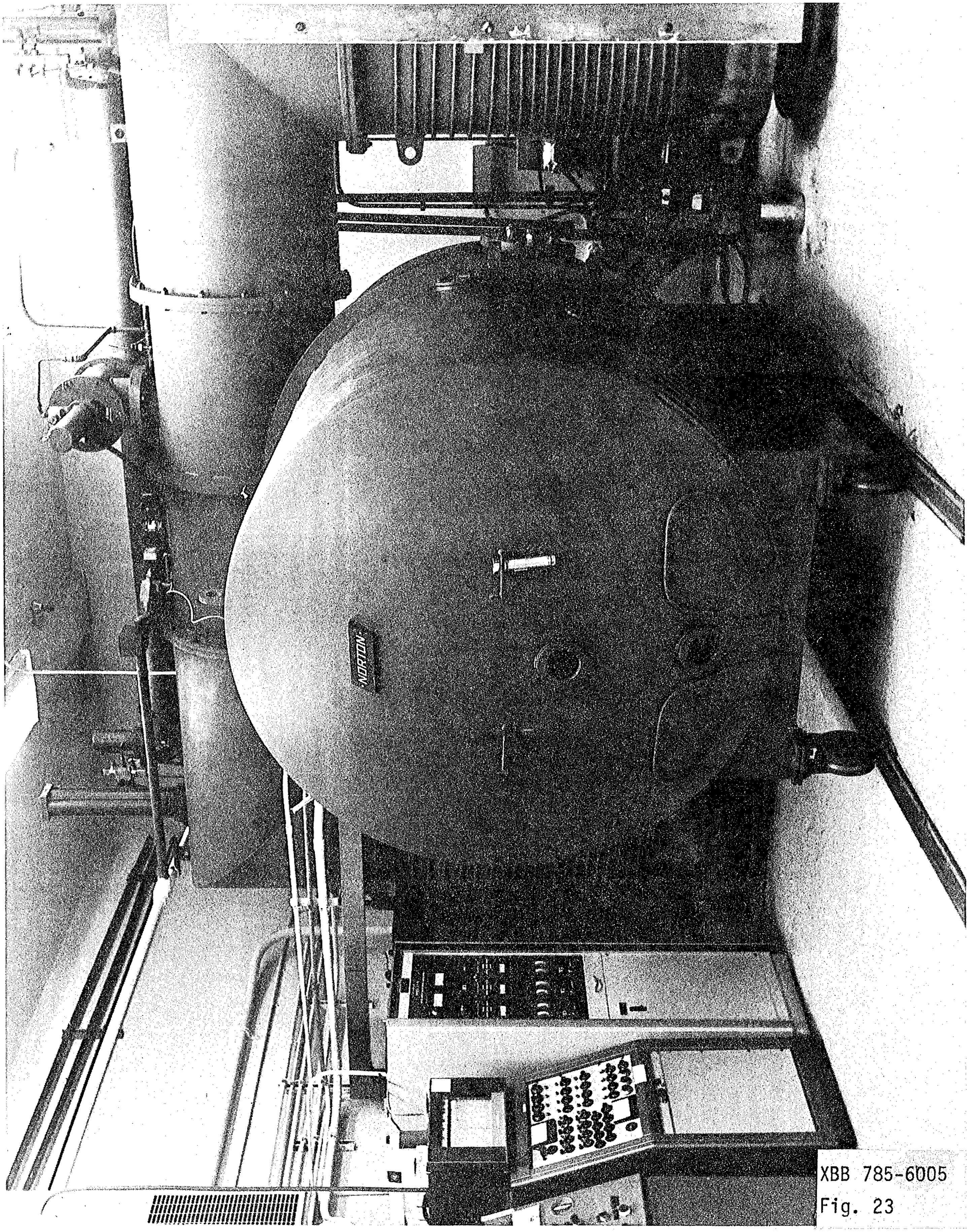
DETECTOR: PM ______

PbS ______

ANALYST BRT

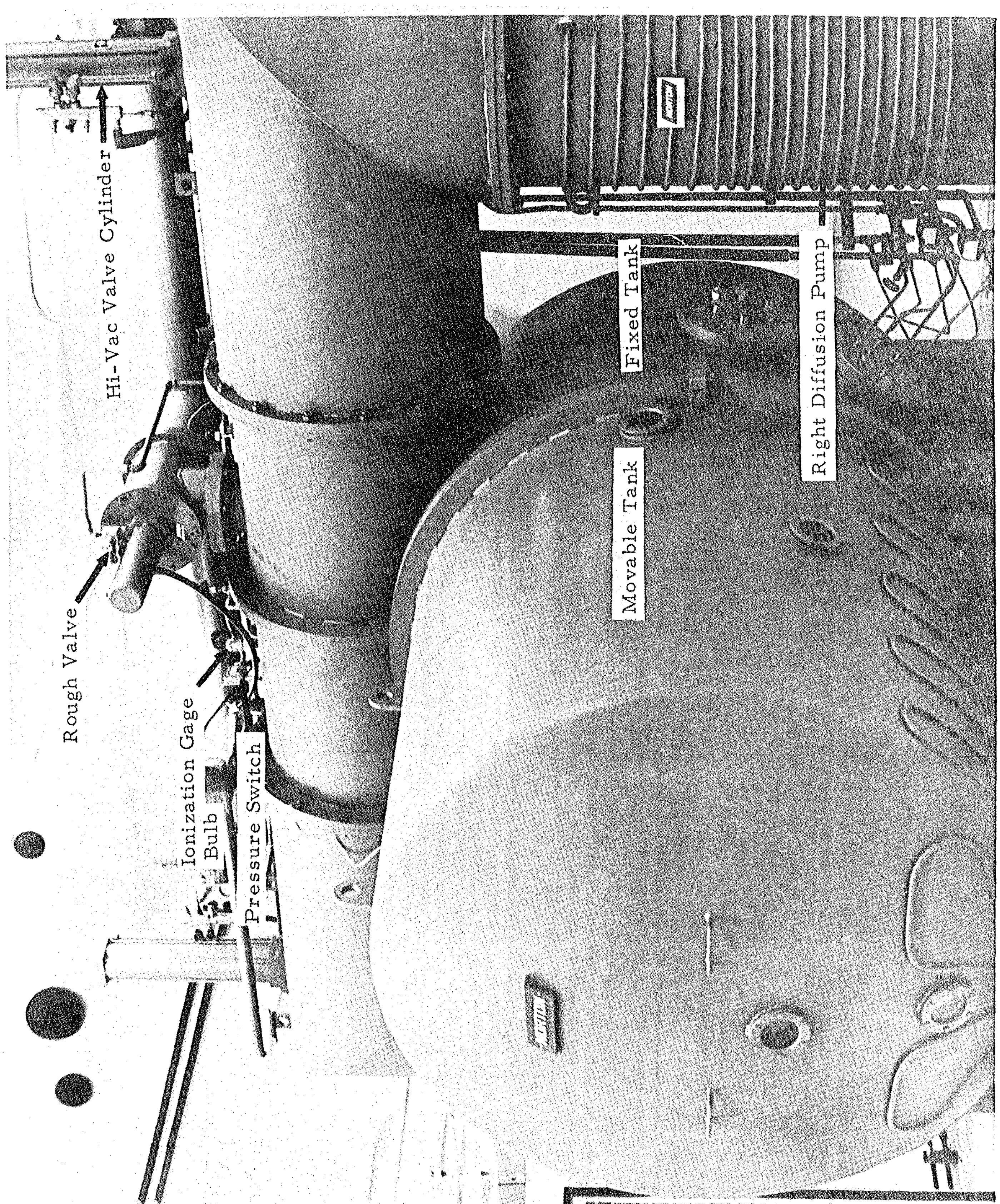
DATE 9-13-77

Fig. 22



XBB 785-6005

Fig. 23



NORTON VACUUM SYSTEM

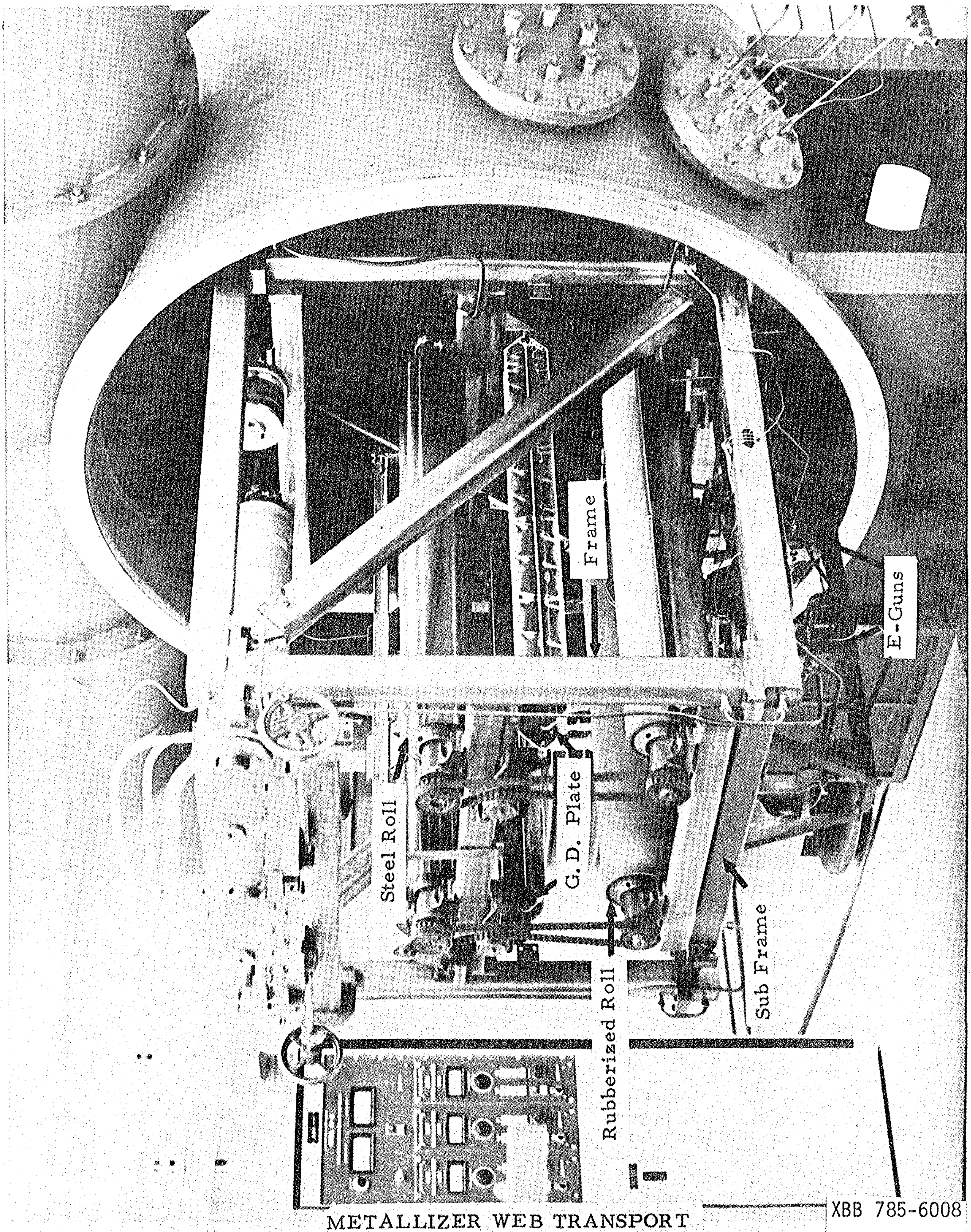
XBB 785- 6006

Fig. 24

METALLIZER CONTROL CONSOLES

Fig. 25

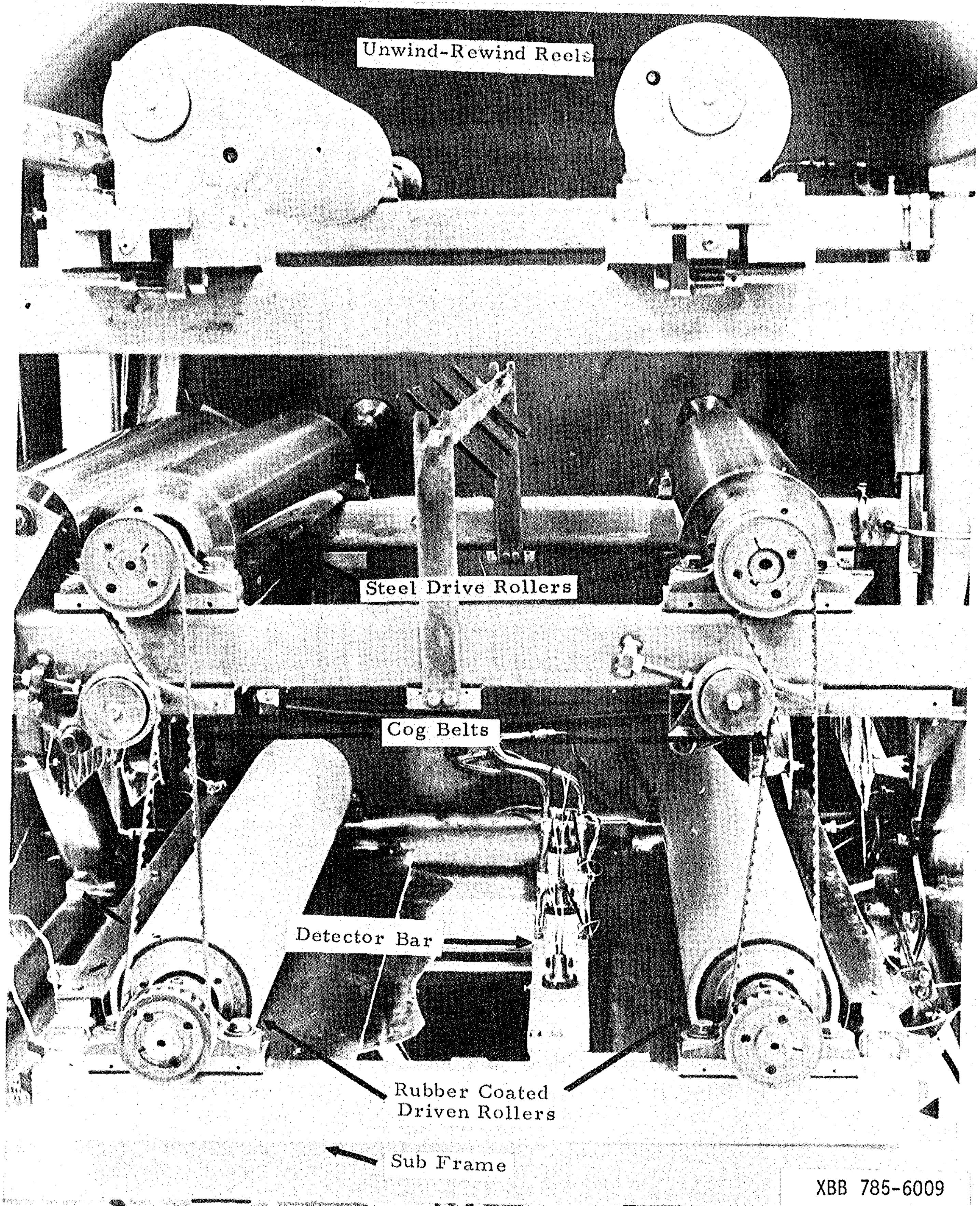
XBB 785-6007



METALLIZER WEB TRANSPORT APPARATUS

XBB 785-6008

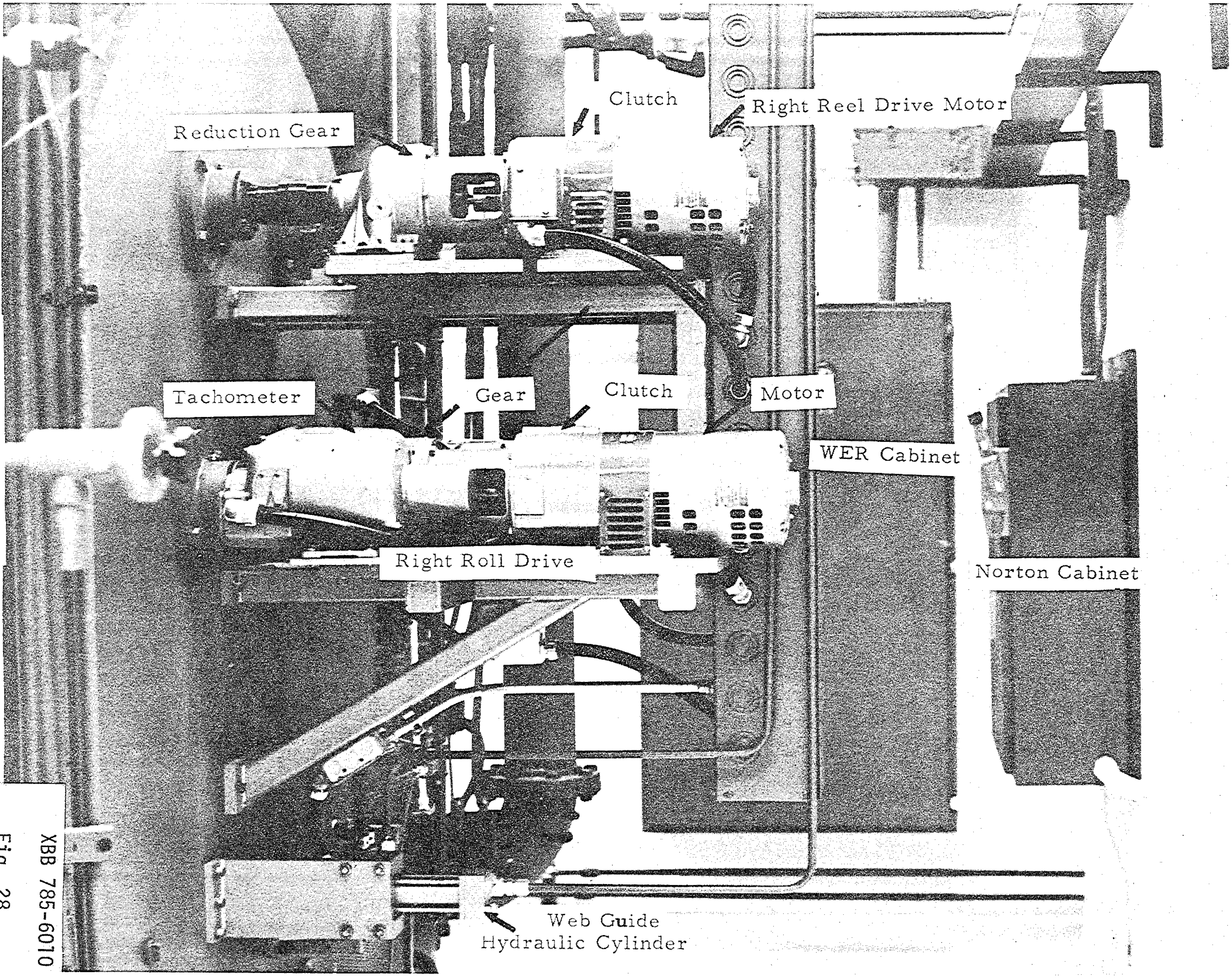
Fig. 26



METALLIZER WEB TRANSPORT

XBB 785-6009

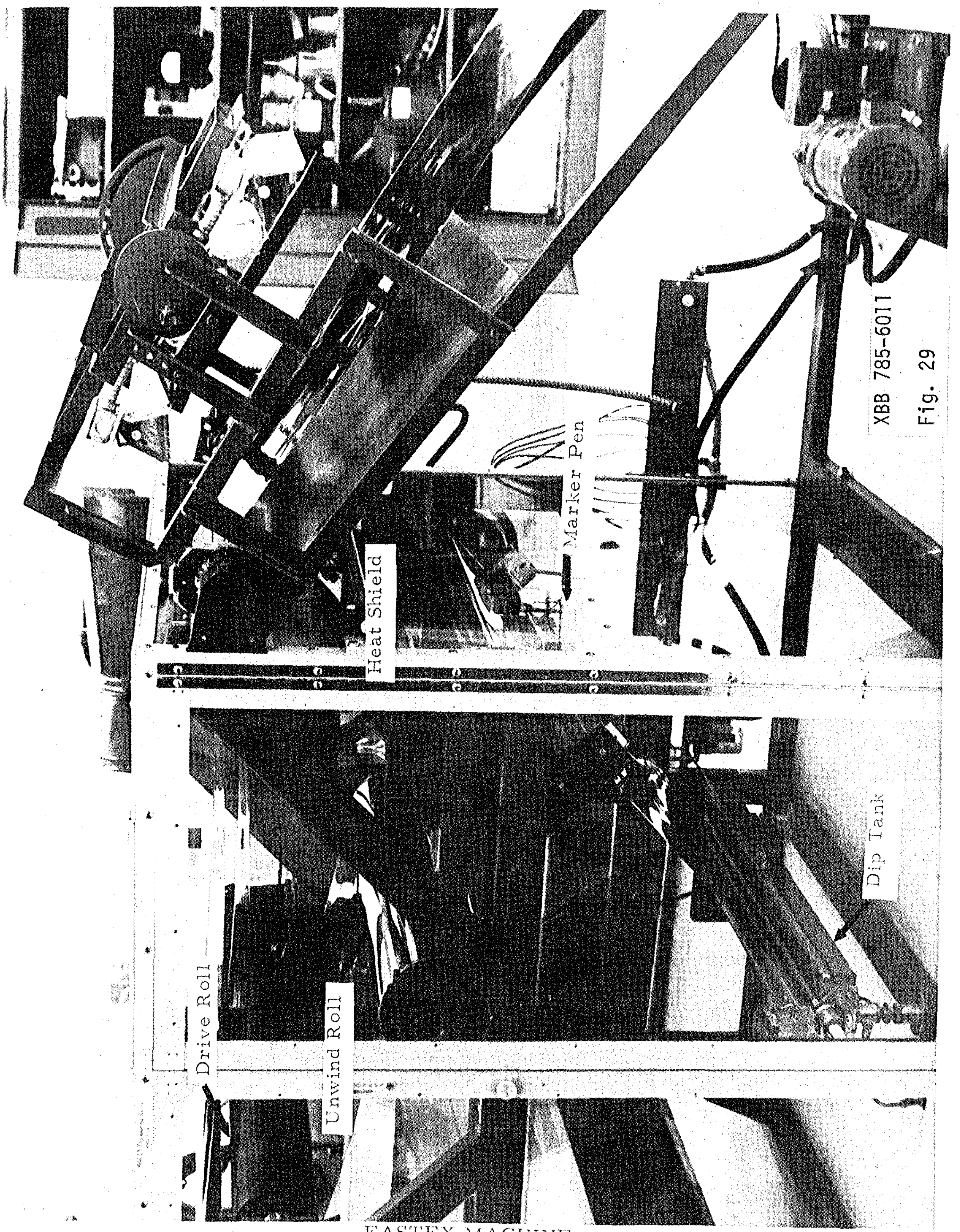
Fig. 27



WER DRIVE SYSTEM

XBB 785-6010

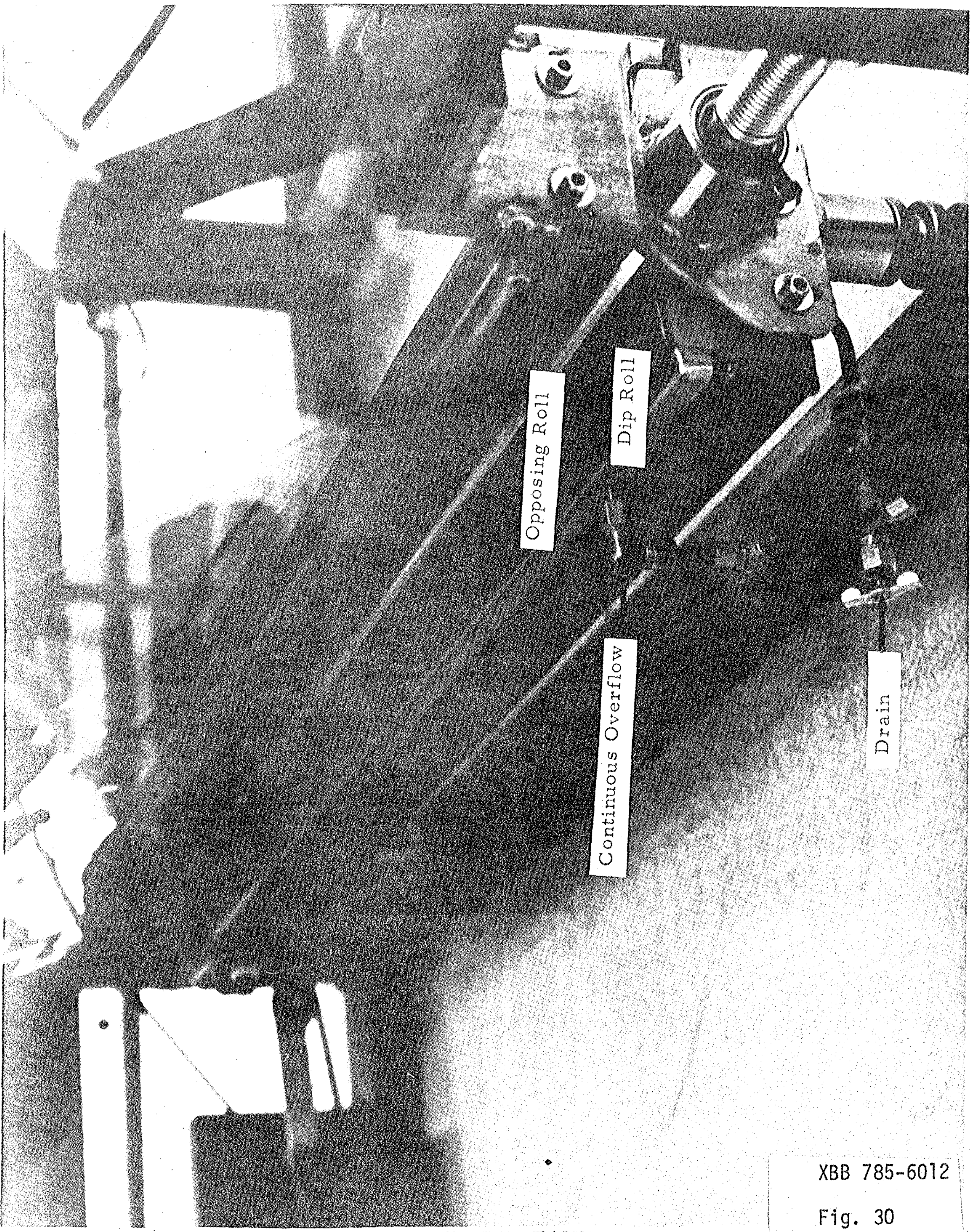
Fig. 28



XBB 785-6011

Fig. 29

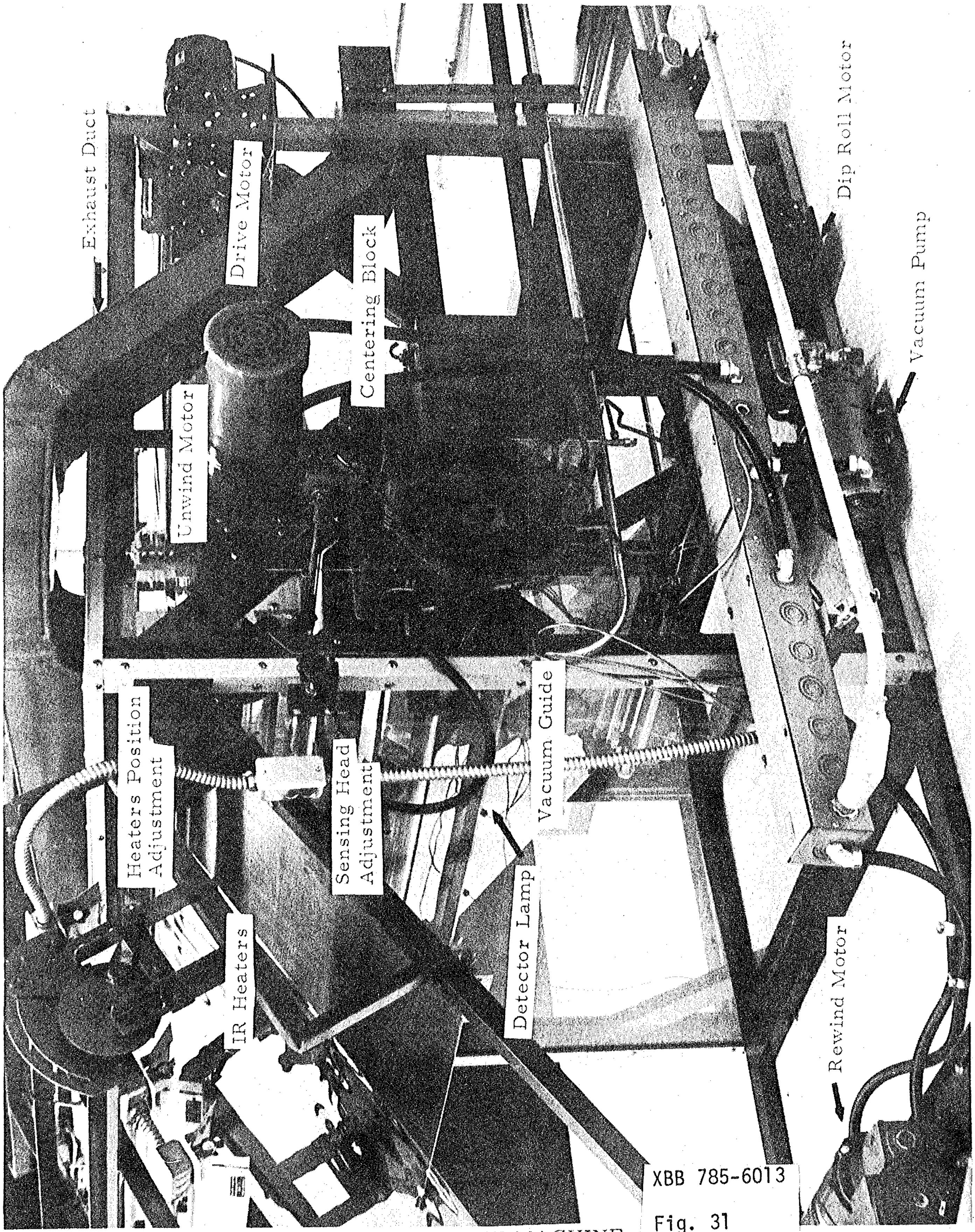
FASTEX MACHINE



XBB 785-6012

Fig. 30

FASTEX DIP TANK



XBB 785-6013

Fig. 31

FASTEX MACHINE

REPRODUCTION SYSTEMS **U.S. PRICES/ EFFECTIVE MAY 2, 1977**

DU PONT
MYLAR®
POLYESTER FILM

ROLLS OF "MYLAR"

"MYLAR" polyester film is an exceptionally strong, durable, transparent film with an unusual balance of properties that suits it to many industrial uses. It has high tensile, tear and impact strength, is inert to water, is moisture-vapor resistant and is unaffected by and does not transmit oils, greases and volatile aromatics. It retains these outstanding properties, remaining flexible and tough from — 80°F. to over 300°F.

			PRICES	YIELD AND COST INFORMATION				
TYPE	GAUGE	NOMINAL THICKNESS IN MILS	ROLL PRICES (Per Pound) Widths 6" and Over (1)	APPROX. FEET per Standard Length Roll 3" I.D. — 9½" O.D. 6" I.D. — 11" O.D.	APPROXIMATE YIELD (Per Pound)		APPROXIMATE PRICE PER	
					Sq. In.	Sq. Ft.	1000 Sq. In.	Sq. Ft.
S	25	0.25	$3.70	20,000	83,000	576	$ .0446	$.0064
	48	0.48	2.10	10,400	41,600	289	.0505	.0073
	75	0.75	2.10	6,650	26,700	185	.0787	.0114
	92	0.92	2.05	5,400	21,500	149	.0953	.0138
	142	1.42	2.05	3,500	14,000	97	.1464	.0211
	200	2.00	2.05	2,500	10,000	69	.2050	.0297
	1000	10.00	1.75	500	2,000	14	.8750	.1250
	1400	14.00	1.75	350	1,430	10	1.2238	.1750
D	300	3.00	1.95	1,700	6,700	47	.2910	.0415
	400	4.00	1.95	1,250	5,000	35	.3900	.0557
	500	5.00	1.95	1,000	4,000	28	.4875	.0696
	700	7.00	1.95	700	2,850	20	.6842	.0975
EB-11	48	0.48	3.40	10,400	41,600	289	.0817	.0118
	75	0.75	2.90	6,650	26,700	185	.1086	.0157
	92	0.92	2.60	5,400	21,500	149	.1209	.0174
	200	2.00	2.25	2,500	10,000	69	.2250	.0326
	300	3.00	2.25	1,700	6,700	47	.3358	.0479
	500	5.00	2.25	1,000	4,000	28	.5625	.0804
T	30	0.30	4.20	16,800	67,000	465	.0627	.0090
	48	0.48	2.80	10,450	41,800	290	.0670	.0097
	92	0.92	2.80	5,450	21,800	151	.1284	.0185
A	48	0.48	1.95	10,400	41,600	289	.0469	.0067
	75	0.75	1.95	6,650	26,700	185	.0730	.0105
	92	0.92	1.85	5,400	21,500	149	.0860	.0124
	142	1.42	1.85	3,500	14,000	97	.1321	.0191
	200	2.00	1.85	2,500	10,000	69	.1850	.0268
	300	3.00	1.80	1,700	6,700	47	.2687	.0383
	500	5.00	1.80	1,000	4,000	28	.4500	.0643
	750	7.50	1.60	650	2,650	18	.6038	.0889
	1000	10.00	1.60	500	2,000	14	.8000	.1143
	1400	14.00	1.60	350	1,430	10	1.1189	.1600

Standard Put-Ups:*

	Core inside diameter (I.D.)	Standard outside diameter (O.D.)
Standard Length	3"	9½"
	6"	11"
Double Length	3"	13"
	6"	14"

*Quotations on non-standard items furnished on request.
(1)For roll widths 1-1/2" to under 6" add $.10/lb. to above roll prices.

Fig. 32

ITEM	TYPICAL VENDOR	Sept./Nov. 1973 Quotes 1.	Material including Outside vendor labor. Updated Estimate 10% per year Compounded	New Requirements Due to 62" Web	Sierracin Labor Updated to 1977 including new requirements		Material Updated per New Requirements	Travel
					M.M.	Cost		
Web Transport Transport Mech.	Springborn Lab.	$ 51,700	$ 77,500	Lengthen Machine			$ 82,000	
Drive System	WER Corp.	24,638	37,000	More Power			37,000	
Vacuum System	Varian	113,185	170,000	Lengthen Tank			171,000	
Redesign Transport & Vac Tank, 2 months including design review	Springborn Lab. plus Sierracin liaison			New Drawings	1	3,700	10,000	2,000
E-Guns Power Supply Beam Sweep	Airco Temescal	6,800 15,900 6,600 } 29,300	44,000	Increase from 4 gun system to 5 gun system			55,000	
Engineering Assistance and East Coast liaison	Springborn Lab.	1,500	2,250	New Design Req. Renewed Sub. Cont. Liaison			5,000	2,000
Deposition System				Increase from 4 channels to 5 channels. Design complete but detector needs redesign. Rest needs update	3	11,100	28,000	
Controller	Sierracin	8,400 plus 6-8 MM						
Recorder	Texas Instruments	3,900	18,500 Material					
Edge Guides	Sierracin	Included	14,000 Labor					
Facilities & Related Installation Costs	Sierracin and Outside Contractors	1973 64,000 (Est.)	96,000				96,000	
Tech. Installation & Tests	Sierracin	4½ MM Labor	(16,600)		4½	16,600	500	
Contingencies		10,000	15,000					
TOTALS		Approximately $320,000	490,850		8½	31,400	484,500	4000

NEW TOTAL
$519,900

1. References: RD 73-616
Varian Quote 11/6/73

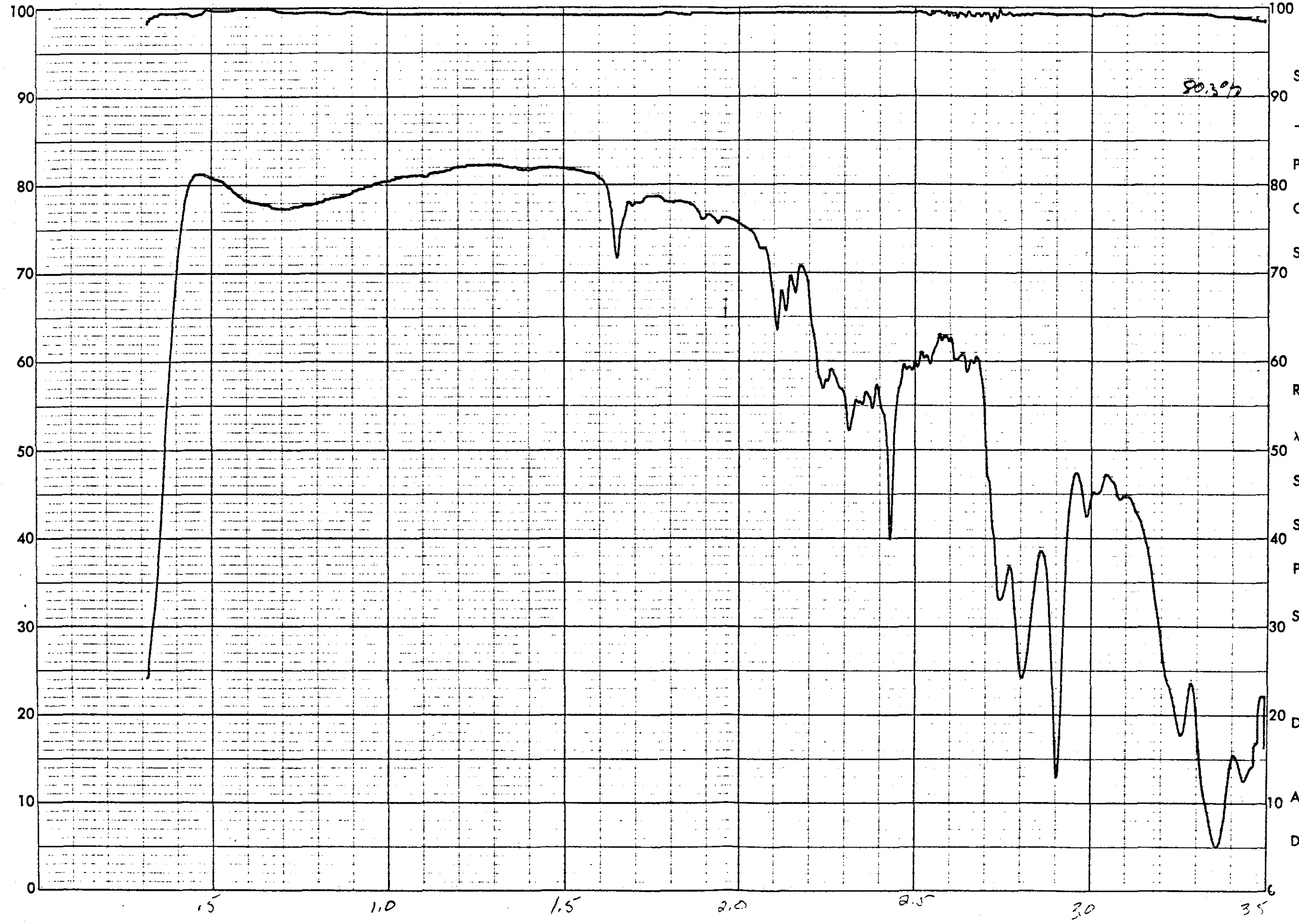
Fig. 33

Printed in U.S.A. 69TW740

Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.

T
23



SAMPLE ITO
71.6
VTA

PATH ____ cm

ORIGIN ____

SOLVENT ____

REF Air

λ SPEED: ____ nm/min

SCALE 0-100

SENS 70

PERIOD ____

SOURCE: W x

H₂ ____

D₂ ____

DETECTOR: PM ____

PbS x

ANALYST BRT

DATE 9-20-77

Fig. 34

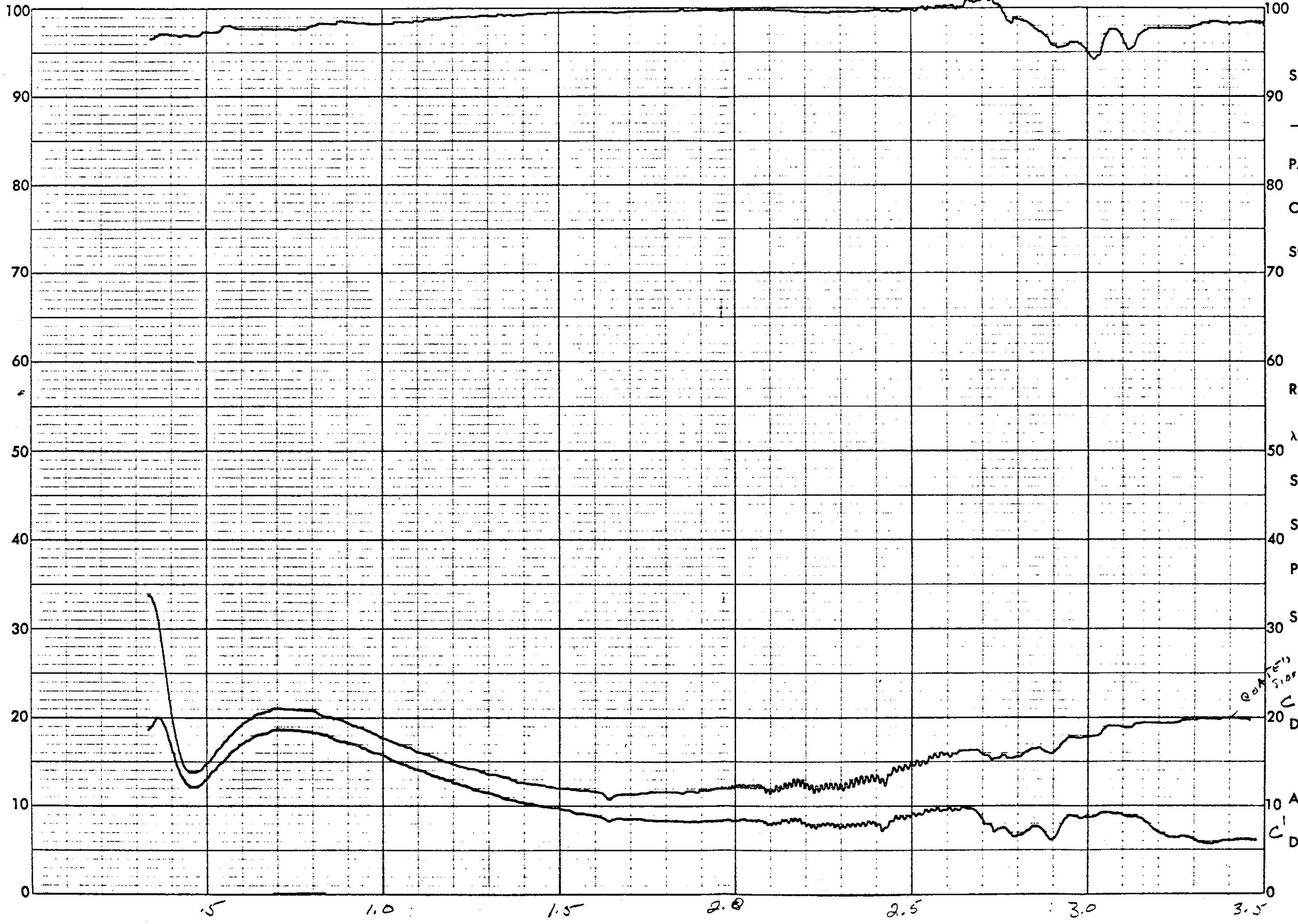
Printed in U.S.A. 69TW740

Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.

R

24



SAMPLE ITO

71.6

VTA

Refl

PATH ______ cm

ORIGIN ______

SOLVENT ______

REF Ag

λ SPEED: ______ nm/min

SCALE 0-100

SENS 70

PERIOD ______

SOURCE: W X

H₂ ______

D₂ ______

DETECTOR: PM ______

PbS ______

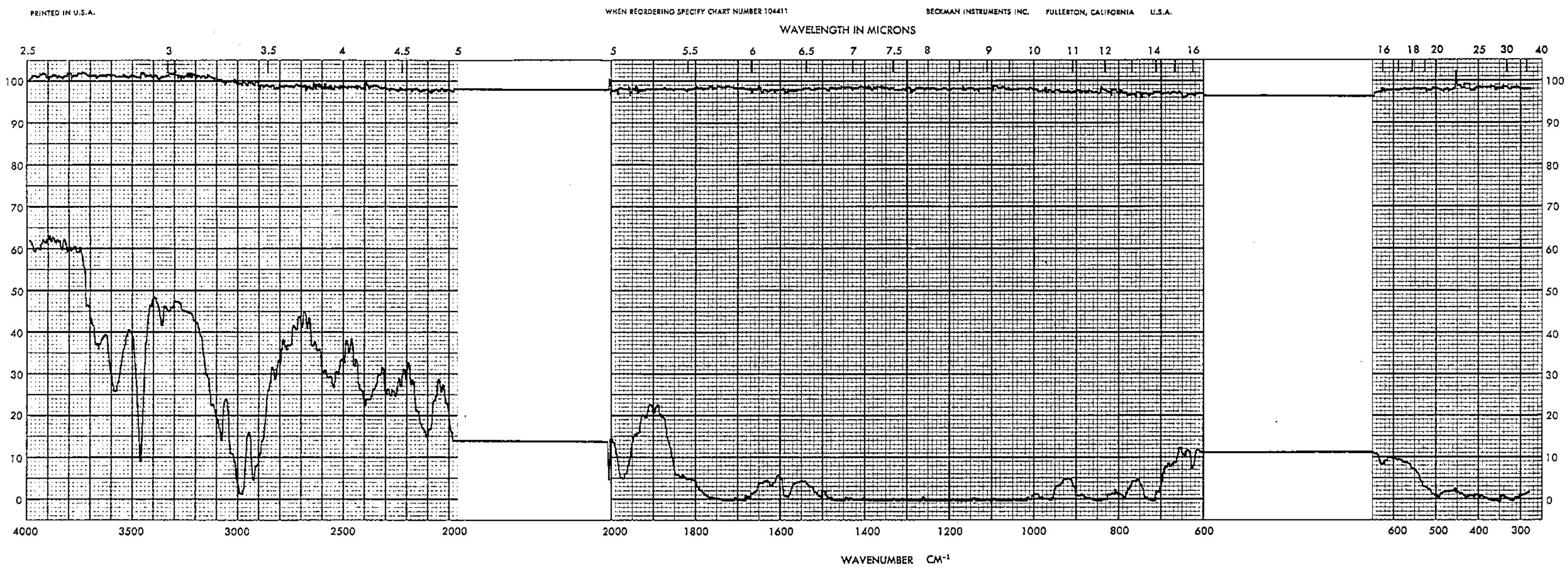
ANALYST BRT

DATE 9-21-77

Fig. 35

T

25



SPECTRUM NO.
DATE 9-20-77
SAMPLE ITO on PET
71.6 Ω/□
Transmission
SOURCE
STRUCTURE

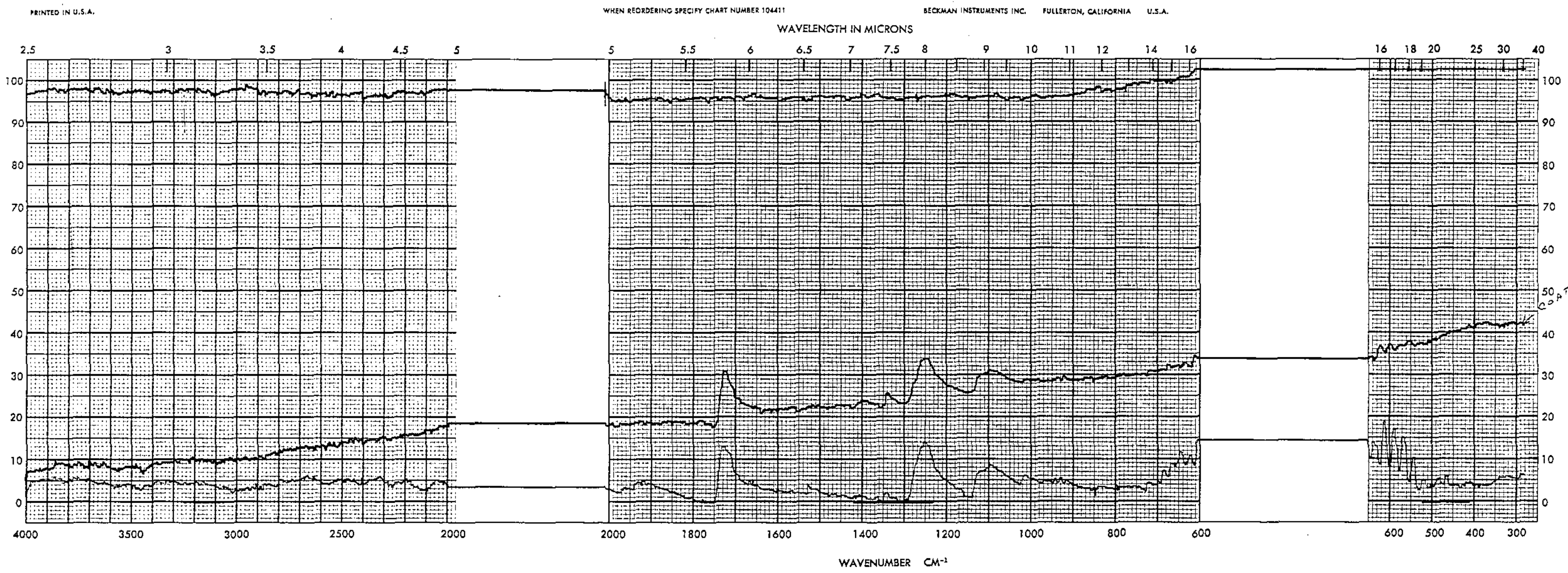
PATH mm
SOLVENT
CONCENTRATION
PHASE
COMMENTS

ANALYST

BECKMAN®

INFRARED
SPECTROPHOTOMETER

Fig. 36



SPECTRUM NO.
DATE 9-20-77
SAMPLE ITO on PET
71.6 Ω/□
Reflectance
SOURCE
STRUCTURE

PATH mm
SOLVENT
CONCENTRATION
PHASE
COMMENTS

ANALYST

BECKMAN®

INFRARED
SPECTROPHOTOMETER

Fig. 37

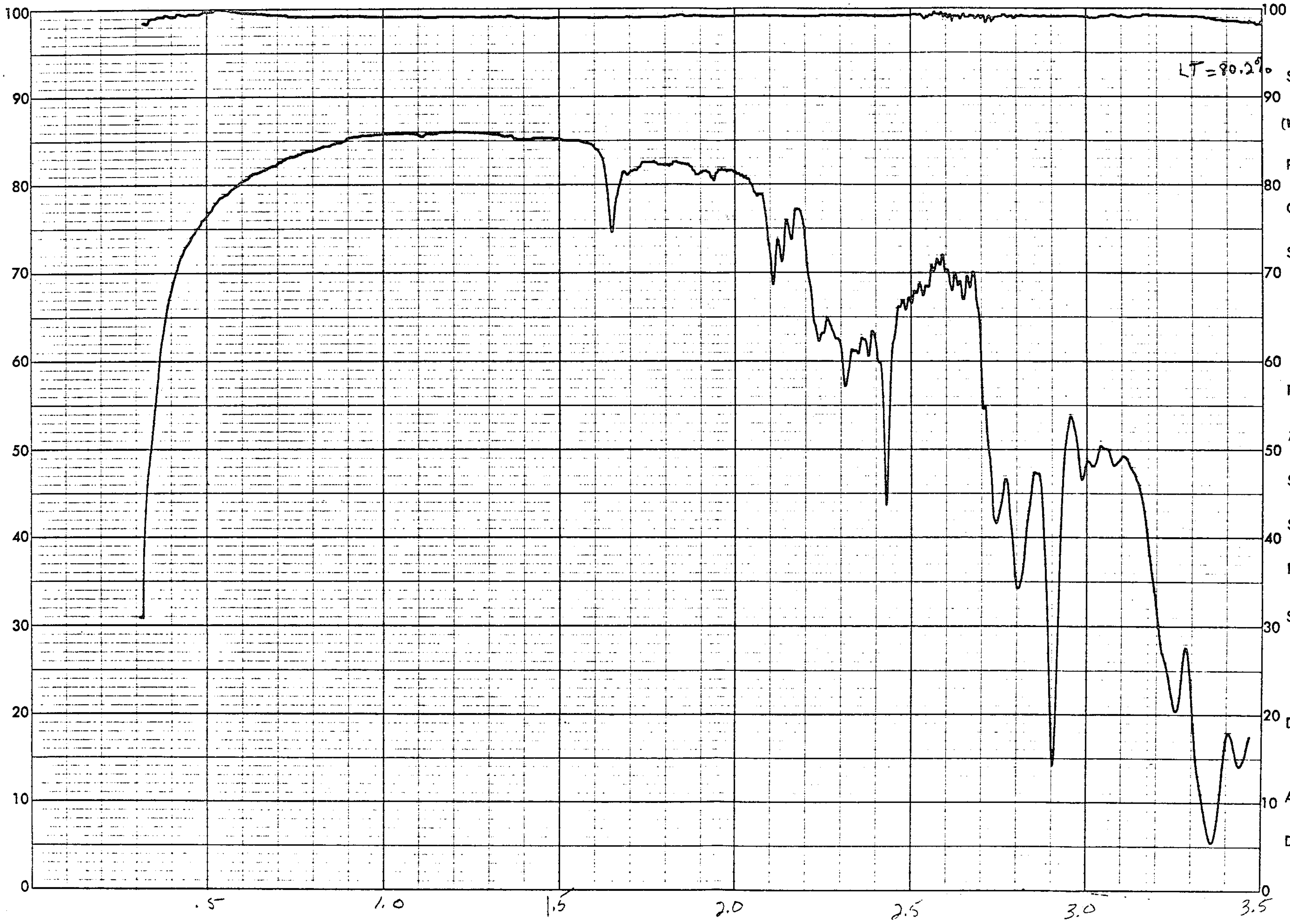
Printed in U.S.A. 69TW740

Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.

T

27



LT = 80.2%

SAMPLE ITO
140 Ω/□
(White)

PATH______ cm

ORIGIN______

SOLVENT______

REF Air

λ SPEED:______ nm/min

SCALE 0-100

SENS 70

PERIOD______

SOURCE: W X

H_2______

D_2______

DETECTOR: PM______

PbS______

ANALYST BRT

DATE 9-20-77

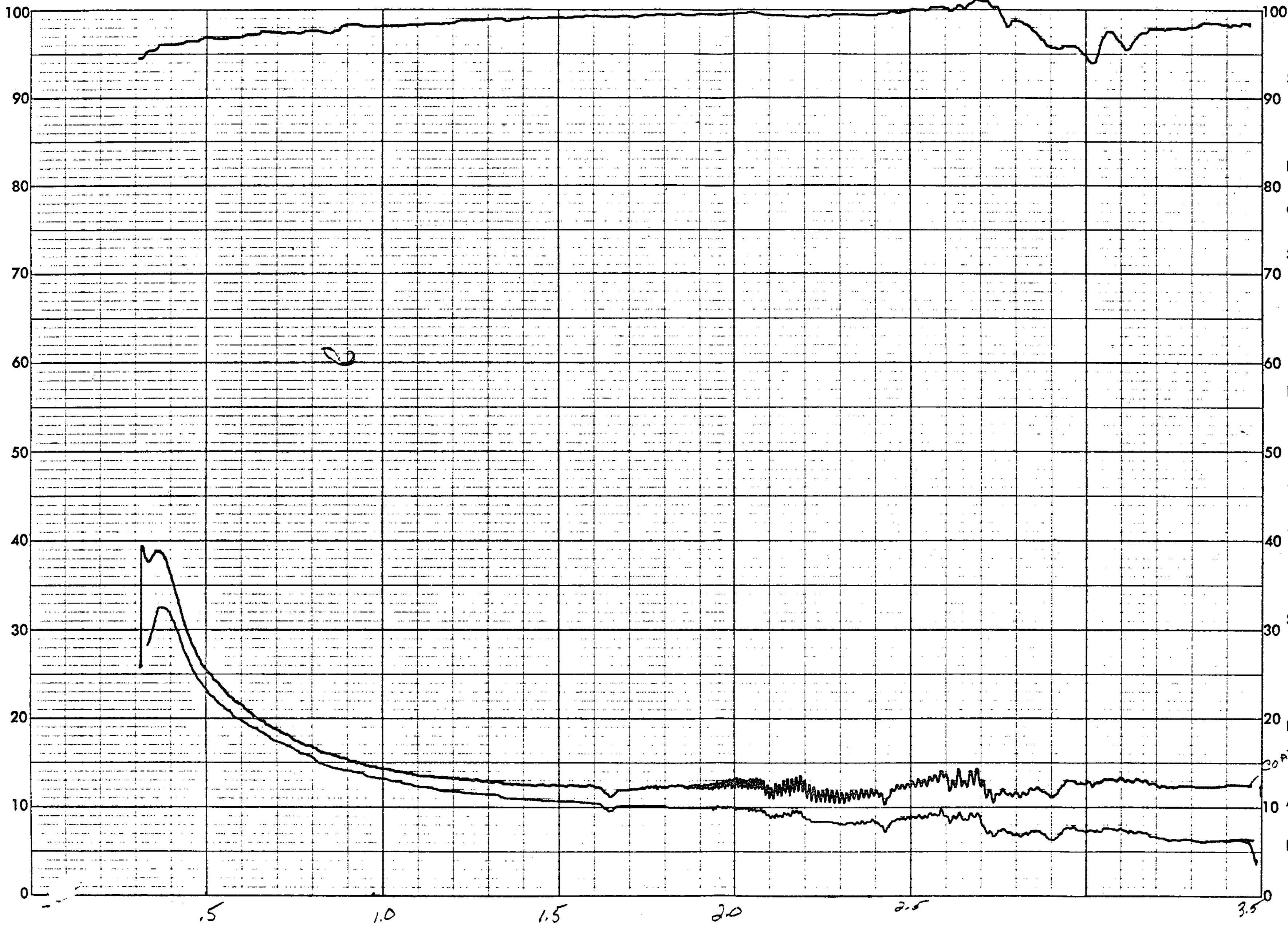
Fig. 38

Printed in U.S.A. 69TW740

Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.

R
28



SAMPLE ITO
140 Ω/□
White

PATH_____cm

ORIGIN_____

SOLVENT_____

REF Ag

λ SPEED:_____ nm/min

SCALE 0-100

SENS 70

PERIOD_____

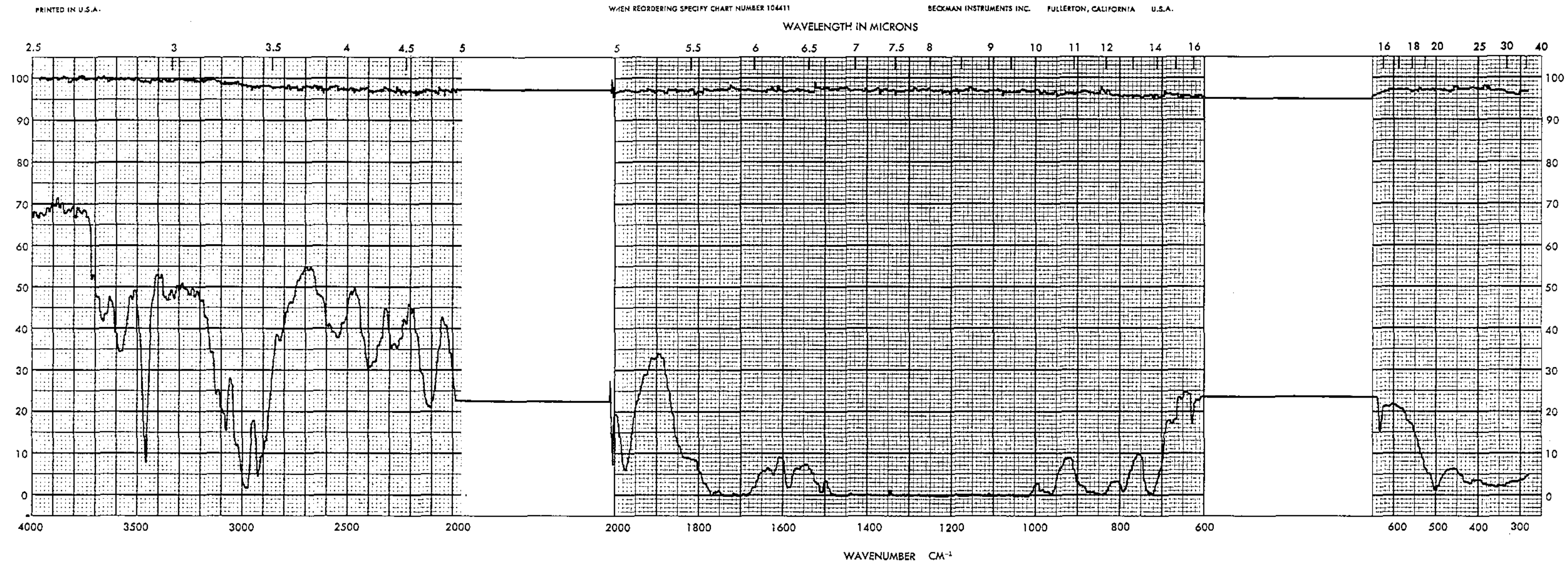
SOURCE: W x
H₂_____
D₂_____

DETECTOR: PM_____
PbS_____

ANALYST BRT

DATE 9-20-77

Fig. 39



SPECTRUM NO. ______
DATE 9-20-77
SAMPLE ITO 140 Ω/□
(White)

SOURCE ______
STRUCTURE

PATH ______ mm ______
SOLVENT ______
CONCENTRATION ______
PHASE ______
COMMENTS ______

ANALYST ______

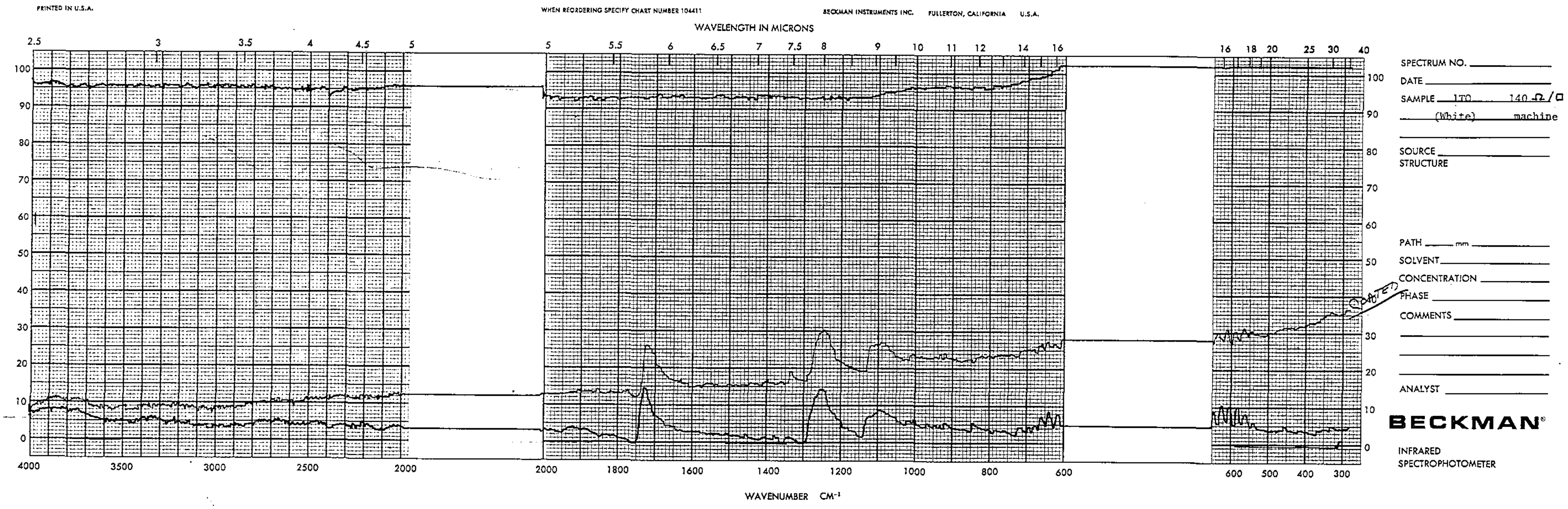
BECKMAN®

INFRARED
SPECTROPHOTOMETER

Fig. 40

R

30



SPECTRUM NO. ________

DATE ________

SAMPLE ITO 140 Ω/□

(White) machine

SOURCE ________

STRUCTURE

PATH ____ mm ________

SOLVENT ________

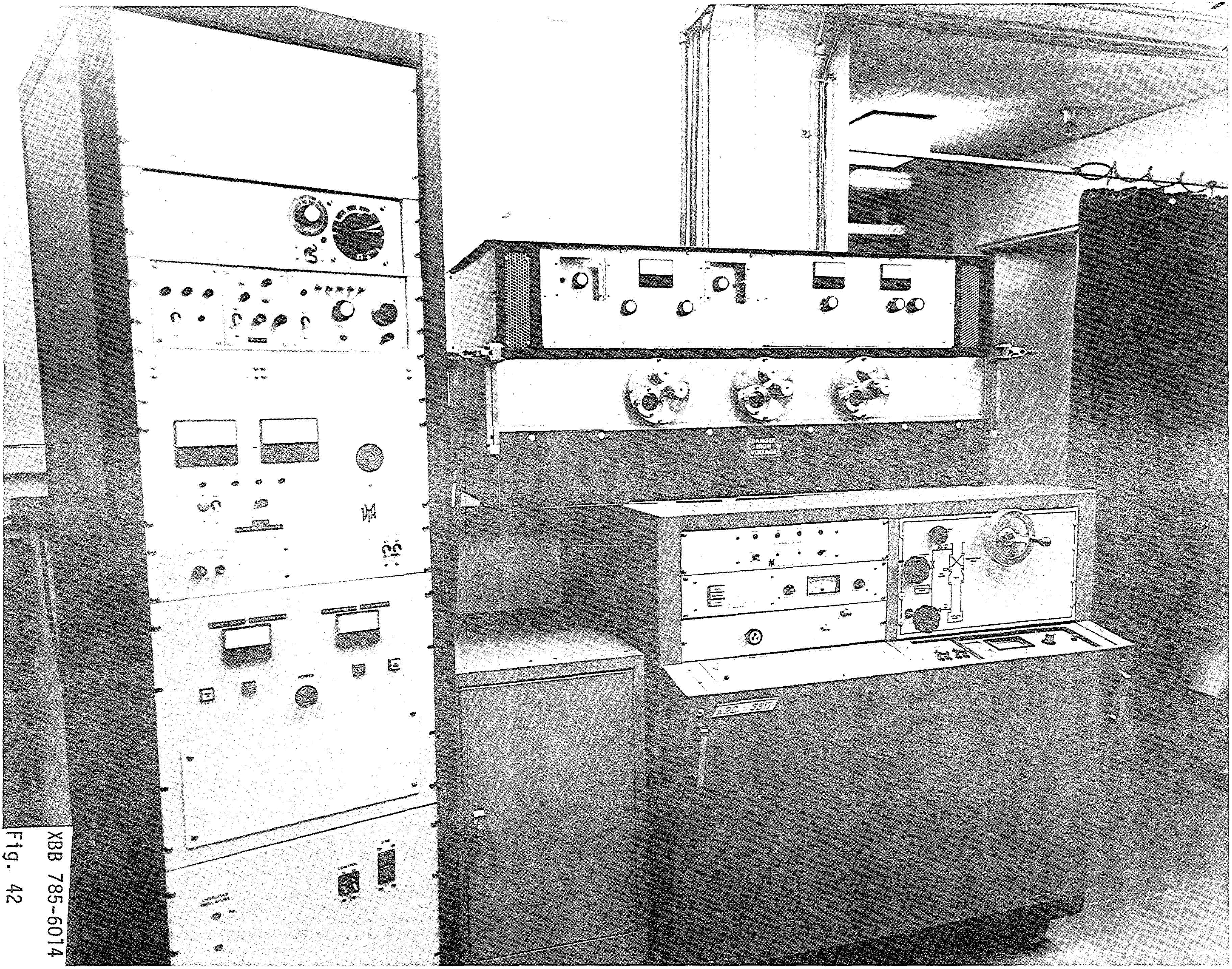
CONCENTRATION ________

PHASE ________

COMMENTS ________

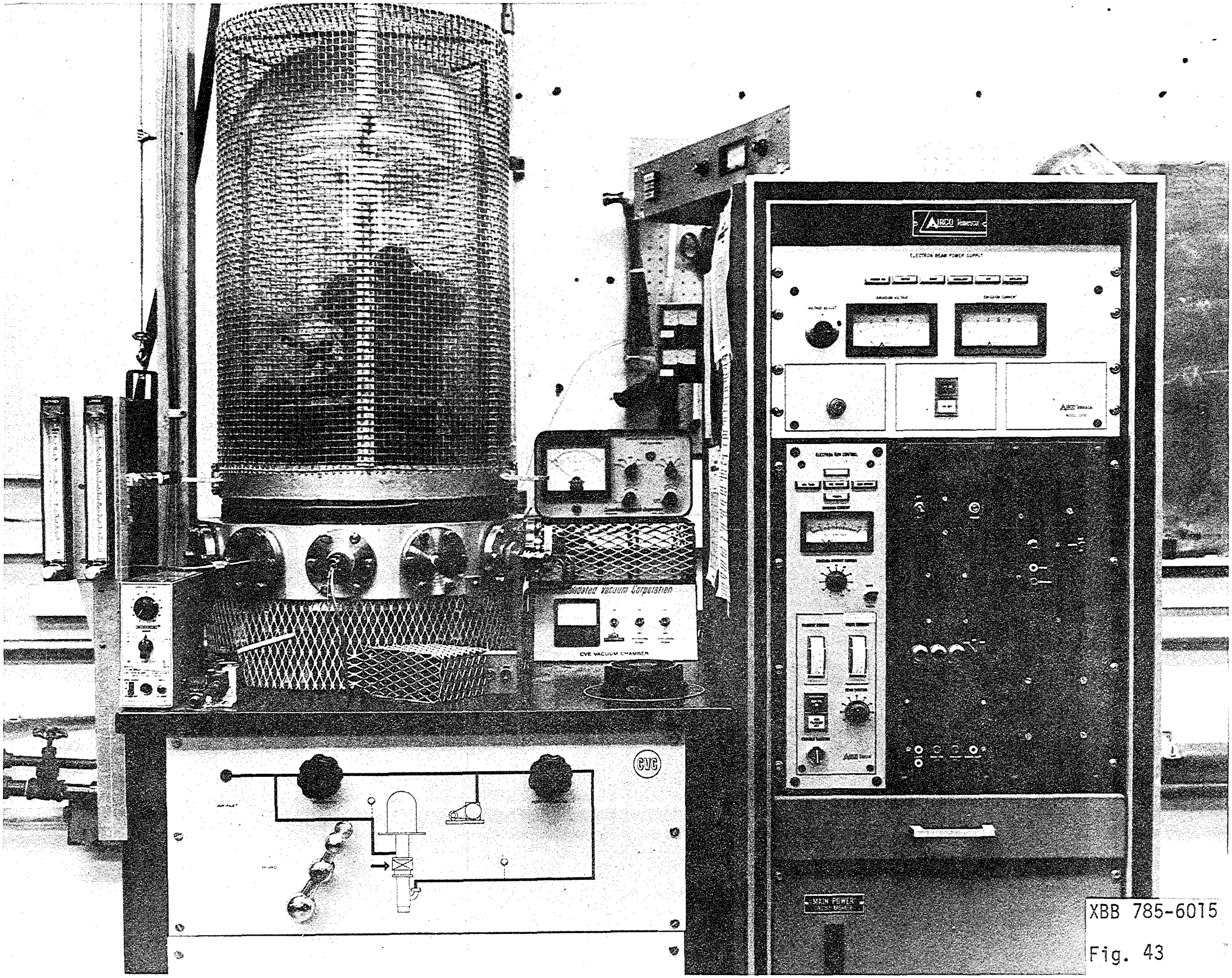
ANALYST ________

Fig. 41



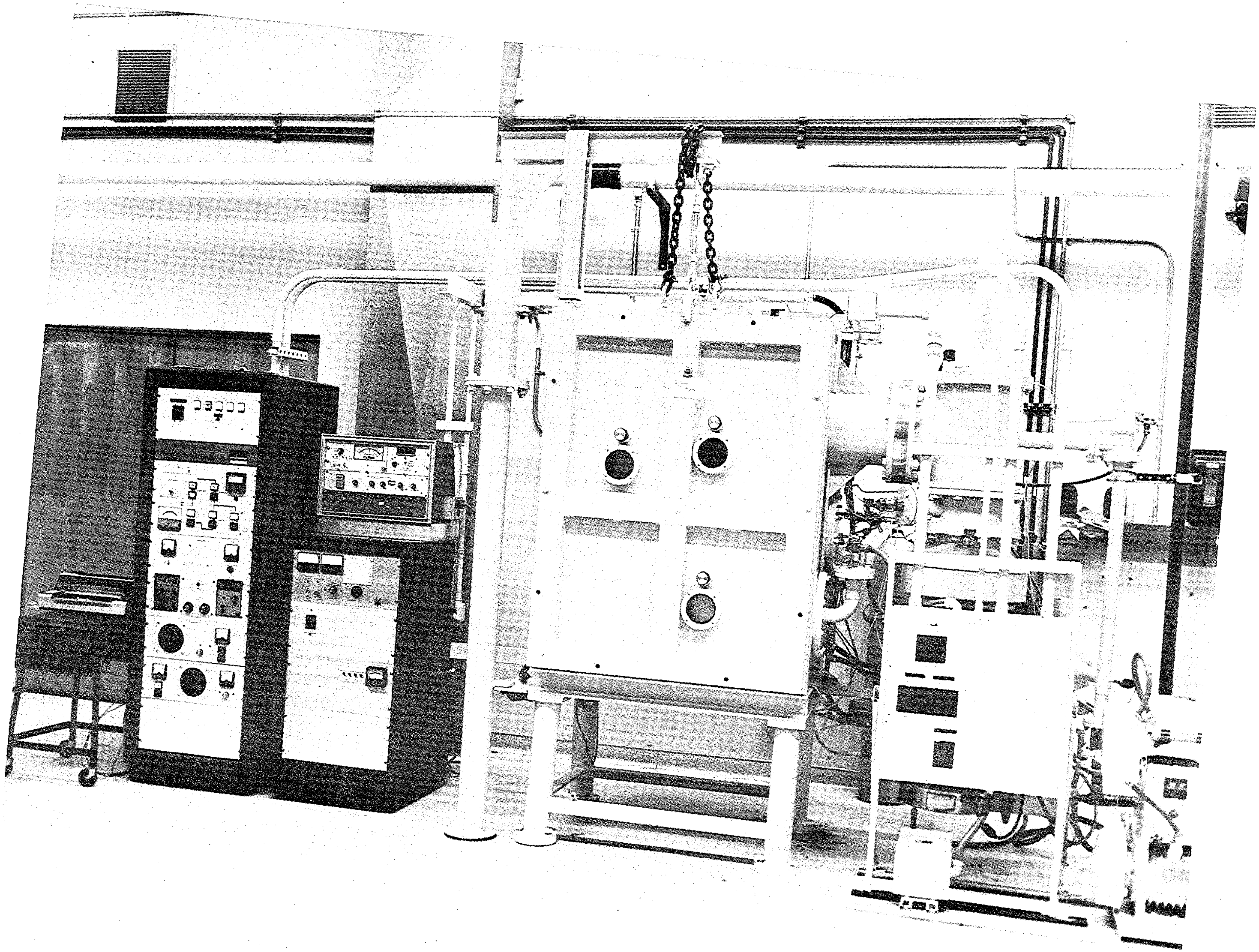
XBB 785-6014

Fig. 42



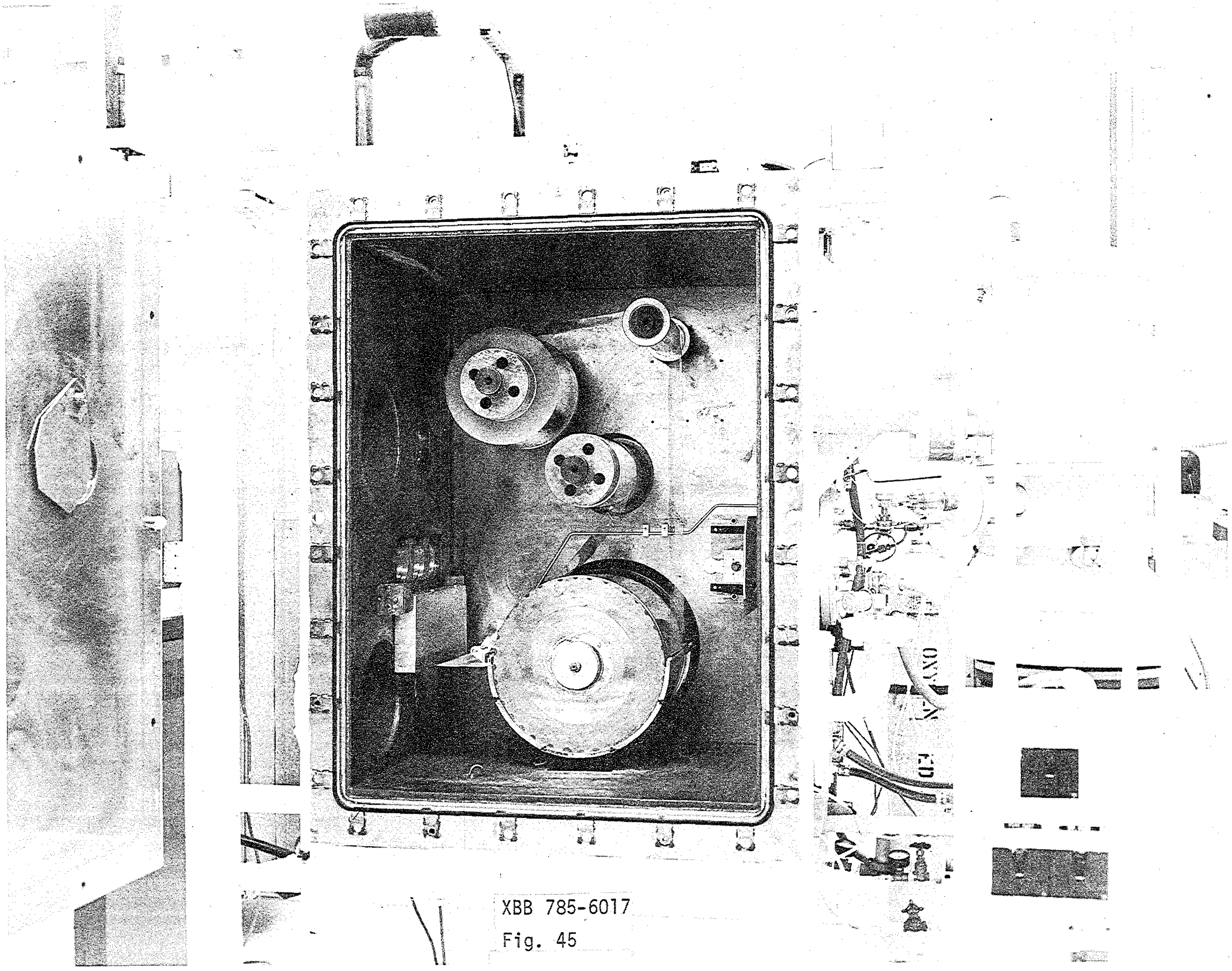
XBB 785-6015

Fig. 43



XBB 785-6016

Fig. 44



XBB 785-6017

Fig. 45

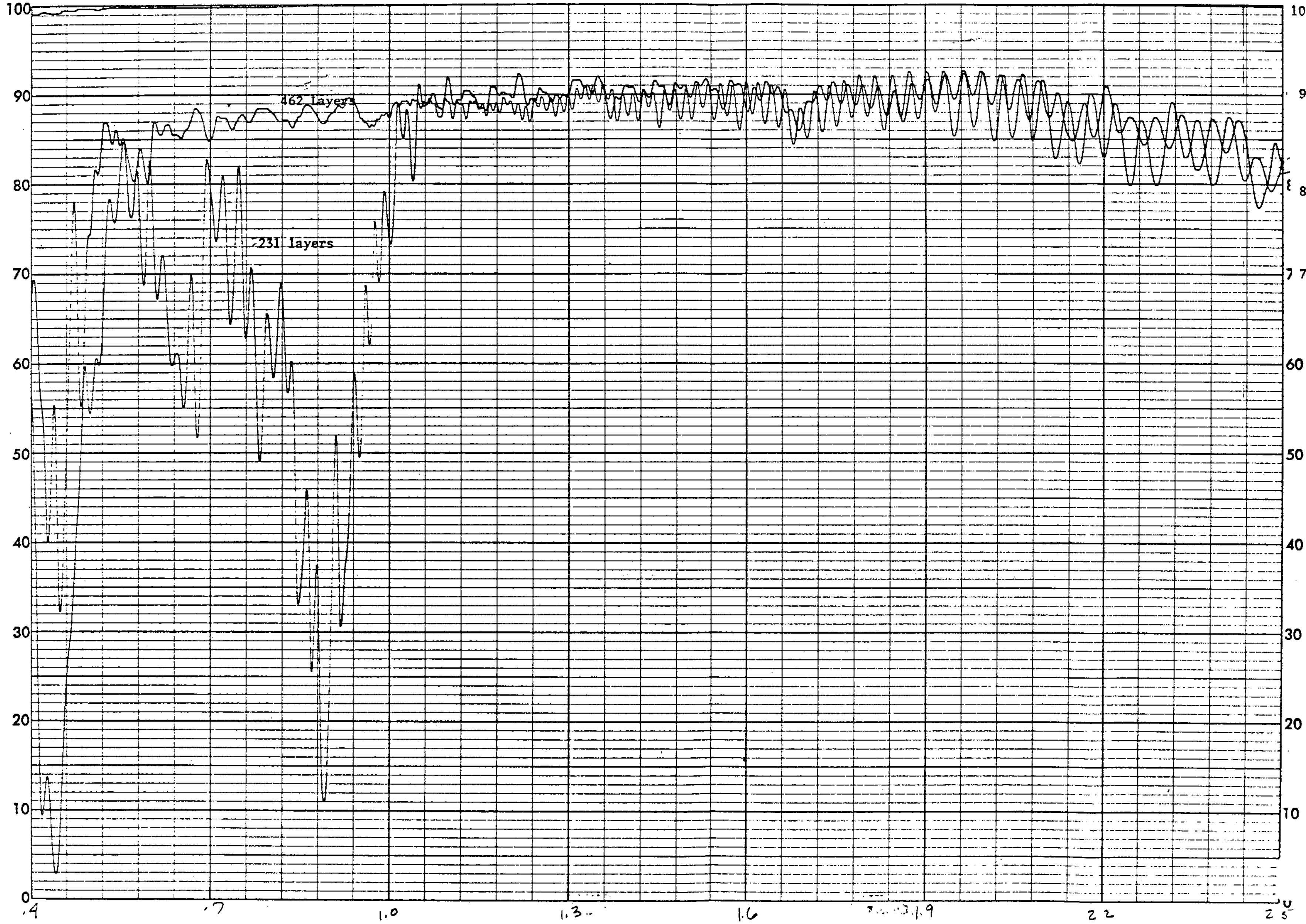
T

35

Printed in U.S.A. 69TW740

Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC.,



Dow Multilayer
Plastic

Transmission

REF

λ SPEED: 50 nm/min

SCALE 0-100

SENS 1/2

PERIOD

SOURCE: W X

H₂

D₂

DETECTOR: PM

PbS X

ANALYST BRT

DATE 1-17-72

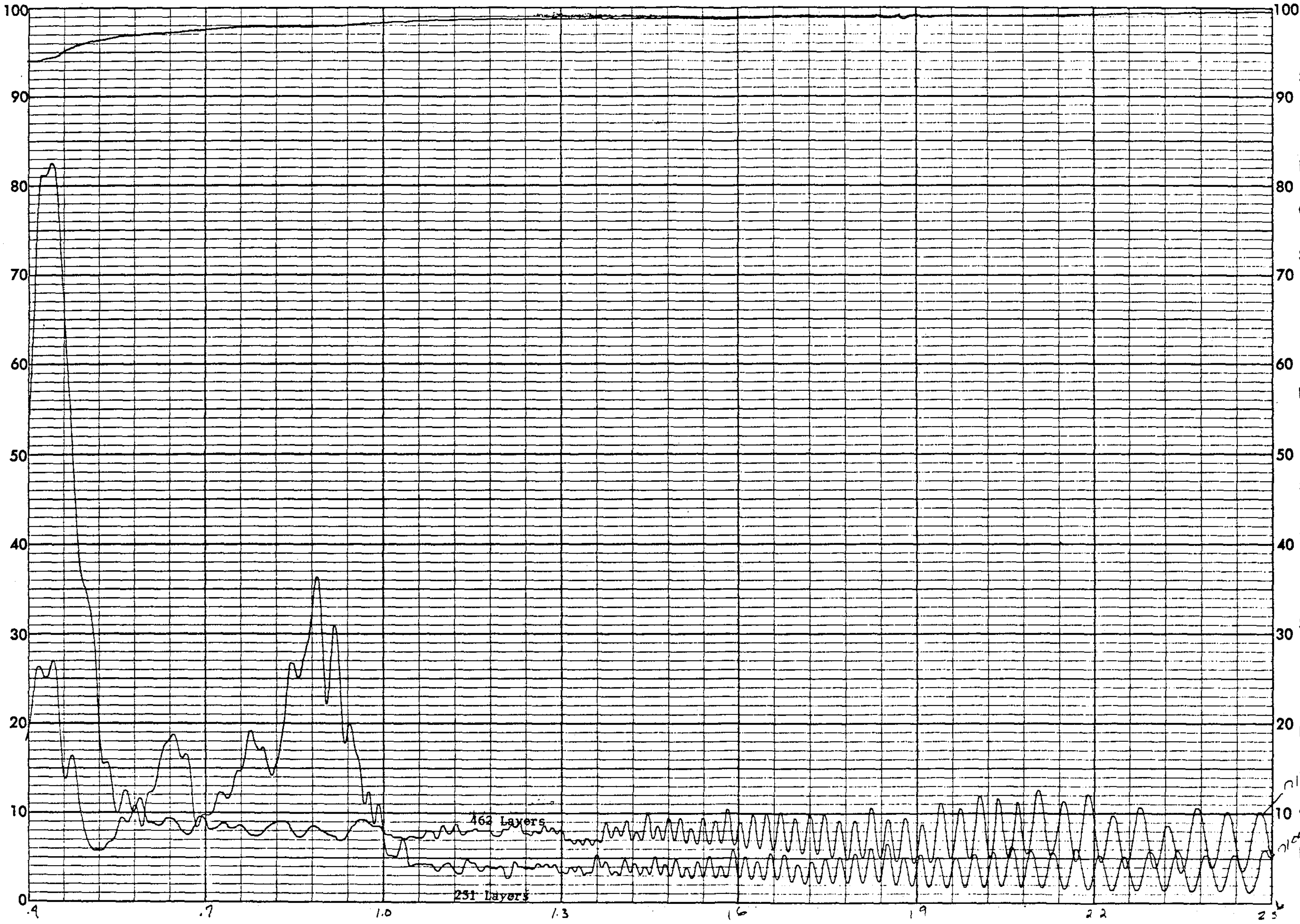
Fig. 46

Beckman Instruments, Inc.

Printed in U.S.A. 69TW740

Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.



Dow Multilayer plastic

R

36

SAMPLE Dow Multilayer Plastic

PATH _____ cm

ORIGIN _____

SOLVENT _____

Reflectance

REF _____

λ SPEED: 50 nm/min

SCALE 0-100

SENS 12

PERIOD '

SOURCE: W X

H₂ _____

D₂ _____

DETECTOR: PM _____

PbS X

ANALYST BRT

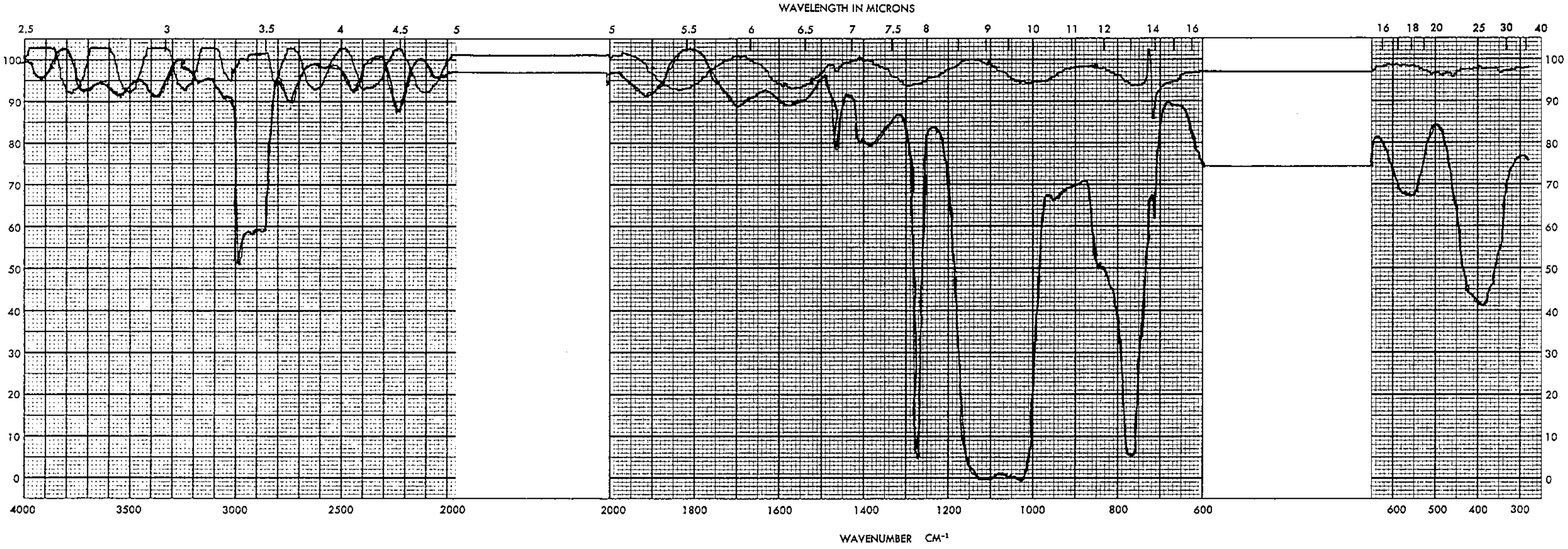
DATE 1-17-72

Fig. 47

T

37

PRINTED IN U.S.A. WHEN REORDERING SPECIFY CHART NUMBER 104411 BECKMAN INSTRUMENTS INC. FULLERTON, CALIFORNIA U.S.A.



SPECTRUM NO. ______

DATE 9-23-77

SAMPLE EX 54 on P.E.

Ref P.E.

SOURCE ______

STRUCTURE

PATH ___ mm ______

SOLVENT ______

CONCENTRATION ______

PHASE ______

COMMENTS ______

ANALYST ______

BECKMAN®

INFRARED
SPECTROPHOTOMETER

Fig. 48

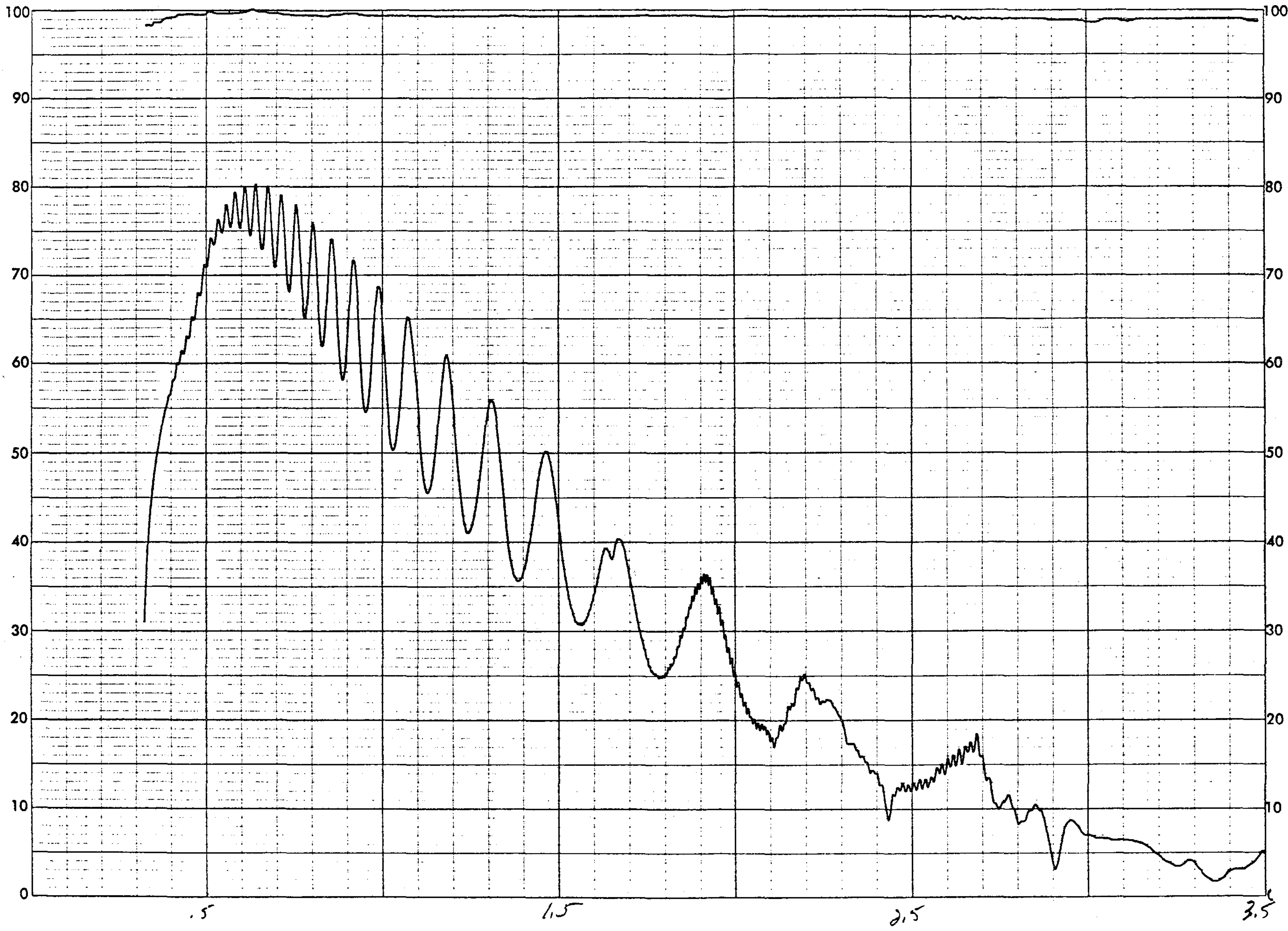
Printed in U.S.A. 69TW740

Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.

T

38



SAMPLE
Intrex
W/Standard FX54
Coating

PATH T-26 cm

ORIGIN

SOLVENT

REF Air

λ SPEED: nm/mir

SCALE 0-100

SENS 30

PERIOD

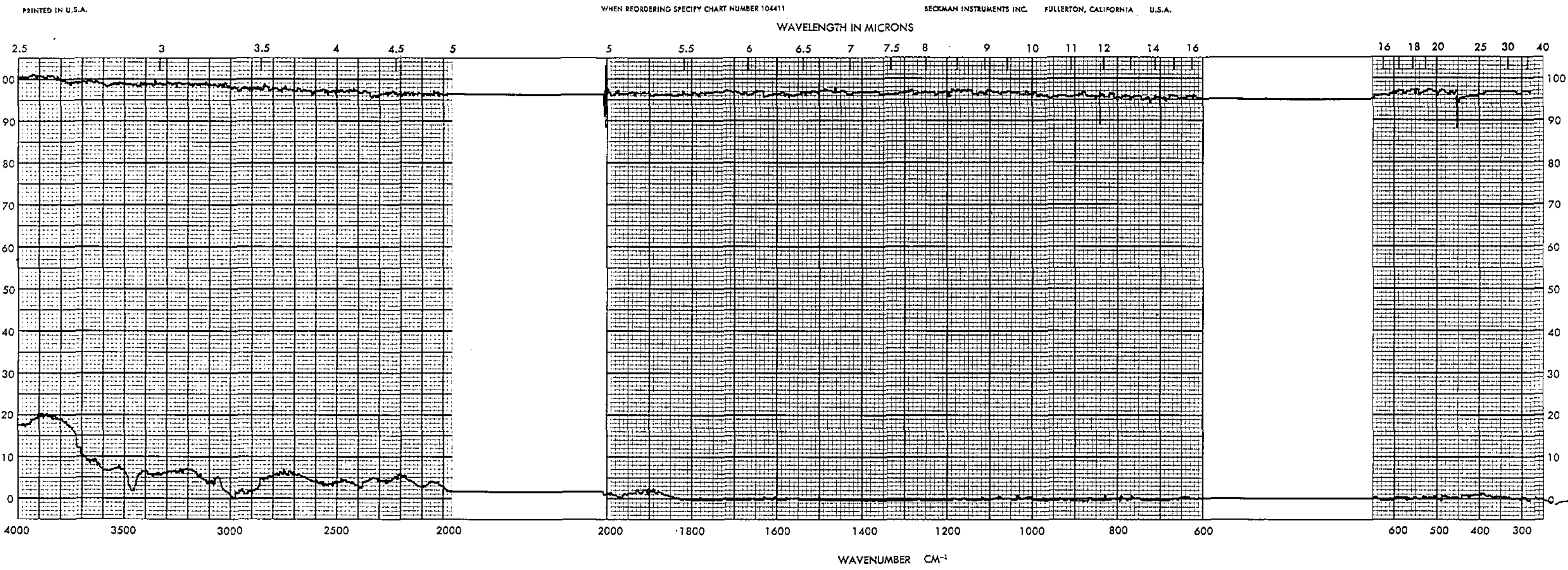
SOURCE: W x
H₂
D₂

DETECTOR: PM
PbS

ANALYST BRT

DATE 9-23-77

Fig. 49



SPECTRUM NO. ______

DATE 9-29-77

SAMPLE FX 54 on T-26

Transmission

SOURCE ______

STRUCTURE

PATH ______ mm ______

SOLVENT ______

CONCENTRATION ______

PHASE ______

COMMENTS ______

ANALYST ______

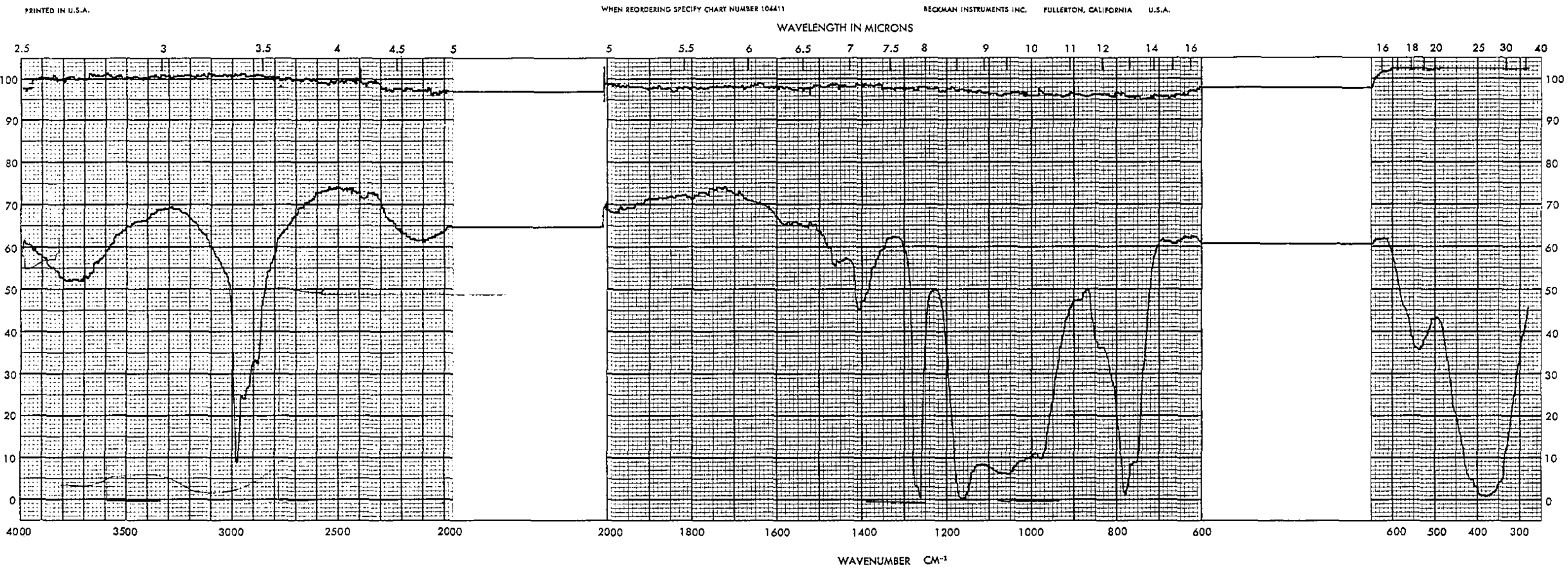
BECKMAN

INFRARED SPECTROPHOTOMETER

Fig. 50

R

40



SPECTRUM NO.

DATE 9-23-77

SAMPLE FX 54 on Intrex T-26

Au Reference

SOURCE

STRUCTURE

PATH mm

SOLVENT

CONCENTRATION

PHASE

COMMENTS

ANALYST

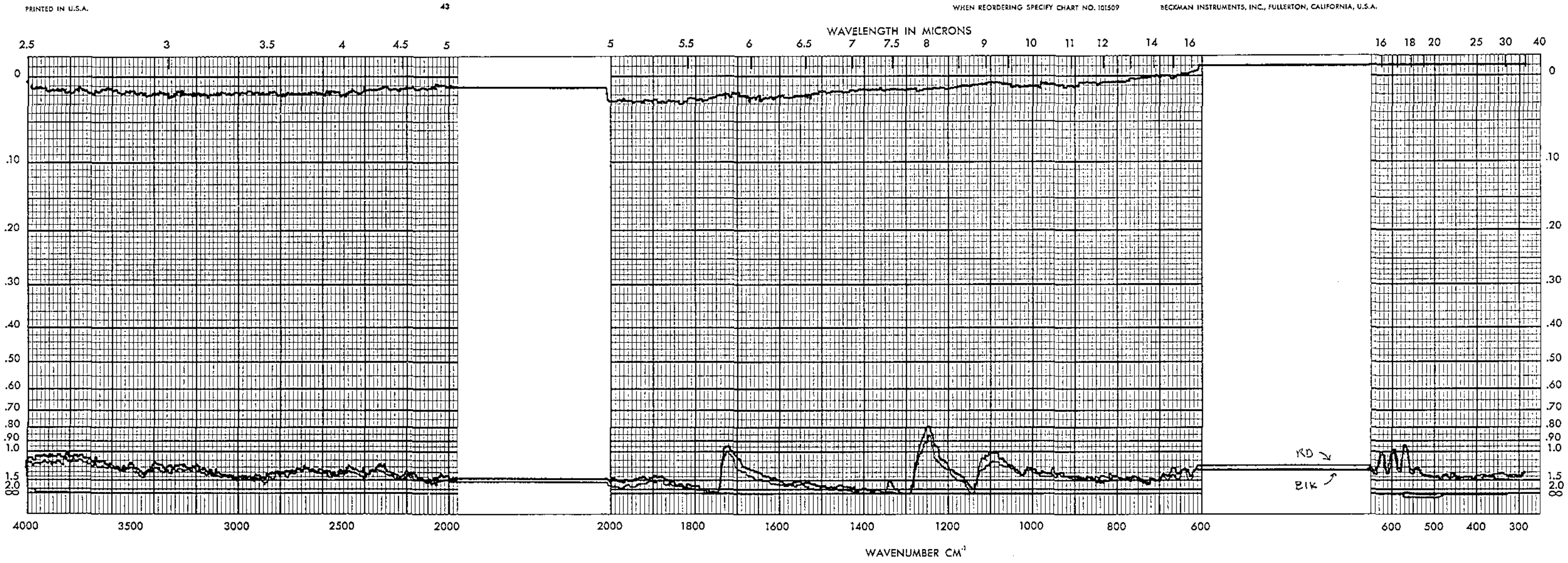
BECKMAN®

INFRARED
SPECTROPHOTOMETER

Fig. 51

R

42



SPECTRUM NO.________

DATE_____

SAMPLE__ Mylar 4 Mil
W/FX - 43

SOURCE
STRUCTURE

REflectance

PATH______mm______

SOLVENT________

CONCENTRATION________

PHASE________

COMMENTS________
Blk CTD EX
RD Side Opposite

ANALYST________

Beckman®

INFRARED________
SPECTROPHOTOMETER

Fig. 52

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720