WEED RESEARCH ORGANIZATION

TECHNICAL REPORT No.83

A LABORATORY POT SPRAYER FOR USE WITH CONTROLLED ENVIRONMENT CHAMBERS

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February 1985

Price - £2.50

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Begbroke Hill, Yarnton, Oxford, OX5 IPF

ISSN 0511 4136
ISBN 0 7084 0323 9

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SIMMONS, R.C. and DRINKWATER, J.A. A laboratory pot sprayer for use with controlled environment chambers. Technical Report Agricultural and Food Research Council Weed Research Organization, 1985, No. 83, pp 15.

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INTRODUCTION

When investigating the effects of environmental factors on pesticides, using environmental chambers, it is often desirable to spray the plants without removing them from the chamber. It has not been possible to do this with conventional laboratory sprayers which are permanently installed in fixed locations. So, we examined ways in which a sprayer might be made to operate inside or close to a walk-in plant growth chamber. There are many problems associated with spraying plants inside a room which has predominantly recirculated air. Contaminated air is a hazard to other plants in the room and to the operator. Any traces of herbicide remaining on the walls and floor of the room are also potential hazards. Pots usually require sorting from a randomised layout before spraying for which extra space is required. A sprayer inside the room will encroach on the available space which may be very limited if the room is being used to maximum capacity. We therefore decided to concentrate on developing a sprayer which could be attached to the doorway of a walk-in growth room. The mechanism of the sprayer could then be made a convenient size and a unit arranged to accept plants from an operator within the room and return it to him after spraying. A ventilation system which draws air from the room and expels via a filter has the dual effect of minimizing contamination of the room's air and of causing the sprayer interior to adopt the environmental conditions of the host room.

DESIGN REQUIREMENTS

The controlled environment rooms at WRO are Votsch VKZPH units with an internal area of approximately 5 x 3m. Plants are grown on 19 trolleys, each 0.7m x 0.7m arranged in three rows of six, with a gangway between two of the rows, and a single trolley at the end of the gangway.

Throughput

The first requirement for a sprayer to be used with these rooms is that the throughput of plants is sufficient to allow experiments to be sprayed in reasonable time. Using a conventional laboratory sprayer 2 people can spray 8 batches of 8 plants, changing herbicides between batches, in about 40 minutes, so it seemed reasonable to expect the same order of throughput from the new sprayer. There would not be any time spent wheeling trolleys of plants to and from the sprayer but time must be allowed for moving the unit from room to room. If 10 minutes out of the 40 are allowed for such things as changing herbicides then the unit must be capable of spraying 64 plants in 30 minutes, i.e. just over one plant every 30 seconds.

Airflow

A flow of air out of the controlled environment chamber through the sprayer via a vent pipe and filter to the atmosphere is required. This performs two purposes. First, it ensures that air containing spray drops and vapour is removed from the operating area of the spayer. Second, the air in the sprayer tends to have the same temperature and humidity as the room from which it came. This minimises environmental shocks and allows spraying to be performed at conditions close to those of the growth chamber. The air velocity must be great enough to overcome turbulent effects at the doorway but not so great that it distorts the spray pattern or causes excessive demands on the room's air conditioning. Smoke tests indicated that a velocity greater

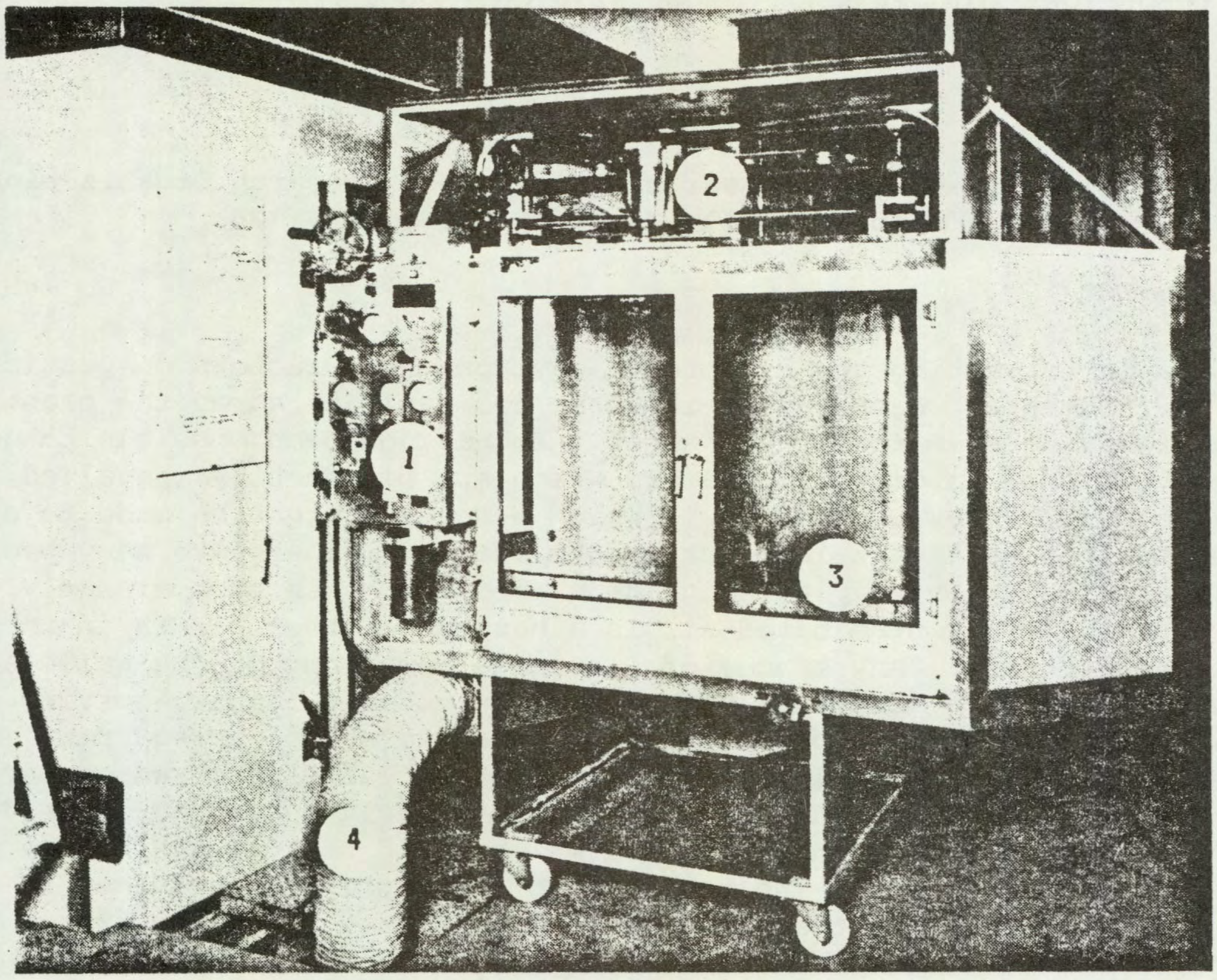
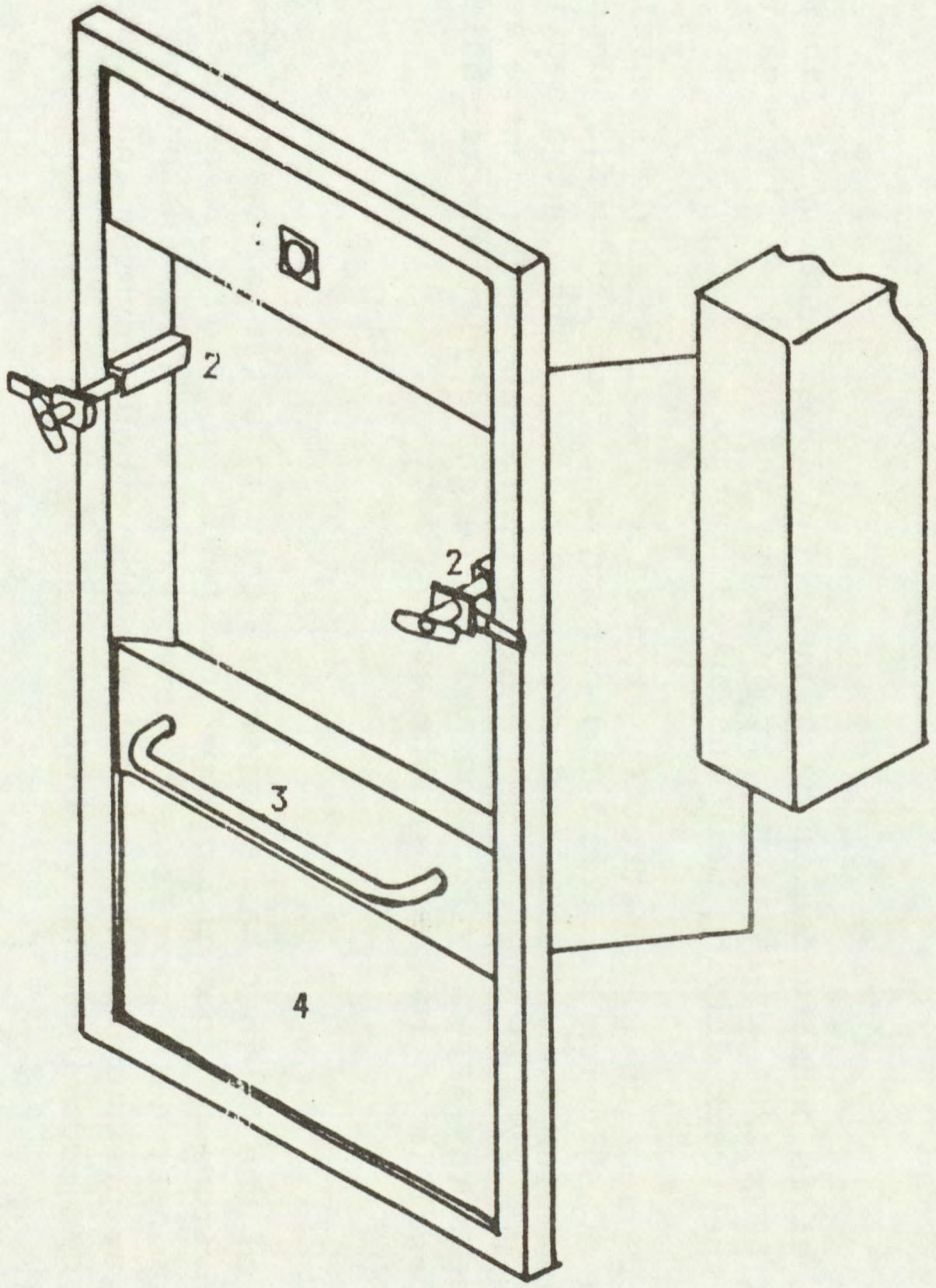
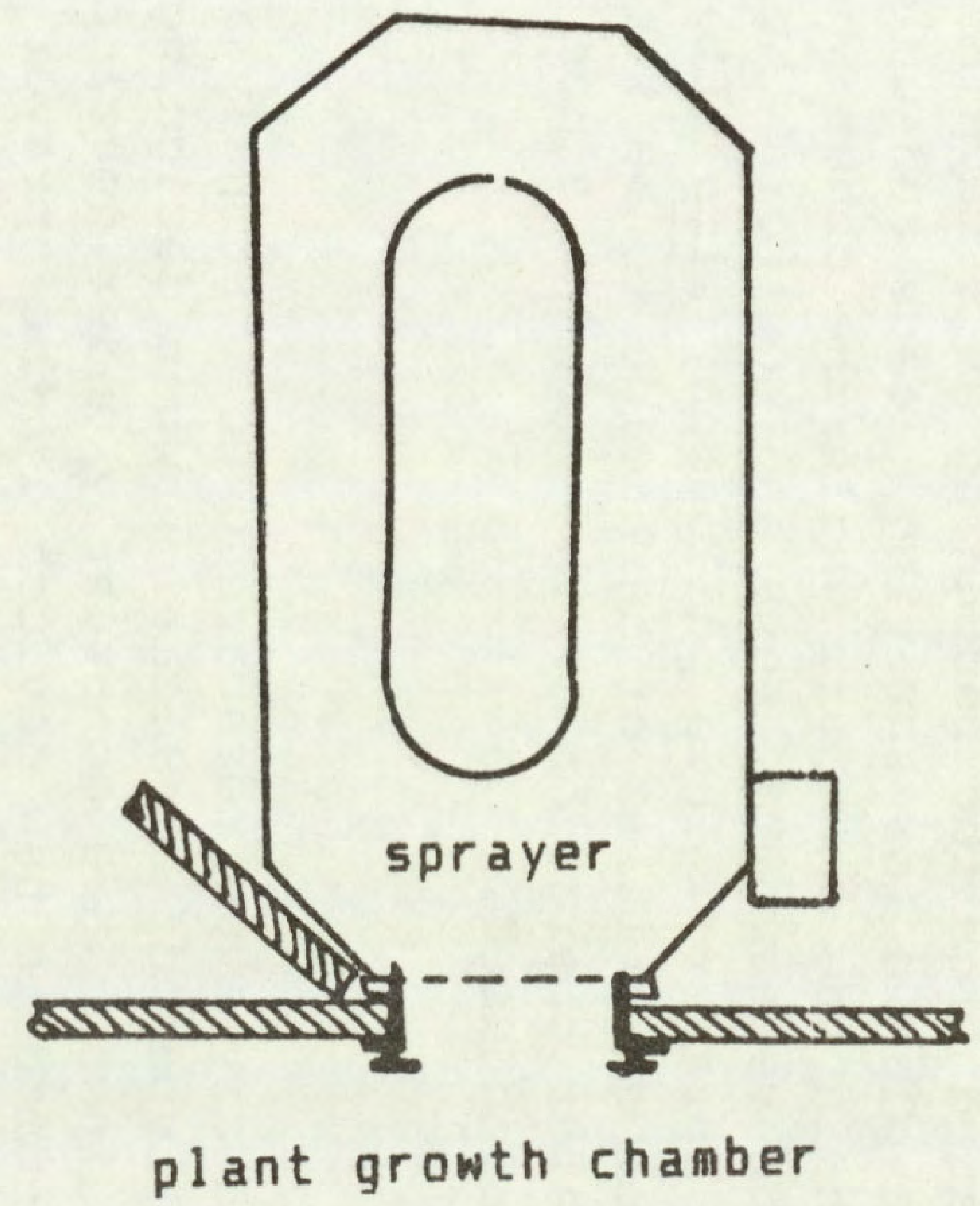


Fig.1 Controlled environment sprayer locked onto plant growth chamber.

1. Control panel
2. Spray assembly (elevated to highest position for clarity)
3. Moving track
4. Waste air outlet





Plan view

Fig. 2 Docking Door

1. Track stop switch
2. Docking clamps
3. Manoeuvreing handle
4. Emergency exit panel

than 0.05 m/sec was required at the sprayer door junction. To achieve even this velocity an air loss rate of about 150 cubic metres an hour is required. This is 50% more than the normal air exchange in the growth room.

Operating staff

The WRO unit was envisaged from the beginning as a machine requiring two operators. One prepares the plants for spraying, loads and unloads them and returns them to their places in the chamber, while the other who works from outside the machine fills the reservoirs, sets and monitors the operating conditions and controls the sprayer. This philosophy simplifies the design of the unit, avoids the need for quantities of herbicide to be taken into the growth chamber and allows safer operation of the machine since two people are always present when it is being used.

Spraying methods

Hydraulic nozzles and rotary atomizers are used routinely at WRO and provision was made for both types of application when designing the sprayer. New types of application equipment are constantly under development and it is desirable to be able to accommodate new devices in the sprayer if necessary. The sprayer was therefore designed with this in mind. The rotary disc unit is removable to allow other units to be installed and both electrical and pneumatic signals are available for operating equipment.

CONSTRUCTION

Main features

The sprayer (Fig. 1) consists of an insulated cabinet mounted on a wheeled frame. Inside the cabinet an ovoid track encircles a central pillar which contains the air exhaust outlet. A spray assembly is suspended above one of the straight portions of the track, and comprises a moving spray head, driven pneumatically, and a fixed head fitted with a rotary disc atomizer. The spray assembly height is adjustable. One end of the cabinet has a docking doorway intended to mate with the doorway of a controlled environment chamber.

Cabinet

The cabinet is constructed in sections. The lower section is fabricated from 1.5" x 1.5" x 1/8" angle iron; it supports the track and main cabinet and contains the track driving unit and speed control.

The centre section is constructed from 2" x 2" x 1/8" angle iron clad all around with a 2.25" thick hardboard and polystyrene foam sandwich. On one side is an aluminium framed double glazed access door. The centre section also supports the exhaust systems and docking door. Above the centre section is mounted the spray assembly housing and the height adjustment mechanism. The control panel is to the left of the access door.

Docking door

One end of the cabinet has an aperture that fits the doorway of the controlled environment room and clamps into position (Fig. 2). An underfloor duct runs from near each room to a filtered exhaust. A fan in the duct induces a lower pressure in the cabinet via the exhaust system and draws the air from the C/E room into the cabinet.

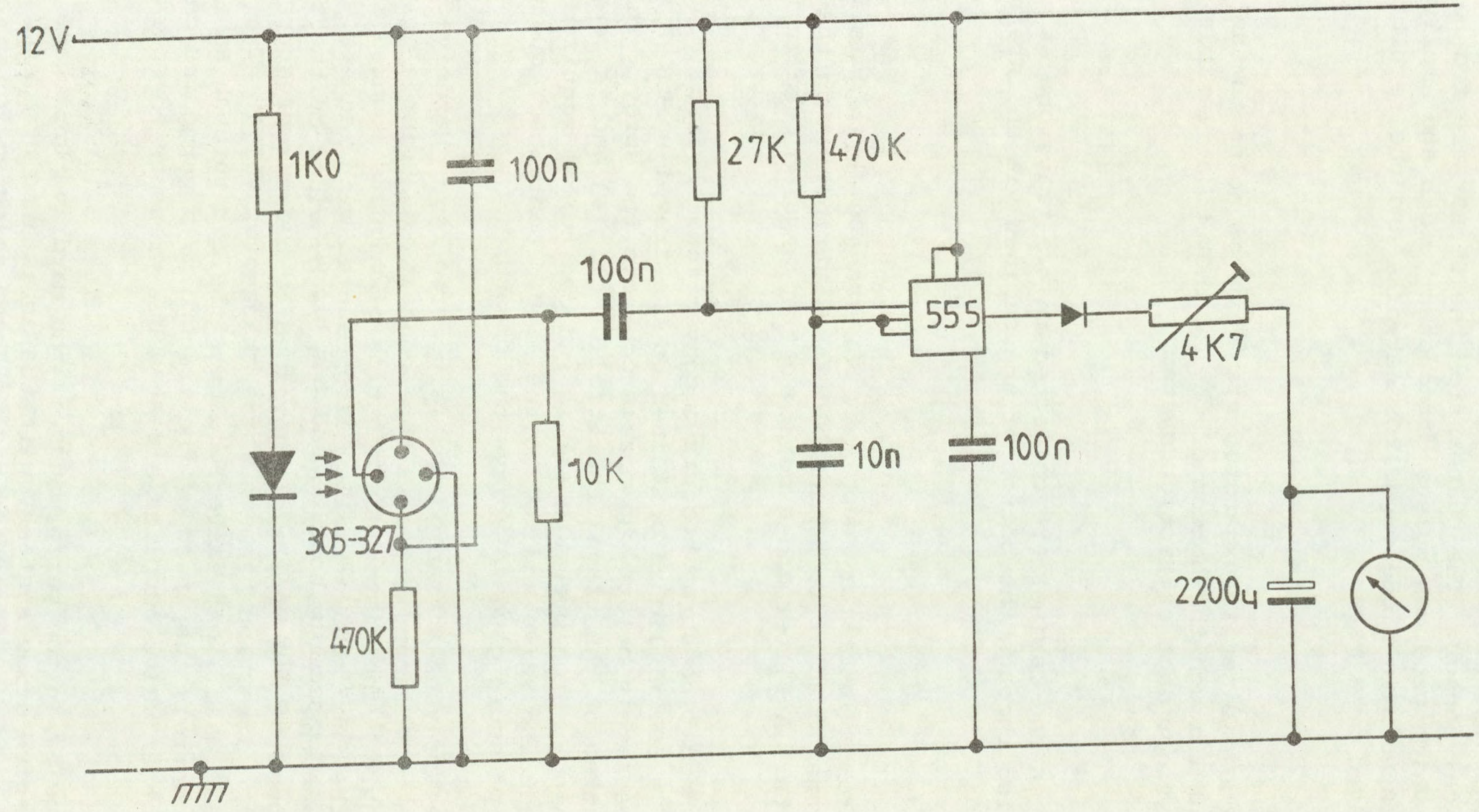


Fig. 3 Track speed indicator circuit

Safety door The lower part of the docking door assembly is blocked by an insulated panel which may be pushed outwards to allow escape from the room in an emergency. The wheeled frame is recessed to allow easier egress.

Track

The track is oval with a moving surface of plastic slats attached to a continuous chain driven from below by a sprocket, governed by a reduction gear and differential pulley driven by a 3 phase electric motor. Metal trays ride on the track, the plants to be sprayed are placed on the trays.

Track speed indicator The track speed is indicated by an electronic tachometer (Fig.3). A slotted disc is attached to the output shaft of the track drive and this interrupts a light beam passing between a light emitting diode and an optical sensor. The pulses from the sensor are fed to the input of a '555' timer which produces pulses of constant width and amplitude. These pulses are integrated by a diode-capacitor network, and the resulting DC voltage is displayed on a meter.

Exhaust system

The air in the cabinet is exhausted via a row of holes to the rear of the centre column, out through the bottom of the cabinet to a flexible pipe connected to the floor duct extraction system.

Drainage

All liquids in the cabinet are collected in two trays one at each end of the cabinet and fed through the bottom of the cabinet via an interconnecting pipe to the drain.

Spray system

Air inlet Air from a laboratory supply at 552 kPa (80 lb/in^2) is fed via a self-sealing bayonet coupler to a manifold for distribution to the three pneumatic circuits. A filter and a moisture trap are included in the supply line.

Hydraulic spray head The spray head is a conventional hydraulic nozzle fitted to the bottom of a 500 ml liquid container on the travel unit. A solenoid valve fitted immediately before the nozzle controls the spray. The spray container is mounted on the travel unit trolley (fig 4) and is removed for filling or cleaning. High pressure air is reduced to the required spray pressure by a reducing valve and fed to the liquid container mounted on the travel unit. A pressure gauge displays the pressure.

Travel unit The spray head transporter is powered by a 'Mardrive' pneumatic transport system. This consists of a tube containing a piston driven to and fro by air pressure. The piston has a series of magnets mounted in it, and on the outside of the tube runs a trolley also mounted with magnets. The connection between the trolley and the piston is provided by the fields of the magnets. The speed of the trolley is governed by the air pressure acting upon the piston and the direction by means of a changeover valve. Two pressure control valves are used. One valve regulates the air through an inline lubricator and controls the speed of the transport; a gauge indicates the pressure. The other valve supplies air at a set pressure to operate the control valves.

Inconsistencies in the performance of the Mardrive unit have led us to consider alternative drive systems, with the assistance of NIAE. At the time of writing, however, an alternative has not been selected for trial.

A commercially available timer chip and display are used to show the time taken to travel over the central 0.5 m of the Mardrive track. Microswitches

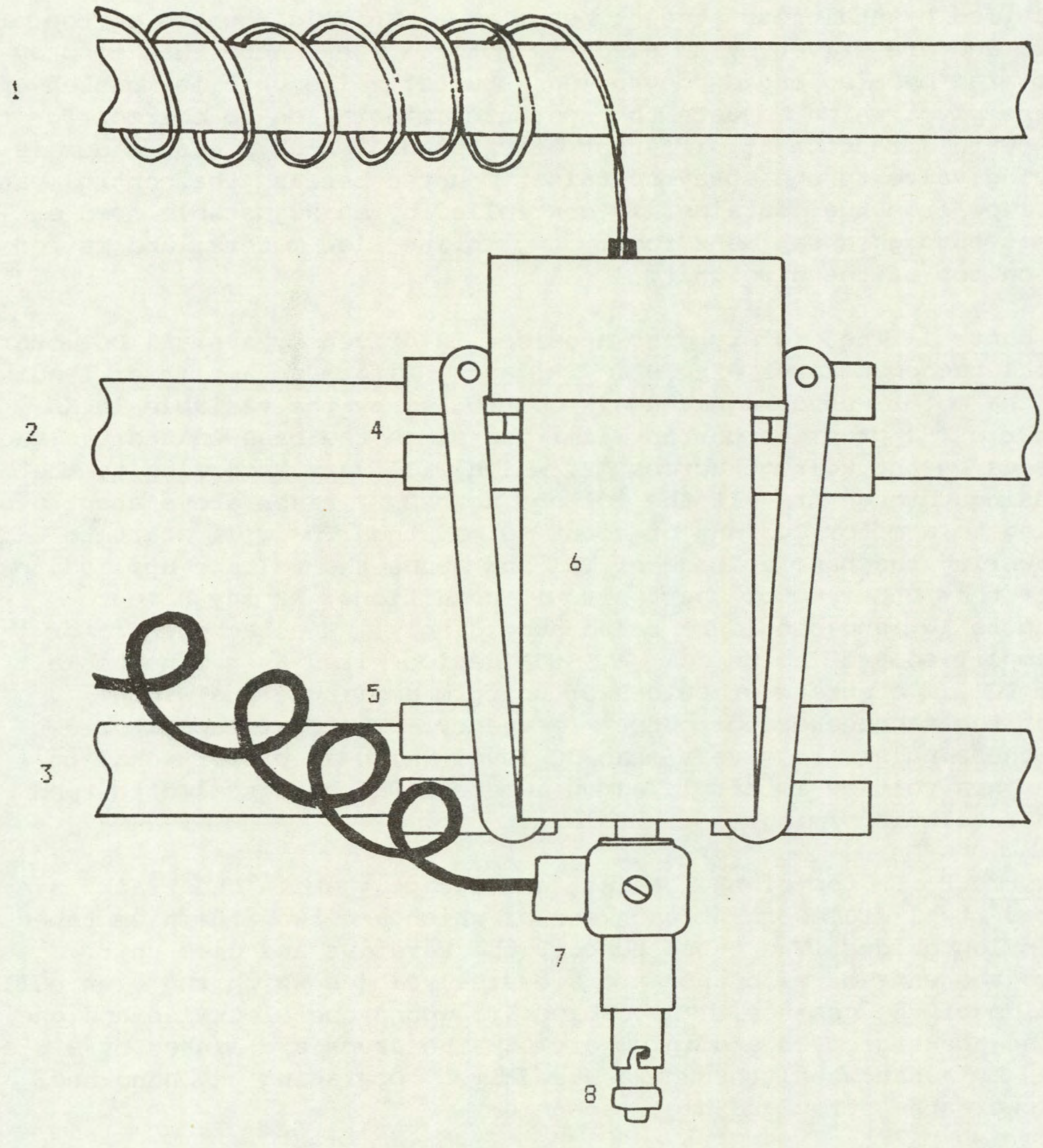


Fig. 4 Spray head

1. Tube supporting air supply pipe
2. Tube for stabilising trolley
3. Tube with magnet-carrying piston inside
4. Stabilising trolley
5. Driven trolley with attached magnets
6. Detachable pressure vessel
7. Solenoid valve
8. Spray nozzle on bayonet mount

mounted on the track supports are used to trigger the timer.

Spinning disc unit The multiple disc unit is completely shrouded in a plastic chamber and has a separate drain to the bottom of the cabinet. The discs are individually fed by stainless steel tubes from a manifold mounted on top of the chamber, and are driven by an electric motor. The chamber has a spray aperture covered by a solenoid controlled shutter. The unit is mounted upon an off-centre pivot which adjusts the aperture orientation to correct for the changes in swath direction at different disc speeds. High pressure air is fed via a reducing valve to the spray container mounted beneath the control panel. The liquid flow from the container is controlled by an adjustable needle valve, passes through a tap measured by two inline flow meters, and is fed to a manifold on top of the disc unit.

Disc speed control The rotary disc atomiser is driven by a small DC motor with integral tachogenerator (fig 5). TR1 and TR2 form an amplifier feeding a voltage to the motor whose magnitude is controlled by the variable 10 KΩ potentiometer. TR3 provides current limiting since the base-emitter voltage of TR3 depends on the voltage across R2, which will vary according to the current passing through it. If the voltage across R2 rises above about 0.6V, corresponding to a motor current of about 90 ma, then TR3 will start to conduct, lowering the base voltage of TR1 and hence the voltage applied to the motor. Note that under motor short circuit conditions, R2 may have to dissipate up to 1W, and should be rated accordingly. The tachogenerator output is amplified and fed to IC1, a '555' device wired as a monostable. The output from IC1 is a stream of pulses of uniform amplitude and width, generated at the tachogenerator output frequency. The 22μf capacitor integrates these pulses to give a mean DC level which is proportional to frequency. This voltage is displayed on a meter, which is scaled to read directly in revolutions/minute.

Height adjustment On top of the cabinet and directly above the track is a double glazed steel framework at each end of which are two aluminium tubes running in nylon guides. The tubes support the Mardrive and disc unit. Connected to the ends of each tube are two steel cables which run over pulleys to the outside of the cabinet. The cables are wound one clockwise and one anticlockwise about grooved aluminium drums. The drums are linked by a steel shaft driven by a handwheel through a wormdrive. Operating the handwheel raises or lowers the spray and disc mechanisms.

Control system

The need to accommodate different spraying methods, and to allow for future developments, means that the sprayer must have several modes of operation. These modes allow for different combinations of track and sprayhead movement as well as operation of the appropriate spray solenoid or disc shutter. In addition, manual operation of each part of the unit is possible.

Plant detector For all the automatic modes a photoelectric detector senses the presence of an object on the track as it passes into the straight section of the track. The signal from this detector starts the appropriate cycle of operations. During a cycle, further detector signals are ignored, thus preventing premature restart of the cycle. The dectector is a commercial unit made by Photain Controls. It consists of a light source and detector head mounted side by side in the cental pillar of the sprayer, and a reflector mounted on the opposite side of the track. Any interruption of the beam will trigger the detector and activate its output relay.

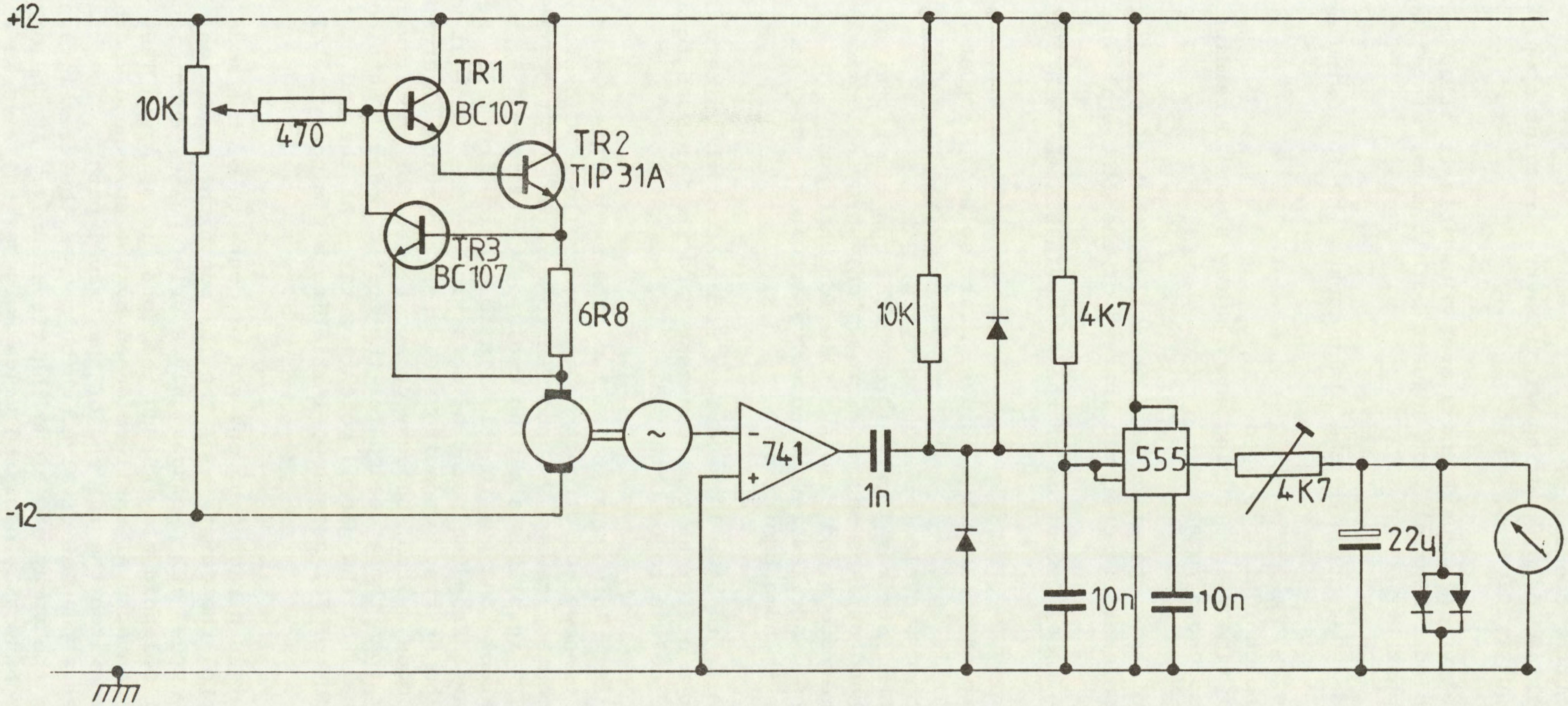


Fig. 5 Rotary disc atomiser speed control and indicator circuit

Modes of operation

Disc mode In this mode, the detection of the plant pot causes the following sequence of events:

1. Time delay.
2. Disc shutter opens.
3. Further time delay, during which shutter remains open.
4. Disc shutter closes.

The time delays in steps 1 and 3 are adjustable to allow for changes of track speed, a single control knob adjusts both timers, since the ratio of the two is always constant.

Static spray mode Detection of the plant causes the following events:

1. Time delay.
2. Spray solenoid is operated.
3. Further time delay, during which spray solenoid remains actuated.
4. Spray solenoid releases.

The logic of this operation is identical to that of the disc mode, except that the spray solenoid is operated instead of the disc unit shutter.

Travelling spray mode Detection of the plant initiates this cycle:

1. Time delay.
2. Spray solenoid actuated, travel start solenoid actuated momentarily.
3. Spray head travels forward, spraying.
4. Spray head strikes first microswitch, run timer starts.
5. Spray head strikes second microswitch, spray solenoid releases, run timer stops and displays time for that run.
6. Spray head strikes reversing valve actuator, spray head returns to home position.

The time delay in step 1 is derived from one of the timers used in the other modes, but a different time constant capacitor is used to allow the correct range of delays to be obtained.

Sequence controller This consists of two timers plus associated relays and switches. Fig. 6 shows the circuit of the controller. Closure of the detector relay contact causes TR1 and TR2 to turn on. TR1 operates the counter, while TR2 initiates a timing cycle of the first '555' timer. This is wired as a monostable and its function is to provide the delay necessary for the plant to travel from the point of detection to the point at which the spraying operation starts. Capacitors C1 and C2 provide alternative ranges, selected by the mode switch, because delays needed for the travelling spray mode are shorter than those needed for the static modes. Setting of the delay time is by one half of the ganged potentiometer. At the end of the delay period, the output of IC1 goes low, initiating a timing cycle of IC2, also a '555' device.

IC2's output is directed by one set of contacts of the mode switch while another set control the duration of the 'output high' condition. In the travelling spray mode, IC2 produces only a brief pulse, sufficient to energise the travel start solenoid via TR5 and the spray relay A via TR6. A latches on through its own contacts A1 until released by the sprayhead reaching and operating a microswitch the far end of the travel path.. The travel start solenoid operates a pneumatic valve, which causes the travel reverse valve to operate, sending the sprayhead along the travel unit. At the other end of the travel path a mechanically operated valve releases the reverse valve allowing the sprayhead to return to its home position.

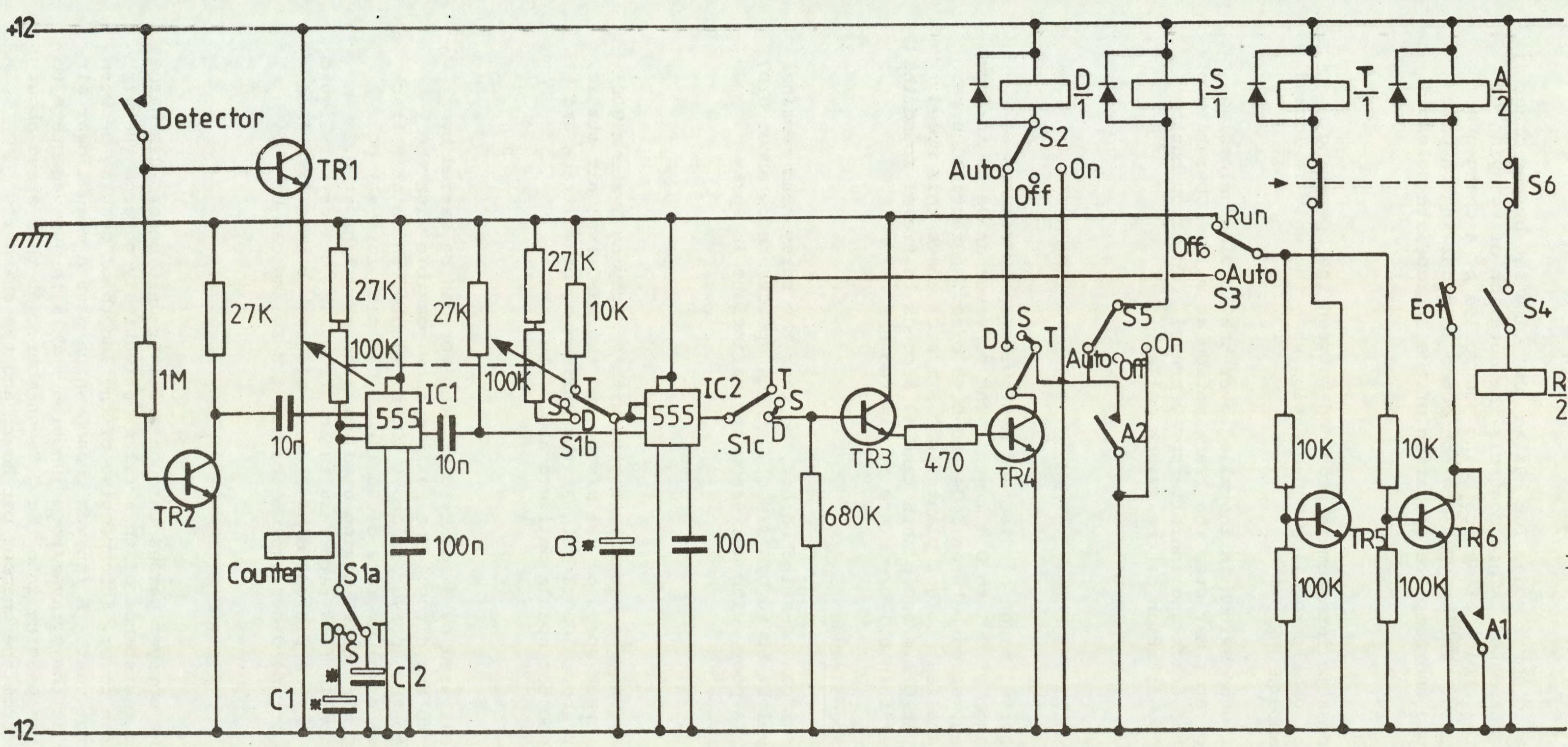


Fig. 6 Sequence controller circuit

SWITCHES

S1 Mode (disc, static, travelling)
S2 Disc shutter
S3 Travel (run position is non-locking)
S4 Track
S5 Spray
S6 Emergency track stop
EOT End of travel microswitch

RELAYS & SOLENOIDS

A Spray hold relay
D Disc shutter solenoid
R Track motor contactor
S Spray solenoid
T Travel solenoid

C1-C3 are selected on test to give correct delay ranges.

In the disc or static spray mode, IC2 has an 'ON' time set by the other half of the ganged potentiometer. This controls the duration of spraying or disc shutter opening, the choice of device being controlled by a changeover contact on the mode switch. TR3 and TR4 are connected as a darlington pair amplifier to ensure rapid and complete operation of the appropriate solenoid.

Miscellaneous features

Intercom A low cost domestic intercom is provided between the operating position and the control panel, to allow conversation when the unit is locked onto an environment chamber.

Safety devices A track stop switch is installed over the loading/unloading aperture so that the operator may stop the track motion at will. Operation of the stop button halts the track and inhibits spray travel. The stop button latches until released by rotation of the switch collar.

PERFORMANCE

Track speed range

To achieve the required range of disc and hydraulic spray volumes we needed a track speed range of 0.1 to 0.4 m/sec. The conveyor drive is in fact capable of running at any speed between 0.04 and 0.46 m/sec. Practical upper limit for all but the smallest target plants is 0.3 m/sec; above this speed plants tend to shake. At 0.1 m/sec plants take 48 seconds to travel round the conveyor so speeds lower than 0.1 m/sec are of limited use.

Spray canister travel speed range

The travel mechanism can be switched off, so that the spray head remains stationary, or can travel at up to 0.5 m/sec. At low speeds, below about 0.07 m/sec, speed stability is poor, with corresponding variations in spray deposit.

Spray volume rates

The hydraulic spray unit is normally fitted with a Spraying Systems 8001 'Teejet' nozzle. At a track speed of 0.1 m/sec, and the mardrive unit static, the nozzle will deliver about 1000 l/ha. At the maximum combined track and travel speed of 0.9 m/sec the nozzle delivers about 110 l/ha.

Disc volume rates

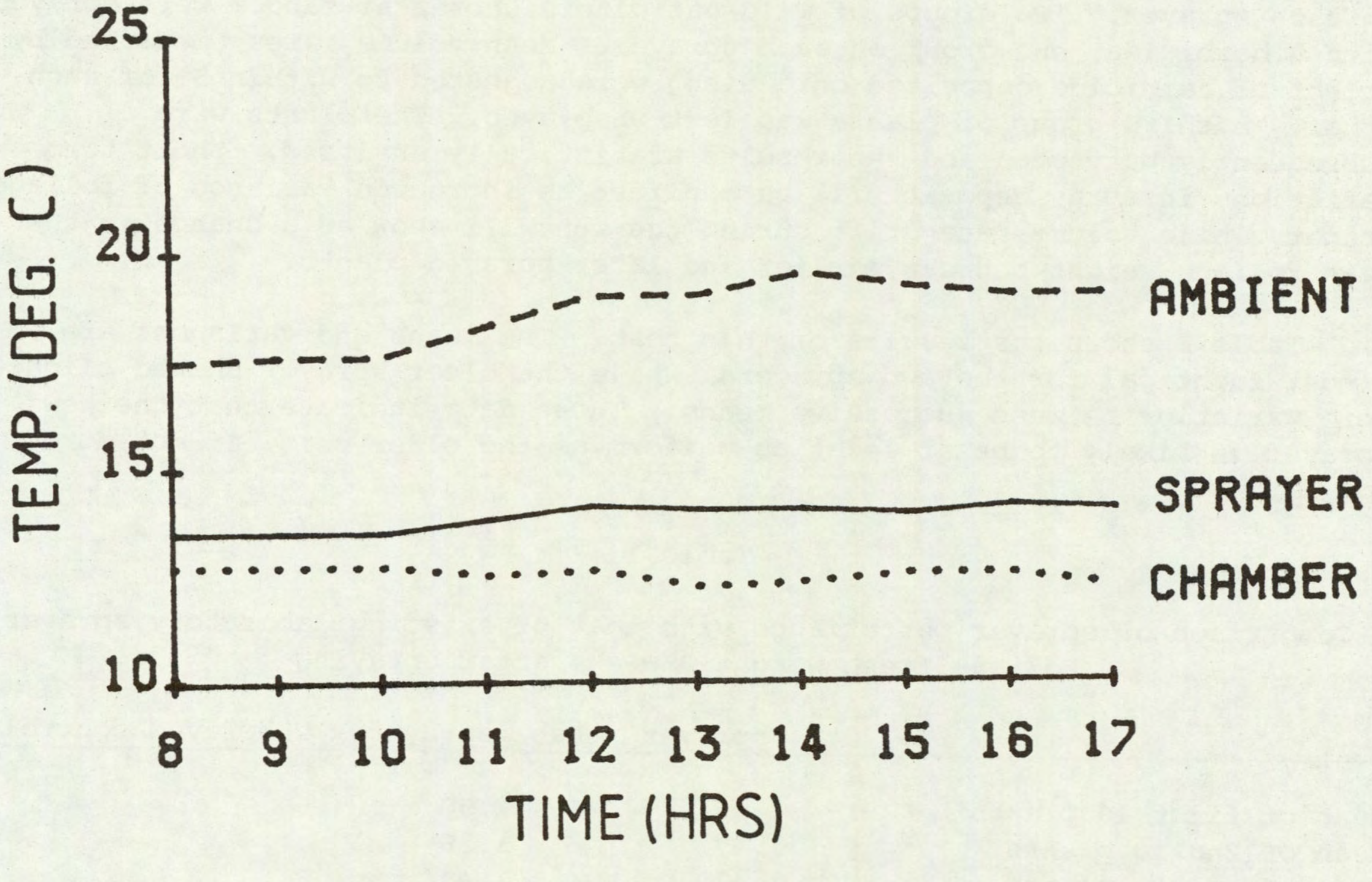
The volume rate delivered by a rotary disc atomizer can be varied by changing the flow rate to the discs. The maximum flow possible with the four-disc unit fitted to the sprayer is about 100 ml/minute, which at a track speed of 0.1 m/sec gives a volume rate of 90 l/ha. The flow rate may be reduced to as low as 20 ml/minute, giving a volume rate of 9 l/ha at 0.2 m/sec. Further reduction in flow rate results in irregular delivery of liquid to the discs, but this may be prevented by closing off one or more disc feed pipes. Using just one of the discs, volume rates of 2-3 l/ha can be produced.

Air flow

The air leaving the sprayer passes through a filter unit before discharge to the atmosphere. The resistance of this filter effectively governs the air flow rate for a given fan power, irrespective of the length of ducting between the sprayer and discharge vent. A fan was chosen which gave a mean linear air velocity of 0.05 m/sec at the sprayer/room junction. This is just adequate to prevent spray vapour from passing into the C.E. chamber. At this speed about 150 m^3 of air is drawn from the chamber per hour, and the chamber's environmental control equipment has sufficient capacity to condition the

Graph 1

SPRAYER TEMPERATURE TEST



corresponding quantity of fresh air drawn in to replace it.

Temperature and humidity

The sprayer draws air from its host room, but is subject to conductive and radiative exchange of heat with its surroundings, and to leakage of air via the track drive. The conditions inside the sprayer are therefore not identical to those in the room, but the plant being sprayed experiences gradual rather than abrupt changes, and the temperature and humidity differences are less than would be experienced if the sprayer was ventilated by ambient air. Graph 1 is an example of the temperature inside the sprayer for given ambient and chamber conditions.

Uniformity of spray deposition

The sprayer was tested under conditions as similar as possible to a typical experiment. It was compared with a travelling boom pot sprayer which had been in use for several years and was generally considered to have satisfactory evenness of spray deposition. The same type of nozzle was used on each sprayer. Two groups of wild oat plants chosen at random were sprayed with a herbicide, one group on each sprayer. Mean volume rates (measured by weight of herbicide deposited on a dish) were adjusted to within 5% of each other. A third group of plants was left unsprayed. The plants were subsequently harvested and the results statistically analysed. Short term variations in spray deposit will be manifest as increased variance of foliage weight, while volume rate drift during the run will show as a change in the mean foliage weight between earlier and later sprayed plants.

Table 1 shows the results of this test. The means and variances are almost identical for the two sprayers, while the older sprayer showed slightly more variation between successive means. These data indicate that the new sprayer is likely to be at least as uniform as the older unit, if not more so.

Table 1

Comparison of sprayer performance with that of existing laboratory sprayer
Foliage fresh weight 3 weeks after spraying

	C.E. sprayer	Lab. sprayer	Unsprayed control
Mean of first 10 plants	1.46	1.50	
Mean of 2nd 10 plants	1.47	1.36	
Mean of 3rd 10 plants	1.41	1.49	
Grand mean	1.45	1.46	5.13
Variance	0.077	0.077	0.45
Coefficient of variation	19.6	19.3	13.3

ACKNOWLEDGEMENTS

The authors would like to thank Mr R. Kibble-White and Mr R.Foddy for their help in the design and construction of the sprayer, and Mr C.J. Stent for the design and assembly of the electronics. Dr J.C. Caseley and Mr C.R. Merritt lent their valuable expertise in the initial design.

APPENDIX

<u>List of suppliers</u>

'Mardrive' pneumatic drive	Marine Engineering Ltd Stockport, Cheshire
'Rex' flexible chain conveyor	LSP Engineers Ltd. Collingwood Ironworks 18 Northdown Street London N.1.
Electronic components	R S Components Ltd P O Box 99 Corby Northants NN17 9RS
Pneumatic components	Enotts Ltd P O Box 22 Eastern Avenue Litchfield, Staffs.

ABBREVIATIONS

ångström	Å
Abstract	Abs.
acid equivalent*	a.e.
acre	ac
active ingredient*	a.i.
approximately equal to*	$\simeq$
aqueous concentrate	a.c.
bibliography	bibl.
boiling point	b.p.
bushel	bu
centigrade	C
centimetre*	cm
concentrated	concd
concentration	concn
concentration x time product	ct
concentration required to kill 50% test animals	LC50
cubic centimetre*	cm^3
cubic foot*	ft^3
cubic inch*	in^3
cubic metre*	m^3
cubic yard*	yd^3
cultivar(s)	cv.
curie*	Ci
degree Celsius*	$^\circ$C
degree centigrade	$^\circ$C
degree Fahrenheit*	$^\circ$F
diameter	diam.
diameter at breast height	d.b.h.
divided by*	÷ or /
dry matter	d.m.
emulsifiable concentrate	e.c.
equal to*	=
fluid	fl.
foot	ft
freezing point	f.p.
from summary	F.s.
gallon	gal
gallons per hour	gal/h
gallons per acre	gal/ac
gas liquid chromatography	GLC
gramme	g
hectare	ha
hectokilogram	hkg
high volume	HV
horse power	hp
hour	h
hundredweight*	cwt
hydrogen ion concentration*	pH
inch	in.
infra red	i.r.
kilogramme	kg
kilo (x10^3)	k
less than	<
litre	l.
low volume	LV
maximum	max.
median lethal dose	LD50
medium volume	MV
melting point	m.p.
metre	m
micro (x10^{-6})	μ
microgramme*	μg
micromicro (pico: x10^{-12})*	μμ
micrometre (micron)*	μm (or μ)
micron (micrometre)*†	μm (or μ)
miles per hour*	mile/h
milli (x10^{-3})	m
milliequivalent*	m.equiv.
milligramme	mg
millilitre	ml

† The name micrometre is preferred to micron and μm is preferred to μ.

millimetre*	mm	pre-emergence	pre-em.
millimicro* (nano: $x10^{-9}$)	n or mμ	quart	quart
minimum	min.	relative humidity	r.h.
minus	-	revolution per minute*	rev/min
minute	min	second	s
molar concentration*	M (small cap)	soluble concentrate	s.c.
molecule, molecular	mol.	soluble powder	s.p.
more than	>	solution	soln
multiplied by*	x	species (singular)	sp.
normal concentration*	N (small cap)	species (plural)	spp.
not dated	n.d.	specific gravity	sp. gr.
oil miscible concentrate	o.m.c. (tables only)	square foot*	ft^2
organic matter	o.m.	square inch	in^2
ounce	oz	square metre*	m^2
ounces per gallon	oz/gal	square root of*	$\sqrt{\ }$
page	p.	sub-species*	ssp.
pages	pp.	summary	s.
parts per million	ppm	temperature	temp.
parts per million by volume	ppmv	ton	ton
parts per million by weight	ppmw	tonne	t
percent(age)	%	ultra-low volume	ULV
pico (micromicro: $x10^{-12}$)	p or μμ	ultra violet	u.v.
pint	pint	vapour density	v.d.
pints per acre	pints/ac	vapour pressure	v.p.
plus or minus*	±	varietas	var.
post-emergence	post-em	volt	V
pound	lb	volume	vol.
pound per acre*	lb/ac	volume per volume	v/v
pounds per minute	lb/min	water soluble powder	w.s.p. (tables only)
pound per square inch*	lb/in^2	watt	W
powder for dry application	p. (tables only)	weight	wt
power take off	p.t.o.	weight per volume*	w/v
precipitate (noun)	ppt.	weight per weight*	w/w
		wettable powder	w.p.
		yard	yd
		yards per minute	yd/min

* Those marked * should normally be used in the text as well as in tables etc.

WEED RESEARCH ORGANIZATION

TECHNICAL REPORTS

(Price includes surface mail; airmail £2.00 extra)

(* denotes Reports now out of print)

6. The botany, ecology, agronomy and control of Poa trivialis L. rough-stalked meadow-grass. November 1966. G P Allen. Price - £0.25

7. Flame cultivation experiments 1965. October 1966. G W Ivens. Price - £0.25

8. The development of selective herbicides for kale in the United Kingdom. 2. The methylthiotriazines. Price - £0.25

10. The liverwort, Marchantia polymorpha L. as a weed problem in horticulture; its extent and control. July 1968. I E Henson. Price - £0.25

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