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A Low Level Radioactivity Monitor for Aqueous Waste

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ABSTRACT

A system is described for continuous monitoring of very low levels of radioactivity in waste water containing typically 3.5 g/l dissolved solids. Spray evaporation of the water enables the dissolved solids to be recovered in the form of an aerosol and collected on a filter tape where the radioactivity is measured by a radiation detector. The advantage of this method compared with a direct measurement is that the attenuating effect of the water is removed and thus greater sensitivity is obtained. Compensation for background and any contamination is achieved by feeding distilled water to the aerosol generator every alternate sampling period and recording the count difference between two successive sampling periods. A printed record of the totalised count difference is obtained once per hour during the integration time of one month. For β radioactivity the minimum values of specific activity measurable extend from $1 \cdot 10^{-6}$ Ci/m^3 to $6 \cdot 10^{-8}$ Ci/m^3 depending on the β end-point energy in the range 167 KeV to 2.26 MeV. The estimated minimum measurable specific α activity is $6 \cdot 10^{-8}$ Ci/m^3.

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1. INTRODUCTION

A common requirement in the radioanalysis of water is the measurement of gross activity of a given kind. Gross activity is defined as the total activity of all radioelements present expressed in terms of a particular radioelement used as a standard of comparison. The standard should have the same geometry as the samples, contain the same weight of the same or similar solids, and be prepared on the same kind of counting dish.

The measurement of activity defined in this way is relatively simple and is used in those cases where it is not required to know the concentration of a given radioelement, or where prior treatments of the water have resulted either in the removal of elements of special significance, or in the assessment of their concentrations.

At AB Atomenergi´s research establishment at Studsvik the effluent water is divided into various categories according to the amount of radioactivity it is expected to contain. A water category of particular interest is the effluent from washrooms, toilets and kitchens which because of its large rate of production and very low specific activity would have made satisfactory monitoring by sampling and subsequent laboratory analysis a very expensive procedure.

The authorities have laid down maxima of $3.6 \cdot 10^{-2}$ Ci/month β activity and $2.4 \cdot 10^{-3}$ Ci/month α activity which may be transported to the sea by the monthly production of $24 \cdot 10^{3}$ m^{3} of water in this category. It is thus necessary to measure specific activities of $1.5 \cdot 10^{-6}$ Ci/m^{3} β activity and 10^{-7} Ci/m^{3} α activity.

The waste water from the various buildings on the site runs through a system of pipes which terminates in a rectangular channel at the Waste Disposal Section and from this channel the water runs into a control tank. Ideally this tank´s discharge valve remains closed until it has been established that the water is safe for dumping into the sea but because of limited tank capacity this situation is rarely realised in practice.

The present method of monitoring the water is as follows. An automatic proportional sampler working on an intermittent cycle pumps water from the rectangular main channel to a hold-up tank.

The sampling rate is about 50 ml/min. so that about 70 litres are collected in the hold-up tank every 24 hours. Once per day a 5 litre sample is taken from the hold-up tank, evaporated to dryness, and the remaining solids are ground to powder. One half gram of this powder is transferred to a planchette and its radioactivity measured with a suitable detector (GM tube for β activity, scintillation detector for α activity).

A standard is prepared by adding a known amount of a Tl^{204} solution to the dust and thoroughly mixing to ensure uniform distribution. When dry, 0.5 g is transferred to a counting dish and a measurement of the increase in count rate due to the Tl^{204} enables the detector to be calibrated.

A second sample is taken daily from the hold-up tank and transferred to another container. At the end of every month the contents of this container are thoroughly stirred before drawing off a 5 litre sample and processing this in the laboratory in the same way as for the daily samples. The result of this measurement gives the total amount of radioactivity disposed during the month, and allowing for decay, will agree with the sum of the radioactivities of the daily tests. Obviously there is a 24 hours delay in reporting the water activity and this can be important near the end of a month if an abnormally high discharge takes place during the course of one day.

In the automatic system to be described spray evaporation of the water enables the dissolved solids to be recovered in the form of an aerosol and collected on a filter paper. The radioactivity of the recovered solids is then measured by a radiation detector. After compensation for background the net count obtained from the collected solids is recorded once per hour. The recorded total count at any given instant of time is a measure of the average specific activity of the water. To obtain the total activity carried away to the sea the mean specific activity as obtained from the monitor must be multiplied by the total volume of water disposed of. This volume is obtained by noting the water level in the proportional sampler hold-up tank. Thus the time delay between sampling of the water and reporting the total activity disposed to the sea is reduced to one hour.

2. SYSTEM

2.1 General description

Fig. 1 is a block diagram of the system. The aerosol is formed in the aerosol generator to which the water is pumped through an atomiser at a constant rate of 1 litre/hour. Compressed air at a pressure of about 5 kg/cm^2 is mixed with the water in the atomiser to produce a spray of fine droplets. Hot, filtered air pumped through the aerosol generator evaporates the water from the droplets and a sample of the resulting finely divided solids is collected on a filter tape. The air flow through the aerosol generator is 0.56 m^3/min. and the outlet temperature is thermostatically controlled at about 115 ^{o}C.

A cyclone filter which was specially designed for these conditions and which has an efficiency of 99 % [1] prevents aerosol particles passing into the heat exchanger and main air pump. The heat exchangers protect the pumps by limiting the inlet air temperatures.

The aerosol sample is extracted isokinetically from the aerosol generator outlet pipe and taken to the collection unit where the aerosol particles are collected on the filter tape. The sample flow rate is 0.056 m^3/min. The collection period is nominally 30 min. after which time the tape moves so that the dust deposit is positioned under a scintillation detector sensitive to β particles. A new collection period is commenced and when the filter tape is again moved forward the first dust deposit comes to rest beneath a scintillation detector sensitive to α particles. The detector pulses are amplified and fed through pulse height discriminators to improve signal-to-noise ratio before reaching the reversible scalers. Scaler counting time is controlled by the timer which can be set for counting times ranging from 1 min. to 28 min.

To compensate for background and any contamination the aerosol generator is fed every other 30 min. period with distilled water. Before counting the deposits collected during these periods the programme unit sets the scalers to the reverse counting mode. After having measured the activity of such a "blank" deposit and that of a dust sample obtained from the water to be monitored, the scalers display a count which represents the activity of the monitored water with background subtracted.

Alarm setting facilities are built into the scalers such that an alarm can be obtained at any pre-determined count, positive or negative. The signal count detected per counting period is less than 1 % of the background count measured over the same time and in order that the alarm be sensitive only to the activity in the dust layer the background is measured during the first 30 min. period and stored in the scaler as a negative number. At the end of the next 30 min. period the scaler total (ignoring statistical variations) will be positive and will correspond with the activity of the dust deposit. This count is printed out by an electromechanical printer. Thus a printed record of the totalised count is obtained once per hour since the scalers are not reset after each counting cycle but accumulate counts over a period of one month.

2.2 Alarm circuits

Two types of alarm are employed. The first, or type 1 alarm, warns of increased specific activity in the water and operates when the total number of counts exceeds the scaler alarm setting. The second, or type 2 alarm, indicates a system fault. Type 2 alarm signals are obtained from the pressostats P_1, P_2 and P_3, and the thermostats T_1, T_2 and T_3 shown in Fig. 1. Separate external circuits are employed in order to distinguish between the two types of alarm. In the event of a type 1 alarm the hold up tank drain valve would be closed (see Fig. 1) and appropriate action taken. For a type 2 alarm an annunciator lamp, corresponding to the particular fault and located on the front panel of the programme unit, lights. In addition certain other precautions may be taken to prevent damage to the equipment (see Table I).

2.3 Sample extraction

A representative sample is ensured by isokinetic sampling of the aerosol at a point on the axis of the tube and distant 5 pipe diameters upstream of a mixing baffle. The recommendations of Stairmand [1] have been followed in the dimensioning of the sampling system which is shown in Fig. 2.

3. PROGRAMMING AND CONTROL

3.1 Normal monitoring sequence

The programme unit controls the collection and measuring sequences. Timing is provided by a synchronous motor (SM1) which drives at a rate of 1 rev/hr an axle upon which are mounted 7 cams, C_1 - C_7. These cams operate microswitches thus generating electrical signals which are used for the control instructions shown in Fig. 3. A second synchronous motor (SM2) which rotates at a speed of 1 rev/min. and which starts in response to a signal from either C_6 or C_7, drives a cam C_8 which supplies 10 volt pulses at a rate of one per minute to the timer which counts them. When the number of pulses counted by the timer equals the preselected counting time the timer stops and closes the signal gate in each channel. On receipt of the "tape feed" signal from the programme unit the tape transport motor is switched on for a time sufficient for the driving axle to make one revolution (58 sec.). Seven seconds after starting the transport motor the vacuum pump is switched off for 22 sec. to enable the filter tape to be moved forward.

The filter tape is unclamped 4 sec. after the driving unit receives the "tape feed" signal and after a short delay (7 sec.) is moved forward 90 mm. Seven seconds after coming to rest the tape is reclamped and a new collection period can commence.

3.2 Facilities

3.2.1 Rapid resetting of programme unit

The synchronous motor SM1 actually drives the axle upon which the cams C_1 - C_7 are mounted through a solenoid operated gearbox having input to output speed ratios of 1:1 and 1:60. The latter speed ratio is selected by the automatic energising of the solenoid at the moment of switching on the mains supply to the programme unit and ensures that the cam axles driven by SM1, SM2, and the tape transport motor rapidly take up the required angular positions prior to commencement of the collection and measuring sequence. The correct phase relationships between these three axles are obtained after a delay period whose max. value is of the order of 2 min. but whose actual value in any given case depends upon the initial relative positions of the axles. During this period the filter tape may be fed forward twice. Once the axles are in their correct angular positions SM1 stops, the solenoid current is switched off, and thus the 1:1 gearbox ratio is regained.

3.2.2 Delayed opening of counting channel gates

During the first half hour after start there are no dust deposits to count and thus the counting gate in each channel is maintained closed until the filter tape has been fed forward and the second collection period begins. The dust collected during the first half hour is now situated opposite the β detector and the gate in this channel is opened so that counting commences. Opening of the α channel counting gate must be inhibited for a further half hour since the first dust deposit does not reach the α detector until 60 min. after start.

3.2.3 Delayed stop instruction

Since the amount of filter tape which can be accommodated in the collection unit is sufficient for one weeks operation, and the normal integration period for the measurement is one month, a facility is provided whereby the programme unit may be stopped half way through a tape feed operation so that the movable cone J (Fig. 4) is at its max. distance from the filter tape.

The used roll of filter tape can then be replaced by a fresh one. When the programme unit is restarted the second half of the tape feed operation is completed and about one minute later the filter tape is fed forward again.

Counting is inhibited in both channels until one hour after restart in order that the original counting sequence may be continued; counting of two samples of contaminated water could otherwise easily occur and cause discontinuity and error of measurement. Loss of data during this delay period is not serious.

The delayed stop instruction is generated by placing the appropriate switch (located on the front panel of the programme unit) in the "delayed stop" position anytime between tape feed operations; the programme unit will stop half way through the next tape feed operation as described above.

3.2.4 Tape feed instruction

After having changed a roll of filter tape and before restarting the programme unit, the filter tape can be checked for correct tracking by means of the "tape feed" switch mounted on the programme unit front panel. The switch is spring loaded and must therefore be held in the "on" position. The filter tape will move forward in a succession of normal tape feed movements. Measuring elapsed time from the instant of operation of the "tape feed" switch, there will be an 11 sec. delay followed by a tape feed movement lasting 15 sec., then a 45 sec. delay, tape feed, etc. until the switch is released when the transport unit will stop in the normal position, i.e. with clamped filter tape.

4. COLLECTION AND DETECTION UNIT

The following description refers to Fig. 4. The filter paper which is in the form of a 65 mm wide tape, passes from the supply spool A under a tracking spool B, over the large roller C and guide plate D, then under the large roller E and onto the take up spool F. The two guide rollers G and H are gear driven from the rollers C and E and rotate with the same peripheral speed as these rollers, which are geared together so that they rotate with indentical speeds.

A spring mechanism holds the take up spool F in contact with the guide roller H so that when the rollers rotate the take up spool is friction driven by H. For neoprene rubber O rings protrude about 1 mm above the curved surface of the roller H; their function is to provide enough friction to ensure that the filter paper is tightly wound onto the take-up spool F.

The collection area is defined by the line of contact of the bases of two conical tubes: one fixed, the other movable. When an aerosol sample is being collected the filter paper is clamped by the movable tube J and the guide plate D which is perforated over a circular area corresponding to the base area of the conical tubes. In addition to providing support for the filter tape the guide plate D also maintains a constant distance between filter tape and the radiation detectors K and L. The distance between the horizontal axes of the detectors is equal to the distance between the horizontal axis of detector K and the common horizontal axis of the two conical tubes.

The driving motor, which is situated behind the mounting plate S, drives a disk M upon which is fixed an eccentric pin N. The gear wheel T is gear driven from the same axle and drives the arm P which in turn moves the conical tube J in and out along its horizontal axis.

The large rollers C and E are rotated one quarter revolution for each revolution of the motor axle. One quarter revolution of the rollers C and E corresponds with the distance between the axes of the detectors K and L. The movement is transmitted by a "maltese cross" Q which ensures gradual acceleration and deceleration of the rollers to minimise the stress set up in the filter tape.

In Fig. 4 the maltese cross, the disk M, and the operating arm P are shown in the positions occupied when an aerosol sample is being collected. On the arrival of an intitiating pulse from the programme unit the drive motor is started and rotates through 24.8° before a step on the operating arm hinge engages with a corresponding step on the cone retracting arm R and the filter tape is unclamped by the cone J beginning to move away, see Fig. 10.

After a total angular rotation of 47.3° the vacuum pump is switched off by a microswitch operated by cam II (Fig. 4). When the total angle of rotation is 69.8° the eccentric pin N engages with the maltese cross Q and sets the tape transport mechanism in motion which moves the filter tape a distance of 90 mm in 15 sec. so that the collected aerosol sample comes to rest opposite the β detector K.

When the filter tape comes to rest the total angle through which the motor axle has rotated is 159.8°. At 182.3° total angular rotation the vacuum pump is switched on, and at 204.8° total rotation the step on the operating arm hinge loses contact with the step on the cone retracting arm hinge and the cone J reclamps the filter tape. The motor continues to rotate until one whole revolution has been completed and is then switched off by a microswitch operated by cam I.

The hinge delay mechanism is employed in order i) to maximise the sampling time per measuring cycle by reducing to a minimum the time for which the vacuum pump is switched off, and ii) to reduce the time for which unfiltered air from the surroundings is drawn through the filter tape during the intervals between unclamping the tape and switching off the vacuum pump, and switching on the vacuum pump and clamping the tape.

The end of the shaft which drives the large roller E is shaped to engage with a diametral slot in the end of the roller axle. This axle is spring loaded and may be disengaged from the driving motor by lifting and turning through 90° the small knob W situated in the centre of the thumb wheel V mounted on the roller E.

When disconnected from the driving motor, the tape transport mechanism can be driven manually by means of the thumb wheel. This is necessary when changing the roll of filter tape as the end of the new roll must be threaded over and under the respective rollers and attached to the take-up spool.

A scraper U mounted beneath and in contact with the roller H ensures that dust does not build up on this roller and impair the operation of the transport mechanism.

Access to the tape transport mechanism, radiation detectors, and collection system is by means of a light tight door at the front of the cabinet. The space between door and front surface of the mounting plate forms a sealed compartment. The driving unit is supplied with its own protective cover but is otherwise freely accessible from the near of the cabinet. The complete unit comprising transport mechanism, driving unit, collection system and radiation detectors is suitable for mounting in a standard 19" rack.

5. EXPERIMENTAL

5.1 Filter paper

Glass fibre paper in the form of a 65 mm wide tape and with a breaking strength of 68 g/mm^2 was chosen as dust collection medium as it displayed no change of dimension or weight when subjected to the hot, humid aerosol stream.

Activated water samples were fed to the aerosol generator and the effect of dust penetration of the filter paper was measured for various thickness of the dust deposit (at constant activity). In Fig. 5 the results are expressed in terms of the variation of β count rate with thickness of the dust layer for S^{35} and Y^{90}. From the figure it is evident that for thicknesses in excess of 1 mg/cm^2 self absorption in the dust layer predominates.

5.2 Thickness of dust layer

The thickness of the dust deposit was determined by measuring the increase in weight of a piece of filter tape used to collect the dust from an aerosol sample extracted isokinetically from the aerosol generator output pipe. The air flow rate through the filter paper was one tenth that through the aerosol generator. This procedure was repeated a number of times and the weight of dust deposit was found to be 17 ± 0.4 mg for a collection time of 30 min. Since the diameter of the deposit is 5 cm the dust thickness is 0.865 mg/cm^2.

5.3 System response time

The speed of response of the system to a sudden change at the aerosol generator input was measured as follows.

Dust from waste water was generated for 5 min. after which time the inlet tube to the feed pump was switched over to the distilled water container. By allowing a short column of air to enter the inlet tube during water changeover it was possible to observe (through the transparent feed tube) when the distilled water reached the aerosol generator. At this instant the "tape feed" switch on the programme unit was moved to the "up" position and held there for about 5 sec. thus causing the cone J in the collection unit to retract and the vacuum pump to stop. A weighed piece of filter paper was inserted between the cone and the guide plate and held in position until the cone returned and clamped it. By operating the "tape feed" switch as described above 53 sec. after restart of the vacuum pump the filter paper could be withdrawn and a fresh piece inserted before the cone J returned to the clamping position. The resultant collection time for the sample was thus 60 sec. (see Fig. 7).

This procedure was repeated until 3 samples of the aerosol had been obtained during the first 4.5 min. after water changeover.

Reweighing the samples enabled the weights of dust collected to be determined.

A similar procedure was followed for the changeover from distilled water to waste water (Fig. 6).

From Figs. 6 and 7 it is seen that a) for both cases the response time was 140 sec. measured from the instant of operating the "tape feed" switch, and b) the duration of the first sampling period was in fact only 30 sec. because of the delay between the instant the waste water reaches the atomiser and the instant the aerosol appears at the sampling nozzle. This delay is one minute.

5.4 Background measurements

5.4.1 Leak testing

The natural airborne α radioactivity was used as a tracer since the low detector background (~ 15 cph) made this a sensitive method. Glass fibre filter paper of the same type as used in the collection unit was used to filter the aerosol generator inlet air. Air drawn through the aerosol generator was sampled by the collection unit and the α radioactivity measured by the α detector. A counting time of 25 min. was used and the count displayed at the end of each such period was noted. A number of these measurements were made and the mean count determined.

This procedure was carried out for the following cases:

a) air drawn through aerosol generator before all leaks were sealed

b) air drawn through aerosol generator after all leaks sealed

c) air drawn through a separate glass fibre filter in series with a delay volume equal to the volume of the aerosol tank,

and d) unfiltered air drawn direct into the collection unit.

The arrangement c) described above was easily made leak tight and was used to measure the effectiveness of leak sealing of the aerosol generator. The results are set out in Table II.

5.4.2 Contribution from compressed air supply

When the compressed air supply to the atomiser was turned on the α count for case b) above was more than doubled. Insertion of a 50 mm diameter glass fibre filter paper in the air line reduced the α count to about the same level as that obtained before the compressed air was turned on, see Table II.

5.4.3 Background under operating conditions

The aerosol generator was run at an output temperature of 115° and using distilled water during consecutive sampling periods the mean α count was found to be insignificantly different from that obtained from the cold test described under 5.4.2.

5.4.4 β background

The effect of filtering the aerosol generator inlet air was barely observable in the β channel because of the β detectors relatively high background (cosmic + γ radiation). A mean background level of 1600 counts/25 min. was measured. Variations of the order of 10 % of this value occurred and usually corresponded with the variations of the natural airborne radioactivity.

5.5 Sensitivity

5.5.1 Test with activated waste water

A ten litre sample of waste water contained in a polythene flask was activated with Y^{90} (containing 20 μg/g YCl_3 stable carrier) such that the specific activity was $51 \cdot 10^{-6}$ Ci/m^3. This water was then fed to the aerosol generator and the system response is as shown in Fig. 8 together with the corresponding background values. An initial rising portion of the response curve indicates loss of active material to surfaces [2] with which the water comes in contact before reaching the atomiser. Measurements were continued throughout the day (6 values) and were recommenced the following morning after the equipment had stood idle overnight. As Fig. 8 shows the rate of dimunition of count rate, measured over a period of 24 hours, seems to be more rapid than can be accounted for by the decay rate of Y^{90} alone. This is presumably due to overnight adsorption of the yttrium by the walls of the polythene flask.

When a supply of inactive waste water was substituted for the active waste water the counting rate fell rapidly to return almost to background level after two hours.

The sensitivity to Y^{90} as calculated from the last 4 measured values of count rate obtained on the first day of the test is $8.3 \cdot 10^4$ cps/Ci/m^3 and the corresponding figure as calculated from the first 3 measured values of count rate obtained on the second day is $7.5 \cdot 10^4$ cps/Ci/m^3.

In Fig. 8 it is clearly seen that the background varied slightly during the experiment but as no independent measurement of the natural background was made it is impossible to correlate this variation with effects imposed by the experiment.

5.5.2 Minimum measurable specific β activity

The sensitivity to S^{35}, based on the results of an earlier measurement [3], was found to be $5 \cdot 10^3$ cps/Ci/m^3 and the sensitivity to Tl^{204} is $2 \cdot 10^4$ cps/Ci/m^3.

From these values of sensitivity minimum measurable specific activities were calculated using the method of reference [2]. Fig. 9 shows the minimum measurable specific activity as a function of β end-point energy for a total integration time of 1 month.

5.5.3 Minimum measurable specific α activity

No direct calibration of the α channel has yet been carried out, but the estimated minimum measurable specific activity is $6 \cdot 10^{-8}$ Ci/m^3. This estimate is based on a measured mean background rate of 2 c.p.m. for the detector used in this system, and a sensitivity of $1.25 \cdot 10^4$ cps/Ci/m^3 as obtained for an α detector of similar construction.

5.6 Comparative measurements

Dust taken from the cyclone filter was counted using the same technique and equipment (see Introduction) as for the normal manual sampling routine. The dust samples from the cyclone were taken after the monitor had been in operation for periods of 3 days and 10 days respectively. Dust samples prepared by the conventional technique were obtained from a mixture of the daily water samples so that an average value of net counting rate was obtained for the appropriate period.

Table III shows that close agreement exists between the two methods, and thus no significant loss of active material occurs during the continuous monitoring process.

5.7 Calibration

A direct calibration of the β channel was made by relating the total counts recorded during the 10 day test with the average specific activity of the water for the period as determined by the manual method.

Fig. 11 illustrates the build up of counts with time. From this curve it was found that a rate of increase of 6 c.p.h. corresponds with a mean specific activity of 10^{-7} Ci/m^3.

The system measures specific activity only and since the daily effluent water production rate is by no means constant the total activity t hours after commencement of a monitoring sequence is the product of the mean specific activity and the total volume of water disposed of, i.e.

$$A = \bar{\rho} \sum_{t=1}^{720} v_t$$

Now $\bar{\rho}$ at time t hours after start is given by

$$\bar{\rho} = \frac{N_t \cdot k}{t}$$

Hence

$$A = \frac{kN_t}{t} \sum_{t=1}^{720} v_t$$

and since k has been found to be $\frac{1}{6} \cdot 10^{-7}$ then

$$A = \frac{1}{6} \cdot 10^{-7} \frac{N_t}{t} \sum_{t=1}^{720} v_t$$

The total volume of water disposed of t hours after start of a monitoring sequence is obtained by noting the height of the water in the proportional sampler hold-up tank, and since t is known and N_t is displayed by the monitor the total activity is readily obtained.

6. CONCLUSION

There are no memory effects in the system as described and for a given detector the net counting rate from the dust produced by the aerosol generator is the same as is obtained from dust produced by the present manual method.

A specific β-activity of $1.5 \cdot 10^{-6}$ Ci/m^3 corresponds to the maximum allowable total β-activity of $3.6 \cdot 10^{-2}$ Ci/month which may be transported to the sea by effluent of this category. This specific activity also corresponds with a total monthly count of 64800. An alarm level set at 40000 counts should therefore give sufficient warning.

Two commercial water monitors, Landis & Gyr type D51 and Frieseke & Hoepfner type FH59, are comparable with the system described as regards minimum measurable specific activity but have effective integration times of the order of 10 mins.

In the Landis & Gyr instrument the water to be monitored is sprinkled onto a slowly moving filter tape. Heat is applied to the underside of the tape to evaporate the water thus leaving a dry residue which is scanned by a radiation detector. The Frieseke & Hoepfner instrument, in common with the system described in this report, makes use of the spray drying principle but in contradistinction to this system, employs full flow filtering.

Apart from the fact that the detectors in these commercial instruments are well screened (β background ca. 15 cpm for both systems) no corrections are made for variations in the background counting rate caused by contamination or fluctuations in the external background.

For the system described in this report an effective integration time of 15 days is required in order to measure $5.25 \cdot 10^{-8}$ Ci/m^3 ($E_{\beta_{max}} = 2.26$ MeV). This time could be considerably reduced by improved detector design, better shielding to reduce background from the present 90 cpm (β detector) to about 20 cpm, and by full flow filtering, i.e. collecting on the filter all the dust produced by the aerosol generator instead of only 10 % of it as currently practised. Full flow filtering conditions cannot be realised with the present system since it is not possible to operate the aerosol generator with an air flow less than 500 l/min.

instead of only 10 % of it as currently practised. However, full flow filtering conditions cannot be realised with the present system since it is not possible to operate the aerosol generator with an air flow less than 500 l/min.

These improvements should result in an integration time of the same order of magnitude as that used with the commercial instruments mentioned above. However, for a given value of minimum measurable specific activity the system described must inevitably have an integration time $\sqrt{2}$ times greater than these commercial systems because of the continuous background correction feature.

Haberer [4] has surveyed the performance of various water monitoring systems, special attention having been given to the spray drying and evaporation methods. He has assumed a constant background counting rate but has not investigated to what extent contamination of the equipment modifies this assumption. Neither has the question of loss of active material to surfaces been considered. Such losses have been observed (see section 5.5.1 of this report) and can be quite considerable [2].

The mode of operation used in the system described was chosen in order to minimise the build up of contamination on components and the consequent variation in background counting rate, as well as to compensate for external background variations. The indications are (see section 5.5.1) that these aims have been fulfilled.

TABLE I

Precautions taken in the event of an equipment fault

Detector	Quantity sensed	Fault	Precaution
P_1	Air pressure at the spray unit	Pressure less than 5 kg/cm^2	1. Air heater switched off 2. Water feed pump switched off 3. Main pump switched off
T_1	Aerosol generator output temperature	This thermostat has controlling function only, i.e. maintains output temperature between 110° - 120° C.	
P_2	Main circuit air flow	Too low	1. Air heater switched off 2. Water feed pump switched off 3. Main pump switched off
T_2	Main circuit air temperature at input to pump	Too high	1. Air heater switched off 2. Water feed pump switched off 3. Main pump switched off
P_3	Sampling circuit air flow	Too low	1. Vacuum pump switched off
T_3	Sampling circuit air temperature at input to vacuum pump	Too high	1. Vacuum pump switched off

TABLE II

Use of the α background as a measure of leak tightness

Conditions of measurement		Counts per 25 min.
a	Filtered air from aerosol generator before leaks sealed	1000
b	Filtered air from aerosol generator after all leaks sealed	60
c	Filtered air through delay volume	32
d	Unfiltered air direct	1590
e	As for case (b) above plus unfiltered compressed air	148
f	As for case (b) above plus filtered compressed air	52
g	Actual running conditions	40

TABLE III

Comparison of count rates from dust samples prepared by manual and automatic methods

Present manual method	Monitor	Remarks
c.p.m.	c.p.m.	
2.93 ± 0.42*	3.89 ± 0.64*	Average values for period June 6 - June 9
3.20 ± 0.44*	3.16 ± 0.44*	Average values for period June 12 - June 22

* Note: Errors are one standard deviation

NOMENCLATURE

		unit
A	total activity	Ci
c.p.h.	counts per hour	$(\text{hour})^{-1}$
k	a calibration constant	$\text{Ci/m}^3.\ (\text{c.p.h.})$
N_t	recorded count at time t	-
$\bar{\rho}$	mean specific activity of effluent	Ci/m^3
t	time elapsed since start of monitoring sequence i.e. number of complete counting periods	hour
v_t	volume of effluent produced during the t^{th} hour after start of monitoring sequence	m^3

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FIGURE CAPTIONS

Fig. 1	System block diagram
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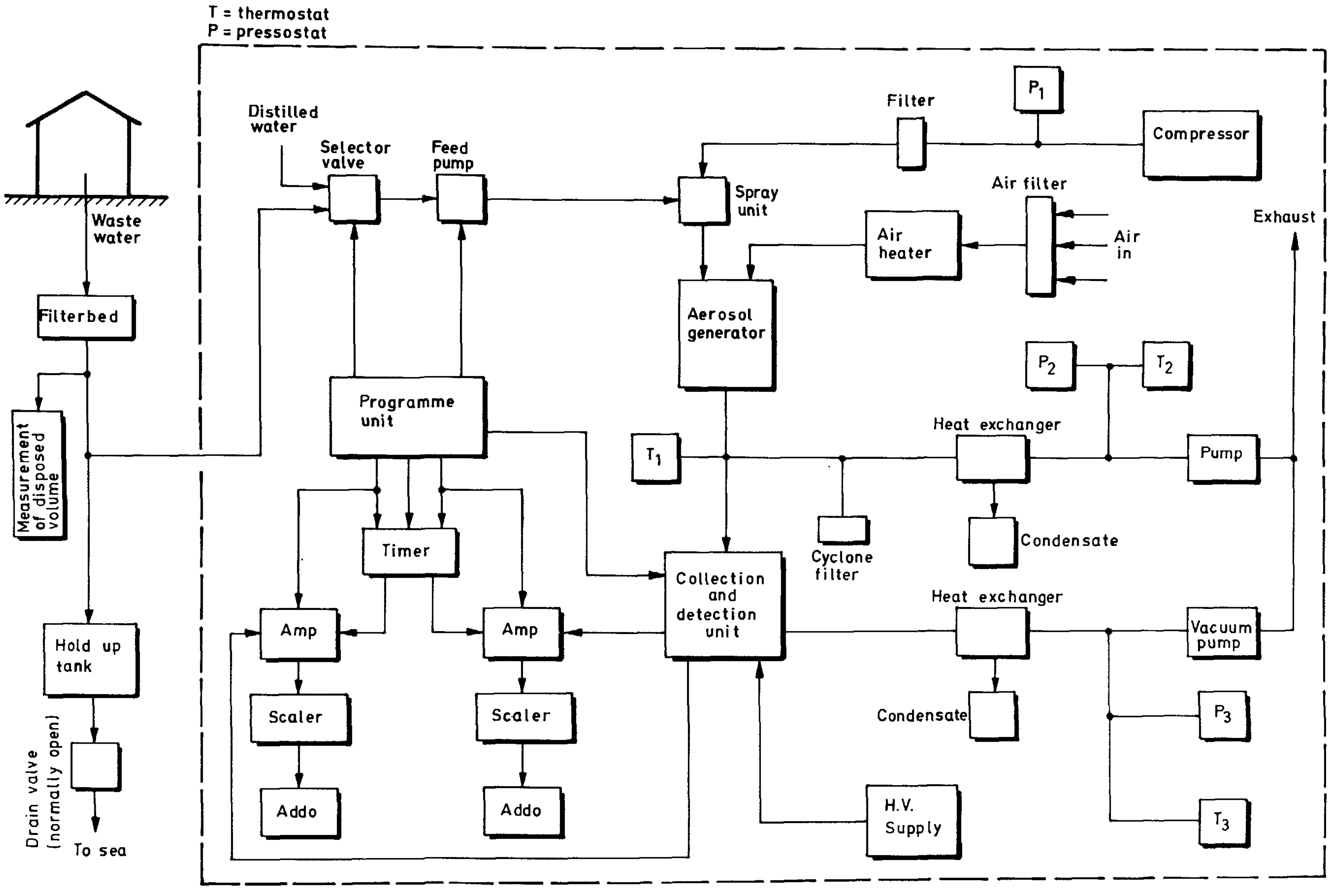


Fig. 1 SYSTEM BLOCK DIAGRAM

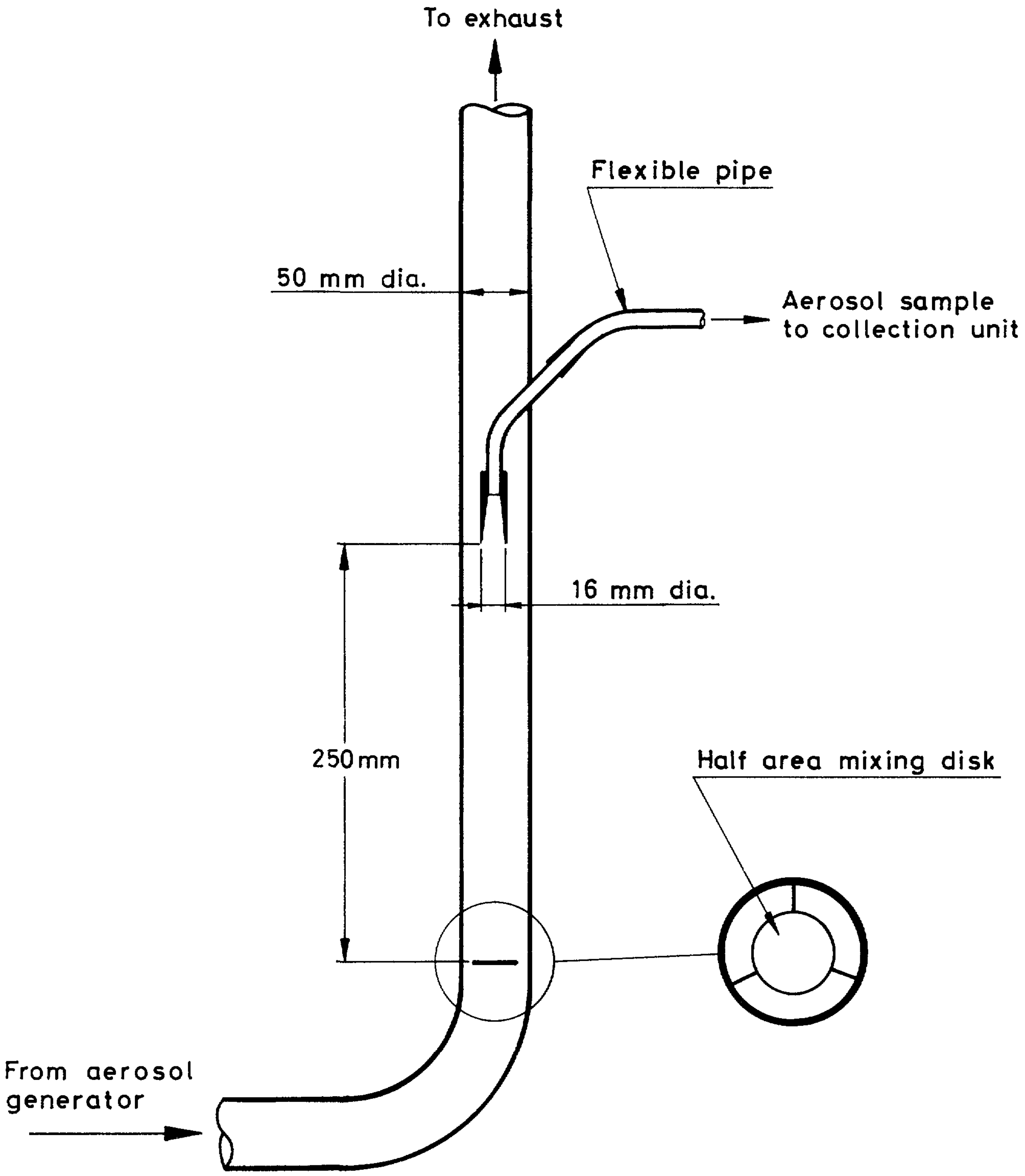


Fig. 2 SAMPLE EXTRACTION

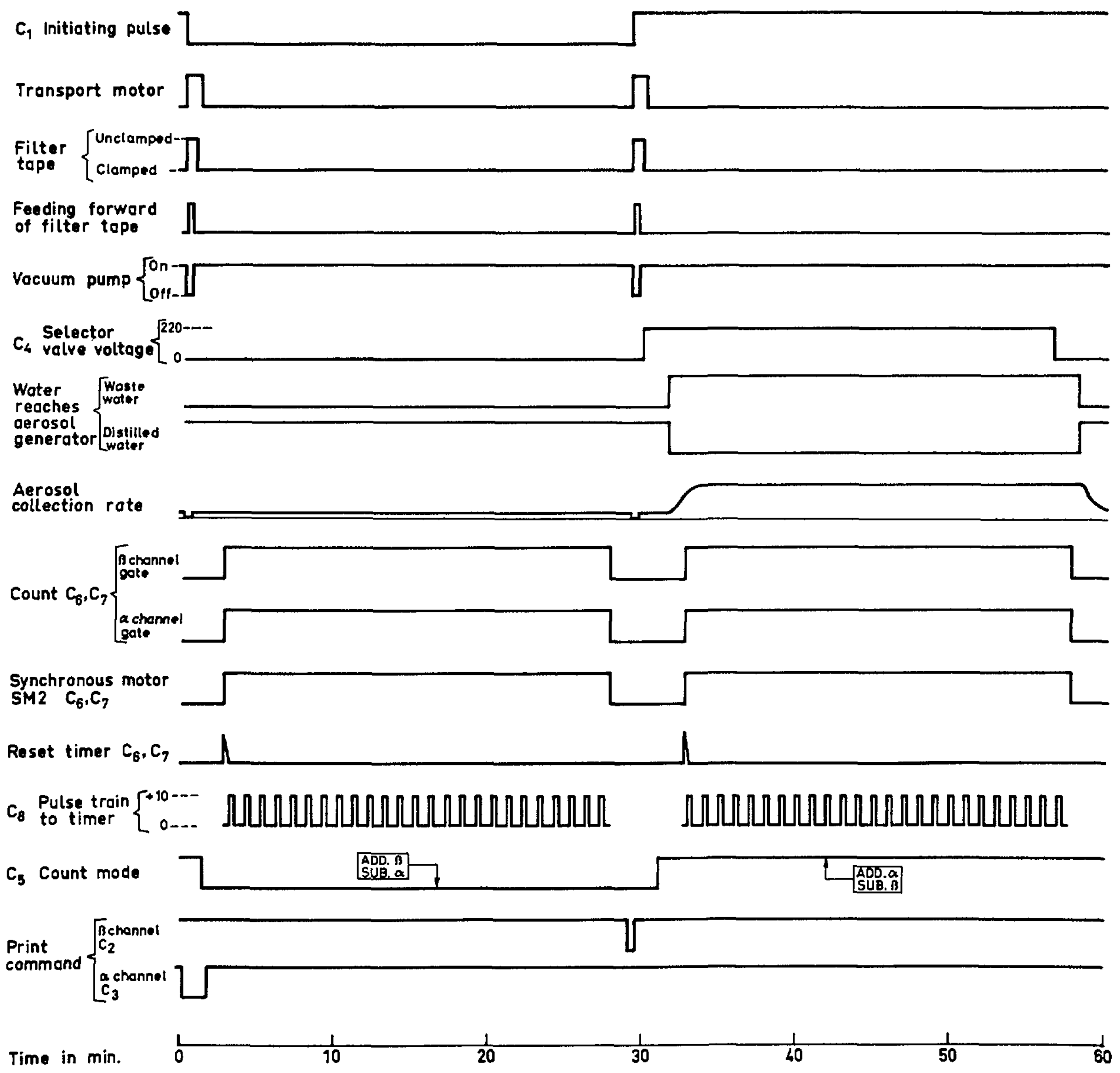
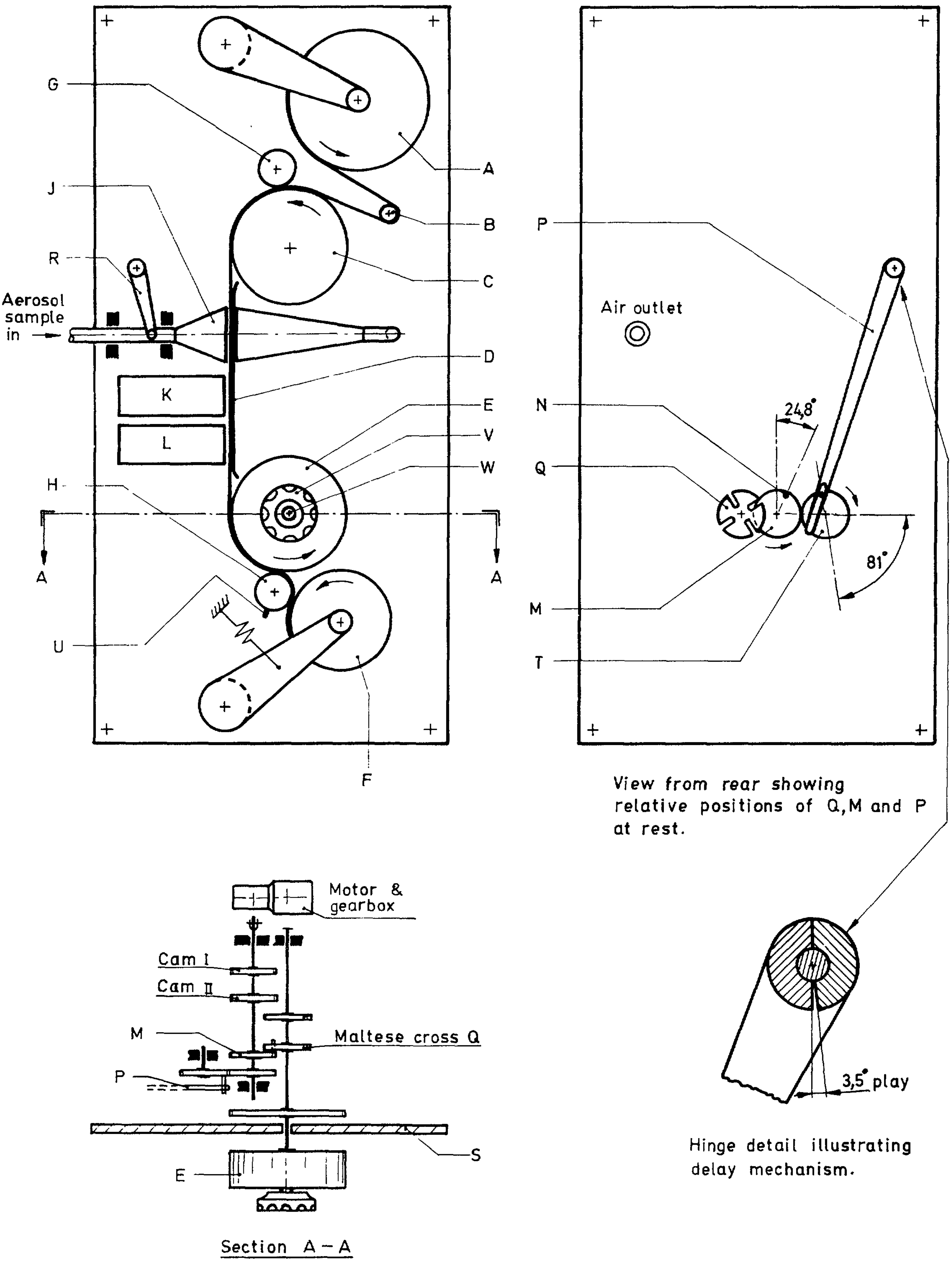


Fig. 3 TIMING DIAGRAM



View from rear showing relative positions of Q, M and P at rest.

Section A – A

Hinge detail illustrating delay mechanism.

Fig. 4 COLLECTION AND DETECTION UNIT

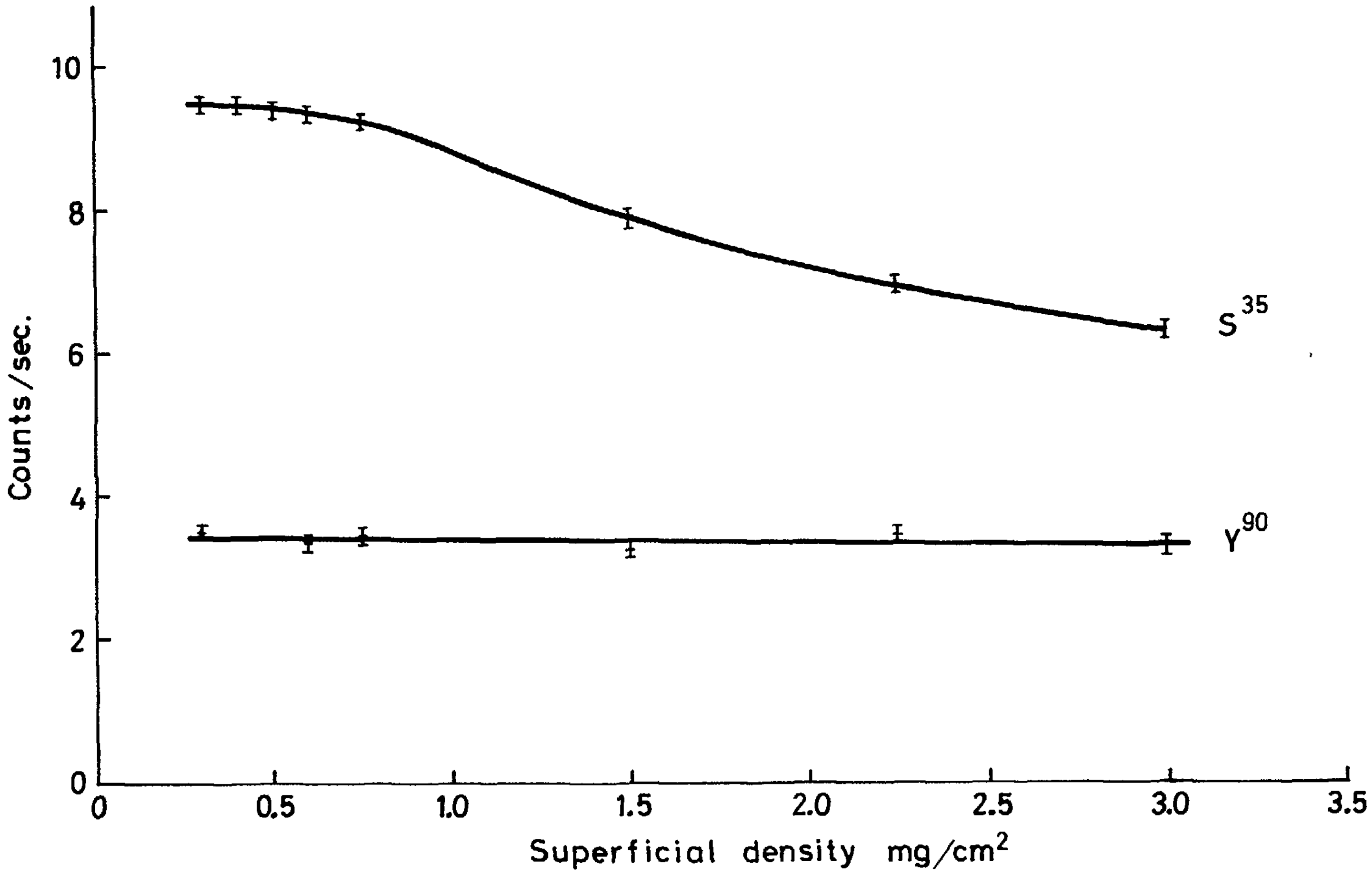


Fig. 5 SELF ABSORPTION CURVES FOR THE DUST LAYER

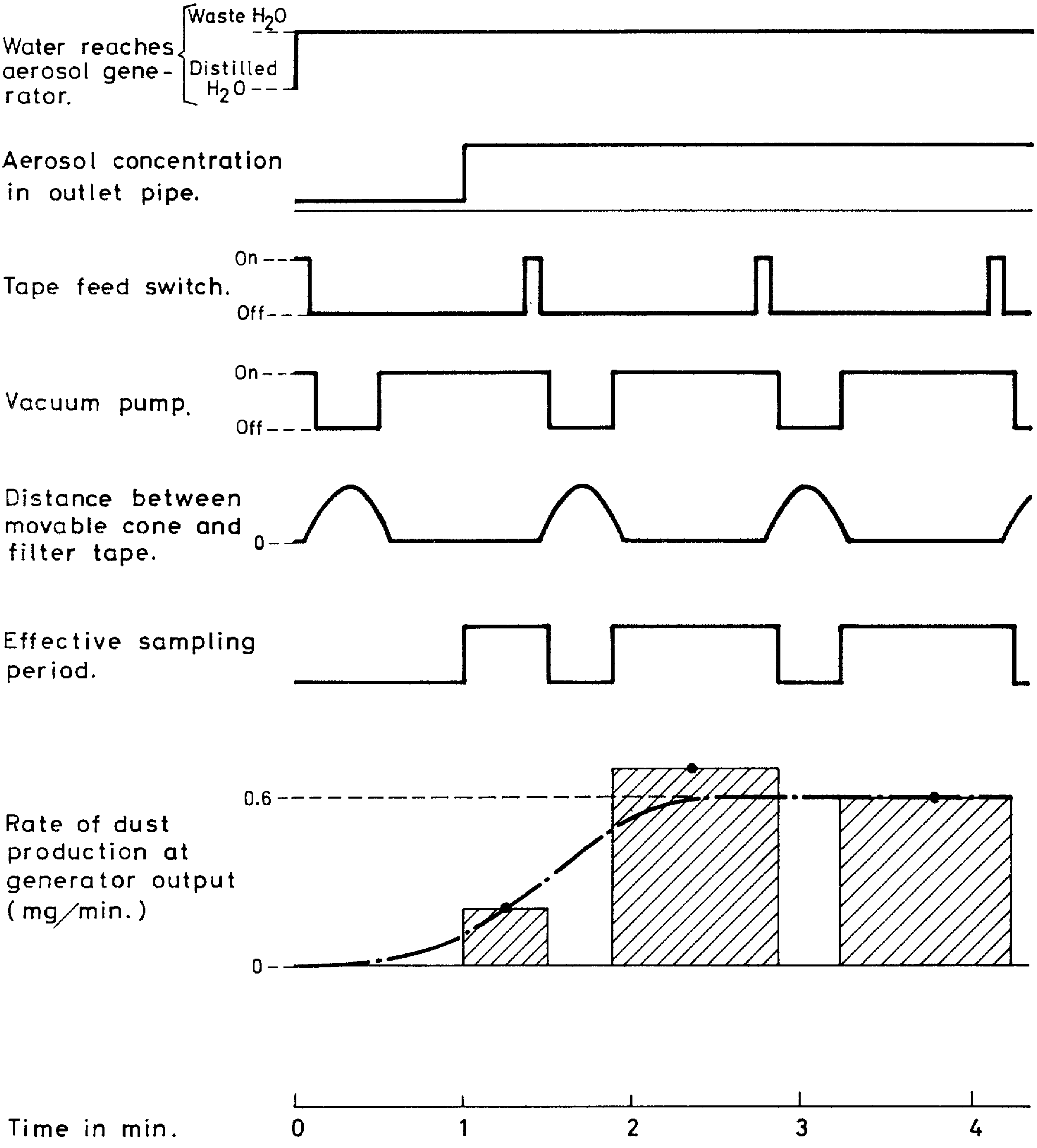


Fig. 6 RESPONSE OF SYSTEM TO CHANGE FROM DISTILLED WATER TO WASTE WATER

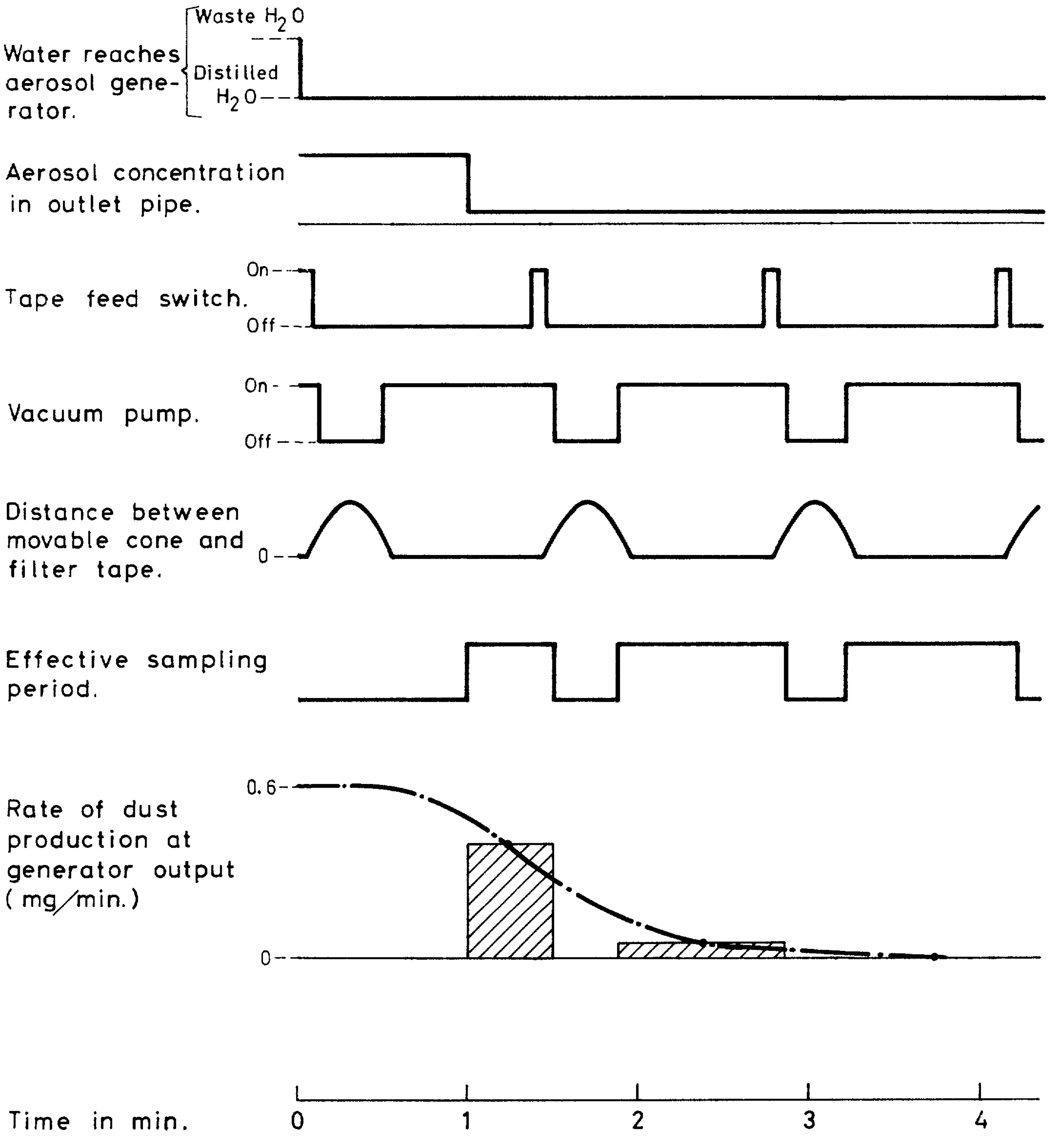


Fig. 7 RESPONSE OF SYSTEM TO CHANGE FROM WASTE WATER TO DISTILLED WATER

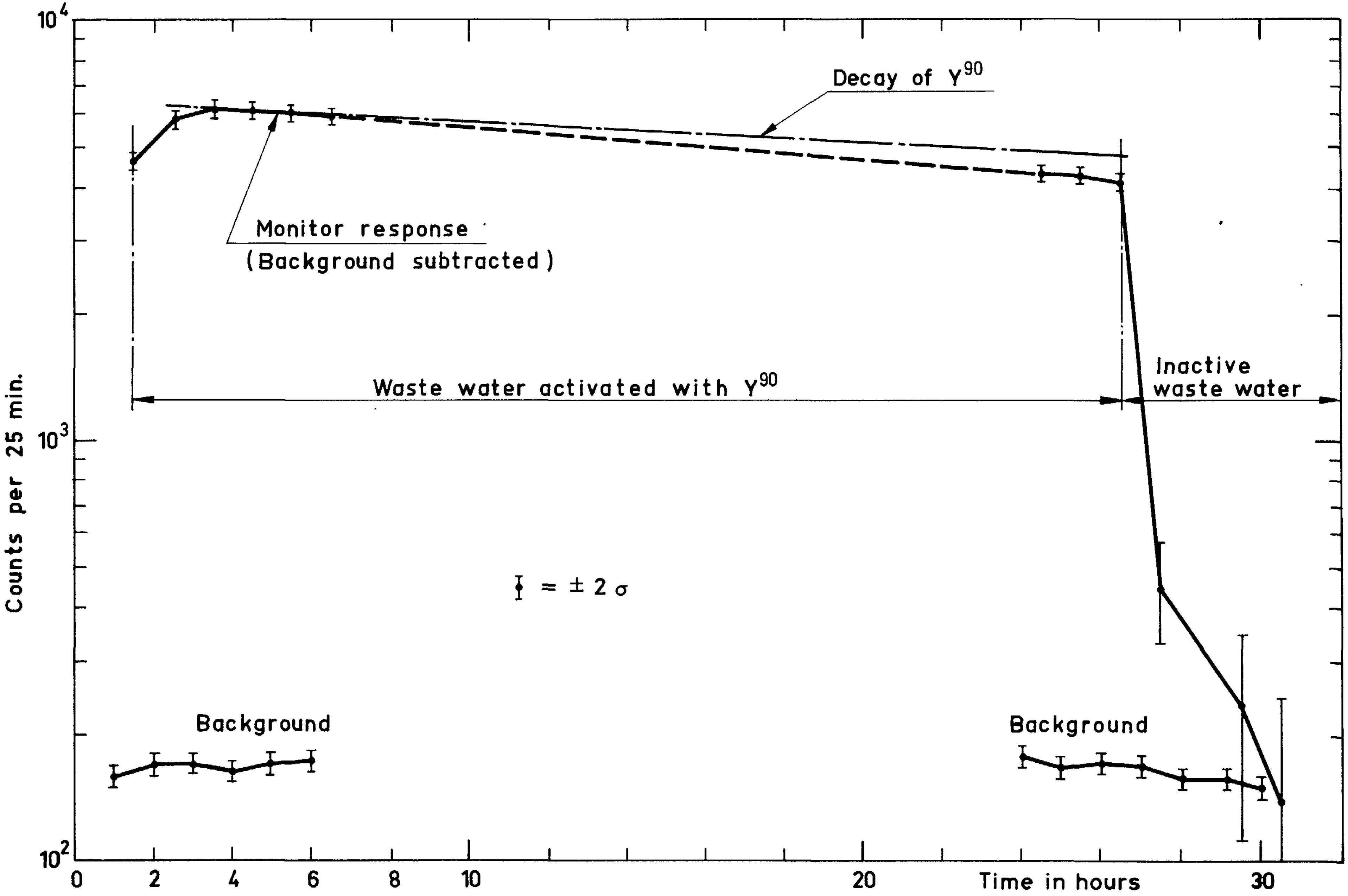


Fig. 8 MEASUREMENT OF SENSITIVITY TO Y^{90}

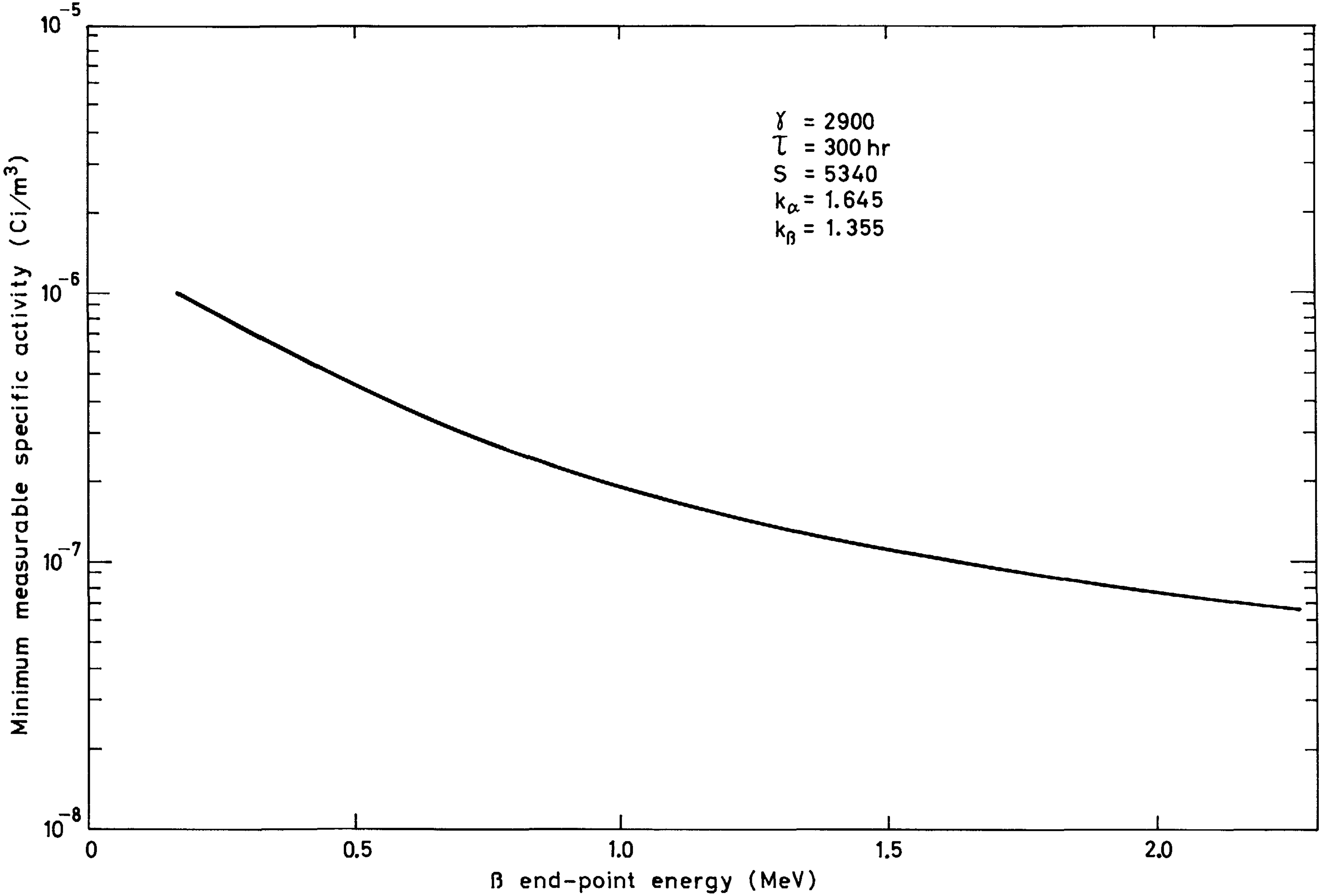


Fig. 9 MINIMUM MEASURABLE SPECIFIC ACTIVITY AS A FUNCTION OF β END-POINT ENERGY

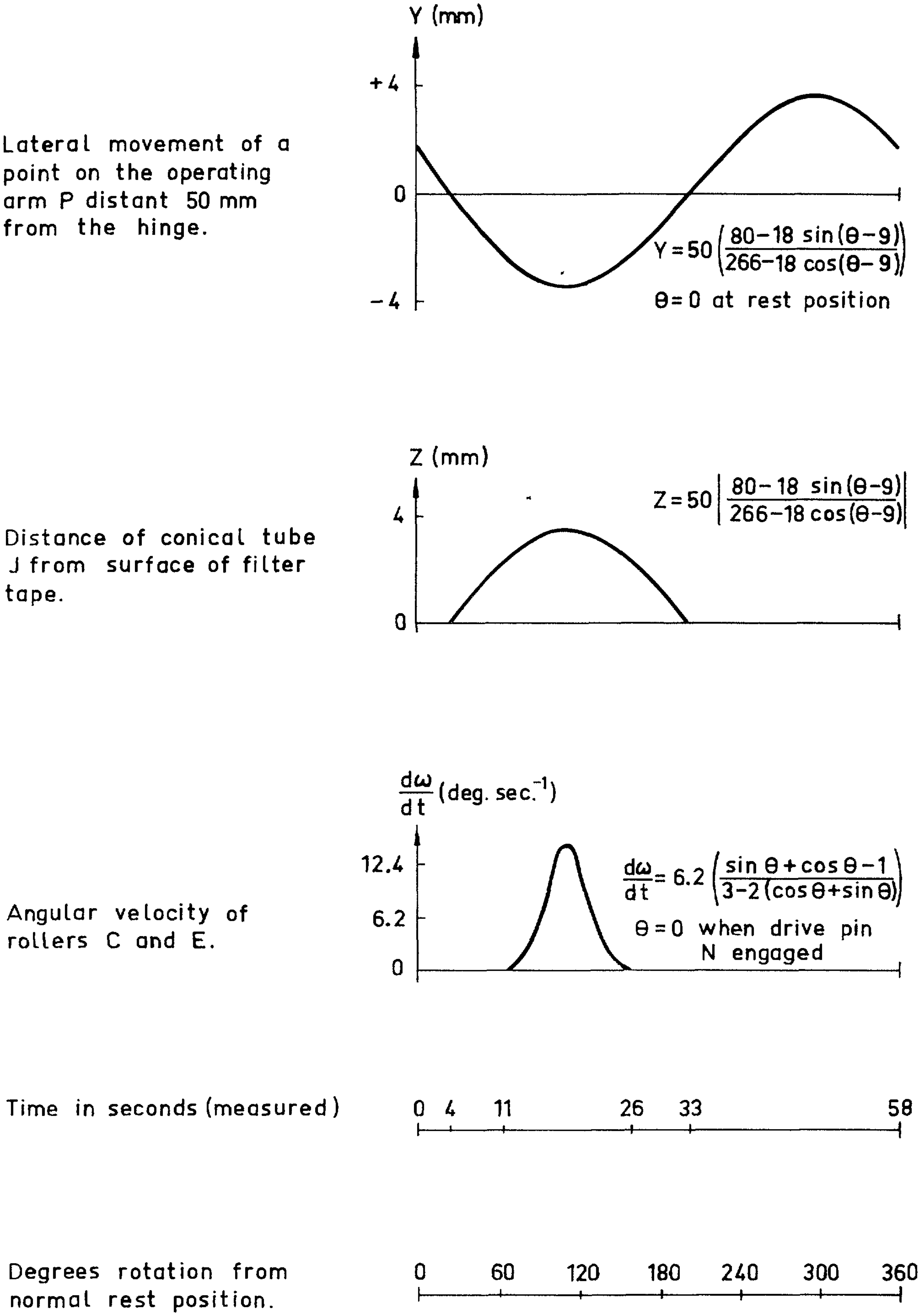


Fig. 10 EQUATIONS OF MOTION FOR TAPE TRANSPORT MECHANISM

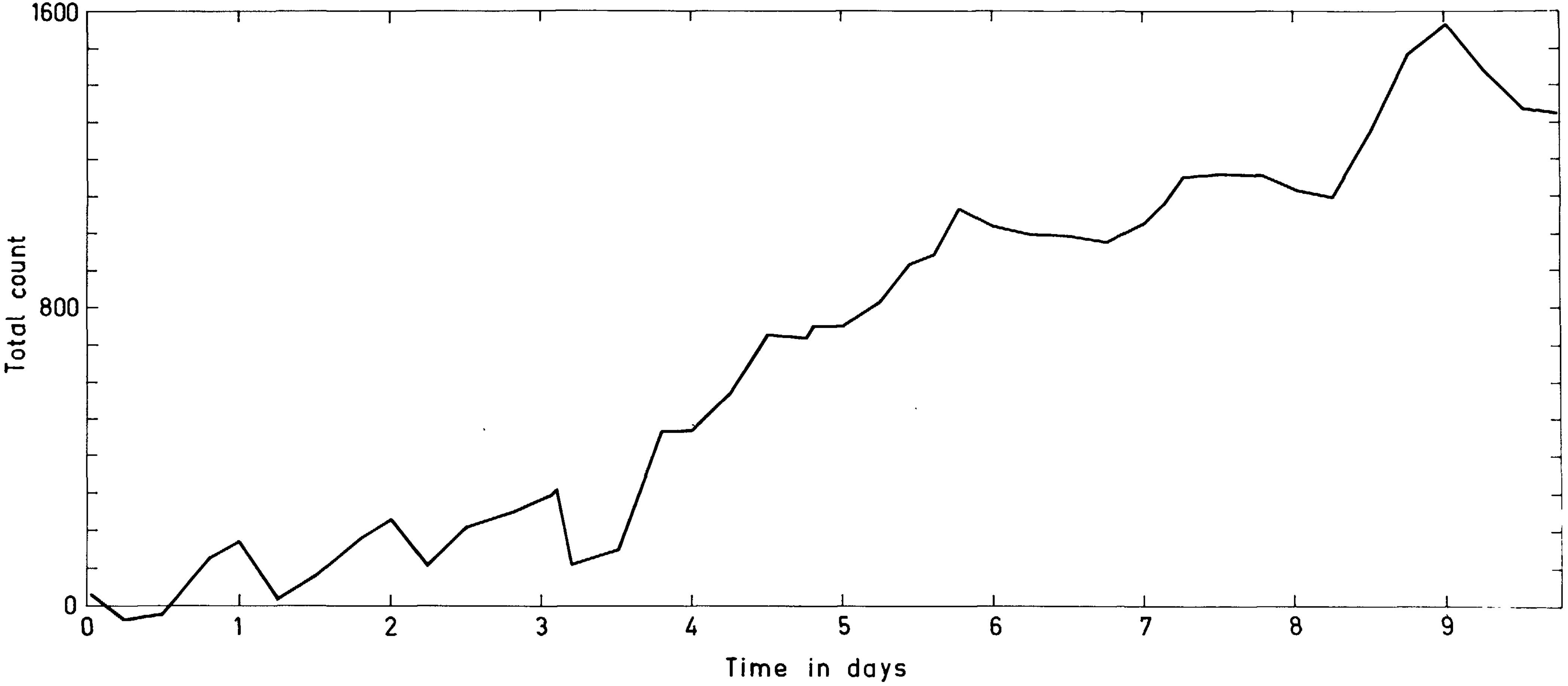


Fig. 11 TYPICAL COUNT INTEGRATION CURVE

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