INTRODUCTION

This publication is one of a series of monographs dealing with the association of prominent men of science with the Cambridge Instrument Company Ltd. For the most part they will relate the pioneer development of various scientific instruments that have had a marked effect on the progress of scientific achievement or industrial development. It will be seen how frequently the laboratory instrument of the day becomes the industrial tool of the future.

The object of these monographs is to place on record the indubitability of the instrument makers, and indeed the whole world, to these men of science and to detail the story of the collaboration before the all destroying hand of time blots it from the memory of those who had part in it.

WITHDRAWN

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Emeritus Jacksonian Professor of Natural Philosophy, Cambridge
Born 1869

The above portrait is reproduced by kind permission from the original oil painting by James Gunn in the possession of the Sidney Sussex College, Cambridge.
FOREWORD

by

Professor Sir W. Lawrence Bragg, O.B.E., M.C., F.R.S., M.A.
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I am glad to have the opportunity to write a foreword to this monograph dealing with C. T. R. Wilson's Cloud Chamber, because I was his pupil and I learnt more from him in my undergraduate days than from any of my other teachers. He lectured to us in Optics, and these lectures, I believe, first gave me interest in interference and diffraction which has largely determined my own lines of research. Their manner of delivery was not perhaps ideal; the blackboard bored more sometimes than we did. But his way of looking at a problem was fascinating, and I confess I've used the notes of his lectures for my own ever since. I still have the old books with some thumb-nail sketches of C. T. R. lecturing in the margins. His practical class was also an education in itself; he made the students feel that a practical experiment was not an exercise to finish but a little research.

Mr. Barron has referred in his account to C. T. R.'s patience in building apparatus. Time has always seemed to mean nothing to him! I well remember showing him some stereoscopic pictures of our crystal models which were being produced for distribution, and Wilson saying to me 'I recall I had a letter about a year ago asking me about the production of stereoscopic pictures of my cloud tracks. I really must reply to that letter'.

The time of the discovery of the tracks was a thrilling one. I can bear now Wilson saying to us in great excitement 'They are as fine as little hairs'. He had hoped that some localization of the cloud would reveal the tracks, but the precision with which it did so was as great a surprise to him as to everyone else. I was then in his Part II experimental class, and he took me to London to help work the first cloud chamber at the Royal Society Soiree. That was indeed an occasion.

The Wilson cloud chamber is one of the most prized treasures of the Cavendish Museum, together with ancillary apparatus and his electroscope. I showed it to him last year, and asked whether this, certainly one of the most famous units of apparatus in the history of physics, was correctly described as the original Wilson Cloud-Chamber. Wilson thought for a little and then said with some surprise 'But I never made but the one'.
Frontispiece: Wilson's first prototype cloud chamber (1910–11).
C. T. R. WILSON AND THE CLOUD CHAMBER

BY

S. L. BARRON

It has been a commonly accepted belief that the Cloud Chamber for making visible ions and the tracks of ionising particles, first described by Mr. C. T. R. Wilson in a communication to the Royal Society in April 1911 was devised, around that date, from first principles in an endeavour to make visible the tracks of alpha particles, the corpuscular nature of which had by that time become reasonably established. The Cavendish Laboratory staff, of which he was then senior demonstrator, during that period were much engaged in researches concerning the nature and properties of radioactive particles and it would be reasonable conjecture to believe that the method was devised, at that time, by one of the research staff visibly to implement the theoretical knowledge that already had been built up.

That this was hardly the case, has been shown by Mr. Wilson in his Nobel lecture, delivered in Stockholm on the 12th of December, 1927.

The work had its unconscious origin in 1894 when Mr. Wilson was staying at the Observatory on the summit of Ben Nevis. He had been greatly impressed by the wonderful optical phenomena produced when the sun shone on the clouds surrounding the hill top and especially the coloured rings surrounding the sun, and similar effects. This caused him to decide to try to imitate the phenomena in the laboratory.

In 1895 he made some experiments in causing clouds in a closed chamber by the expansion of moist air and in so doing accidentally discovered a phenomenon that promised to be of much greater interest than that of the optical phenomena which it had been his first intention to study. He found that moist air when freed from Aitken's dust particles did not produce a cloud upon small expansion but did produce a cloud when a high degree of supersaturation was produced by considerable sudden expansion. A critical value for expansion ratio \( \frac{V_2}{V_1} = 1.25 \) corresponding to fourfold supersaturation was established as being a minimum requirement. In such conditions and in the absence of dust particles a shower of droplets could be formed within the chamber, and the process could be repeated again and again, thus proving that the nuclei upon which the droplets presumably formed were always being regenerated in the air. They were in fact electric charges due to ions or isolated electrons although knowledge of atomic physics at that time did not permit of it being fully recognized (Camb. Phil. Soc., May 1895) [Fig. 1].
In autumn 1895, J. J. Thomson (later Sir), Cavendish Professor of Physics at Cambridge, was investigating the conductivity of air exposed to the newly-discovered X-rays. Wilson decided to use one of Thomson’s X-Ray tubes, made in the Cavendish Laboratory by Mr. E. Everett, in an endeavour to produce a cloud upon the ions produced by a beam of X-Rays. Mr. Wilson recalls his delight when he found, on the first trial, that whilst no drops were formed in the chamber when exposed to X-Rays when the expansion was less than the critical value, a fog, which took many minutes to clear was formed when the expansion was of the correct calculated value. These were probably the first deliberately planned manifestations of ions ever to be seen, and although indeterminate and in the form of a cloud were in fact produced by a great confusion of tracks of ionising electrons projected by absorption of X-Rays in the expansion chamber (Royal Soc. Proc., March 1896) [Fig 2]. It is doubtful if at this early date, a full realization could be made of the epoch-making nature of this wonderful experiment and its impact on the subsequent rapid growth of knowledge in the field of atomic physics.

The next important step took place in 1898 when Wilson was able to prove that the nuclei causing the cloud formation could be removed by applying an electric field between the top and the bottom of the cloud chamber and thus proved that the nuclei on which the droplets were formed were ions. This dispersal and the rapid clearing of the chamber by an applied voltage became very important at a later stage, as it made possible the development of a reciprocating piston chamber in which the cloud was formed and the chamber subsequently cleared and prepared for another expansion. The rate of consequent expansions could be as high as 200 a minute (see page 9).

It was not until 1910 that further experiments were made with a view to increasing the usefulness of the condensation method. By this time much theoretical work already had been done on the nature and properties of alpha and beta particles and X-rays by Sir J. J. Thomson and others, and Wilson conceived the idea of making visible the track of an ionising particle and photographing it during the moment of suspension and before the droplets began to fall. Thus it would be possible visually to confirm or disprove many theories on the characteristics and behaviour of particles that had been built up by purely physical and mathematical study.

In 1911 a first rough apparatus was constructed in the Cavendish Laboratory workshops and a first test made (‘with little expectation of success’) with a stream of X-Rays projected into the chamber and to the great delight of Mr. Wilson, the chamber was seen to be filled with little wisps and threads of cloud—the very first well-defined tracks of electrons [see frontispiece]. Tracks from alpha particles obtained from the radium-tipped metal tongue of a spintharoscope contained within the chamber and tracks from other suitable sources quickly followed. This epoch-making experiment was the subject of a short communication to the Royal Society in April 1911 and confirmed in a remarkable way much that had been conjectured from interpretation of electrical measurements upon ionisation phenomena. Thus an investigation started in 1894, for an entirely different reason, culminated in 1911 in making visible the tracks of ionised particles or the presence of ions, later enthusiastically described by the late Lord Rutherford as ‘the most wonderful experiment in the world’.

The expansion chamber of this preliminary equipment was a glass cylinder fitted with a top
plate and a carefully ground glass piston that could rapidly be lowered by evacuating the space below the piston until it fell upon a fixed stop. The expansion ratio was adjusted by regulating the pressure of the gas below the piston and thereby the initial volume of the space above the piston prior to expansion.

The construction of this instrument called for the utmost skill and patience. This is exemplified in a story often told by the late Lord Rutherford of how he remembered seeing Wilson in the Cavendish Laboratory workshop patiently grinding the glass piston into the cylindrical chamber. He was called away from Cambridge for many weeks and on his return found Wilson, in precisely the same position, still doing precisely the same, not very exciting practical job. Wilson had recognized how very essential it was that the piston should be a perfect fit otherwise the accurately controlled degree of expansion would be invalidated if there was the slightest leak into the chamber from the atmosphere or from the chamber into the evacuated area below the piston. Such a leak would also give rise to turbulence within the chamber that would destroy the shape of the tracks.

During the summer of 1911 Wilson worked on the design of a much improved apparatus with a large chamber and capable of adjustment of the expansion ratio over certain limits. This cloud chamber was built with a carefully fitted metal piston with a plate glass top and was 16.4 cms. in diameter. The piston could be rapidly sucked down by evacuating the space below the piston to the required degree of vacuum. A rubber stop arrested the piston and an external scale was fitted to enable desired expansion ratio accurately to be set. In operation a vacuum pump produced the required vacuum within a large flask connected by a tube to the base of the piston but with an opening and closing cock in the connecting pipe line. With the cock closed the base of the piston remained at atmospheric pressure, and when opened to the evacuated flask would cause the piston to be rapidly drawn down on to the rubber stop and the moist air
within the chamber rapidly expanded the required amount to produce the necessary degree of supersaturation. The initial volume of the Chamber could be adjusted so as to give exactly the desired degree of expansion for tracks from differing radio-active sources to be clearly formed. A potential difference could be applied between the top and bottom plates of the chamber in order to remove the ions which would otherwise accumulate in the chamber prior to expansion and which would on expansion form a thick uniform cloud instead of well defined tracks of only those ions which traversed immediately on the beginning of the expansion stroke [Fig. 3].

The new cloud chamber was illuminated by a beam of parallel light so that the tracks, when formed, would appear as bright threads against a dark background, each thread being an almost continuous line of tiny water droplets produced by condensation of vapour upon the ions formed by ionising particles from the active source under investigation. These threads or

(a) Alpha tracks from radium. Some particles have traversed before expansion and the tracks have therefore commenced to disintegrate.

(b) Alpha tracks from radium. All particles have traversed immediately after expansion and are therefore well defined.

tracks were sufficiently bright to be photographed before dispersal and the first series of photographic records of the tracks were thus obtained. These beautiful photographs formed the basis of a paper communicated to the Royal Society in June 1912 (Proc. Roy. Soc. A., Vol. 87, 277, 1912), which created great interest and excitement among physicists throughout the world [Fig. 4a-b].

The system of illuminating the chamber for photographic purposes had points of interest. For this purpose Mr. Wilson provided instantaneous illumination by using a Wimshursts machine and a Leyden jar discharge through mercury vapour, the discharge being automatically timed to take place immediately after the formation of the cloud. For visual observation a Nernst filament lamp was employed. To render the glass top of the piston and the glass top plate of the chamber electrically conductive a film of clear gelatine containing copper sulphate was employed. The base plate film also contained Indian ink so as to make the background sufficiently dark for the tracks to be clearly observed or photographed.

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(c) Enlargement of portion of (b) showing a collision and recoil.  
(d) Alpha tracks from radium emanation.

(e) X-Ray tracks produced by an X-Ray beam about 2 mm. diameter.
(f) Portion of (e) enlarged to show individual ions produced along a portion of one cathode-ray track.
The thoroughness with which this first complete cloud chamber was conceived by Mr. Wilson and constructed in the Cavendish Laboratory with the help of Mr. Lincoln and Mr. Roff is best shown by the fact that this instrument was the only one employed by C. T. R. Wilson for the many researches made by him during the whole of his subsequent active career. As related by Sir Lawrence Bragg in his foreword, this fact was made clear many years afterwards in reply to a question as to whether the instrument in the Cavendish Museum was the very original model, he replied, 'I never used or made but one.' The instrument is still preserved at the Cavendish Laboratory and today, 40 years after its construction, is as capable of producing perfect ray tracks as when it first was demonstrated.

The most important purpose of the photographs of tracks obtained at this time was positively to confirm conclusions as to the character and behaviour of electrons and X-Rays that had already been reached by less direct means and which, in some cases, had not yet found ready acceptance.

Two photographs showing the effect of altering the expansion ratio: (b1) Expansion ratio $V_2/V_1 = 0.35$  
(b2) Expansion ratio $V_2/V_1 = 1.28$.

Mr. Wilson relates that on showing the late Professor Sir William H. Bragg one of the first good pictures of alpha-ray tracks soon after it was made, Sir William produced a diagram which he had just published (Arch. Rontgen Ray, April 1911) showing what he considered,
from theoretical considerations, to be the forms for the paths of alpha rays. The similarity between the actual photograph and Bragg’s ideal picture was astonishing.

The publication of the Royal Society paper in 1912 created considerable excitement and interest in Physics Laboratories throughout the world, and workers in atomic physics became anxious to procure a cloud chamber similar to the one made by Mr. Wilson.

By 1913 the Cambridge Scientific Instrument Company, then controlled by the late Sir Horace Darwin, F.R.S., who maintained the closest contact with the University, had been approached as to whether they could undertake to make an instrument of this type. Mr. Wilson and the Professor of Physics (Sir J. J. Thomson) at the Cavendish Laboratory were contacted and readily accorded their permission for this to be done, and Wilson generously helped, in an advisory capacity, in the design of the apparatus.

The first instrument produced by the Cambridge Company was fundamentally a copy of Mr. Wilson’s instrument, except that Horace Darwin, introduced small alterations with a view to making the instrument self-contained and compact, and also easier to construct. The diameter of the chamber was 16·5 cm, and it was water sealed. The flask and controlling vacuum gauge were contained on or attached to the instrument frame. Nevertheless in all essentials, the instrument was a faithful copy of the successful Cavendish model. For all the information on technique and the establishment of the correct expansion ratios for obtaining tracks from different radioactive substances, the Company were entirely dependent upon the experience and help of Mr. Wilson, and this help was accorded unstintingly [Figs. 5 and 6].

This model proved successful and a small number were made for Physics Laboratories throughout the world. It is these instruments that played a considerable part in the rapid progress of knowledge in atomic physics during this early period.
Mr. Wilson prepared a set of beautiful lantern slides of various tracks and these were marketed, through the Cambridge Company. They were used for instructional purposes in many laboratories throughout the world, and although greatly extended, have never been surpassed. The illustrations in Fig. 4a to 4b are from the original negatives of these early photographs.

The advent of the 1914–1918 war halted further work on this development and no radical change was made until 1921, when a new and in some respects more useful laboratory model was created.

At this time, working at the Cavendish Laboratory, was a young physicist named Takeo Shimizu who, at the instigation of the late Professor Lord Rutherford (then the Cavendish Professor), undertook a research into the development of a continuous cloud producing process in the place of the single expansion, thus to investigate the possibility of maintaining continuously throughout a certain volume, sufficient supersaturation to cause condensation on ions in order that the tracks of a continuous stream of ionising particles should be made visible.

Shimizu found that the sudden expansion of the Wilson instrument was not absolutely essential for the formation of a cloud and he designed a working model in which the piston could be made to rise and fall by turning a handle, thus providing for any number of expansions in sequence. This premise of Shimizu, as to the rate of expansion, was later found not to be entirely valid for research work of the highest accuracy, especially where exceptionally well-defined tracks or those of high velocity and low mass particles were required to be formed. Later work called for the return of the single expansion chamber. Reverting to the Shimizu Wilson in applying an electrical potential between the top and bottom plates of the chamber, through a commutator attached to the driving wheel. This commutator could be so adjusted that the voltage was applied at the desired moment some time after the expansion had taken place and during the compression stroke. The instrument was also arranged so that it could be
continuously driven by a motor through a reduction gear [Figs. 7 and 8]. Mr. Wilson has stated that this device was entirely due to Shimizu, he himself having been away from the laboratory (suffering from whooping cough), for the period in which Shimizu devised his apparatus.

C. T. R. Wilson had never patented his original instrument, but Shimizu applied for and obtained a patent for this revised reciprocating form.

The prototype model of the reciprocating piston cloud chamber was submitted to the Cambridge Scientific Instrument Company, and a new instrument was designed embodying these principles and called the Wilson-Shimizu Raytrack apparatus. In this model the chamber

was illuminated by a parallel beam of light from a pointolite lamp, which provided sufficient light for photographs to be taken of a series of expansions.

A small hole was ground into the side of the chamber, so that a close-fitting tapered pin carrying the radio-active material could be inserted into the chamber, from outside, without the necessity of dismantling the chamber between experiments. The top plate was covered with conductive gelatine solution as before and the glass top to the metal piston was dispensed with. The top of the piston continued to be covered with black gelatine in order to retain a black background.

The expansion ratio could be varied between limits by the adjustment of the position of the piston within the cylinder by two toggle nuts. In this model the diameter of the chamber was reduced to 35 cm., which was not sufficient for the entire length of some alpha tracks in air. In such cases it was recommended to place a thin mica or aluminium screen in front of the radio-active material and thus reduce the velocity of the particles and retain them within the confines of the chamber. With this instrument expansions could be obtained from about 50 to 200 times per minute.

This new model enabled many thousands of serial expansions to be studied to ascertain the frequency of collisions between particles and the nuclei of the gas within the chamber.

The next development in 1924 was of a special photographic camera for obtaining stereoscopic pictures of the tracks at each consequent expansion. The shutter and film driving mechanism of this camera were coupled to the moving piston so that exposure could be made

Fig. 8. Wilson-Shimizu ray track apparatus, by the Cambridge Instrument Company Ltd. (1921).
at a precise moment immediately after the expansion took place. By examining the photographs stereoscopically the actual positions of the tracks of ionising particles in space could be determined. In this camera the photographic lens pointed vertically downward over the expansion chamber and an arrangement of mirrors enabled two photographs to be taken simultaneously viewed in two directions approximately at right angles [Figs. 9, 10 and 11]. Shimizu and Blackett did much work on stereoscopic examination of various track formations.

One of the Shimizu instruments was in 1927 used by the writer, in conjunction with the late Sir William Bragg for obtaining a cinema film of the tracks being formed and dissipated. The cinema camera was mounted over the chamber which was illuminated by an automatic arc lamp. This film was subsequently used by Sir William Bragg in his Christmas lectures to a juvenile auditory at the Royal Institution of which he was then Director. The effect of a large 'live' picture projected on the screen was quite remarkable, each droplet being clearly visible.

The instruments previously described were intended primarily for research investigations and were relatively expensive owing to the precision required in their manufacture. A demand had, however, arisen for a simple form of cloud chamber suitable for schools and technical institutes in which the phenomena could be observed, but where photographs of the tracks were not required. In 1927 a new simplified model was constructed for this purpose. It followed the general lines of the Shimizu apparatus with a reciprocating piston but with a fixed ex-
pansion ratio. In this instrument it was found that the best tracks could be obtained if the rate of expansion was quickest at the beginning of the stroke and in order to obtain this effect the driving spindle was set off centre in relation to a cam bearing on the base of the piston. A heavy spring kept the cam firmly bearing on the piston. To prevent leakage the instrument was fitted with a water seal. This demonstration instrument having a fixed expansion ratio was suitable only for showing alpha tracks. Illumination of the chamber was from a metal filament incandescent lamp, and the instrument was manually operated [Figs. 12 and 13].

Large numbers of these demonstration models have been made and it has now entirely replaced the more expensive Shimizu pattern for this purpose. It still is in demand by schools and laboratories for teaching purposes and has the great advantage that students themselves can carry out the whole operation without difficulty. It is of interest that two of these manually-operated models were shown and continuously operated by visitors in the Science section of the Festival of Britain Exhibition for the whole five months with the minimum of attention. It is estimated that some 5000 people each day operated the instruments.

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In addition to these standard models, special instruments have been made from time to time for definite research applications and reference will be made to a few of them.

In 1927 an instrument was specially designed for the use of Dr. Chadwick, then working in the Cavendish Laboratory. This cloud chamber was of the single expansion type and had a diameter of 16.6 cm. It was capable of adjustment of the expansion ratio from $V_2/V_1 = 1.25$, to $V_2/V_1 = 1.37$. It was made much more rigid than the older patterns and the fitting and grinding of the piston were of a very precise nature. The lower section of the cylinder was fitted with large orifices communicating with a vacuum chamber of considerable capacity. The stroke of the piston was adjustable by means of nuts and the lower end of the piston provided with a plunger entering an oil damping cone by means of which the rate of damping could be varied. Thus it was possible to adjust with precision the rate of expansion together with the expansion ratio. It was with this instrument that Dr. Chadwick was able to obtain tracks showing clearly the delta rays [Figs. 14 and 15]. He also did much work using different gases within the chamber, notably argon.

Another chamber of similar construction was used by Dr. P. Kapitza for showing that the trajectory of alpha particles could be deflected by the application of a very intense magnetic field applied externally to the chamber. The strength of the field for this experiment was in the region of 40,000 gauss. This work was done in what was then the new Mond Laboratory extension at the Cavendish Laboratory [Fig. 16]. Other cloud chambers in which a collapsible rubber diaphragm replaces the piston, have been used by Blackett and Occhialini in which the whole operation has been started by Geiger-Müller counters in which the actual particles to be observed themselves fired the operating mechanism of the cloud chamber. This work was particularly valuable in determining the frequency of the presence of cosmic rays in the atmosphere. Anderson, Blackett and Occhialini demonstrated the positron in 1932 and Anderson and Nedermayer first obtained photographs of the meson in 1937. In 1932 Dr. (later Professor) P. I. Dee used a chamber made by the Cambridge Company to obtain photographs of the newly discovered processes of artificial disintegration of the elements, following
Cockcroft and Walton's original work on the disintegration of lithium by protons. It was with this chamber that he photographed the pair of oppositely recoiling helium atoms produced in that disintegrating process.

The most recent new model was one specially constructed for the Atomic Physics section of the 1951 Festival Exhibition at the South Bank, London. This was a self-contained motor-driven model of the Shimizu type with constant illumination and so arranged that by means of reflecting mirrors the formation of alpha tracks could be observed by visitors. This was one of the only working exhibits in this section and with the normal servicing attention was kept running during the whole period of the Exhibition. It produced approximately 50 expansions a minute for 12 hours a day, 7 days a week for 5 months—nearly six million distinct sets of tracks. Thus a great section of the general public were able to obtain a more realistic impression of atomic activity than would be possible in any other way [Figs. 17 and 18].

![Fig. 16. Photographs made by Dr. P. Kapitza, showing the bending of tracks of alpha particles by an intense magnetic field.](image)

The usefulness of the cloud chamber in atomic physics has been greatly influenced in recent years by the work of Lattes, Occhialini and Powell who have developed the technique of using special fine grain photographic emulsions for trapping and recording nuclear reactions. This simple technique has great advantages in many directions, particularly for photographing the tracks of heavy particles, but there still remain many specific and controlled observations of individual nuclear reactions that can only be studied by the cloud chamber device and these instruments remain in use for practical demonstrations and research in the many Physics Laboratories throughout the world. More recently cloud chambers have been made in which the falling piston has been replaced by a collapsing rubber diaphragm.

In October 1919 Wilson was appointed Reader in Electrical Meteorology and left the Cavendish Laboratory for the Solar Physics Observatory although continuing to maintain the closest connection with the Laboratory. In 1923 he was made Jacksonian Professor of Natural Philosophy and did much important work on cloud chambers and in particular on Lightning discharges, and the Earth's electrical field. In 1934 he retired with the title of Emeritus Professor, and in 1936 left Cambridge to settle in Edinburgh.

Professor C. T. R. Wilson has received many honours for his great work in developing the cloud chamber and for the many investigations afterwards carried out by its aid. He was
appointed a Fellow of Sidney Sussex College, Cambridge; in 1900 he was elected to the Fellowship of the Royal Society and later was created a Companion of Honour. In 1927 he received the crowning but greatly deserved honour of the Nobel Prize for Physics.

Although now enjoying a well-earned retirement, the name of C. T. R. Wilson, associated with his invention and his work is used daily in all laboratories and technical institutions throughout the world where Physics is taught.

Fig. 17. Cambridge Reciprocating Cloud Chamber for the 1931 Festival Exhibition, London, dismantled to show construction.

The author is greatly indebted to the following: Sir Lawrence Bragg for permission to use photographs from the Cavendish Laboratory for the Frontispiece and Figs. Nos. 2, 3, 11 and 15 and for kindly undertaking to write the Foreword. Professor P. I. Dee for kindly reading the proofs and for helpful suggestions. Mr. George Crowe of the Cavendish Laboratory, Cambridge for the preparation of photographs and for his kind assistance in recalling incidents of interest during the early days of the development of the cloud chamber.

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This cloud chamber was specially built for exhibition in the Atomic Science Section of the Dome of Discovery at the South Bank and was on display for the full five months, during which time it continuously produced, for visual observation, nearly six million sets of alpha tracks.