August 30, 1950

Dr. Wolfgang Huber
Electronized Chemicals Corporation
846 Lefferts Avenue
Brooklyn 3, New York

Dear Dr. Huber:

I enclose a copy of a letter which I have received from Chancellor Benitez of the University of Puerto Rico.

I may not have told you that for a number of reasons The University of Chicago and the University of Puerto Rico are quite close together. Would you regard it as fantastic to consider having Leo Szilard make some affiliation with the University of Puerto Rico, probably on leave of absence from The University of Chicago, so that he could direct any work which should be done there? Leo is away. I have no idea what his reaction might be.

The general program which I should like to discuss with you and which I shall put down in very short form here so that our discussion may be purposeful is as follows:

1. We might form a corporation in Puerto Rico to establish a pilot plant, using one capacitron which you would contract to furnish on some suitable basis.

2. Such a corporation might be given a very favorable royalty rate for a period of years in return for which Electronized Chemicals would receive a controlling stock interest. (Quite likely the voting shares in the corporation would have to be subordinated as to profit participation to shares issued to others presumably in Puerto Rico and perhaps to the government agency which provides capital for such purposes.) Part of the purpose of

setting up such a pilot operation is that it might at some later time be sold to a large company, thus permitting all the shareholders to realize a capital gain instead of a continuing income.

3. The University of Puerto Rico would undertake the routine testing of the products and would engage such personnel as might be necessary to this end. We would hope to have some kind of collaboration with men of established reputation at The University of Chicago.

4. The pilot plant would be equiped with packaging machinery supplied on loan or lease by Food Machinery or by one of the canners.

5. I think we can get Puerto Rico to give us a building and land.

6. The pilot plant would undertake to process fruits and vegetables grown in Puerto Rico and would sell these to specialty retailers and distributors in the United States. For example, R. H. Macy in New York, S. S. Pierce in Boston, Stop and Shop in Chicago, etc. The attempt would be made to operate the pilot plant on a profitable basis.

7. We would have to get enough money to engage personnel capable of managing the pilot plant and having enough technical skill to work out the problems of mechanical handling etc.

In general I believe that the entire project would be advanced a great deal by having a going pilot plant and particularly by being in the position of selling foods. Puerto Rico is, of course, a remote location. This has its advantages and its disadvantages. Any preliminary discouragements will not be widely known, any later successes will be harder to demonstrate. It is hard to get in Puerto Rico various supplies, equipment etc., so there would probably be delays which would not occur in a place like New York City.

On the other hand the likelihood of being able to get good financial backing without too great a sacrifice seems to be a very real one because of the motivation of Puerto Rican officials to do things which will help the local economy.

I do not think of this undertaking as excluding continued efforts to get commercial licensees in the United States. Rather it would further such efforts.

I shall telephone in a day or two to see whether we can set a convenient date for a discussion. Perhaps some of the stockholders ought to be available.

With kindest regards.

Very truly yours,

Lynn A. Williams, Jr.

LAW:ad
Enclosure

August 28, 1950

Dear Jaime:

Thank you for your letter of August twenty-second. I am trying to arrange now to go to New York during the first week in September for the necessary discussions with the scientists there in order to arrange the meeting or meetings which you suggest.

It seems to me that it would be helpful if we could forward to you a fairly full statement of an agenda so that you and your associates could arrange the necessary appointments and so that each would have some advance notice as to what we want to talk about. I suppose it is quite likely, however, that no matter what plans we make in advance it may be necessary to regard any first meeting as preliminary with the hope that it may focus our attention on the specific matters upon which further and more detailed discussions may be necessary at a later time.

I ought to be able to write to you toward the end of next week.

Very truly yours,

Lynn A. Williams, Jr.

LAW:ad

Dr. Jaime Benitez, Chancellor
University of Puerto Rico
Rio Piedras, Puerto Rico

August 23, 1950

Dear Jaime:

Your speech is wonderful. You should send it to Harpers, or let me.

I look forward to hearing from you on the other matter.

Very truly yours,

Lynn A. Williams, Jr.

LAW:ad

Dr. Jaime Benitez, Chancellor
University of Puerto Rico
Rio Piedras, Puerto Rico

August 21, 1950

Dr. Arno Brasch
c/o Electronized Chemicals Corporation
846 Lefferts Avenue
Brooklyn 3, New York

Dear Arno:

You will be interested, I think, in the enclosed copy of a letter from Dr. Benitez of the University of Puerto Rico.

During the past several weeks I have been talking with a number of people and have formulated some ideas of my own which I should like to lay before you some time soon.

Has Huber returned? Would it be convenient for you to see me some day during the week after Labor Day?

What would you think of my calling on Clinton Foods whose headquarters are now in New York at the same time? It is not clear to me whether they are licensees of Research corporation. I will try to learn more about this. Perhaps you already know or could easily find out. If they are, and if the tie-up is a close one, we might wish to be a little cautious.

The key people at Libby McNeill & Libby are on vacation now, but I will have had a chance to see them before talking with you.

My inquiries about the Quartermaster Corps suggest that this is not a promising line at the present time. The larger grants are referred to the National Research Council and would likely wind up in long delays and considerations of a somewhat political nature.

Very truly yours,

Lynn A. Williams, Jr.

LAW:ad
Enclosure

August 15, 1950

Dr. Jaime Benitez, Chancellor
The University of Puerto Rico
Rio Piedras, Puerto Rico

Dear Jaime:

Here is the article referred to in my letter of August first. There is a good deal of additional literature, but this one gives a fairly good over-all presentation in non-technical language. If you or any of your associates would like the other material, I think I could get it together for you.

I shall appreciate your returning this reprint after you have finished with it.

Very truly yours,

Lynn A. Williams, Jr.

LAW:ad
Enclosure-Electronic Preservation of Food

August 1, 1950

Dr. Jaime Benitez, Chancellor
The University of Puerto Rico
Rio Piedras, Puerto Rico

Dear Jaime:

I am writing you now not with respect to the Great Books (which you helped to their feet in Indiana several years ago) nor even with respect to the higher learning, although your university might be involved in the matter about which I should like your counsel.

Some months ago one of our scientists, Leo Szilard, called to my attention some research work being done in New York by a group of scientists who came to this country from Germany in the late thirties. They have been experimenting with the use of electronic radiation for the purpose of sterilizing foods. Their work has now come to the point where it is possible to preserve a great many kinds of food without canning and particularly without the long overcooking process normally necessary and without freezing. All that is necessary is that the food which is to be preserved be passed under the radiation tube. This kills the bacteria and other organisms which cause decay. It is necessary, of course, that the food be packaged in such a way as to prevent access of air-borne bacteria, but it is not necessary to use refrigeration.

The process is at the point where it is ready for commercialization. One of the meat packing companies now has under way an extensive study program with this in mind.

Obviously, the process is revolutionary and has most important consequences for food distribution and for agriculture.

The New York group is interested in some affiliation with The University of Chicago, aimed first at detailed and authoritative studies of the effects on enzymes and food values, and aimed later at possible development of new and smaller apparatus.

It is obvious that the greatest immediate application of this process is to fresh fruits and vegetables where the spoilage problem is severe. On the other hand, there is some initial resistance on account of the fact that in many parts of this country the crops are highly seasonal so that it is hard to make maximum year-round utilization of the equipment which, because of its newness, is fairly costly.

With these considerations in mind, and because I have been told somewhat fantastic stories about the possibility of assistance from Puerto Rican agencies in capital financing, it has occurred to me that a pilot plant installation might advantageously be made in Puerto Rico. This would require the building of a small plant and the installation of one of the radiation devices together with packaging machinery.

I would guess that the complete layout together with necessary working capital would amount to less than $500,000. Of this amount approximately 20 per cent, or $100,000, would be constituted by the radiation apparatus necessary. This amount could, I think, be subscribed by the financial backers of the New York development.

An additional 50 or 75 thousand dollars might be required for packaging machinery. I would hope that this could be obtained on loan or rental from one of the companies which makes this kind of equipment. As to the building I would think that $100,000 would cover the cost of the necessary structure in this country. Whether it would cost more or less in Puerto Rico, you would know better than I. Additional funds necessary to purchase raw food and to carry some inventory would be required, although bank loans could be used for this purpose. Some funds would also be necessary to pay staff personnel up until the time the plant was in operation.

The productive capacity of this equipment is very great. On an eight-hour day, five days a week, it can process some 10 million pounds of food.

The feasibility of this project depends, of course, upon the availability of agricultural produce in Puerto Rico, and about this I have only the haziest information. I have been told that much of the produce is not normally acceptable for United States distribution because of the reputation for causing stomach ailments. This process would, of course, kill any and every organism of this kind. I would hope that it would be possible in Puerto Rico to grow many vegetable crops on a year-round basis so that the apparatus could be utilized a large portion of the time. If this is at all possible, I would suppose that the ultimate effect on the agricultural economy would be most beneficial. Meanwhile, there is every possibility that the venture might be quite profitable to any local organization which provided the necessary financial backing over and beyond that which would be arranged on this side. This technique would permit the export of fresh produce of many varieties out of season (so that it would command higher prices here.)

At the same time there is no requirement for high-speed shipment so that low-cost transportation would be used.

There are, as you probably know, many wholesale food distributing concerns in this country which could handle the marketing problems.

While this pilot plant would not in and of itself contribute directly to The University of Chicago, I should think it might make an arrangement with the University of Puerto Rico to get assistance from your scientists on the technical aspects of this development and might accordingly make some arrangement for sharing the profits with your university (although I have been told that your institution is in no way concerned with money--a most fortunate situation, if true). The University of Chicago would hope to participate in the long run in the broader development of this process and in the profits which might follow from it.

Perhaps you would put me in touch with the appropriate people in your island who could tell me enough about the agricultural situation, its present and its potential, so as to form some opinion as to whether the project is reasonable on that score. Perhaps you could tell me also the names of the person or persons with whom I should communicate with respect to financial backing.

It is my impression that a great many buccaneers regard Puerto Rico as a happy hunting ground for unfair exploitation with little value to Puerto Rico and much value to themselves. I am sure that this project is not of that kind, and if you could convey this fact to any of the people with whom I should correspond or visit, I would be most appreciative.

I enclose a copy of an article which gives some description of the technical processes that are involved.

Very truly yours,

Lynn A. Williams, Jr.

P. S. I am not able to lay my hands on the publication referred to. I am leaving for about a week's vacation and will forward it as soon as I return.

LAW:ad

X-ray

Maurice Rosenblatt

Lawrence ~~Rotte~~ lburg

Ass. Plant manager — Streptomycin A.B.

Aaronberg Vice Pres.

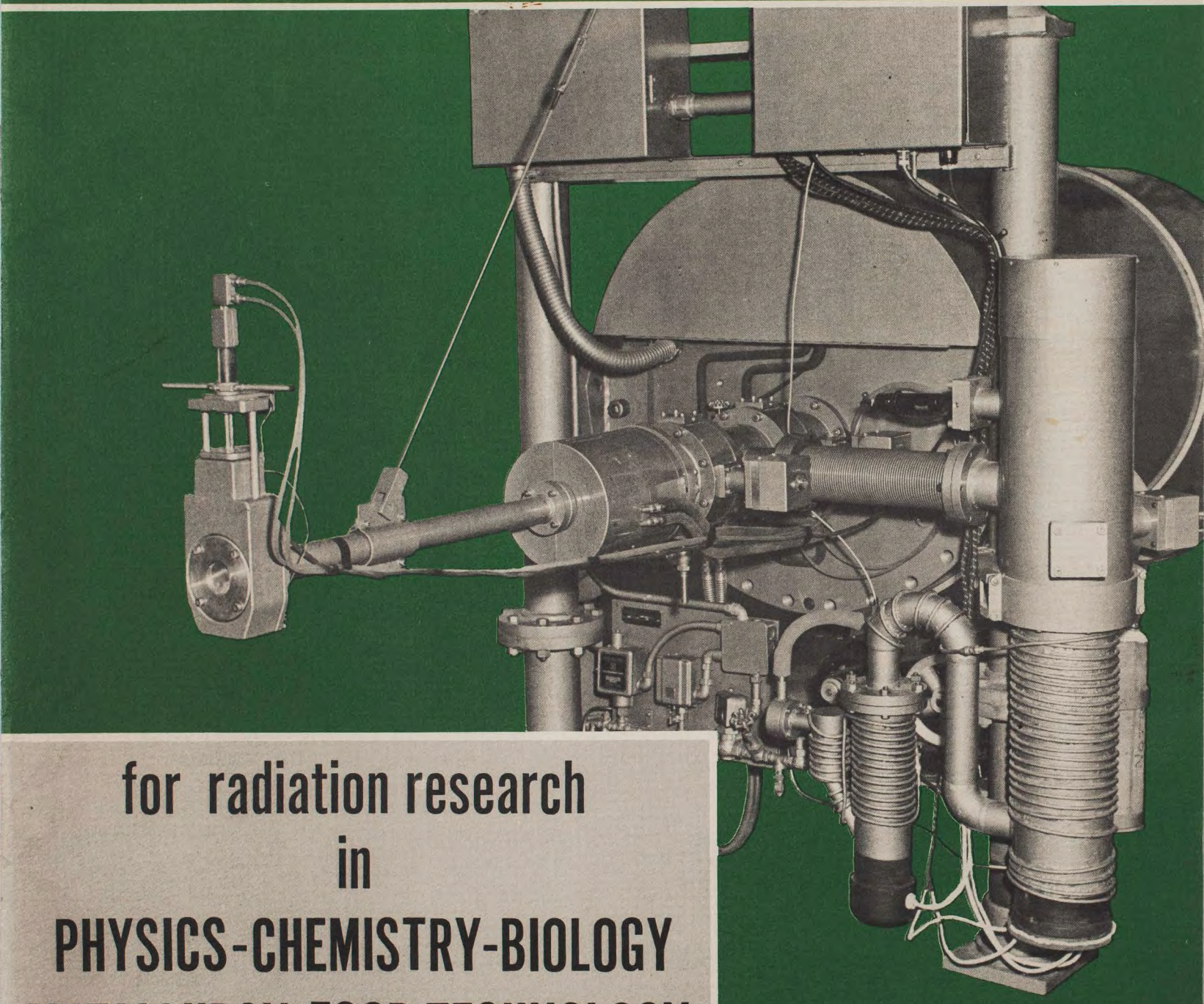
2nd SADOFF

Schenley Laboratories Inc.

Dr. Kurt ~~Lan~~ Landenburg ↔ Dir. of Res. and Development

BULLETIN A-5

Van de Graaff® TWO-MILLION-VOLT ELECTRON ACCELERATOR



Photograph through the courtesy of University of Notre Dame

for radiation research in PHYSICS-CHEMISTRY-BIOLOGY METALLURGY-FOOD TECHNOLOGY

HIGH VOLTAGE ENGINEERING CORPORATION

7 UNIVERSITY ROAD CAMBRIDGE 38, MASSACHUSETTS

Van de Graaff®

TWO-MILLION-VOLT, CONSTANT-POTENTIAL ELECTRON ACCELERATOR

TYPE A MODEL S

High voltage radiation . . . .

The Van de Graaff electron accelerator, manufactured by High Voltage Engineering Corporation, is a reliable and controllable source of high-energy radiation for scientific research and industrial applications. The radiation output from the 2 million-volt, 100-microampere electron beam produces in the order of 30 million roentgen-equivalent-physical units per minute. Using a gold target in the path of the accelerator's beam, the x-ray output is 300 roentgens per minute at a distance of 50 centimeters in the forward direction. Although the radiation is appreciable from this electron and x-ray source, equally important is the fact that adjustments can be made by varying current and voltage over a wide range. Predetermined levels of radiation energy and intensity can be obtained. Repetitive tests under identical conditions can, therefore, be conducted.

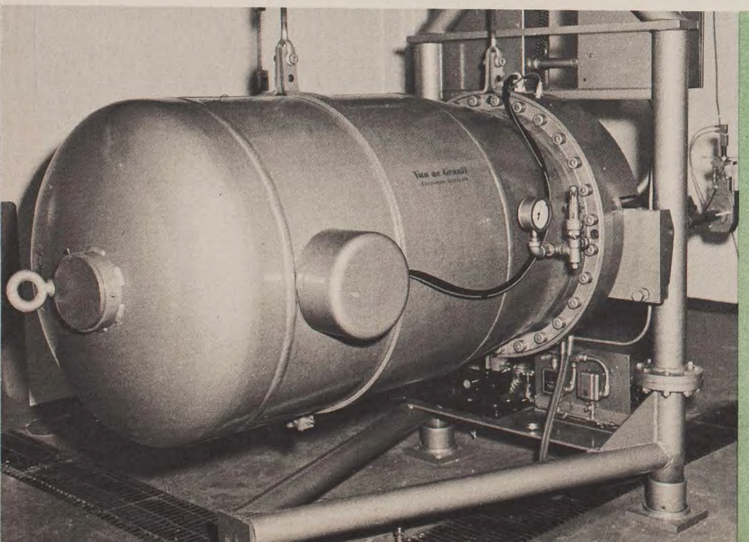
from a homogeneous electron beam . . . .

The accelerator has a cathode-ray window assembly at the end of the vacuum tube system from which electrons can emerge into the atmosphere. The beam can be used to produce ionization directly in target materials, or the samples to be irradiated may be placed in thin-walled containers which are sealed off. For some research, the electron beam can be brought into experimental apparatus directly attached to the terminating flange of the accelerator. Under this condition, a pumping restriction should be included to prevent contamination of the tube system from any reactions of the irradiated materials. Since the electron beam is continuous and essentially monoenergetic, an annular magnet on the machine can be adjusted to give an extremely fine focal spot of the electron beam to a diameter in the order of 0.5 mm.

The versatility of this Van de Graaff accelerator is greatly increased by the use of a retractable, water-cooled, gold target which can be inserted in the path of the electron beam to produce x-rays. This target is manually adjustable without altering or affecting the vacuum conditions of the tube, and the change from cathode-ray output to x-ray output can be accomplished in only a few minutes. The gold x-ray target has a high heat conductivity and an improved efficiency over the target materials normally used. This type of target is particularly suited for use with the Van de Graaff accelerator since the point source of radiation obtainable from the fine focal spot causes a high concentration of power in a small volume of the target.

gives science and industry . . . .

Five of these compact Van de Graaff accelerators, built by H. V. E. C., are now in operation in various research establishments and have proved their usefulness in diverse applications. One unit is directly connected as an injector for a large electron linear accelerator. Three units provide high-intensity radiation of organic and inorganic materials under various controlled conditions. Another accelerator supplies a cathode-ray beam for industrial research work on the sterilization of pharmaceutical and packaged food products. This latter application is proving extremely effective in maintaining complete sterility of commercial products.



1 Two-Million-Volt, Horizontal, Type S Electron Accelerator Installed in a Radiation Chemistry Laboratory

This compact Van de Graaff accelerator has a water-cooled retractable gold target on the tube extension. The tube terminates in a thin aluminum cathode-ray window, not shown on this photograph. The steel accelerator enclosure is suspended from the mount, which is an integral part of the unit, by means of the adjustable turnbuckles and steel bands. After initial adjustment of these turnbuckles, the tank can be unbolted from the fixed base flange and rolled conveniently to the left for easy maintenance and returned to its initial position without further adjustments. The small housing on the front of the tank encloses the generating voltmeter. The head of the tank has a lead block which absorbs excessive reverse radiation, characteristic of high-voltage x-ray tubes. The eye-bolt in the head of the tank is used initially for rigging the tank into position.

Photograph through the courtesy of University of Notre Dame

chemistry, biology, food technology, metallurgy . . . .

In the field of radiation chemistry, the Van de Graaff accelerator is a source of ionizing radiation for important work by chemists in determining the spatial distribution of molecules activated by the radiation. Experiments are now in progress to study the reactions of many solutions; the experiments may yield new information on the breakup and recombination of molecules.

The data obtained by these studies with electron bombardment may also provide a basis for determining the effects of similar irradiation on proteins and related substances fundamental to living organisms. In studying biological effects of radiation, quantitative results are greatly facilitated by the use of this equipment, which can produce small intensities of radiation, at known energies or high precision.

Although research to date has shown that foodstuff can be preserved and purified by irradiation, the feasibility of applying cathode-ray sterilization must be determined for each individual class of product. This Van de Graaff electron accelerator has an output which is generally adequate in research to determine the quantity of irradiation needed for complete or partial sterilization and for determining the effect of irradiation on taste, color, food value, and other characteristics.

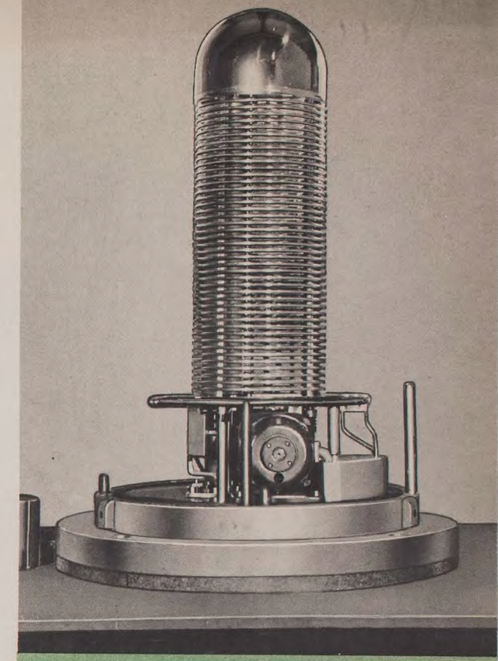
With its inherently reliable operation for long periods of time, this electron accelerator performs well for metallurgical research. Investigations in this field often require days of continuous irradiation and automatic operation of the accelerator at its rated output.

a working tool for research.

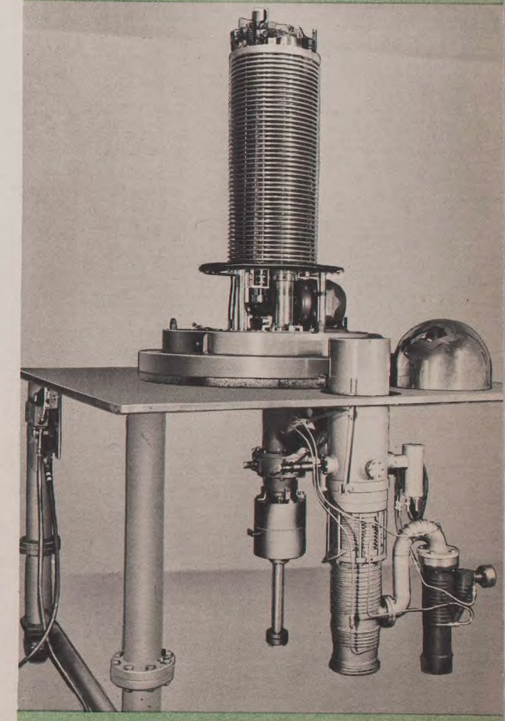
These Van de Graaff accelerators incorporate the most advanced developments in the field. They are thoroughly tested in the factory prior to supervised installation. Since the units are completely self-contained and require only a small amount of power and space facilities, they can generally be installed in existing buildings. High Voltage Engineering Corporation cooperates fully with the user in suggesting means for eliminating radiation hazards to personnel and in providing economical solutions for any radiation problems.

This controllable source of high-energy radiation can be initiated and discontinued at will. The intensities available permit numerous experiments to be conducted simultaneously or in rapid sequence for the accumulation of data in sufficient quantities to give vital statistical records. The units, providing hundreds of hours of operation without important maintenance, have become a vital tool for both fundamental and industrial research.

The Type A, Model S, accelerator is one of several designs which High Voltage Engineering Corporation can provide to meet your specific requirements.

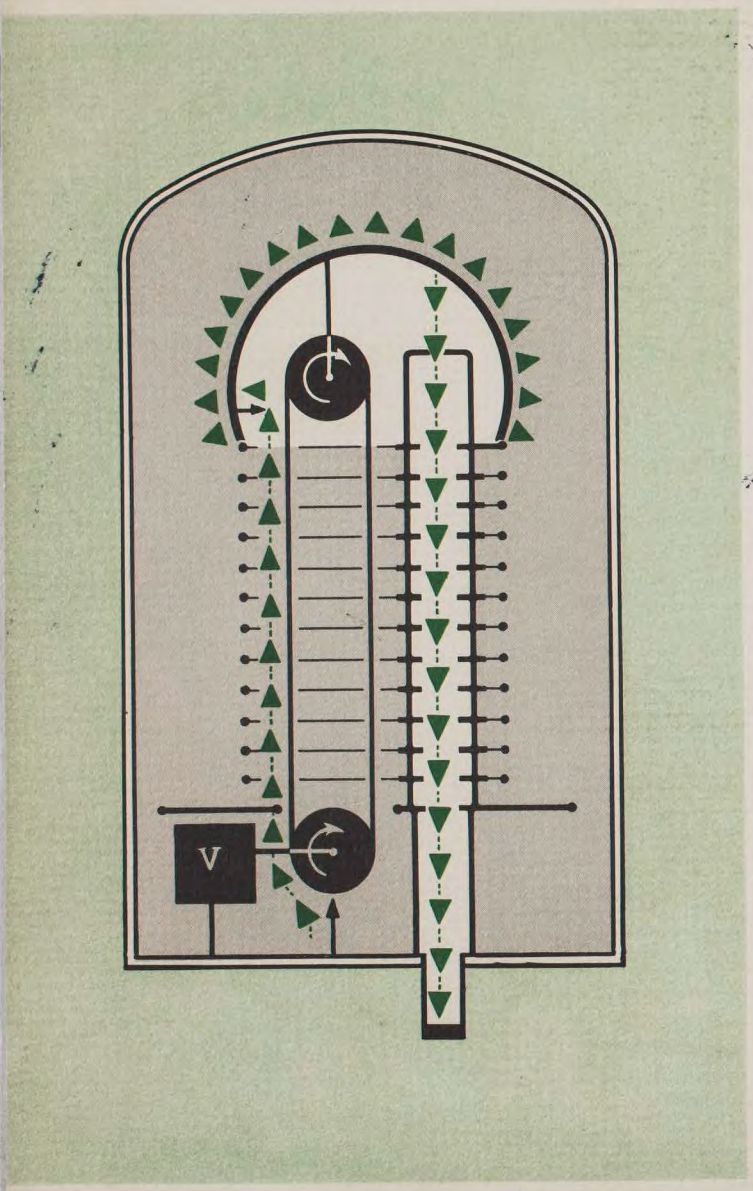


2 A vertical, two-million-volt, Type S Van de Graaff accelerator showing the base flange positioned on a steel mounting ring cushioned by a cork mat to prevent building vibrations from affecting the accelerator beam.



3 This vertical accelerator is shown in its factory-test setup with the tube extension with its gate valves and annular focusing magnet. The tube extension terminates with a simple cathode-ray window.

Van de Graaff®
CONSTANT - POTENTIAL GENERATOR



OPERATING PRINCIPLE

An electric charge is sprayed onto a moving belt of high dielectric strength and carried into the field-free space of a conducting hemispherical terminal, well insulated from ground. This high-voltage terminal is positioned at the end of a column which is constructed to provide a uniform voltage distribution along its length, and which contains both the belt and the accelerating tube. Charged particles originating in the terminal end of the tube are progressively accelerated and focused by specially designed electrodes forming a uniform electric field along the tube. These electrodes obtain their potential by connection to corresponding equipotential planes in the insulating column of the generator.

The steady, constant potential of the terminal is maintained by a balance between the controllable current brought to the high-voltage terminal by the belt, the voltage-distribution current down the generator column, and the current accelerated along the vacuum tube. The generator voltage is brought to any equilibrium value by regulating, from the control panel, the charge sprayed on the belt.

Since the particles coming down the tube are essentially homogeneous in energy, they can be well focused or deflected by a magnetic field at the grounded end of the accelerator tube. The apparatus is contained in a tank of dry compressed gases (nitrogen and carbon dioxide) at pressures up to 25 atmospheres. This pressurizing makes possible high-voltage insulation across comparatively short gaps, and is the primary factor in obtaining the unusual compactness of Van de Graaff generators. For the two-million-volt machines the power required is only 5 KVA, 0.7 power factor, supplied at 208 volts, 3 phase, 60/50 cycles. Ordinary voltage and frequency fluctuations have little effect on the performance of the apparatus; the generator may, therefore, be used under unusually stringent field conditions.

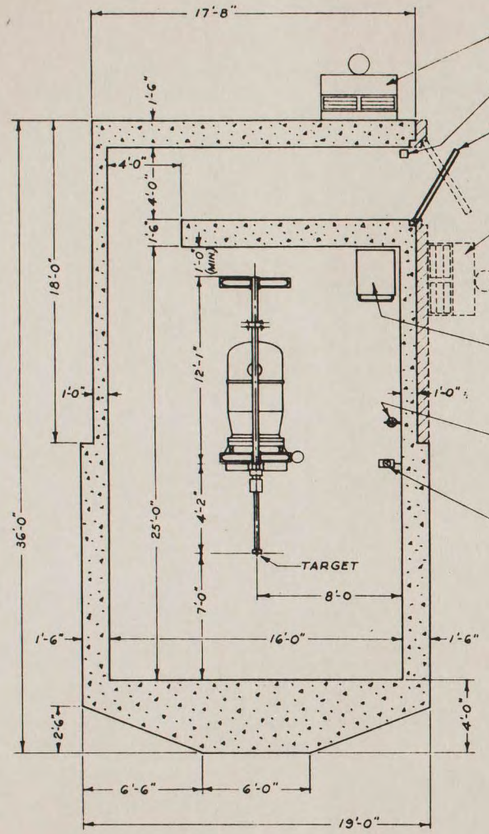
Several unique characteristics, inherent in the principle and design of the Van de Graaff high-voltage generator, differentiate this type of equipment from other accelerators. These include:

- **Accelerated particles well collimated and homogeneous in energy.**
- **Constant-potential source of power easily controllable in energy and output.**
- **Adaptable for production of electrons and x-rays, positive ions and neutrons.**

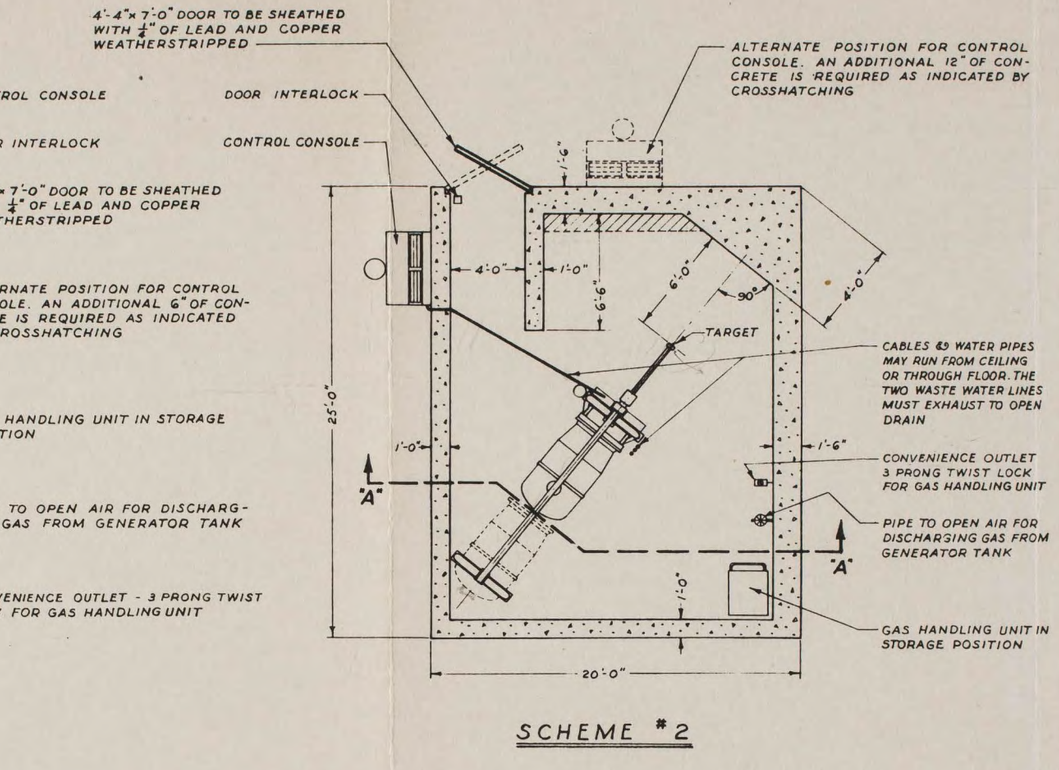
HIGH VOLTAGE ENGINEERING CORPORATION

7 UNIVERSITY ROAD CAMBRIDGE 38, MASSACHUSETTS

D-AS-25



SCHEME #1



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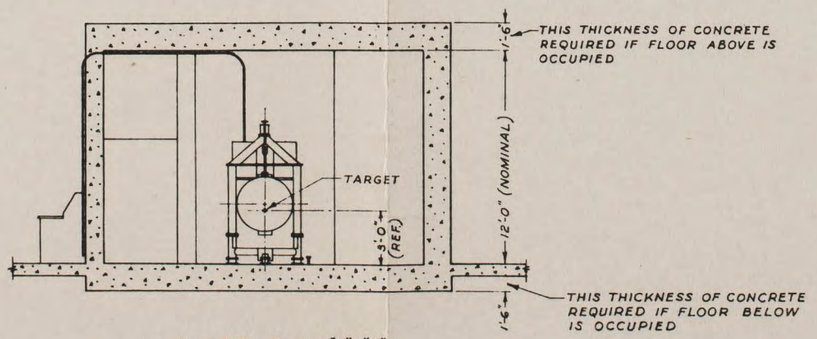


SECTION "A"-"A"

GENERAL NOTES :-

TWO TYPICAL ROOM ARRANGEMENTS ARE SHOWN FOR A HORIZONTALLY MOUNTED GENERATOR.

1. PROTECTION DETAILS ASSUME :-
   - (a) ROOM SIZES SHOWN
   - (b) LOCAL ATTENUATION (NOT SHOWN) OF DIRECT BEAM TO 100 MILLIROENTGENS PER HOUR AT 10 FEET AT RATED VOLTAGE AND CURRENT. SHIELDING TO BE SUPPLIED BY CUSTOMER OR THROUGH SPECIAL ORDER.
   - (c) RADIATION LEVELS OUTSIDE BARRIERS NOT IN EXCESS OF 6 MILLIROENTGENS PER HOUR

   IN THIS ENERGY RANGE, 4.8" OF CONCRETE = 1" OF LEAD. PREFERRED LOCATION OF ROOM : BELOW GROUND TO UTILIZE EARTH AS RADIATION BARRIER. CONCRETE THICKNESSES SHOWN ARE FOR POURED CONCRETE, DENSITY = 2.35 (IF REQUESTED, H.V.E.C. WILL GIVE RECOMMENDATIONS ON INDIVIDUAL REQUIREMENTS OF PROTECTION)
2. ELECTRICAL POWER REQUIREMENTS :-
   - (a) 5 KVA (MAX.), 208 V., 3 PHASE, 50/60 CYCLE, 4 WIRE (STAR CONNECTED, NEUTRAL GROUNDED) TO CONTROL CONSOLE POSITION
   - (b) 4 KVA, 208 V., SINGLE PHASE, 50/60 CYCLE, 3 WIRE (2 LINES & GROUNDED NEUTRAL) FOR GAS HANDLING UNIT
3. WATER SUPPLY REQUIREMENTS :-

   COOLING WATER 2 GALLONS PER MINUTE, 70° MAX. INLET TEMPERATURE. OUTLET TEMPERATURE IS ABOUT 5° ABOVE INLET. (WASTE LINE MUST EXHAUST TO OPEN DRAIN.) AMBIENT TEMPERATURE OF GENERATOR ROOM - 100°F. MAX.
4. APPROXIMATE WEIGHT OF GENERATOR & MOUNT = 5000 LBS.
5. PROVISION SHOULD BE MADE FOR THE STORAGE OF DRY ICE, GAS CYLINDERS, TOOLS & SPARE PARTS

2 1 0 2 4 6 8 10 12 14

APPROX. SCALE IN FEET

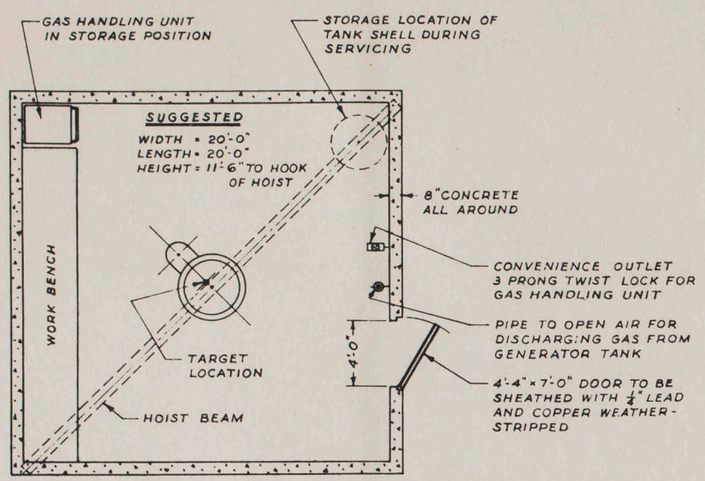
JOB NO.	NO. REQ.			D				
				C				
				B				
				A				
		ASSY USED ON						
SCALE	DRWN. BY / DATE	CHKD. BY	MFR	APP'D BY	AT	WAS	DATE	MADE BY / APP'D BY
	A.L.EARLE 6-7-50	J.H.S.	G.V.D.G.		REVISIONS			

HIGH VOLTAGE ENGINEERING CORPORATION CAMBRIDGE, MASS.

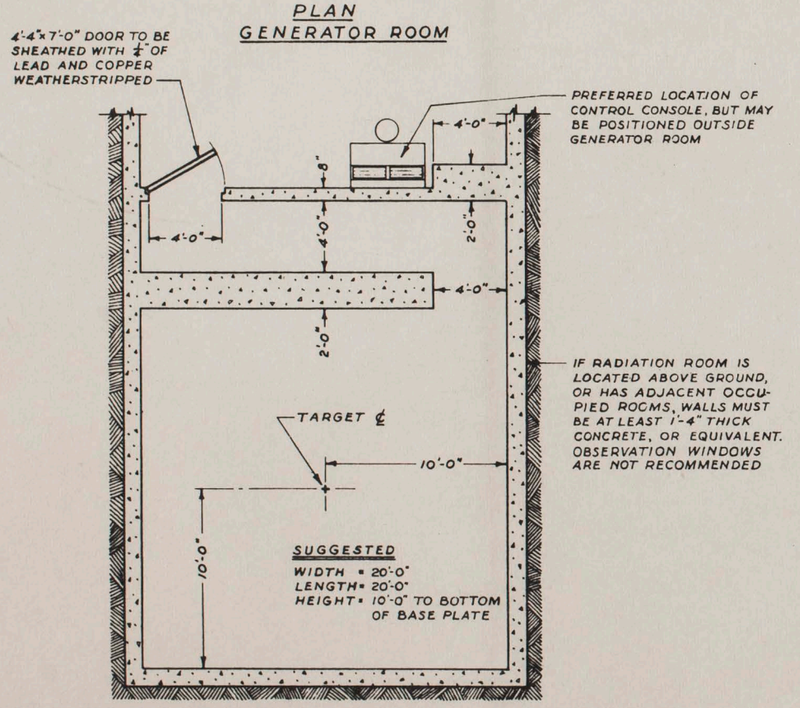
Van de Graaff ELECTRON ACCELERATOR Model AS-Horizontal-Suggested Space Requirements

D-AS-25

D-AS-26



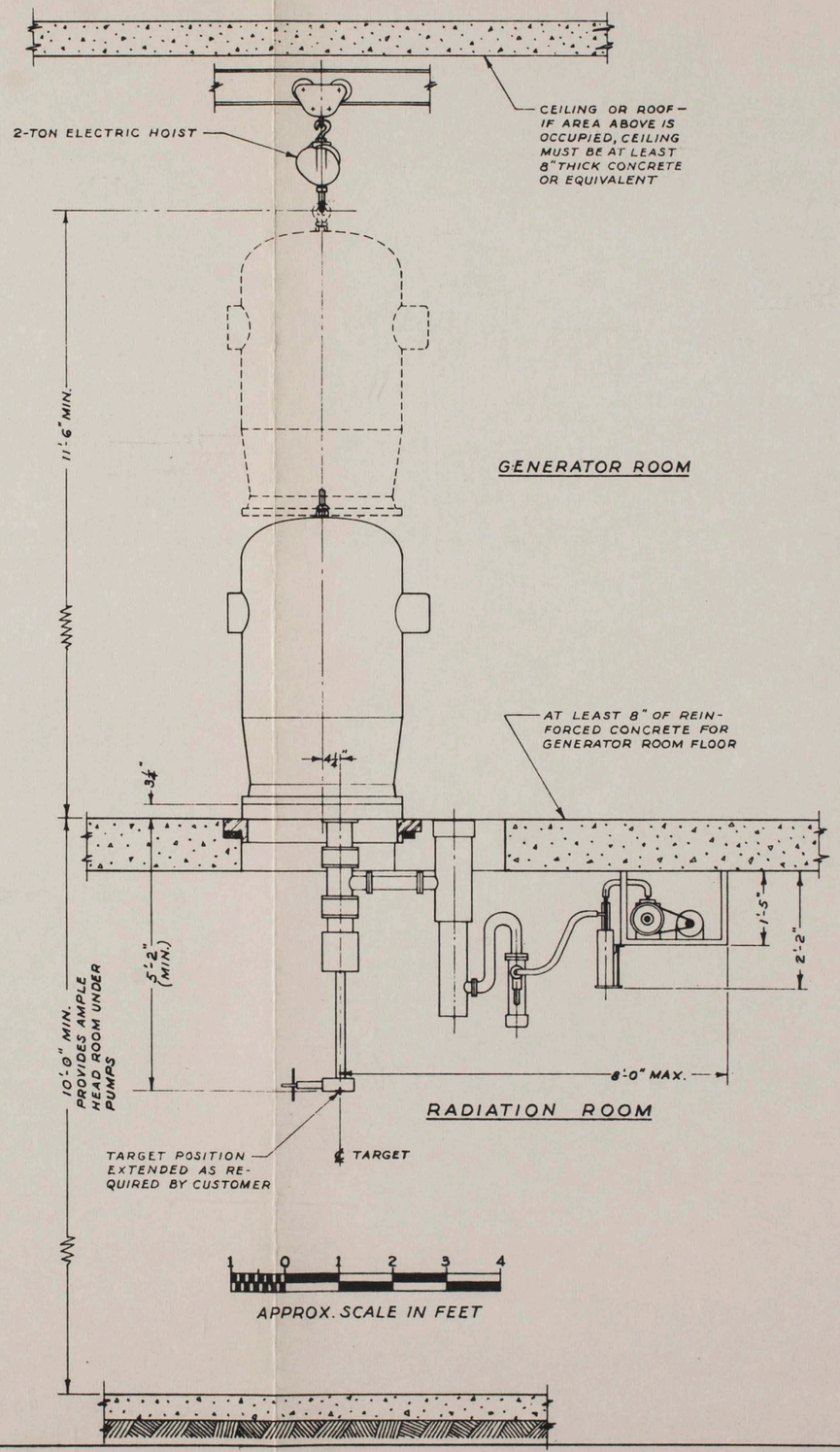
PLAN
GENERATOR ROOM



PLAN
RADIATION ROOM

2 1 0 2 4 6 8 10 12 14

APPROX. SCALE IN FEET



GENERATOR ROOM

RADIATION ROOM

1 0 1 2 3 4

APPROX. SCALE IN FEET

GENERAL NOTES :-

1. PROTECTION DETAILS ASSUME :-
   - (a) ROOM SIZES SHOWN
   - (b) LOCAL ATTENUATION (NOT SHOWN) OF DIRECT BEAM TO 100 MILLIROENTGENS PER HOUR AT 10 FEET AT RATED VOLTAGE AND CURRENT. SHIELDING TO BE SUPPLIED BY CUSTOMER OR THROUGH SPECIAL ORDER.
   - (c) RADIATION LEVELS OUTSIDE BARRIERS NOT IN EXCESS OF 6 MILLIROENTGENS PER HOUR

   IN THIS ENERGY RANGE, 4.8" OF CONCRETE ≈ 1" OF LEAD. PREFERRED LOCATION OF ROOM : BELOW GROUND TO UTILIZE EARTH AS RADIATION BARRIER. CONCRETE THICKNESSES SHOWN ARE FOR POURED CONCRETE, DENSITY = 2.35 (IF REQUESTED, H.V.E.C. WILL GIVE RECOMMENDATIONS ON INDIVIDUAL REQUIREMENTS OF PROTECTION)
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4. APPROXIMATE WEIGHT OF GENERATOR & ACCESSORIES

   SUPPORTED BY FLOOR = 4000 LBS.

   WEIGHT OF TANK ONLY = 1450 LBS.
5. PROVISION SHOULD BE MADE FOR THE STORAGE OF DRY ICE, GAS CYLINDERS, TOOLS & SPARE PARTS.

JOB NO.	NO. REQ.			D					
				C					
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Distribution of Ionization in Materials Irradiated by Two and Three Million-Volt Cathode Rays

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(Received November 4, 1949)

Measurements are reported on the distribution of ionization in depth of aluminum produced by steady beams of two and three million-volt electrons. The variation of cathode-ray current density in a plane transverse to the beam, the effect on this transverse distribution of additional aluminum scattering foils, and a practical method of cathode-ray dosage computation are given.

INTRODUCTION

IN the study of the physical and biological effects of high energy cathode rays[1] it is desirable to know the actual distribution of the ionization energy in the absorber material. An earlier paper[2] reported measurements on the distribution of ionization in depth of water, aluminum, copper, and lead produced by monoenergetic electron beams over the energy range from 0.3 to 1.5 million volts. In the present studies, ionization distribution in depth of aluminum and intensity distribution across the beam were measured for steady streams of electrons in the two and three million-volt range. In order to secure greater uniformity across the field, a study was made of the effect of scatter produced by aluminum foils inserted in the beam. A method of dosage computation which facilitates the determination of maximum, average, and minimum cathode-ray dose on a sample of given size is included.

CATHODE-RAY SOURCE

A pressure-insulated Van de Graaff electrostatic accelerator[3] was used as the source of high energy electrons. These were directed toward the absorber in a continuous stream, homogeneous in energy and controllable over the range from 1 to 3.5 million volts. The electrons emerged from the tube through an aluminum window 0.003 inch thick on which they impinged as parallel particles over an area of about 5 mm diameter. Voltage was measured by a generating voltmeter which had been calibrated at 1.63 million volts by making use of the beryllium (γn) reaction and observing the threshold with a BF_3 counter.

MEASUREMENT TECHNIQUE

A thin parallel-plate ionization chamber was used to measure the distribution of ionization in depth caused by the high energy electrons in their passage through aluminum. The chamber consisted essentially of a stretched aluminum diaphragm 0.0006-inch thick, insulated and separated by 1 mm from a thick aluminum plate which formed the other electrode. The area of the air gap was large compared with that of the cathode-ray beam at the region of measurement. As shown in Fig. 1, the chamber was mounted close beneath the cathode-ray window of the accelerator tube. Thin aluminum sheets were inserted between the cathode-ray window and the ionization chamber to give the effect of placing the chamber at progressively greater depths below the surface of the absorbing material.

A constant beam current I_1 of high energy electrons was directed at the absorber system. Two microamperes of beam current produced maximum ionization currents I_2 or I_3 of approximately 40 μa. I_2 represents the negative ionization current plus the portion of the beam current which passed through the aluminum sheets, and I_3 the positive ionization current minus the portion of the beam current which was absorbed in the aluminum sheets.

Linearity of the ionization chamber was checked by using a fixed thickness of aluminum absorber above the chamber and observing the constancy of the ratio I_2/I_1

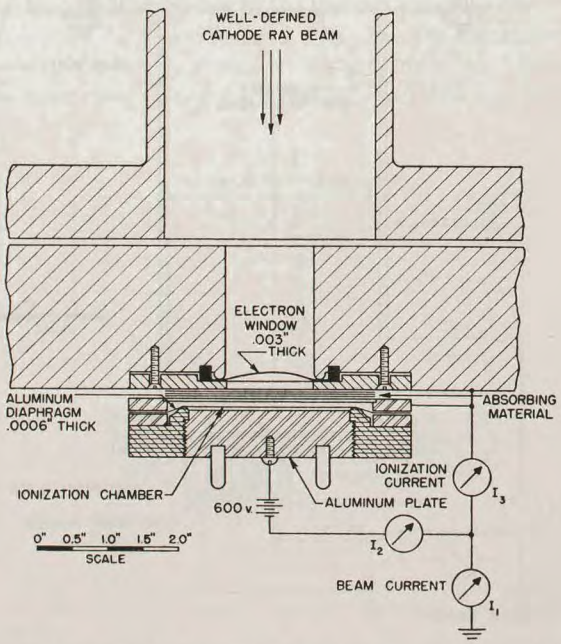

FIG. 1. Apparatus for measuring the distribution of ionization in depth of aluminum produced by high energy electron beams.

[1] J. G. Trump and R. J. Van de Graaff, J. App. Phys. **19**, 599 (1948).
[2] Trump, Van de Graaff, and Cloud, Am. J. Roentgenology and Rad. Therapy **43**, 728 (1940).
[3] J. G. Trump and R. W. Cloud, Am. J. Roentgenology and Rad. Therapy **49**, 531 (1943).

over a wide range of beam currents I_1. The collecting voltage was maintained constant at 600 volts, this voltage having been found to be well above the amount for saturation. This check indicated linearity of response to within ± 2 percent for the range of currents used in the experiment.

The distribution of current density in a plane transverse to the beam was measured with the arrangement shown in Fig. 2 by collecting the current passing through spaced holes in an aluminum plate at a distance of 40 cm from the exit window of the accelerator tube. The minimum or inherent scattering of the electron beam was caused by both the 0.003-inch aluminum window and the 40 cm of intervening air. Faraday cages were placed beneath the individual holes spaced radially at $\frac{1}{4}$-inch intervals from the center of the plate. Holes which did not have Faraday cages beneath were plugged to eliminate stray currents. The $\frac{1}{8}$-inch diameter holes in the lower aluminum plate were drilled so

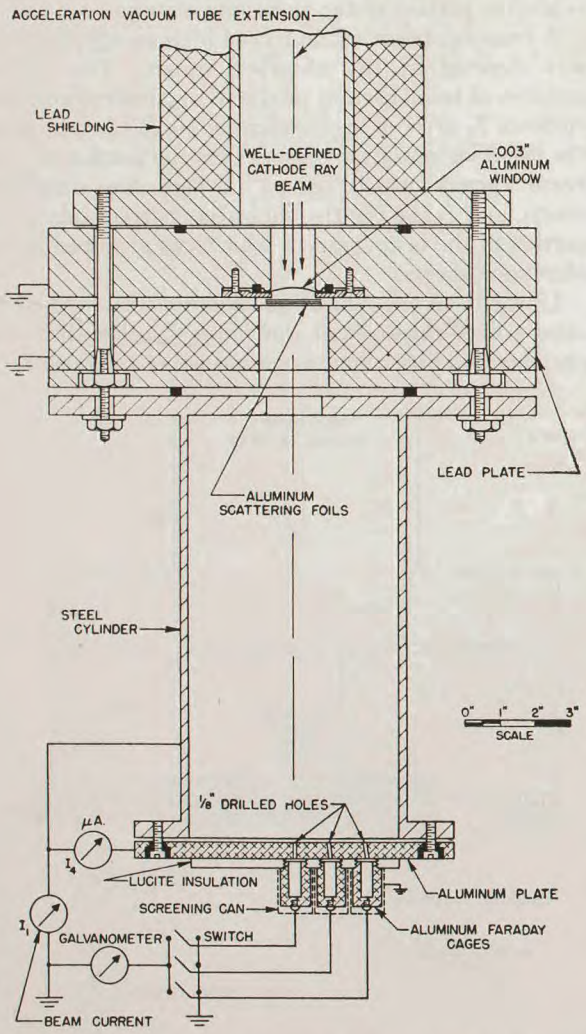

FIG. 2. Apparatus for determining the cathode-ray current density transverse to the beam and the effect of additional aluminum scatterer.

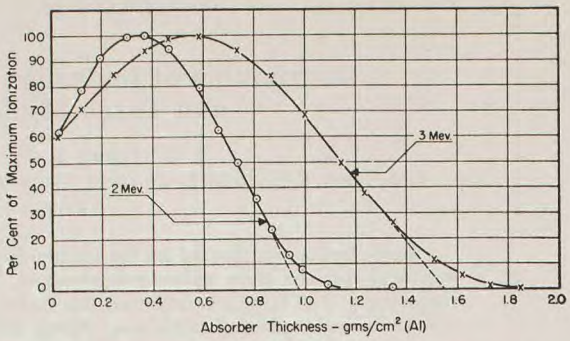

FIG. 3. Distribution of ionization in depth of aluminum produced by cathode rays with energies of two and three million volts.

that their angles with respect to the beam axis were determined by the center of the exit window and the radial distance of the holes from the center of the plate. It was found necessary to shield the individual Faraday cages from ionization in air caused by x-rays. For these measurements the total beam current I_1 was held constant at 50 μa, and the resultant Faraday cage currents of the order of 10^{-8} amp. were read on a galvanometer.

IONIZATION DISTRIBUTION IN DEPTH

Figure 3 shows the ionization distribution in depth of aluminum produced by electron beams of two and of three million volts energy. It is observed that the ionization has a broad maximum at about one-third the greatest range, this previously reported distribution[2] arising from the high scattering tendency of the primary electrons within the absorber. The penetrating power of electrons in aluminum is close to 1 g/sq. cm per two million volts, as determined by the interpolated curve intercept. From other studies[2] at lower electron energies, a corresponding range was found for water, aluminum, copper, and lead, and the general shapes of the ionization distribution curves were closely similar. The range in centimeters can be obtained by dividing the range in g/sq. cm by the density of the absorber material. The tail of the distribution curve is due primarily to those few electrons which have made relatively undeviated paths through the absorber. Ionization due to x-rays produced within the absorber can easily be shown to constitute a negligible addition to the measured ionization currents.

Since the area of the ionization chamber was large in comparison with that of the beam, the curves of Fig. 3 represent approximately the distribution of ionization in depth along the axis of the beam and more accurately the total ionization at each depth. In addition to its primary dependence on electron energy and absorber density, the distribution of ionization energy in an absorber irradiated by essentially parallel and monoenergetic electrons is profoundly affected by electron scattering. Although the ionization density is greatest near the end of the path of a single electron,

the effect of scattering on a beam of such particles is to shift the region of highest ionization and energy absorption to a depth of about one-third the maximum penetration for that energy.

BEAM INTENSITY DISTRIBUTION ACROSS THE FIELD

Figures 4 and 5 show the intensity distribution of two and three million-volt cathode-ray beams in a transverse plane 40 cm from the exit window. The upper curve of each figure shows the distribution resulting from the inherent scatter consisting of the 0.003-inch aluminum window and 40 cm of atmospheric air. The remaining curves show the beam-spreading effects of additional aluminum scatterer placed immediately below the window.

The greater directivity and reduced scatter obtained at the higher beam energies is evident from a comparison of Figs. 4 and 5. In the irradiation of an area four inches in diameter at the 40-cm distance, two million-volt

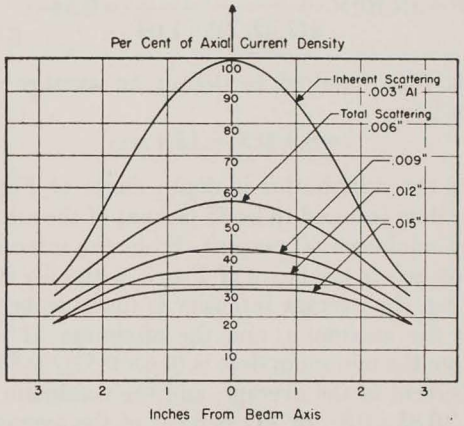

FIG. 4. Distribution of current density for two million-volt cathode rays in a transverse plane 40 cm from the 3-mil aluminum window.

cathode rays with inherent scatter would deliver 52 percent of the axial intensity to the sample edges, while a three million-volt beam would deliver but 30 percent to the edges. Additional scatterer inserted in the beam rapidly increases the uniformity of beam intensity over the selected area, but is attended by loss of charge to outside regions. Modification of the intensity distribution to the transverse plane can readily be accomplished by the addition of solid scatterer or an increase in the air path to the absorber. Because the ratio of scatter to absorption increases with atomic number, it would be preferable to use foils of gold or other high atomic-number metal as the scattering material.

DOSAGE COMPUTATIONS

At the present time there exists a considerable interest in the physical, chemical,[4] and biological[5] effects of high energy cathode rays on living and non-living materials. For such irradiation studies, the cathode-ray equipment may be set up as in Fig. 2 with a solid lower aluminum plate. A current-collecting disk is placed on, and preferably flush with, the top of this plate, but electrically insulated from it. A suitable shutter is used to provide accurate control of the exposure time.

In principle, the cathode-ray dosage rate can be specified with great exactness inasmuch as it is determined by the number of impinging electrons per second and their accelerating voltage. In practice, account must be taken of the distribution of the ionization energy both in depth and across the transverse plane of the absorber. For the case of stationary samples, dosage computations can readily be made with the aid of information contained in Figs. 3–5. The dose delivered to liquids in continuous flow or to solids on a moving belt may often be derived more simply by direct comparison with the known chemical or bactericidal effects of cathode rays as determined on stationary samples.

The total cathode-ray power falling on a disk of diameter D is EI where E is the accelerating potential and I the total beam current to the disk. The average power P absorbed per gram of material distributed uniformly over this disk to a depth R expressed in g/sq. cm is

$$P=[EI/\pi(D/2)^2R]K_1K_2\text{watts/g},$$

where K_1 is the fraction of the total power absorbed in range R and K_2 is a factor close to unity which takes account of the possible change in electron backscatter from the disk area after a sample of the same diameter has been placed upon it. The value of K_1 may be obtained from Fig. 3 by dividing the area under the curve for a sample thickness R by the total area of the curve of energy E. The value of K_2 requires the measurement of electron backscatter for different materials,[6] but can be kept close to unity by making both disk and sample

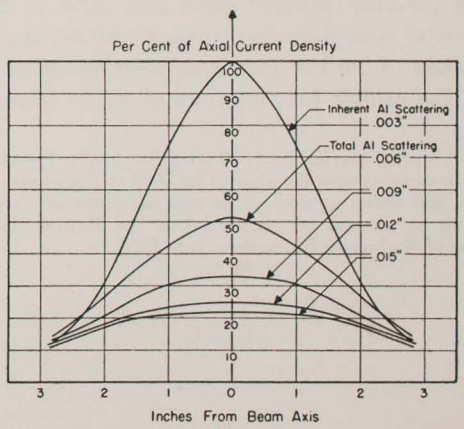

FIG. 5. Distribution of current density for three million-volt cathode rays in a transverse plane 40 cm from the 3-mil aluminum window.

[4] A. O. Allen, AEC Report MDDC-363 (September, 1946).

[5] Dunn, Campbell, Fram, and Hutchins, J. App. Phys. **19**, 605 (1948).

[6] J. G. Trump and R. J. Van de Graaff, Phys. Rev. **75**, 44 (1949).

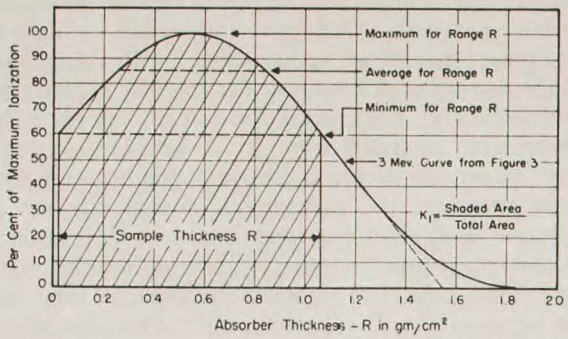

FIG. 6. Ionization-in-depth curve for three million-volt cathode rays applied to a 1.03-g/cm² sample to determine maximum, average, and minimum doses.

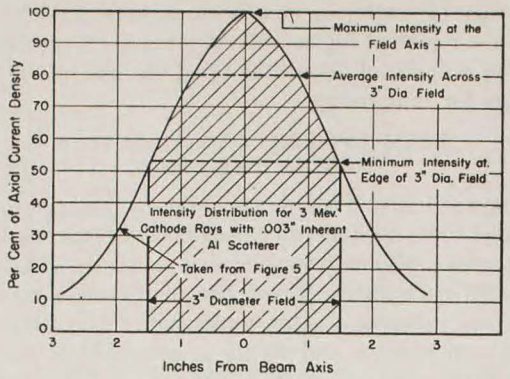

FIG. 7. Transverse beam intensity curve for three million-volt cathode-ray beam applied to a three-inch diameter sample at 40-cm distance to determine maximum, average, and minimum intensities.

cover of the same low atomic number material, such as aluminum.

Cathode-ray dose is best expressed in ergs and joules for physical studies, but may be specified in equivalent roentgens for biological studies. The conversion factors for these units of radiation energy are 1 joule $=10^7$ ergs; 1 roentgen equivalent physical[7] (rep) $=83$ ergs per gram of tissue; 10^6 reps $=8.3$ joules per gram of tissue. The irradiation time is found by dividing the desired dose expressed in joules by the average dosage rate P.

Maximum and minimum doses can be calculated from the average by applying the appropriate dose ratios both for the distribution in depth and the transverse distribution as given in Figs. 3–5. Consider the specific case in which it is desired to irradiate a stationary sample three inches in diameter (7.62 cm) with three million-volt cathode rays. The current to the three-inch collecting disk is taken as 10 μa. For convenience, the sample depth R in g/sq. cm is chosen so that the entrance and exit doses are the same percent of the maximum dose. From the three million-volt curve of Fig. 3 or 6, R is found to be 1.03 g/sq. cm. The ratio of the area included under this curve to depth R to the total area gives coefficient $K_1=0.84$. If care has been taken to use low atomic-number materials and to mount the sample for minimum effect on backscatter, then K_2 can be taken as unity. Then

$$P=3\times10^6\times\frac{10\times10^{-6}}{\pi(7.62/2)^2}\frac{0.84\times1}{1.03}=0.54\frac{\text{watts}}{\text{g}}$$

and the time required to deliver an average dose of 10^6 reps is

$$t=8.3/0.54=15.4 \text{ sec.}$$

From the distribution-in-depth curve of Fig. 6 the average dose is found to be 85 percent of the maximum, and the minimum 60 percent. From the intensity distribution across the beam of Fig. 7, with only inherent scattering, the average intensity is found to be 80 percent of the maximum, and the minimum 52 percent. Therefore the minimum dose is $(0.6\times0.52)/(0.85\times0.8)$, or 46 percent of the average, and the maximum dose is $(1\times1)/(0.85\times0.8)$, or 147 percent of the average. The spread between maximum and minimum doses may be controlled by suitable selection of absorber depth, width, scatterer, and irradiation distance.

ACKNOWLEDGMENTS

We desire to pay tribute to Arthur M. Clarke, our associate on this paper, whose death on January 19, 1949, ended seven years of devoted and effective work in the High Voltage Research Laboratory. The help of Dr. E. W. Webster in making some of the measurements is gratefully acknowledged. This work was assisted by the Joint Program of the ONR and the AEC.

[7] R. D. Evans, Nucleonics 1, 39 (October, 1947). Proposals that 1 rep be associated with the absorption of 93 ergs per gram of water or tissue and that the value of 83 ergs per gram be restricted to absorption in air will be considered at the Sixth International Congress of Radiology in London, July 1950.

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Irradiation of Biological Materials by High Energy Roentgen Rays and Cathode Rays

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(Received February 16, 1948)

In this work roentgen rays and cathode rays of several million-volts energy have been applied to an investigation of their biological, photo-chemical, and germicidal effects, particularly as they are related to the processing of foods and biological materials. A constant-potential electrostatic generator, together with an acceleration tube, was used to produce continuous streams of electrons with homogeneous and controllable energy. [R. J. Van de Graaff, K. T. Compton, and L. C. Van Atta, Phys. Rev. **43**, 149 (1943).] These high energy electrons were utilized both for the production of penetrating roentgen rays and for the direct irradiation of materials. The mechanism of the biological action of both roentgen rays and cathode rays is discussed, as well as the energy considerations in their application to various absorbers. The companion paper [C. G. Dunn, W. L. Campbell, H. Fram, and A. Hutchins, J. App. Phys. **19**, 605 (1948)] reports on measurements of the lethal action of these radiations on a wide variety of micro-organisms and also on the effect of the radiations on enzymes, vitamins, and certain whole food products. Both investigations have been conducted cooperatively by the Departments of Electrical Engineering and Food Technology at the Massachusetts Institute of Technology.

The systematic and quantitative study of the effects of roentgen and cathode rays on various elementary forms of living matter is regarded as an essential prelude to their possible widespread application to the preservation of foods and the sterilization of various biological materials. It was realized that the mechanisms of biological action of high energy roentgen rays and cathode rays are similar and depend closely upon the ionization energy absorbed per gram of material. The studies were begun with roentgen rays since these were immediately available and permitted quantitative measurement of the energy absorbed in the biological materials. Later, the water-cooled gold x-ray target was replaced with an aluminum cathode-ray window, and corresponding studies were begun on the direct application of high energy electrons to these materials. During the period of these biological studies the x-ray source was also used in a daily clinical program of deep cancer therapy under the medical direction of Dr. Richard Dresser and also in the investigation of the physical properties of high energy radiations. [R. Dresser, *Radiology*, in publication.]

ELECTROSTATIC SOURCE OF IONIZING RADIATIONS

THE source of high energy radiation was a pressure-insulated electrostatic generator of the belt type at the Massachusetts Institute of Technology rated at 3-million volts constant potential.[1] This generator, shown in Fig. 1, is completely contained in a steel pressure tank $4\frac{1}{2}$ feet in inside diameter and about 12 feet high, containing air at 13 atmospheres pressure.

The high voltage terminal of the generator is a stainless steel hemispherical spinning about 24 inches in diameter supported by an 88-inch high insulating column of metallic equipotential members separated by glass spacers. A single 3-ply butyl rubber cotton fabric belt 12 inches wide travels at 4000 feet per minute within the column and transfers negative electric charge continuously from ground to terminal. Although both sides may be utilized, it has been more convenient to spray charge merely on the upward run of belt. Under these conditions the continuous current available for the acceleration tube has been about 500 microamperes at full voltage.

The generated voltage may be controlled from values of a few hundred thousand volts to a maximum of about 4 million by regulating the amount of charge sprayed on the belt for a given fixed setting of the electron current in the tube. The negative voltage of the terminal is divided uniformly lengthwise the column by means of a variable corona gap between each of the separated equipotential planes.

The acceleration tube is mounted within the generator column and in a position parallel to the charge conveyor belt. The source of electrons is

[1] J. G. Trump and R. W. Cloud, Am. J. Roentgenology and Rad. Therapy **49**, 531 (1943).

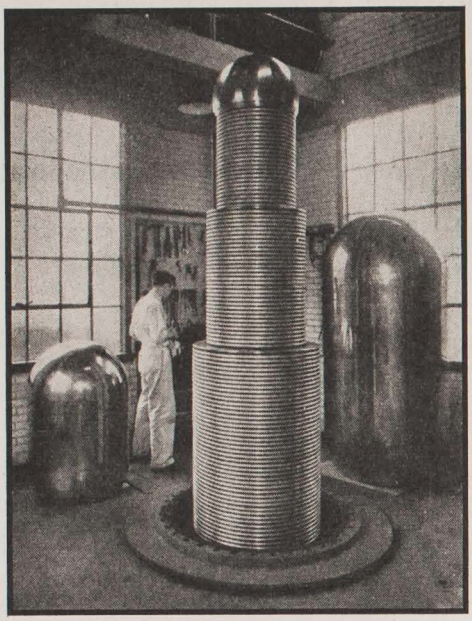

FIG. 1. 3-million volt pressure-insulated electrostatic accelerator with tank removed.

a hot tungsten filament supplied with power from a small permanent-magnet generator contained within the high voltage terminal and driven by the upper pulley. The insulating column of the tube is a rigid self-supporting structure made of alternate glass rings and flat stainless steel disks sealed together by a thermoplastic-film technique developed in this laboratory. Each disk has an axial 3-inch diameter hole and is electrically connected to the equipotential plane of the generator column at that level. The electrons are thus progressively accelerated as they pass from the filament axially downward through the planes of the diaphragms. The ground potential end of the tube extends on through the tank base into the room below and terminates in the target arrangement shown in Fig. 2. X-rays are produced when the electrons impinge on the water-cooled gold disk, which is 0.25 inch thick. The electrostatic focusing action of the tube diaphragms brings the electrons to the target in a focal spot about 10 millimeters in diameter. This may be brought to less than 0.25 millimeter by passing d.c. current through an axial magnet coil at the grounded end of the tube. By withdrawal of the gold disk from the path of the stream the electrons may be allowed to pass through the 0.002-inch aluminum window into the atmosphere as a high energy cathode-ray stream, as shown in Fig. 3. This target arrangement has permitted great flexibility in working alternately with x-rays and cathode rays since it eliminates the necessity for breaking the vacuum and thereafter reconditioning the electrode surfaces. The acceleration tube is continuously evacuated by a mercury diffusion pumping system.

In the roentgen-ray studies the biological material was placed in a thin metal or glass container located an average distance of 3 centimeters below the x-ray source. The dosage rate at this position could be adjusted to a maximum of about 5000 roentgens per second. A small special ionization chamber was mounted directly under the sample and connected to an integrating circuit to measure the total ionization dose received by the material. The total doses applied to samples ranged from 10-thousand to 2-million roentgens, a roentgen being defined as that amount of radiant energy which, when passing through 1 cubic centimeter of air at standard temperature and pressure, will release 1 electrostatic unit of charge. Figure 4 shows containers of 0.005-inch aluminum and 0.01-inch stainless steel used in this work, together with the carrier for sample and ionization chamber which could be automatically moved into or out of the beam of radiant energy.

NATURE OF THE BIOLOGICAL REACTION TO RADIATION

The photo-chemical and biological reactions produced by the absorption of x-rays and cathode rays are similar in their physical nature and require closely equivalent energies. When matter is traversed by x-rays, energy is absorbed from the x-ray photons by the photoelectric, Compton scattering, or pair-production mechanisms, and electrons are accelerated with related amounts of energy. These energetic secondary electrons excite and ionize many other atoms in their path and may thereby produce low energy tertiary electrons still capable of excitation and ionization. Chemical changes in an absorber are brought about primarily by the ionization and to a lesser extent by the excitation of the constituent atoms. These higher energy states generally favor the dissociation of complex molecules, though

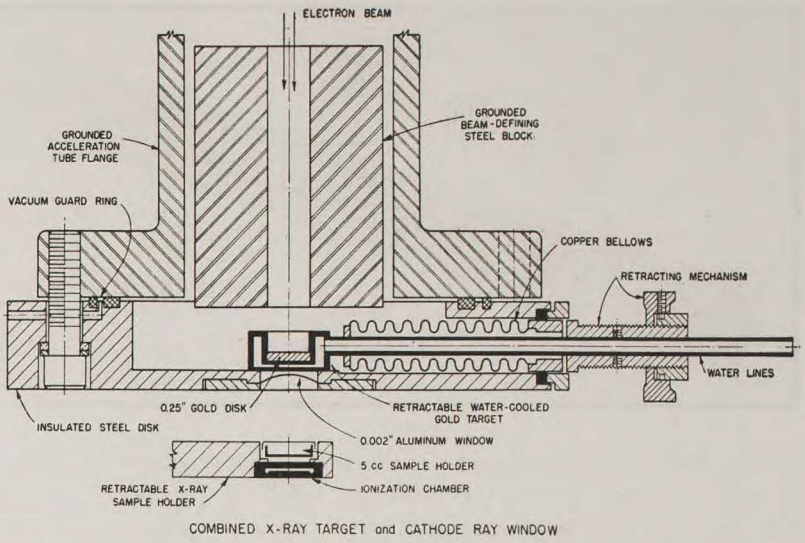

FIG. 2. Combined x-ray target and cathode-ray window.

combination is also often made possible, as in the formation of hydrogen peroxide by the irradiation of water. The ionizing energy is imparted so directly to the absorber that profound chemical changes may often be accomplished with negligible gross heating effects. In the case of living tissue, injury—and in the limit death—of a cell is the result of physiochemical changes brought about by direct absorption of ionizing energy or indirectly by the reaction of surrounding irradiated tissue. Much is now known concerning the influence of dosage rate, the linear ion density along the track of the high energy particle, and the influence of the surrounding medium on the complex response to radiation of molecules, cells, and microorganisms. Ultimately, the physiochemical and biological reactions depend on the number of ionizing electrons produced in the passage of the radiation through the material.

In cathode-ray irradiation electrons are directly projected into the material and produce ionization similar in its general characteristics to that produced by x-rays. Each high energy electron in the cathode-ray stream proceeds into the material, losing energy by collision and causing the excitation or ionization of thousands of atoms in its path. These primary electrons thus distribute the energy of the cathode-ray stream through the volume of the absorber. Many of the secondary electrons produced in these encounters may themselves possess sufficient energy to act as biological agents by the ionization of other atoms. The biological effects are produced by these excitation and ionization events.

In general the primary difference between the action of supervoltage x-rays and cathode rays on

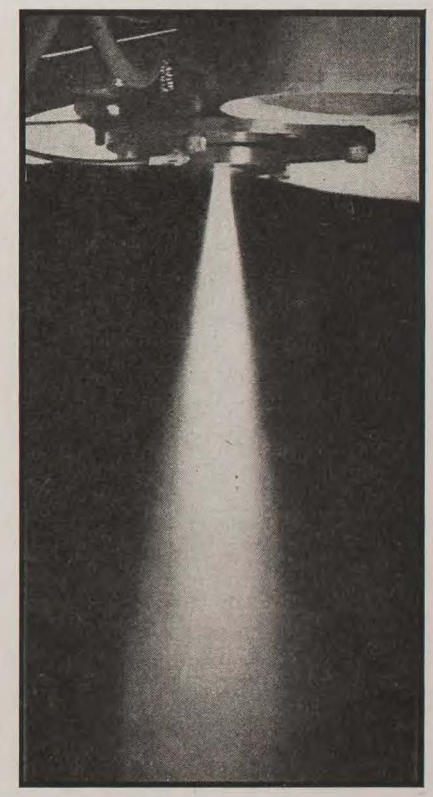

FIG. 3. 3-million volt cathode-ray beam.

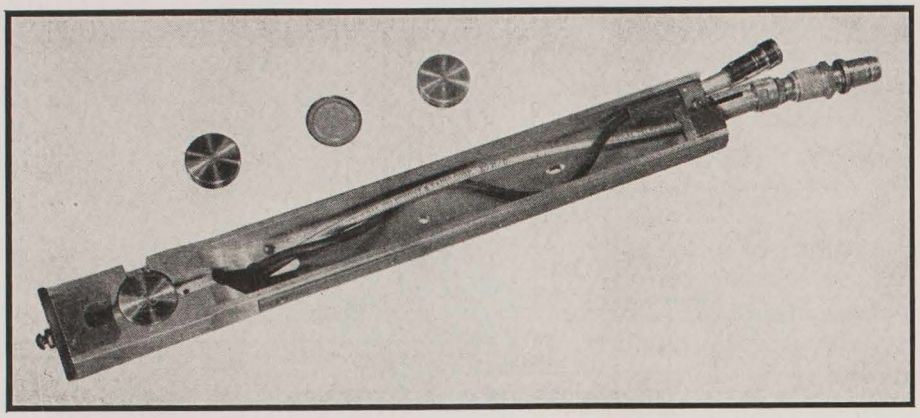

FIG. 4. Retractable carriage with ionization chamber and sample holders for x-irradiation.

living matter is in the gross distribution of the ionization energy within the absorber. Whereas cathode rays may penetrate into water a maximum distance of about 1 centimeter for each 2-million volts of energy and produce no effect beyond this maximum range, x-rays are relatively penetrating and diminish exponentially in passing through an absorber. Thus the intensity of a 2-million volt roentgen-ray beam diminishes almost one-half for each 10 centimeters of water through which it passes.[2] In the case of initially parallel cathode rays of homogeneous energy, the maximum ionization density produced in an absorber occurs at about one-third the maximum range.[3] This location of the region of maximum ionization toward the forward part of the maximum range for any given voltage is due to the naturally high scattering tendencies of electrons and would be accentuated if the cathode-ray beam were accelerated by pulsed or varying voltages. The insert of Fig. 5 compares the gross distribution of ionization produced by a beam of 3-million volt x-rays traversing water with that produced by cathode rays passing through the same material.

ENERGY ABSORBED AND TEMPERATURE RISE OF IRRADIATED MATERIAL

The amount of energy absorbed in a gram of air when 1 million roentgens of x-radiation pass through it can be measured and calculated. Irradiation of air with a dose of 1 million roentgens is equivalent to the absorption of 8.5 joules of ionizing energy per gram of the absorber.[4] Over a wide range of wave-lengths this relation between energy absorbed per gram and x-ray dose in roentgens also holds fairly closely for water which has constituents of atomic number close to those of air. Dependence upon the atomic number of the absorber becomes pronounced for radiation of less than 100 kilovolts energy because of the photoelectric absorption process and above several million volts where pair production becomes an influential absorption mechanism. For the energy region between, in which the Compton scattering process predominates, the energy absorption per gram is nearly independent of atomic number.

In another investigation[3] we have found, as might be expected, that this relation likewise holds when cathode rays are directed at an absorber. In our physical measurements close equivalence has been found between the number of ion pairs produced by the absorption of a given amount of roentgen-ray energy and the same amount of cathode-ray energy. It is therefore reasonable to expect that experimental studies of the biological and photo-chemical effects of x-rays conducted under conditions of high physical control can usually be correlated to closely corresponding effects obtained with equal amounts of cathode-ray energy.

The energy absorbed by the passage of roentgen-ray or cathode-ray energy through a material ultimately appears as heat and is manifested by a corresponding temperature rise. The temperature rise in water produced by an x-ray dose of 1 million roentgens or by the absorption

[2] D. E. Lea, *Actions of Radiations on Living Cells*, The Macmillan Company, New York, 1947).

[3] J. G. Trump, R. J. Van de Graaff, and R. W. Cloud, Am. J. Roentgenology and Rad. Therapy **43**, 728 (1940).

[4] L. H. Gray, Proc. Roy. Soc. **A156**, 578 (1936).

of 8.5 joules per gram is 2.04°C. This temperature rise is directly proportional to the x-ray dose and inversely proportional to the specific heat of the absorbing material. Since 6000 roentgens is a high cancericidal dose and 1 million roentgens is a 100 percent bactericidal dose, it is evident that pronounced biological and photo-chemical effects are realized with amounts of radiation which produce a relatively unimportant temperature rise in the absorbing material. The energy of these penetrating radiations is not expended directly in raising the average thermal energy of the molecules as in the case of heat sterilization, but is used more efficiently to induce by the process of excitation and ionization discrete changes in the atomic and molecular structure of the irradiated material.

CHARACTERISTICS OF CATHODE RAYS FOR IRRADIATION

The advantage of cathode rays over x-rays in the irradiation of living materials lies primarily in the high inherent efficiency of this process and in the controllability of the cathode-ray dosage under proper conditions. The efficiency of utilizing the electron beam energy can ordinarily be several hundred times higher in cathode-ray irradiation than when x-rays are used. In utilization of the cathode rays accelerated in a constant-potential vacuum tube, an over-all efficiency approaching 100 percent is realizable. All of the emergent cathode-ray beam energy may be directed into the absorber and expended in ionization processes within the well defined maximum electron range, which increases linearly with voltage. The efficiency and controllability of the electrostatic cathode-ray process makes possible the continuous delivery of ionization doses equivalent to millions of roentgens in a small fraction of a second.

With x-radiation, on the other hand, most of the kinetic energy of the electrons within the acceleration tube is lost as heat at the target. At 100 kilovolts only 0.2 percent of the energy of the electron stream is converted into x-radiation. At 2-million volts about 5 percent is transferred into radiant energy. Moreover, since x-rays are penetrating and proceed in all directions, only a small fraction of the x-ray energy can readily be absorbed uniformly within the desired volume of the selected absorber.[5]

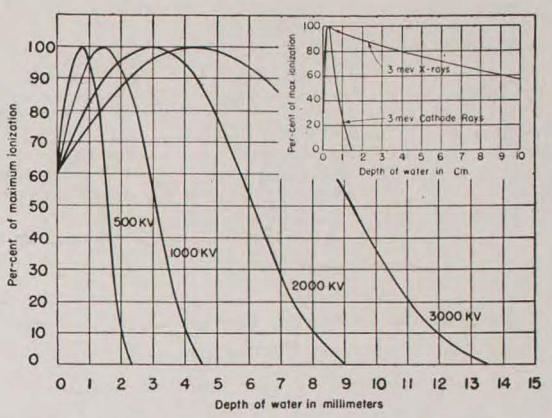

FIG. 5. Distribution of ionization in water by 0.5-, 1-, 2-, and 3-million volt cathode rays and by 3-million volt x-rays.

The cathode-ray dosage falling on an absorber can be completely specified with great exactness as it is determined by the number of impinging electrons per second and their accelerating voltage. With the constant-potential electrostatic

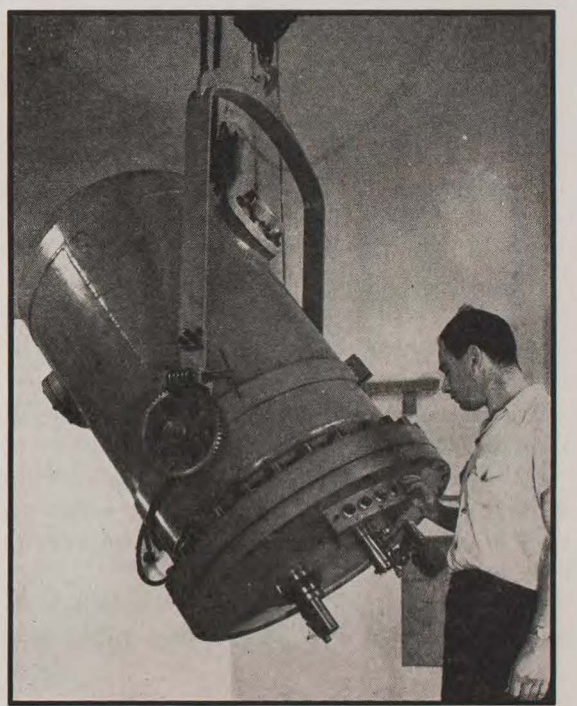

FIG. 6. Compact 2-million volt x-ray or cathode-ray source using pressure-insulated electrostatic generator.

[5] J. G. Trump, C. R. Moster, and R. W. Cloud, Am. J. Roentgenology and Rad. Therapy **57**, 703 (1947).

TABLE I.

Rate per	10^5r dose (0.85 joules/gram)	10^6r dose (8.5 joules/gram)
Second	500 grams	50 grams
Minute	30 kilograms	3 kilograms
Hour	1800 kilograms	180 kilograms
Day	43,000 kilograms	4300 kilograms
300 24-hr. days	13,000,000 kilograms	1,300,000 kilograms

accelerator the ionizing power of the incident cathode rays can be accurately determined by direct measurement of the voltage and current. Thus the ionizing power of the compact 2-million volt generator shown in Fig. 6 operating with an electron beam current of 250 microamperes is 500 joules per second, or 500 watts. Applied to the sterilization of water-equivalent materials, such a cathode-ray source can produce a sterilizing dose of 8.5 joules per gram (equivalent to 1 million roentgens) in about 50 grams of material per second. Table I gives the calculated sterilizing rate in continuous-processing applications for the cathode-ray source shown in Fig. 6 and operating with 500 watts output.

The distribution of ionization produced in water by a cathode-ray beam of 1-, 2-, and 3-million volt energy is shown in Fig. 5. For the 2-million volt electrons, for example, the maximum range in water is seen to be close to 10 millimeters, and the maximum ionization density occurs in a broad-thickness region centering at a depth of 3 millimeters. For many continuous processes a 2-million volt stream of cathode rays would be capable of irradiating effectively a stream thickness of about 6 millimeters. Two such cathode-ray sources irradiating from opposite sides would deliver a fairly uniform dose to approximately twice this thickness. Correspondingly higher voltages would be required for the irradiation of greater thicknesses, and allowance must be made for absorption by an intervening wall materials.

When the cathode-ray beam emerges into the atmosphere from the acceleration tube, some divergence of the beam results from the normal scattering by the window diaphragm. Hence the area which is irradiated by the beam increases with distance from the cathode-ray window. The cathode-ray stream may also be magnetically diverged. Thus the depth of penetration of cathode rays is determined by the voltage and the density of the absorbing material, while the area which is irradiated can be controlled by selection of window-absorber distances, by magnetic deflection, and by suitable scattering arrangements.

CONCLUSION

High energy cathode rays and x-rays now offer a new and effective means of producing biological, bactericidal, and even chemical changes on a practical scale. These changes are brought about by excitation and ionization of constituent atoms of the absorber and need relatively small amounts of ionizing energy. Cathode rays produce similar reactions and can be utilized with several hundred times the efficiency of x-rays. The temperature rise evoked by cancericidal doses of these radiations is about 0.01°C, while complete sterilization of bacteria can be accomplished with ionization doses resulting in a 2°C rise. The constant-potential output of electrostatic accelerators is well suited to quantitative radiation studies and to large-scale sterilization and inactivation processes.

ACKNOWLEDGMENTS

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Biological and Photo-Chemical Effects of High Energy, Electrostatically Produced Roentgen Rays and Cathode Rays

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INTRODUCTION

IN a companion article by Trump and Van de Graaff the physical characteristics of electrostatic accelerators for the production of high energy roentgen rays and electrons are discussed, together with factors influencing their application to the irradiation of biological materials. The principal portion of the research reported herein is concerned with the lethal action of x-rays produced at high voltages on pure cultures of microorganisms and those found in spices, apple juice, milk, soil, water, and catgut sutures. Some preliminary data on cathode rays are included.

MICROBIOLOGICAL INVESTIGATIONS WITH X-RAYS

Literature

A number of scientists have studied the lethal and sublethal effects of x-rays (particularly those produced at low or comparatively low voltages) on microorganisms. References to some of the more important of these papers are given at the end of this report.

Proctor, Van de Graaff, and Fram (1942) carried out research concerning the action of x-rays produced at high voltage on finely ground beef and observed that the bacterial counts were considerably reduced as a result of the irradiation. The present research was suggested as a result of these findings.

Microorganisms Used

Of microorganisms investigated to date the main emphasis has been on bacteria. Those examined consisted of food spoilage, heat-resistant, Gram-positive, Gram-negative, spore forming, non-spore forming, and pathogenic organisms. The yeasts included both active and dormant cultures; the molds, two of the more commonly occurring species.

The microorganisms used were obtained from the stock collection of the Department of Food Technology, M.I.T.; the American Can Company; and the National Canners' Association.

Procedure

The lethal effects of high voltage x-rays on pure cultures of microorganisms were determined essentially as follows. The organism was grown in a medium (liquid or solid) and at a temperature conducive to the development of a large number of cells or spores. A uniform suspension of the organism was prepared either in a broth medium or in sterile distilled water. When necessary, the culture was shaken with sterile glass beads in order to obtain a uniform suspension. Occasionally the supernatant portion of the suspension was transferred aseptically to a second sterile tube before use. The suspension thus prepared was pipetted into the sterile glass or stainless steel containers which were used for irradiation purposes. The containers with their contents were placed successively in the x-ray field and subjected to various roentgen doses, varying from as low as 10,000 to as high as 8,000,000 roentgens. At the time of irradiation, data were recorded concerning the dosage in roentgens, the voltage in megavolts, the electron beam current in microamperes, and the exposure time in seconds or minutes. The irradiated samples were immediately plated in a solid medium suitable for the growth of the organism. The plates were incubated at temperatures favorable for the growth of the survivors and the visible colonies were counted with a Quebec Colony counter after a suitable incubation period. Details concerning some of the experimental data are presented in Table I of this report.

Suspensions containing viable bacterial spores were prepared by heating suspensions of the organisms being investigated at 80°C for 10 minutes or at the boiling temperature for five or more minutes. The suspensions thus contained the viable bacterial spores and the heat-destroyed vegetative cells and weaker spores.

The spices examined were purchased on the open market. One-gram samples were used for irradiation purposes. Control and irradiated samples of the spices were shaken with sterile distilled water in wide-mouth glass bottles containing sterile glass beads and dilutions prepared therefrom. Aliquot portions of various dilutions were plated in duplicate in Bacto nutrient agar and incubated at 30°C for three to six days before final observations were made.

TABLE I. Some experimental data.

Culture	Source of culture	Medium in which grown	Temperature at which grown, °C	Age of culture (in days)[f]	Composition of irradiation container	Medium in which bacteria suspended for irradiation	Plating medium	Incubation temperature °C	Incubation period (in days)
Aerobacter aerogenes	Stock collection[a]	Bacto nutrient broth	37	1	Glass	Nutrient broth	Bacto nutrient agar	37	1
Escherichia coli	Stock collection	Bacto nutrient broth	37	1	Glass	Nutrient broth	Bacto nutrient agar	37	1
Pseudomonas aeruginosa	Stock collection	Bacto nutrient broth	37	2[b] 3	Stainless steel	Nutrient broth	Bacto nutrient agar	37	2
Pseudomonas fluorescens	Stock collection	Bacto nutrient broth	24–26	1[b] 3	Stainless steel	Nutrient broth	Bacto nutrient agar	24–26	3–4[d]
Serratia marcescens	Stock collection	Bacto nutrient agar	30	2	Stainless steel	Nutrient broth	Bacto nutrient agar	26	2
Sarcina flava	Stock collection	Bacto nutrient broth	30	1[b] 2	Stainless steel	Nutrient broth	Bacto nutrient agar	30	4.5
Staphylococcus aureus	Stock collection	Bacto nutrient broth	37	1	Glass	Nutrient broth	Bacto nutrient agar	37	1
Bacillus mesentericus, strain	Manioca sirup	Bacto nutrient broth			Stainless steel	Nutrient broth	Bacto nutrient agar	26	3
B. sterothermophilus	American Can Company	Dextrose tryptone broth	55	1	Stainless steel	Dextrose tryptone broth	Bacto dextrose tryptone agar	55	2
B. thermoacidurans (No. 43-P)	National Canners Association	Special proteose peptone agar[c]	37	5[b] 7	Glass	Distilled water	Special proteose peptone agar[c]	52–54	1–4[d]
Canco 6B	American Can Company	Bacto nutrient agar	37	3[b] 5	Glass	Distilled water Nutrient broth	Bacto nutrient agar	37	2
Flat sour (No. 1518)	National Canners Association	Bacto dextrose tryptone agar	53	3 4	Glass	Distilled water	Bacto dextrose tryptone agar	53	3–4[d]
Spore former	Catgut suture	Bacto nutrient agar	37	2[e] 4	Stainless steel	Nutrient broth	Bacto nutrient agar	37	3

[a] Department of Food Technology, Massachusetts Institute of Technology.
[b] Some tests carried out using cultures of one age, some using cultures of another age.
[c] Refer to Food Research 7, 186 (1942).
[d] The incubation period varied between these limits, depending on the test.
[e] Held at room temperature for several days in addition.
[f] At time of irradiation.

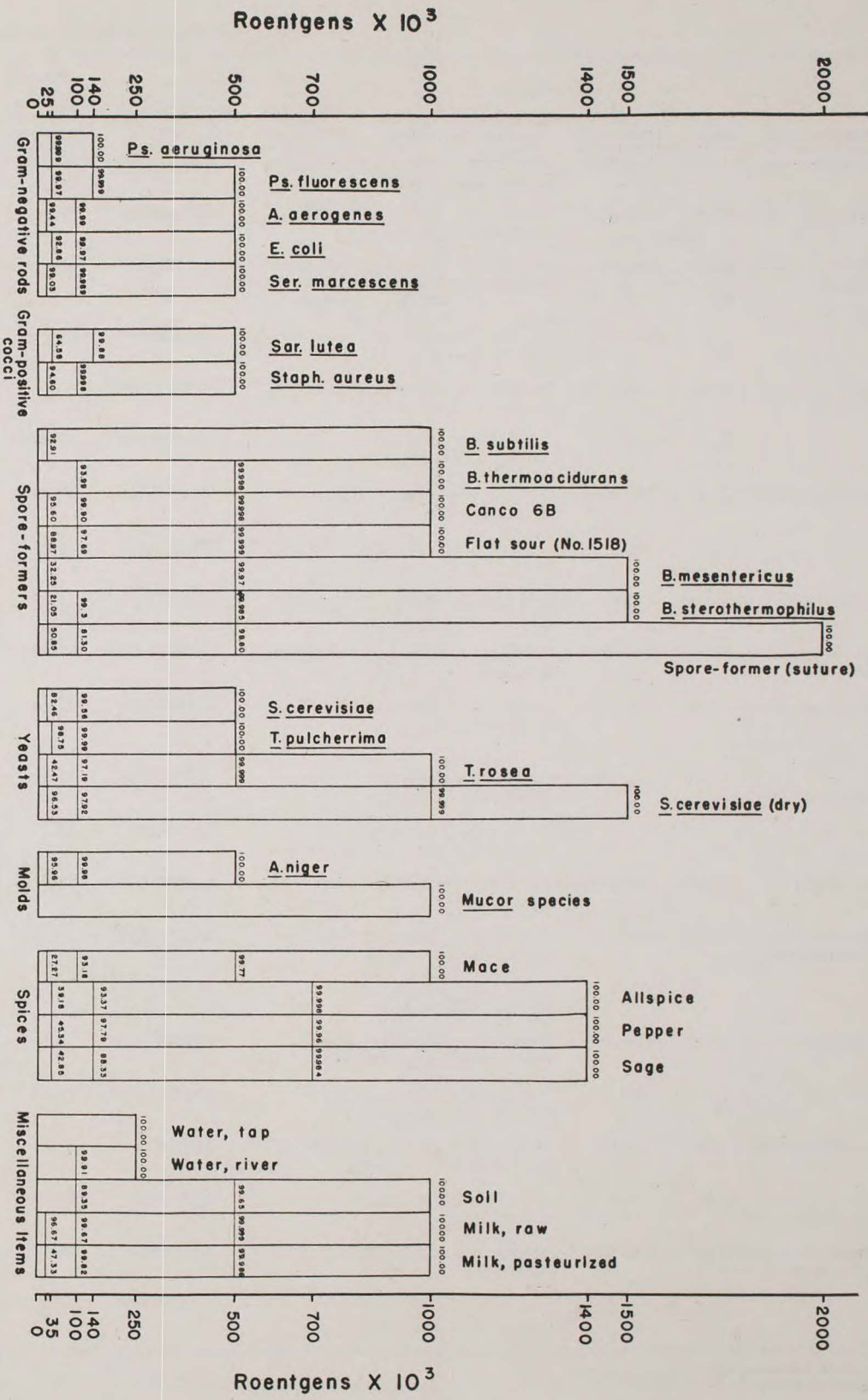

FIG. 1. Lethal effects of x-rays on microorganisms. (Roentgen doses *versus* percentages destroyed.)

TABLE II. Summary of data on lethal

Organism	Morphology	Gram reaction	Relation to oxygen	Sporulation	Pathogenicity	Number of organisms per ml	Percentage destroyed by 25,000 roentgens	Percentage destroyed by 35,000 roentgens
Aerobacter aerogenes	Rods	Negative	Aerobic, facultative	None	None	238,000,000	99.44	——
Escherichia coli	Rods	Negative	Aerobic, facultative	None	None	700,000,000	——	92.86+
Pseudomonas aeruginosa	Rods	Negative	Aerobic, facultative	None	Pathogenic to some small animals	760,000,000	——	99.999+
						400,000,000	——	99.999+
Pseudomonas fluorescens	Rods	Negative	Aerobic	None	None	2,090,000,000	——	99.97
						337,000,000	99.999+	——
Serratia marcescens	Rods	Negative	Aerobic facultative	None	None	990,000,000	99.39	——
						380,000,000	98.68	——
Sarcina flava	Cocci	Positive	Aerobic	None	None	2,400,000	——	64.58
Staphylococcus aureus	Cocci	Positive	Aerobic facultative	None	Pathogenic	1,000,000,000	94.60+	——
Bacillus mesentericus, strain	Rods	Positive	Aerobic facultative	Spores	None	6,200,000[a]	32.25	——
Bacillus sterothermophilus	Rods	Negative	Aerobic facultative	Spores	None	65,000,000	15.4	——
						75,000,000	26.7	——
Bacillus subtilis	Rods	Positive	Aerobic facultative	Spores	None	4,800,000[b]	92.91	——
Bacillus thermoacidurans	Rods	Positive	Aerobic facultative	Spores	None	240,000,000[b]	——	——
						44,500,000[c]	——	——
Canco No. 6B	Rods	Positive	Aerobic, facultative	Spores	None	400,000,000[b]	——	——
						420,000,000[b]	95.60	——
Flat sour (No. 1518)	Rods	Positive	Aerobic, facultative	Spores	None	2,200[b]	81.8	——
						1,100,000[b]	96.15	——
Spore former from catgut suture	Rods	Positive	Aerobic, facultative	Spores	None	22,000,000[b]	46.4	——
						13,000,000[b]	55.3	——

[a] The sample contained 40.32 percent of spores.
[b] A mixture of spores and vegetative cells.

effects of x-rays on selected bacteria.

Percentage destroyed by 100,000 roentgens	Percentage destroyed by 140,000 roentgens	Percentage destroyed by 500,000 roentgens	Percentage destroyed by 700,000 roentgens	Number of roentgens required for destruction	Age of culture	Special comments
99.99	——	100.00	100.00	Less than 250,000 but more than 100,000	1 day	
99.97+	——	100.00	100.00	Less than 150,000 but more than 90,000	1 day	Of sanitary significance
——	100.00	100.00	100.00	Less than 140,000 but more than 35,000	2 days	Produces Fluorescence
——	100.00	100.00	100.00	Less than 140,000 but more than 35,000	3 days	
——	99.999+	——	100.00	Less than 350,000 but more than 140,000	1 day	Produces Fluorescence
100.00	——	100.00	100.00	Less than 100,000 but more than 25,000	3 days	
99.98+	——	99.999+[d]	——	——	2 days	Produces red pigment
99.999+	——	100.00	100.00	Less than 500,000 but more than 250,000	1 day	
——	99.88+	——	100.00	Less than 350,000 but more than 140,000	2 days	Produces yellow pigment
99.998	——	100.00	100.00	Less than 250,000 but more than 100,000	1 day	Produces orange pigment
——	——	99.97	——	Less than 1,500,000 but more than 1,000,000	——	Strain especially resistant to heat; isolated from manioca starch
99.0	——	99.99	——	Not destroyed by 1,000,000		
99.6	——	99.98	——	Destroyed by 1,500,000 but not by 1,000,000		
——	——	——	——	Less than 1,000,000	1 day	
95.41	——	99.997+	——	Less than 1,000,000 but more than 500,000	7 days	Produces flat-sour spoilage of tomato juice
92.58	——	99.999+	——	Less than 1,000,000 but more than 500,000	7 days	
98.1	——	99.996	——	Not destroyed by 500,000	3 days	Causes spoilage of canned foods
99.90	——	99.999+	——	Less than 1,000,000 but more than 500,000	5 days	Source—American Can Company
95.41	——	100.00	100.00	Less than 500,000 but more than 250,000	4 days	Causes flat sour spoilage
99.97	——	99.999+	——	Less than 1,000,000 but more than 500,000	3+ days	Source—National Canners Association
71.0	——	98.0	——	Not destroyed by 1,500,000	4 days	Resistant organism isolated from catgut suture
91.6	——	99.6	——	Less than 2,000,000 but more than 1,500,000	5+ days	

[c] All spores—no viable vegetative cells.
[d] Only one organism survived. In three other tests, the organism failed to survive the application of 500,000 roentgens.

TABLE III. Summary of data concerning lethal effects of x-rays on yeasts.

Designation of yeast	Percentages of yeasts destroyed by 25,000 roentgens	100,000 roentgens	250,000 roentgens	500,000 roentgens	1,000,000 roentgens	1,500,000 roentgens	Number of roentgens required for destruction
Saccharomyces cerevisiae strain 1	85.70	99.98+	99.999+	100.00	100.00		Less than 500,000 but more than 250,000
S. cerevisiae strain 2	86.20	98.62	99.966	100.00	100.00		Less than 500,000 but more than 250,000
S. cerevisiae strain 3	58.98	99.45	99.998+	100.00	100.00		Less than 500,000 but more than 250,000
S. cerevisiae strain 4	93.75	99.82+	99.998+	100.00	100.00		Less than 500,000 but more than 250,000
S. cerevisiae strain 5	87.70	99.95	99.997	99.999+	100.00		Less than 1,000,000 but more than 500,000
S. cerevisiae (dry state) strain 4	96.53	97.92			99.999+	100.00	Less than 1,500,000 but more than 1,000,000
Torulopsis pulcherrima	98.75[a]	99.99+	99.999+	100.00	100.00		Less than 500,000 but more than 250,000
Torulopsis rosea	67.30	97.98	99.90	99.999			More than 500,000
	17.64	96.41	99.95	99.999+	100.00		Less than 1,000,000 but more than 500,000

[a] Received 28,500 roentgens.

Irradiated and control samples of raw and pasteurized milks, apple juice, soil, and waters, after appropriate dilution with sterile distilled water, were plated in Bacto nutrient agar and incubated at approximately 25°C for two to five days before making final observations.

Vials containing catgut sutures rolled on a spindle and partly submerged in liquid were subjected to irradiation by the high voltage x-rays. The tubes were dipped in alcohol and flamed following irradiation and broken at scored points. The catgut sutures were removed aseptically and placed in large culture tubes containing nutrient broth enriched by the addition of 0.5 percent sodium chloride and 0.1 percent of dextrose.

TABLE IV. Lethal effects of x-rays on Aspergillus niger.[a]

Dose in roentgens	Average percentage destruction of molds	Range of percentage destruction of molds
25,000	95.96	91.29 to 98.25
50,000	99.63	98.93 to 99.96
100,000	99.98	99.954 to 99.999
250,000	99.999	99.999 to 100.00
500,000	100.00	100.00 to 100.00

[a] The results are based on a minimum of five separate tests. The ages of the cultures irradiated varied from 2 to 28 days. The molds were grown on Bacto Sabouraud's dextrose agar and suspended in Bacto malt extract broth for irradiation.

Observations were made after incubation for one week at 37°C.

Observations and Results

Many of the observations and results concerning the lethal effects of x-rays produced at high voltage are summarized in Tables II to VI, inclusive, and in Fig. 1.

Discussion of Results

An examination of Table II reveals a number of interesting facts. The non-spore forming bacteria, both Gram-negative and Gram-positive, were destroyed by doses of less than 500,000 roentgens and from 64.5 to 99.999 percent of them were destroyed by 35,000 roentgens. *Pseudomonas aeruginosa* and *Ps. fluorescens* were particularly susceptible to the lethal action of x-rays, the former being destroyed by less than 140,000 roentgens. Bacterial spores, however, were considerably more resistant to the action of x-rays produced at high voltage than the vegetative cells and generally required more than 500,000 roentgens for destruction of all cells. The most resistant spore-former investigated required more than 1,500,000 but less than 2,000,000 roentgens for destruction. However, under the conditions of the tests, most spores were destroyed by the

TABLE V. Summary of data concerning lethal effects of x-rays on the microorganisms in some spices.

Spice	Number of organisms per gram	Percentage destroyed by 35,000 roentgens	140,000 roentgens	350,000 roentgens	700,000 roentgens	1,400,000 roentgens	Number of roentgens required for destruction
Allspice, ground	740,000	39.18	93.37	99.45	99.998	100.00	Less than 1,400,000 but more than 700,000
Pepper, white, ground	8,600	45.34	97.79	99.88	99.96	100.00	Less than 1,400,000 but more than 700,000
Sage, ground	84,000	42.85	83.33	99.70	99.994	100.00	Less than 1,400,000 but more than 700,000
		Percentage destroyed by 25,000 roentgens	100,000 roentgens	250,000 roentgens	500,000 roentgens	1,000,000 roentgens	
Mace	2,200	27.27	93.18	97.72	99.77	100.00	Less than 1,000,000 but more than 500,000

application of less than 1,000,000 roentgens and from 15 to 96 percent were destroyed by 25,000 roentgens.

The yeasts (Table III) examined appeared to be slightly more resistant on the average to x-radiation than the average non-spore forming bacteria. Destruction of all cells of four strains of *Saccharomyces cerevisiae* occurred with the application of less than 500,000 roentgens and from 58.9 to 93.7 percent of the cells of five strains of *S. cerevisiae* were destroyed by 25,000 roentgens. It required more than 500,000 but less than 1,000,000 roentgens to effect complete destruction of a strain of *S. cerevisiae* in the dry state. Two species of *Torulopsis* were destroyed by less than 1,000,000 roentgens. *T. rosea* appeared to be somewhat more resistant to x-rays than *T. pulcherrima*.

Research carried out on two species of molds indicated that considerable variation in susceptibility to x-rays may be expected amongst different species. In four out of five tests (Table IV), *A. niger* was destroyed by the application of 250,000 roentgens. Both the youngest (2 days old) and the oldest (28 days old) cultures of *A. niger* were destroyed by this dosage. In five tests carried out with a mold of a species of the genus *Mucor*, using essentially similar procedures as for *A. niger*, a dose of 1,000,000 roentgens destroyed all of the individual molds, whereas 500,000 roentgens destroyed over 99 percent of them. The species of *Mucor* was thus considerably more resistant to x-rays produced at high voltage than the strain of *A. niger* used.

The microorganisms associated with ground allspice, mace, white pepper, and sage (Table V)

TABLE VI. Summary of data concerning lethal effects of x-rays on microorganisms found in miscellaneous items.

Item	Number of organisms per ml or per gram of unirradiated sample	Percentage destroyed by 25,000 roentgens	100,000 roentgens	250,000 roentgens	500,000 roentgens	1,000,000 roentgens	Number of roentgens required for destruction
Apple juice	440,000[a]			99.47	99.96	99.999+	
Milk, raw	1,550,000	96.67	99.67	99.998	99.999+	100.00	Less than 1,000,000 but more than 500,000
Milk, pasteurized	15,000	47.33	99.82	99.98	99.986	100.00	Less than 1,000,000 but more than 500,000
Soil	8,000,000[b]		91.7	98.9	99.4	100.00	Less than 1,000,000 but more than 500,000
	14,000,000[b]		87.0	98.0	99.9	100 00	
Water, tap	146			100.00			Less than 250,000
Water, river	12,000		99.91	100.00	100.00	100.00	Less than 250,000 but more than 100,000

[a] The apple juice contained 200,000 molds per ml and 240,000 bacteria and yeasts per ml. No molds survived the application of 1,000,000 roentgens.
[b] Organisms per gram of sample.

TABLE VII. Summary of data concerning the lethal effects on some microorganisms of cathode rays produced at high voltage.

Culture	Medium in which grown[a]	Temperature at which grown, °C	Age of culture (in days)[a]	Plating medium	Number of organisms per ml[a]	Equivalent roentgen value required for destruction	Time required for destruction (in seconds)
Staphylococcus aureus	Bacto nutrient agar	37	1	Bacto nutrient agar	56,000,000	1,400,000	Less than 5
Escherichia coli	Bacto nutrient agar	37	1	Bacto nutrient agar	381,000,000	1,000,000	Less than 5
Bacillus cereus	Bacto nutrient agar	37	5	Bacto nutrient agar	28,000,000	1,900,000	Less than 20
Serratia marcescens	Bacto nutrient agar	30	1	Bacto nutrient agar	480,000,000	275,000	Less than 6
Torulopsis rosea	Bacto malt extract agar	30	1	Bacto malt extract agar	7,800,000	610,000	Less than 29
Saccharomyces cerevisiae	Malt extract broth	30	1	Bacto Wort agar	19,700,000	[b]	[c]
Aspergillus niger	Sabouraud's dextrose agar	30		Bacto Sabouraud's dextrose agar	52,000	52,000	Less than 3

[a] Prior to irradiation.
[b] Survived equivalent of 180,000 roentgens, the largest dose used.
[c] Maximum period used was 5 seconds.

were destroyed by doses of less than 1,400,000 roentgens, but in all cases there were survivors after the application of 500,000 roentgens. From 27 to 45 percent of the organisms were destroyed by 35,000 roentgens, which indicates that destruction was less rapid during the initial stages than when pure cultures of microorganisms were irradiated.

Preliminary tests carried out with raw and pasteurized milks, soil, and waters (Table VI) indicate that sterilization may be accomplished by doses of less than 1,000,000 roentgens. It required less than 250,000 roentgens to destroy the organisms associated with the tap and river waters. Apple juice was not rendered sterile by the use of 1,000,000 roentgens, although over 99.999 percent of the microorganisms were destroyed by this dosage (based on one experiment only).

BIOCHEMICAL INVESTIGATIONS WITH X-RAYS

A limited number of preliminary tests have been carried out to determine the effects of x-rays produced at high voltages on fats, vitamins, and enzymes.

Fats

Butter and olive oil were subjected to roentgen doses varying from 0 to 1,000,000 roentgens and their peroxide oxygen values determined by the method described by Lea.[35] There were slight increases in the peroxide oxygen values (ml 0.002*N* thiosulphate per g of fat) for both the butter and olive oil. The rate of increase did not appear to be linear. It was observed that the orange yellow color of the butter was progressively destroyed with increased radiation.

Vitamins

Preliminary tests were carried out to determine the effect of x-rays produced at high voltage on ascorbic acid in pure solution and in fresh fruit juices. The ascorbic acid used was U.S.P. Reference Standard Ascorbic Acid (20 mg made up to 100 ml with 0.5 percent oxalic acid). The fruit juices were grapefruit and orange juices, freshly

expressed and strained through several layers of cotton gauze. Two-milliliter amounts were placed in each of the stainless steel dishes for irradiation. The x-ray doses were varied from 10,000 to 500,000 roentgens. Reduced and total ascorbic acids on control and irradiated samples were determined by the Indophenol Colorometric Method.[4]

The application of 500,000 roentgens resulted in rather high losses in the reduced ascorbic acid contents of the pure ascorbic acid solution and the fruit juices. However, the losses in total ascorbic acid were considerably less—23.4 and 18 percent for the ascorbic acid solution and the orange juice, respectively.

Enzymes

Preliminary tests were carried out to determine whether x-rays produced at high voltage had the ability to destroy or inactivate those enxymes in vegetables which may be inactivated by the heat process known as blanching. The tests commonly used to check the efficacy of heat blanching by steam or hot water were used as an index of the value of x-rays as a blanching agent. Tincture guaiacum (1 percent in ethyl alcohol) and tincture benzidine (1 percent in 50 percent ethyl alcohol) were used to determine the presence of peroxidase in $\frac{3}{8}$-inch slices of white potatoes, before and after irradiation. Hydrogen peroxide (1 percent) was used to accelerate the tests and to detect the presence of catalase.

The slices of potato showed positive tests for peroxidase and catalase even after the application of 8,000,000 roentgens.

Treatment of comminuted pieces of chicken liver with as high as 5,000,000 roentgens (which required 25 minutes) failed to destroy all of the catalase in the liver, although boiling for six minutes in water accomplished destruction of this enzyme.

Preliminary qualitative tests indicated that x-rays produced at high voltage destroyed or inactivated much of the amylolytic activity of the enzymes in dilute (1 to 10 percent) malt syrup preparations when applied in doses of 1,500,000 to 3,000,000 roentgens.

The actions of x-rays produced at several million volts on crude enzyme preparations appear to be in agreement with those found by other investigators when using x-rays produced at low or comparatively low voltages. Scott[56] reported that enzymes are inactivated by x-rays only after enormous doses. Dale,[11] as a result of researches with hard x-rays on crystalline carboxypeptidase and partly purified polyphenoloxidase, showed that the percentage inactivation of both enzymes was a function of its concentration for a given dose of radiation and also that the rate of inactivation of the enzyme preparation depended on its purity. Similar findings were made by Tytell and Kersten[59] while investigating the effects of soft x-rays on catalase and urease. They demonstrated that crude preparations of catalase did not show inactivation in dilute or concentrated solution after long irradiation. However, they showed that crystalline preparations were partially inactivated by large doses of soft x-rays. Forssberg[18,19] showed that catalase was extremely radioresistant *in vivo*, whereas dilute water solutions of the pure enzyme proved to be rather sensitive. Catalase appeared to be highly protected from roentgen rays when in its natural cell environment.

MICROBIOLOGICAL STUDIES WITH CATHODE RAYS

Only a limited number of tests have been carried out on the uses of cathode rays produced at high voltages. The results of a few such tests are shown in Table VII.

THE TREATMENT OF CONTINUOUSLY FLOWING RAW MILK WITH CATHODE RAYS

The effect of cathode rays produced at high voltage on raw milk continuously passing through the irradiation field was determined.

The raw milk was allowed to flow by gravity from a glass carboy reservoir through the irradiation field to a receiving glass carboy through glass tubing with rubber connectors. The carboy reservoir, located on the floor of the room directly above the irradiation room, was equipped with inlet and outlet tubes. The inlet tube, which was plugged with cotton, entered the top of the carboy through a rubber stopper. Its purpose was to allow sterilized air to enter the carboy to replace milk withdrawn. A glass outlet tube, located at the bottom of the carboy, led to the exterior of the container through a rubber stopper

to a short length of rubber tubing. A screw clamp was attached to the rubber tubing and was used to regulate the flow of milk through the field of irradiation.

Glass tubing, with an external diameter of six mm and an internal diameter of about four mm, was used as the means of conducting the milk through the field of irradiation. The area occupied by the wound portion of tubing exposed to irradiation (3.5 turns) was about four inches square. This portion of the tubing, which was to receive the irradiation, was coated with graphite to prevent damage by static effects to the glass during the irradiation.

Below the irradiation unit was another short piece of rubber tubing which served as a connection between the former and a piece of glass tubing which led through a rubber stopper to approximately the middle of the receiving glass carboy. The carboy was also provided with an air-inlet tube which allowed air to be displaced aseptically as the irradiated milk was collected.

Before initial use, both carboys and all of the tubing and connections were sterilized in a steam autoclave.

The raw milk was irradiated with cathode rays produced at 2,000,000 volts.

Bacterial counts were made on the raw and cathode ray treated samples of milk, using Bacto nutrient agar as the plating medium and incubation for 2 days at 30°C. There were 37,000,000 bacteria per ml in the raw milk and two bacteria per ml in the irradiated milk.

Cottage cheese was prepared from the raw milk and from the milk treated with cathode rays, using lactic acid "starters" obtained from a local source. Outside of the fact that the raw milk appeared to curd a little more rapidly (undoubtedly associated with the large number of viable bacteria present before inoculation with the starter), there appeared to be no important organoleptic differences between the cheeses produced from the raw and cathode ray treated milks.

CONCLUSIONS

1. X-rays produced at high voltage (approximately 3 megavolts) readily destroyed bacteria, yeasts, and molds in massive concentrations in pure culture and when associated with liquid or solid substrates such as milk, water, apple juice, ground spices, soil, and catgut sutures.

2. Spoilage types, spore formers, non-spore formers, Gram-positive and Gram-negative, pigmented and fluorescent bacteria were destroyed by high voltage x-rays. The spore formers were most resistant and the fluorescent bacteria the least resistant of the bacteria examined to date.

3. The application of 25,000 roentgens destroyed from 94 to 99.999 percent of the non-spore forming bacteria. However, it occasionally required 10 to 20 times as many roentgens to achieve complete destruction of the residual bacteria.

4. Doses of 500,000 roentgens usually destroyed all non-spore formers and 99.9 percent or more of the spore formers.

5. In only one case did a spore former survive the application of 1,500,000 roentgens. Some spore formers were destroyed by 1,000,000 roentgens.

6. The dose required to destroy bacteria with cathode rays appears to be similar to that necessary with x-rays. However, it was possible to obtain the result with cathode rays much more rapidly than with x-rays because the available output in roentgens per minute of cathode rays is much greater than when using the same equipment for x-rays. Preliminary tests indicate the possibility of sterilizing fluids by a continuous process.

7. Potatoes cannot be blanched successfully with x-rays, although preliminary investigations have shown that there is some destruction of oxidative and amylolytic enzymes, especially on prolonged radiation.

8. The peroxide oxygen values of butter and olive oil are increased slightly by x-radiation.

9. Preliminary tests indicate there is a gradual decrease in the reduced form of ascorbic acid with increasing doses of x-rays, especially when a pure solution (in oxalic acid) of the acid is irradiated. Similar trends, but at a slower rate, were shown when orange and grapefruit juices were x-radiated. However, it was indicated that most of the ascorbic acid was oxidized only to the dehydroascorbic acid stage.

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EQUIPMENT SPECIFICATIONS

TYPE A, MODEL S

TWO-MILLION-VOLT, CONSTANT-POTENTIAL ELECTRON ACCELERATOR

GENERAL DESIGN

The following specifications describe a Van de Graaff, constant-potential accelerator for scientific research. This electrostatic apparatus, designed and built to incorporate the latest techniques and improvements, provides a well-collimated beam of homogeneous electrons. This electron beam may be brought out from the anode-end of the tube through a cathode-ray window, or the beam may be absorbed in a water-cooled gold target for the production of x-rays.

ACCELERATOR DESIGN

The Model S accelerator is designed for either horizontal or vertical operation. If a vertical machine is desired, the apparatus is supported on a forged-steel ring which rests on the building facilities furnished by the Purchaser. The alternative horizontal design of this unit is assembled on a mount which contains its own hoisting facilities for tank removal. The latter arrangement requires a minimum of time for installation at the site.

The apparatus is completely self-contained within a grounded steel chamber, except for the remote-control station and minor accessories. The generator enclosure is tested and approved for operation with internal, insulating-gas pressures not exceeding 25 atmospheres. The insulating gas is a mixture of commercial nitrogen and carbon dioxide.

ACCELERATOR OUTPUT

1. Voltage

The generator provides a maximum constant potential of two million volts. The voltage may be manually adjustable within the range of 0.75 to 2.0 MV and is held stable within plus or minus 1% by automatic stabilization.

2. Current

The maximum electron current output from the anode-end of the accelerator tube is 100 microamperes through a thin window or into other equipment having a comparable vacuum by direct coupling at the flanged termination of the tube. At a particular voltage setting within the range specified above, the electron beam current can be adjusted from the remote-control station to any predetermined value from 0.01 microamperes to 100 microamperes.

The water-cooled gold target may be inserted into the path of the electron beam directly before the cathode-ray window. This target arrangement is such that it can be manipulated readily by manual adjustment without affecting the vacuum of the system. The electron beam impinging on the water-cooled gold target can be adjusted up to 250 microamperes. By utilizing an annular electromagnet surrounding the anode-end of the accelerator tube, the focal spot of the electron beam may be varied from an inherent size in the order of 5 mm diameter down to 0.5 mm. The x-ray output from the gold target has an inherent filtration of 11 mm of lead, a half-value layer of 12.5 mm copper, and a maximum dosage rate of 300 roentgens per minute at 50 cm.

LIST OF COMPONENTS

The apparatus consists essentially of a Van de Graaff generator, mounting device, and controls.

Over-all length of steel enclosure	67 inches
Outside diameter of steel enclosure	36 inches
Operating pressure	25 atmospheres
Total net weight of generator and horizontal mount	5000 pounds

(The steel enclosure is constructed in accordance with ASME Code, and carries Underwriters' Approval.)

Generator Operating Mechanisms

Inside the steel enclosure the following mechanisms are provided to produce the two-million-volt, constant-potential radiation:

1 - Constant-speed, squirrel-cage, induction motor, rated: 3 HP, 3450 rpm, 208 volts (line to line), 3 phase, 60 cycles, (2850 rpm at 50 cycles) heavy-duty ball bearing, with Class B insulation, complete with insulated lower pulley assembly.

1 - Charge-conveying, endless, multi-ply belt.

1 - 30-kilovolt, pressure-insulated, rectifier unit for supplying electric charge to the belt.

1 - Set of 45 equipotential planes and insulating spacers assembled as one complete section, 33 inches long, to provide uniform gradient from high-voltage terminal to ground potential.

1 - High-voltage terminal assembly complete with upper pulley.

1 - 70-watt, permanent magnet a-c generator for x-ray tube filament power supply.

1 - Filament current control variable by remote operation.

1 - Polished metal terminal having a dome radius of 7-1/2 inches and a lower cylindrical portion of 7-1/2 inches radius and 4 inches in height.

1 - Generating voltmeter, calibrated for voltage measurements within $\pm$ 1% accuracy.

1 - Annular magnet and power supply for beam focusing.

Accelerator Tube

1 - Multi-section, electron acceleration tube column.

1 - Removable cathode.

1 - Tube extension system with 2-inch gate valves extending from the base of the accelerator for attachment of the vacuum pumping system and anode termination.

1 - Flanged anode termination having a cathode-ray window (or suitable for the attachment of experimental equipment) and complete with a retractable water-cooled gold target, manually operated.

Tube Rating: 2 million volts, 100 microamperes, constant-potential cathode-ray current; 2 million volts, 250 microamperes x-ray target current.

Vacuum Pumping System

1 - Complete vacuum system for evacuation of the multi-section tube, consisting of:

1 - Multi-jet, mercury-diffusion pump and built-in cold-trap. Maximum rated pumping speed approximately 50 liters per second. Ultimate pressure of blanked-off pump is 10^{-6} millimeters mercury at pump entrance.

1 - Mercury-diffusion backing pump.

1 - Fore-vacuum trap.

1 - Mechanical fore-vacuum pump.

3 - Ionization gauges.

1 - Thermocouple and vacuum protective circuit.

Necessary control cable and hardware for vacuum system.

Remote-Control Station

The remote-control station is a console located outside the accelerator room and connected with the accelerator by means of multi-conductor cables furnished with the unit. The control station contains the necessary operating switches, controls, and indicating instruments for the complete apparatus and gives a continuous reading of generator voltage, target current, focusing magnet current, and vacuum system conditions.

Mounting Facilities

For Vertical Mounting:

A forged-steel mounting ring and supporting pad is supplied for placing the apparatus in a vertical position over a hole furnished by the Purchaser in a floor or platform. Hoisting facilities, to be furnished by the Purchaser, should be installed in a room of height sufficient to give a minimum hoist hook position of 12 feet from the generator base. See Drawing D-AS-26 for details.

For Horizontal Mounting (Alternative)

The mount consists of a framework of steel capable of simultaneously and independently supporting the removable steel enclosure and the fixed components of the accelerator. The accelerator is held in a fixed horizontal position so that

the center line of the accelerator is approximately 36 inches above floor level. The accelerator base flange is held to the framework of the mount with bearings and adjusting screws for limited angulation. The enclosure is held by two steel bands and is suspended from trolleys which travel along an overhead rail. This suspension permits adjustment in vertical position so that the steel enclosure can be lined up with the base flange. The overhead rail which forms a portion of the mount provides travel of the steel enclosure approximately 80 inches to the rear of the accelerator base flange for ease of servicing. All mount supports have independent floor-leveling adjustments of $\pm$ 3/4 inch. The vacuum system, junction boxes, and tube extension are fastened to the mount. See Drawing D-AS-25 for details

Standard Accessories

1 - Gas-handling unit for evacuating the steel enclosure and for drying the commercial nitrogen and carbon dioxide insulating gases used to pressurize the steel enclosure of the generator.

1 - Set of special tools to facilitate the maintenance of the apparatus.

1 - Instruction Manual for operation and preventive maintenance.

Standard Special Parts

1 - Set of manufacturer's spare parts for generator and mount.

Robert J. Caldwell
June 5, 1950