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Electron Beams: National Bureau of Standards and the New Technology

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Applications of electron beams have been revolutionized by recent improvements in the production, detection, and utilization of high-energy electrons. These improvements are the basis of an era of expansion of the application of electrons to physics, chemistry, biology, and the applied sciences that may be as significant as the era of neutron applications in the atomic-energy technology 20 years ago. I shall describe the new electron-beam technology, with particular emphasis on the present and future roles of the National Bureau of Standards.

Present Role of NBS

The Bureau establishes and maintains the central basis for the system of physical measurement that U.S. science, industry, and government use in domestic and international commerce. The Bureau meets its responsibilities to industry and government through research, measurement services, technical information, and consultation.

In various areas of radiation science, the Bureau provides accurate and uniform techniques of physical measurement by investigating, developing, and improving radiation sources and standards (*1*); by providing calibration services for standard measuring instruments, materials, foils, fields, and sources; and by advising other government agencies on radiation measurements. Services with standard instruments and sources developed or being developed by NBS are listed in Table 1 (*2*, *3*).

These services (Table 1) are provided for radiation fields consisting of x-rays, gamma rays, radionuclides, and neutrons. None now exists for electron fields. However, because of the developments in electron-beam technology (which I shall describe) the Bureau plans to respond with new electron-measurement services; these services, together with services for other radiation fields, are now under development in a new laboratory (*4*) containing radiation facilities that are predominantly electron-beam sources and that operate in the radiation-energy range from 10 kev to 200 Mev. These facilities include x-ray machines, an electron dynamitron, electron and positive-ion Van de Graaffs, an electron synchrotron, and a linear electron accelerator (linac). The characteristics of the three most intense electron sources now operating at the laboratory are summarized in Table 2.

Facilities of this type are comparable individually with those to be found in industrial, university, and government laboratories, but such a combination, as well as the special attention that has been given to stability and accuracy of the operations, uniquely equips the new laboratory for development of measurements with electron beams.

The use of electron beams has been significantly improved during the last 5 years. The improved production of intense and well-resolved electron beams, primarily by the traveling-wave linear accelerator, resulted, for example, in generation at the Bureau in July 1966 of electrons with powers up to 80 kilowatts at 80 Mev and with energy resolutions and stabilities better than 0.05 percent at lower powers (see Fig. 1) (*5*). The NBS accelerator and similar high-intensity, high-energy, electron linear accelerators have particular possibilities for varied applications that I shall enumerate.

To nuclear physicists the generation of stable, well-resolved beams of electrons brings the possibility of obtaining unique nuclear data with electrons. No longer need the millibarn cross sections characteristic of photonuclear phenomena (compared to barn cross sections for nucleons) be a hindrance in the use of electrons for nuclear research. The electrons now are available with sufficient intensity and resolution to produce nuclear data comparable in quality and significance to data obtainable with positive ions such as protons and deuterons.

For atomic physicists the subsidiary production of intense, vacuum-ultraviolet radiation (in the 50- to 500-angstrom range) in circular electron accelerators (*6*) and of far-infrared radiation (in the 10- to 1000-micron range) in linear electron accelerators (*7*) means new phenomena in a well-developed science. For example, study of the vacuum ultraviolet with the NBS synchrotron has resulted in discovery of hundreds of new resonances in the photoionization continua of the rare gases—resonances caused by excitation of inner atomic electrons or by simultaneous excitation of more than one electron.

For radiation chemists the controllable generation of intense electron pulses having nanosecond-to-microsecond durations means a new world of reaction-rate chemistry. Important basic information on the decomposition of water into free radicals and molecular products has been obtained from atomic spectroscopic examinations of the decomposition products immediately fol-

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Table 1. Services of the National Bureau of Standards in measurements of radiation.

Radiation	Service: Present	Service: Possible future
A. X-rays 1. 10 kv–3 Mv	(a) Cavity-chamber calibration in roentgens	(a) Same (b) Calibrations in joules/cm^2
2. 3 Mev–180 Mev	(a) Transmission-chamber calibrations in joules	(a) Same
B. Gamma rays	(a) Radioactivity standards and source calibrations in microcuries (b) Source calibrations in roentgens per hour at 1 meter	(a) Same (b) Same (c) Source calibrations in watts per cm^2 at 1 meter
C. Electrons	(a) None	(a) Faraday-cage calibrations of transmission monitors in amperes (b) Absorbed-dose calibrations under special radiation conditions and irradiation geometries
D. Neutrons	(a) Neutron-source standards in neutrons per second (b) Neutron-source calibrations in neutrons per second (c) Foil calibrations in thermal neutron-flux facility in neutrons per cm^2 second	(a) Same with larger variety of radioactive sources (b) Same with larger variety of radioactive sources (c) Same with larger fluxes; with reactor standard fluxes (d) Monoenergetic radioactive neutron-source standards (e) Monoenergetic accelerator neutron calibrations

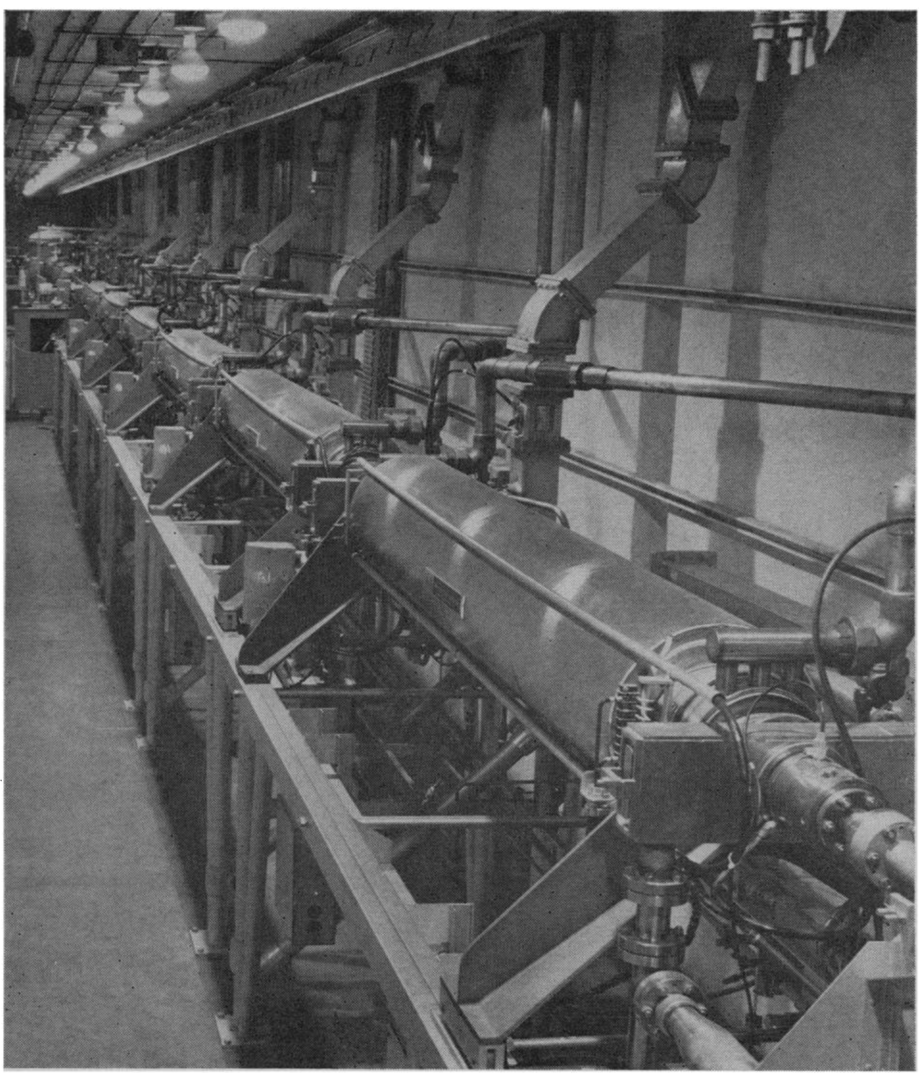


Fig. 1. The NBS traveling-wave linear accelerator that can generate 80 Mev–80 kilowatt electrons in a 3-mm-diameter beam.

lowing the radiation pulse obtained from an electron linac (*8*).

For industrial and medical processors the production of controllable, energetic, intense, economic beams of electrons means a whole new dimension in the processing of materials that will rank with heating, freezing, dehydration, and ultrasonic techniques. For example, the sterilization of foods and pharmaceuticals by electron beams can be accomplished at absorbed-dose levels lower than 5 megarads and electron energies lower than 10 Mev, so that the rise in temperature of the product is a fraction of 1°C and the processing cost is a fraction of 1 cent per kilogram. As a result, pharmaceuticals that cannot tolerate elevated temperatures have been sterilized and made available commercially. Also, because electrons can be precisely controlled and concentrated with power densities of the order of 100 megawatts per square centimeter at energies of the order of 100 kev, this concentrated heat is being used to melt, refine and evaporate refractory metals for deposition as thin films for electronic devices (*9*). Finally, since electrons may have energies thousands of times greater than energies required to ionize molecules or break chemical bonds, they can more effectively cross-link plastics than can conventional heat sources (*10*). As a result, a whole new family of plastics with heat-shrinking or superior insulating properties has been produced.

Characteristics of Electron Beams

The new dimensions provided by electron-beam technology are directly related to the basic characteristics of electrons and of electron beams. The more important characteristics are:

Electron wavelengths: The uniqueness of electrons at energies up to 100 Mev for nuclear physics comes from the particle wavelength associated with a specific electron energy, as contrasted with that of protons of the same energy. For example, the electron wavelength for electrons of kinetic energy E_e is

$$\lambda = (2\pi \times 1.97 \times 10^{-11}\ \text{cm})/E_e(\text{Mev}) \text{ or } 2\pi \times 10^{-12}\ \text{cm for } E_e = 20\ \text{Mev} \quad (1)$$

The comparable wavelength for protons is given by

$$\lambda = (2\pi \times 4.55 \times 10^{-13}\ \text{cm})/\sqrt{E_p}(\text{Mev}) \text{ or } 2\pi \times 10^{-13}\ \text{cm for } E_p = 20\ \text{Mev} \quad (2)$$

Therefore the longer electron wavelength will result in a coherent interaction over the entire volume of the nucleus, and the nuclear states excited by electrons will be strongly collective in character, in contrast with the markedly single-particle excitations and interactions with protons (*11*). Similarly, electron excitations are predominantly to those few nuclear states that have strong transition probabilities to the ground state, and the electron carries few units of angular momentum. In contrast with this very selective process, many levels of energy are excited by protons and many units of angular momentum can be carried by them.

Energy resolution of electron detectors: Ability to detect and measure the energies of electrons and x-rays (or gamma rays) has improved by a factor of from 3 to 100 within the last 3 years. A specific example of the improvement in electron spectroscopy is the magnetic spectrometer built at NBS (Fig. 2) (*12*); it is double focusing and has a deflection angle of 169.8 degrees, an entrance solid angle of 0.08 millisteradians, and a momentum resolution of 0.04 percent for electrons with energies up to 250 Mev. This resolution is three times as good as that of comparable earlier spectrometers. An example of an improved x-ray and electron spectrometer for lower energies is a total-absorption spectrometer, employing lithium-drifted germanium, that has demonstrated 2-kev resolution for 1-Mev gamma rays (*13*); this resolution is 40 times better than that of a comparable sodium iodide scintillation spectrometer. When the spectrometer output is processed by a small computer using a special analysis technique (*14*), a gamma-ray line spectrum shows a remarkable set of lines in the computer output (Fig. 3) with almost no distortion by the spectrometer.

High excitation energies: The energies up to 100 Mev and the beam intensities that are available from traveling-wave linear accelerators mean that any nucleus can be photodisintegrated into various component parts with sufficient intensity to be usable in many different ways. For example, some very early preliminary experiments with the NBS linac served to identify all reactions in ^{209}Bi from (γ, 3n) to (γ, 9n) and to yield rough information on production rates (*15*). Such reactions require x-ray energies of the order of 100 Mev, with considerable x-ray beam power. This information should prove of considerable value in the testing of nuclear models. In addition, several specific gamma-ray sources have been produced by (γ, 2n) reactions in sufficient quantities to be suitable for unique Mossbauer experiments (*16*); previous efforts to produce comparable sources by other techniques were costly and relatively unsuccessful. An example is the 58-kev gamma ray in ^{61}Ni, produced by a (γ, 2n) reaction on ^{63}Cu and a subsequent positron decay.

Improved electron-beam optics and energy: The techniques in electron-beam optics required for electron microscopy

Table 2. Characteristics of the new NBS accelerators; pps, pulses per second; d-c, direct current.

Accelerator	Energy (Mev)	Current (ma)	Power (kw)	Dimensions (diameter × length; m)	Beam diam. (mm)	Pulse length (μsec)	Repetition rate (pps)
Linac	80	1	80	0.5 × 30.5	3	0.01–6.0	≤ 720
Van de Graaff	4	1	4	2 × 8.2	10	1 (or d-c)	≤ 500
Dynamitron	1.5	10	15	1.2 × 7	2	(d-c)	(d-c)

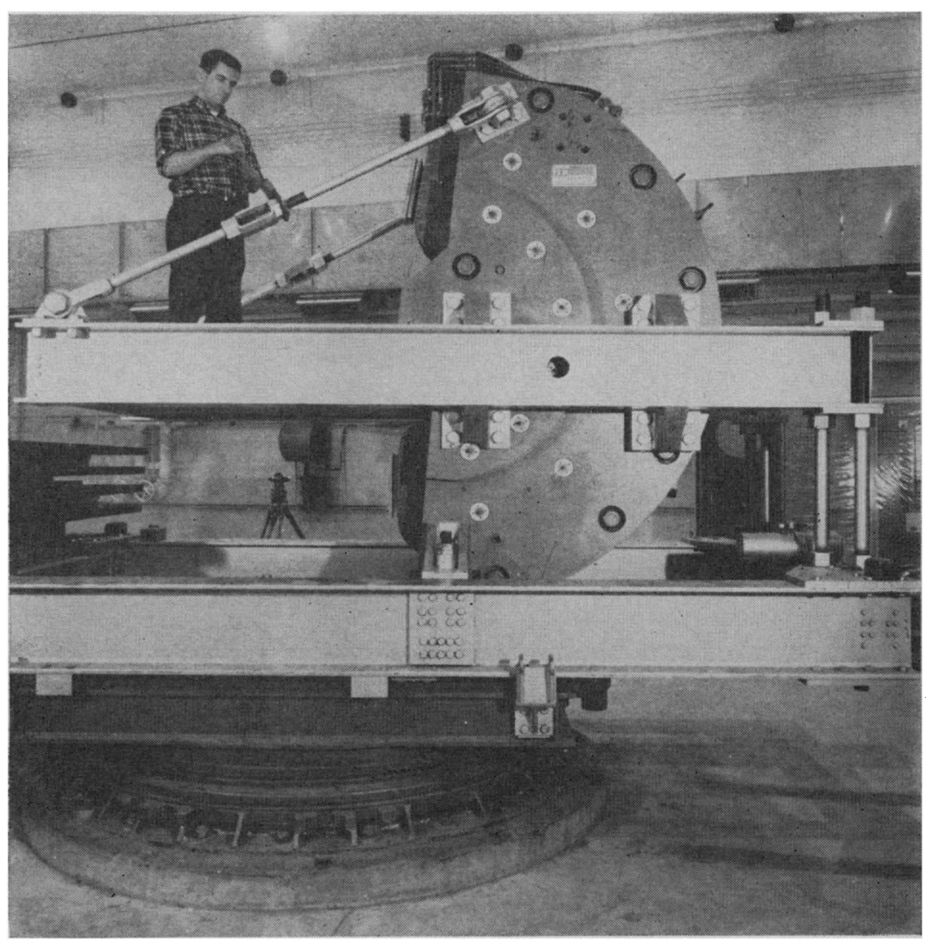


Fig. 2. An improved magnetic spectrometer for analyzing 200-Mev electrons.

Table 3. Characteristics of heat sources.

Heat source	Min. area (cm^2)	Max. power density ($watt/cm^2$)
Oxyacetylene flame	10^{-2}	10^4
Electric arc	10^{-3}	10^5
Electron beam	10^{-7}	10^9

Table 4. Threshold energies to produce lattice defects with electrons.

Target atom (atomic wt)	Energy of bombarding electron (Mev)
10	0.10
50	.41
100	.68
200	1.10

have improved so much that electron microscopes are being actively proposed having electron energies up to 5 Mev (*17*). These microscopes will enable examination of specimens of greater thickness with better spatial resolutions than are attainable with conventional electron microscopes having electron energies of 100 kev; the spatial resolution of 100-kev microscopes is about 1.8 angstroms. The resolution obtainable at 5 Mev is still difficult to predict.

Intense electron-beam powers: Power up to 200 kilowatts, in concentrated, controllable electron beams, permits melting, evaporating, welding, and machining operations in special gas atmospheres (or under partial vacuum) if necessary. The uniqueness of electron beams for these purposes can be expressed by a comparison of the minimum areas and maximum power densities of various heat sources (Table 3) (*9*); electron beams are far superior on both counts.

Applications of electrons to industrial fabrication have resulted not only from improvements in electron power and optics, but also from the very urgent needs for new industrial materials and techniques in diverse areas such as microelectronics, electron-beam recording on films, and vacuum melting of metals. The new materials are frequently required to be extremely pure, deposited in thin layers, intricately fabricated, and joined to dissimilar materials. Electron beams provide new capabilities in satisfying all these requirements.

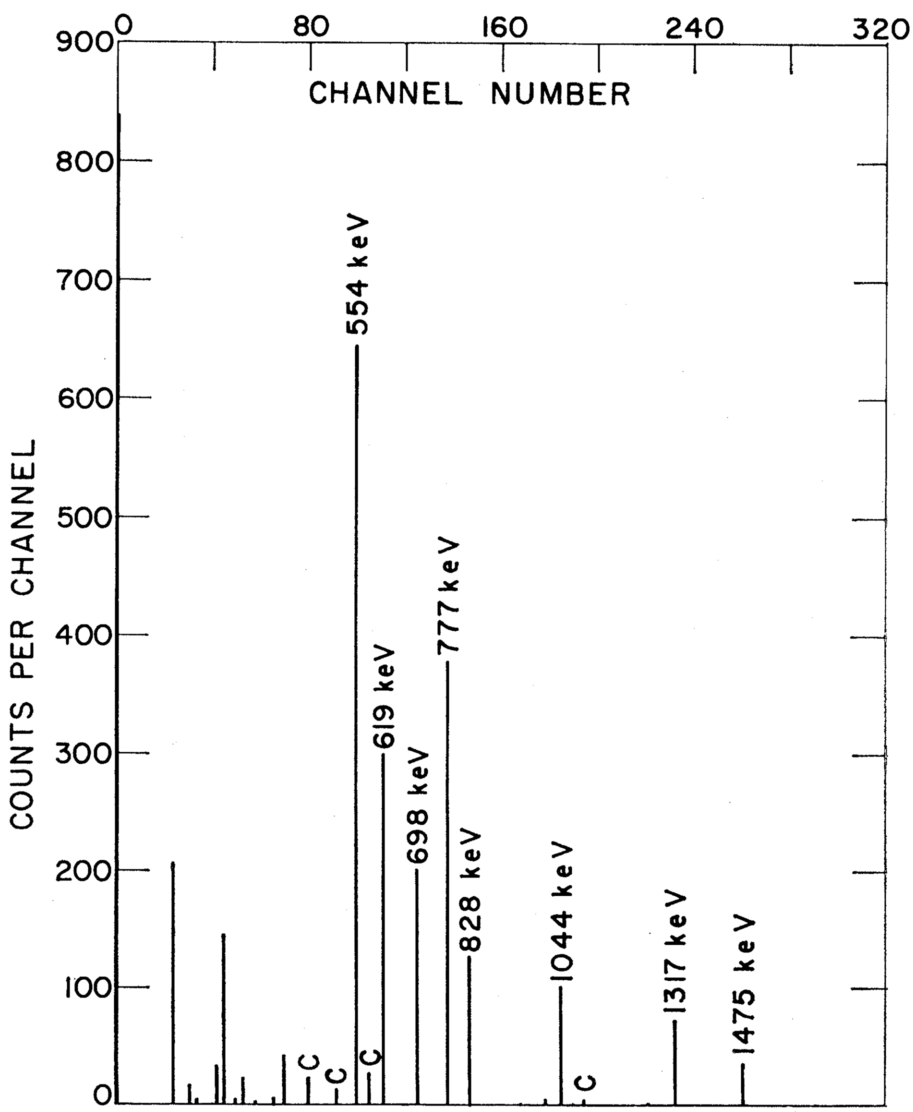


Fig. 3. Gamma-ray spectrum from a neutron-activated bromine sample. The energies (kev) of the prominent ^{82}Br gamma-ray lines are indicated. The associated Compton edges are identified by the letter *C*.

Table 5. Percentage efficiency in the production of x-rays by electrons.

Electron *E* (Mev)	Efficiency (%)	
	Aluminum target	Tungsten target
0.5	0.3	0.9
1.0	.7	2.0
2.0	1.3	4.1
3.0	1.9	6.2
5.0	3.1	11
10.0	6.3	19

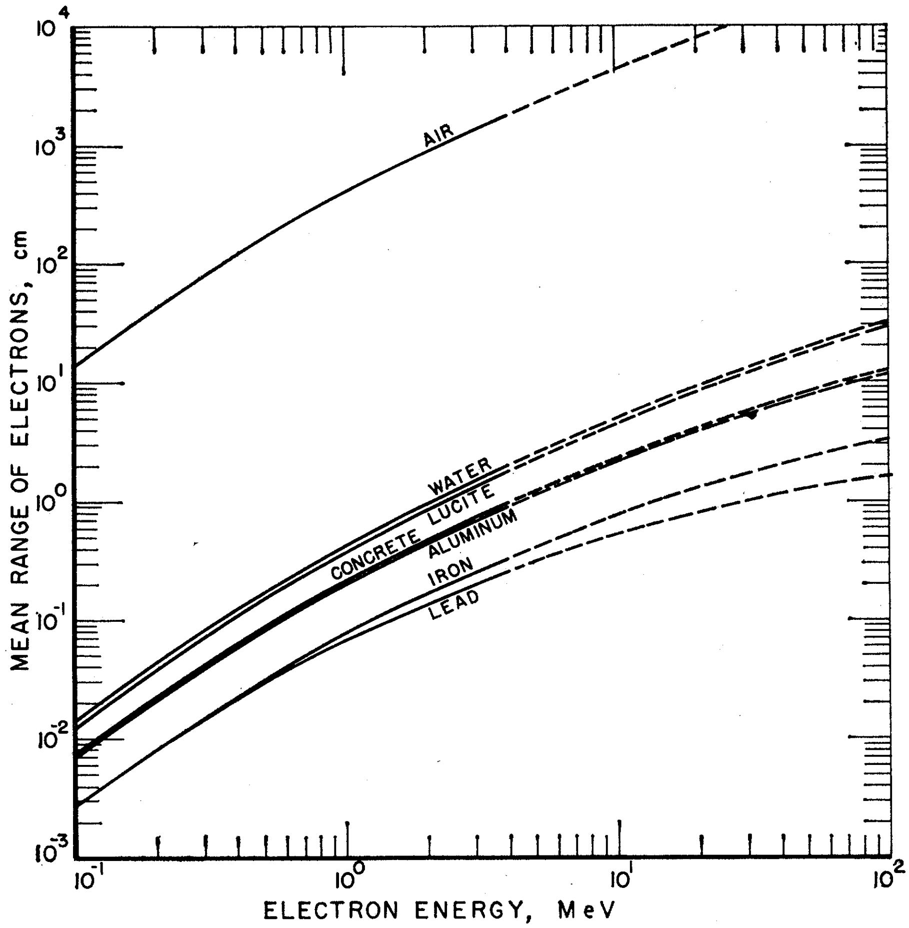
Momentum-transfer characteristics: Important for solid-state research and applications is the ability of electrons to effect displacement of atoms by elastic collisions. The maximum energy T_m that can be transferred in such a collision is given by

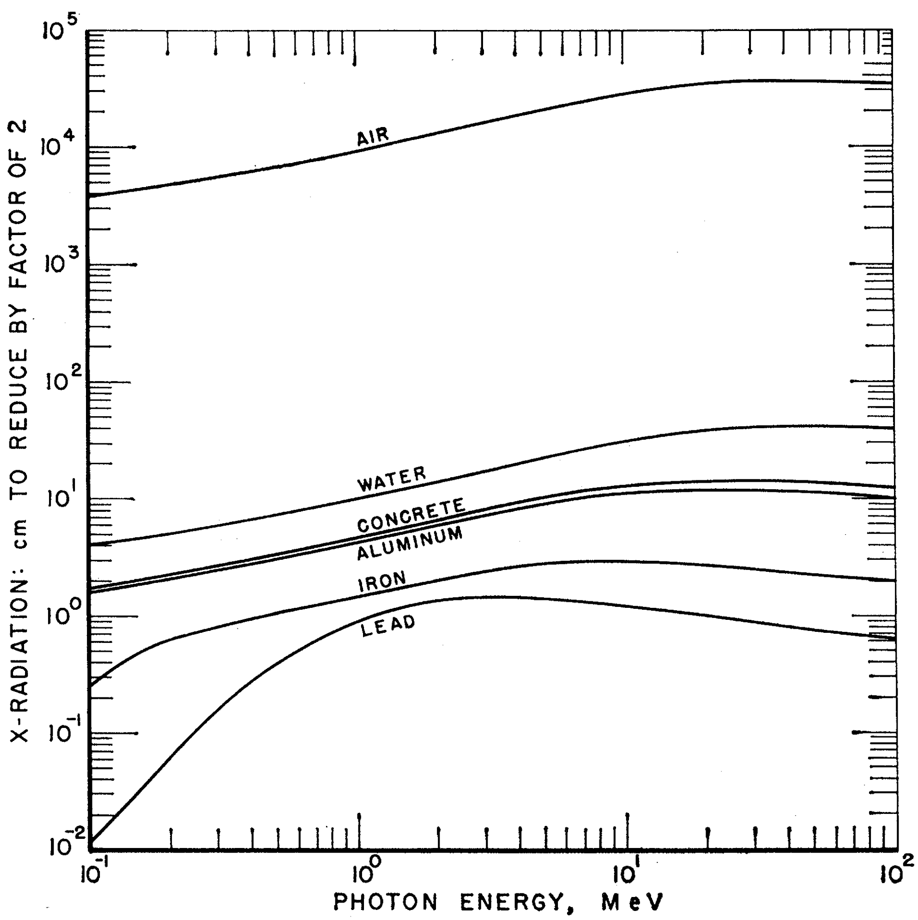
$$T_m = [2(E + 2m_0c^2)E]/Mc^2 \quad (3)$$

where E and m_0 are the energy and mass of the incoming electron and M is the mass of the struck atom (*18*). If one assumes that an energy, T_m, of 25 ev is required to displace atoms from their lattice positions, the typical values of threshold electron energies, E, to produce displacements and vacancies are obtained from Eq. 3 and are given in Table 4 for a range of atomic weights of the target atoms. Atomic displacements produced by electron beams are being used for the production-line processing of transistors to obtain permanently improved current gains or switching characteristics (*19*).

Electron and x-ray penetration: The surface treatment of materials with electrons and the deep penetration of x-rays in radiography are applications made possible by the characteristics of penetration and diffusion of electrons and x-rays. For example, the proposed polymerization of plastic coatings for prefinishing wood (in place of paint coatings) and skin irradiation of oranges to eliminate mold depend on the controllable but limited penetration of electrons, as shown by graphs of electron ranges in various materials

Fig. 4 (top right). Mean ranges of electrons. Fig. 5 (bottom right). Half-value thicknesses for x-ray photons.





(Fig. 4) (*20*). Figure 5 shows the appreciable penetration by x-rays, measured by the thickness of materials required to halve the x-ray intensity (*21*).

Characteristics of chemical effects: Electron beams can controllably and effectively provide absorbed doses to materials being processed, and can produce the variety of chemical and biologic effects listed in an accompanying diagram (Fig. 6) (*22*). Many such effects are being actively applied by an industry that now has an annual sales volume of at least $200 million.

A critical characteristic of any radiation processing is the sizable amount of power required to permit a plant production capacity that interests commercial processors. The characteristic can be specified by a simple relation of the dose of radiation required to the total radiation power that can be delivered to and absorbed in the processed material. The relation, which applies to electrons and x-rays as well as to gamma rays, is (1 lb = 0.37 kg):

$$1 \text{ kw (absorbed radiation power)} = 800 \text{ Mr} \cdot \text{lb/hr} \quad (4)$$

For a sterilizing dose of 5 megarads

$$1 \text{ kw} = 160 \text{ lb (product)/hr} \quad (5)$$

Since this production rate is low for a power of 1 kilowatt, it is obvious that electron accelerators producing up to 200 kilowatts of power will be needed for high-volume, economic production.

Production of Subsidiary Radiations

An important characteristic of a high-powered electron beam is the generation of intense beams of secondary radiations. The NBS linac (Table 2) has produced an electron beam having 80 kilowatts of power at 80 Mev. Because the beam is pulsed with pulse lengths between 0.01 and 6 microseconds and repetition rates up to 720 pulses per second, peak power during short pulses has been as high as 300 megawatts. This beam, covering a spot 3 millimeters in diameter, can be expressed as 9×10^{12} electrons per pulse, which can effect an absorbed dose of 3×10^5 rads per pulse (1 rad = 100 ergs of absorbed dose per gram of any material). If the beam is absorbed in a uranium target, 10^{12} neutrons per pulse can be generated by photonuclear reactions. When used to generate x-rays, the beam can produce up to 600 rads per pulse 1 meter from the target. X-ray power is produced by electron power with 19-percent efficiency at an electron energy of 10 Mev (Table 5) (*23*). Moreover, optical radiations can be generated by linacs in the infrared and by synchrotrons in the ultraviolet, as I have said.

Need for Electron-Measurement Program

The variety and uniqueness of the research and industrial applications that I have described place a premium on the development of an electron-measurement science. Measurements are required to characterize and control the electron fields as well as the radiation effects produced by exposure of materials in these fields. Characterization of an electron field under the conditions under which it is to be used is just as important to the research scientist, the industrial radiation processor, the industrial radiographer, or the medical therapist as the characterization of an electrical current generator may be to the research scientist, the industrial electroplater, or the electrical engineer. To be specific, the nuclear physicist must monitor his electron and x-ray beams to accuracies of the order of 0.1 percent in order to determine the significant and unique nuclear data that will contribute to the general understanding of nuclear phenomena. The food processor must control his electron, x-ray, or gamma-ray beam to accuracies of the order of 5 percent in order to avoid overdosing or understerilizing his food products. Electron-beam welders, wood-plastic polymerizers, fabricators of transistors, and medical therapists must check, monitor, and control production of the specific radiation effects that are of interest to them; otherwise their efforts in production are worthless. Each of the production efforts using electron beams requires thousands of measurements daily and therefore requires the development of a measurement science that can control, define, and measure radiation beams reproducibly and accurately.

General needs for development of techniques for measuring electron currents have been demonstrated by recent surveys of the standards for measurement of radiation that are available in this country. These surveys were made to determine from various users of radiation the need for (i) standard radiation fields; (ii) standard measuring instruments that can be used to intercalibrate radiation fields and to relate the measurement system for radiation quantities to the measurement systems for other physical quantities; (iii) standard units, definitions, and symbols; (iv) standard radiation data; and (v) standard procedures for measurement. The surveys have resulted in analysis of the national capabilities for measurement of radiation and of the present role of the Bureau in radiation and electrical measurements.

A standards area that will be important to measurements of electron beams is the area of electricity in which electron currents in conductors are measured. The Bureau provides extensive test and calibration services in

Table 6. Services of the National Bureau of Standards in electrical measurements. Abbreviations: a-c, alternating current; d-c, direct current; rf, radio frequency.

Services	
1. Resistance measurements	7. Electrical instruments
a. Precision standard resistors	a. Standard resistors
b. Precision resistance apparatus	b. Volt boxes
c. Multi-megohm resistance standards	c. a-c and d-c Instruments
2. Inductance and capacitance measurements	d. a-c and d-c Wattmeters
a. Standard inductors	e. Watt-hour meters
b. Standard capacitors	f. Current transformers
3. Magnetic measurements	g. Current-transformer comparators
a. Normal induction and hysteresis	8. Low-frequency region
b. Magnetic materials	a. Signal sources
c. Magnetic testing apparatus	9. High-frequency region
4. Dielectric measurements	a. rf Voltmeters
a. Dielectric constant and dissipation factor	b. rf Calorimeters
5. Voltage-ratio and high-voltage measurements	c. rf Micropotentiometers
a. Voltage dividers	d. Coaxial bolometer units
b. Voltage transformers	e. Pulse power, peak measurement
c. Voltage-transformer comparators	f. Plus eight other items
d. Kilovoltmeters	10. Microwave region
6. Standard voltage cells	a. Waveguide bolometers, etc.
	b. Cavity wavemeters
	c. Plus five other items

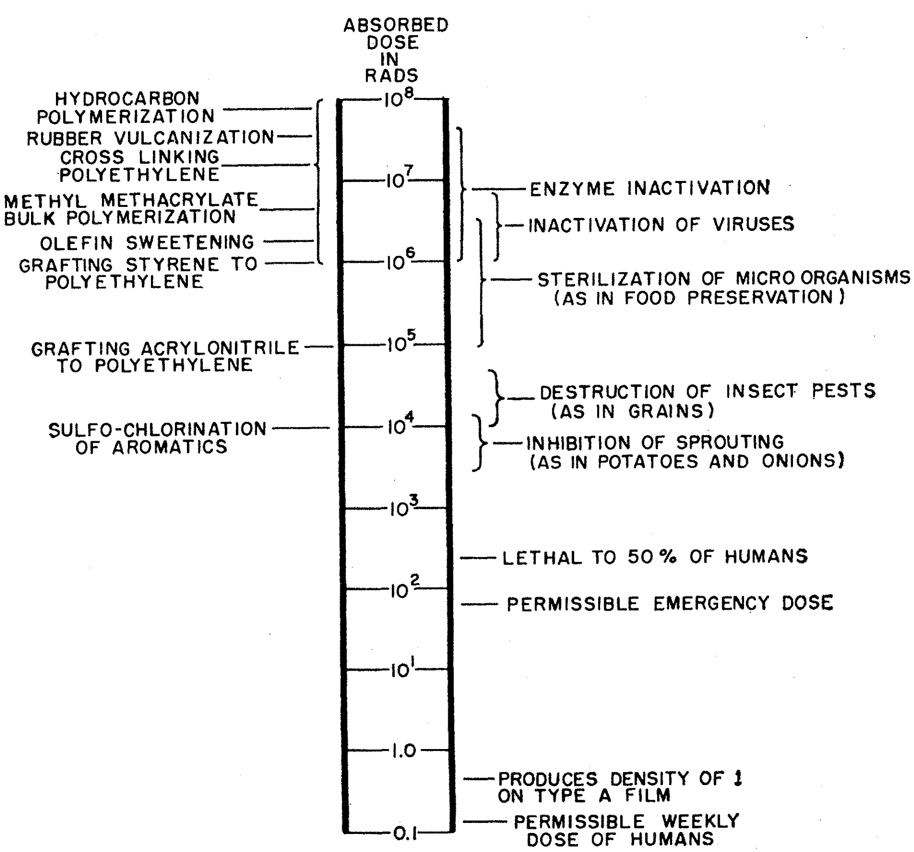


Fig. 6. Radiation effects versus absorbed doses (rads) produced by electrons (1 rad = 100 ergs per gram).

electrical measurements that are of interest in the present discussion. Hopefully, these well-developed measurement techniques and standards for electron currents in conductors will provide a basis for measurement of electron beams in vacuum.

Conductor currents can be measured to accuracies of a few parts per million (*24*), which are attainable by a first-principles measurement of forces between conductors of specific dimensions and geometries. Only two of the world's national standards laboratories, the National Physical Laboratory (England) and the National Bureau of Standards, have made and periodically repeat first-principles measurements of currents (*25*).

The results of such measurements are combined with first-principles measurements of resistance to determine the absolute voltage of standard cells. The standard cells and resistors then preserve the unit system, and calibration services in terms of current are not provided (*2*).

The early direct-current measurements and standards for electron currents in conductors (*26*) have been extended to greater accuracies and to a variety of conditions of frequencies and electrical quantities; Table 6 lists the electrical-calibration services of the Bureau (*2*).

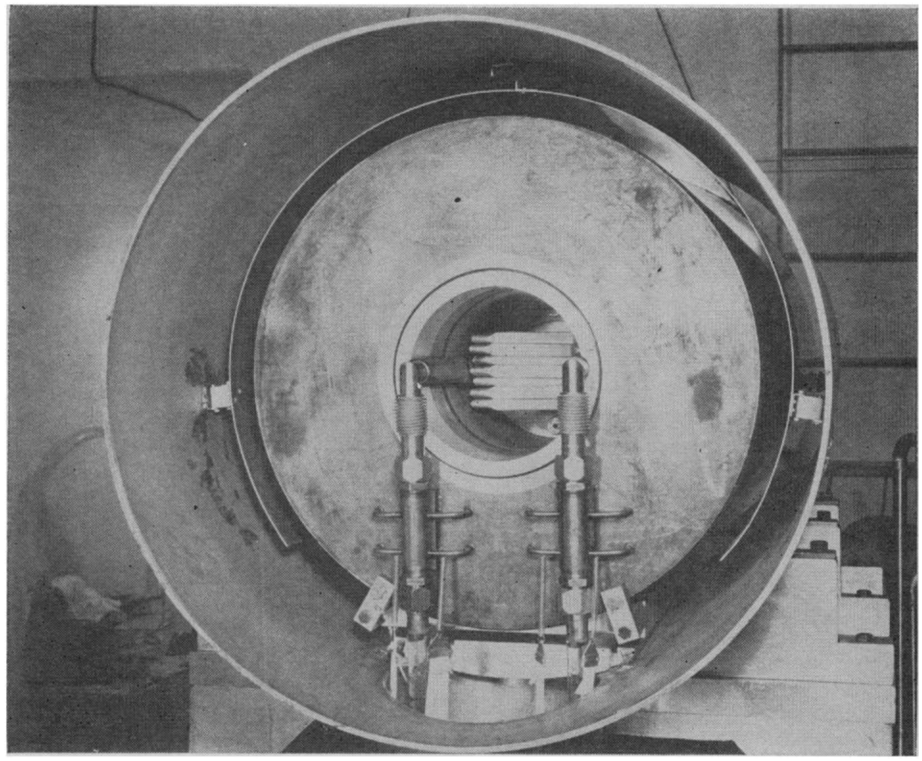


Fig. 7. NBS 100-kilowatt Faraday cage.

Future Role of NBS in Electron-Beam Measurements

In the future, the Bureau will develop, coordinate, collaborate in, and encourage acceptance, on a national scale, of the standards, data, and techniques required for accurate and convenient measurements for the new electron-beam technology. This goal is of national importance, as is evident from the present sparsity of techniques and standards for electron-beam measurement and from the increasing use of electron beams in industry, medicine, and research.

The development of electron-beam standards will undoubtedly follow the history of measurements in conductors, which have been based on extensions and expansions of the methodology employed for direct currents in conductors. In the case of direct as well as alternating electron currents in conductors, all the physical quantities related to these currents under direct-current, alternating-current, and pulsed conditions are examined, defined, and standardized when practical needs for these quantities exist. A listing (Table 6) shows, for example, that low-frequency, high-frequency, and microwave calibration services are available, as well as services for measurement of resistance, inductance, capacitance, and dielectrics.

Similarly, there are many physical quantities associated with electron beams, with the material effects produced by electron beams, and with related atomic and nuclear phenomena. Characterization, definition, and standardization of some or all of these quantities may well be necessary for proper development of the technology. The important radiation quantities are energy, current, and power, and the various derived time or spatial variations such as energy flux density. Quantities important for electron beams, but not for electron currents in conductors, are electron number and the current-density distribution within the beam. The quantities important in effects are absorbed energy, absorbed power, absorbed dose, stopping power, and various attenuation or interaction probabilities. The important radiation data that can assist in characterization of fields and effects are exemplified by levels and thresholds of atomic and nuclear energy; radionuclidic half-lives; physical constants of electron mass, speed of light, electronic charge, and nuclidic masses; and nuclear quadrupole moments and form factors.

However, the problems of measuring any of the physical quantities are severe at many of the levels of electron power that make the new electron-beam technology feasible and attractive. The severity of the problems can be illustrated by description of the method employed to measure the current of the NBS linac electron beam (*27*). The method employs a Faraday cage. an insulated metal block that becomes electrically charged when it intercepts the beam. A typical block (Fig. 7), 40 centimeters in diameter by 20 centimeters long, of lead and stainless-steel components, has a 30-centimeter-deep reentrant cavity on the front face where the beam enters. Unfortunately the linac beam, with its 3-millimeter diameter at 80 Mev and 80 kilowatts, can drill a hole through the block in seconds if no provision is made for cooling. Radiant cooling would be impractical, since the block would have to operate at 2200°C in order to radiate 80 kilowatts. Water cooling is therefore employed in the NBS device (Fig. 7). However, provision of water cooling, together with electrical insulation of the Faraday cage, has proven to be a major problem in design, which hopefully has been solved. When the development is completed, the Faraday cage will be used as the basis for calibration of all the current-measuring devices sent to NBS for calibration at high levels of current, energy, and power.

Two specific recent discussions with groups of users have been initiated to develop electron-beam techniques and measurement recommendations. A committee of the American Society for Testing Materials, chaired by D. Trageser (*28*), has formulated a list of electron-beam parameters (current, energy, beam profile and size, and scan width and speed) that must be defined and measured for accurate application of electron beams in industry. A committee of the American Association for Physicists in Medicine, chaired by J. S. Laughlin (*29*), has developed a protocol for measurements of absorbed dose and electron output that are required in medical therapy. The Bureau is actively participating with these two groups and with others in developing a sound philosophy and procedure for measurement of electron beams.

References and Notes

1. A standard for radiation measurements may be a physical representation of a unit of a fundamental radiation quantity, or a device or a procedure that provides a measure of a unit of the quantity. Standards for measurement of radiation are usually standards defined by agreement; they are also usually derived standards that can be expressed in terms of the six base standards for the quantities of length, mass, time, current, temperature, and luminous intensity. Examples of radiation standards are total-energy ionization chambers for measuring energies of x-ray beams in joules, and radioactive sources of neutrons for defining a neutron-emission rate. The category of radiation standards includes nuclear standards.
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Regulation of Food Intake and Obesity

The regulation of food intake is complex; a number of abnormalities may cause obesity.

Jean Mayer and Donald W. Thomas

Understanding of the physiological determinants of feeding behavior and their phenomenal correlates—hunger, appetite, and satiety—has for centuries challenged students of varied disciplines seeking to solve practical problems and resolve theoretical issues. Philosophical speculation and limited physiological evidence at first suggested that food intake is controlled by specific peripheral sensations which reflect the state of the stomach and gut and determine the subjective level of hunger. In recent years more sophisticated research techniques have revealed a powerful and complex central regulatory system, one capable of closely matching energy intake to energy expenditure in the face of marked variations in the energy requirements of the organism and the nutritional value of the diet. Although transient factors may momentarily override its control, this central system normally prevails, maintaining the energy balance of the organism with remarkable accuracy.

When for some reason this balance is upset in such a way that energy intake consistently exceeds energy expenditure, the inevitable result is obesity—the accumulation of excess body fat, once prized in certain societies but now recognized as a major public health problem. Although some cases of obesity are attributable directly to failure of the central regulatory mechanism, others may be the single end result of neurological, endocrine, enzymatic, and psychological conditions which have very little in common. Thus, the regulation of food intake and obesity, the topics of this review, represent problem areas which are in a sense relatively independent and, therefore, can most conveniently be discussed separately, but which overlap and interact in a complex manner.

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Hunger and Regulation

Ancient philosophical speculation suggested that the feelings of hunger assumed to control food intake originated in the abdominal cavity when-