The lessons learned from an environmental study of a radium therapy clinic and a medical study of its staff may be applicable to any institution using radioactive materials.

Radioactive Contamination
in a radium therapy clinic

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THE PROPOSED REMOVAL of a radium therapy clinic in Baltimore, Md., to new quarters in 1952 presented the city's health department with an unusual and interesting public health problem: the need for assessing the radioactive contamination about the premises occupied by the clinic. Consequently, at the request of the health department's bureau of industrial hygiene, the Occupational Health Program, Public Health Service, assisted in making an environmental study of the clinic building and a medical study of its staff. Although radium therapy clinics are relatively uncommon in the United States, the lessons learned from this experience seem to warrant a brief report.

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Historical Note

The clinic was organized in 1904 and made its first purchase of radium in December of that year. At one time, it possessed 5 grams of radium, then the world's largest single, privately owned supply. In 1914, the clinic started a radon emanation and purification plant to prepare radon applicators for therapeutic use. At that time the health hazards associated with radium were not fully appreciated, and practices that now would be considered extremely dangerous were then the normal procedure. It was not until 1918 that a radiochemist was employed to supervise the radon plant and chemical laboratory.

During the early years, the lack of more than minimal safety precautions may have been responsible for the death from aplastic anemia of 1 and possibly 2 radon pumpers. The radiochemist had a nearly fatal attack of the same disease at about the same time, and soon thereafter additional safety precautions were instituted. Since that time no health damage has been reported.

Over the years, radon applicators were collected and given to various research laboratories for investigative purposes. Lord Rutherford and Sir James Chadwick, noted British physicists, used material from the clinic in their early work, which led to the discovery of the neutron (*1*). Thus, indirectly, the institution played an important role in the development of atomic energy.

The Physical Plant

The clinic had been continuously located in a converted three-story brick, duplex residence. At one time, an adjacent building was used as a hospital for inpatient care. One-half of the clinic's duplex building was used primarily as offices and service rooms, and the other half housed laboratories and treatment rooms. Immediately behind and connected to the duplex was an added wooden structure which, on the second floor, contained a radiochemical laboratory and preparation, surgical, and treatment rooms. The radon emanation plant was contained in an elevated brick vault in the rear of an adjacent garden and was connected to the wooden structure by a walkway.

Two fires in recent years had gutted the wooden structure, and the latter of the fires had severely damaged the main building as well. Radiochemical equipment was involved in the second fire.

Basic Physics

To insure that the reader understands the physical basis of the report, the pattern of radium decay is shown in table 1. Commencing with uranium and proceeding by natural radioactive decay processes to stable lead, the radioactive elements produce various radiations. Each of the elements has its own characteristic half-life, that is, the time in which one-half the material originally present will have decayed to the next lower substance in the series.

Radon, the seventh radioisotope in the series,

Table 1. The radium decay series

Radioelement	Historical name	Symbol	Half-life
Uranium	Uranium I	$_{92}U^{238}$(UI)	4.51 x 10^{9} years.
Thorium	Uranium X_1.	$_{90}Th^{234}$(UX_1)	24.1 days.
Protactinium.	Uranium X_2.	$_{91}Pa^{234}$(UX_2)	1.14 minutes.
Uranium	Uranium II	$_{92}U^{234}$(UII)	2.32 x 10^{5} years.
Thorium	Ionium	$_{90}Th^{230}$(Io)	8.3 x 10^{4} years.
Radium	Radium	$_{88}Ra^{226}$	1,600 years.
Radon	Radon	$_{86}Rn^{222}$	3.825 days.
Polonium	Radium A	$_{84}Po^{218}$(RaA)	3.05 minutes.
Lead	Radium B	$_{82}Pb^{214}$(RaB)	26.8 minutes.
Bismuth	Radium C	$_{83}Bi^{214}$(RaC)	19.7 minutes.
Polonium	Radium C′	$_{84}Po^{214}$(RaC′)	1.5 x 10^{-4} seconds.
Thallium	Radium C″.	$_{81}Tl^{210}$(RaC″)	1.32 minutes.
Lead	Radium D	$_{82}Pb^{210}$(RaD)	22.2 years.
Bismuth	Radium E	$_{83}Bi^{210}$(RaE)	4.97 days.
Polonium	Radium F	$_{84}Po^{210}$(RaF)	139 days.
Lead	Radium G	$_{82}Pb^{206}$(RaG)	Stable 23.6% abundance.

is a gas; all others are solid. The possibility of this gas spreading beyond its intended confines is ever present. It can then, on decay, settle out as a particulate in areas far removed from contaminated areas or be tracked from contaminated areas to places still farther removed. Sealed containers of radium prevent the escape of radon gas, and within a month after encapsulation the radon will reach equilibrium with were taken, positive identification of loose sursion of penetrating gamma radiation.

Gamma radiation is very penetrating in contradistinction to alpha radiation which can be stopped by a sheet of paper. Beta radiation is only slightly more penetrating than alpha, but the latter, because of its great ionizing power, is a serious hazard once introduced into the body as a contaminant. As may be seen from the table, radon quickly decays to produce radium C. So, in the absence of radium to replenish it, a given concentration of radon is soon depleted.

The clinic used both radium and radon sources for external and interstitial therapy. Multicurie amounts of radium in the form of liquid radium bromide were used in the radon emanation plant for the production of radon seeds and needles. The radon was purified by freezing the impurities in liquid nitrogen and thence drawing it into glass bulbs or platinum needles. The seeds or needles were then delivered to the calibration room for activity determinations and thence to the treatment room or to a storage vault.

At the time of the survey, the number of patients treated at the clinic had been reduced; therefore, the radiation exposures received by personnel were proportionately reduced. It was possible, however, to observe some of the standard operating procedures, including the operation of the emanation plant, which was in limited production.

Radiation Contamination Survey

A radiation contamination survey of the main building and of the adjacent building was made using instruments sensitive to alpha as well as beta and gamma radiation (a Samson alpha survey meter (SIC–49A) with a useful range corresponding to 200–25,000 alpha disintegrations per minute, an alpha-beta-gamma ion chamber (AN/PDR–T–34) with 5–50,000 mr./hr. scale, and a Geiger counter (SGM–2C) with maximum scale range of 20 mr./hr. beta-gamma). Simultaneously, wipe samples were taken in various areas throughout the clinic. These wipe samples, made by smearing 1¼-inch disks of Whatman No. 41 filter paper over approximately 100 square centimeters of surface, were used to estimate the extent of removable surface contamination. Each disk was numbered and kept carefully separated from the other disks until it was counted in a gas flow alpha proportional counter (NICC scaler with NHC PCC–10 converter).

No attempt was made in the survey to evaluate contamination on the surfaces of known sources of radiation, such as radium capsules. Only fixtures, floors, and other exposed surfaces were monitored and wiped.

Air samples were taken at the filtration and capsule preparation operations. The samples were collected with calibrated, portable Hudson and Willson pumps. Both membrane and Whatman No. 41 filter papers were used.

Survey Findings

Materials containing removable alpha-emitting radiation were found throughout the clinic. In several areas the alpha contamination, resulting from the use of radioelements for almost half a century, was truly astounding. Counts as high as 30 million disintegrations per minute were recorded. This figure is in marked contrast to the 0–500 disintegrations per minute at present regarded as the maximum permissible level. Of the 30 million disintegrations per minute, removable contamination constituted 25,000 disintegrations per minute, considerably less than 30 million but certainly more significant than the fixed contamination because of the possibility of its being inhaled or ingested. A summary of the results of alpha counting on the first floor of the clinic is recorded in figures 1 and 2.

Furniture, carpets, floors, stairs, offices, and medical equipment were all found to be contaminated with radioactive materials. Although it was difficult to survey the burned areas of the building, wherever wipe samples were taken, positive identification of loose surface radioactivity was made. Radium contamination appeared to have been spread by water during the fire fighting and as a result of the subsequent traffic. The drains of several sinks, including that in the dining room, contained radioactivity.

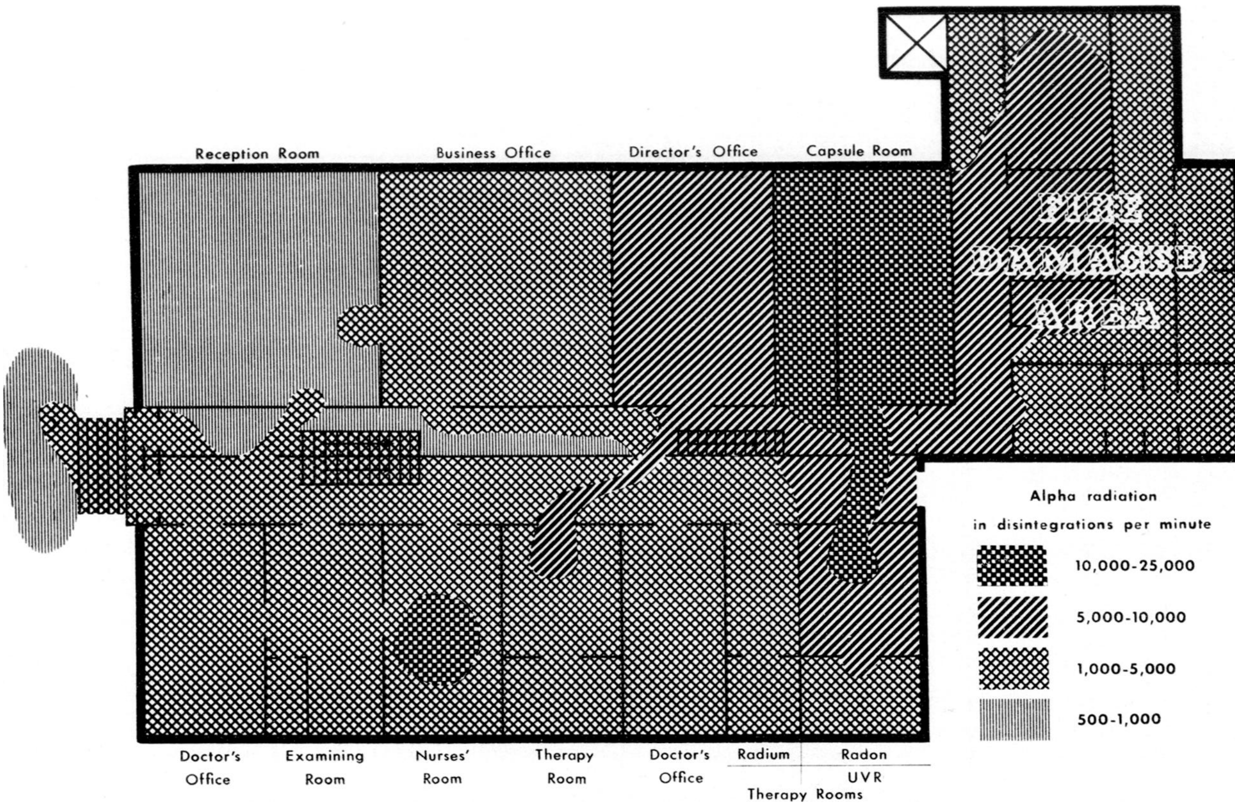
The adjacent building, which had been used as a hospital 15 years earlier, was also found to be contaminated with radioactive materials.

In the course of the survey, a misplaced radium source of approximately 40 millicuries was found in an office safe. In the same safe were several other sources in a strong box whose key had been misplaced years before. One of these sources contained 16 millicuries of radium. In another office, 6 "empty" radium capsules, each containing approximately 10 millicuries of activity, were found. A flask containing radium solution with 21 millicuries of activity was also located.

Personnel Monitoring

Because of the cumulative nature of radiation exposures, occupational radiation dosages are a function of the length of employment as

Figure 1. First floor: Fixed radioactive contamination on floor surfaces.



well as the amount and manner in which the radioactive materials are handled by an individual. Personnel radiation monitoring was provided for staff members at the clinic by means of pocket chambers and film badges. Because alpha radiation is easily stopped, neither film badges nor pocket chambers are of value in estimating exposure to this type of radiation. They are of value for estimating exposure to beta and gamma radiation if they are not contaminated by radioactive particulate matter, but prevention of such contamination was impracticable for persons working in the radon emanation plant.

To evaluate radiation dosages received by the clinic personnel, special film badge monitoring of employees not working in the radon plant was conducted for two short periods during the environmental radiation study. The film badges of two employees, a radium nurse and a physician, indicated that appreciable amounts of radiation were received during daily therapy procedures. This exposure may account, in part, for the medical findings among the radium nurses and the one physician whose employment periods were relatively brief.

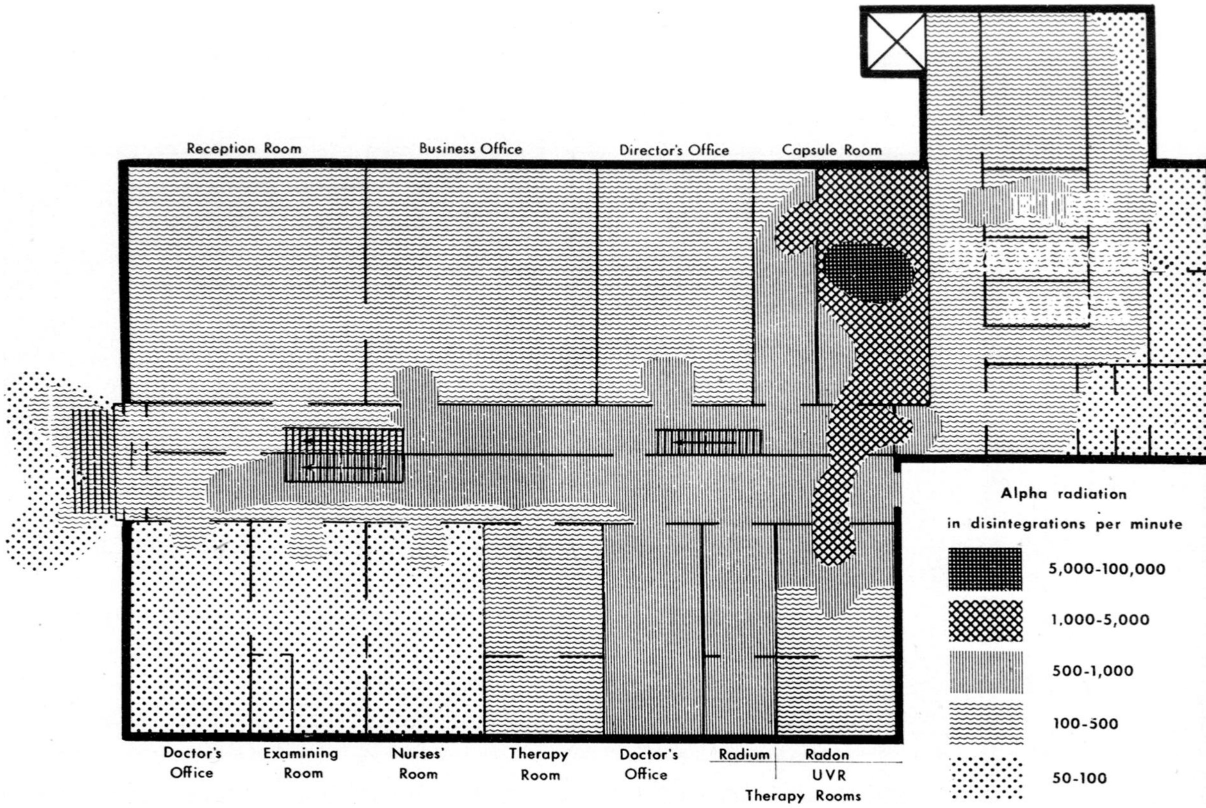
Medical Study

At the time of the study, 11 people were employed by the clinic full or part time. Six of these appeared voluntarily for examination upon request of the city health department and the present owner of the clinic. Four former employees of very recent date also appeared for examination on request of the clinic owner and former colleagues.

The length of employment of the 10 persons examined varied from 1 to 39 years and totaled 195 years. However, duration of employment is not necessarily synonymous with length of exposure as will be noted from the following job descriptions for clinic employees.

Radium nurse. Provides general care for clinic patients and assists in the administration of radiation treatment. (Generally, workers remain only 3 months of the year at this job.

Figure 2. First floor: Loose radioactive contamination as estimated from wipe samples taken from floor surfaces.



It is known that adequate protection is difficult to achieve in this type of work.)

Nurse. Provides general patient care but is not exposed to radiation except from material implanted in patients.

Physician. Plans and administers radiation treatment. (No rotation of personnel is stipulated.)

Radon pumper. Pumps radon off the radium after cleaning the vacuum system, requiring approximately 1 hour of work per day. (The usual rotation is 2 weeks on this duty and 6 weeks off, but periods of rotation have varied over the years.)

Medical History of Personnel

Since 1921 periodic blood counts have been done by the clinic on many of those employees exposed to radiation. In all, 310 employees had blood counts done on one or more occasions during this time. No findings of clinical significance could be discovered from inspection of these counts, and there were too few counts per person to warrant subjecting the figures to statistical analysis.

The supervising radiochemist had been employed for more than 35 years. Early in his career at the clinic, he did considerable radium chemical research and radon pumping. He reported that he had had a nearly fatal attack of aplastic anemia in 1920 and his blood counts have been low ever since. The others examined had a number of ailments of medical significance but not any of a nature that is likely to be confused with radiation damage except for one person in whom epidermophytosis of the hands had been treated with X-ray in 1937 and another who had had three series of nasal radon applications for "prevention of colds."

Examinations

On the basis of previous experience, it was believed that any external radiation effects were most likely to be observed in the skin, nails, and hair (*2*). Routine hematological and urine examinations were performed on all those examined. Roentgenograms were taken of the chest, right humerus, and right femur for the purpose of finding any evidence of radiation osteitis. The chest films were standard 14-inch x 17-inch posterior-anterior projections at a 6-foot focal distance. The films of the humerus and the femur were standard posterior-anterior projections. Finger ridge impressions were made for confirmation of skin changes. These were made on Kerr Dental Impression Compound after first heating the material under a heat lamp. Impressions of the thumb and index finger of the right hand were taken since these would be the digits most likely to be exposed in manipulation of radium or radon by right-handed individuals.

To determine the radon content of the expired air, samples of the breath were taken, using the method described by Harley and his associates (*3*). Compressed air that had been aged for more than 30 days was used for rebreathing. Aging the air allows the natural radon present to decay to less than 1 percent of its original concentration resulting in less variability of the basic radon content in the inspired air and greater sensitivity of radon assay. Samples were taken from all employees except two, at least 48 hours after they left their duties at the clinic. (Sampling equipment was supplied and analyses were made by the New York Operations Office, Atomic Energy Commission.)

Radon concentrations in the range of 0.1×10^{-12} to 0.2×10^{-12} curies per liter of expired air are the usual findings in unexposed persons sampled by this method at one Atomic Energy Commission installation. Occasionally, in unexposed persons, a radon concentration as high as 0.3×10^{-12} curies per liter has been recorded. In the series of breath samples taken from the clinic employees, the only one that showed a radon content higher than 0.3×10^{-12} was taken a few hours after the employee had worked in the clinic. On a second sample from this employee, taken after he had been away from the clinic for at least 24 hours, the result was 0.1×10^{-12} curies per liter of expired air.

The urine samples collected from the six males showed elevated radium and polonium levels. The samples, however, were not collected under strictly controlled conditions as the urine was collected at home in order to furnish a sufficient quantity. For technical reasons, the urine from the four females was not analyzed for radium and polonium.

Physical Findings

All of the employees examined were in good health, age considered. There were no serious disabilities or infirmities other than those due to trauma. Six of the employees (2 of the 3 radium nurses, 2 of the 3 radon pumpers, the general supervisor, and 1 of the 2 physicians) had gross changes of the skin and nails of the fingers or a history of loss of nails. The cutaneous manifestations ranged from punctate hyperkeratosis on the dorsum of the fingers to minimal degrees of atrophy of the skin, particularly on the palmar surface of the distal phalanges. The nail changes consisted of transverse or longitudinal ridging and unusual brittleness. No analyses of the finger ridge impressions were made.

There were no other medical findings which could be definitely associated with radiation exposure.

The results of the laboratory studies were of significance when reviewed in combination with the medical histories. One of the employees, a physician with 35 years' exposure to radiation, showed pulmonary infiltration of unex-

Table 2. Serial hemograms of one employee

Date	White blood cells	Hemoglobin (grams)	Polymorphonuclear leukocytes			Lymphocytes	Monocytes
			Neutrophils	Eosinophils	Basophils		
4-9-53	3, 500	13. 0	45	5	----	48	2
6-2-53	3, 200	----	----	----	----	----	----
7-6-53	6, 350	----	----	----	----	----	----
6-16-53	3, 300	15. 4	45	2	3	47	3
7-28-53	3, 500	----	56	2	1	40	1
9-8-53	4, 850	14. 7	50	2	----	45	3
9-29-53	4, 200	15. 7	----	----	----	----	----
11-6-53	4, 700	----	----	----	----	----	----
12-3-53	7, 200	----	----	----	----	----	----
1-19-54	4, 750	14. 6	50	1	----	48	1

plained nature on the chest roentgenogram and changes in the humerus suggestive of radiation osteitis. At least two other employees had abnormal hemograms for which the physical examination and other laboratory reports provided no explanation. The possibility that they might be due to radiation exposure must be considered (*4*). It is of interest to notice the white blood counts and differentials of one employee, a physician with 5 years' exposure (table 2). It can be seen how unreliable one count would be if 4,500 white blood cells per cubic millimeter is taken as the lower limit of normal. It can be said only that the counts for this man lie in the low range of normal values. Whether they have any further significance is impossible to predict at this time.

Summary and Conclusions

A radiation survey of a radium clinic showed gross surface contamination by alpha-, beta-, and gamma-emitting contaminants to be widespread throughout the building and adjacent areas. There was also a high level of gamma radiation from inadequately shielded radium and radon and significant airborne contamination. The employees and temporary occupants of the clinic were exposed to the possibility of inhaling or ingesting these radioactive contaminants and thereby subjecting themselves to internal radiation from radium and its decay products fixed in their bodies.

Although it was impossible to determine the exact cause of the extensive contamination, it was believed that it arose from (*a*) tracking of radioactive substances from the radon separation area and radiochemical laboratories where it had leaked from the radon plant or had been spilled; (*b*) improper disposal of radioactive materials and wastes; (*c*) breakage, loss, and improper storage of radiation sources; and (*d*) damage to the radiochemical area by fire and the techniques used in fighting the fires. It was impossible to quantitate an employee's integrated exposure due to the lack of any personnel radiation monitoring or survey information. In addition, the radiation hazards had varied during the years of the clinic's existence.

Evidence of possible minor radiation injury in 6 of the 10 employees was found on physical examination. However, because of the small size of the sample in relation to the total number employed over the years and the impossibility of defining individual past exposure, it was not feasible to correlate duration of exposure and medical findings. For the same reasons, it was not possible to correlate the heavy environmental contamination with the medical findings. There is no way of predicting the possible long-term effects of radiation exposure on the individual, but it is obvious that for those six persons in whom physical changes were found future radiation exposures should be minimized.

Recommendations

This study sharply pointed up the need for the observance of certain precautions in the handling of radioactive materials. The recommendations listed below apply specifically to radium therapy clinics and more broadly to any clinic using radioactive materials.

1. Radiation therapy clinics should maintain a complete inventory of all sources of radioactivity and establish a source control system.
2. Radon plants should be designed to provide maximum protection against air and surface radioactive contamination (*5*).
3. A contamination control system should be established whereby all equipment and areas subject to contamination are monitored at frequent intervals (*6*, *7*). Decontamination should be carefully carried out if contamination occurs.
4. Waste disposal procedures should follow methods used by the Atomic Energy Commission for disposing of long half-life, artificially produced radioisotope wastes.
5. Local health authorities should be cognizant of radiological and radiochemical procedures used in order to assure occupational safety.
6. Fire officials should be informed in advance of the location of the radon plant and radioisotope storage so that proper fire-fighting techniques can be used if fires should occur (*8*, *9*).
7. Prospective radiation workers should receive pre-employment physical examinations. Previous occupational and therapeutic radia-

tion exposure history should be obtained and evaluated prior to allowing additional radiation work.

8. Personnel radiation monitoring should be maintained and evaluated. Whenever excessive exposure (greater than currently accepted maximum permissible limits) is detected, proper medical examination should be performed, and techniques devised to reduce exposure to permissible levels.

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On February 13, 1954, the 2-gram supply of radium remaining at the former clinic was transported to the new location. The transfer took place without incident and was done in private vehicles. At this writing, nothing definite is known about the final disposition of the old buildings.

At the present time, most of the recommendations contained in this paper have been put into effect in the new building.

REFERENCES

(*1*) Beyer, R. T. Compiler: Foundations of nuclear physics. Facsimiles of thirteen fundamental studies as they were originally reported in the scientific journals. New York, N. Y., Dover Publications, 1949, footnote, p. 7.

(*2*) Aub, J. C., Evans, R. D., Hempelmann, L. H., and Marland, H. S.: The late effects of internally deposited radioactive materials in man. Medicine 31: 221–329, September 1952.

(*3*) Harley, J. H., Jetter, E., and Eisenbud, M.: A method of obtaining reproducible breath radon samples. A. M. A. Arch. Indust. Hyg. & Occup. Med. 4: 1, July 1951.

(*4*) Williams, E. K.: The problem of hematological procedures in the control of hazards to persons occupationally exposed to ionizing radiations. Atomic Energy Research Establishment, Ministry of Supply, Med/R 831. Harwell, England, The Establishment, 1951.

(*5*) Harrington, E. L.: Radium: Radon plants. *In* Medical physics, edited by O. Glasser. Chicago, the Year Book Publishers, 1951, vol. 1, p. 1193.

(*6*) Curtiss, L. F.: Prevention and control of hazards in the radium dial painting industry. J. Indust. Hyg. & Tox. 24: 131–144, June 1942.

(*7*) Saenger, E. L., Gallaghar, R. G., Anthony, D. S., and Valaer, P. J.: Emergency measures and precautions in radium accidents. J. A. M. A. 149: 813–815, June 28, 1952.

(*8*) International Association of Fire Chiefs: Radiation hazards of radioactive isotopes in fire emergencies—An introductory report. New York, N. Y., The Association, 1950.

(*9*) Gallaghar, R. G.: Firemen must be protected against radiation hazards. Occup. Health 13: 45–48, March 1953.

Applications for Grants in Cancer Research

Acting for the American Cancer Society, the Committee on Growth of the National Academy of Sciences-National Research Council is accepting applications for grants-in-aid for cancer research in the United States. Applications received before October 1, 1955, will be considered during the winter and grants recommended at that time become effective July 1, 1956. Investigators now receiving support will be notified regarding application for renewal.

The committee feels that an understanding of cancer depends upon a deeper insight into the nature of the growth process, normal and malignant. Therefore, the scope of the research program is broad and includes, in addition to clinical investigations on cancer, fundamental studies in the fields of cellular physiology, morphogenesis, genetics, virology, biochemistry, metabolism, nutrition, cytochemistry, physics, radiobiology, chemotherapy, endocrinology, and carcinogenesis. The committee is particularly interested in encouraging research in the epidemiology of cancer.

Application blanks may be obtained from the Executive Secretary, Committee on Growth, National Research Council, 2101 Constitution Avenue NW., Washington 25, D. C.