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Reported Ambient Levels

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Foreword

The *United States Armed Forces Medical Journal* is the medium for disseminating information of administrative and professional interest to all medical personnel of the Department of Defense. The Assistant Secretary of Defense (Health and Medical) and the Surgeons General of the several services invite all medical officers, dental officers, Medical Service Corps officers, Nurse Corps officers, and officers of the Veterinary Corps of the Armed Forces, and the medical consultants of the Army, Navy, and Air Force to submit manuscripts for publication in this *Journal.*

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RADIATION HAZARDS ABOARD A GUIDED MISSILE CRUISER

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THE presence of high-energy radar apparatus on vessels equipped with guided missiles has added new and pressing problems in preventive medicine aboard ship of direct concern to the medical officer. Recognition and solution of such specific problems requires familiarity with the physical aspects, technics of measurement, and biological effects of microwave (radar) and ionizing (x-ray) radiations. This article is presented as a summary of basic information and practical experience both ashore and afloat to enable the ship's medical officer to understand the problems and to ensure that proper measures are taken to protect his crew against the potential hazards of radiation such as were encountered aboard the U. S. S. *Galveston.*

SHIPBOARD RADIATION PROBLEMS

The U. S. S. *Galveston* is the third ship in the United States Navy armed with guided missiles and the first such light cruiser in the world equipped with the Talos weapons system which directs guided missiles to the target by high-powered radar beams. She was commissioned at this shipyard on 28 May 1958 (fig. 1). In addition to multiple radar transmitters of various power for tactical purposes mounted throughout the length of the superstructure, this ship is unique because she carries two AN/SPG-49 radar fire-control transmitters for offense mounted on the afterpart of the superstructure. Each such radar has two components: (1) an "acquisition" beam to scan the sky and locate the target; and (2) a "tracking" beam to lock on target and track

From the Medical Dispensary, U. S. Naval Shipyard, Philadelphia, Pa.

its evasive flight while the ship's guided missiles are prepared, launched, and directed to intercept and destroy enemy planes. These very high-power radars are the large domes situated above the missile launcher on the fantail of the cruiser, as shown in

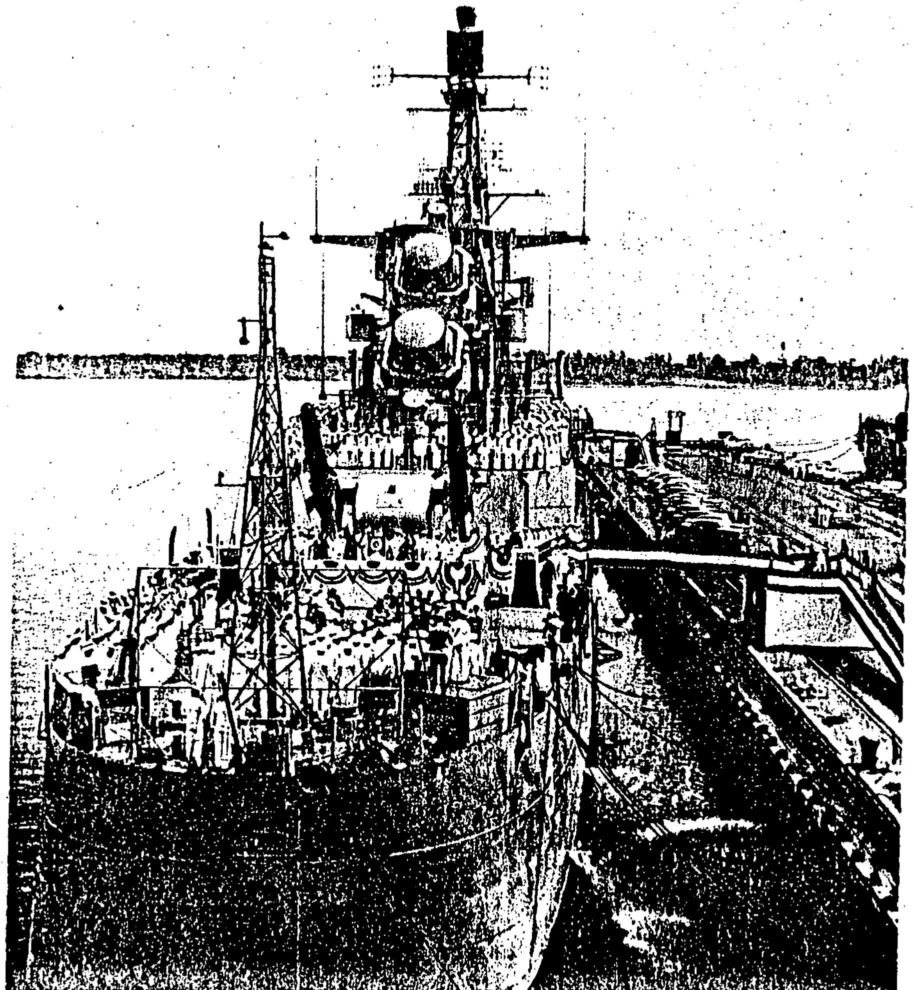

Figure 1. Commissioning ceremonies, U. S. S. Galveston, *U. S. Naval Shipyard, Philadelphia, Pa., 28 May 1958. Note two Talos guided missiles in launcher; also, above the missiles, two large radar domes, AN/SPG-49.*

figure 1. Two separate and distinct radiation problems were found to be associated with the operation of this equipment. One has to do with high-power microwave radiation (radar beam), the other with ionizing radiation (x-ray).

MICROWAVE RADIATION

It is well known that in experimental animals, microwave radiation associated with radar beams of high intensity can cause cataract formation, corneal opacity, or testicular degeneration, and in sufficient intensity may be lethal. However, this may not necessarily apply to the human "animal." Nevertheless, on the basis of existing information the level of 0.01 watts/cm² (10 milliwatts per square centimeter of body surface) has been arbitrarily established as the maximum safe level of microwave radiation for human beings for indefinite periods of time.[1] Higher values are considered hazardous.

Accordingly, in an attempt to establish safe distances from the AN/SPG-49 radar antennas under varying conditions of operation, measurements of the radio-frequency field density were made on 14 March 1958 on the *Galveston* using a new portable radio-frequency power-density meter known as a "microline radiometer;" Model 647 is produced as a research instrument by the Sperry Gyroscope Company. The distance at which the intensity of the radar beams under the various possible operating conditions reached 10 milliwatts/cm² was determined, using this radiometer with the results shown in table 1.

TABLE 1. *Distances for 10 mw/cm²*

Condition	Measured result (feet)
One track beam	92
Two track beams	130
One acquisition beam	162
Two acquisition beams	230
All on simultaneously	265*

*Calculated estimate using measured values for various conditions. (Due to a difference of 90° in polarization of the acquisition and track radar beams, it is not possible to measure accurately the intensity of the radio-frequency field of the combination simultaneously.)

These measurements were made in the center of the beam, with all four beams directed at the same point, either individually or simultaneously.

The beam angle of the ray from these radars is approximately plus or minus 1°, and the intensity falls off rapidly as the measuring apparatus is moved away from the center of the beam. Accordingly, no detectable radio-frequency radiation was found on the fantail when both radars were directed at the ship's boresight tower above it.

The area behind the radar lens adjacent to the AN/SPG-49 radar was below any readable value. A maximal value of 5 mw/cm² was found immediately adjacent to the acquisition screen. The entire area about the radar apparatus does not show any radio-frequency power-density in excess of 10 mw/cm² except directly in front of the lens, thus ruling out significant "side-lobe" effect.

During sea trials early in 1958, conducted by the Naval Board of Inspection and Survey before acceptance of a ship as an operating unit of the fleet, additional measurements were made using the microline radiometer. No detectable radio-frequency radiation was encountered on the signal bridge of the ship located on the forward part of the superstructure when the uppermost AN/SPG-49 beam was pointed directly at it with the acquisition and tracking beams both on full. However, the afterpart of the superstructure was found to have levels of microwave radiation in excess of 10 mw/cm² when the uppermost of the two AN/SPG-49 antennas was pointed directly at the measuring area with only the acquisition beam energized. In addition, the entire fantail of the ship was found to have levels of radiation in excess of 10 mw/cm² when the AN/SPG-49 antennas were both energized on acquisition and track and depressed at an angle of approximately -7° to the horizon so that they pointed directly at the deck of the fantail. No radiation was detectable, however, when both AN/SPG-49 antennas were energized on track and acquisition but were pointed at the boresight tower located on the fantail.

It is apparent from these measurements that certain portions of the after section of the *Galveston* are potentially dangerous when the AN/SPG-49 radar transmitters are pointed directly at them. Personnel, therefore, are not allowed in such areas during activation of the equipment. Under normal operating conditions, no general quarters station aboard this ship is exposed to levels of microwave radiation in excess of 10 mw/cm².

While measurements were being taken of the radar beam intensity aboard this cruiser, each investigator wearing copper-mesh goggles to protect the eyes against overabsorption, it was found that neon lamps will light up if held in these radar beams when the intensity is approximately 5 or 6 mw/cm² and thus well within the safety range. Therefore, as a ready means of detecting intense levels of radiation, crew members working in the area of these radar transmitters have installed small neon lamps (series NE-51, standard U. S. Navy stock) inside their caps. Whenever they think the level of radiation may be excessive, they simply take off their caps and look at the bulbs; if they are lit the men immediately remove themselves from the area. Ordinary photographic flashbulbs are even more sensitive to radar beams, and were found to discharge at a level of approximately 1 or 2 mw/cm². These makeshift detection devices can be quite useful under circumstances where men are occasionally required to enter areas of potentially excessive microwave radiation.

To date there has been no known overexposure of personnel to microwave radiation on the U. S. S. *Galveston,* and none of the men have reported with signs or symptoms which can be ascribed in any way to effects of high frequency radar.

Because the biological effects of microwave radiation[2] have not been described as extensively as those of ionizing radiation (caused by x-rays, alpha and beta particles, gamma rays, neutrons, and cosmic rays), a short résumé of the action of very high frequency radar beams on living tissue is presented.

BIOLOGICAL EFFECTS OF MICROWAVE RADIATION

Microwave radiation is non-ionizing in character. Nonionizing radiation is produced by that portion of the electromagnetic spectrum with a frequency lower than x-rays; *e. g.,* television, radar beams, infrared, visible and ultraviolet light (fig. 2). Radiation in this frequency range exerts its influence on matter by creating heat, by means of a dielectric effect. Atoms and molecules having asymmetric electrical charges undergo rapid rotation in an alternating electrical field. This "dielectric effect" is characteristic of electromagnetic (microwave) radiation which, biologically, apparently results only in the production of heat.

Under normal circumstances heat generated in the deep tissues of the body is transferred by the circulating blood to the skin where it is dissipated into the environment. Equilibrium of the body temperature as a whole is established when the rate of heat dissipation equals the rate of heat production. The temperature at which this occurs is a function not only of the intensity of incident radiation but also of the capacity of the body to dissipate heat. The existing biological condition, therefore, is influenced to some extent by the environmental temperature, relative humidity, and rate of circulation of air.

Certain parts of the body, because of relatively poor vascular supply, are not well equipped locally for the dissipation of heat and, therefore, sustain greater temperature increments than the body as a whole when exposed to microwave radiation. In addition, local collection of fluids, for example, within the lumen of the gut or bladder and the aqueous and vitreous humors, cannot dissipate heat as readily as an equal volume of vascularized tissue. For these reasons the eyes, the gut, and the bladder are especially susceptible to damage from excessive dosage of microwave radiation. The testicles, although well provided for the dissipation of heat, have an exceptionally low threshold to thermal damage, and therefore also are more readily injured by exposure to microwave radiation.

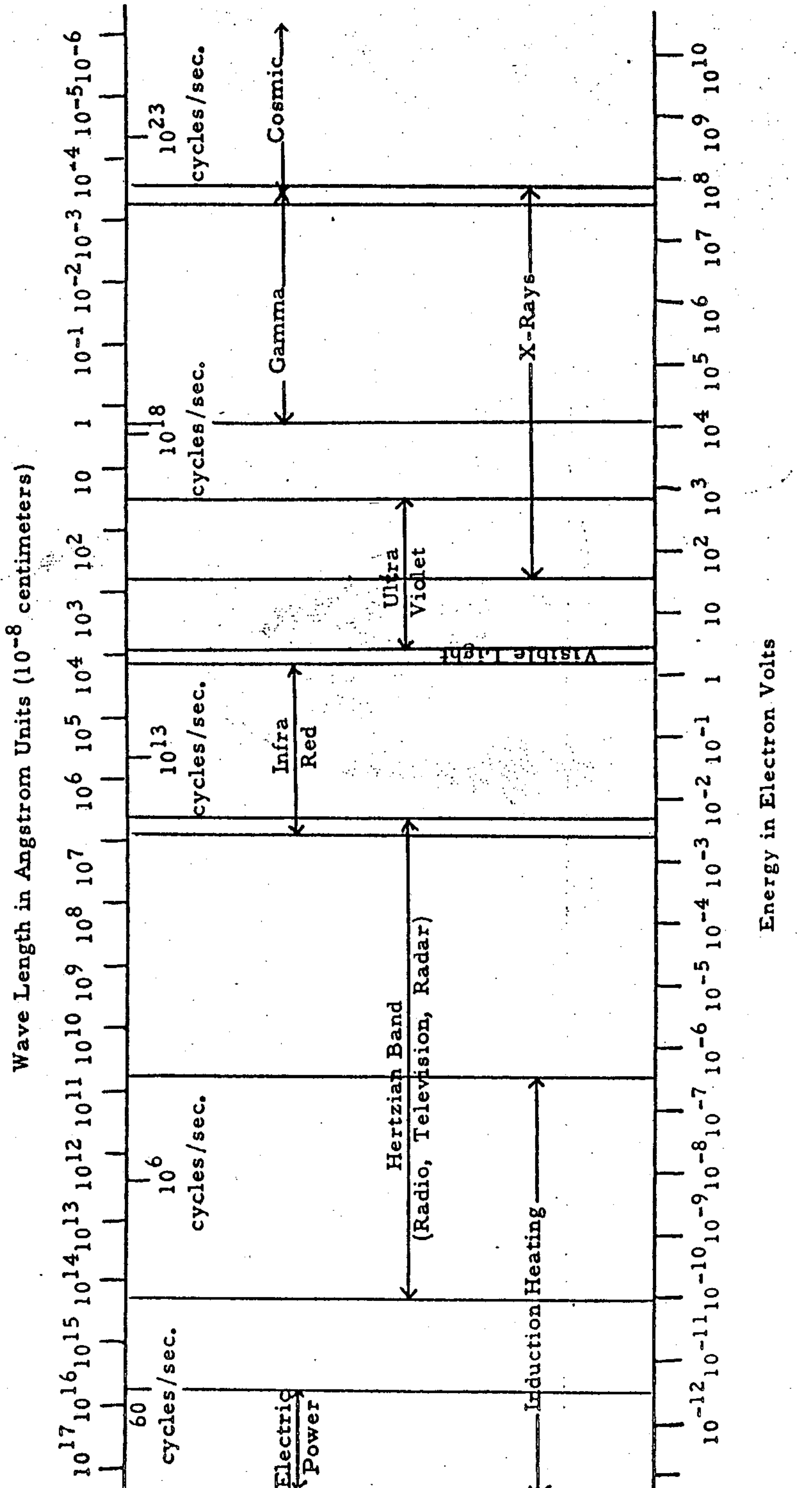

Figure 2. The electromagnetic spectrum.

Experimental work with animals[3] shows that cataracts can be produced in rabbits by several minutes of exposure to power densities in the range of 500 to 600 milliwatts/cm² The threshold of experimental ocular injury for a single sustained exposure of 270 minutes was found to fall between 120 and 220 mw/cm². (The frequency used in these experiments was not stated.) In the same and subsequent experiments, the temperature threshold for cataract production at the posterior lens capsule was determined to be 49° to 50° centigrade. It was recommended that these thresholds be considered hazardous for man; that prolonged exposure to microwaves at a power density of 120 milliwatts/cm², or greater, carried the possible risk of cataract formation. It should be noted that these levels are far in excess of that which can be tolerated by the body as a whole. Parenthetically, ultra-high-frequency radiation at an intensity of 60 mw/cm² is not cataractogenic in experimental rabbits because it does not produce heating in the region of the lens.[4]

The steady state (*i. e.*, indefinite time) threshold for testicular damage in the rat is only 5 to 10 milliwatts of power density. Again, it is estimated that this threshold should pertain to man's genital area.[1]

In a four-year study at the Lockheed Aircraft Corporation, Barron and Baraff[5] compared 226 radar-exposed employees to 88 nonexposed "control" subjects. An extensive system and organ inventory of each person was performed at 6-months, and at 1-year and 2-year intervals, with emphasis on ocular structures, central nervous system, gastrointestinal and urinary tracts, hematapoietic system, and skin. These investigators uncovered no pathologic changes caused by either single or repeated exposures which varied from an occasional incidental contact with the radar beam to as much as four hours' daily close exposure for periods up to four years. Exposures of several minutes a day at distances of less than 10 feet from the radar equipment were not uncommon. Protective clothing was not worn while in or near the radar beams energized in the 400 to 9,000 megacycle range and with occasional peak power output exceeding 1 megawatt.

"The incidence of death and chronic disease, sick leave, and subjective complaints was comparable in both groups. A high percentage of eye pathology was identified, but none with casual relation to the hyperthermia produced by the microwave absorption. Fertility studies revealed essentially the same findings for both groups,"[5] exposed vs. nonexposed employees.

In short, the majority of radars in common use today are relatively low powered and as such do not induce pathologic changes in human beings. In the near future, however, radar beams of much greater power density undoubtedly will become operational, especially in the military services. This brings into focus the problem of "safe dosage," which in the Armed Forces[6,7] is recommended at not more than 0.01 watt/cm².

A factor of considerable importance in determining safe levels of microwave radiation is the distinction between average and absolute intensity. Most radar apparatus operates on a pulsating rather than continuous output. For example, a specific radar transmitter may use an intermittent signal at a frequency of 1,000 pulses per second, each pulse perhaps only one millionth of a second in duration. In this case the average intensity of the radiation is only one one-thousandth the pulse value. The heating effect of this pulsating radiation is determined by the average rather than the absolute intensity. Fortunately, the usual techniques of measurement determine only the average intensity and therefore the results are directly applicable regardless of whether the apparatus operates on a pulsating or a steady state principle.

Be that as it may, our radiation problems aboard the guided missile cruiser did not end with differentiation of the safe from the hazardous areas of microwave emanations from the high frequency radars for intercepting and tracking enemy targets. Another form of radiation, x-ray, was given off by the klystron tubes within the antenna domes of the AN/SPG-49 radars. Radiologic surveys were made by the industrial hygienist (V. H. K.) at the Philadelphia Naval Shipyard before the U. S. S. *Galveston* was commissioned. These surveys revealed intensities of x-radiation at the immediate rear of the traverse member housing the klystron tubes (with the "clamshell" open) as high as 10 roentgens per hour. This is about thirty times the permissible weekly dose for occupational exposure.

Because the presence of these high levels of x-ray were not anticipated, eight men had had duties in this area during intermittent operation of the equipment for several weeks prior to the measurements. Although no record of the time each spent in that area of ionizing radiation is available, it was estimated that several individuals may have received exposure for more than one hour, thus far exceeding the individual permissible weekly dose of 0.3 roentgens. No symptoms of radiation sickness were experienced by any of the men presumably so exposed and to date (six months later) follow-up ophthalmological examinations have remained negative for cataracts.

When the excessive levels of ionizing radiation were discovered, temporary additional lead shielding of the klystrons was installed at once, reducing the radiation levels well within the recommended permissible dose rates. Eventually, the klystron tubes will be replaced with new tubes provided with built-in shields which will reduce the ionizing radiation to an absolute minimum. Meanwhile, the following safety precautions were recommended:

1. Traverse members (interior of the "clamshell") to be designated controlled areas in which the occupational exposure of personnel to radiation is under the supervision of a radiation safety officer, and appropriately posted under supervision of the ship's radiation safety officer (a Medical Corps officer).

2. Personnel having access to and working in said controlled areas shall be monitored by film badges or pocket dosimeters during their occupancy.

3. Such personnel to receive instruction in safe working practices and periodic physical examinations, in compliance with Bureau of Medicine and Surgery Instructions.

With the precautions listed above, based on scientific measurement of the intensity of the microwave radar beams and x-rays during actual sea trials of the scanning and tracking instruments (AN/SPG-49), no hazard to the health and welfare of the ship's company has been encountered and none is anticipated.

MEASUREMENT OF MICROWAVE RADIATION

The determination of the intensity (power density) of microwave radiation requires special equipment not readily available to ships. Furthermore, an understanding of the technic involved requires a certain degree of familiarity with electronic principles not commonly possessed by medical officers. It therefore would be superfluous to discuss the procedure in this article. For those interested, practical details for the determination of power density at microwave frequencies are outlined in reference.[8]

It is expected that in the not too distant future portable apparatus for measuring microwave radiation will be available for routine use in the power-density determinations aboard the U. S. S. *Galveston*. Meanwhile, neon lights will glow when exposed to microwaves producing approximate energy of 5 or 6 milliwatts per square centimeter. Photographer's flashbulbs will "fire" at 1 or 2 mw/cm². As practical safeguards to avoid excessive exposure to radar waves, they are ideal.

SUMMARY

Microwave, nonionizing radiation (radar beams) in sufficient intensity can produce testicular damage, lenticular and corneal opacities in experimental animals, and possibly even death from "cooking" of viscera by excessive diathermy.

Ionizing radiation (x-rays) in sufficient intensity will initiate the "acute radiation syndrome"[9]; low doses over long periods of time are cumulative, increase the incidence of malignancy and possibly may shorten the life span or produce undesirable genetic mutations. A comparison of the major aspects of ionizing (x-ray) and nonionizing (radar) radiation is presented in table 2.

Both types of radiation (ionizing and nonionizing) were encountered aboard the U. S. S. *Galveston* at hazardous levels; some personnel were inadvertently exposed to presumably excessive doses of x-ray prior to commissioning of this vessel, but without ill effect, then or six months later.

TABLE 2. *Comparison of major factors of ionizing (x-ray) and nonionizing (radar) radiation*

Factor	X-ray (ionizing radiation)	Radar (nonionizing radiation)
Etiologic agent	Alpha particles Beta particles Neutrons X-rays Gamma rays Cosmic rays	Microwaves (radar) Radio and television Infrared Visible light Ultraviolet
Unit	Roentgen Roentgen-equivalent-man (rem)	Watts per square centimeter
Mechanism	Ion-pairs	Dielectric effect = Dipolar alternation = Molecular motion, heat
Clinical	In man: Acute radiation syndrome Prodromal Cerebral Gastrointestinal Hematopoietic Cumulative effect Genetic damage Shortening of life span (?) Leukemia Carcinogenesis	In animals: Cataracts Testicular damage Hyperthermia Necrosis of gut Hyperpyrexia Death
Monitors	Geiger counter Film badge Pocket dosimeter	Microline radiometer Neon lamp Photographic flashbulb
"Safe" dosage	0.05 rem/day or 0.300 rem/wk but not over 5.000 rem/yr	.01 watt/cm^2—may be continuous (10 milliwatts per square cm) No time limit

Temporary measures have been taken with complete success to protect the crew from both types of radiation, and other more effective measures are proposed for the future. Small neon lamps (series NE-51, USN) will glow at 5 to 6 mw/cm^2 and photographer's flashbulbs will "detonate" at 1 to 2 mw/cm^2 of power density. Thus, they are excellent practical safeguards to prevent overdosage of personnel.

The seriousness and irreversibility of overabsorption of both types of radiation, and the usual absence of symptoms at the time of exposure, warrant the most careful precautions and safeguards to give the crew adequate protection from these potential hazards. In the last analysis such matters are problems of public health and preventive medicine and are of vital importance to military as well as civilian personnel. This entire area is a prime responsibility of the medical officer, both ashore and afloat.

ACKNOWLEDGMENT: The authors are indebted to Mr. Frank Fecher, ordnance engineer, U. S. Naval Shipyard, Philadelphia, Pa., for technical assistance in preparation of the electronic aspects of this report.

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HEALTHY PARTNERSHIP

I believe the goal of a healthy citizenry is a challenge to all of us in the health profession, both in and out of government. It is a challenge that calls for concerted and cooperative action by all groups that have a stake in better health. We in government would like to be a helpful partner in this vast enterprise. The results of the years of partnership between the government, the people, and the medical profession are evident in every phase of national health. We need only to move forward together to achieve even better health care for the people of this country.—Aims C. McGuinness: The Role of the Federal Government as it Relates to Medicine. *Southern Medical Journal,* December 1958.