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Animal Toxicology

Non-occupational Human Exposure

Occupational Exposure

Epidemiology

Standards

Manufacturing

Uses

Reactions

Sampling/Analytical Methods

Reported Ambient Levels

Measured Methods

Work Practices

Engineering Controls

Biological Monitoring

Methods of Analysis

Treatment

Transportation/Handling/Storage/Labelling

Clinical Problems In Aviation Medicine

MR632

Evaluation of an Alleged Case of Radiation Induced Cataract at a Radar Site

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The use of radar is becoming more commonplace throughout the world. Attendant to its use is injury from microwave and ionizing radiation. Evaluation of radar sites for radiation hazards requires special instrumentation, practice and experience. Stray RF energy and high heat levels were noted to give erroneous values to survey teams. Types of equipment and the methods used are explained.

In this case a radiation induced cataract was claimed but not found. However, there was every opportunity at first glance for the employee to be convinced that his cataract was radiation induced.

The need for knowledgeable, prompt medical support in evaluating suspected injuries was emphasized by its absence early in the case history. However, the most important asset to employee morale and efficiency was found to be the high degree of understanding and general educational background of the technicians. As the use of radar spreads to areas with lower educational levels the importance of such training should increase.

AS RADAR, in its various applications, becomes more common throughout the world the medical problems attendant to its use will appear more frequently. Evaluation of hazards at each site will have unique problems but many practical points were learned in this case which should apply overall.

Radiation-induced cataracts became a medical entity in 1908. Duke Elder credits Birch Hershfeld[1] in 1908 with the first reported case of lenticular injury by ionizing radiation.

The sensitivity of the lens to various forms of radiation injury has been legally established. In England, glass blowers' cataract was established as an occupational disease in 1907.[2] Since then other forms of radiation have been incriminated, such as ultraviolet radiation and microwave radiation as produced by microwave diathermy and radar.

Radar sites, of which this FPS-20A site is typical, have a potential dual hazard:

1. Microwave radiation (radio frequency or RF energy).
2. Ionizing radiation.

The microwave hazard, from both the power source and the radar beam, has been proven to cause cataracts in local exposure. However, with proper work discipline, sharply localized exposures are an extremely unlikely happening considering the size of radar beams. Experiments[3] performed using whole body exposure with microwave radiation have shown that death occurs due to "cooking" of the entire animal before cataracts can be produced. Since heat production is the only significant effect of RF radiation there is no problem of cumulative doses as in ionizing radiation.

The equipment producing the ionizing radiation at this site was associated with the radio frequency oscillator or amplifier, called a klystron, and the modulator, called a thyratron. The radiation is a form of X-radiation, differing from gamma radiation, and is derived from a high energy electron stream while gamma radiation is derived from a nuclear source. The intensity of X-radiation and its penetration power is largely a function of the voltage gradient between the cathode and anode. Thus, the radar's klystron tube operating at 115 kv and the thyratron at 30 kv will produce moderately hard and soft X-rays respectively.

As the anode voltage drops and the ionizing radiation becomes softer the target will absorb a greater portion of the energy, causing more ionizing events with greater cellular damage; this relation continues up to the point that penetration is so superficial that ionization takes place in dead, surface, epithelium.

Roentgen for roentgen the "softer" radiation produced by these tubes should be as dangerous or worse than that produced by modern X-ray machines and still worse than the "harder" radiation produced at Hiroshima and Nagasaki. Merriam[4] found that as little as 200 roentgens of 250 kv X-rays would produce a few stationary cataracts, if delivered to the orbit in a single dose. Five hundred was required if given over three months.

In the construction of the radar power sources the manufacturers took this hazard into consideration. The klystron was enclosed by several inches of close fitting lead shielding and further enclosed by the steel cabinet. The thyratron, which produces soft X-radiation,

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is enclosed only by the steel cabinet. Since taking over maintenance at the site the Federal Aviation Agency employees performed maintenance on the equipment with the power source on and the protective doors ajar. (Figure 1). The interlocks were over-ridden to keep the power supply energized, while the technicians looked through the opening, possibly exposing their eyes to ionizing radiation.

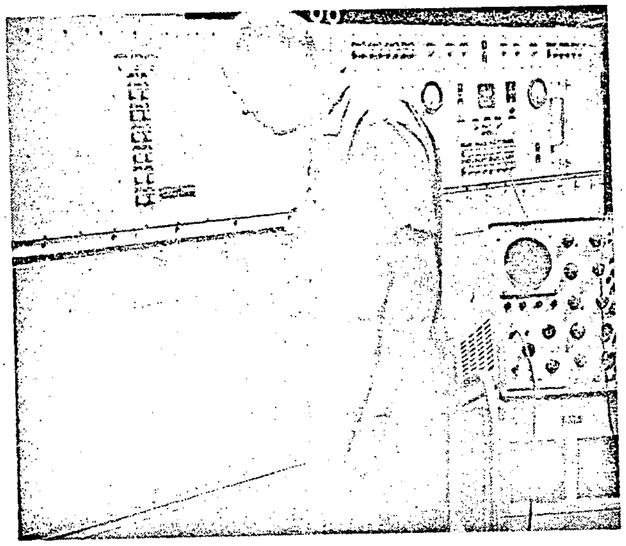


Fig. 1. Equipment configuration.

The medical problem in this case was a 29-year old electronic maintenance technician employed at a "joint use" radar site providing aircraft separation for the Federal Aviation Agency and air defense surveillance for the USAF. He noted a slight blurring of his vision in the left eye and after several days without improvement visited an Aviation Medical Examiner. The examiner found his central acuity very slightly diminished by a large star-shaped cataract. The technician was referred to an ophthalmologist for further evaluation.

Because of a long waiting period involved the technician decided to secure his own consultation with another practitioner who limited himself to the diseases of the eye. Immediately after this examination the technician was asked, "Do you work with radiation?" Upon answering, "yes," he states that he was advised, "You have a radiation cataract."

Hearing this other employees at the facility questioned the safety of the site. Local supervisors then requested a survey for radiation hazards.

In anticipation of possible radiation exposure problems the Federal Aviation Agency had designated and trained Regional Radar Safety Teams. A typical team includes the Regional Flight Surgeon, Regional Safety Engineer and an Electronic Maintenance Engineer. This team evaluates all new radar sites prior to commissioning and other sites as needed. The survey, conducted within the week, centered on two areas:

1. A thorough inspection for both microwave and ionizing radiation hazards to include an analysis of dose rate for all sources found;
2. A medical evaluation of the employees and their work habits. If the technician did, in fact, have a radiation induced disorder, it was planned to medically evaluate all employees at the site who were similarly exposed.

Procedures: Three methods of detection are available for use in study of ionizing radiation.

1. Ionization of gas within an enclosed chamber;
2. Exposures of photographic film;
3. The liberation of light by certain crystals when exposed to radiation. The first two types are normally used in radar surveys.

The ionization chamber device is calibrated to read roentgens per hour directly on an indicating meter. Unfortunately the radio field around electronic equipment can cause erratic or incorrect readings of the ordinary instrument used for detection of nuclear radiation. A specially shielded instrument is required to prevent interference due to the RF field.

Properly protected from heat and accidental exposure the film provides a reliable indicator of radiation. By careful control of exposure time and development, film can be used to obtain a quantitative analysis of X-radiation intensity in terms of roentgens.

The study began with a radiation instrument survey of the radiation levels adjacent to and within the thyratron and klystron cabinets and survey of the waveguide sections near the klystron output. The areas of potential ionizing radiation in work areas of this equipment were surveyed using the FA 7035 shielded instrument. (This instrument is not affected by RF fields). These areas were at the door faces of the thyratron power supply rectifier and klystron cabinets with the doors open, and the area around the waveguide joints. No readings of any significant value were obtained using this method.

These tests included both channels of the FPS-20 but since both produced similar results, only channel # 1 will be used for discussion in this report.

Film pack exposures were made at key points within the thyratron and klystron cabinets and outside the cabinets with access doors closed. Several exposures were obtained on each of the two radar equipment channels. (Each channel has a thyratron and a klystron). The film pack measurements were considered to be the most valid source of data. These film packs were prepared and developed by the USAF Laboratory at Wright Patterson Air Force Base. The interpretation of the film was made at the USAF Radiation Laboratory with film densiometer equipment. Eight-inch by ten-inch film plates were used to get time exposures of the same areas evaluated with the test instrument. Two film plates were suspended on the inside of the door surface of each cabinet and exposed for 8.1 hours with the equipment under normal operating conditions. Each film plate is divided into four areas and the amount of radiation recorded is the highest level detected in each area of the plate.

Test #1—The results of the test showed greater than 2,500 millirems, the maximum readable limit of the film, for area 1.

Test #2—Since the value of radiation in Area 1 of the Power Supply Rectifier cabinet exceeded the maximum readable limit on Test #1, it was decided to use the same procedure but reduce the time of exposure to

TABLE I. RADIATION SURVEY DATA, 8" X 10" FILM PLATES, SAN ANTONIO FPS 20

Units in Millirem

Power Supply Rectifier

Test Number	Exposure Time	Areas of Measurement 1	2	3	4	5	6	7	8
1	8.1 hrs.	>2500	2375	1700	1087	1575	2000	837	1100
2	4.0	82	63	200	137	44	107	144	325
3	4.3	62	44	117	80	32	91	82	77

approximately one-half. This was to bring the test results within measure limits. The team was surprised to find that the values in Test #2 were far less than one-half of Test #1. It was at this point that the importance of heat in the cabinet was first considered.

Test #3—To further determine the importance of heat another test was run under the exact conditions of Test #2 but fans were used to circulate cooler (room temperature) air through the cabinets. An exposure time of 4.3 hours was used.

In view of the low radiation levels detected from the power supply rectifier (Table I, Test #3), dose rates calculated on the basis of known employee exposure time in accomplishing maintenance indicated that no hazard exists from this cabinet. Consequently no further exposure patterns were made.

Under these conditions all areas show a decrease in the amount of radiation recorded. The results for Test #2 and Test #3 correlate well with these results indicating an insignificant amount of radiation. The results of this test were accepted as evidence that the high heat generated by the rectifier was affecting the film and resulting in higher radiation readings. It was concluded that the film deteriorated more rapidly (heat damage) as the time of exposure increased (as shown in Test #1 of 8.1 hours).

TABLE II

Units in Millirem

Modulator Hydrogen Thyratron

Test Number	Exposure Time	Areas of Measurement 1	2	3	4	5	6	7	8
1	8.1 hrs.	5	1350	612	5	5	1750	1900	5
2	4.0	16	875	2300	12	15	1525	1750	15
3	4.3	15	800	1775	12	16	1800	1250	12

Tests #1 & 2—The values obtained in this cabinet for the 4.0 hour test show a decrease from values obtained during the previous 8.1 hour test, with the exception of area #3 where the value increased from 612 to 2,300 millirems. In view of the erratic values the film plates were repeated in this cabinet with fans.

Test #3—The cooling had little effect on the film in the thyratron cabinet. This equipment produces a small amount of heat as compared to the Power Supply Rectifier equipment. The composit of tests 1, 2, and 3 in the thyratron indicates the problems attendant to measuring radiation levels with portable field equipment. The test reported on Figure 3 show variations of 50% in tests 2 and 3, even more if test 1 is included.

Test #4—Since the Modulator Hydrogen thyratron equipment demonstrated varying values of radiation levels inside the cabinet the entire door surface was covered with film plates and exposed for 4.0 hours. This was done by placing 12 plates on a board that completely covered the door facing to give an exact radiation picture (Figure 2).

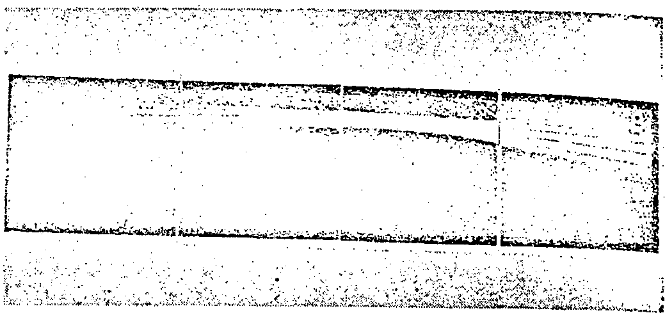
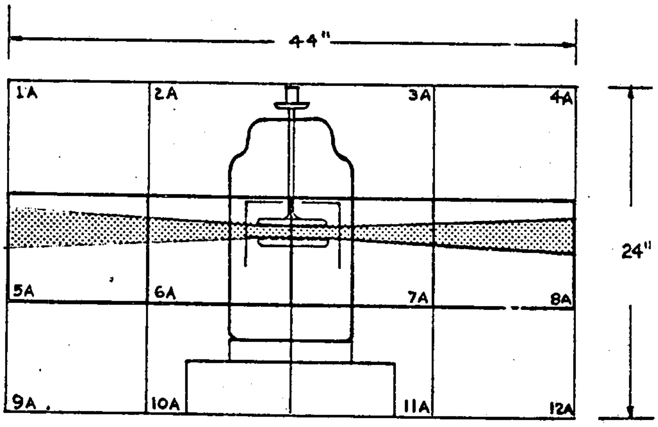


Fig. 2. Film plate location on door.

The radiation pattern as shown on this test with locations corresponding to plates 5A, 6A, 7A and 8A revealed values very near those in test 3, (Table II), indicating test 3 to be the most accurate for the thyratron.

The actual radiation pattern is close to the theoretical pattern pictured by the appropriate USAF Tech Order[5] (Figure 3). No other radiation was detected on the adjoining plates. This band of radiation is so located that it is blocked even with the steel door open to the inspection position (Figure 1).



Modulator Hydrogen Thyraton
Cabinet Opening

Fig. 3. Film plate arrangement showing radiation pattern.

Tests with film packs outside the steel cabinet door showed no measurable radiation with the doors open only to the inspection position or to the closed position. Each door is interlocked and procedures require that the doors be closed during normal operations.

Next the team centered its attention on the microwave hazard. The electromagnetic energy associated with the waveguide and antenna system is known as radio frequency energy and lies below the visible spectrum on the infrared or long wave length side of visible light. This asociation with infrared and heat forms a close analogy of the effect of this type of radiation on man.

The exposure limits for this type of radiation are conservatively based on power levels which have caused tissue damage in experimental tests. It is convenient to express this power level in watts per square centimeter and measure the results in terms of heating or heat gain to the object exposed to the radiation.

The frequency of the RF energy determines whether the heating can be easily perceived by the senses. Radiation at frequencies below 100 MC causes heating deep within the body and is not detected by the heat sensing receptions in the epithelium. Frequencies above 3000 megacycles also cause heating of the outer or skin tissues similar to infrared or sunlight. The radar equipment in this case operates at approximately 1300 MC and the effect of excess radiation *may* not be detected before damage occurs depending on the percentage of energy actually absorbed by the tissue. It is important to note that the heat gain of any object exposed to RF radiation is directly related to the *average* power level expressed in watts per square centimeter. In the case of radar equipment the average power delivered to the antenna system, the beam shape, antenna rotation speed, beam vertical angle and distance from the antenna must all be considered in evaluation and measurement of power levels.

Instrumentation used to measure RF power levels sample a known area of the RF field through an RF antenna system and uses the collected energy to heat a temperature sensitive resistor (thermistor) placed in one leg of a resistance bridge. After initial balancing of the bridge the heat detected by the thermistor unbalances the bridge causing deflection of a sensitive volt meter. This deflection is calibrated in watts per sq. centimeter. The NF 157 power Density Meter manufactured by Empire Devices, Inc., a USAF standard, was used in measurement of radiation levels on the height finder radar tower adjacent to the FPS-20 search radar antenna. The survey was accomplished at points of exposure extended to the antenna enclosures with the antenna individually stopped and operating at normal power.

Initial tests of the RF field power density were inconclusive in that no detectable level was found. These tests were repeated with another instrument of different type which verified a very low RF power level on the FPS-20A antenna catwalk external to the radome and at the maximum accessible level on the FPS-6 height finder tower (Figure 4, area 2). These tests indicated that the main beam of the FPS-20A searched an area which was not accessible to technicians at any time.

Similarly, the effects of FPS-6 height finder radar on personnel working on the FPS-20A tower were determined by utilizing survey instrument and adjusting antenna tilt of FPS-6 so that the FPS-20A tower catwalk was illuminated (Figure 5). This test also revealed no significant RF power density being experienced due to the FPS-6 antenna. In addition, the FPS-6 height finder antenna and radar equipment is gated, or blanked, to prevent the FPS-6 radar from searchlighting the FPS-20A antenna system. At this point all technical testing was finished with no hazard found. However, the individual technician was still concerned about his original diagnosis.

It was requested that the technician be evaluated by USAF School of Aerospace Medicine, Brooks Air Force Base, Texas. He was examined thoroughly by the departments of Internal Medicine, Ear, Nose, and Throat, Radiology, Aviation Medicine, and Ophthalmology. The following is quoted from the ophthalmologic section of the "Comments and Recommenda-

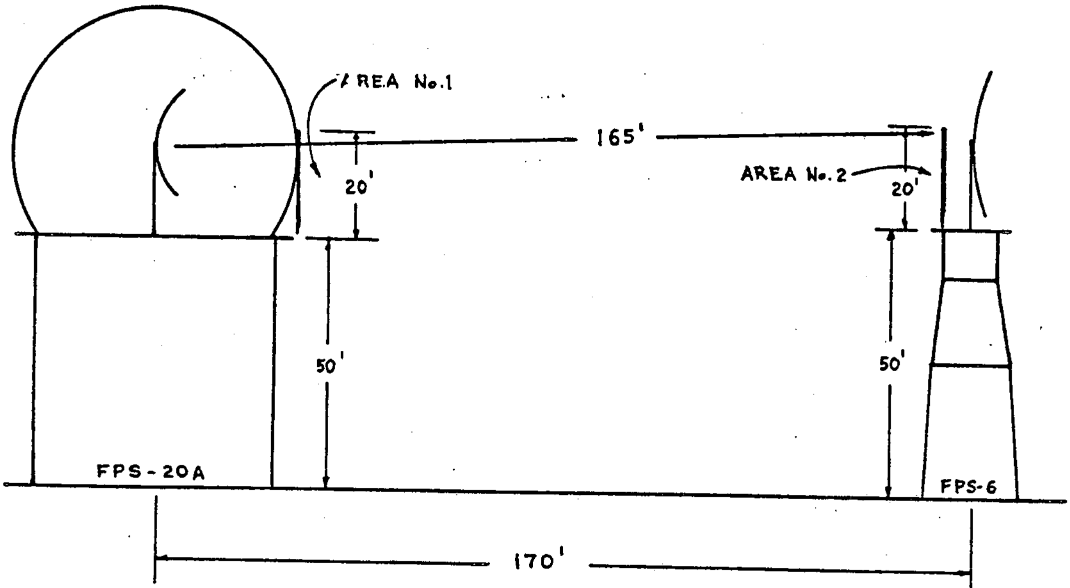


Fig. 4. Survey Conditions.

1. FPS—20A
   a. Antenna tilt *classified*
   b. Antenna azimuth *centered on FPS-6 Tower*
   c. Transmitter output *6KW Ave. Pwr.*
2. FPS-6
   a. In standby condition, transmitter *off*.
3. Area #1 dimensions, 0 to 20 ft. above FPS-20 antenna deck.
4. Area #1 detector meter reading *0* MW/CM².
5. Area #2 dimensions, 0 to 20 ft. above FPS-6 antenna deck.
6. Area #2 detector meter ready *0* MW/CM².
7. All readings taken with Sperry Electromagnetic Radiation Detector Model B86B1.

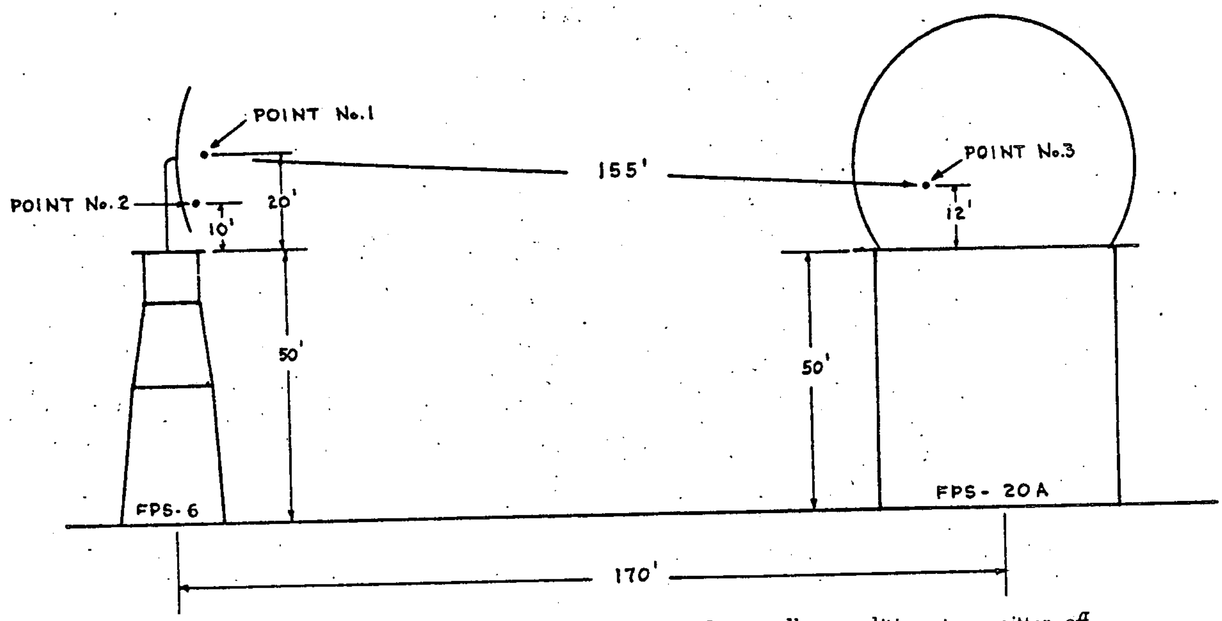


Fig. 5. Survey conditions.

1. FPS-6
    - a. Antenna tilt *locked at -2 degrees.*
    - b. Antenna azimuth *centered on FPS-20 tower.*
    - c. Transmitter output *3.1KW Ave. Pwr.*
2. FPS-20
    - a. In standby condition, transmitter *off.*
3. Point #1 detector meter reading *10* MW/CM^2.
4. Point #2 detector meter reading *10* MW/CM^2.
5. Point #3 detector meter reading *0* MW/CM^2.
6. All readings taken with Sperry Electromagnetic Radiation Detector Model B86B1.

tions" of the final report by the Aviation Medicine Consultant Service.

Ophthalmologic Evaluation:

"A comprehensive ocular evaluation was performed on (the technician). His visual function is excellent. Previously forgotten was the fact that he was hit in the left eyeball at about age 10 to 12 by a thrown, wrapped caramel candy. He was seen by a physician several times after this, apparently to follow the healing of the resultant corneal abrasion. There was no other noteworthy history.

"The only positive physical eye finding is the cataract in the left eye. Morphologically it is a classical 'contusion cataract' and it is so well confined within a single lens lamella that the time of lens injury can be roughly fixed at more than 10 years ago. The anterior and posterior subcapsular and cortical fibers are completely normal, indicating no lens insult or trauma for over 10 years. The lens o.s. could be described as follows: there is a thin, rosette-shaped, diaphanous opacity confined in the anterior adolescent cortex; within the same lamella there are punctate opacities which extend toward the equator and, to a slight extent, posteriorly; the anterior and posterior cortical and subcapsular regions are normal.

"It is entirely possible that an injury such as is described above could have caused this cataract. There are no features of the cataract which would suggest radiation as an etiology. There is clear evidence that the etiologic incident was acute, monocular and occurred at least 10 years ago. Thus the morphology of the lesion and the history establish the diagnosis of contusion cataract. It is likely that progression, if any, will be slow and that he will adapt to any visual incapacitation. The cataract should be followed by an ophthalmologist at yearly intervals."

Berliner[6] states: "That certain characteristic types of lens opacities are peculiar to nonperforating contusion . . . is now generally agreed." The rosette-shaped lamella cataract is the most typical of these opacities. Concerning prognosis, Berliner states: ". . . in most instances the opacities resulting from contusions are permanent and nonprogressive." However, it is true that senile changes may be accelerated by a contusion and result in late progression of visual symptoms. This may occur even when the contusion cataract itself has been stable for many years.[6]

The findings and the prognosis were explained in detail to the patient. The more he understood about his case, the happier he became. When he left Brooks Air Force Base he was grateful and pleased with the outcome.

It is clear that ophthalmologic evaluation can be used to great advantage in the clarification of problem cases such as this. The medico-legal advantages are obvious but more important was the groups improved morale which resulted from the delineation of the nature of the technician's ocular defect.

At the conclusion of the survey the entire employee group was satisfied with the thoroughness of the team. The technician reported his satisfaction with his evaluation and ultimate diagnosis.

In this case the Federal Aviation Agency was fortunate in one area . . . the educational level of the employees. Through their electronic background and training regarding the local radiation hazard and the general educational level, they were convinced that there *should not* be a hazard present . . . regardless of the initial diagnosis. Radiation hazards were not a mysterious occult influence but a predictable, understandable problem to them.

SUMMARY

In reviewing the evaluation several features appear worthy of comment:

1. Early education of employees in radiation hazards is essential for environments such as this radar site.
2. Thorough screening of the site before operation should be documented and explained to the employees.
3. Changes in operating procedures which present new hazards, not surveyed, must be subject to engineering review and be medically monitored.
4. *Prompt, accurate* medical evaluation should be the first order of business in any new case.
5. The creation and training of a radar safety team is invaluable when a real hazard is suspected. Prior practice and training proved essential to us and should to future teams.
6. As all weather sea and air traffic control increase throughout the world so too will radar control, bringing this problem to organizations where personnel are not so cooperative or well-trained. The lower the general educational level the more importance attached to employee training in radiation hazards.

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Book Reviews

PRINCIPLES AND METHODS OF MEASURING HUMIDITY IN GASES—Volume One. Edited by Robert E. Ruskin. Reinhold Publishing Corporation, 430 Park Avenue, New York, New York 10022, 704 pages, $30.00.

Humidity measurement has been important in instrumentation and endeavors throughout a long history. Both the capabilities and the number of types of humidity instruments have expanded steadily to the present time. The 1963 International Symposium on Humidity and Oisture was planned to bring up to date the start of the art, and this volume was planned to form a quite complete reference work on instrumentation for water vapor measurement. An unexpected bonus from the symposium has been an apparently increased interest among workers in the humidity field, resulting in more rapid improvements in instrumentation and more difficulty in keeping informed of the latest developments. Among the promising new developments are simplified automatic dew-point hygrometers which increase the possibility of their eventual use in radiosondes for network observations. Other possibilities for improved expendable humidity instrumentation are almost certain to result from progress being made in aluminum oxide, barium fluoride and piezo-electric crystal developments.

In this volume the principles and methods of measuring the humidity of gases are divided into several general categories, each category starting with the papers of more fundamental or general nature, followed by more specific embodiments of these principles in instruments. A final miscellaneous section contains those papers which either do not fit any of the main sections or which discuss instruments of more than one of the categories.

This volume forms a complete reference work on instrumentation for water vapor measurement. It brings together comprehensively, authoritatively and definitely important and essential information vital to the successful control of humidity and oisture and treats in detail all modern methods of determining moisture content. The latest developments, the latest researches, the latest studies and investigations are presented. There are sixty-eight chapters, divided among six general sections: I. Psychrometry, II. Dew-Point Hygrometry, III. Electric Hygrometry, IV. Spectroscopic Hygrometry, V. Coulometric Hygrometry, VI. Miscellaneous Methods.

This is the first of a four-volume work representing the expanded proceedings of the First International Symposium on Humidity and Moisture Control held in Washington, D. C. The more than 230 chapters deal with topics ranging from humidity standards and fundamentals, through means of measuring and controlling humidity and moisture to specific applications. The applications vary from measurement of air humidity for meteorological purposes to determination of moisture in grain, an important factor in storage. Of particular interest are chapters on applications in biology and medicine, describing the use of controlled humidity in treatment and the relationship of symptoms to humidity level.

RADIATION SOURCES. Edited by A. Charlesby. Pergamon Press Limited, Oxford, England, Distributed by The Macmillan Co., New York, New York, 1964, 268 pages, $12.00.

Public interest in nuclear science has been largely focused on its applications in the production of power, and in its military implications. Less attention has been paid to the utilization of nuclear radiation as a means of modifying materials, although this aspect has received a considerable amount of scientific study. Investigations have been carried out on radiation effects in such varied fields as physics, chemistry, biology, medicine and agriculture. Both for purposes of research and application, an ever-increasing range of radiation sources has become available in the last few years. These sources can either be based on some form of nuclear reaction (as in reactors, fuel elements, radioactive isotopes) or on the acceleration of charged particles to high energies by purely electrical means. For many purposes the choice of the most appropriate equipment is obvious; for others there is considerable controversy between the protagonists of radioactive isotope sources and those of electrical accelerators. Many of the scientists engaged in one or other specialized field of radiation work are not specifically concerned with details of source design, but wish to have a general comparison of all available sources. They particularly appreciate information on such practical aspects as installation, running cost, dosimetry, maintenance, flexibility and reliability. It is to cater for such research and industrial scientists and engineers that this volume was planned.

It soon became obvious to the editor that, while rapid progress in the design of radiation sources was of the greatest value to the research worker, it greatly handicapped any attempt to present adequate and up-to-date reviews of all the relevant aspects within a single volume. Novel devices, techniques and applications are constantly appearing, and industrial experience is being accumulated. Furthermore there is a strange discrepancy in time scale: scientific authors can devise extremely complex equipment for measurement of times less than 10^{-9} sec, but are sometimes unable to forecast their own schedule to better than 3×10^{7} sec. It was therefore decided to present the subject in several short volumes, appearing as new developments and information emerge. It is nevertheless hoped that the present contributions will be of value to radiation users, both actual and potential.