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ASD-TDR-63-697

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Radiation Physics: Its Impact on Instrumentation

Rudy C. Beavin
1st Lt., USAF

TECHNICAL DOCUMENTARY REPORT NO. ASD-TDR-63-697

September 1963

presented at



ASD 1963 Science and Engineering Symposium ■ ■ ■ ■ ■

Aeronautical Systems Division
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

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FOREWORD

Each year the Aeronautical Systems Division (ASD), Air Force Systems Command (AFSC), sponsors a Science and Engineering Symposium in advance of the Annual Air Force Science and Engineering Symposium. This provides a specific motivation for ASD personnel to prepare papers that reflect the results of their efforts. The variety of subjects also provides an opportunity for interdisciplinary exchange of information that is becoming ever more important.

This year the symposium papers are being published individually to facilitate distribution and retention. However, each paper carries this same foreword which lists the titles of all papers together with the authors and the ASD Technical Documentary Report (TDR) numbers. Readers who are interested in obtaining copies of other papers are urged to contact the authors directly or the Defense Documentation Center, Alexandria, Virginia. It should be noted that certain papers are classified and are available to only those persons having proper security clearances and a "need-to-know."

This paper is one of 21 presented at the "ASD 1963 Science and Engineering Symposium" held at Wright-Patterson Air Force Base, Ohio, 18-19 September 1963. They consist of 17 CONTRIBUTED and 4 INVITED papers, listed below. *The 5 contributed papers that are asterisked were also presented at the 10th Annual Air Force Science and Engineering Symposium held at the Air Force Academy, Colorado Springs, Colorado on 8, 9 and 10 October 1963.

CONTRIBUTED PAPERS

*Operation Fishbowl - Close-In Thermal Measurements, UNCLASSIFIED Title,
SECRET-RESTRICTED DATA Paper
F. D. Adams
ASD-TDR-63-691

Radiation Physics: Its Impact on Instrumentation
R. C. Beavin, 1st Lt, USAF
ASD-TDR-63-697

*Application of Aerodynamic Lift in Accomplishing Orbital Plane Change
R. N. Bell, 1st Lt, USAF and W. L. Hankey, Jr., Ph. D.
ASD-TDR-63-693

Controlled Thermonuclear Reactions for Space Propulsion
R. F. Cooper and R. L. Verga
ASD-TDR-63-696

Comparison of Approaches for Sonic Fatigue Prevention
M. J. Cote
ASD-TDR-63-704

Air/Ground Communications Via Orbiting Reflectors
C. C. Gauder
ASD-TDR-63-702

***Ring Laser Techniques for Angular Rotation Sensing**

D. A. Guidice and W. L. Harmon
ASD-TDR-63-694

Zero Gravity Pool Boiling

L. M. Hedgepeth and E. A. Zara
ASD-TDR-63-706

An Analytical Study on Liquid Cesium Purification in View of Current and Projected Needs

R. H. Herald
ASD-TDR-63-703

***Preliminary Weight Estimates for Advanced Dynamic Energy Conversion Systems**

G. D. Huffman
ASD-TDR-63-705

Force Balance Determination of Inlet Performance for Advanced Vehicle Applications to Orbital Velocities Using Internal Drag Measurements

P. H. Kutschenreuter, Jr.
ASD-TDR-63-701

Thermal Insulations for Aerospace Applications: -423° to + 3000°F

M. L. Minges, 1st Lt, USAF
ASD-TDR-63-699

The Rankine Cycle Air Turboaccelerator (RATA) Engine — A New Cryogenic Engine system, UNCLASSIFIED Title, CONFIDENTIAL Paper

H. E. Pope
ASD-TDR-63-692

How PERT is Used in Managing the X-20 (Dyna-Soar) Program

R. M. Sadow
ASD-TDR-63-698

Liquid Metal Magnetohydrodynamic Power Conversion

G. B. Stafford
ASD-TDR-63-700

System Components Information Center

M. G. Toll
ASD-TDR-63-695

***Aerospaceplane — An Advanced System Planning Study, UNCLASSIFIED Title, SECRET Paper**

Alan Watton
ASD-TDR-63-690

The following four invited papers were prepared by the listed authors covering Air Force effort in the subject areas and were presented at the 10th Annual Air Force Science and Engineering Symposium. Copies of these papers may also be obtained from the authors or the Defense Documentation Center.

ASD-TDR-63-697

INVITED PAPERS

Summary of Laminar Flow Control Techniques for Aircraft
P. P. Antonatos, R. X. Mueller and J. P. Nenni
ASD-TDR-63-689

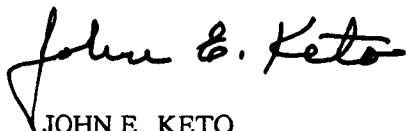
Materials for the Space Age
H. D. Colwick, Capt, USAF, D. H. Cartolano and C. W. Douglass
ASD-TDR-63-688

V/STOL Systems Technology Today and Tomorrow, UNCLASSIFIED Title, SECRET Paper
G. E. Dausman, Joseph Jordan and W. A. Summerfelt
ASD-TDR-63-687

Limited War/COIN, UNCLASSIFIED Title, SECRET Paper
D. A. Rook, Capt, USAF
ASD-TDR-63-686

A large percentage of the above listed authors are with organizational elements that have been or are being transferred from ASD to the recently established Research and Technology Division (RTD). These scientists and engineers from the Air Force Aero-Propulsion Laboratory, Air Force Avionics Laboratory, Air Force Flight Dynamics Laboratory, Air Force Materials Laboratory, and the Systems Engineering Group have, in some cases, prepared the symposium presentations as well as the published documents jointly with technical personnel remaining in ASD.

These 21 papers represent only a small portion of the ASD/RTD effort which spans from basic research through engineering and includes various aspects of technical management. They are illustrative of the competence of our technical personnel and we proudly dedicate them to all our scientists and engineers.



JOHN E. KETO
Chief Scientist
Aeronautical Systems Division

BIOGRAPHY

LIEUTENANT RUDY C. BEAVIN attended the Speed Scientific School of the University of Louisville, Louisville, Kentucky, receiving a B.S. degree in electrical engineering and a commission as a 2d Lieutenant in the Air Force in 1961. While attending the University, he served in an executive capacity in several fraternities, was editor of the Speed Engineer, Vice-President of the Tommy Mantell Squadron of the Arnold Air Society, and Cadet Wing Commander. Lieutenant Beavin received the Gold Medal of the American Society of Military Engineers and the Chicago Tribune Medal as outstanding cadet of the year in 1961. He is presently assigned to the Flight Control Division, AF Flight Dynamics Laboratory, Research and Technology Division, Wright-Patterson Air Force Base, Ohio, as project engineer in radiation physics.

ABSTRACT

Presented is an argument for exploiting radiation physics for the solution of problems in the instrumentation area. A brief review is given of basic physics connected with radiation. Several problems in the flight control area are stated and possible solutions presented using radiation physics concepts. Three of these problems, low altitude altimetry, high altitude altimetry, and fuel mass measurement, are examined in detail and experimental and analytical results given. A program philosophy and the establishment of an in-house experimental facility for exploitation of radiation physics are also reported.

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INTRODUCTION

We realized, approximately two years ago, that there was great potential in radiation physics for solving some of our more critical problems which refused to yield to "conventional" approaches. The Flight Control Division, AF Flight Dynamics Laboratory, Aeronautical Systems Division (ASD), now a part of the Research and Technology Division, conducted an investigation into the application of radiation physics to make flight measurements for aerospace vehicles. Within the term "radiation physics," the interaction of all nuclear and atomic emanations with their environment is implied. Particularly included are the interactions of beta particles and gamma and X-ray photons with fields and matter. Other emanations such as neutrons and alpha particles may indeed prove important in the future, but the three chosen are at present most promising.

More familiar forms of electromagnetic radiation such as heat and radio waves, along with such physical phenomena as displacement and strain, are the means presently used to sense and measure our surroundings. These "conventional" phenomena are limited in their application and their use sometimes results in large and complex equipment with outputs unsuited for direct or efficient utilization. It is felt that many of these problems may be overcome, and others reduced to an acceptable level, only through exploitation of unconventional approaches such as are represented by the application of radiation physics. That the phenomena may be unfamiliar should, rather than providing justification for ignoring their application, provide incentive to use a new tool for solving problems which are also unfamiliar or impossible to solve with "conventional" means.

The area of flight control, because of the wide technological spectrum embracing its problems, has been prompted to use any and all techniques available for the solution of these problems. Not all of the problems have been solved with "conventional" techniques and not all will be solved through applications of radiation physics, but there are several which seem amenable to solution by applications of radiation physics because of the unique nature of the interactions that occur. The following are representative of these problems.

- a Altimetry from 100,000 to 300,000 feet.
- b Altimetry and other aids for the terminal phase of flight.
- c Ranging for scoring or intelligence.
- d Fuel management, including measurement of both stored mass and mass flow.
- e Terminal phase rendezvous and docking.
- f Instrument lighting for limited power or power off situations.

Problem a might be solved by making use of the phenomenon of Compton scattering. With an instrument configured as in Figure 1, photons or particles emitted by the source and scattered in the sensitive volume are counted by the detector. The rate of counting is a measure of the density in the scattering volume.

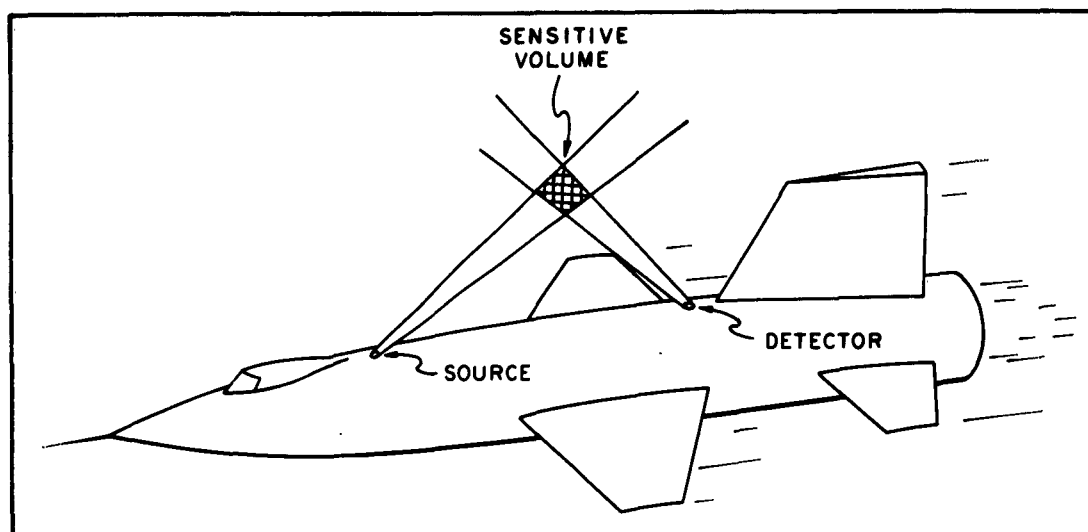


Figure 1. High Altitude Altimeter

A solution to problem b takes advantage of the phenomena of absorption of radiation by matter and straight line propagation of photons of radiation for its implementation.

For problem c a solution is achieved by making use of the inverse dependence of the intensity of photon radiation on the square of the distance between a source and detector as shown in Figure 2.

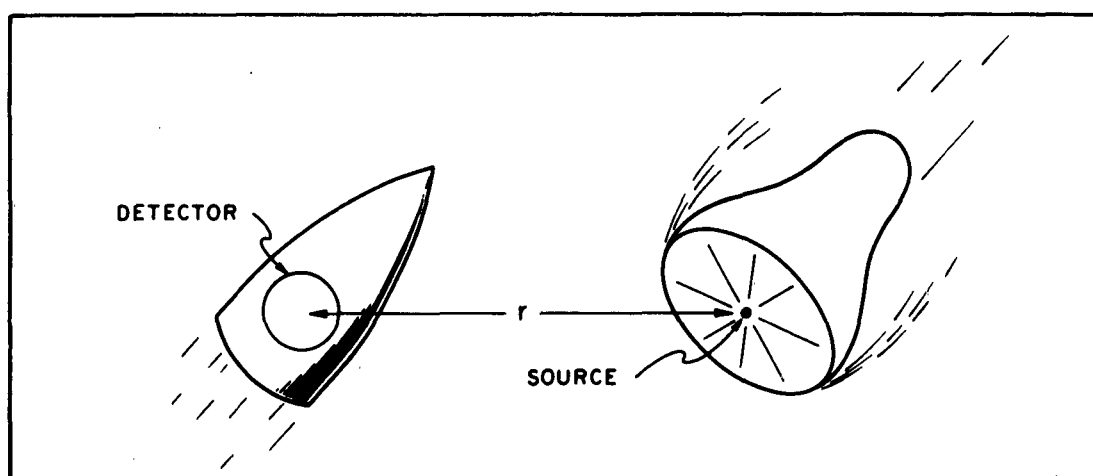


Figure 2. Ranging and Scoring

Absorption, straight line propagation and scattering are all important for the solution of problem d.

Figure 3 shows a solution to problem e taking advantage of the inverse proportionality of intensity to distance and collimation to achieve rather precise alignment. Use might also be made here of the Mossbauer effect to measure the very slow closing rates necessary for the docking maneuver. By taking advantage of the energy of radiation to excite atomic states which then emit light photons, light sources as required by problem f may be secured which use radioactive materials as the power source.

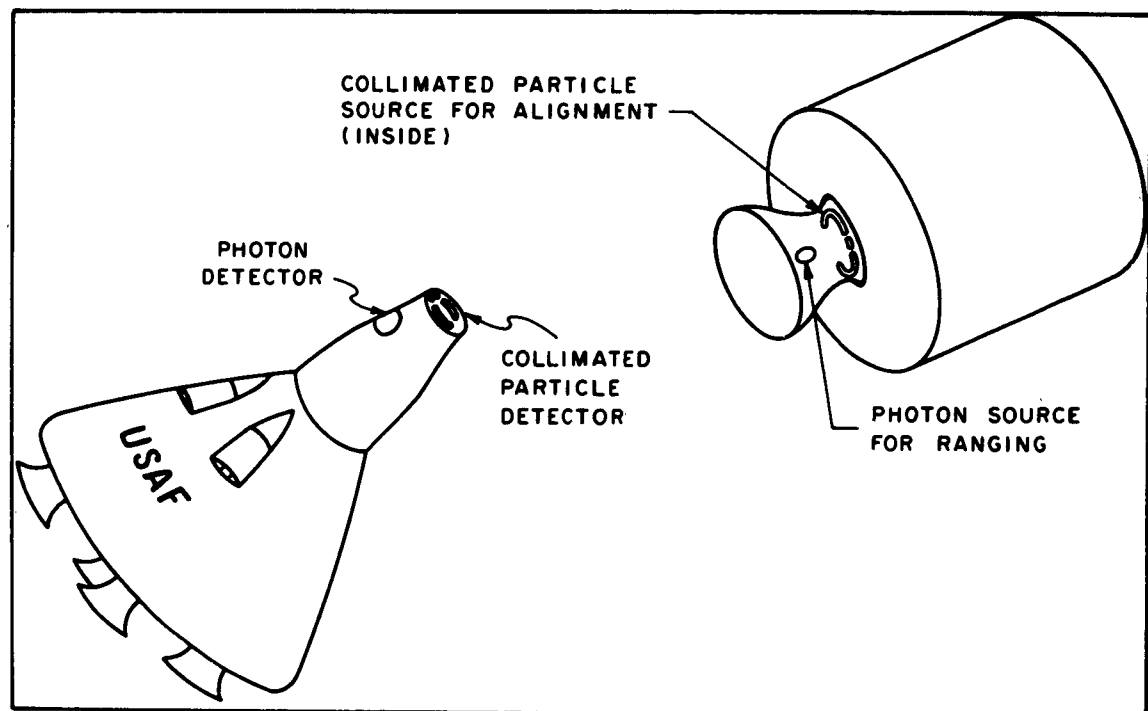


Figure 3. Rendezvous and Docking

BASIC PHYSICS OF INTERACTIONS

Before discussing application we briefly review the phenomena involved and the physics governing them, i.e., (a) absorption and transmission; and (b) scattering.

Considering first the beta particle, note that it originates within the nucleus, being emitted along with the neutrino, which accounts for there being a spectrum of beta energies upon the decay of the excited nucleus. The beta particle so emitted may be either positively or negatively charged as the physics of the situation require. When it carries a negative charge it is seen to be identical with an energetic electron. Should the beta particle carry a positive charge, it is termed a positron and except for the positive charge and its very short lifetime in the presence of matter, it is also identical with the electron. The short lifetime results from the high probability of a positron meeting an electron near a heavy nucleus. Two gamma photons are created to conserve the energy of the subsequent annihilation.

We shall treat only the negatively charged beta particle and consider beta particles and energetic electrons as being governed by the same physics in their interactions with matter.

In a field free vacuum, electrons will travel in a straight line at a constant velocity, i.e., they will experience no accelerations. If either a magnetic or an electric field is present, the electron will be accelerated as a result of the interaction of the field of the electron and the ambient field. Since the electron carries a charge and does not occupy a quantum state, it will, in accordance with Maxwell's laws, emit electromagnetic radiation which is seen as a continuum in the X-ray region of the electromagnetic spectrum and termed bremsstrahlung. The radiation represents an energy loss which is only important when the interactions are very strong.

When matter is present, the chief mechanisms for energy loss of electrons having less than 10MeV of energy, especially in the presence of heavy nuclei, are excitation and ionization of atoms along the path of the electron. This is a result of the interaction of the field of the electron and that of the orbital electrons of the atom. For electrons with energies greater than 10MeV, the chief mechanism, again particularly in the presence of heavy nuclei, for energy loss is through bremsstrahlung as a result of Rutherford scattering (interaction of the Coulomb field of a nucleus with the field of the moving electron).

The above are the important mechanisms for energy loss from an electron. Others, such as annihilation through combination with a positron, elastic collisions with atoms, recombinations, and dissociation of molecules contribute very little to the energy loss and/or absorption of electrons.

Considering gamma rays and X-rays, we observe that they differ only in their origin, the former resulting from nuclear de-excitation or annihilation of an electron-positron pair, and the latter from de-excitation of electronic states or the acceleration of electrons. We also note that gamma rays and X-rays are photons of energy which must interact wholly, i.e., the photons are quantum mechanical in nature and thus the entire photon must be either created or destroyed in one interaction.

In a field free vacuum there are, of course, no interactions. Even when a field is present, there are no interactions observed since gamma and X-ray photons have such short wavelengths that they cannot interact with ordinary fields and the probability of their interacting with each other is vanishingly small.

The three major interactions of photons with matter are photoelectric effect, Compton scattering, and pair production. Others, such as molecular dissociation and photonuclear processes contribute only slightly to the observed phenomena.

The photoelectric effect, which dominates for low energy photons, is the interaction of a photon with an entire atom, the result being the ejection of an orbital electron. The electron involved is normally one in the highest energy state. Although, for certain very low photon energies, a process having very high probability of occurrence, termed K absorption, occurs which involves the lowest energy orbital electrons. In both cases, the incident photon is totally absorbed, as required. The electron then acquires a kinetic energy equal to the energy of the photon minus the electron's binding energy. No new photon appears.

Compton scattering, which dominates the interactions for photons of moderate energy, is the result of an interaction between the incident photon and one of the orbital electrons. Under the condition that the energy of the incident photon be large when compared to the binding energy of the target electron (this condition is always met in the region where Compton scattering is important), the target electron may be treated as being free. The

interaction then may be analyzed as an elastic collision between the photon and the electron. The result of this interaction is an energetic electron and a new photon of lesser energy than the incident photon traveling in a different direction. The electron and new photon share the energy of the incident photon, it having been totally absorbed. Should the energy of the incident photon be very near or less than the binding energy of the target electron, coherent scattering (wherein the incident photon interacts with the entire atomic system) may occur. In this instance, the new photon has an energy very nearly equal that of the incident photon.

Pair production may take place when photons having energies in excess of 1.02MeV, twice the rest mass energy of an electron, are in the presence of heavy nuclei. This phenomenon completely dominates the interactions for high energy photons. In this process, a photon near a heavy nucleus, or at least within the sphere of influence of the nucleus's Coulomb forces, is completely annihilated with the result that an electron-positron pair is created. Any energy carried by the photon in excess of that required for creation of the two particles is seen as kinetic energy of the particles and as recoil energy of the heavy nucleus.

SOME APPLICATIONS

LOW ALTITUDE ALTIMETRY

In fiscal year 1962, the General Electric Company under contract with the Flight Control Laboratory, investigated the application of gamma ray interactions to low altitude measurement. The effort was based on an unsolicited proposal by the contractor and an in-house effort by Flight Control Laboratory personnel. The following is based on this effort, the resulting report, ASD-TDR-62-648, and subsequent personal analyses.

In Figure 4, a view of the system from a position perpendicular to the centerline of the runway, we see that the aircraft passes through a series of triangular shaped patterns in its descent. Figure 5, a view of the system from along the path of the aircraft, shows that the pattern extends across the entire runway. The resultant pattern is as shown in Figure 6, i.e., a series of wedges in space with known apex angles θ and a known distance ΔS apart.

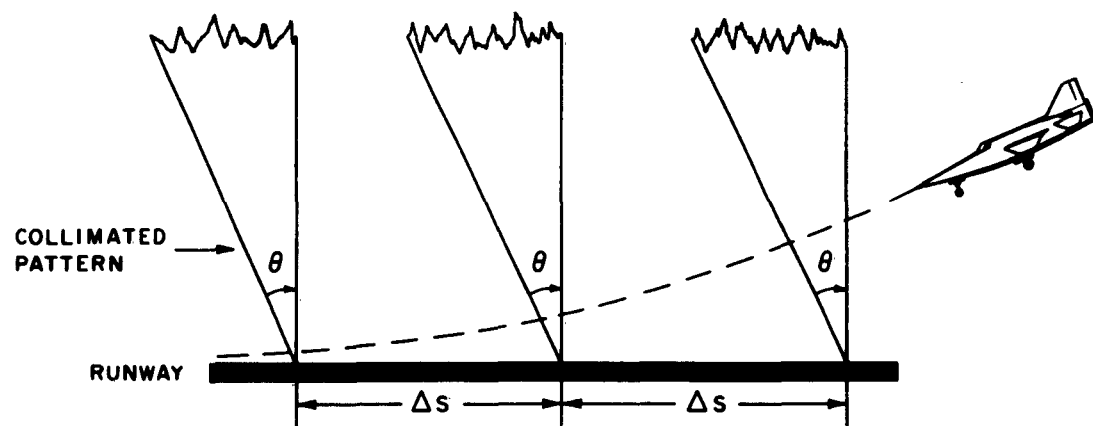


Figure 4. Radiation Pattern Viewed Across Runway

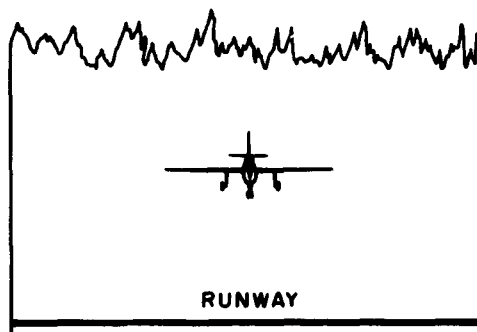


Figure 5. Radiation Pattern Viewed Along Runway

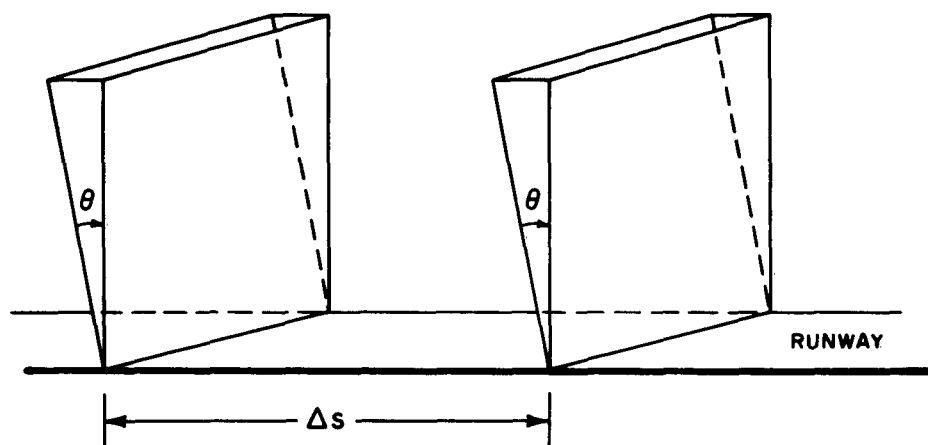


Figure 6. Radiation Wedges

If we can determine his velocity along the ground and also tell whether he is within or without the pattern, it should be possible, because of the geometry existing, to reach conclusions as to the altitude of his aircraft above the runway. Figure 7 shows an aircraft traveling with a velocity V directed at an angle α below the horizontal. The component of V parallel to the runway is the ground speed of the aircraft which equals $V_g = V \cos \alpha = \Delta S / t_0$ where t_0 is the time required to travel between the leading edges of two successive patterns, points A and C. Knowing V_g the distance across the first pattern, W_1 , may be found from $W_1 = V_g \times t_1$, where t_1 is the time required to travel from point A to point B. W_2 may similarly be found. Knowing W_1 and θ , and that β is a right angle, the altitude of the aircraft upon its departure from the first beam, h_1 , may be found from

$h_1 = W_1 / \tan \theta$; h_2 may similarly be found. V_d , the descent speed, may be found from $V_d = \Delta h / t_o$, where $\Delta h = h_1 - h_2$. The glide slope angle, α , may be found from $\alpha = \tan^{-1} V_d / V_g$. The aircraft velocity may be found from $V = V_g / \cos \alpha = V_d / \sin \alpha$. Errors arise because of uncertainties in ΔS , t_o , t_1 and θ . As the required patterns are generated by collimation either of gamma ray or X-ray sources with finite collimators, the errors in θ dominate except for altitudes near the upper limit of the system. Figure 8 shows that four types of photons are present in or near the desired pattern. Photons of type 1 are typical of these being propagated into the pattern defined by the collimator. Photons of type 2 lie outside the desired pattern and have been transmitted through the collimator walls. Because of the high probability of photon interaction in the lead walls of the collimator, the intensity of photons of type 2 as compared with that of type 1 is very small. Photons of type 3 also lie outside the desired pattern as a result of Compton scattering off the surfaces of the collimator; the intensity of these as compared with type 1 is also very small. Photons of type 4 are the ones primarily responsible for errors in θ and also in ΔS , t_o and t_1 . These photons result because the source used must have a finite size.

This effect may be minimized by either reducing the physical dimensions of the source or by increasing the collimator dimensions. Experimental results for a wedge shaped collimator with $\theta = 15^\circ$, sides = 8 in. and a 0.9 Curie source, 0.125 in. in diameter by 0.125 in. in length, are shown in Figure 9. The data was taken with a 1 in. $\times$ 1 in. NaI(Tl) scintillation crystal at the indicated distance from the source for positions across the wedge. For each distance, the rectangular area represents the ideal pattern while the other area bounded by the curve represents fringing.

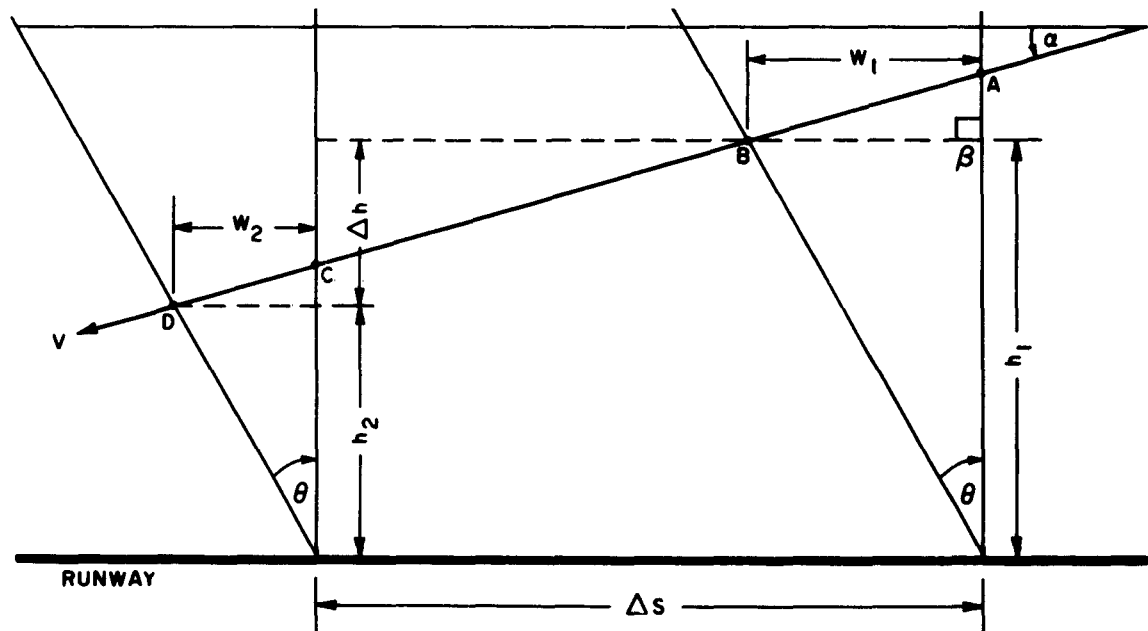


Figure 7. Landing Profile

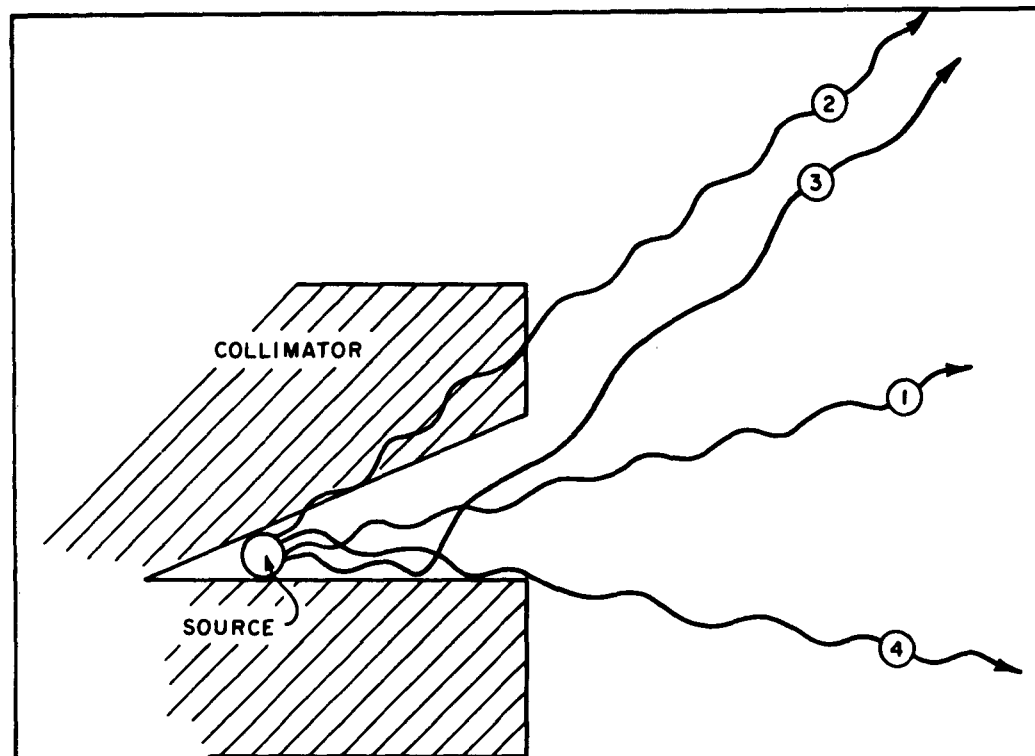


Figure 8. Radiation Pattern Fringing

Because of this fringing of radiation, errors are made in determining the exact locations of the edges of the radiation patterns. Errors are also introduced because (1) the detector has finite dimensions and (2) the time measurement is performed in a pulsed mode. By setting the radiation detector to indicate that it is within the pattern whenever it detects a radiation level greater than half the intensity in the pattern at the highest altitude to be measured, very satisfactory results may be obtained.

For the flight test performed, it was required that 5 photons be detected within 1 millisecond to say that the aircraft was in the pattern. Once it was known that the detector was in the beam, pulses from a crystal oscillator were counted until the detector left the pattern. The accumulated counts could be used with digital logic elements to produce the desired information. Using the raw data generated during the experiment, that is, the measured times in the pattern and ground speeds calculated from photos taken during the experiment, altitudes have been calculated and compared with those measured on the photos of the experiments. The results are shown in Table 1.

The altitudes were calculated by multiplying V_g by the time in the pattern, TIP, to obtain a measured beam width, W_1 . To correct for fringing, both W_1 and θ must be adjusted before calculating the altitude. Even the simple correction of subtracting 1.6 ft from W_1 and using 15.2° instead of 15° for the wedge angle gives good agreement for a wide range of altitudes. The altitude, h , is therefore found from $h = (W_1 - 1.6 \text{ ft}) / \tan 15.2^\circ$. Further experimentation has shown that V_g is always between its correct value and 2 ft/sec greater than this. Using the maximum error of 2 ft/sec, the altitudes from Table 1 have been recalculated yielding the results shown in Table 2.

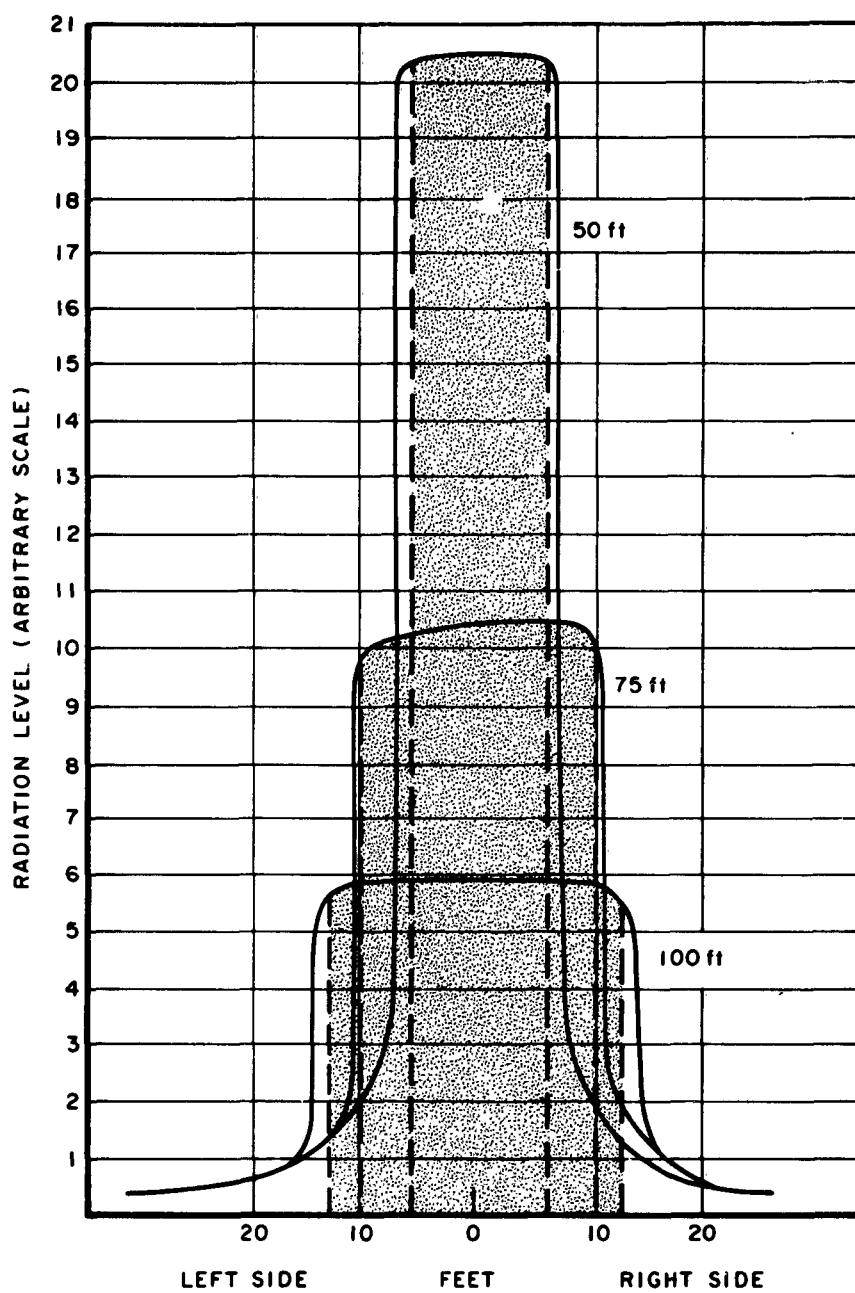


Figure 9. Intensity Cross Radiation Pattern

TABLE 1

ALTITUDE CALCULATED WITH TRUE V_g

Actual Altitude (Feet)	Calculated Altitude (Feet)	Deviation (Feet)
18.7	18.9	+0.2
28.0	27.2	-0.8
36.6	35.3	-1.3
72.8	72.0	-0.8
80.3	80.0	-0.3

TABLE 2

ALTITUDE CALCULATED WITH TRUE $V_g + 2$ ft/sec

Actual Altitude (Feet)	Calculated Altitude (Feet)	Deviation (Feet)
18.7	19.0	+0.3
28.0	28.0	0.0
36.6	35.9	-0.7
72.8	73.5	+0.7
80.3	80.3	0.0

Assuming a 150-foot wide runway, $V_g = 250$ ft/sec, $\alpha = 6^\circ$ and 0.25 curie Co^{60} sources, it has been shown by analysis that a satisfactory landing may be accomplished under all weather and tactical conditions. During this landing, personnel on board the aircraft receive a total radiation dose of less than 9 microroentgens, i.e., 1/2220th of the AEC approved allowable dose for one day.

HIGH ALTITUDE ALTIMETRY

In fiscal year 1963, the application of radiation physics to the opposite end of the altitude spectrum from that of low altitude altimetry application was investigated under Contract AF33(657)-8464 with Giannini Controls Corporation and Contract AF33(657)-8509 with Parametrics, Incorporated. Both contracts were administered by the Flight Control Laboratory. Also two candidates for Master's Degrees, Captains Rupp and Eskridge, from the Air Force Institute of Technology have worked on this problem with Flight Control Laboratory support. Based on both in-house and contractual efforts, the subsequent reports (ASD-TDR-62-880 by Giannini, ASD-TDR-63-283 by Parametrics and "An Investigation of the Use of Radiation from Radioisotopes to Measure Density Altitude" by Captain Rupp), and subsequent personal analyses, there are two basic decisions to be made as to the techniques to be used.

First we must choose among charged particles and photons, then secondly, between measuring the attenuation of direct beam radiation and measuring the radiation scattered from the direct beam. Both beta particles and photons appear promising because of their relatively long range. Measurement of scattered radiation is more attractive because: (1) the scattering concept, with certain restraints, yields an output directly proportional to density, the parameter to be measured, while that of attenuation involves an exponential dependence; (2) the scattering concept allows a measurement of the ambient density to be made whereas using attenuation the vehicle influences cannot be made negligible; and (3) the change in the intensity of the measured radiation per unit change in density is orders of magnitude higher for the scattering concept than for attenuation. For these reasons the emphasis of the investigation has been in the area of measuring scattered radiation, particularly, small angle beta scatter has been investigated because of the relative ease of shielding and the availability of adequately sized altitude chambers for experimentation.

Figure 10 illustrates the basic concept of small angle beta scatter. Beta particles passing through a window in the vehicle skin, traveling to the scattering volume (defined by the collimation of source and detector), experiencing scatter through θ degrees and passing back through a window into the vehicle are counted, their number being nearly proportional to the ambient density. Analysis and experimentation have shown the proportionality to be very good from about 85,000 feet to nearly 300,000 feet for a configuration similar to that of Figure 10.

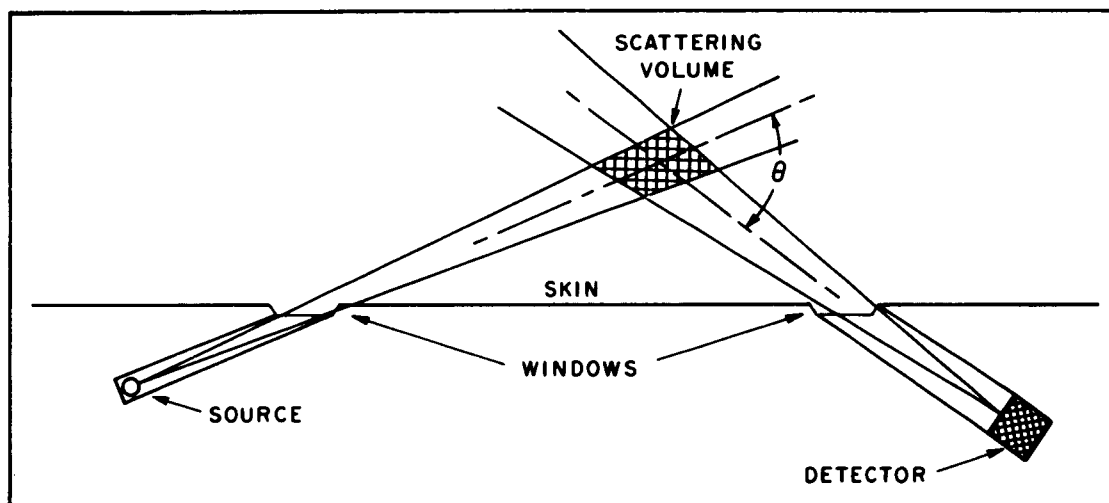


Figure 10. Small Angle Beta Scatter

The departure at lower altitudes from proportionality results from attenuation of the beta beam by the atmosphere both before and after it reaches the scattering volume. For the higher altitudes this effect is insignificant since almost all of the betas reach the scattering volume, however, at the upper end of the range the atmospheric density is so low that the signal from the cosmic ray background is significant as compared with that from the scattered betas.

The use of beta particles presents some other problems which are not wholly appreciated until the operational environment is taken into account. Among these are: (1) Necessity of using two very thin windows in the vehicle skin which is very difficult from a structures viewpoint. (2) Influence of magnetic and electric fields. Since beta particles carry an

electric charge, they will be influenced by ambient fields. The magnitude of this problem has not been fully assessed. (3) Extreme difficulty in measuring the true ambient density because of the low probability for scatter associated with the large θ required to place the scattering volume outside the shock wave.

The use of gamma rays or X-rays, however, overcomes many of these problems. It should be possible to realize a workable system using one or the other. Even photons of low energy have great penetrating power, because of their electromagnetic nature, hence the window problem is considerably reduced in magnitude. Ordinary electric and magnetic fields do not interact with photons. For low energy gamma rays and high energy X-rays, the probability of scattering occurring is nearly as great as it is for energetic betas. Furthermore, the probability of scattering through nearly 180° is very close to that of scattering through small angles. This suggests a concept as shown in Figure 11.

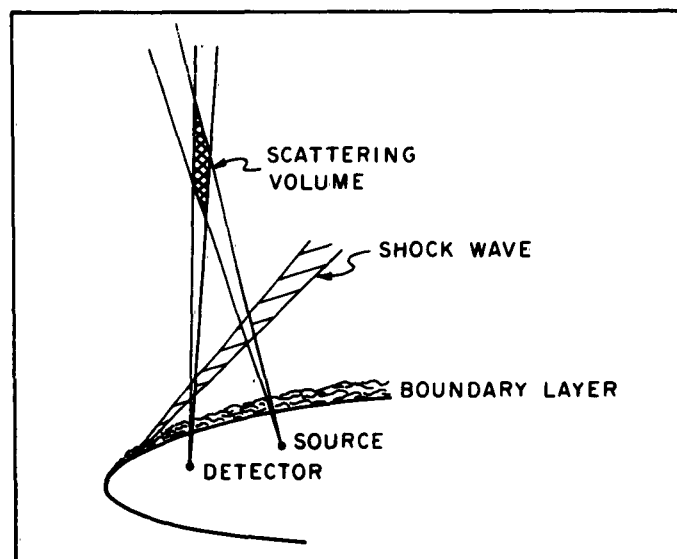


Figure 11. Photon Back Scatter

The scattering volume for this configuration is well beyond the shock wave so that the true ambient density may be measured. The errors from shock wave and boundary layer effects may be kept small by making the length of the scattering volume large as compared with the thickness of these layers. This somewhat lowers the lower altitude limit. The upper altitude limit may be overcome only by information processing techniques. Since gamma photons, and gamma photons scattered through fixed angles have well defined energies, it should be possible to use energy discrimination to separate signal from noise. Also, miniaturized X-ray equipment may be operated in a pulsed mode to facilitate signal discrimination and reduce the shielding requirements imposed by use of photons.

FUEL MASS MEASUREMENT

The problem of accurately determining the fuel mass available in a vehicle's tank has always been difficult. In a zero gravity environment with the problems of two-phase mixtures, fuel breakup, sloshing and cryogenic fluids, the problem is particularly severe.

It is desirable to measure the available fuel mass regardless of whether the fuel is a solid, liquid, or a two-phase mixture, is adhesive or cohesive in nature, restrained or free to slosh, has high or low density or is conductive or insulative. Because of the nature of the interactions of photons with matter, it seems likely that a technique using gamma rays or X-rays might solve this problem.

Three conceptual configurations for a fuel measurement device are shown in Figure 12. Simple analysis using the small angle absorption coefficient, thus neglecting build-up and wall scatter, will prove these designs to be generally unfeasible. However, for the arrangements shown here build-up and wall scatter cannot be neglected, except perhaps in the case of B. In fact, these effects prove to be beneficial. Figure 13 illustrates build-up. Photons of the type 1, which are scattered from the small angle beam, are returned to it as a result of further scatter. Photons of type 2, not originally in the beam, are scattered into it. Photons of type 3, which are scattered from the small angle beam, are still counted because of the large dimensions of the detector.

By properly placing the sources, choosing the photon energies, and taking advantage of geometry effects such as increasing build-up by adding reflective material near the sides of the container, or increasing or decreasing the detector size, it has been shown experimentally that, for configurations similar to that of A (Fig. 12), it is possible to obtain an output from the detector which is unique for a fixed mass regardless of slosh, position or phase considerations. Unfortunately, this technique is not generally applicable since both the detector and the source must cover at least an appreciable portion of the tank and the dimension of the detector must not be small as compared with the largest dimension of the vessel.

If the fuel is restrained, as in a bladder tank, then configuration B (Fig. 12), with the detector located at the center, represents a reasonable solution. Analysis, using the 7094 computer at ASD, shows that for a detector radius about $1/8$ the tank radius, the detector output varies inversely with the thickness of the fluid sphere covering it. The small angle attenuation coefficient represents a reasonably good approximation for this configuration, because of the practical necessity for keeping the detector small. Unfortunately, the sensitivity to small mass changes for this configuration is rather low, because of the small solid angle subtended by the detector.

Configuration C (Fig. 12) represents a system which should give reasonably good sensitivity and further offers the possibility of using build-up in the fuel and external reflectors to optimize the response of the instrument. It has the disadvantages of requiring a very large detector and sources covering a large area. These, however, may be largely overcome by using a liquid or plastic scintillator instead of a crystal, such as NaI(Tl), and taking advantage of electro-depositing techniques. It is almost a certainty that determination of the feasibility of this configuration will have to be by experimental methods rather than through analytical techniques because of the extreme difficulty involved in treating the build-up in a real fuel and scatter from the interior of any but the simplest vessel shapes.

TANK CONFIGURATIONS

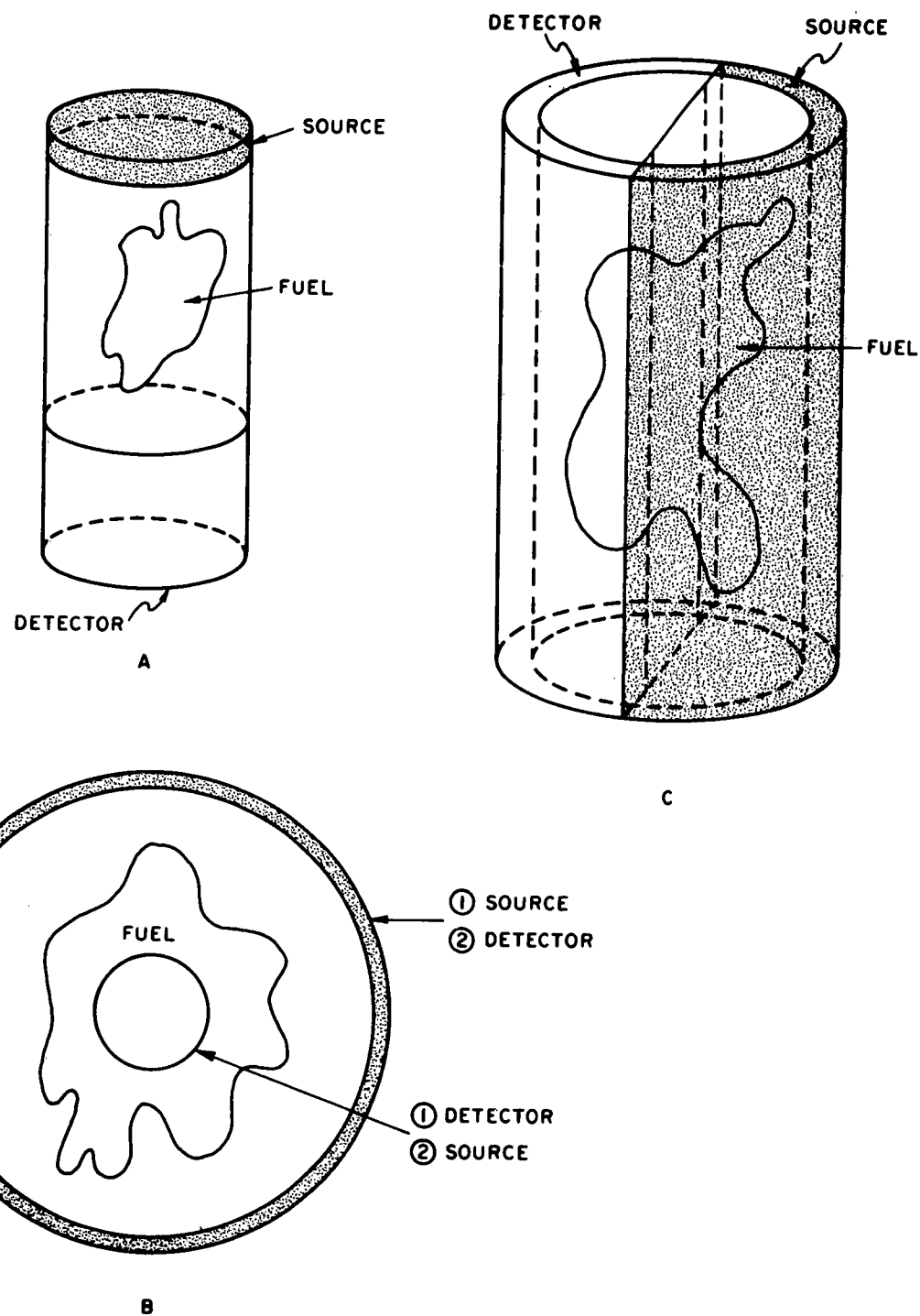


Figure 12. Fuel Mass Measurement

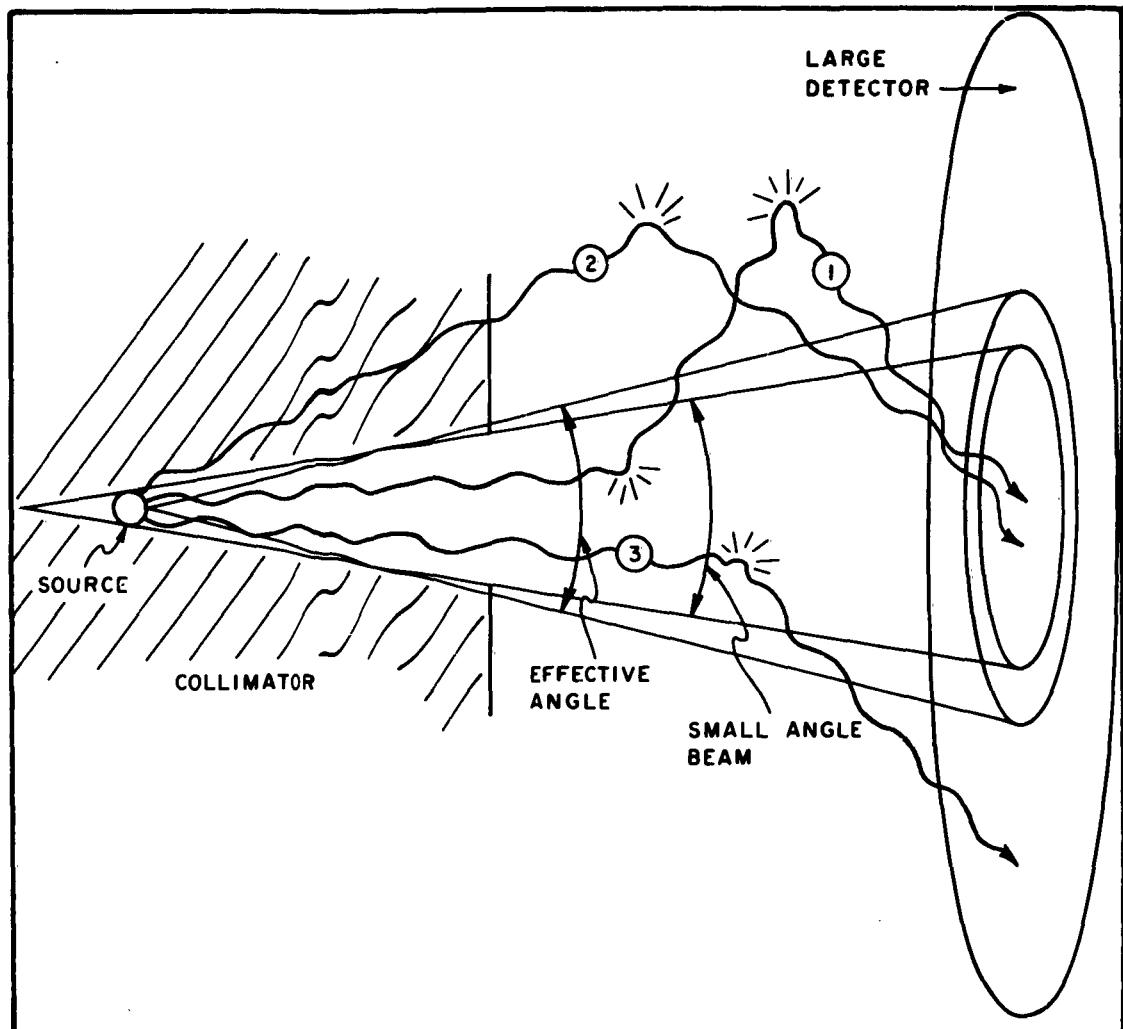


Figure 13. Build-up Gamma Radiation

CONCLUSION

The preceding examples, though limited in scope, serve to point up the potential to be realized through exploitation of radiation physics. All of the examples are in the general area of data sensing as it pertains to flight control, but extensions to other areas are not difficult to envision, especially in light of advantages to be realized in the following areas.

a. Reliability — Radioisotopes have no moving or electronic parts to fail and detectors such as ion chambers and Geiger-Mueller tubes, along with their associated electronics, have long since proved their reliability. Even for sources such as pulsed X-ray units and NaI(Tl) scintillation crystal-phototube assemblies, it is not beyond the state of the art to build reliable long-lived systems. The weakest element in the system is presently the detector, especially as its environment becomes hostile from heat, cold or vibration.

b. Power Consumption — If radioisotopes are employed as the source, then of course no power is required to produce the radiation. Typically the detectors require power only

on the order of a milliwatt for operation. Even the power to operate a miniature X-ray tube, particularly in the pulsed mode, need not be large and certainly not more than a few milliwatts continuous. From the detector, conventional data processing and transmitting equipment may be employed.

c. Output — From most radiation detectors one obtains an inherently digital signal consisting of pulses corresponding to the detection of individual photons. The remainder yield analog signals corresponding to the rate of photon detection. Especially for the digital case, simplifications in data processing may be realized as well as increased reliability and accuracy in data transmission.

To more efficiently exploit the advantages to be gained from using radiation physics, the Flight Control Division has established a coordinated contractual and in-house program. An abandoned propulsion test building is being used to establish an in-house facility which will be manned by a physicist, an electronics engineer and a laboratory technician. The present building configuration is shown in Figure 14.

Renovations to the building include:

- a. Pouring a level concrete floor in one of the former test cells to make it suitable for use as a counting room.
- b. Cutting doors through the foot thick concrete walls to provide internal access to all parts of the facility.
- c. Providing regulated power at strip outlets completely around the radiochemistry, counting and repair rooms.
- d. Providing air-conditioning to maintain an environment with a temperature of 68°F, plus or minus 4°F, and relative humidity less than 50 percent for the precise equipment obtained for the facility.

Major equipment acquisitions include the following: high voltage power supplies; charge sensitive pre-amplifiers; scintillation crystal-photomultiplier tube assemblies; linear amplifiers; count rate meters; electronic scalars; electronic timers; and coincidence circuitry to make up two single-channel pulse height analyzers. We also secured a 400-channel transistorized multichannel pulse height analyzer and its peripheral equipment which includes coincidence circuitry, pre-amplifiers, a computer typewriter, and an X-Y plotter. Several specialized items have been designed and constructed. These include a stainless steel fume hood for radiochemistry work, a 3 ft x 3 ft x 3 ft lead well for controlled scattering experiments and background reductions, two large lead caskets for radioactive material storage, and two experimental tables for controlled geometry coincidence work.

The radiation physics program is being pursued under the following philosophy:

- a. Recognize the requirement for solutions to classes of problems.
- b. Maintain contact with the literature and industry to continually update and expand knowledge of potential techniques.
- c. Analyze, in house, those techniques which seem promising.

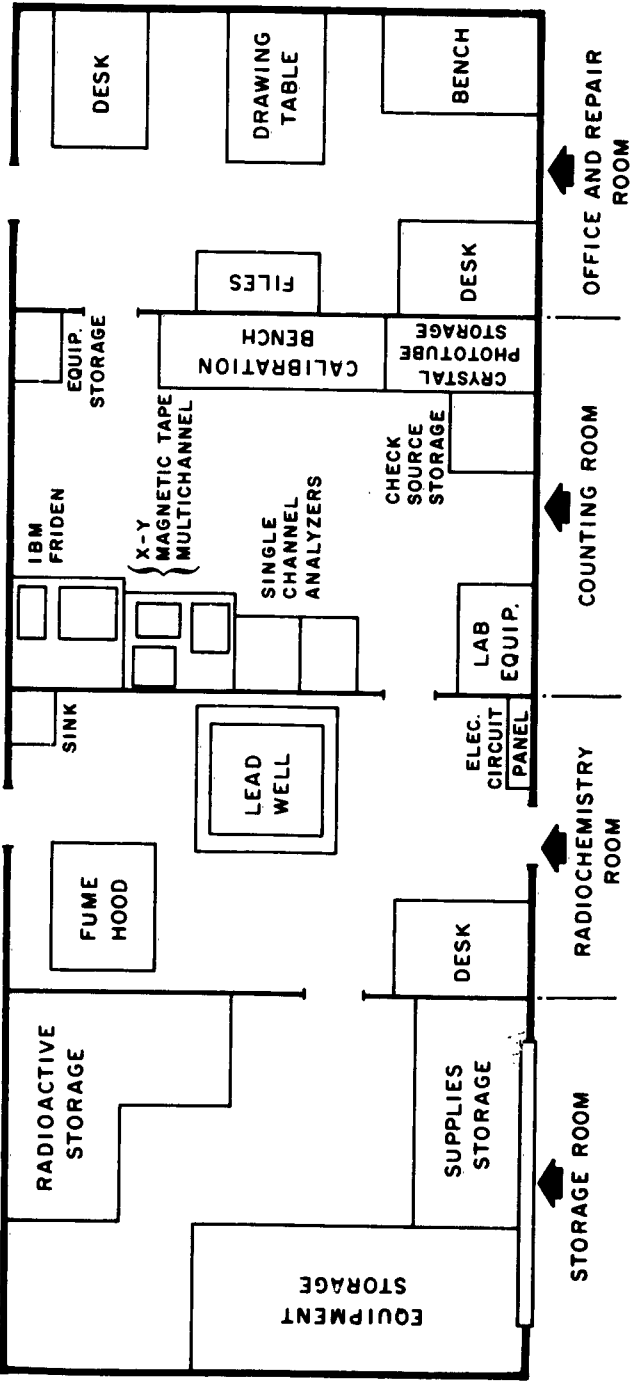


Figure 14. Radioisotope Laboratory

- d. Explore experimentally, in house, techniques which analysis shows to have potential.
- e. Having reduced the problem to pursuing an extremely promising solution to culmination or of clearing up details, use contractor personnel thus freeing both the facility and its personnel for new creative work.
- f. Take advantage of contractor personnel at all stages to solve long, arduous, detailed problems for which a good understanding is possessed by facility personnel, but for which there are insufficient resources available.
- g. Use both the facility and personnel to evaluate both contractor performance and solicited and unsolicited contractor ideas.

Current areas being worked on are VTOL/STOL altitude sensing, tactically oriented low altitude altimeter for conventional aircraft, high altitude altimeter for conventional aircraft, high altitude altimeter for the X-15, Dyna-Soar class of vehicles and fuel gaging. To satisfactorily solve these problems analytical and experimental investigations are proceeding, both in house and contractually, on gamma ray and X-ray collimation and build-up determination in real fuels and geometries. Work will also be initiated to provide an environmentally hardened radiation detector.

The potential to be realized from application of radiation physics to the area of instrumentation is believed to be great. This new area should be fully exploited and its limitations fully understood. It is toward this end that this paper has been written. A new tool exists; discover what it can do, and then use it whenever it provides more or better information.

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