The University of Michigan

FALLOUT SHELTER ANALYSIS COURSE
Lectures and Sample Problems

Edited by

Glenn G. Mastin

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INTRODUCTION

Reproduced herein are the lectures and examples used for the series of eight two-weeks courses in Fallout Shelter Analysis presented at The University of Michigan during the academic year 1961-62 under the sponsorship of the office of Civil Defense, Department of Defense, in cooperation with the Extension Service of The University of Michigan.

The intent of the courses was to give architects and engineers facility in the design and evaluation of protection against gamma radiation from radioactive fallout.

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Subsequent to preparation of the example used for the courses, the method of analysis with respect to mutual shielding was changed.

FIRST WEEK

	1st hr.	2nd hr.	3rd hr.	4th hr.	5th hr.	6th hr.	7th hr.	8th hr.
Mon.	Registration	Introduction to Course	Preliminary Discussion of Effects of Nuclear Weapons and Fallout Radiation		Attenuation of Nuclear Radiation		Structure of Matter and Radioactivity	
Tues.	Review and Problem Solving		Shielding Methodology	Simple Structure Shielding		Biological Effects of Nuclear Radiation	Characteristics of Nuclear Explosions and Nuclear Weapons Effects	
Wed.	Simple Structure Shielding						Shelter Criteria	
Thurs.	Simple Structure Shielding		Shafts and Passageways		Space and Environmental Engineering		Simple Structures Shielding	
Fri.	Compartmentalized Structures							

SECOND WEEK

	1st hr.	2nd hr.	3rd hr.	4th hr.	5th hr.	6th hr.	7th hr.	8th hr.
Mon.	Compartmentalized Structures				Public Utilities	Compartmentalized Structures	Examination	
Tues.	Use of the AE Guide as a Survey Manual				Use of the AE Guide			Introduction to Fallout Shelter Field Problem
Wed.	Fallout Shelter Field Problem				Review of Fallout Shelter Field Problem		Introduction to Master Problem	
Thurs.	Master Problem							
Fri.	Review of Master Problem				Examination		Special Shielding Problems	

PRELIMINARY DISCUSSION OF EFFECTS OF NUCLEAR WEAPONS AND FALLOUT RADIATION

Glenn G. Mastin

The basic purpose of this course is training in the fundamentals of the design and evaluation of protection against fallout radiation. First you need some back ground as to the source of this radiation.

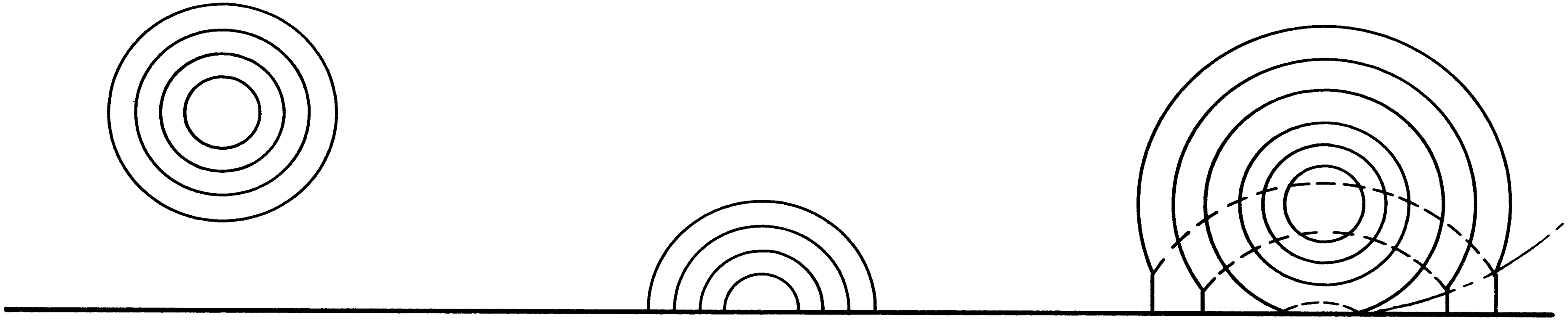
In a thermonuclear explosion there are four effects, the first letters of which form the word BRIT.

Most awesome is the blast into which 50% of the released energy goes, (Figure 1). A fraction of a second after the explosion a high-pressure wave or "blast wave" develops and moves outward from the fireball. The front of the blast wave, called the "shock front," like a moving wall of highly compressed air, travels rapidly. About 50 seconds after a 1 MT burst the blast wave has traveled about 12 miles. Its velocity is then about 1150 ft per second, or slightly faster than the speed of sound.

Striking the ground, the blast wave is reflected back,(Figure 2). At some point, depending on height and yield of burst, the direct and reflected shock fronts fuse. This phenomenon is called the "Mach effect". The "over pressure" at the front of the Mach wave is generally about twice as great as that at the direct shock front.

When the shock front strikes a surface reflection occurs,(Figure 3). This reflection causes a further build up in the over pressure. The actual pressure attained depends on several factors, such as the strength of the wave and angle of incidence.

EFFECT OF TYPE OF BURST ON AIR BLAST



FREE AIR BLAST

- SPHERICAL PROPOGATION
- NO (OR INEFFECTIVE) REFLECTION FROM GROUND

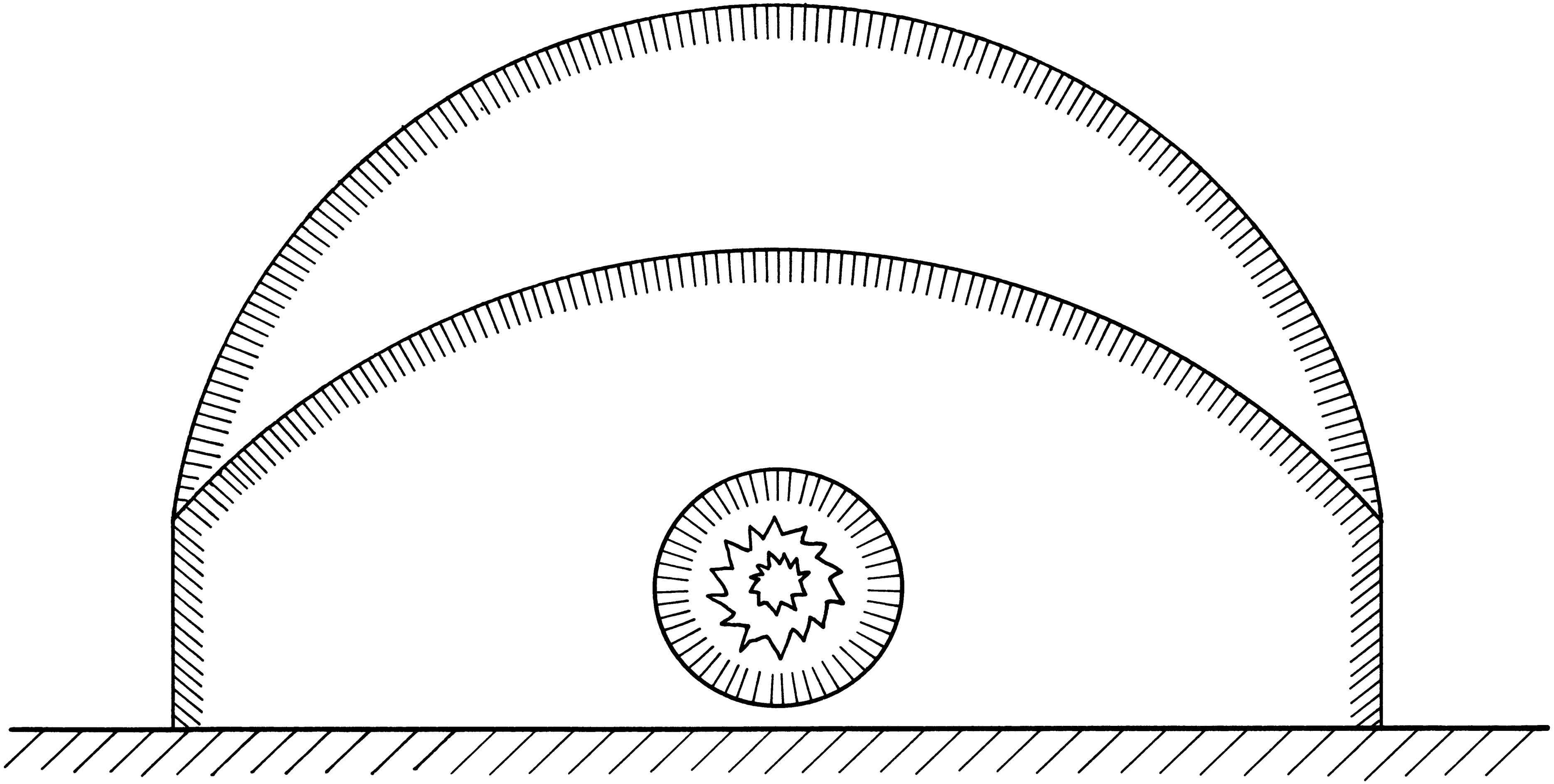
SURFACE BURST

- HEMISPHERICAL PROPOGATION
- BLAST EFFECTS OF A FREE AIR BURST OF TWICE THE YIELD
- ALSO PRODUCES CRATERS AND GROUND SHOCK

AIR BURST

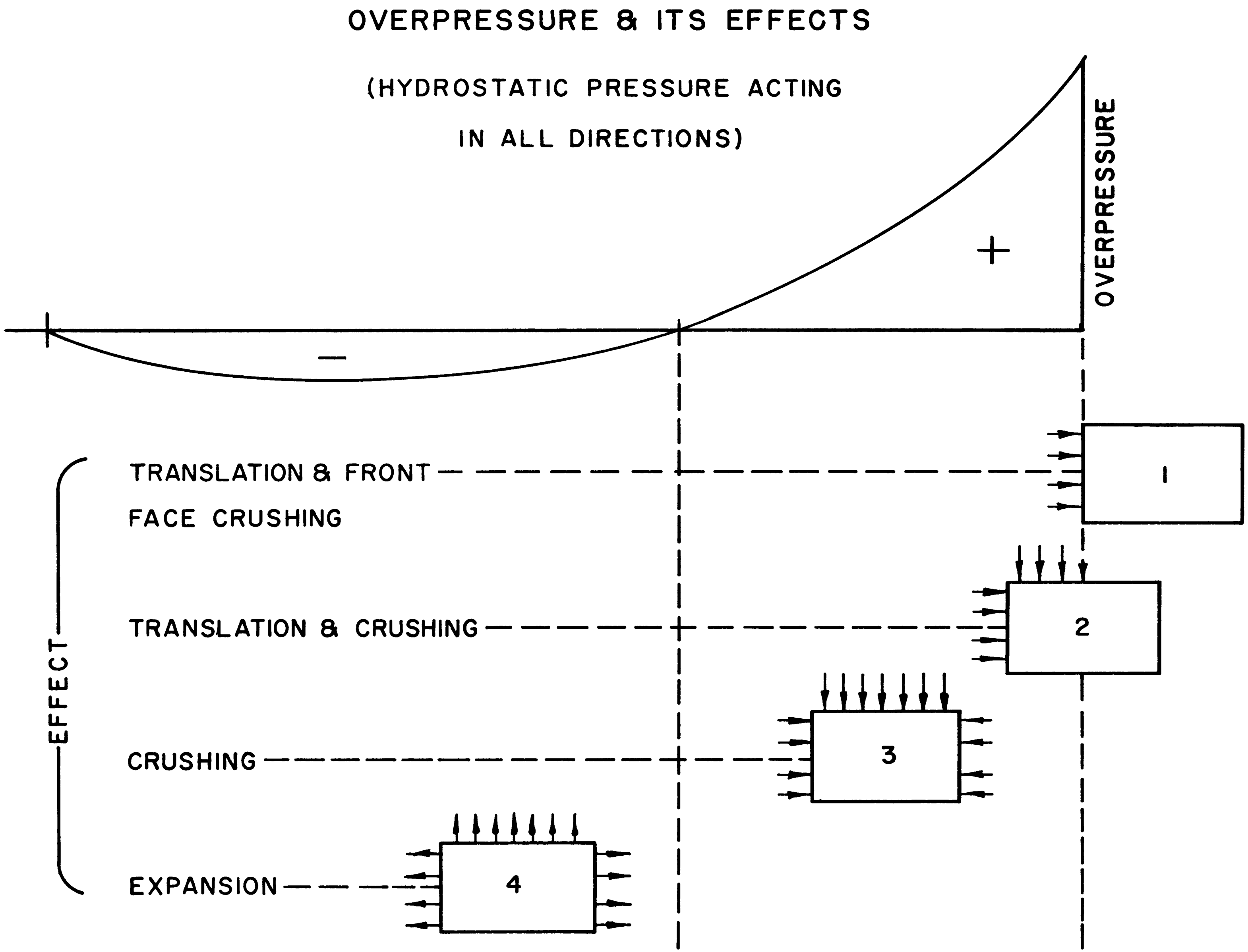
- GROUND REFLECTS AND STRENGTHENS BLAST WAVE
- REFLECTED AND INCIDENT WAVES FUSE FORMING A REINFORCED WAVE CALLED THE MACH. STEM
- HEIGHT OF MACH. STEM INCREASES AS IT MOVES OUTWARD

Figure 1



MACH REFLECTION

Figure 2



OVERPRESSURE & ITS EFFECTS

(HYDROSTATIC PRESSURE ACTING IN ALL DIRECTIONS)

Figure 3

As the shock front moves forward, the over pressure on the face drops rapidly toward that produced without reflection. At the same time the wave "diffracts" around the structure, so that the structure is eventually engulfed with approximately the same pressure on all surfaces.

While the structure is being engulfed by the pressure wave, it is subject to a translational force, due to a pressure differential on front and back faces, known as the "diffraction loading." When the structure has been completely engulfed, it will still be subject to a crushing pressure, unless openings have permitted a rapid built up of pressure inside.

Directly behind the shock front are strong transient winds which cause a dynamic pressure loading or "drag loading" on the structure, Figure 4. Like the diffraction loading it is equivalent to a translational force, but of relatively longer duration. The dynamic pressures at the face of a building are much less than the peak over pressures due to the blast wave and its reflection, Figure 5.

The effect of drag loading constitutes an important difference between nuclear and conventional detonations.

Most spectacular is the thermal radiation moving out from the fireball with the speed of light. 35% of the energy released appears as thermal radiation.

Just as the pressure from the blast drops with distance the intensity of thermal radiation drops. The intensity required to cause fire in different materials or burns of different degrees is known. This intensity increases with increase in weapon yield because the time in which a given quantity of thermal energy is received is greater.

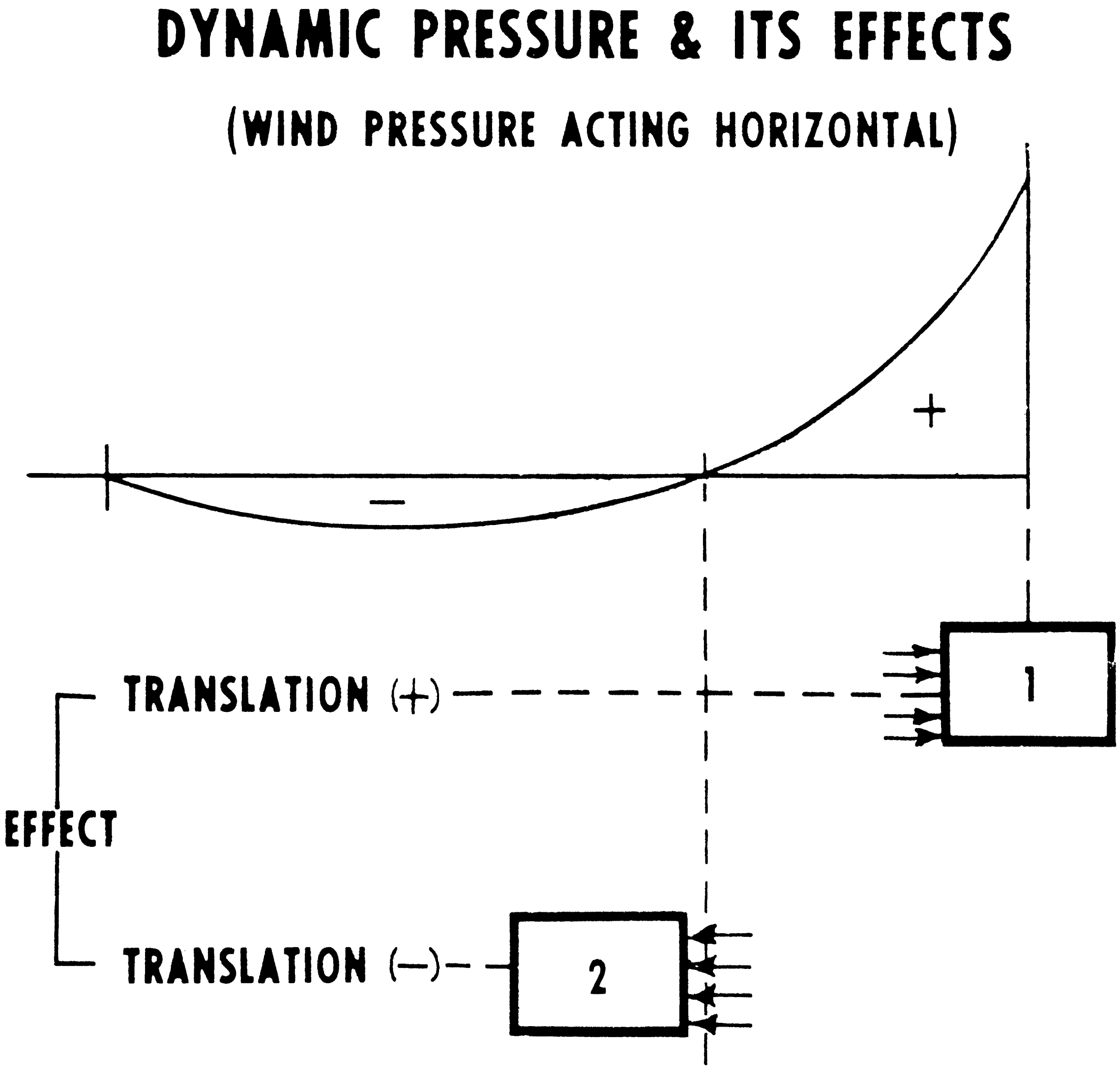

DYNAMIC PRESSURE & ITS EFFECTS
(WIND PRESSURE ACTING HORIZONTAL)
+
—
TRANSLATION (+)
1
EFFECT
TRANSLATION (—)
2

Figure 4.

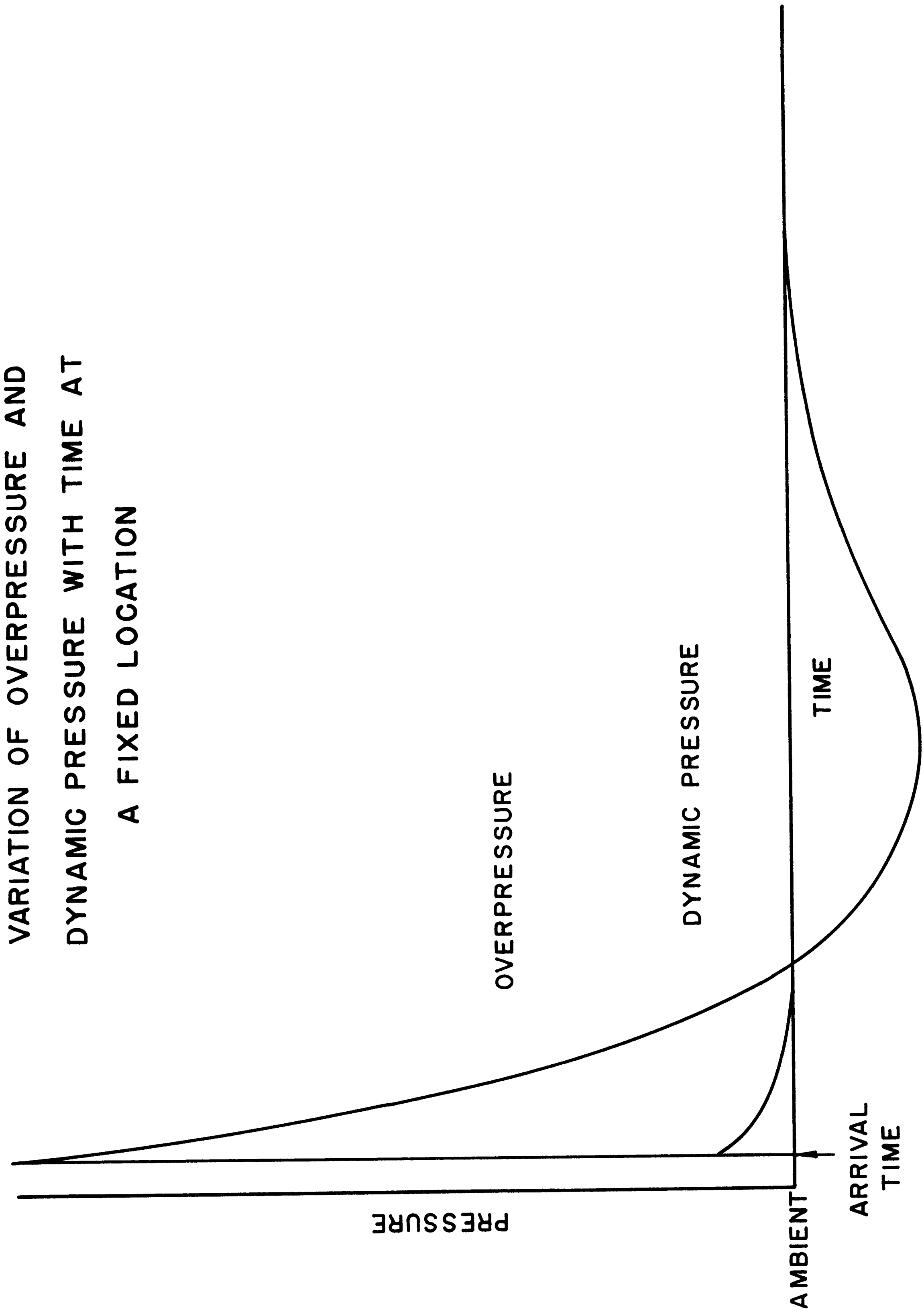

VARIATION OF OVERPRESSURE AND
DYNAMIC PRESSURE WITH TIME AT
A FIXED LOCATION
OVERPRESSURE
DYNAMIC PRESSURE
TIME
PRESSURE
AMBIENT
ARRIVAL
TIME

Figure 5

The remaining energy is released as nuclear radiation. 5% is initial radiation and 10% residual radiation.

Range of Effects of 10 MT Surface Burst.
Moderately Clear Atmosphere.

	Range, mi.	Area, mi.^{2}
Blast (5 psi) Frame buildings destroyed	6	120
Thermal (2nd degree burns) 9 cal/cm^2	15	700
(fires started) 12 cal/cm^2	12	450
Initial Radiation (100 rem)	2 1/2[1]	20
Residual radiation (1000 r.max.biol.dose)	250[2]	6000[2]

[1] Gammas to 3 mi.
[2] Function of scaling wind velocity.

Time and Duration (~ 5 mi.)

	Arrival Time	Duration
Blast (6 psi)	~ 20 sec.	few sec.
Thermal Radiation	0-(3-5 sec.)	~ 1 min.
Initial Radiation	0	~ 1 min.
Residual Radiation	~ 1/2 hr.	months

The initial nuclear radiations consist mainly of gamma rays and neutrons. Both of these can travel great distance through the air and can penetrate considerable thicknesses of material. They can be neither seen nor felt. At a distance of 1 mile from a 1 MT air burst about 1 foot of steel of 4 feet of concrete would be required to give an individual reasonable protection from initial nuclear radiation.

The initial radiation is generally defined as that emitted from the ball of fire and the atomic cloud within the first minute after the explosion. In this time the cloud will have risen to a height greater than the effective range of the gamma rays and neutrons.

The residual radiation, while coming from 10% of the energy release, can be just as deadly, much more widespread, and occur over a much longer period of time than any other lethal nuclear effects. It is that nuclear radiation occurring subsequent to one minute after the detonation.

Residual radiation reaches the earth in the form of fallout which is the process of the falling back to the earth's surface of particles contaminated with radioactive material from the radioactive cloud. Fallout also refers to the particles as deposited on the surface.

There are two types of fallout, Figure 6. Early fallout reaches the ground during the first 34 hours, or so, contaminating large areas with intensity great enough for immediate biological hazard. Delayed fallout consists of very fine invisible particles that settle in low concentrations over the earth's surface in two weeks to two years. This is not an immediate hazard, but has possible long time hazards. Before undertaking a development of protective measures, a thorough understanding of fallout is necessary.

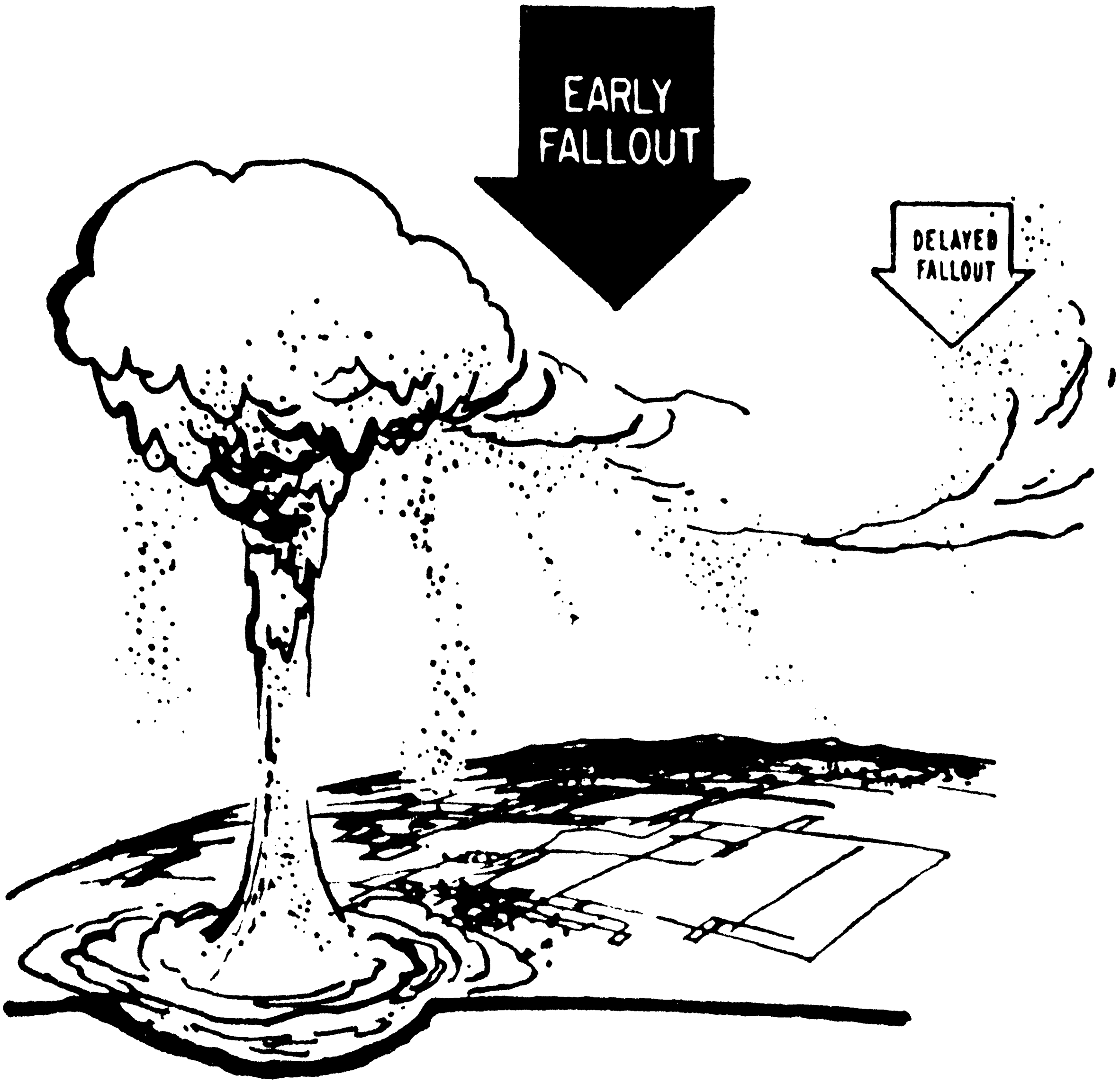


Figure 6. Formation of Fallout.

Factors that influence fallout, Figure 7,

a. Yield

1. One KT of fission energy yield produces about 2 ounces of fission products.
2. Calculations show that if all the fission products of a 1 MT fission yield were spread evenly over a smooth area of 10,000 sq. miles the radiation dose after 24 hours would be 8 roentgens per hour at a level of 3 feet above the ground. This is the height at which the detector is assumed to be located in evaluating protection.
3. With a 1 hour reference dose rate (rate 1 hour after detonation) of 1000 r. there will be about 30 gm per sq. ft of fallout about 1/32 inch thick.

It will be well to define Roentgen (r), a unit of exposure dose of gamma (or X) radiation, at this time. It is defined precisely as the quantity of gamma (or X) radiation such that the associated corpuscular emission per 0.001293 gram of air produces, in air, ions carrying one electrostatic unit quantity of electricity of either sign. It is estimated that 1 r of gamma or X ray would result in the absorption of 87 ergs of energy per gram of air. A flux of 5.5×10^5 gammas of 1 M ev/cm^2/sec. → dose rate of 1 r/hour.

b. Height of burst and fallout

1. Airburst.
    - (a) The radioactive bomb residues condense into very small particles and remain suspended for long periods of time. Radiation does not reach the ground.

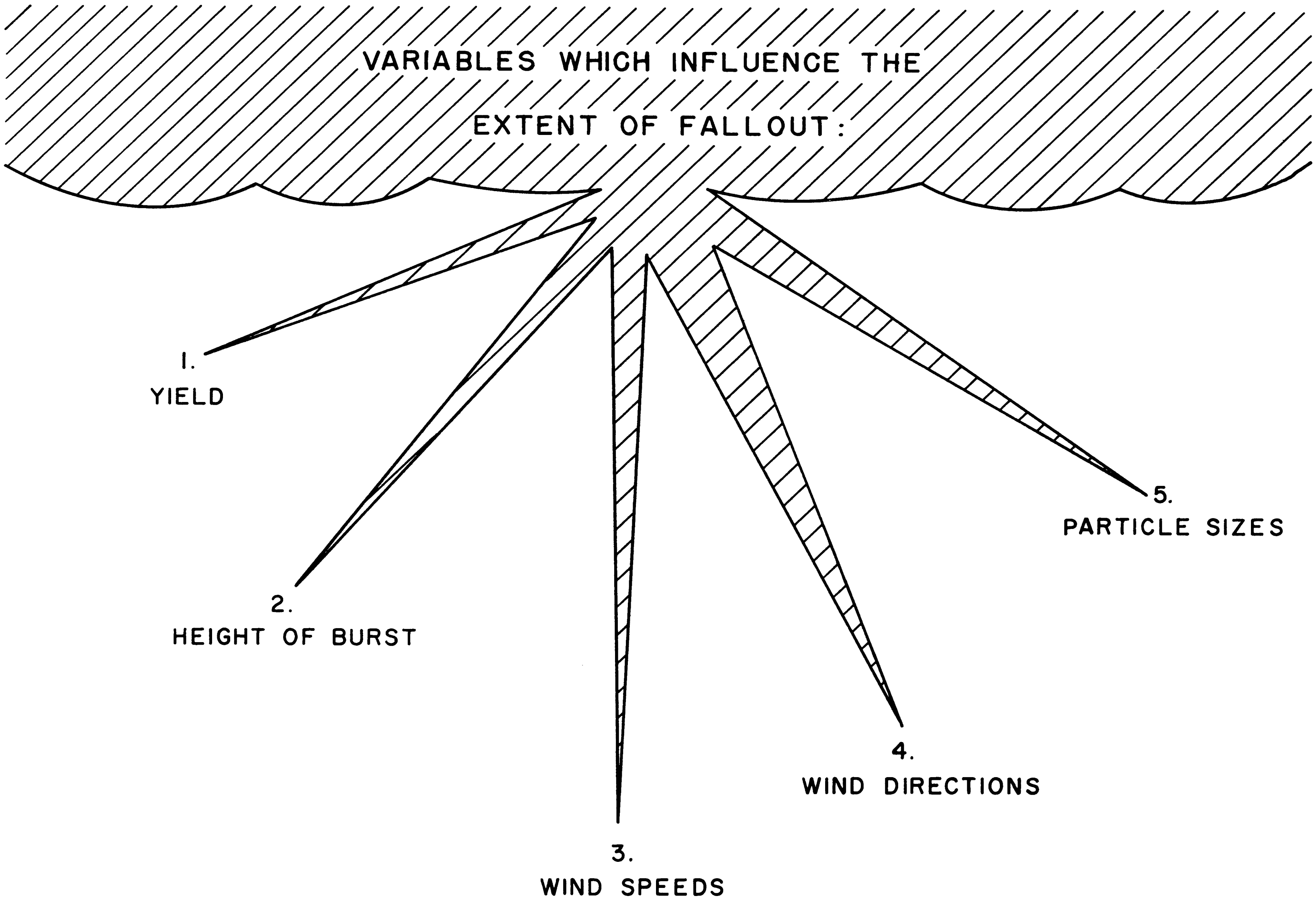

VARIABLES WHICH INFLUENCE THE
EXTENT OF FALLOUT:
1.
YIELD
2.
HEIGHT OF BURST
3.
WIND SPEEDS
4.
WIND DIRECTIONS
5.
PARTICLE SIZES

Figure 7

(b) Delayed fallout - no early.

2. Surface and sub-surface.

(a) Difference in initial and residual more indefinite (some radiation will reach ground at all times) so that categories tend to merge.

(b) Surface - considerable early, some delayed; sub-surface - some early and some delayed.

As the HOB decreases from that which gives no significant early or local fallout, the amount of earth, dust and debris from the earth's surface increases. It is enveloped in the fireball, vaporized by the tremendous heat, and mixed with the bomb residues. On cooling, many small particles form which contain radioactive material or to which radioactive material is attached.

The particles will settle back to earth at varying rates. The coarser ones, approximating medium sand in size, will fall back first and close to ground zero, while fine silt like particles will settle out in 1/2 to 2 days near to or far from ground zero depending upon the wind. Between these extremes will be intermediate sized particles with a generally ununiform distribution. This constitutes early fallout.

Still smaller particles, generally invisible to the naked eye, will take two weeks to two years to fall. This is delayed fallout.

(c) Fallout variables. Proportion of total residual radioactivity present in early and delayed fallout.

1. Land surface - early f/o - 50% to 70%.

2. Shallow underground -some- what higher values for early f/o.

3. Water surface - somewhat lower values for early f/o.
4. Standard conception land surface burst - 60% early, 40% delayed.

(d) Distribution of contamination, Figure 8.

1. Winds - variable in direction and velocity at different altitudes.
2. 110 seconds after 1 megaton detonation radioactive cloud has a diameter of four miles.
3. Range of particle sizes complicate efforts to predict a fallout pattern, Figure 9.
4. Distribution of radioactivity within the mushroom cloud.
5. Because particles of different sizes descend at different rates with different amounts of radioactive contamination, the fallout pattern will depend to a great degree on the size distribution of the particles in the cloud after condensation has occurred. In general, larger particles fall more rapidly and are more radioactive, so that a high proportion of such particles will lead to greater contamination near ground zero, and less at greater distances, than if small particles predominated.

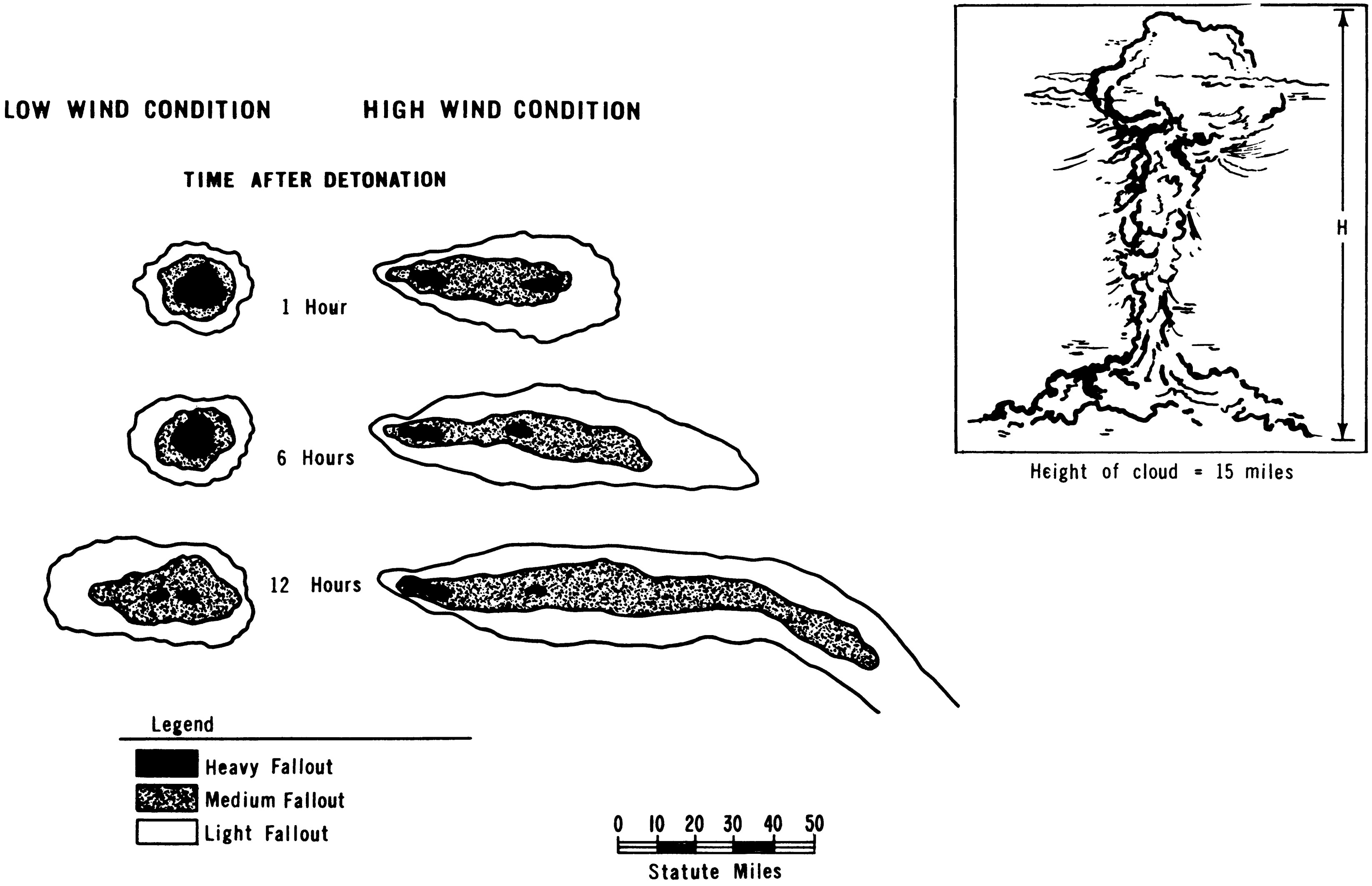


Figure 8
Idealized Regional Distribution of Fallout from Single Nuclear Weapon in Megaton Range

Size	Diameter, microns	Fall velocity,* fpm	Fall time,* hours	Travel distance,* miles
Silt (dust)	50	40	34	Over 300
Very fine sand	100	160	8	120
Fine sand	200	640	2	30
Medium sand	400	2500	½	Under 10

*Approximated by Stokes Law under standard atmospheric conditions and assuming spherical particles, specific gravity 2.65, uni-directional wind 15 mph, initial altitude of particle 80,000 ft. and no turbulence in atmosphere. For sand size particles, the Stokes Law underestimates fall time. For example, the fall time for medium sand might be closer to 1-1/2 hours than 1/2 hour.

Figure 9
Particles of Early Fallout

(e) Theoretical effects of precipitation.

1. Surface burst of low yield weapon. Radioactive cloud may be contained entirely in the rain layer resulting in rapid deposition of very nearly 100% of the fallout within a few hours. This might result in considerably higher initial dose rate over a smaller area than with no precipitation.
2. Air burst of low yield weapon. Heavy rain might result in almost as much early fallout as for a surface burst of the same fission yield.
3. Air burst of high yield weapon. Usually, all the radioactivity would be carried above the rain-bearing layer and there would be little or no early f/o. Thunderstorms higher than 60,000 ft may cause hot spots even many miles from G. Z.

Components of Residual Radiation.

a. Fission products.

(1) 200 isotopes of 35 elements.

(2) Each KT yield produces about 2 oz. of fission products.

(3) Mainly beta and gamma.

(4) Decay of fission product activity.

(a) Complex mixture, fairly standard yield or make-up resulting from fission.

(b) Reference dose rate is DR_1 (r per hour at one hr. after burst), Figure 10. DR_1 vs DR_t .

(c) Total dose = DR dt. Integraded curve for total dose based on DR_1, Figure 11.

(d) Example:

1.5 r/hr 2 hrs after explosion
DR dt in next 12 hrs
$DR_2/DR_1 = 0.43$
$DR_1 = DR_2/0.43 = 1.5/0.43 = 3.5$ r/hr
$DR_{t=2}/DR_1 = 7.0$
$DR_{t=14}/DR_1 = 8.4$

Dose in 12 hrs = $DR_1(8.4 - 7.0) = 1.4 x 3.5 = 4.9$r

b. Unfissioned nuclear material.

(1) Incomplete fission of all nuclear material.

(2) Alpha emitters - not penetrating, but dangerous if ingested.

c. Neutron - activated material.

(1) Bomb casing.

(2) Soil and water.

(a) Oxygen ($t_{1/2}$ = 7 sec.)

(b) Nitrogen forms carbon - 14.

<u>1</u>. Beta particles - no gamma.

(c) Sodium ($t_{1/2}$ = 14.8 hrs.).

(3) Beta and gamma emitters.

(4) Slower decay than fission products, but no significant effect on fission product decay rate if both are present.

DECREASE OF DOSE RATE OF FISSION PRODUCTS WITH TIME

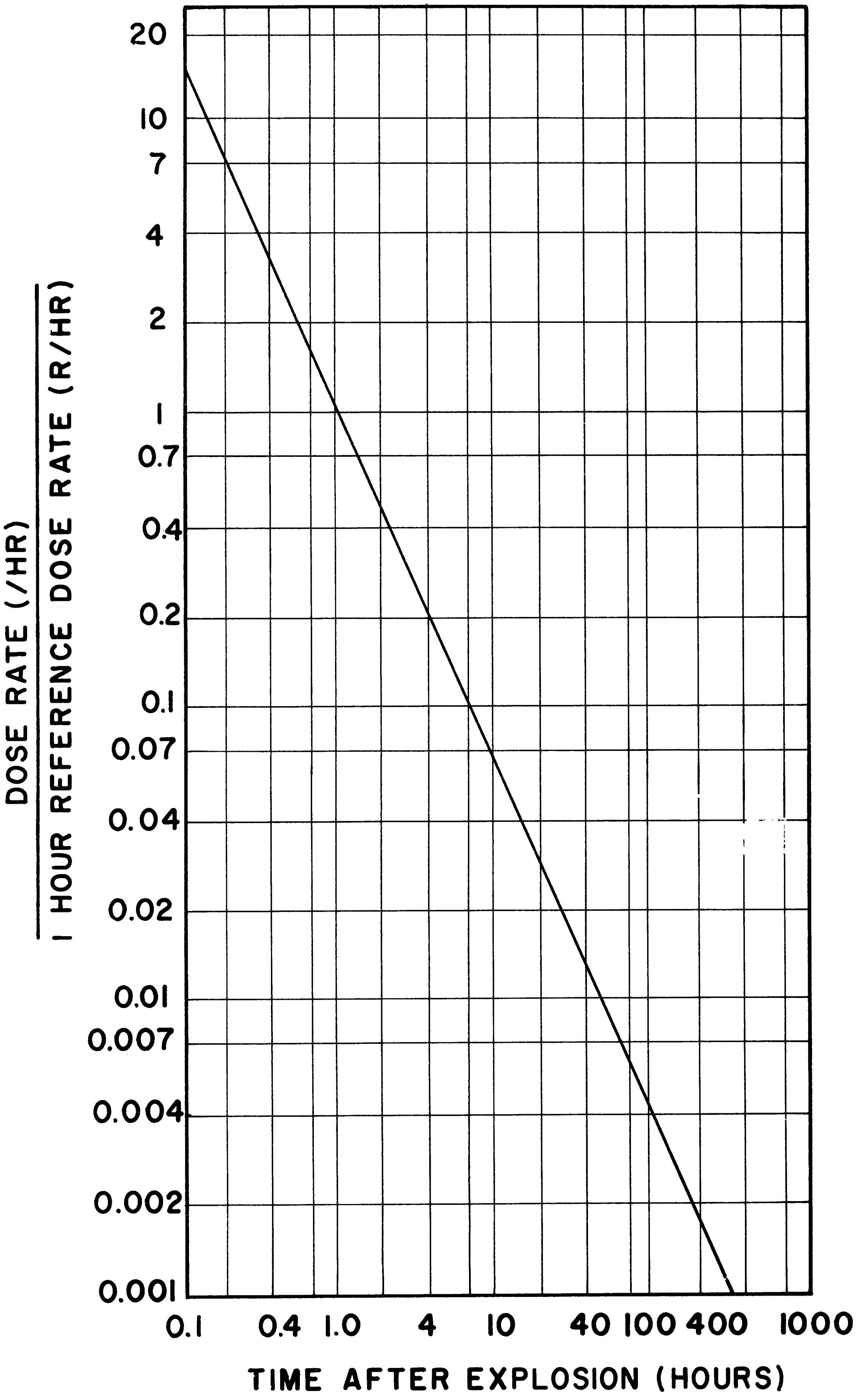


Figure 10

ACCUMULATED TOTAL DOSE
OF RESIDUAL RADIATION
FROM FISSION PRODUCTS
FROM I MINUTE AFTER
THE EXPLOSION

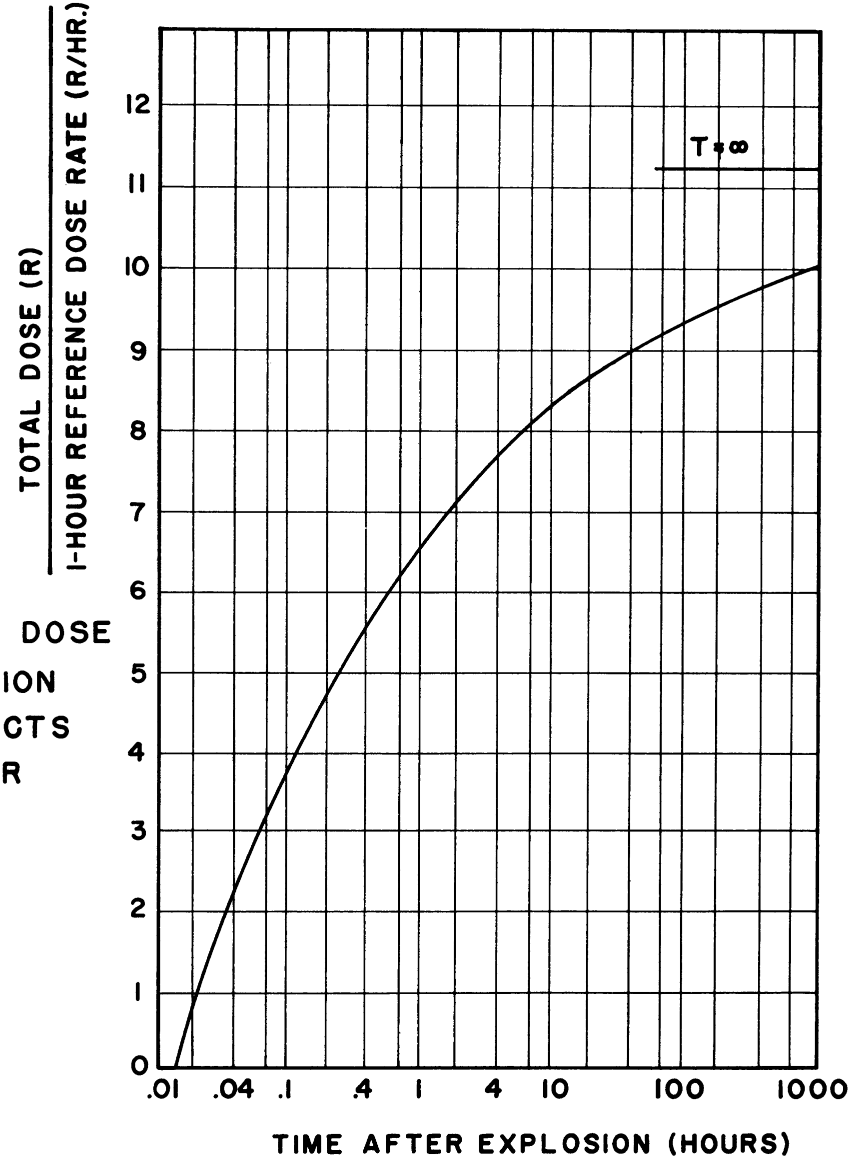


Figure 11

Comparison with intial radiation.

a. No neutrons.

b. Residual radiation an area source, hence, more effective whole body dose given, Figure 12.

c. Irradiation over longer periods.

d. Lower energies. Same amount of shielding gives more protection from residual radiation than from initial.

Personnel hazards from residual radiation.

a. Acute exposure.

b. Chronic exposure.

c. External - gamma penetration and beta burns.

d. Internal - ingestion or inhalation of isotopes.

   (1) Alpha and beta emitters most serious short range, high energy.

   (2) Seek out particular parts of the body e.g., Sr^{90} - bones, I^{131} - thyroid.

Types of residual radiation.

a. Induced radiation (air burst).

b. Fallout radiation.

Induced radiation.

a. Initial neutron flux activates elements in soil to depth of about 1 1/2 ft., depending upon chemical content of soil.

NUCLEAR RADIATION CRITERIA FOR CASUALTIES

TIME FOR NONEFFECTIVENESS	TOTAL DOSE	
	INITIAL (REM)	RESIDUAL (R)
IMMEDIATE	5000	5000
1 HOUR	1000	1000
2 HOURS	750	600
4 HOURS	500	300
24 HOURS	300	150

Figure 12

b. Difficult to decontaminate.

c. Persistent ($T_{1/2} = 15$ hrs).

e. Above ground air burst - induced pattern in area virtually destroyed by blast and fire.

Fallout radiation.

a. Definition - radioactive particles produced by a nuclear detonation that settle to the earth at varying distances from G. Z.

b. Components.

    (1) Fission products.

    (2) Unfissioned nuclear material.

    (3) Neutron - activated material.

c. Pattern and extent of local fallout.

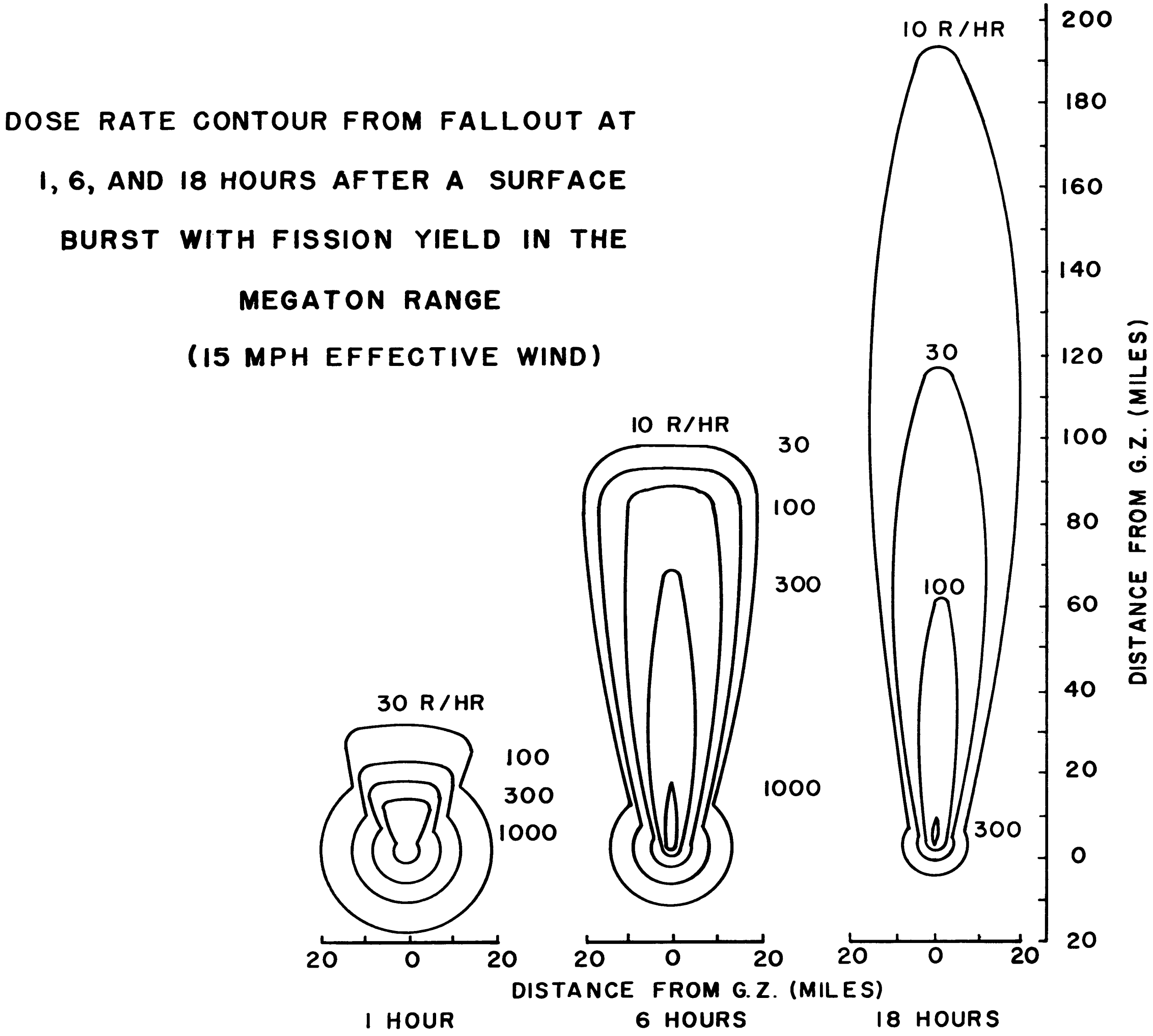
    (1) Dose rate contours 1, 6, 18 hours after surface burst with fission yield in MT range (15 mph effective wind), Figure 13.

    (2) Total dose contours 1,6,18 hours, Figure 14.

    (3) Rules of thumb.

        (a) For each seven-fold increase in time there is a 90% decrease in radioactivity. This approximate rule applies from 0 to 200 days.

        (b) $DR_t = DR_1 t^{-1.2}$ applies from time of detonation to 2 or 3 years.


DOSE RATE CONTOUR FROM FALLOUT AT 1, 6, AND 18 HOURS AFTER A SURFACE BURST WITH FISSION YIELD IN THE MEGATON RANGE

(15 MPH EFFECTIVE WIND)

Figure 13

TOTAL (ACCUMULATED) DOSE CONTOURS
FROM FALLOUT AT 1, 6, AND 18 HOURS
AFTER A SURFACE BURST WITH FISSION
YIELD IN THE MEGATON RANGE
(15 MPH EFFECTIVE WIND)

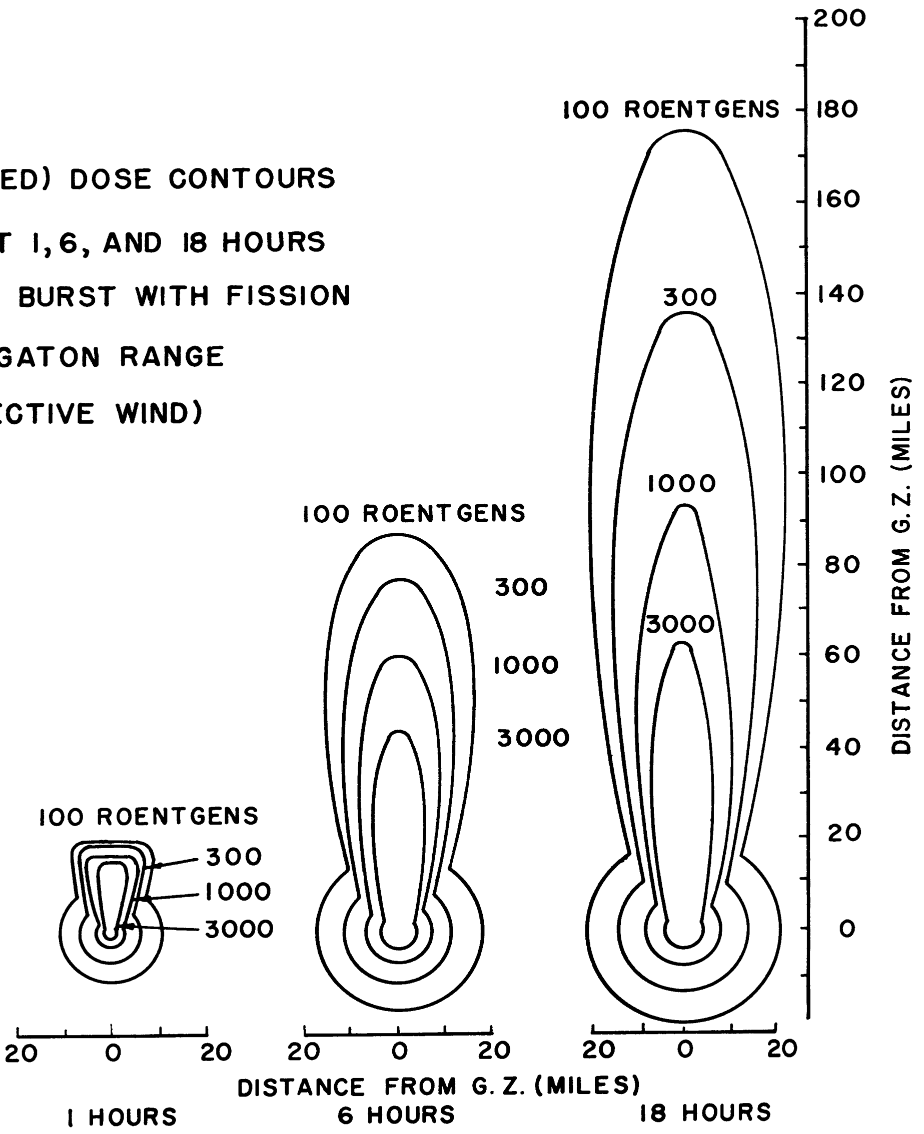


Figure 14

(4) For person in contaminated area starting one hour after detonation, all fallout having arrived, and remaining for a long period of time (months or more) the total dose received equals (numerically) $5 \times DR_1$.

d. Defenses against residual radiation.

(1) Decontamination.

(a) Effective for fallout.

(b) Impractical for induced radiation.

(2) Distance.

(3) Shielding.

ATTENUATION OF NUCLEAR RADIATION

Robert W. Kindig

I. Define Attenuation

Participants now have some knowledge of structure of matter, radioactivity, effects of nuclear weapons, and fallout -- now we will discuss how radioactivity is "attenuated" or reduced in strength.

II. Purpose - to give a qualitative explanation of the theory of radiation attenuation. We will talk about initial and residual radiation, α, β, γ and neutron radiation attenuation and try to give the picture of how these elements apply later in the course when you are using charts and analyzing buildings.

III. Two factors of attenuation:

1. Distance
   - (a) from explosion
   - (b) from emitter (horizontal and vertical)
2. Shielding
   - (a) barrier
   - (b) geometry

IV. Four terms used in these two factors

1. <u>Inverse Square Law</u> - dose received in inversly proportional to the square of the distance.

   γ rays are diverging radially away from their point of origin, and will be spread more thinly the farther out they travel, therefore dose a measured by a detector will decrease with distance r from source in proportion to r^2 because detector can only respond to a fraction $a/4\pi r^2$ of total flux.

See page 349 ENW Chart 8.35a and 8.35b.

This is 1-min exposure for γ ray in initial radiation.

Chart 8.35a checks with the inverse square law.

This is a principle of distance $\frac{\phi_1}{\phi_2} = \frac{(r_2)^2}{(r_1)^2}$

2. Exponential Attenuation

Each gamma photon penetrates through a material until an interaction occurs - but the interactions are by chance. By adding more layers of material the chances of interaction are increased - by how much depends on the density of the material. Successive layers of the same material reduce the number of unscattered photons by the same fraction.

This is a principle of shielding (barrier)

$$I = I_0 e^{-\mu x}$$

μ = linear absorption coefficient
x = distance (th. of material)
I_0 = original intensity

3. Build-Up Factor

Gamma photons continue to scatter as they increase their distance from the source. All "orders of scattering" must be considered to get a more accurate measure of the radiation intensity. Therefore, the exponential factor (accurate for unscattered photons) is modified by a "build-up factor" to account for the scattered γ rays.

Now our intensity (photons/cm^2/sec) formula becomes:

$$I = I_0 B e^{-\mu x}$$

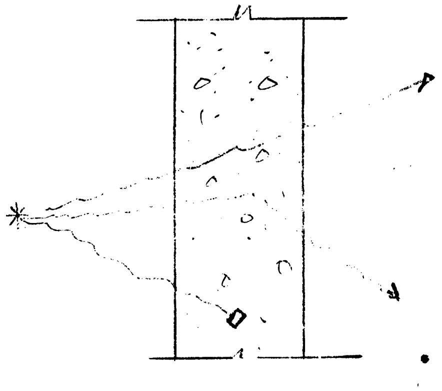
Build-up factors are generally obtained experimentally for they depend on type of radiation, shield material, and geometry.

4. Albedo

Gamma rays can have interactions in a material which reverse their direction, have more interactions and eventually be "back-scattered". This can occur in air as well as in dense materials. In air it is sometimes called "skyshine".

These terms are to give you an over-simplified introduction to the principles of attenuation of principally gamma rays. Later we will discuss neutron radiation. You have learned in the other lectures that the range of alpha (1 1/2" in air) and beta (10' in air) particles is short and is ignored except for ingestation. In residual radiation the β emitters are of low intensity and the lightest of barrier, such as clothing, will protect against them. Most of our attention will be on the attenuation of gamma and neutron radiation.

Barrier Shielding



In photoelectric absorption the photon disappears completely. Part of its energy is used to knock the electron loose, the rest is given to the electron as kinetic energy. In the Compton effect, when a photon hits an electron in the outer orbit it imparts only part of its energy which results in a photon of different energy and an electron.

The idea of shielding is to put enough of the proper material (regard to density) between the person and the radiation to cause enough of these interactions so the exposure dose can be reduced to negligible proportions.

Half value thickness - the effectiveness of a given material in decreasing the radiation intensity is represented by a quantity called "half-value thickness".

Do examples 8:46 and 8:47, pp. 354, 355, ENW.

Note this is for initial gamma radiation.

Half-Thickness Charts for Residual Radiation

Page 403, pg. 9.36, residual radiation, includes gamma, alpha, and beta. Another way to get half value thickness for residual radiation is to divide 300 by density of material; 800 for initial radiation.

In our earlier discussion of exponential attenuation, this shielding ability was expressed by the linear absorption coefficient.

The average energy of γ rays in initial radiation is 4.5 MEV. for making shielding estimates. But basically what you are concerned with is the R and R/hr dose and barrier factors, B_e , B_i , etc. Neutron and γ rays have similar biological effects on human cells which will be explained in detail in later lectures. From the chart you can see that close to ground zero neutron radiation is greater than the gamma but after 2 miles out, for a 1 KT weapon, it becomes negligible. The charts that you will be using in shielding calculations will give you total doses which takes these factors into consideration.

V. Three Methods of Attenuating Neutrons

1. Elastic Scattering

When a neutron collides with a nucleus, some of the kinetic energy transferred is conserved. Light nucleus will gain a lot of energy from a neutron so materials rich in hydrogen (water, cement) are often used as shielding.

2. Inelastic Scattering

The fast neutron is temporarily absorbed by the nucleus, re-emitted at a lower energy. The larger the mass of the nucleus the more inelastic scattering, therefore a heavy material should be mixed with a material of light nucleus to obtain the shielding advantages of both effects. However, inelastic scattering is followed by γ ray emission which must be considered in the problem of what shielding materials to select.

3. Absorption

The probability of fast neutron absorption is very slight - so it will be neglected here. Slow neutron, resulting from interactions, can be absorbed in hydrogen, boron and cadmium.

STRUCTURE OF MATTER AND RADIOACTIVITY

Arthur J. Solari

SOLARI:

I am going to give two talks, one on the structure of matter, and the other on the effects of nuclear weapons. I would like to give a couple of references for those who are interested in doing some further reading on the subject. This is the "Biological and Environmental Effects of Nuclear War," which is a report of the hearing held in June 1959 before the Joint Committee on Atomic Energy. Write your congressman or representative to get a copy.

QUESTION:

Where was this hearing held?

SOLARI:

In Washington, D. C. It was before the Joint Committee on Atomic Energy. There are also some hearings entitled "Civil Defense," which were held in front of the Committee on Government Operations. Unfortunately, I could not get them, because they are out of print. Another general reference with all sorts of information in it is the book called Fallout, edited by John Fowler and printed by Basic Books for $5.50. It has a little bit of everything in it, from peacetime fallout, nuclear war, detecting tests, to everything else imaginable.

Let us start off with the structure of matter. In modern physics there are three fundamentals or basic building blocks from which all matter is created. These three are the neutron, the proton, and the electron. From these three simple building blocks all matter, no matter how simple or how complicated, is created. We can start off with the periodic table and see how nature has built up these atoms. The very simplest atom known is the hydrogen atom, which has one proton in the center and one electron in orbit around the outside.

In this picture of the atom, which is the Bohr theory (Bohr is the name of a Danish physicist who won the Nobel prize for this work), the atom is depicted as a miniature solar system. There are further refinements on his theory, which, unfortunately, tend to completely confuse the issue for the layman so that it is almost impossible to visualize the atom any more with these more sophisticated theories. However, the Bohr theory is adequate for our purposes.

According to the Bohr theory, this (see Figure 1-A, p. 107,[1] Physics Classical and Modern) is ordinary hydrogen. The central section, which in this case is just a proton, is the nucleus, and the electron is a little particle that revolves around it like a planet around the sun. The next most complicated atom is helium which has two protons drawn with a plus sign on them and two neutrons in the nucleus and two electrons running around in the orbit outside. This is helium (Figure 1-B). The next most complicated atom is lithium, which has three electrons in orbit (actually in two orbits) and has three protons and four neutrons in the nucleus. This is lithium (Figure 1-C).

Now the proton has a single positive charge on it; the electron has a single negative charge; and the neutron has no charge. The atom as a whole, you see, is electrically neutral. For each proton in the nucleus there is one electron in orbit. The atom, therefore, is electrically

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[1] Similar figures are reproduced on page 41.

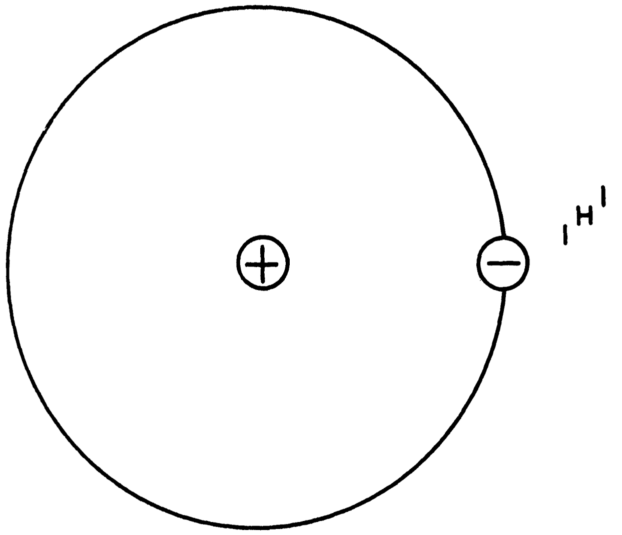


Figure 1-a. Hydrogen.

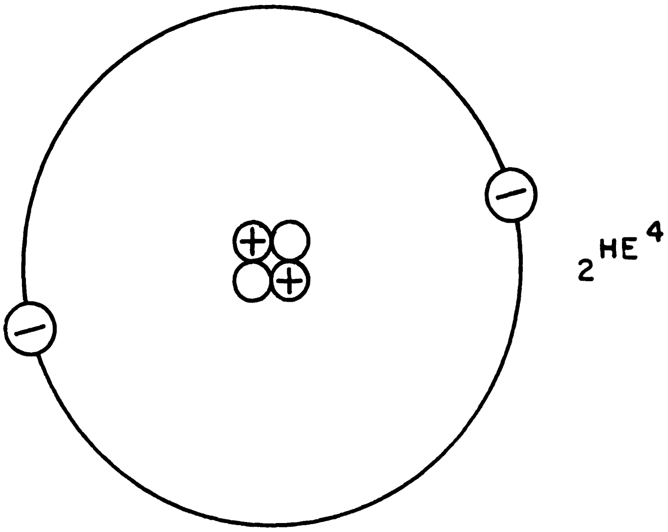


Figure 1-b. Helium

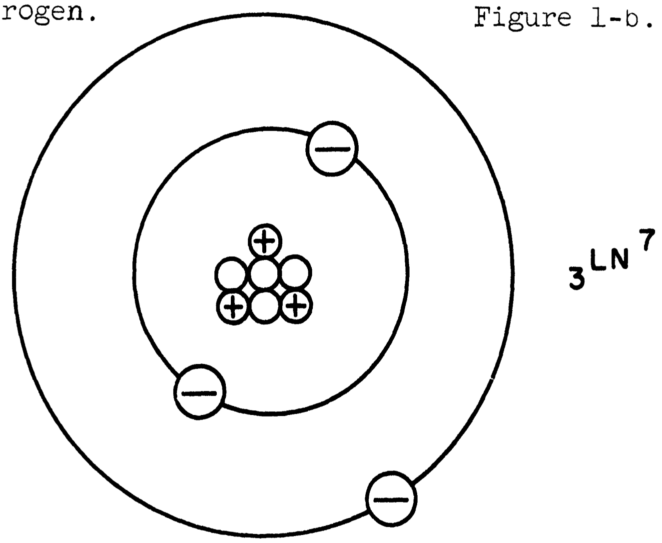


Figure 1-c. Lithium

neutral. The atom is held together by electrostatic charges, i.e., the positive charge in the nucleus tends to pull the electron in towards it, and the centrifugal force of the electron whirling around in orbit tends to make it fly away. The two forces just balance and the electron remains where it is.

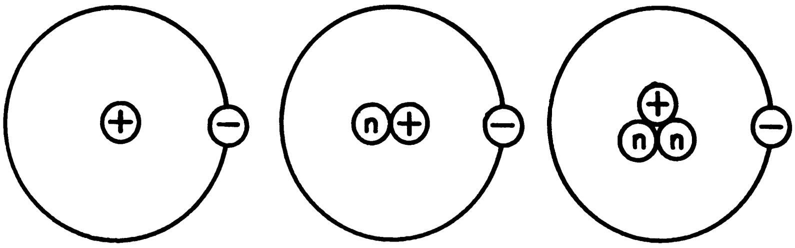
At the moment no one knows how the nucleus sticks together at all, since you have two protons in a very close proximity, practically jammed together in the nucleus. No one quite knows what this nuclear glue is that holds the thing together. The term, "glue," is used figuratively, since ordinary glue is, of course, composed of atoms itself. The radius of the nucleus has a dimension in the order of 10^{-13} centimeters. The radius of the atom as a whole is in the order of 10^{-8} centimeters. That is a ratio of about 10^5 or 100,000. Take an inch for the nucleus radius and, if drawn to scale, the first electron is over a mile and a half away! It is surprising that solid matter like a blackboard, or the brick that you stub your toe against, is, according to this theory, mostly empty space, and your toe is mostly empty space too.

When the physicist measures atomic weight he does it slightly differently from the chemist; and some rather peculiar things have been found by the physicist's measurements. For example, when the physicist measures hydrogen, it turns out that not all hydrogen is built as shown in Figure 1-A. You will find some atoms of hydrogen that have a neutron stuck in the nucleus as well as proton, and you can also find a few atoms of hydrogen that have one proton but they have two neutrons -- one proton and two neutrons in the nucleus. (See p. 24, Fundamentals of Nuclear Warfare.)

Similarly, you can find that some atoms of helium, which have two electrons in orbit, two protons in the nucleus, but only one neutron. Now, most of the mass of an atom is in the nucleus. The neutron or proton weighs roughly the same -- 2000 times as much as a single electron. So almost all the weight is in the nucleus. So this one weighs roughly twice as much as this (demonstration on blackboard). This weighs three times as much as the ordinary hydrogen atom.

When these differing atoms were found, there was a question whether to re-define what was meant by a chemical element or whether to keep it as it was, defining elements in terms of their chemical behavior. The old definition was kept and these are all considered hydrogen -- or all the same element. They are called isotopes of hydrogen. When the chemist talks about hydrogen, he means a mixture of these three different isotopes of hydrogen in the relative abundance in which they exist in nature. The word "isotope" comes from the Greek words meaning the same place, that is, all these three different types of atoms belong in the same place in the chemical periodical table.

If you want to refer to a specific isotope of hydrogen, then the letter "H" or the word "hydrogen" is not enough. You need something additional to tell your audience which one of the three isotopes you are talking about. What is used is a number which is placed in the upper righthand corner of the chemical symbol. This number refers to the total number of particles in the nucleus. So this is hydrogen and written as H^1. This one would be called hydrogen-2, written "H," superscript 2(H^2); and this one would be called hydrogen-3 (Figure 2).



NUMBER OF PROTONS	1	1	1
ELEMENT	HYDROGEN	HYDROGEN	HYDROGEN
ELEMENT SYMBOL	H	H	H
NUMBER OF NEUTRONS	0	1	2
NUMBER OF NUCLEONS	1	2	3
COMPLETE SYMBOL	${}_1H^1$	${}_1H^2$	${}_1H^3$

Figure 2. The Isotopes of Hydrogen.

This is where the number comes from -- as in strontium-90, a specific isotope of strontium that has 90 neutrons and protons in it. Iodine-131, with 131 neutrons and protons, and phosphorus-23, etc. This is normally the only way you can describe a specific isotope. There are a few elements (and hydrogen is one) which are used often enough that names have been given to the isotopes. Hydrogen-2 is often called "deuterium" and hydrogen-3 is called "tritium."

QUESTION:

Pardon me, is hydrogen-1 an isotope?

ANSWER:

Well, they are all isotopes. Hydrogen-1 is the most common isotope of hydrogen. Hydrogen-2 is the isotope of hydrogen that was used to make heavy water. Hydrogen-3 comes in handy if you are building hydrogen bombs. All the atomic species, i.e., all the isotopes of all the elements, are referred to under the general term of "nuclides."

Some years back it was discovered that certain atoms were radioactive, i.e., they gave off radiation spontaneously. This was discovered by Henri Becquerel, the French scientist, in 1896, mostly by a fortuitous accident. Roentgen had discovered x-rays and scientists knew that certain things would fluoresce in the dark when they were struck by x-rays. Because this mysterious x-ray radiation, whatever it was, produced fluorescence, Becquerel was trying to reverse the process and see if fluorescence would produce x-rays. He was using uranium salts which fluoresce when exposed to sunlight.

Becqueral's experiment was as follows. He would wrap a photographic plate in a light-tight paper; put uranium salts on it, and expose it to the sunlight. X-rays had the ability to penetrate paper, so if they were produced during the experiment the film would be darkened. He did it this way and when he opened up the paper, the film was dark. (Apparently, the experiment was a success.) He repeated the experiment a few times until one day there was no sun shining in Paris. He had this little package of film made up to be exposed to the sunlight, so he placed it in a desk drawer. The sun did not shine for two or three days. When the sun finally came out he decided, for reasons which are not known, to try developing the film without exposing it to the sun, even though it would not supposedly show anything on it according to his theory. Lo and behold, it was blacker than it had ever been before, even though the uranium crystals had never been in the light. He quickly found out, after some bewilderment and some more experiments, that the sunlight had absolutely nothing to do with it. The uranium itself spontaneously emitted radiation which had the ability to penetrate paper and make a film dark. This was the discovery of radioactivity. We know now that this radiation comes from the nuclei of the atoms of the material; hence, the term "nuclear radiation."

Further experiments by Becquerel and others showed that the emissions of the radiation by certain substances (called radioactivity substances) was completely unaffected in any way by anything that could be done in the laboratory. The radiation was unaffected by heat, light, pressure, vacuum, chemicals, chemical form of the substance or anything they could dream up at that time. This made the new discovery quite exciting and puzzling.

At first it was believed that the rays from radioactive material were all the same kind and similar to x-rays. Madame Curie performed an early experiment and identified three different kinds of radiation. She did it as follows. A sample of radium (which she had discovered) was placed at the bottom of a lead container with a hole in the top. It was a simple block of lead with a hole drilled into it. (See p. 28, Figure 6, Fundamentals of Nuclear Warfare.)

The radiation came flying out in a narrow beam. She put an electric field across the path and it turned out that some of the radiation bent in this direction and some bent in this other direction, and some went straight up, unaffected by the electric field. Now, these were labeled alpha, beta, and gamma. The reason for this order of marking, I believe, is because they did not find the gamma rays for a while.

What are these three different types of radiation that were discovered way back then? The alpha rays turned out to be a particle. It was a particle that consisted of a combination of two neutrons and two protons stuck together. This was emitted spontaneously by the radium. You will notice if you will look back in your notes that this alpha ray or particle is the same as the nucleus of the helium atom. Put a couple of electrons around it and you have the ordinary garden-variety helium atom. Put a couple of electrons around it and you have, in fact, one of the ways used to identify the alpha particle as the helium nucleus. In one experiment the alpha rays were trapped in a sealed container. After a period of time it was possible to measure a build-up of helium atoms. This confirmed the hypothesis that an alpha particle was the same entity as a helium nucleus. Now, this is the alpha particle. It travels essentially in a straight line and is not very penetrating. You can stop it with a couple of sheets of newspaper or even one sheet of newspaper. It is able to travel in the order of 5 or 6 centimeter in air.

The beta particle was identified as an electron, and we shall have a little more to say about this in a minute. The beta ray travels in the order of a few meters in the air. It is rather light, so it tends to get scattered around, taking a rather tortuous route as it travels several meters in the air away from the point of origin. You can stop beta rays easily. In fact, either one of these books should be able to stop them. They are not very penetrating, but they are penetrating enough to cause skin burns.

The gamma ray turned out to be electromagnetic energy or electromagnetic radiation. A fancy term which denotes a whole category of radiation, including radiowaves, infra-red, ultra-violet, visible light, x-rays, and a few others tossed in for good measure. These are all electromagnetic radiation. The gammar ray is very similar to an x-ray, but usually has even more penetrating power. It will travel quite a distance in the air (almost indefinitely) and will go through wood and lead, steel, and things of this nature.

If you take your copy of Physics, Classical and Modern and turn to page 122, you will see some examples given on that page of various types of emission. The first one that is mentioned is the alpha emission in general terms, as zX^A and so forth; then as an example uranium-235 going spontaneously into 2-helium-4 plus 90-thorium-231. The question was asked, "Where does the 90 come from?" Well, take uranium-235. This has a total of 235 neutrons and protons in the nucleus. The number in the lower left-hand corner, 92, refers to the number of protons in the nucleus. By subtracting 92 from 235 you can find the number of neutrons in the nucleus. Uranium spontaneously kicks out two neutrons and two protons as an alpha particle from the nucleus. This is what is listed in there as helium-4 -- the 2 helium-4 -- the "4" referring to the four particles, subscript 2 for the two protons. Well, you started out with 235 particles. Four of them left the nucleus as an alpha particle, so you end up with 231 particles in the nucleus. But two of the protons left. They took off as part of the alpha particle, so only 90 protons remain. The element with a charge of 90 in the nucleus is thorium. Thus, uranium spontaneously changes into the thorium by the emission of an alpha particle. And there is no way to stop it. There is no way to make it go faster. It just spontaneously changes into thorium at its own sweet rate. It is this uranium-235 which is used to make bombs. If we wait long enough, it will all become thorium and no one will be able to build any more.

QUESTION:

Does uranium just emit alpha -- just an alpha emission?

ANSWER:

Yes. However, it turns out that the thorium's also radioactive and this emits something, and there is a whole series that we can get into; but that is the next page. Let us just stick to this one.

The next example is a beta emission. The first equation is given in general terms to show how the equation is written. The second one is the example of lead-209 giving off a beta particle and becoming bismuth-209. Notice that the beta particle has a mass of essentially zero in the upper right-hand corner, and an electrical charge of minus 1. You will notice in this equation also, the mass number (the upper right-hand corner) adds up on both sides of the equation to the same number for both sides. And so do the electric charges at the bottom.

Now, beta emission caused a great deal of confusion because the beta particle came from the nucleus. We said that the beta particle was an electron, and this beta particle is coming from the nucleus. If you have not fallen asleep along the way, you will remember that there is no electron in the nucleus. How can this beta particle be coming from the nucleus? This can create, as you can well imagine, a good deal of confusion. At first there was an attempt to sort of sneak the electron into the nucleus by saying, "Well, maybe the neutron is really a proton and an electron stuck together. This is why it has no charge " But this created more problems than it solved. This interpretation of the neutron is sometimes found in the older high-school physics texts.

The answer to the dilemma is that the neutron spontaneously changes within the nucleus into a proton and an electron. This electron gets kicked out at the instant of its birth, and this is what we see as a beta particle. Now, if we skip the next two equations and go down to the bottom, you will see an equation for positron emission, and then the example, P-28 emitting a positron and turning into silicon-28. You will notice that if you look at this beta particle, as it is written here, and compare it to the one at the top, that this one has apparently got the wrong sign. This one has a positive charge, so this is an electron with a positive charge.

What happens in this one? Somehow a proton changes into a neutron plus a positive electron which gets booted out and this is what we see as a positron. Now, you have one reason why you cannot say a neutron is a combination of a proton and an electron: because now you would have to say a proton is really a neutron plus a positron, and so on *ad infinitum*. In some way, the neutron and the proton are more or less the same beast, as they seem to be able to change sex, so to speak, *ad lib* from one to another. They are perhaps two manifestations of the same thing. The discovery of the positively charged electron was done by Anderson in California and a Nobel prize was won for it.

I can digress for a minute, I assume. The positron was discovered in a cloud chamber photograph. The cloud chamber is a standard tool of the physicist. With it you get a supersaturated atmosphere of moisture. When charged particles pass through they ionize the air, and droplets form along the path -- the equivalent of a vapor trail. You have all seen vapor trails of jets. Even if the jet is far too high for us to see, we can see the vapor trail. The alpha and beta rays are too small to see, but they leave a visible vapor trail in the cloud chamber. Anderson had a cloud chamber up on the roof taking pictures, and he had a magnetic field on it. Now, the only way to get the power to run this magnet was from the aeronautical engineers in the basement. These engineers used to plug jacks into the walls at night and energize the magnet upstairs. (If this story is not true, it should be true, because it is so good.) An electron would bend in the magnetic field. One night there was just one photograph made. This was a picture of what appeared to be the track of an electron, but it bent in the wrong direction. This meant that either it had a positive charge, which would be a great discovery, or the engineers in the basement had switched the jacks, thus reversing the polarity.

The engineers were questioned and they swore up and down they had plugged the jacks in right. But they were not a breed to be trusted. They were always playing practical jokes. There was a statue of Appollo out in the hall, and their favorite stunt was to decorate various parts of his anatomy with lipstick. So you see that dependence on the engineers not pulling a joke was like leaning on a rubber crutch.

Anyhow, Anderson rigged it up so that no matter how they plugged the magnets in he would know what the scoop was. And sure enough, the next day or two later, he found the track of a positive electron. This is the photograph that he actually published in his historical article. After that, everybody began looking at their cloud chambers pictures and lo and behold, everybody had pictures of positrons that he had been mistaking for scratches in the film or other artifacts. This is the story of the positron and how it was discovered.

Now, let us return to the text. Look at the neutron emission and the example of krypton-87 giving off a neutron and turning into krypton-86. I will get to the asterisk in a minute. In moving up the page, we get gamma emission with the example for zirconium-95 giving off a gamma ray which has neither charge nor mass, so it is 0 - 0, and you end up with zirconium-95. Notice that the gamma ray has energy, so it looks as if you get something from nothing when you start off with zirconium-95 and end up with a gamma ray plus zirconium-95 (but do not believe that you get anything from nothing).

This is the reason for the asterisk. To the physicist this asterisk indicates that the original nucleus was in an excited state. He calls it an excited state, which simply means that it has a surplus of energy. It gets rid of this energy by emitting a gamma ray and the gamma carries off the energy.

Now, if you turn to page 124 (Physics, Classical and Modern) you can see a more complicated series decay. You start off with neptunium-237 and this gives off an alpha particle. And, incidentally, the figure ignores the emission of gamma rays because these do not change either the charge or the mass number. The neptunium-237 then changes to paladium-233; and this gives off a beta particle and changes to uranium-233. This is followed by an alpha particle, and you have thorium-229. Another alpha particle leaves the nucleus and you have radium-225; then a beta leaves and you have actinium-225; and then an alpha to give you francium-221, and so forth down the line. You will notice that when you get down to bismuth-213 it has its choice of which way to go; whether to emit an alpha to become tantalum-209 or whether to emit a beta to become polonium-213. Notice that you end up with bismuth-209, with is stable, and the whole process comes to a halt. Most of these long-chained decay patterns end up with some isotope of lead, which is stable, as the end product.

Now, I want to get a couple of definitions in here. One definition describes radioactivity, and this is the curie (from Madame Curie) which is defined as the amount of radioactive material, such that you have 3.7×10^{10} disintegrations per second. Using standard prefixes you will get the millicurie which is 1,000th of a curie; and the microcuries, which are a millionth of a curie. The curie is the amount of radioactivity in one gram of radium. At least, one gram of radium is very nearly a curie. The curie was once defined in terms of the disintegration rate of a gram of radium, which meant that every time someone measured it a little more accurately, the number changed. Now, it is defined as 3.7×10^{10} disintegrations per second. However, no one bothers to define what a "disintegration: is. So you have to get this by the way it is used in the literature. It is usually used as the complete process of changing from one atom to the next one.

QUESTION:

Why are there more disintegrations in a gram, or rather a different number of disintegrations in a gram than there are in a pound or a ton?

ANSWER:

Because there are more atoms in there. Each radioactive atom has a certain constant probability of decaying in the next second. The more atoms of an isotope the greater the number of disintegrations.

If you will look at your notes you will see uranium-235 giving off an alpha particle and changing to thorium-231. This is a single disintegration. Another example: radioactive phosphorus changes into sulphur-32 by giving off a beta particle. If you had a curie of phosphorus-32, you would be getting 3.7×10^{10} beta particles being emitted per second.

On the other hand, take something like cobalt-60; as it changes into nickel-60, it gives off a beta ray, a gamma ray, and then a second gamma ray before it settles down to being a stable isotope. So, if you had a curie of cobalt-60 you would be getting 3.7×10^{10} gamma rays being given off each second. To get some vague feeling for the curie, a radium-dial wrist-watch contains in the order of one microcurie or less of radium, while the atom bomb releases millions of curies when it is detonated.

Now, the other peculiar feature of radioactivity is that once an atom has disintegrated, you no longer have the original atom left. For example, your phosphorus has been changed into sulphur or uranium has been changed into thorium. Therefore, you have gotten rid of an atom. You have less radioactive phosphorus than you had a few minutes ago, because some of it has disintegrated. Now this rate, or how fast it changes or disintegrates -- how quickly it changes from one atom to another -- depends upon its own peculiar whims. If you have a single radioactive atom, you would not know when this atom is going to emit a ray. With a large number of them, you can predict on a statistical basis how many will change. Now, once an atom has changed you no longer have that radioactive atom. It is out of business as far as radioactivity is concerned. So you keep losing radioactivity in this manner. You start off with a certain amount and in a little while later you have less and still later you have less, and so forth. Now, the term generally used to describe this is the "half-life" which physically is how long do you have to wait before half of this original material has disintegrated away. For example, if you have radioactive phosphorus, half of the atoms have been changed into sulphur -- ordinary stable sulphur -- in 14.3 days.

QUESTION:

Is this a spontaneous reaction? In other words, if a beta particle is being given off, what causes this?

ANSWER:

It is spontaneous. Apparently, there are certain combinations of neutrons and protons in the nucleus that are stable. If you deviate from these combinations, the thing is unstable and changes spontaneously to get more stable. But there is no known reason exactly why it does, though we are getting measurements of unstability and good agreement with experiments.

QUESTION:

Is this all continuous action? This only happens once?

ANSWER:

For each atom, yes; it disintegrates once.

QUESTION:

I mean this half-life.

ANSWER:

I am not sure what you mean. If you have one curie -- that is to say, let us give you an example. For instance, iodine-131 has a half-life of around eight days. If you have a curie of radioactive iodine-131 in a bottle so that no atoms could get out, at the end of 8.14 days you would only have half a curie, although you have not lost any of the atoms; they are all still in the bottle, except that some (in fact, half) are no longer atoms of I-131; they are atoms of xenon, which is non-radioactive. At the end of another half-life (16.28 days) half of that remains, so you are now down to 1/4 of what you started with. At the end of three half-lives you are down to (1/2)(1/2)(1/2) which equals one-eight of the original activity.

Of course, after a while when you get down to a few atoms, the whole concept of half-life breaks down. You cannot just talk about a few atoms, you have to have a lot of them. It is like having a large number of dice (If you were in the armed services you are familiar with dice.) and you throw them. The probability of throwing an ace is one out of six, so if you take billions of dice and throw them all at once (say, you have six billion dice) then you would expect that one billion of them would show up as aces. If you discard these, you have five billion left. Then you toss them again, and you figure that on each toss about 1/6 of them (the remaining dice) are going to be removed. But when you get down to six dice and throw them, the odds of three of them coming up as aces are fairly high compared to the chance of throwing six billion dice and getting three billion of them to come up as aces. So, if you talk about a few atoms the whole concept of "half-lives" breaks down. You have to have a lot of them to make any sense. Otherwise, you will have to start talking about individual probabilities rather than half-lives. But we are always dealing with very, very large numbers of atoms, even if we deal with micro-micro grams.

QUESTION:

Does every element have a half-life?

ANSWER:

All of the radioactive isotopes have their own half-life. I suppose you could say that even the stable isotopes have an infinite half-life.

QUESTION:

Where does the breaking line on the periodic chart come in? Is there such a thing?

ANSWER:

I am not sure I know what you mean. I am not sure what you mean by a break.

QUESTION:

I have heard questions in chemistry that after a certain atomic number they become unstable. Is that right?

ANSWER:

That is true from bismuth on up to the periodic table; however, bismuth has a very long half-life.

QUESTION:

What does iodine-131 become?

ANSWER:

Xenon-131. Let me give you some examples of half-life now. For example, gold-198 has a half-life of 2.7 days. Carbon-14 has a half-life of 5580 years. Radium C' has a half-life of, to point up the diversity, .00015 seconds. Uranium-238 has a half-life of four and 1/2 billion years. It takes a little while for uranium to die away.

QUESTION:

Is carbon used as something to tell the age of ....?

ANSWER:

Yes. You see, all the natural radioactive elements, like uranium or radium, have very long half-lives compared to the age of the earth, or are created by the disintegration of something with a long half-life. Radium C' has a half-life of .00015 seconds and is being created in the radium chain. That is, radium, as it decays, at one time becomes radium C'. So radium C' is being continuously manufactured by the decay of radium. Carbon-14 is an interesting naturally-occurring radioactive substance because its half-life is not long compared to the age of the earth. However, C-14 is being created continuously in the atmosphere by cosmic rays. This is the basis of the C-14 dating technique. That is, a certain percentage of the carbon in the air exists as C-14. We inhale it; the trees take it in by photosynthesis; and all other living material has this same certain percentage of the carbon in it as radioactive carbon-14. Now, when a tree dies or when a man dies the intake of carbon-14 then stops because the carbon-14 is formed in the upper atmosphere, not within our bodies. At death, the carbon-14 begins to die away -- with this long half-life. Someone can come along years later and analyze the amount of carbon-14 and compare it with the ordinary, non-radioactive, carbon in the body and say that this is only half of what it should be, so this thing must have died 5580 years ago. This is the basis for carbon-14 dating. So, these boys look for very sensitive instruments. If they could double the sensitivity so that they can detect only half as much carbon-14 as they could before, then, you see, they could date for another 5,000 years further back.

Let me give you a few examples of this decay. It is not really that difficult to do. Do you all have this Radiological Health handbook?

QUESTION:

Is an alpha particle an isotope of the helium atom?

ANSWER:

More accurately, you say it is the nucleus of the helium atom. The number of radioactive atoms which you have at any time N(t) is equal to the number that you started out with (No) times a decay factor (DF) which is a function of time:

$$N(t) = No(DF(t))$$

So, let us do a very simple problem. The hospital here buys 250 millicuries of radioactive iodine every week. Now, when you buy and pay for 250 millicuries, they measure out 250 millicuries as of 8:00 A.M. of the shipping day. However, we do not get the shipment until the next noon, so it has had a chance to decay in transit for 24 hours plus four hours, which equals 28 hours (one day and four hours). Look in the table on page 108 and you can see how much it has decayed: a decay factor of .9055. Therefore, the amount that we get is what we actually ordered (250) times .9055, or roughly 226 millicuries. So you see we actually order and pay for 250 millicuries, but we really only get 226 millicuries. Now, if it sounds like we are getting short-changed, look at sodium-24 with a half-life of 15 hours or so. Suppose you order 250 millicuries of sodium-24, and it takes 28 hours to get here. What is the decay factor? From page 114 the decay factor is .2576 for sodium-24 for 28 hours. Therefore, we are down almost one-fourth, or 62 millicuries. We lost 75 percent of what we paid for, because it decays so fast. Now, let us say that you have a mixture of radioactive iodine and radioactive sodium, and someone says, "I've got a hundred millicuries of this mixture. How much am I going to have in 24 hours?" First, you have to ask him, "How many millicuries of sodium do you have, and how many millicuries of iodine?" You see, you have to do these calculations for each independently.

When you add a third isotope to that, it gets a little messier, and as you now start with three independent radioactive substances it is more complicated. If you had four it would further worsen. When you talk about the mixtures which exist in fallout, you are talking about 200 different nuclides. This is a good job for a computer. Life is too short to do the calculations the way I have demonstrated. Fortunately, it turns out that this $t^{-1.2}$ gives you a good approximation of the way it decays. Note that use of the $t^{-1.2}$ law means that you tacitly assume a specific relative abundance of all the radioactive fission products.

It has one drawback in the sense that you cannot ask about a half-life for fallout, because it is a mixture and you cannot define a half-life. That is, the short-lived stuff dies away soon, and the longer lived begins to dominate as time goes by. Although it is a very sloppy sort of approximation, you can say that fallout acts as if it had an instantaneous half-life which is roughly equal to how old it is. That is, if it is a day old, it acts as if it had a half-life of one day (roughly); or if it is one hour old, then it acts as if it had a half-life of one hour (roughly) at that instant. This means that if you are working decay problems, you have to know how old the fallout is. You have to have some idea of how old the fission products are or your calculations break down completely. Decay calculations are much easier with a single isotope, because the half-life remains the same all the time, and you can go backwards and forwards in time with your calculations as much as you wish.

QUESTION:

What about that argument sometimes where they say, "Well, don't worry about the fallout; it's not going to affect this, that, and the other thing." Are they talking about this half-life business?

ANSWER:

I do not know what they are talking about. Will it affect what?

QUESTION:

Well, there is always that argument. One fellow says the fallout contains <u>this</u> that is going to hurt you, and the other fellow says, "Oh, No!"

ANSWER:

No, it is a lot more complicated a problem than that -- than just a consideration of the half-life. It is a case of interpretation of data, value judgments, and bias too. For example, you can talk about the <u>average</u> amount of radioactivity that people receive from testing, and say, "This is so little it is no problem." But you assumed, for example, that strontium-90 is distributed uniformly throughout the whole bone structure. However, there is evidence that it does concentrate in spots in growing children, so the peak concentration in one part of the bone might be ten-times what the average sum is. Then your opponent can say, "You are way off." You, therefore, have the "averagers" versus the "hot-spotters."

Or let us say that we can make these calculations and know the numbers well enough so that we can agree that a certain level of strontium-90 in everybody in the world would cause 100,000 deaths over the period of the next ten years. Now, you say it cost 100,000 people their lives. This way it sounds like a big number. (I am just picking these numbers out of the air.) However, suppose I want to minimize it. I say this is only 10,000 a year on the average for the world population of 600,000,000 (or whatever it is). Then I get .000-something percent. Nonetheless, you and I are both still talking about the same number. Do you want to talk about absolute numbers, or do you want to talk in percentages? It is not surprising that the people who approve bomb-testing belong to the "averagers" and "percenters." The fellows that are opposed to testing use the biggest numbers they can find in their calculations, and they belong to the "hot spot" and "absolute number" school of thought. The data that both sides use to make these calculations are not very good to begin with. The book I mentioned, Fallout, gets into this type of argument.

I want to bring another definition in here. The amount of energy emitted during radioactive decay is rather small, so that a new unit is used for energy. This is a unit used by the physicists for energy, and it is entitled Mev, which is an abbreviation for million-electron-volts. A million electron volts is the amount of energy that a single electron will have if you accelerate it between a potential difference of one million volts. An electron volt is the amount of energy that a single simple electron would gain if you accelerated it across a potential difference of one volt. What is it equal to in other terms? In other terms, one Mev is equal to 3.82×10^{-14} gram calories. The calorie is the energy required to raise the temperature of one cubic centimeter of water by one degree Centigrade. If you want it in other units, one Mev equals 1.6×10^{-6} ergs. The energy that we are talking about in radioactivity is for alpha particles in the order of 5,000,000 electron volts = 5 Mev, and for the gamma ray a few tenths of a Mev to two or three Mev.

Again, let me digress for a minute. We have talked about radioisotopes. I just wanted to make a few comments on why we use them at all at the University. We have about fifty labs around The University of Michigan that use radioisotopes from time to time. They are actually useful to us in many ways. For example, take a biologist working with isotopes. Now, you and I could do a biology experiment that the geniuses in biology could not do thirty years ago. If somebody asked the question, "How long does it take sodium to appear in perspiration after we swallowed some as salt?" The biologist of thirty or forty years ago would be completely stumped. There was no way he could design an experiment to give him the answer. Today, it is simple, to the point of imbecility. We get some radioactive sodium, make salt with it, then drink it. Then you check the perspiration with a Geiger counter. When the Geiger counter starts counting there it is.

It is very simple and very trivial because we now can use radioactivity. Experiments are done with various types of patients, where they feed them radioactive materials, salts, fats, etc., and they collect stools and urine and so forth, and do this type of measurement. This radioactive material acts as sort of a tag. You can differentiate this particular atom from all the other ones that are already there in the system.

I will give another example of something that is almost impossible to do, except that we have this ability to label or tag, as they call it, some atoms. Suppose someone wanted to find out how much sodium you have in your body. Now, if you would give this problem to a chemist and he did not have radioisotopes, he would scratch his head and say, "Well, the only way I could do it is if you will just shove this fellow into the Waring Blender and grind him up into hamburger, then I'll take an aliquot of this hamburger and I shall be able to tell you how much sodium there is in there." By this time the patient has lost all interest.

With the radioactive sodium, a physician can give the person a certain amount of radioactive sodium, and give it a chance to get into equilibrium. Then he can take a sample of the blood or urine and analyze for the radioactive sodium in there, and analyze for the ordinary stable sodium. This method tells you how much your radioactive sodium is diluted with ordinary sodium already in the body. For example, (if you put it in atoms it would be easier to understand, I think) if you had in the sample 6,000,000 atoms of stable sodium and one atom of radioactive sodium, and you say for every radioactive sodium atom that I rejected, he had six million atoms of sodium already in there. You know how many atoms you injected; you compute the amount of sodium in the body. This is a simple experiment that is done to give you information that you cannot get any other way. This is using radioactivity as a "tag" and "label."

You can also use the radiation from them without any thought of their chemical properties. For example, architects and engineers will run into the problem of a radiant heating system which has developed some leaks. It is often very difficult to find where the pipe is broken, especially if it is under three or four inches of concrete. I can take some radioactive sodium and dissolve it in the water in the heating system, run it through the heating system, and pressurize it if possible. This will force the radioactive sodium out through the leak in the pipe. We just flush this all out with clean water and get rid of all the extraneous radioactive sodium that is in the pipe. We run a Geiger counter around the floor until it finds a hot spot. This is where the radioactive sodium has leaked out.

Another example: iodine-131 is given to patients because iodine concentrates in the thyroid gland and gives the physician a measure of how biologically active the thyroid gland is by permitting him to measure the rapidity with which the thyroid gland picks up this trace amount of radioactive iodine. Iodine gives off both a beta and a gamma ray. Therefore, the short-ranged beta ray tends to be absorbed in the thyroid gland. A physician can actually destroy a part of the thyroid gland with iodine-131. Then again, you can do all sorts of useful things with these radioactive isotopes.

You can do things like getting nuclear reactions the same as you get chemical reactions, except you do quite a bit more work. We mentioned radioactive sodium. You can take sodium-23 which is non-radioactive and expose it to neutrons. It will pick up a neutron and become radioactive sodium-24. You can bombard beryllium with alpha particles and it will emit a neutron. There is one reaction, which is the reason why we are here. If you take uranium-235 and hit it with a neutron, the uranium atom splits roughly in half and this is called "fission." If this is all there were to fission, we would not be here today. The crucial thing is that when fission occurs, there is a release of two or three neutrons (the actual average number is 2.5 I think). We started out with uranium-235 plus a neutron. We split the uranium atom (it gives off a certain amount of energy) and we end up with some neutrons, in fact, more than we started out with! This means that if we had enough uranium around, you could lose 1.5 of them that wandered off somewhere and did not do anything useful; but this remaining neutron splits another atom of uranium-235, and you start it all over again.

Thus, a small chunk of uranium-235 will have a lot of neutrons escaping out of it before they have a chance to split another atom of uranium-235. If you make this chunck of U-235 bigger you will reach a point sooner or later where, for every atom that fissions, 1.5 neutrons leave the pile, and one gets captured and causes another fission. The thing can keep going forever. This amount of uranium you have now piled up is called a "critical mass." This is what is done in a reactor. Now, if you make this critical mass just slightly bigger, when a neutron comes wandering in and causes a fission you get something as follows. Let us assume three neutrons are released per fission for simplicity. Let us say the pile is so big that only one of these neutrons gets out and the other two get captured inside it. Now, you have two atoms of uranium that are splitting, giving you six neutrons, of which approximately 1/3 get out. Now we have four left inside. We have then four atoms of splitting uranium with 12 neutrons released. Again 1/3 of them get out of the pile. The next "generation" has eight fissioning atoms. Its succeeding generation has 16, then the next has 32, and so forth. Each generation takes place in the order of a few microseconds. This is the atomic bomb, using uranium-235 or plutonium-238.

QUESTION:

What determines how many escape?

ANSWER:

Essentially, the geometry of it.

QUESTION:

If you have a critical mass, do you get this doubling?

ANSWER:

No. The critical mass, as defined by nuclear engineers, would just keep a constant number of neutrons. If it were just critical, the number of neutrons would remain constant -- they would not decrease or increase. For example, if you threw ten neutrons in there they would always be ten neutrons flying around. They would not be the same ones; but the density of the neutrons in the pile would remain a constant. Nothing would happen. However, the term "critical mass" is often used in nuclear weapons texts to mean what I am calling a "super-critical mass."

Now, if you made this chunk of uranium super-critical, then the number of neutrons keeps on increasing. The amount of energy being released, as more and more uranium atoms are being split in each generation, increases. It is then not controlled. It just runs away....a population explosion with neutrons instead of people.

QUESTION:

What is it that is splitting?

ANSWER:

It is the uranium atom or the plutonium atom that splits in half.

QUESTION:

Does it start decaying?

ANSWER:

Yes and no. The uranium-235, when it is hit by a neutron, will split in half, and the two atoms that are formed are radioactive and begin decaying immediately. This is the fallout problem. However, the important fact to a physicist is not only does the uranium-235 split, but more than one neutron is emitted during fission. You only needed one neutron to split this U-235 atom. You get energy from splitting the atom, and you get a bonus back of two or three neutrons which, in turn, can split other ones. Now, if you make up a big enough pile of uranium, the reaction will go on spontaneously. However, anyone making a bomb out of U-235 runs into this problem. Uranium-235 is not abundant. Less than one percent (.72 percent) of the atoms in ordinary uranium are U-235, and the other 99.28 percent are uranium-238, which does not fission readily. To split uranium-238 requires a very energetic neutron, but with uranium-235 any low energy neutron will split it.

QUESTION:

Is there any other kind of element that will do the same thing?

ANSWER:

Almost anything above uranium can theoretically do it. Plutonium, the other favorite, is a man-made element. This was made by taking uranium-238 and permitting it to capture a neutron in a reactor, thus becoming uranium-239. Uranium-239 then changed to Nb-239 and then to Pu-237 by two beta emissions. The plutonium could be taken chemically from the uranium.

One problem in building a bomb is the triggering mechanism. If all this material were assembled into a super-critical mass, a stray neutron (which is always somehow present) would set the thing off. What is needed is some mechanism which would assemble two or more separate sub-critical chunks into a single super-critical mass. In the super-critical position, neutrons are captured by the U-235 or Pu-239 nuclei at a rate faster than they can escape through the surface area of the mass. The result is an explosion.

There are at least two separate mechanisms for doing this. The results are the "Thin Man" bomb or the "Fat Man" bomb. The thin man has a cylinder with a mass of Pu-239 at each end. To detonate the bomb, one piece of plutonium was fired at the other and formed a super-critical mass. The thin man was used at Hiroshima with uranium-235 as the fuel.

The other and more sophisticated mechanism has the name "Fat Man" bomb. It used "implosion" to form a super-critical mass. Incidentally, this is the secret that the spy, David Greenglass, passed on to the Russians. Although all the details have not been revealed, we can guess at possible ways of using an implosion. The fissionable material could be in the shape of a hollow sphere, perhaps with a neutron source in the center. This sphere is surrounded by shaped charges of TNT. When the TNT is detonated so that all the charges fire simultaneously, there is an implosion toward the center. This collapses the hollow sphere into a dense super-critical mass. The neutron source starts the reaction while the implosion pressure helps to hold the mass together. (See page 106, Fundamentals of Nuclear Warfare, Figures 32 and 33.)

The fat man was tested at Alamogordo and used at Nagasaki. The thin man was never tested beforehand. Its mechanism is so simple that everyone felt sure it would work. Presumably, modern weapons are of the fat man type because it is more economical of fuel, more efficient, and perhaps less susceptible to an accidental detonation.

The energy in the atomic bomb is obtained by splitting or fissioning Pu-239 or U-235. When these atoms are split, the two resulting atoms are radioactive.

There is another way of getting nuclear energy, and it is just the reverse of fission. That is, by putting smaller atoms together and making them bigger atoms. You will find these reactions listed in the text on nuclear weapons near the front, i.e., page 16. This table shows various isotopes of hydrogen getting together to form isotopes of helium. There is one reaction that they do not list there, although it is no secret anymore:

$$_3\mathrm{Li}^6 + n \rightarrow {}_1\mathrm{H}^3 + {}_2\mathrm{He}^4 + 4.8 \text{ Mev}$$

To get the listed reactions to go requires a considerable amount of heat -- about 100,000,000 degrees Farenheit. The reactions listed in there are actually the source of energy of the sun. This may be startling news to you, but the sun is not a big chunk of grade-A anthracite burning up there in space. It actually is a gigantic thermonuclear reactor which is converting tons of hydrogen into helium per second, and this is the source of the energy.

Let me draw a chart. It may be confusing at first, but bear with me; it will sink in. We plot what they call binding energy per nucleon (this means the particle in the nucleus -- the proton and the neutron) versus the mass number. Now, this binding energy per nucleon -- this is the amount of energy that would have to be fed into a nucleus for each one of the neutrons and protons in it to break it up into its constituent neutrons and protons -- and the chart goes like so. Now, this curve represents the amount of energy that you would have to feed into the nucleus to break it up into neutrons and protons. By shifting your mental gears, you can consider it the amount of energy which would be given off by each neutron or proton if you took a handful of separate ones and stuck them together in the form of a nucleus. (For reference, see page 61 of Lapp and Andrews, Nuclear Radiation Physics.)

Now, as you know, energy is conserved so that in our imagination we can go from any part of this curve to any other part of this curve, keeping track of the energy we feed in or remove. Then, we can see how much we gain. Now, you start out with uranium-235 and you split it, as in the bomb, and the fission products are in this band in the center. So, if you look at this and say, "How much energy do I get out of fission?" you will say, "Well, in my imagination, I will feed in this much energy (about 7.5 Mev) for each neutron and proton." Now, I stick them together to form the fission products, say, Sr-90 + Cs-137, and I get this much energy (about 8.4 Mev) being given off for each one, and so I have gained this much energy (referring to the difference in heights on graph between U-238 and Sr-90 or Cs-137).

Let me repeat. This curve can be interpreted in either of two ways -- the amount of energy you feed into a nucleus to tear it up into separate neutrons and protons; or, conversely, the amount of energy which is released if you take a handful of neutrons and protons and stick them together to form some nucleus. Using both of these interpretations, how much energy does this graph say we are going to get by splitting uranium-235?

You can do it mentally by saying, "We feed in this amount (referring to U-238 on graph) to break it up into constituent neutrons and protons, then we have this amount (curve from number 50 to 140) when we put it together." So, we will end up with a net gain. The difference in heights on the graph between any two mass numbers gives the energy released. Now, you might say, "How can I get a little bit more, or a bigger bang for a buck in return?"

Well, if nature had been a little kinder, or more brutal, depending on your point of view, this curve for high mass numbers looks as if it is going to keep going down a bit, so we could get more energy if we used something with mass number 260. But if you look at the small mass numbers, Hey, man, here's hydrogen down low and there's helium up high. Hence, the idea of a hydrogen bomb. There is another advantage. If you look at that table in ENW, the end products are either helium-4, which is non-radioactive, or you end up with hydrogen-3, which, though radioactive, has a beta so weak that you can stop it with a single sheet of paper, and no gamma ray at all. You should not get any radioactive fission products.

Although I am probably getting off the track a bit again, a lot of people are working on the controlled conversion of hydrogen-2 (heavy hydrogen) into helium; that is, a thermonuclear reactor. You can show that there is H-2 in water, ordinary water, sea water, drinking water. If you could convert all the H-2 that you would find in a gram of water into helium, you would get as much energy as in 300 grams of high-grade gasoline. Let me repeat that. You would get 300 times as much energy from the heavy hydrogen in a gallon of water, if it were converted into helium as you would get from 300 gallons of gasoline. This means, as far as the energy resources of the world are concerned, it would be just as if you could fill up every spring lake and ocean 300 times over again with petroleum. There are a lot of people working on this. You do not have any end-fission products to worry about as you do in an ordinary reactor.

The first hydrogen bomb, exploded on November 1, 1952, was about a three-megaton bomb. It wiped out the island of Elugelab in The Marshalls. It was referred to as a thermonuclear "device" rather than a "bomb." They were using hydrogen-3, which is a gas. To keep this in a condensed form, they refrigerated it. They had something like 65 tons of refrigeration equipment out there to keep this thing condensed. The hydrogen-3 is radioactive with a half-life of 12.4 years. This makes it a little bit of a nuisance. You have to keep manufacturing it. However, by using lithium-6 which is stable and adding a neutron, you create hydrogen-3 plus helium-4. Lithium is a metal, so we can make lithium-hydride; for lithium, we use the Li-6 isotope and for hydrogen we use the H-2 isotope. So, here, by making it this way, Li^6H^2, we can create hydrogen-3 at the instant we need it, and we have the hydrogen-2 already there. Besides, we do not have it as a gas; we have it as a solid. So the hydrogen bomb, if you want to look at it this way, is a lithium bomb.

You will notice, if you look at that table, too, you have neutrons on the right-hand side. This is on page 15, ENW. The thermonuclear reactions that are listed there are of possible interest. You will notice that some of these reactions have neutrons left over and these neutrons have a terrific amount of energy. From this they got a bonus which they attempted to keep a secret, but which did not stay a secret long.

Let me describe what I went through at the time of the March 1, 1954, test, having the information that you have now, not a heck of a lot more, except that, perhaps, I was a little more familiar with it. The AEC exploded a bomb at Bikini and radioactivity fell out on the Lucky Dragon, a Japanese fishing boat. I was completely confused by this radioactivity, and so were a bunch of other fellow students. If this was a hydrogen bomb, where was all this radioactivity coming from? After all, when you fuse hydrogen you turn it into stable helium or hydrogen-3, which is not violently radioactive -- no gamma rays. You should get a clean bomb. What made it so dirty?

As far as I know, the AEC has not bothered to write up much about it, but the Japanese have explained it in great detail. One of the Japanese scientists, who was called out to analyze the fallout on the Lucky Dragon, was a fellow by the name of Kimura. He analyzed the fallout and found a rather rare isotope of uranium -- uranium-237 -- on the ship. This let the cat out of the bag, especially since Kimura had discovered this isotope ten years before. Kimura knew how you made uranium-237. He knew that when you bombarded U-238 with energetic neutrons, it sometimes captured the neutron and emitted two neutrons, leaving uranium-237. This does not look like much, but Kimura knew that in order for this to happen, you really had to belt this uranium-238 with a very energetic neutron. This is how he had done it. But he also knew that when you belted uranium-238 with a very fast neutron, sometimes what happened was this: the U-238 would fission; it would split in two.

$$\text{U-238 + fast neutron} \rightarrow \text{fission}$$

So Kimura immediately figured out what our Top Secret hydrogen bomb was. The bomb must have had a thick blanket of U-238 surrounding its fission-fusion core. The fast neutrons formed during the fusion process, fissioned the U-238 blanket, thus increasing the energy output as well as increasing the amount of radioactive fission products. You thus did not "waste" the neutrons from the fusion.

The hydrogen bomb is essentially a fission reaction, followed by a fusion reaction, followed by another fission reaction, a three-stage job. Fowler estimated, if you want some numbers, that this probably had a 220-pound core of uranium-235, plus an equivalent amount of lithium-deuteride (to emphasize the fact that it was made with a heavy hydrogen) plus several thousand pounds of uranium-238. Uranium-238 gives another bonus in here, inasmuch as uranium-238 is so massive (it is one of the heaviest things that we know) that its sheer inertia probably tends to hold the bomb together, so that you get a bigger explosion. Well, this was a big secret of the hydrogen bomb.

QUESTION:

What was the purpose of the TNT in that bomb?

ANSWER:

The TNT was just to get a critical mass by implosion.

QUESTION:

I mean, what was the equivalent?

ANSWER:

The March 1, 1954, bomb was between 15 and 20 megatons. It is estimated that about two megatons of the total energy came from the fusion reaction, and the remainder came from the fission. Most of the energy came from the fission of uranium-238.

QUESTION:

It was the fusion that gave the fast neutrons?

ANSWER:

Yes. The fusion gave us very fast neutrons and permitted the fission of uranium-238. Now, before, uranium-238 had been a sort of garbage that you threw away. They had to go through the laborious work of separating out uranium-235 from uranium-238. However, uranium-235 and uranium-238 are the same chemically. This meant that you could not separate uranium-235 from uranium-238 chemically in any way. You had to go to physical processes which depend on the fact that the heavy uranium would take a little longer to diffuse through a barrier, and thus get a slight enrichment. This is a very expensive way of doing it. Or, you had to make plutonium in a reactor by converting uranium-238 into plutonium. This is chemically different from the uranium so you do a chemical separation, but this means you had to build reactors to make a lot of plutonium.

QUESTION:

Did you say what the center sphere was?

ANSWER:

This is just empty space. There probably is a neutron source in it, made by mixing up plutonium and beryllium. The alpha particle from plutonium, when it hits beryllium, will cause a neutron to be emitted.

QUESTION:

Then the first fission reaction caused the heat to start a fusion reaction and fusion?

ANSWER:

Yes, and then was followed by a second fission. Now you have a three-stage job.

QUESTION:

Suppose you leave this 238 out of the outer shell; is that what they call a clean bomb?

ANSWER:

This would presumably clean it up a bit, yes, because almost all of the fallout is coming from this. How clean it would be is another question; you would still have the first stage of fission.

QUESTION:

What percent of force did you get from that outer shell -- 60 percent or 70 percent?

ANSWER:

In that first one they figured something like 70 to 80 percent of it came from this outside shell. If it is not known to be otherwise, it is usually assumed as a 50-50 partition, that is, half the energy comes from fusion and half the energy comes from fission.

QUESTION:

Well, do you think these test shots that they are shooting now are something on the order of 50 megatons?

ANSWER:

Well, according to what I read in the paper, the big bomb they set off was mostly a fusion device. Instead of using U-238 around the outside, they used lead, which would not contribute to the explosion but supplies equivalent inertia. If this is true, then they essentially tested the 100-megaton bomb by testing the 50 and getting most of the yield from the fusion. Now all they have to do is remove the lead and put uranium-238 around it, and they are all set to go.

Unfortunately, the biggest gain, as Fowler emphasizes, from the three-stage device, was economy. If you make a 20-megaton bomb out of U-235, and this is an isotope which is laboriously separated from U-238, it will weigh about 11,000 pounds, assuming that 20 percent of the fuel is fissioned. Because of the laborious cost of separating the uranium-235 from uranium-238, it is estimated that a 20-megaton weapon made of pure U-235 would cost about 100 mega-bucks. If you made this out of conventional TNT, it would cost about ten billion dollars. By using this three-stage weapon, the fission-fusion-fission method with U-238, it went from 100 mega-bucks apiece to four for 1,000,000 dollars, i.e., $250,000 apiece. Any idiot can afford that one.

In fact, I was at a meeting during a presentation from the AEC and they were willing to sell a one-megaton bomb for peaceful uses (just in case you want to dig a big hole some place). They were going to sell it complete with personnel and everything else for one-million dollars, or the equivalent of one dollar each ton of TNT. So it cannot be too expensive to build them, at least in mass production.

QUESTION:

What does 20,000,000 tons of TNT cost?

ANSWER:

About ten billion dollars is the estimate.

QUESTION:

That is TNT?

ANSWER:

Yes. TNT. If you want a 20-megaton bomb, make it with TNT and you pay ten billion dollars; make it with U-235 and you pay 100-million dollars; make it into this three-stage weapon and you pay $250,000. I will end on somewhat of a gloomy note.

You have probably read somewhere of an ultra-gas centrifuge that is being developed. The ultra-gas centrifuge is one of the methods of separating U-235 from U-238. It was tried in the early days of the Manhattan District and was discarded out when the gaseous diffusion plant worked so well. The gas centrifuge outfit was a small outfit. You could separate a little bit of U-235 at a time. It is a small gadget that you can hide almost anywhere. It is not one of these huge plants that is spread over a couple of acres. If it works well, it means that any fool can start separating U-235 from U-238. Once he has this done (you see, this is the expensive part of the weapon) he has U-238 left over in a corner somewhere. You now put this little gadget to work separating out lithium-6, then hydrogen-2. Almost anybody can go into the bomb business for himself.

I shudder at the thought of 80 or 90 countries having these things in their basements, turning this stuff out. Apparently, it is not a problem today, but if we assume a technical break-through in the future, the problems of arms-control become exceedingly difficult.

QUESTION:

What do you call this?

ANSWER:

The ultra-gas centrifuge.

QUESTION:

Where do we go from here? To the neutron bomb?

ANSWER:

The neutron bomb? I am not sure how a neutron bomb would be built. I think the jacket of uranium-238 would be removed, although there are undoubtedly other ways. The idea of the neutron bomb is to get a weapon which, when exploded, releases a fantastic number of neutrons. These are lethal, same as gamma rays, but if you could set this off and not create any fission products or any other radioactive debris to settle down, you have the equivalent of a death ray. Neutrons are more difficult to shield against than the gamma rays from fallout. You would have a burst of neutrons which would do essentially no damage to buildings, that is, it would not contaminate them too much, but just kill people.

QUESTION:

Then, if we get these fallout shelters built, they will be obsolete?

ANSWER:

Maybe yes, and maybe no. It would depend on the shelter. As you see, this is a handy thing to do, to kill just people. You see, it takes skill and brains to produce buildings, but people are readily produced by unskilled labor in their spare time.

QUESTION:

If a neutron bomb would explode today, how fast would it kill people?

ANSWER:

This depends on how much radiation they receive, but those that would die would be killed anywhere from hours to months, and they would be pretty sick too. What shook me up was when I heard about some kid in junior high saying a neutron bomb would just destroy unimportant things like people. I thought this was a pretty sad commentary on the world today. So with that sort of cheerful note about anybody building these things....

QUESTION:

What about materials? Don't we have to make fresh bombs all the time, since they fall apart?

ANSWER:

Oh, no. Uranium-238 will last thousands of years. Uranium-235, as in the back of that handbook (the tables will give you half-lives) page 334, lists the various types of uranium: U-235: half life of 7×10^8 years; U-238: 4.5×10^9 years; Pu-235: 24,000 years.

QUESTION:

What about stock piling? These things are not made up so that you can go fire them off. Apparently, the materials are assembled, but not the whole thing. Or don't we know?

ANSWER:

I'm sure that they're not unassembled. The Air Force is carrying these things around in SAC bombers. Now, I don't know what the details of this thing are; all I know is what I have been told and what I read in the newspapers. In case one SAC bomber crashes, the crucial part (and I don't know what it is) is not in the bomb. In case of a fire or a crash, the TNT would explode, but you would not get a nuclear explosion. You would not get either the fission or the fusion. Now, apparently this has got something to do with the shaped charges used in the implosion. If they do not go off right, there is no nuclear explosion at all. This, you see, could be one of the disadvantages of the "thin man" bomb. It looks too simple.. I have read that the "thin man" was never tested before it was dropped. They were so sure it was going to work that they did not even bother to test it. The test done at New Mexico on the first weapon used this implosion device because they were not sure how well it was going to work.

QUESTION:

How much TNT did they use?

ANSWER:

I do not know how much TNT they use to trigger these things except that I am under the impression that it is not a trivial amount of TNT -- not a small quantity. It is not the sort of thing that you would want to be sitting close to if the TNT went off. I expect hundreds of pounds of TNT. Understand that in these SAC bombers everything is ready to go, except that one piece is missing. Whatever that piece is, it is essential to get a nuclear explosion. It is probably part of the timing control that insures all the TNT is going off at the same time. This probably is not just one big chunk of TNT around the fission core. This would be too dangerous.

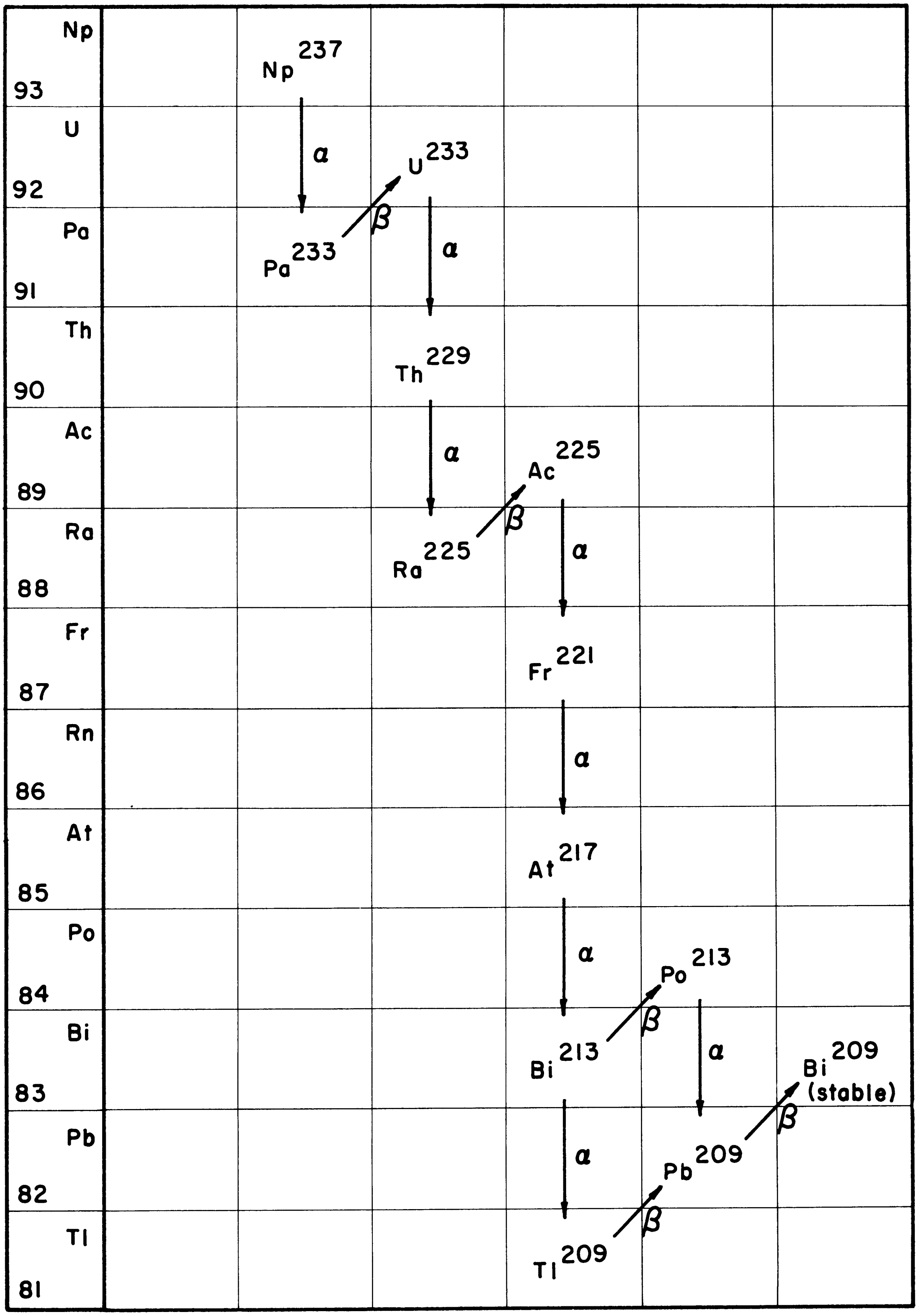


Figure 3. Radioactive Series Having Parents, End-Products.

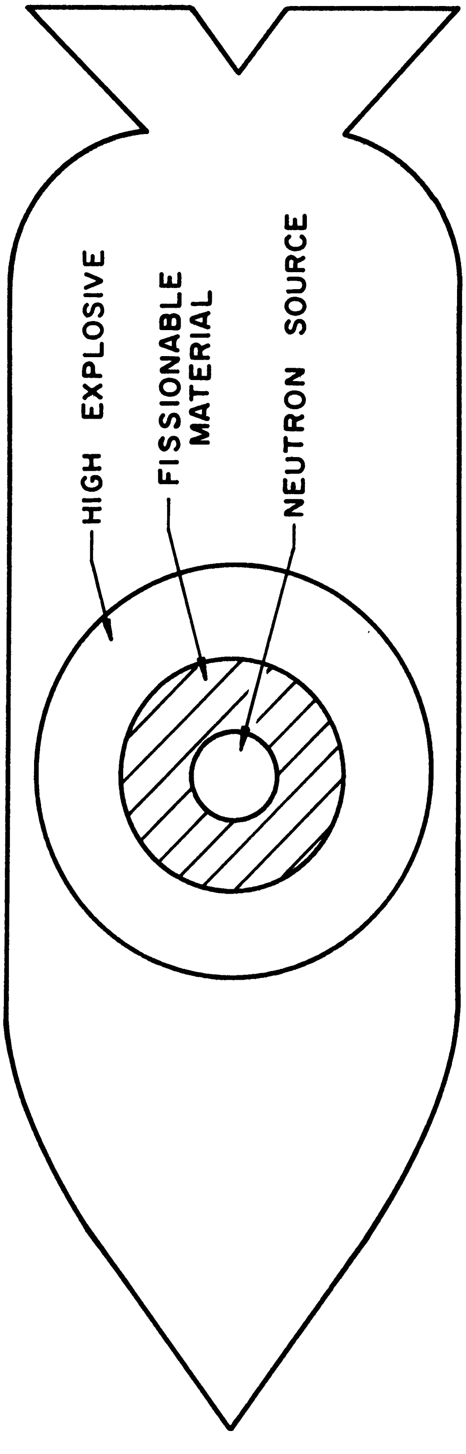


Figure 4. Implosion Type Nuclear Weapon.

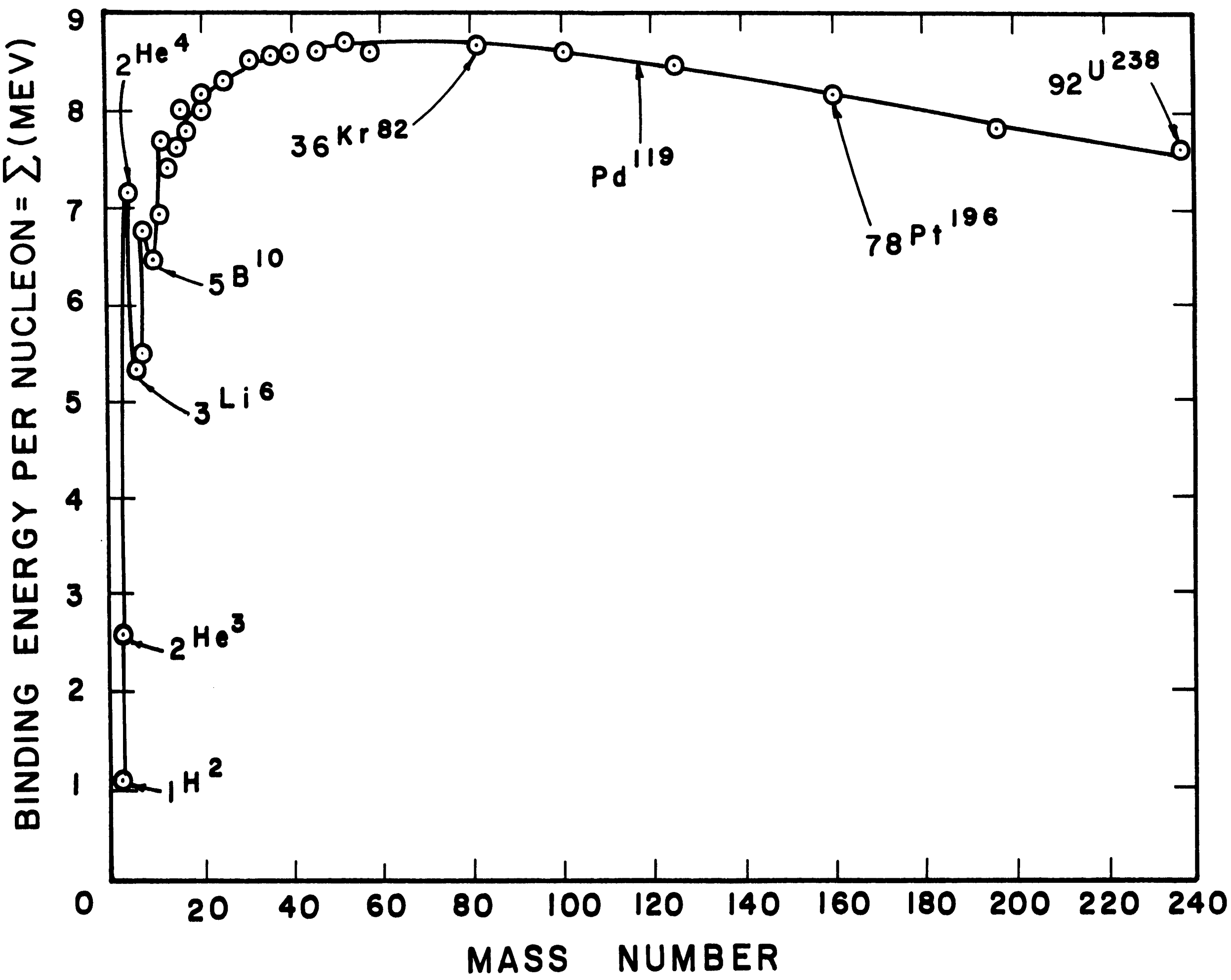


Figure 5. The variation of binding energy per nucleon with mass number.

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ILLUSTRATIONS:

Page 107, 108: Physics, Classical and Modern

Page 24, Fundamentals of Nuclear Warfare

Page 122, Physics, Classical and Modern

Page 124, (Fig. 7.1), Physics, Classical and Modern

Page 61, Lapp and Andrews, Nuclear Radiation Physics

Page 106, Fundamentals of Nuclear Warfare, pages 32 and 33

INTRODUCTION TO SHIELDING METHODOLOGY

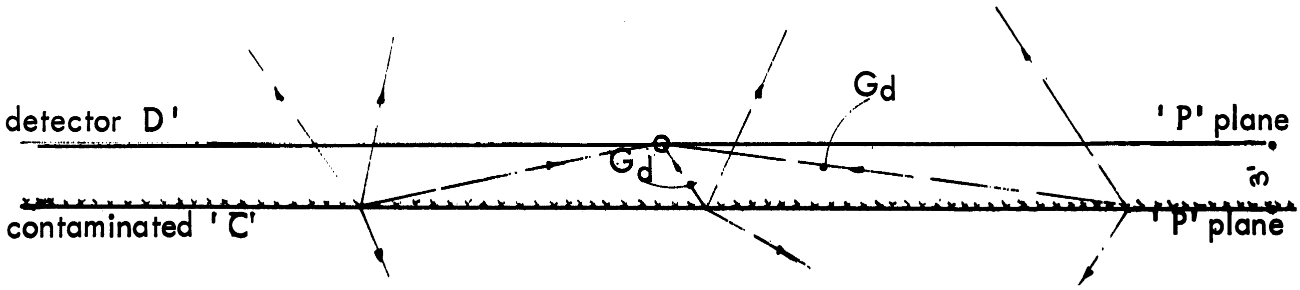
Harold W. Himes

So far we have discussed the effects of nuclear weapons, the structure of matter and radio-activity, and some of the characteristics of the fallout field. So you should be familiar with the nature of fallout radiation and some of the effects this radiation would have. It should also be obvious that some kind of protection from this radiation would reduce these effects. The basic purpose of this course is to provide you with a methodology which will determine the effectiveness of this protection, and the purpose of this lecture is to give you some kind of a qualitative idea about the nature of structure shielding.

Because of the nature of alpha, beta and gamma radiation, we know that if we have shielding from gamma radiation, from an external source, we have more than adequate shielding from the alpha and beta radiation. So when we are concerned with the design and analysis of protective structures we will be concentrating on gamma radiation only. Our basic problem, then, is to determine the source of this radiation, how much of this source will effect a particular location, and what happens to it as it travels from the source to the location.

Because of the complex structure of the fallout field, and the many variations encountered, it is necessary that we must make certain assumptions in order to simplify the methodology. Some of these simplifications may seen arbitrary, but all of them are the results of many experiments and tests as well as sound theoretical judgement. As we develop the methodology in detail we will find ways of modifying these simplifications to allow for the conditions which may require special attention.

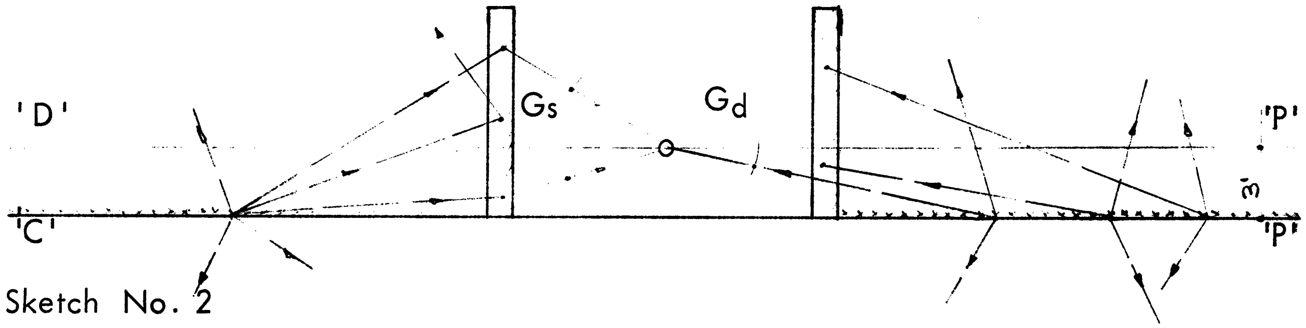
To begin with, we assume that each source, or emmitter, is generally alike, that it is something like a light bulb without a socket, and is sending out gamma rays from the entire surface, or 360° of a sphere We also assume that these sources are equally distributed on a horizontal plane of infinite dimension, as far as the ground is concerned, and that each one is somehow glued in place. Another assumption is that we have a detector, and this is some kind of device that will receive and measure radiation, located 3 feet above this infinite horizontal contaminated plane. This is called the detector plane, defined by the letters D and P in sketch 1 below.



Sketch No. I

So if we have the situation indicated in this sketch, and each little 'x' is considered a source of radiation, it is possible for one ray from each of these sources reach the detector. Some of these rays will go on up into the air above and some will go downward into the earth below. The ray which starts from any source and reaches the detector in a straight line, and we know that gamme radiation travels in a straight line like a light ray or other electromagnetic radiation, is called direct radiation. Because the source of this radiation is on the ground and is reaching the detector directly, or in a straight line, we call this ground direct and give it the symbol G_d So all of the radiation which can reach the detector in this manner must be below the detector location or the detector plane. In essence we are talking about the source geometry of a particular situation.

If, however, we insert a barrier or a wall of some nature as indicated in sketch #2, and we assume that there are no sources of radiation on the ground between the barrier and the detector, all of the radiation must first pass through this wall before it can reach the detector. So we have changed the geometry by moving the sources farther away and have inserted a barrier.



Sketch No. 2

As radiation passes through, or enters a barrier, several things can happen - some of it will be absorbed completely through the process of ionization - some of it will pass through without any inter-action at all - and some will inter-act with matter in the barrier so that it will change direction. It is the latter type which we call wall, or barrier, scatter radiation and we give this the symbol G_s. In other words, it has a source on the ground and will reach the detector because its direction has been changed through inter-action with matter in a vertical barrier. Obviously some of this radiation will also scatter in the barrier and will not reach the detector because it will go back outside or will not emerge in the direction of the detector.

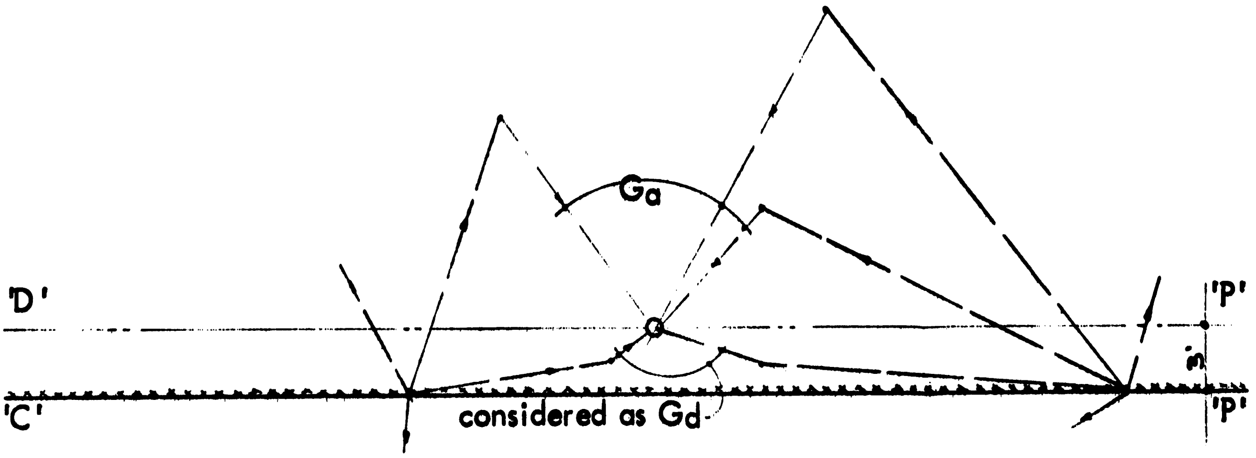
Now the amount of each type of radiation, G_d and G_s, which will emerge from this barrier is related to the mass thickness, or how much the barrier weighs per square foot of area. So when we talk about how thick the barrier is we really mean how heavy it is. We also know that for all practical purposes it does not matter what the chemical composition of the barrier is - it can be anything that has some weight. So it is the mass thickness of the barrier that will determine how much of all the radiation which is emerging from it will be coming through directly, or how much will be scattered. Because each of these types will have different intensities it becomes very important to know what we are dealing with.

We call the G_d and the G_s, Directional Responses. There is also one other type of Directional Response, which we will consider later on in this discussion. If there were no barrier, or one of infinite thinness, there would be no possibility of any inter-action and all radiation would be reaching the detector directly. On the other hand, if we had a barrier of infinite thickness, any radiation which would emerge through it would probably be scattered. In reality the methodology will examine the situation as if we had both kinds of barriers and then modify the results depending on how thick, or how thin, the barrier is. This will account for the different indications in the drawings on Chart #5 in the Engineering Manual. Obviously, if we have a barrier with some mass thickness, some of the radiation will also be absorbed and we will account for this in our barrier reduction factors which will again be explained in detail later on.

All of this may sound somewhat strange and difficulat to comprehend, but if we can remember that gamma radiation is acting much like visible light and that a detector might resemble the human eye, or a light meter, we should be able to understand the situation without too much strain. If we can visualize ourselves in this room, or any other room, with our eye 3 feet above the floor and the walls are constructed of venetian blinds with pretty heavy slats, we should be able to establish a similar situation. When the blinds are completely open all of the light from the outside will come through, or we will be able to see it, as if there were no shades at all. This is similar to the thin wall case. If we closed the blinds completely any light we saw would have had to bounce around through the slats and be relected in some nature. This would be similar to the thick wall situation. Now if we adjusted the blinds so that they were not completely closed, we have a combination of both of the above - some direct - some scatter. And how open, or how closed, we made the blinds would be similar to how thin or thick the barrier is.

One of the major mis-conceptions concerning radiation shielding is what happens to that radiation which is absorbed in the barrier. A great number of people think that if radiation is absorbed in any material it will in turn become radio-active and act as a source of radiation. Again, if we recall that gamma radiation is just like visible light, at much higher energy levels, and we consider the example described in the preceding paragraph, we can clear this up immediately. What has happened to the light that came in contact with our venetian blind, but did not get through? It must have been absorbed in the blind. These light rays have completely lost all of their energy and have disappeared. We know that it is impossible for the blind to act as a source of light because it has absorbed some of the light rays which struck it. Another example of similar nature is the situation of X-rays. Again gamma radiation is like X-ray radiation only of different intensity. If it were possible for any material to become radio-active because it has been exposed to gamma radiation we would all probably become sources of X-ray radiation because I am sure we have all been exposed to this at some time or other. All of this may seem rather elemental but somehow it does become very difficult to convince people there is nothing magic about gamma radiation.

There is this other Directional Response which we must look at now, in order to continue the problem of determining the source of paths of radiation. Again we are still concerned with that radiation which starts from an emmitter on the ground and may reach the detector. If we go back to sketch #1 we can see that much of the radiation starting from an emmitter on the ground goes upwards towards the sky. We have also mentioned that as radiation comes in contact with a barrier of any mass thickness that some of it will be absorbed, some will pass through directly, and that some will be scattered. As this radiation, which is started up, continues on, it is passing through air and air has weight or mass thickness. Because of this we can expect the same effects in air that we found in the vertical barrier. So it is possible for a gamma ray to start from the ground in an upward path and be back-scattered downwards in a direction which eventually could reach the detector. This kind of radiation, shown in sketch #3, we call albedo, or skyshine, and give it the symbol G_a . Because the secondary source of this radiation is the sky we only take it into account from that portion of the area under consideration which is above the detector plane. There will be some radiation which will scatter in the air below the detector plane, but because the change of direction and the decrease of intensity is so small we include this componant in our Directional Response G_d .



Sketch No. 3

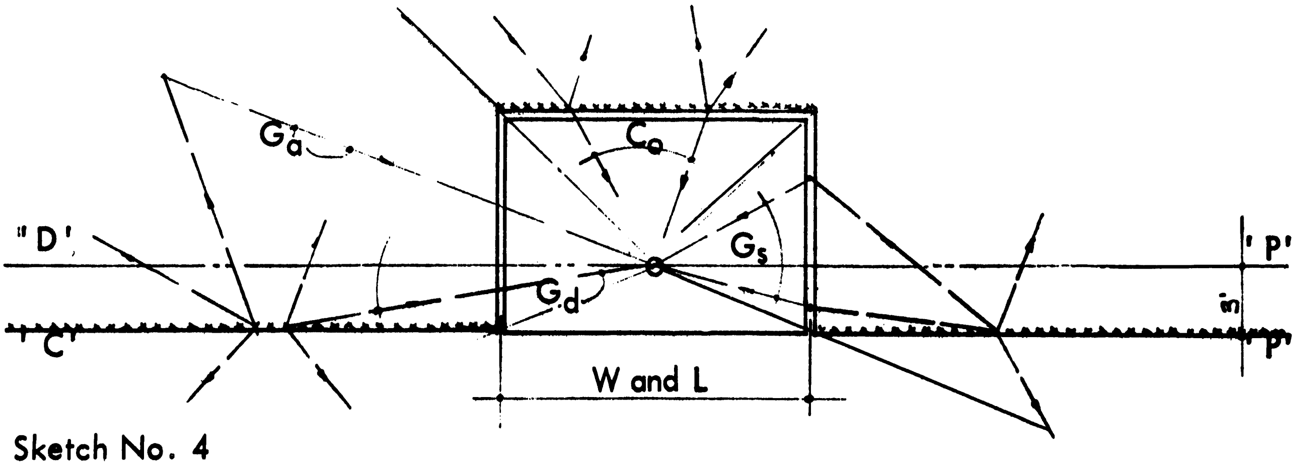
As this type of radiation reaches a vertical barrier it will be effected by it in the same manner as that which reaches the barrier in a direct path from the sources on the ground. When we consider the emergent radiation through the barrier we will find that the scatter componant of albedo will be accounted for in our G_s and so we will handle the G_a in combination, or similar to, our G_d componant.

So the combination of these three types of responses will tell us about all of the radiation that can reach the detector from a source which is located on the ground, and we give this combination the symbol C_g. There is one other source we must take into account, that which is located on a plane, or roof, or overhead, which is above the detector. Generally there is a barrier of some nature and we will also have direct and scattered radiation emerging from this barrier, but the charts we have will combine these into one contribution which we call C_o.

Shielding methodology is a means of determining where the source of the radiation is, how much of the source we can see, and what it must pass through in order to reach a detector placed at any given location. It really only requires that one have the ability to visualize things in the third dimension, an understanding of solid geometry and basic algebra, along with common sense and a facility in simple arithmetic. It will tell us how much, or what percentage, of the total radiation dose outside, in an unprotected situation, will reach the detector in a protected situation.

In order to understand some of the principles of the methodology, in a qualitative sense, a series of examples will follow which indicate some simple structures and the kinds of radiation paths to be considered in the analysis of the particular situation.

In sketch #4 we have a rectangular building located above ground with a detector located in the center of the area enclosed by the walls. The location of the detector in the center of the area is another of the basic assumptions made in the methodology, because all of the charts are based on a symetrical situation. If the detector is not symetrically located we will have to adjust some of the results, but this will be explained later.



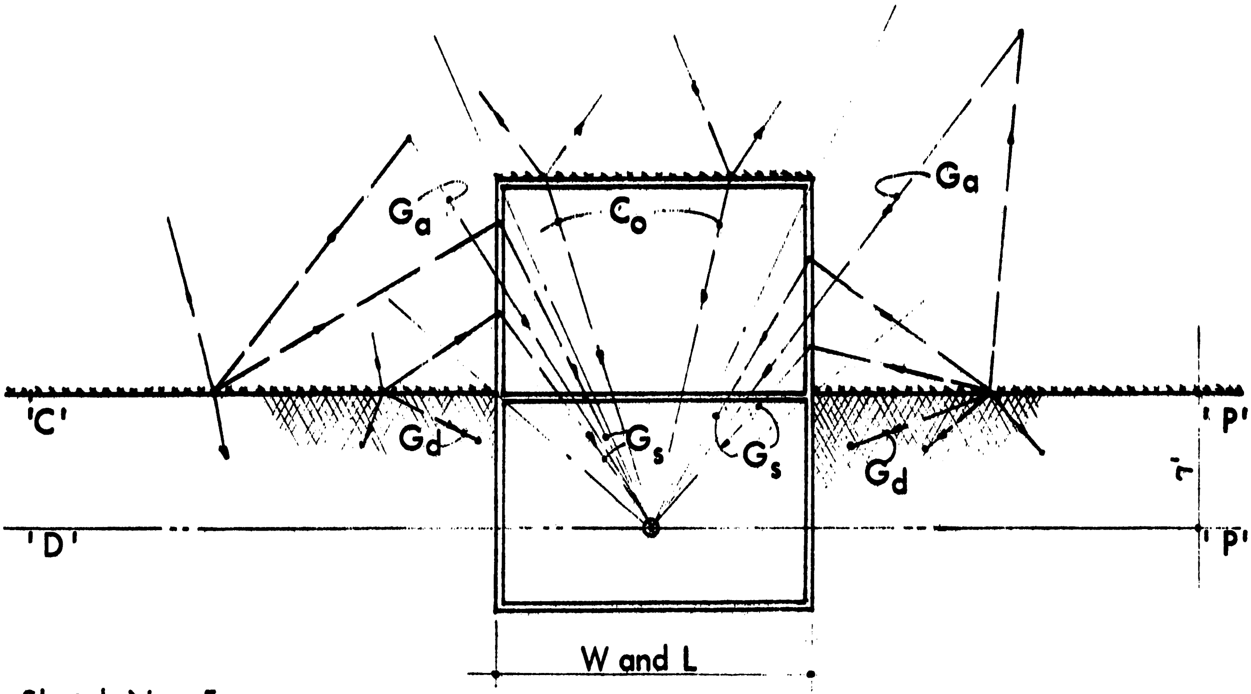
Sketch No. 4

If we consider the ground contribution C_g, in the situation described by the sketch we will see that the radiation which can reach the detector in a direct path from a source on the ground will be removed from the detector by one-half of the distance W or L (the dimensions of the area defined) and must pass through that portion of the wall barrier between the detector plane and the contaminated ground plane. Likewise any radiation reaching the detector as a result of skyshine, or albedo, must pass through that portion of the wall barrier between the detector plane and the intersection of the roof. There will also be some of this type of radiation which will come through the roof itself, but we will neglect this for the moment. We can see that scatter radiation, from sources on the ground can reach the detector through the entire area of the wall barrier both above and below the detector plane. In addition there will be that radiation reaching the detector from the sources on the roof itself.

Justas we get farther away from a source of light, the intensity of it will decrease because of the familiar law of the inverse square of the distance, so will gamma radiation be attenuated by distance. This law will not apply completely because of the action of the air as an attenuator, but the concept is the same. So the greater the distances W and L the more attenuation we will get because of the distances involved. Thus the geometry of the structure becomes quite important. Later on we will take this into account when we develop the concept of the solid angle fraction. We will use these solid angle fractions as one of the parameters of the charts for determining the Directional Responses for the ground contribution and the Reduction Factors for the roof contribution.

So the methodology will require that we first determine these Directional Responses and then modify them by the quality of the barriers which the radiation must pass through in order to reach the detector.

If we take another situation described in sketch #5, where the detector is located in the center of a basement under the building in sketch #4, the radiation which could reach the detector in a direct path from a source on the ground must pass through the earth and the wall barriers of the basement. Because of the weight of earth, which makes it an excellent shield, we have effectively eliminated our G_d. There will be some of this which originates from the sources close to the edge of the building, but it is generally not worth calculating. If it does become important we will determine how to take this into account later on.



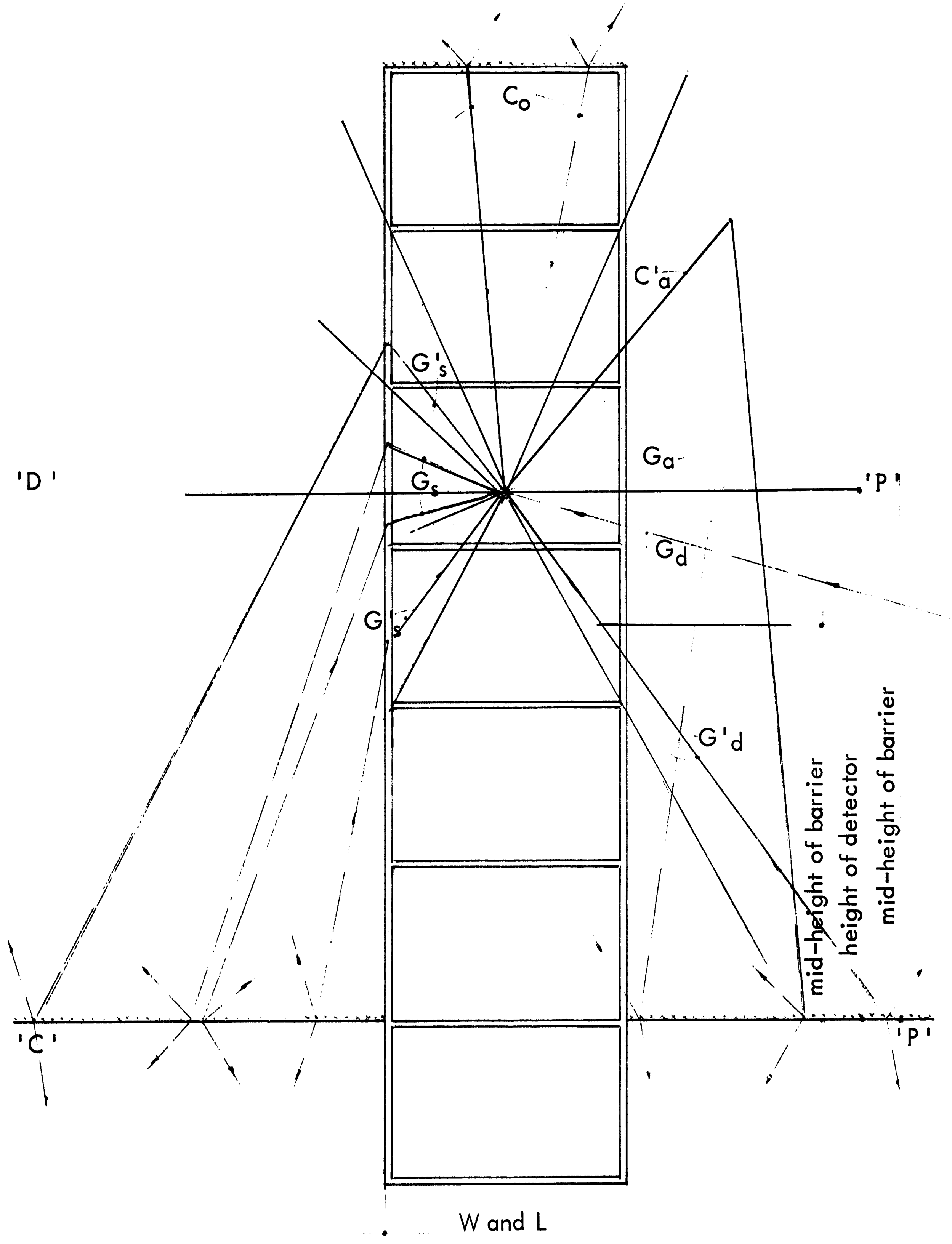
Sketch No. 5

When we examine our G_a and our G_s componants we can see that they must pass through an additional barrier of the floor above in addition to being further away (if we assume the same dimensions as in sketch #4). Also the radiation which might reach the detector from the sources on the roof is further attenuated by additional distance and the floor.

It is the elimination of the G_d componant, which generally is the greatest contribution from the ground, that makes basement areas much better than aboveground areas. At this time, though, let us examine the scatter, or G_s, componant. If the wall between the ground and the roof were not there, or of infinite thinness, there would be no possibility of any scattering in the barrier and so the scatter componant G_s would also be eliminated. If we gradually increase the mass thickness of this barrier up to about 20 pounds per square foot we will be increasing the contribution to the detector because of the introduction of the scattered radiation. We will find that it becomes necessary to increase the mass thickness of the barrier to about 40 pounds per square foot to equal the situation without any barrier. Above this value the absorbtion of the barrier is such that we will better the situation by the addition of more mass. This can be seen if we examine the Reduction Factors from Chart #4 in A&E Guide for an area of 5000 sq. feet and the mass thicknesses indicated above.

You will notice that when we discussed the attenuation because of the floor barrier we did not break the emergent radiation down into the several componants of direct and scatter. When we are interested in any barrier other than the roof and the exterior wall we need not be concerned with anything other than the attenuation because of the absorbtion due to the mass thickness of the barrier. It is not necessary here to discuss the theory behind this.

It was mentioned earlier that radiation was attenuated by the air between the source of radiation and the detector. So if we move the detector to an upper floor of a multi-story building, as indicated in sketch #6, we should be able to anticipate a greater reduction in the intensity of the radiation at this detector because of the increased distance from the source on the ground.


C$_o$
C'$_a$
G'$_s$
G$_a$
'D'
G$_s$
'P'
G$_d$
G'$_s$
G'$_d$
mid-height of barrier
height of detector
mid-height of barrier
'C'
'P'
W and L

Sketch No. 6

If we examine the direct case we can see several different situations. We should recall that the response G_d refers only to that radiation below the detector plane and which will reach the detector in a straight line, and that we have assumed the detector to be 3 feet above the contaminated plane. In this case we assume the detector to be 3 feet above the floor in which it is located and because it is different than our original assumption we must allow for this greater height to account for the increased attenuation. The values for this type of response will be found in chart #6 in the Engineering Manual.

If we extend a line from the detector through the intersection of the floor and the wall on down to the ground, we can see that any radiation which will pass through the portion of the wall between this intersection and the detector plane will have traveled a greater distance before it strikes the wall than it did in the situation described in sketch #4, and that it still must pass through only one exterior barrier. The response, G_d' , however, must penetrate the walls of the story below and the floor immediately below the detector plane. In addition to getting a greater distance between the source of radiation and the detector we will find that the effectiveness of a barrier will increase as it is raised higher above the contaminated plane. This can be seen by comparing some of the values from chart #2. So the barrier factor for the walls adjacent to the detector will be better than for the walls of the story below. If we examined the contribution through the walls of the second floor we would find that there would still be the exterior wall, somewhat closer to the ground, but there would be the addition of another floor barrier. The important thing to remember here, is that we must take the height of the detector above the ground into consideration when we are determining the directional responses for G_d , and the barrier factors for the exterior walls, because the radiation must first of all pass through an additional distance, in air, before it becomes incident on the wall. Because the scatter response only tells us the portion of the emergent radiation which will be scattered in the wall because of the mass thickness only, it is not related to the height of the barrier. But because the radiation can be scattered anywhere in the wall we must determine our scatter componant G_s through the portion of the adjacent wall above and below the detector plane as well as the walls of the story below and the story above as indicated by G_s' in the sketch. And likewise with the skyshine componant through the upper part of the adjacent wall, G_a , and through the wall of the story above, G_a' . Also the responses G_s' and G_a' will be effected by the additional barriers of the floors below and above the detector plane.

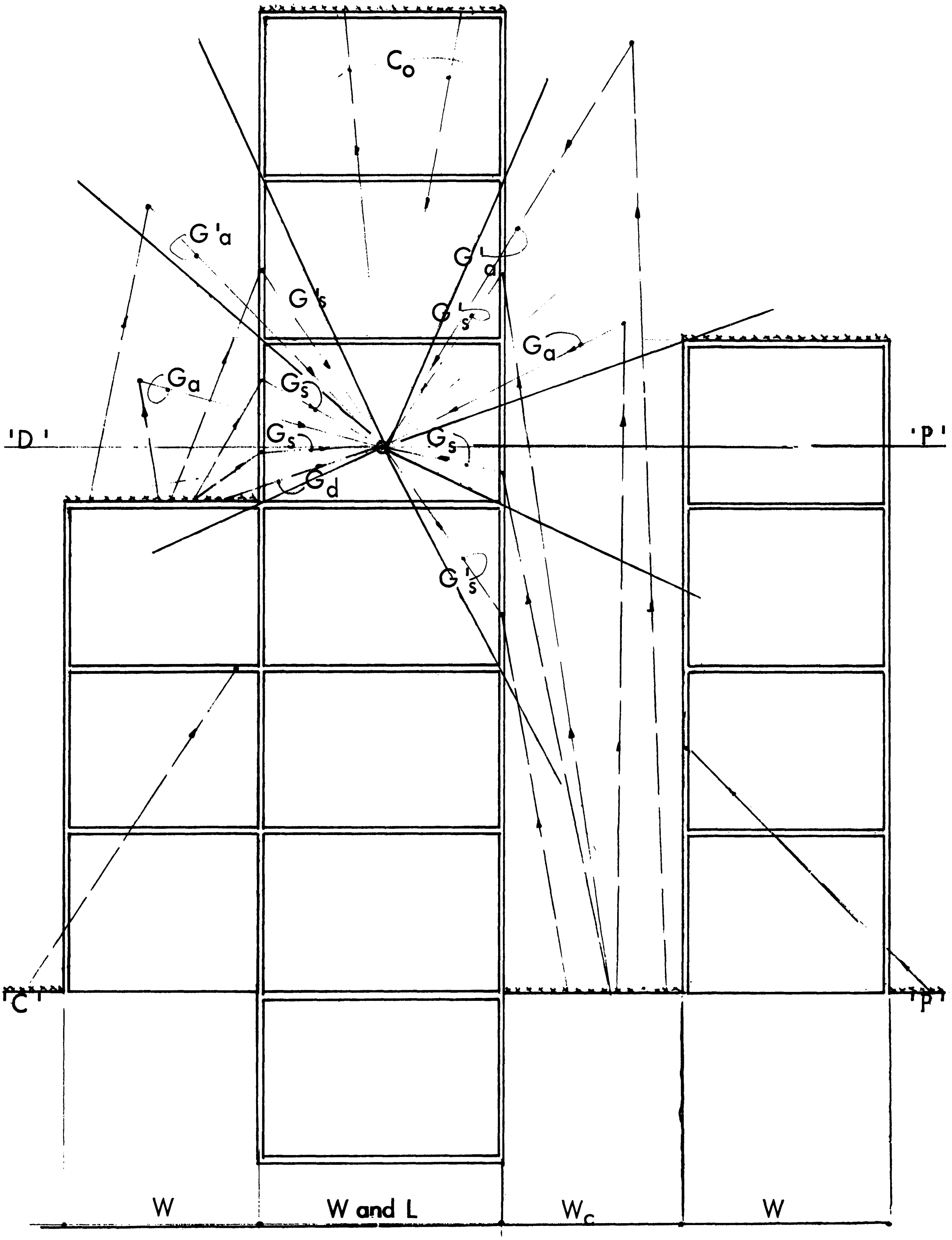
The roof contribution may be smaller because it is farther away and must pass through two floors before reaching the detector. So when we take all these things into consideration we might find that we would be better off on the fourth floor of this building than we would on the ground. Whether we would or not, will depend on the mass thickness of the various wall and floor barriers.

If we would compare the situation in the basement of this multistory building with that shown in sketch #5 we would find that the ground contribution would be the same, if we assumed that the dimensions and the construction were the same, but the roof contribution would be considerably less because of the increased distance and the additional mass thickness of the intervening floors. There might be some additional contribution reaching this detector because of the scatter and the skyshine through the walls of the second floor, but when you get into the calculations of these contributions it will become apparent that they are generally quite small. If the mass thickness of this wall is small there will be little scatter and a greater amount of skyshine - if it becomes larger the scatter would increase but the skyshine would be reduced - and again, both contributions would be effected by the mass thickness of the second floor.

So far the examples we have used have been rather idealized structures and in general we do not find buildings quite so simple. instance, most buildings are divided up into rooms and so we would have additional barriers because of interior partitions. If there was any mass to speak of in these partitions we would be helped considerably, and you will find out just how much when we develop the methodology in detail.

We have also been indicating isolated buildings located in the infinite plane of contamination. But in most of our urban areas there are buildings across the street, next door, etc., and these will have an effect on the relative value of our building, or space, as a protective structure from fallout radiation.

In the configuration shown in sketch #7 (which may be a cross section through a typical city block) there is the multi-story building from sketch #6, but we have added a three story building adjacent to the left and on the right a four story building across the street. In each case we have changed the configuration of the infinite plane of contamination, at least to the right and the left of the detector location.



Sketch No. 7

If the building to the right of the detector location has any mass thickness at all, and generally by time we consider both exterior walls, the interior partitions and the furnishings there would be considerable mass, we have probably eliminated the effect of any radiation from sources beyond this building and have limited the plane of contamination to the width of the intervening street. So if we can eliminate the sources of radiation we are, in essence, turning out some lights and reducing the amount of radiation which might reach the detector. Just as the location of the building on the right helps the detector located in our multi-story building, so would this building help a location in the other building, or each would be of mutual benifit to each other. In the shielding methodology we call this situation Mutual Shielding, and we will demonstrate a means for taking this into consideration.

With the detector still located of the fourth floor, the addition of the building to the left has, in effect, raised the ground right up to the same situation that we would have in sketch #4, except that the strip of contamination would be limited in dimension, and thus would probably be of lesser significance than the infinite plane. But it would be necessary to examine this in detail because the sources closer to the detector are more serious than those farther away. Again, it really comes down to the fact of examining the geometry of the situation. This situation is really one of mutual shielding in somewhat of the reverse from that on the right side.

The protection offered from fallout radiation would probably be better on the ground floor of the situation described in sketch #7 than it would be in sketch #6 because of these mutual shielding conditions. Again this would depend on the mass thicknesses of the walls and floors of large buildings and the building to the left, but the methodology will explain how we take these into consideration.

So, from a qualitative point of view, these examples should give you some idea about the kinds of radiation, direct, scatter, etc., that would reach the detector, and what it must go through in order to reach it. This is really the essence of shielding methodology. First of all make a sketch of the geometry, and generally plans and sections are needed, analyze the locations of the detector and the sources of radiation, determine the directional responses G_d , G_a and G_s , analyze the barriers, walls, floors, etc., determine the variables of height and the dimensions of the contaminated planes, etc. These are all the basic input data which will be required in establishing the functional equations. Once these equations and the values are established, the rest becomes a matter of simple arithmetic.

BIOLOGICAL EFFECTS

Edward A. Carr, Jr., M.D.

Today I'm going to discuss biological effects of radiation and as the biological effects of radiation depend upon the effects of radiation on the materials which it strikes, we will start by a consideration of the effects of radiation on any kind of matter.

I should warn you in advance that as one goes from the initial effects of radiation, in any matter which it strikes, to the long-term biological effects of radiation, there is a change in the time scale, and, therefore, don't be surprised if I talk in terms of an expanding time scale from the beginning of this lecture to the end. The time scale for the first part of the lecture is actually a matter of microseconds; the initial reaction of the radiation with matter. When radiation passes into any form of matter, if it is to effect that matter at all, there must be a transfer of energy from the radiation to the matter, much as a bowling ball must transfer some of its energy to the bowling pins if anything is to happen. Following this transfer of energy the matter is left in an excited and very unstable state for a very short instant and then settles down into a somewhat more stable state, which, however, is still sufficiently different from the initial state of the matter to initiate certain chemical changes. These then take place in the matter. In other words, the material does not return to its initial state, any more than the bowling pins return to their initial state. They fall over somewhere else, and let us assume that after they have fallen over, they are now in a position to initiate other changes. These other changes we will call chemical, and if we were dealing with living matter, the biochemical changes which will subsequently follow. And then in the long run, of course, one will eventually see changes at the physiological level -- changes which the biologist with a physician can actually observe.

Now let's go through these stages again. The first stage -- the stage of transfer of energy from radiation to matter -- the initial stage, you might say, of impact differs from one form of radiation to another. As you know, some radiation is particulate -- alpha particles, beta particles, and so forth. Other forms of radiation are non-particulate: x-rays, gamma ray, and so forth. If, for example, an alpha particle enters any form of matter the alpha particle can excite other atoms, or, being a heavy-charged particle, the alpha particle can actually ionize some of the atoms, that is, strip off some of the electrons in the material it strikes. And if there are high-speed alpha particles there can actually be nuclear collision. In other words, if this represents the atom (there are electrons around them) in the material that the alpha particle is striking, the alpha particle, when it comes in here, may just excite the whole atom, may actually strip off electrons from it and leave the atom charged, or may actually, if it is a heavy alpha particle traveling at high speed, strike the whole nucleus and blow the nucleus apart -- break up the nucleus into fragments. (Figure 1.)

Now, smaller sized particles, beta particles, may be either negatively charged, in this case they are our old familiar negative electrons, or they may be positively charged, called positrons. A negatively

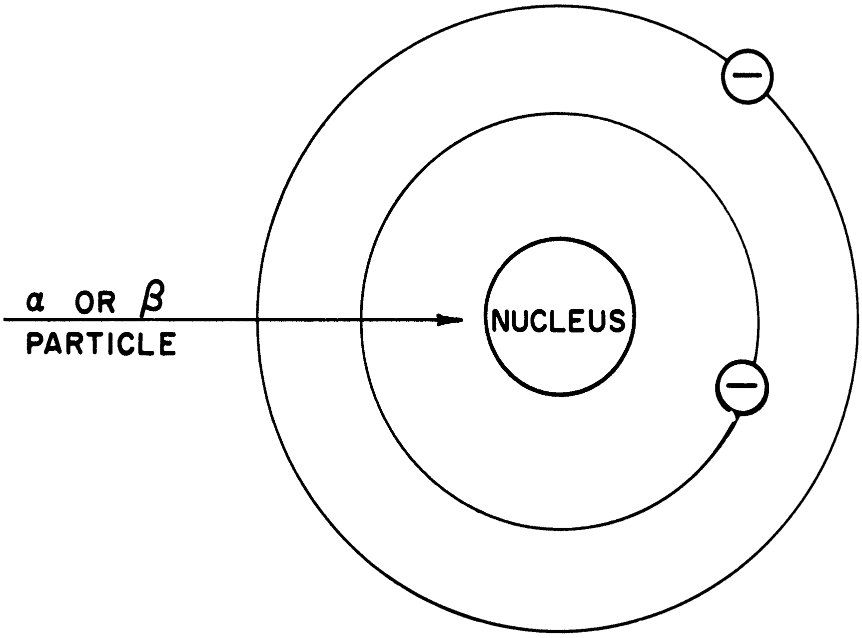


Figure 1. Atom and Particle

charged beta particle may excite or may ionize or it may do a third thing. If a beta particle comes in, as it goes by the atom it may slow down but not be stopped, and as it slows down the energy of deceleration, the energy lost as it is slowing down, comes off in the form of radiation, and this is called by the German term, deceleration radiation or radiation that is slowing down, Bremsstrahlung. A positive electron, positron, will also cause excitation and ionization, but it does not lead to Bremsstrahlung. A positive electron will pick up some negative electrons in the material that it hits, the two will unite, they will be annihilated, and they will give off gamma rays as an annihilation radiation. Gamma rays interact in several ways. Gamma rays are non-particulate. When they enter matter they may knock off electrons (so-called photoelectric effect), they may knock electrons and bump off themselves in a different direction, at a different energy (so-called Compton effect) or they may create a pair -- a positron and a negative electron (so-called pair production).

Neutrons are heavy non-charged particles, and when neutrons enter matter they may take part in so-called elastic collision, which are an exception to what I have described in that there is no energy exchange, or they may take part in inelastic collisions where there is energy exchange, or neutrons may be captured by an atom. A neutron may actually come in and strike an atom and be taken into the nucleus of the atom and therefore make a new atom (so-called activation). And lastly, neutrons can actually sometimes be sufficient as to break up the atom into fragments.

Now, the practical consequences of these are as follows. An alpha particle, being very heavy, can cause all the effects that I described initially here, but being very heavy and very heavily charged or being relatively heavily charged, cannot go very far because it is causing all these reactions very intensely, and therefore, gives up all its energy in a very short time. Therefore, the main point is that an alpha particle won't go very far. My sleeve would be enough to stop an alpha particle. On the other hand, if internally taken, an alpha particle emitter is very dangerous. Because, though the alpha particles won't go very far, if they are already inside you they will irradiate the tissue immediately around them, and they will irradiate it very heavily because they give up a great deal of energy.

A beta particle will travel further; it is more difficult to stop a beta particle because it doesn't give up its energy so quickly. They follow a zig-zag path and it might take more shielding to stop a beta particle.

A gamma particle will travel even further, in fact, theoretically you cannot stop all the energy of a gamma ray. Theoretically you cannot stop all the energy of a gamma ray, but in practice, like if you put up heavy lead shielding you can repulse the gamma rays. Theoretically the gamma cannot be stopped one hundred percent. Gamma rays have much more penetration. Now, gamma rays have these methods of interacting which I just described. And, if you note, one of these methods which I mentioned was the so-called Compton effect method in which an electron is knocked-off and the ray bounces off with a different energy. This means if I have a gamma emitter here, I may still get some irradiation from the gamma ray even though there is some good shielding between me and the gamma emitter. Not only may some come through the shielding, but also may bounce from various other surfaces. This is a rather crude concept; the Compton effect is a better way to describe it, but nevertheless, it gives you the idea that a gamma ray can bounce -- the bouncing ray being at a different energy.

Now, the interesting thing about the neutrons that I described is, that of all those methods of interaction that I described, the one that would interest you the most is the activation. If neutrons hit something, they can make it radioactive. And now we come to the matter of the important difference between being irradiated and being infected. People sometimes think that irradiation is like infection. You cannot see radiation. You cannot see the germs that infect you very easily, but once you pick up the infection, and have the germs you can infect other people. If you are irradiated, do you yourself become radioactive? Now, if you are irradiated with neutrons, you, yourself, can become radioactive, actually the sodium of you body can become radioactive, and people who have been very heavily radiated, as for example in the Yugoslav reactor accident, the doctors themselves became radioactive; their sodium lights up. Some of these people, in fact, I believe most of the people of the Yugoslav reactor accident actually survived, but there wasn't one hundred percent survival, and they were pretty sick. What I'm trying to say is that if you get close enough to a neutron source in order that you get activated, in most practical situations you were in a place where you were pretty heavily irradiated. I suppose that this doesn't theoretically follow; one could mildly activate somebody with a mild neutron source. As a matter of fact, that has been done therapeutically in one situation.

But for practical purposes -- let's go back to an atomic attack -- if you were close enough to get much of the neutron flux, I think you would have been killed about eight other ways before that one killed you and therefore, it wouldn't be a very practical thing to worry about; you have plenty of other things to worry about. That method of getting radioactive, although it exists and although some people could be activated and still survive, from a practical standpoint that doesn't represent any tremendous hazard to other people.

You might think that with all these particles bouncing through you, (for example I mentioned beta rays could give off Bremsstrahlung, could give off radiation of deceleration) if you are irradiated, then shouldn't you be giving off these rays -- these Bremsstrahlung -- which are actually x-rays. Sure, if I irradiated you with beta particles, momentarily at the time of your being irradiated, you might give off some of these, but actually you don't have enough heavy metals in your body to give off very many, if any. From a practical standpoint the irradiation that you would give off from the standpoint of Bremsstrahlung would not be very much. However one way in which you can get radioactive is the simplest way, one which you would know even before I mention it to you, namely, is if you get a radioisotope on you and you were a carrier of the radioisotope, in that sense you are radioactive. In other words, if fallout spills something on you, if material is spilled on my arm, say, if that is emitting radiation, I'm walking around with a radioactive source So you can see that this is a very crude, simple way of being made radioactive, in that you have the stuff on you and it is radioactive. Similarly if you ingest radioactive materials, again you're radioactive in the sense that it's there and the isotope (the radioactive material) is what is giving off the rays, and you, yourself, are, you might say, the passive carrier of it.

Although these hazards exist, they are, I believe, the least of our troubles. I don't believe that it wouldn't help to worry about radiation but I don't think this one is our major hazard. Again, if you get enough radioactivity in you so that you are a hazard to other people, I think again that you are in pretty serious trouble yourself and you are not likely to be around very long, being a hazard to other people anyway, except where certain specific radioisotopes have been given for therapeutic purposes. Once in a while we give people enough of a radioisotope so for a very few days he is relatively hazardous to other people and people can be around him for only short periods each day. This is a very special therapeutic situation where we have isotopes which are well localized in certain areas of the body, and in the accidental or enemy attack situation I don't think this would be a very practical point.

QUESTION: Would it still be true if they developed a neutron bomb, also, or has it changed?

ANSWER: A neutron bomb might change matters, I suppose, because of the fact that there it would be possible to get a neutron flux at a distance without being blasted and killed in several different ways. I am certainly no authority on the technology of these things at all. My guess might be that a neutron bomb would change what I said and people actually could be activated at a distance where they wouldn't necessarily be killed by blast effects. I don't know enough about the thing to tell you, but my guess is that probably it would change matters.

I don't deny that even with just fallout or radioactive material on you, you're radioactive. What I'm trying to get at is that it isn't like an infection in which everybody is carrying it to everybody else. It is the radioactivity in the fallout, the radioactivity in the water, and so forth that really represents the big hazard. I don't mean to completely ignore these other hazards, but it isn't like an epidemic where everybody is carrying it to everybody else. It is the environment that will irradiate everybody that is the principle source of danger.

Now, I have gotten off what I was going to talk about, namely the interaction of radiation with matter. All we did was get through the first stage -- the transfer of energy from the radioactive particles or the gamma rays and so forth to matter. After this we aren't quite sure what takes place. One theory is that if the material is watery the water is actually ionized and the ionized water plays a heavy top role in the effect of radiation in aqueous systems. I do not know whether this is true or not, but I bring it up to stress one point. The irradiation of brick, for example, will produce different changes than the irradiation of cloth or of a solution of electrolytes. In other words, the type of material being irradiated makes a big difference. Whether it is a watery solution or not makes a big difference. Whether there is a high oxygen tension or a low oxygen tension makes a difference.

The practical point is, remember that you and I are, whether we like it or not, watery solutions. When our ancestors crawled out of the ocean eons ago, they kept their environment with them, and we just have a bag of skin over this sea water, but we, ourselves, still have to live pretty much internally in an environment very much similar to sea water out of which we came and we are about 75 percent water. Having walked down here from the hospital, I am about 95 percent water right now, but the rest of you are about 75 percent water. And therefore, whatever reactions take part in an aqueous system are the reactions with which a biologist is concerned.

We aren't sure what happens after this energy is transferred in terms of specific reactions until we get toward the other end of the story, namely the things which you can begin to pick up biologically. We know, for example, that the nucleus of the cell, the central kernel of the cell, is more sensitive to radiation than the sac surrounding it (the cytoplasm of the cell). We know that enzymes and nucleic acids, among other things, may be inactivated, and we know that the synthesis of more enzymes may be inhibited. We know that the permeability of membrane in the cell may be altered, the ability of the cells to divide may be interferred with, and eventually we get changes, usually bursting in the nucleus of the cell, in the chromosome material, in the genetic material, but you can actually begin to see, under a microscope.

Now, we are moving on to changes which show up in the actual life of the animal. Now, we have moved from a scale of microseconds and, as you can see, gradually into an entirely different kind of scale, namely a scale which may go on for generations. Now, let's switch from talking about biology in general to man.

If we think of the effects of radiation on man, let's say man and other higher animals, then it is convenient to talk about an early stage and a late stage. But, by early stage now I don't mean microseconds, I mean things which would take place in hours, days, or weeks. And by late stage I mean things that would take months, years, or generations to take place.

The late effects I will discuss first, even though this may seem a backward way to do it, because I intend to pay less attention to the late effects than to the early effects. In the case of any atomic attack, we are going to have enough to do to survive the early effects without worrying about late effects and they are going to be the ones that are going to have to concern us first, but, nevertheless, we can't run away from the fact that if we survive the early effects, we still have plenty of late effects to worry about.

And late damage would include what? Well, in the long run, of course, it might include damage to subsequent generations, even unborn

(I beg your pardon, even unconceived generations). In addition, of course, there could clearly be damage to conceived but unborn children, in other words, children still in the womb. A pregnant woman's child might be damaged -- the child she was carrying. This is different than damage to your genetic material which would damage children that have not even been conceived yet. In addition to this a neutron radiation, and this might be another matter of the neutron bomb, can produce cataracts in the lens -- can produce damage to the eye. There is a premature aging which comes from exposure to radiation. There is a decrease in fertility and probably leukemia and possibly other forms of cancer may be increased in instances. These are all long-term effects of radiation.

Short-term effects of radiation are the ones, however, with which I will concern myself in the rest of the lecture. What happens to you hours, days, weeks after exposure to radiation? But before describing this in detail, I would like to make some preliminary comments on this aspect of it -- the short term effects. Not all of the tissues of the body are equally sensitive to radiation. For example, rapidly dividing tissues, such as the lining of the intestinal tract, the germinal tissue, by that I mean the tissue of the testes in the man or the ovaries in the woman -- the germinal, gonadal tissue, is sensitive. Skin tends to be quite sensitive. And particularly, blood-forming tissue -- the parts of your body in the bone marrow and lymph nodes that produce blood -- tend to be quite sensitive. As I implied before, embryonic tissue, that is, the tissue of a developing individual, before it is born, is quite sensitive. Some cancers are sensitive to radiation. That is why radiation is used in some cancers. In between, you might say of intermediate sensitivity, are tissues like liver, speen, kidney. And then we come to tissues which are relatively resistant, such as adult nervous system tissue, bone, and so forth.

Now, when one is irradiated, of course, the effects will tend to depend upon whether the radiation hits all of the tissues or whether it hits only a few of them. You are, of course, better off if some of your tissues are spared for at least two, or perhaps more reasons, one, if all of your tissues are irradiated heavily, then none of them can contribute very well to the repair processes. Remember that there is a repair process. A certain dose of radiation which would kill you if you received it all at once, you might be able to tolerate if spaced in several doses several months apart. This shows that there must be some ability to repair the damage from radiation, because you can tolerate a bigger dose if it is spread out over a long period of time. Well, if there is a repair process, then it is not formally necessarily so, but in practice, it seems that you are better off if not all of your organs are irradiated because of the fact that those which are not damaged can contribute to helping you survive. If everything gets knocked out at once, you are obviously in much worse shape. Furthermore, wide-spread radiation has a greater chance of, let's say, knocking out all the bone marrow. If you are very heavily irradiated in one part of your body, the bone marrow in other parts of the body (the bone marrow produces much of the blood, of course) will take over. You are better off if you are irradiated locally than if you are irradiated all over the body.

This brings up a matter of considerable importance when you are thinking about full body radiation. Remember, there is a big difference between saying somebody got 100 R of whole body radiation and somebody got 100 R of thyroid radiation, and it is most important to remember that the roentgen is in a concentration unit, not an amount unit. And the analogy which is a very homely and simple one but one that I like to use for this is the following: There is a difference between having 300 milligrams of aspirin in you (this is a standard aspirin tablet) and having 300 milligrams of aspirin for every cc. of body fluid in you. Just as there is a difference between putting one aspirin in a baby, (you can poison an infant with one or two aspirin tablets) and one aspirin in an adult. Just suppose that somebody has 300 milligrams of aspirin in the whole body, that is one thing. But if he has 300 milligrams per cc. of body fluid, that is obviously another. Furthermore, let's go a little further; let's suppose that we agree to express the aspirin as a milligram per cc. as a concentration unit. Now we say, what is the concentra- of aspirin in somebody, and let's suppose you say one milligram per cc. Well, if it is one milligram per cc. of stomach fluid, this is one thing, but it is one milligram per cc. of all the fluids in the body -- of whole body fluid --, this is something else, because there are only about 50 liters of fluid in the whole body, and there might be 100 - 200 cc. of fluid in your stomach, maybe even less than that. Obviously someone who has one milligram per cc. of stomach fluid has a lot less aspirin in them than someone who has one milligram per cc. of whole body fluid. Similarly someone who has 100 R of whole body radiation has a lot more (thinking of this crudely) radiation in them. He has more than a fellow whose thyroid got 100 R. And as a practical point, we can sometimes give people 10,000 R, from giving them radioactive iodine. We tak a woman with an overactive thyroid, give her 10,000 R she might get from radioactive iodine you gave her, and send her home. But if she ever got 10,000 R of whole body radiation, she would be dead in a couple of hours. There is a big difference between whole body radiation and radiation of a human organ. Now, you can say, how do you get whole body radiation?

Let's phrase that a different way. What are the things which decide whether you get localized radiation or extensive radiation? The things which decide when the radiation is external are geometrical factors, in other words, if I put a source here and stand here, like this, and happen to have shielding up to here, then obviously I will be irradiated up here, but this will be stopped. Fallout tends to fall around and give you, I'm sorry to say, a lot of full body radiation. That is one of the dangers of it. Now, these physical considerations will decide the pattern, you might say, of radiation, whether you get a lot of full body radiation, or whether you get very localized radiation, for external radiation.

What happens about internal irradiation? Suppose you ingest radioactive materials. Then it will depend upon the physiological disposition of what you ingest. If you ingest radioactive iodine which is quite important in fallout time it gets into your thyroid gland and your kidney excretes most of what does not get into your thyroid gland. You are left with quite a bit of radiation in the thyroid gland with most of the rest of the iodine gone from the body by urine excretion. On the other hand if you ingested radioactive cesium, this would eventually distribute pretty well through your muscles. You would get pretty much body radiation because that is the nature of the beast, you might say. That is the way cesium in the inorganic form behaves. And therefore, the method of the distribution will depend upon the isotope that you are dealing with and the chemical form in which it is.

Now with this prolonged disgression let us come back to the matter of the actual effects that one sees in a short-term after exposure. If one is exposed to an appreciable amount of radiation, what is the so-called LD-50, the dose that, without any treatment, would kill about 50 percent of the population. Well, fortunately nobody has had an opportunity to see, but on the basis of experience with people where there have been accidents, and extrapolation of animals, although not all animals have the same LD-50 (as a matter of fact, they don't; there are differences in species sensitivity), but on the basis of one thing and another, it seems as if the LD-50 is for whole-body radiation somewhere between 350 and 450 R. If you get any large areas of humans that have had a single dose and they received 350 to 450 R whole body radiation, this would kill, if there were no treatment, about 50 percent. I do not mean that 50 percent would all drop down and die right off, they wouldn't. And I don't mean that the other 50 percent that survived would all feel well throughout; they wouldn't. But, if you followed it out for, let's say, several weeks, about 50 percent would die, if there were no treatment, and the other 50 percent would eventually recover. Now, then we get a little further along. Where do you begin to lose a great deal of hope and where do you stop worrying at all? Well, somewhere below about 75 - 100 R you don't even know you are sick. If you get less than about somewhere between 75 and 100 you, yourself, may notice nothing. You would never know you were irradiated if somebody didn't tell you. Around 350 to 450 R, as I say, is the Ld-50. If you get up around 600 R of full body radiation, the number of survivors is dropping down extremely rapidly. For all practical purposes, around 600 R, if you get above that, you've had it.

Now, what will medical therapy do to this? Below 75 to 100 R, if the individual knows he has been irradiated, he is likely not to seek medical attention because he doesn't even feel sick. Above 600 R not only is everybody likely to die without medical therapy, but I don't know how many you'd save with it either. You are in real trouble here. The principle place where medical therapy is helpful is, if you get somebody in this range, where without any treatment 50 percent will die, medical therapy can improve this situation considerably. And, indeed, the principal purpose, as far as from the medical standpoint, of fallout shelters or anything else is to keep some form of ordinary medical attention available. It is not as though you have to do magic things. I will describe some of these things later. Ordinary medical therapy can do something for radiation. Radiation damage is not completely untreatable, as you will see in a minute. The great problem of atomic attacks would be that even to get ordinary treatment is likely to be very difficult. And I certainly think that people that get very heavily irradiated are not likely to survive in any large numbers. People who get very light irradiation are not likely to be any medical problem anyway. It is the place in between where the death rate would be 50 percent where one can drop the death rate with proper medical therapy. Now, even with less than this, less than 75 to 100 R, if you actually study the blood carefully; if you perform the proper laboratory examinations, you may be able to detect radiation damage even less than that. I don't mean to say that at 75 to 100 R there is no damage. I mean that you aren't likely to see many symptoms or feel any symptoms of this lesser degree of radiation. Remember that particularly under disaster conditions it is often very difficult to be certain how much irradiation people got. Even in reactor accidents and so forth where things are under considerably better control, and where people are able to go in afterwards and find out, to some degree, what happened, and make fairly shrewd estimates as to the degree of exposure, it isn't too easy to determine how much exposure somebody really had. Therefore one should be very careful from a medical standpoint about just sort of consigning somebody to die because he is supposed to have received so much radiation, and so forth and so on. You can't say to somebody, "Now, you, according to this, have now received so much radiation, please go over in the corner and lie down and die, and stop bothering me because you have had it." Fortunately, we cannot be that certain, and one should be very careful about making too quick assumptions about how much somebody got. Suppose somebody does get a pretty deep slug of radiation. What sort of signs and symptons does he have. Well, he has quite a few. They tend to have nausea, plus or minus vomiting, a feeling of lethargy, a weakness called malaise;

they just don't feel good. They may develop diarrhea. In severe situations, the diarrhea may be bloody. They may have bleeding elsewhere. They may run a fever. They may get an ulceration in the throat, giving them a very sore throat, and, of course, you can imagine that if there is diarrhea they might have ulcerations elsewhere in the intestinal tract. These are the ordinary things that one would expect. If things get bad, they may get not only nausea and vomiting, but they may get intense thirst.

Now, these things tend to occur fairly early after irradiation, a matter of hours afterwards. Let's say, somebody is heavily irradiated, at this point. Here is day 1, day 2, day 3, day 4, 5, 6, 7, 8, 9, 10 and so forth. Now, within the first 48 hours is when he tends to have the trouble. He may not notice anything for the first few hours, but let's say this is the intensity of the symptoms, and this is normal. Somewhere within this first 24 hours, perhaps within 3 or 4 hours, 6 or 8 hours, he may be nauseated, he may vomit, he may feel bad, and this may go on for a day or two. Then it tends to subside and let's suppose he has received 150 R. As it subsides, he then goes into a period of relative well being for a period of 2 or 3 weeks, and then he gets a second reaction, and this second one may last weeks or months, or may not last very long, and during this time the bleeding is likely to be much more severe. He may have a recurrence of diarrhea. Here he is very likely to have bloody diarrhea. He may bleed into his skin. He also has a tendency to a recurrence of the nausea, vomiting, lethargy and so forth. As I said, he's now getting new trouble; he's bleeding into his skin; he may have nose bleeds. Furthermore, the white blood cells which protect against infections have been depressed and he picks

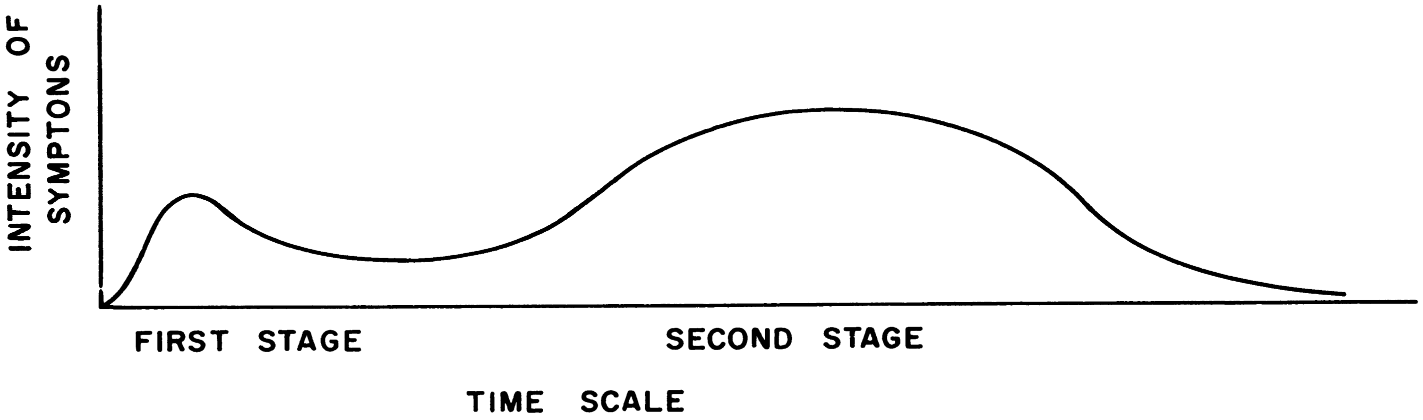


Figure 2

up infection quite easily. As the weeks go on he begins to get pale and anemic. If he survives, this second stage will last for a certain period of time, often weeks or even months, and, of course, in this second stage he may also lose hair, which if he survives, will come back. This is the general pattern of radiation effects. Now, it is important to realize that this general pattern will be modified in one of two directions. The more radiation you get, the more this tends to bunch together, in other words, this intensity gets worse and worse. Furthermore, this period of relative well-being before you get in trouble again gets shorter and shorter until people who are heavily irradiated -- they hardly get over the first stage before they are right back in trouble again. Then you can see what is obviously going to happen. If you get even more radiation, you never get into the period of well-being, you just stay sick and go on out and die.

Now, let's go the other way. People who get less amounts of radiation, not only do they have this prolonged period of well-being, but it tends to be somewhat longer in people who have less irradiation. I think you can see what is going to happen here. These peaks are going to get lower and lower until finally this one may disappear entirely and all that happened was that the fellow got a little nausea the first day and never any of it came back. However, you couldn't see changes in his blood and as far as his system was concerned he never had a secondary reaction, and then you get further, until you get down to 50 R, below 75, the reaction just never occurred; he never got a dose of radiation. This, then is the general pattern of irradiation.

If you get very heavy doses there is one thing I didn't mention. In very, very heavy doses it will kill you in a few hours. Then, finally, the adult nervous tissue, which as I mentioned, is not particularly sensitive to irradiation, finally gets hit and one actually gets convulsions.

QUESTION: What's the explanation for this drop in there?

ANSWER: The delayed effect of irradiation is about the only thing I can say, which isn't saying very much. You said it is delayed and what is the reason for it, and I say the reason for it is because it is delayed. The point is that the first set of symptoms are really the difficult ones; why do you feel sick and so forth. We don't know.

The second set are really the ones which are easy to explain because by this time your blood has been depressed for awhile. The effect has taken a while to build up. But finally your bone marrow has begun to suffer from it. After all, when you irradiate something, many of the effects just do not take place very rapidly and what you are really seeing in that second stage is the damage to the gastro-intestinal tract causing the severe diarreha, bleeding, the ulcers in the gastro-intestinal tract, damage to the blood. The characteristic delayed effects of irradiation, which are so typical of most laboratory experiments in moderate amounts, whatever it does to the cells, the cell is hit, but it does not immediately die; its ability to divide -- its future is compromised, but not immediately.

What is more puzzling is what is going on initially. I do not know. Apparently the initial reaction simply subsides before this long-term time bomb effect takes over. But I think of everything I just got through saying, none of it really explains why it does, but I'm just describing it in other terms and I don't think we know <u>why</u>.

QUESTION: Is the initial phase really secondary as far as importance is concerned:

ANSWER: In most instances, yes, but at Hiroshima, etc., many people died, of course, in the initial phase if they got enough. Some people may die in their initial phase. I think from the standpoint of casualties you can say it is less important in the sense that lots of people sick for three and four weeks at a time are a greater strain on the medical facilities of the community than lots of people sick for two days. But don't get the idea that you cannot die in the initial reaction, because you can. In fact, in one way at least if you survive the initial reaction and go on, there is a certain amount of encouragement associated with that right off, isn't there.

Now, I should mention the final point, and that is: what about prophilaxis and what about treatment. Well, it is obvious that prophilaxis depends on several things, one is to get as far away from radiation as you can, number two, if you have to be around, be around for as short a time as you can, and three, get any shielding in any way you can. And these three things are the phases everybody that works with radiation, right from the beginning, is taught; those three things: time, distance, shielding. Don't get close when you don't have to, don't stay exposed to it any longer than you have to, and shield yourself. Dust and so forth, fallout should be removed, of course, as rapidly as possible, and don't get the impression, incidentally, that it is a waste of time. In fact, if you have something on your skin for a half an hour and it is radioactive, it still makes a big difference whether you leave it there for six hours more or whether you get it off. You may not have been fatally irradiated if it was there for a half an hour, but if you leave it there for 24 hours, that is taking a risk. I, incidentally, failed to mention one form of radiation effect. Radiation may also cause skin burns, skin ulcers, figuratively, so-called beta burns. Beta emitters which cannot penetrate very far if they fall on you or if you are exposed at close angles to them cannot get into the tissues very far unless you ingest them. The energy cannot be delivered deep into the tissue unless the beta emitter is ingested. If it is outside, it cannot penetrate far enough. A beta emitter can penetrate the skin (I mean the beta rays can penetrate the skin) and you can get quite a nasty burn from it.

As far as treatment is concerned, it is clear that the treatment for hemorrhage is, among other things, transfusion; the treatment for anemia is, among other things, transfusion; the treatment of infections depends upon the type of infection. As you know we have lots of antibiotics which will treat infections. The treatment of diarrhea is primarily replacement with fluid. People, when they tend to die with this bloody diarrhea, tend to lose so much fluid through the diarrhea that they really die of dehydration, they are nauseated with vomiting, they are unable to keep anything down by mouth, and as in any other situation, the thing to do is to keep people alive by intraveneous feeding until they can get enough repair of their bowels to hold on to fluids again. These things actually make a considerable difference, and, as I say, the big problem is how one is to survive any form of attack without having intraveneous fluids around to give the people. This is the problem. We can do things if we have everything. One thing that seems to be clear -- it does not do any good to load up your patient with a lot of antibiotics, etc. before he has the effects. In other words, if you were irradiated, should I start you on penicillin and aureomycin and terramycin, etc. It has been pretty clear that you cannot lock the door before the horse is stolen in this particular instance. If one gets ill, then one treats the infection, but if I just load you up with penicillin and terramycin, etc. ahead of time, all that happens is that I will kill off all the germs that are sensitive to penicillin, terramycin, etc., so you will get pneumonia with something that is resistant to them all. This is just like treating a child with measles. If you try to prevent pneumonia with antibiotics you do not get very far. If you try to treat any infections that subsequently develop it is much more effective.

This, then, represents our basic pattern of treatment. People come up and ask me about anti-radiation pills. From the theoretical standpoint, this concept is not a fake as far as I know. There have been substances developed which will in experimental animals offer a moderate degree of protection against radiation effects. I do not know of any which have been shown yet to offer any significant degree in man, and have been shown to be safe when taken for long periods of time. Maybe one exists, but I do not know what it is. They are not phony.

They are not fakes, in the sense that they will do something in experimental animals, but I do not know if any have ever been developed which could be safely recommended to the public, and which would be sufficiently powerful to make it desirable to make them all available. And, remember, they would have to be something that would be safe taken for a long period of time because they are only useful as protection. It has been shown in experimental animals, if the anti-radiation pills are taken even a second or two after irradiation takes place they are no good. They have to be present in the body beforehand, therefore, you have to take them all the time, or at least, they might protect you from fallout, subsequent irradiation, after an atomic attack, if you started taking them as soon as the attack took place. But they would have to be taken ahead of time. I do not know any that have been tested and found to be perfectly safe for human use yet, and so far, the degree of protection is not tremendous. On the other hand, I do not mean that this is a complete fake; these stories you read are not complete fakes; with the experimental animal you can do a little. The trouble is that you do not have any real powerhouses as far as I know.

QUESTION: How about building future immunity to a thing like that?

ANSWER: Yes. This is an entirely different thing. Now first of all, some things -- some species -- are relatively immune, not completely immune, but some species can take a great deal more radiation than man. They did not build it up, they had it to begin with. I do not know of any evidence that people learn -- that any species learns -- to tolerate radiation. Remember, when one uses a spray it is really the same problem as treating an infection with penicillin. The spray, let's say, DDT, or something like that, will knock out a particular metabollic step in, say, the insect's metabolism -- one particular step, and over a period of time you tend to breed up a hardy, by survival of the fittest, group of insects that will survive that one step. Similarly, penicillin will do certain specific things to a germ, and you may tend to breed up a strain of staphylococcus (not that we want to, but do inadvertently), which has learned to by-pass that step. To learn to by-pass radiation effects, I think would require so many new steps that I would be rather doubtful that any species would be much good at being extremely resistant to radiation if they were not to begin with, because it is not just picking out one step and learning your way around, because it does a lot of things.

QUESTION: Well, I was thinking now, if a race ever develops that would be thick-skinned, that would have the tissue that would resist it, it might come about from an atomic explosion. That is a new generation I'm talking about.

ANSWER: Well, I would agree with you to this extent, that over a period of time (I would hate to see an experiment done, of course I'm sure you would too), but over a period of time (when I say LB-50, why do some people survive and some not) I suppose if there were repeated exposures to some which killed off a certain amount of the population and ones that did not, then you are right. Just as we all survive measles, if measles were introduced on an island where they have never had them before they would kill most of the population. I suppose that over that period of time, people who have a little thicker skin might have a better chance of survival and so forth, and over a period of several generations, that I suppose would take place in a gradual way, but I do not think it would be the sharp increase. I do not think that after seven generations of irradiation (perish the thought) that you would have strength increases the way insects are heavily resistant to DDT, but you might do it in a slight degree, that is true. The human race is relatively immune to leprosy and other things that once killed off thousands of people and the survivors have been relatively immune. Nevertheless, I caution against carrying this idea too far because it is not as relatively a simple thing as immunity to infectious diseases.

QUESTION: Well, I'm thinking about what happened in Japan, that newborn babies today from some of the people that went through this thing have shown no effects at all.

ANSWER: Yes, they haven't. That is true. I don't think that it has been proven yet that they are more resistant to radiation than a group of, say, our babies. Apparently they were not damaged badly, and you can say the ones that were more sensitive were the ones that were killed off, and this is the beginning of a radiation-resistant generation. Well, naturally I am just thinking theoretically; it would be impossible, ethically, to consider such an experiment, but if you took one hundred of those babies and irradiated them and, say one hundred American babies, I am not sure if you would pick up much difference in sensitivity yet. Maybe a little bit, but not much -- it would take a long while to get very much. This does not contradict what you say -- that the babies on a whole didn't seem to suffer a great deal. I expect that the people who got heavily irradiated died anyway.

QUESTION: I understand there is a change in the nutritional values, the diet and things of that nature, that would help sustain or quiet any situation.

ANSWER: I don't believe that much is known about the effect of diet on irradiation. As a matter of fact, it is a very interesting thing. I believe that animals that are a little bit underfed early, tend to be resistant to a lot of things, including irradiation, but how striking that resistance is I don't know. Actually, underfeeding animals a little bit, of course, makes them resistant in many ways. I don't mean heavily, I don't mean real starvation, slight underfeeding, and I think this applies to radiation, too, but I'm not certain.

QUESTION: You mean underfed early in life?

ANSWER: Yes. I know you're thinking about later in life. No, even early in life -- these are animal experiments, not human experiments. I'm not talking about starvation levels, or anything, I'm talking about a slight restriction of feeding of animals. This is purely animal experimentation. It tends, surprisingly enough, to make a hardier animal. A slight restriction, I do not mean real starvation. Real vitamin deficiency, of course, is an entirely different matter and will greatly decrease the survival of the animal.

QUESTION: What happens below this 50 R rate? Suppose you were subjected to something like 25 or 30 R for long periods of time; years, let's say.

ANSWER: You mean many exposures of 25 - 30 R?

QUESTION: Yes.

ANSWER: Oh, continuous 25 R -- you would get in trouble. Have you ever had a gastro-intestinal series where they pour barium down and put you in front of a fluorescope, etc. You probably had 25 R with one of those. You get a fair slug of radiation with the G.I. series, but we feel that there isn't much question about it, that the number of lives which are saved from early diagnosis of various cancers and so forth, far-out weighs, any slight danger which might come from the 25 R that you get -- as much as 25, not always 25 R, -- that you get from a G.I. series, and anybody who has chronic indigestion or something is taking a risk with his a lot more by not getting x-rays than getting x-rays. This is a very important thing; I think it is very dangerous that people don't get diagnostic x-rays if they need them. Nevertheless, you talk about 25 R day after day after day, you would get trouble. You notice that the other man in the room with you when you are getting your exposure is sheathed in a lead apron and so forth, with big heavy gloves on, and gets behind screens and so forth. The man who is carrying out these x-rays, if he does get exposed day after day, couldn't take 1 - 25 R exposure after another without eventually getting into trouble.

QUESTION: Is there some limit to what you should be exposed to?

ANSWER: Oh, well, you have now asked the question of questions. This one is capable of starting a donnybrooke. Any group of scientist is -- there is a terrible battle about this subject. -- Just read the scientific literature -- it makes the Kennedy-Nixon campaign look like a love feast compared to the way people are battling about this. The answer, of course, is nobody really knows. There is some evidence suggesting that if you get low enough, eventually you reach a dose which is "harmless." Other people would just have high blood pressure, would be carried out of the room convulsing, if I explained that any dose is harmless completely. It is unknown.

QUESTION: I have another question. Is the effect on a body from being subjected to radiation a function at all of the body surface? For instance, can a child survive this radiation that a larger adult would find is enough to kill him?

ANSWER: Well, how is he getting the radiation? This would be important here. On the whole children are, I think, somewhat more susceptable to irradiation. Yes, because of growing tissues, but remember, let us take the kind of thing we do -- if I give a child the same amount of radioactive iodine as an adult, the whole body radiation of a child is actually greater -- he is getting more R than the adult, isn't he? Because of the fact that there is a given amount of radioactive iodine spread through him gives more radiation per unit of mass.

QUESTION: If a person was subject to radiation and was partially shielded so he received additional on the upper part of his body, does this have a tendency to spread in the sense of a skin disease or a rash or something?

ANSWER: No. It would not. It might tend to get infected, for example, and that is a different matter. Any infection from any reason could do it. Secondly, years and years later, suppose they developed a cancer there, the cancer as you know might metastasize -- spread elsewhere. But if you got a bad burn here and it has really given you a lot of problems, this doesn't -- and the radiation that was delivered there wasn't delivered here -- other than infection in such matters -- this doesn't just spread up the arm. It just doesn't spill over that way. You probably would be getting it infected and so forth.

QUESTION: How about the treatment of water? Did you cover any of that?

ANSWER: This is outside my field. Do you mean, how should water be treated?

QUESTION: That is right.

ANSWER: It is something that ought to be covered. Well, if you irradiate water as such, it is unlikely that just spreading a beam through water is going to cause any permanent change in it, and unlikely to be of great danger. In other words, let's suppose that I have a jug of water, there is nothing in the water, it is full, and here is an x-ray apparatus or any form or source of radiation, and it turns out that we find out later that this thing was on for quite a while and that that water received a heavy amount of irradiation, but it is just a beam going through water. There is no solute in the water or anything else. After this was turned off, and there is now no more radiation going through this water will probably be potable. It would not do very much. Your problem is, let's suppose you have fallout and radioactive material falls into the water. That is what contaminates your water. If we took a jug of water and kept it sealed up and just passed an x-ray beam through it in a very intense degree and then turned the beam off afterward (I mentioned the ionization of water, but this is a very transient stage.) and an hour later, take the water and drink it, it probably won't do you any harm. Irradiating the water doesn't do very much to it. It's letting some radioactive material themselves fall into the water, radioactive iodine, or strontium, or something. That's where the danger comes in. That is what I think you meant by the treatment of water.

QUESTION: Is there a relationship between exposure and what, I think, is called mutations?

ANSWER: Yes, the germinal changes, I mean the changes to future generations, represent radiation-induced mutations. Mutation, of course, is just a fancy genetic word for change, but they mean a specific thing, change, as you know, in the chromosome, in the genetic material. Once it is changed, the change persists and you produce a different kind of offspring, and he continues to have that changed genetic characteristic.

QUESTION: Once a change has occurred then that change is in a sense a normal part of the chromosome from then on?

ANSWER: Well, the word "normal", I suppose, is not the one you mean, but a permanent part of it. Yes. Now, this doesn't mean that it will be passed on from generation to generation, because of the fact that, as you know, even though the blue eyes may continue to run in the family, the children may not have blue eyes for one of several reasons. At any rate, even in the best of families, let's say, the children may still not get blue eyes from the father because things don't work out that way, and similarly, a change induced mutation may not always show up in subsequent generations because it may be mixed with other genes and not express itself, but nevertheless, that particular genetic material has been changed, and changed for good. As far as it is concerned it stays the same way, and that is radiation induced.

Now, your question is, is there a ratio -- is there a rate between the amount of mutation that is produced and the amount of exposure to radiation. On the whole, the best way to think of this is in a probability. Even a small amount of radiation may cause, you might say, a hit on the chromosome and cause a mutation. But the more radiation, it is just like peppering a target with more balls, the greater the chance of getting bullseye. And, furthermore, this mutation effect probably doesn't have the relation to time that I mentioned before, where I said that if you took a large dose of radiation at one time, it might kill you, if you fractionated it over a period of time, you might be able to tolerate it. As far as mutation effects are concerned, probably the total amount you get regardless of how long a period of time in which you get it governs with one exception, of course, and that is if you spread it out not just over days but over years, eventually, of course, you begin to cause changes that no longer have any consequences to future generations because the person who receives them is no longer reproducing. And in that case, of course, he won't pass on any effects. He will just be too old to. But, except for that effect, the time matter is not really very important for mutations.

QUESTION: Is there one more point conversely? Is there any work being done involving the correction, we'll say, of something that might be labeled bad?

ANSWER: In other words, can you change the genetic material that has been induced? At the present time, no. Because of the work of Kornberg and others (I mean, the man that won the Nobel prize awhile ago), there has been a lot of work on the chemical basis for heredity. And now that something about this is known, it is conceivable, but I just use the word conceivable and nothing else, that you could put the right stuff in the germinal tissue and take the wrong stuff out, not only, because we are not only concerned with genetics mutations, we are just as concerned with natural ones, people who have defects in the family, but that is purely theoretical. This is strictly Buck Rogers stuff. I mean, something has been known about the chemistry, but it is one thing to say the chemical here is abnormal. It is another thing to say I can find some way of injecting or shoving this right chemical into somebody, and push the other one out and get the first one in. That, I think, is going to take a bit of doing, and whether it will ever be possible is anybody's guess.

EFFECTS OF NUCLEAR WEAPONS

A. J. Solari

The talk this evening is on the effects of nuclear weapons. The material and data I will present is based primarily on government publications either by the Office of Civil Defense or its predecessors, the Atomic Energy Commission, or Congressional Hearings. If time is available, I do a little brainstorming at the end.

The most important single reference is the 1957 edition of "The Effects of Nuclear Weapons", now out of print. A revised edition is underway and should be available in the next few weeks. This is the reason why you have not been issued one of your own personal copies. As I understand, these copies remain here at the end of the session. Some time in the next few weeks the new 1962 edition will be available from the government printing office so that you may buy them if you wish.

Let us start off at the beginning with the differences between a nuclear explosion and an ordinary TNT detonation. An explosion is defined as the release of a large amount of energy in a short interval of time within a confined, limited volume. In a conventional explosion, such as TNT, the energy arrives from the rearrangement of the atom of the explosive material, and you end up with new chemical compounds. In a nuclear explosion, the energy is produced by the rearrangement of the protons and the neutrons in the nucleus itself. Nuclear weapons are more powerful because the forces which hold the nucleus together, are stronger than the forces which hold atoms together.

In a conventional explosion nearly all the energy released appears immediately as kinetic energy or heat. Almost all of this is converted into a blast or shock. In nuclear explosions roughly 85 per cent of the energy released appears immediately as kinetic energy or heat, and of this, 50 per cent is converted to blast and shock, and the other 35 per cent is converted into thermal radiation. These numbers can be juggled around a little bit by the way the bomb is exploded or the way it is manufactured, but these are good rough guides.

There are some differences in orders of magnitude between conventional, and nuclear explosions. In a TNT explosion the gases that are formed reach a temperature of some 9,000°F. In a nuclear explosion the gases that are formed are several times atmospheric pressure, while in a nuclear explosion we get pressures in the order several hundred thousand times atmospheric pressure. In addition, because of the tremendous amount of energy released, the shock wave or the pressure wave is also followed by a high velocity wind traveling along behind the shock waves.

I have mentioned before this energy partition of a nuclear detonation. It is usually assumed that 50 per cent of the total energy released, appears as blast, 35 per cent as thermal radiation, 5 per cent as initial nuclear radiation (produced within a minute of the explosion) and 10 per cent as residual radiation or fall-out. As I mentioned before, these values can be altered some by bomb design and method of detonation. Thus, it might be possible by some chicanery to release — let us say, 50 per cent of the energy of a bomb as thermal heat with only 35 per cent going into blast.

Let us follow the air burst of a one megaton bomb with time to see how it goes. The explosion takes place in less than a microsecond. However, in this time, the bomb, that is the fuel, the fuse, the casing, the bomb fins, the guidance system, and whatever else is involved in the bomb construction is completely vaporized into a hot gas with a pressure of several million atmospheres. There is formed an intensely hot luminous mass which is roughly spherical in shape called the fire ball. Although the brightness of this fire ball decreases with time as the thing expands and loses its energy, the fire ball from a one megaton air burst would appear to an observer 16 miles away to be 30 times more brilliant than the noonday sun.

The length of time during which the flash will be visible varies with the weapon used. For example, a one megaton bomb — this visible blast would last 24 seconds. With a two megaton bomb the flash would last for 30 seconds. With a 5 megaton bomb 47 seconds, 10 megaton — 67 seconds, 20 megaton — 95 seconds. As a matter of fact, you can estimate the yield of a weapon if you observe the flash by saying that the yield is equal to .0022 times the time (in seconds) squared. In a one megaton explosion, the fire ball expanded to 7200 feet in diameter — about a mile and a quarter — at its maximum. So you can picture about a mile and a half ball of fire. My imagination bogs down at this.

This ball of fire soars like a hot-air balloon, starting off at about 300 miles an hour and going straight up in the air emitting thermal radiation and initial nuclear radiation. After a period of time it has lost its incandescence and becomes a cloud of condensed hot particles. At first the color of the cloud is reddish or reddish-brown due primarily to the nitrogen compounds, primarily nitric acid, which have been formed in the blast from the nitrogen and oxygen in the air. In fact, it has been estimated that in a 1 megaton explosion about 5,000 tons of nitric acid is created from the nitrogen and oxygen in the air. No one bothers to mention that this is one of the effects of the weapon; it is too trivial. The color of the cloud then changes to white due to water droplets and further condensation, and the eventual height it reaches depends on the heat energy of the bomb and the condition of the surrounding air. In megaton tests the tops of the clouds rose to a height of about 25 miles.

When the atomic cloud reaches a level where the density is about the same as that of the surrounding air, or reaching the base of the stratosphere, part of the cloud slows down and it starts to spread out horizontally forming the mushroom cloud. The shock front of the blast wave formed in this explosion breaks away from the fire ball about a tenth of a second after the explosion and behind this shock front blows winds up to 180 miles per hour. The bomb's heat radiation is so large that 5 per cent of the energy for a 1 megaton bomb is sufficient to convert about 100,000 tons of water into vapor, and the residual activity for a 1 megaton bomb, one hour after the explosion, is equivalent to the radioactivity of about 300,000 tons of radium. I do not think that there is more than a few hundred pounds of radium existing in the world today.

If you will look at "The Effects of Nuclear Weapons", on page 36 we can see some diagrams of what we have been discussing. There is a sketch showing an air burst either half a second after a 20 kiloton explosion or 1.8 seconds after 1 megaton. You will notice that there is a difference in the scale given at the bottom. Notice the fire ball giving off nuclear radiation and thermal radiation and the shock front breaking loose from it. And, on the next page, 4.6 seconds after a 1 megaton explosion, the fire ball is still giving off nuclear and thermal radiation, and you will notice that the shock front has hit the ground and reflected. Now if you turn the page, you will see one interesting thing. The reflected shock wave has caught up with the original one, forming a mach front and to reinforce the original shock wave, increasing the over pressure at that particular spot. Notice this mach front (I will describe it here as a point) is actually a circle. This is of extreme interest because this reflection and reinforcement of the shock wave that you get by an air burst tends to extend the area in which you can do damage. Notice in here that we are about three miles away from a 1 megaton explosion where the wind velocity behind the shock front is over a hundred and eighty miles per hour and the 6 pounds per square inch over pressure in the shock wave. And as time goes on, 37 seconds after a 1 megaton on the next page, we see this shock front or blast wave, still further away, some 9 and a quarter miles away from ground zero for the 1 megaton bomb. The rising dust, crud and everything else come up into the cloud, and we see on the last page the development of the much-familiar mushroom cloud.

Within the text you will find similar descriptions for other bursts. On page 50, there is one for shallow underwater bursts. On page 58, for an underground burst, and so forth.

Now there are three main types of bursts, depending on where you set this monster off. These are classified as an air burst, a surface burst, and a sub-surface burst either underground or underwater. Now an air burst is usually defined as one in which the bomb is exploded at such a height in the air that the fire ball at maximum brilliance does not touch the ground. For example, we mentioned the diameter of the fire ball of a 1 megaton goes up to 7200 feet, thus to have a one megaton air burst means that you have to explode it at least 3600 feet in the air. A surface burst is one in which the fire ball touches the ground, and as a result, vaporizing a good deal of the ground in creating a crater. An underwater burst obviously occurs underwater and an underground burst is one that occurs underground.

There is no real sharp demarcation between them all; that is, in your imagination you start off with a bomb exploding high in the air, it is an air burst, and as you move the point of detonation closer to the earth it begins to take the characteristics of a surface burst, and as you go from the surface to beneath the surface it takes on the characteristics of a sub-surface burst. The height of the burst will determine the strength of the original wave and its mach reflection wave, which further decides how far out you will extend the area of blast damage.

There are two types of air burst that are sometimes described. One is called the typical air burst, and the other is called the optimal air burst.

The typical air burst is one in which you select a height such that it is expected to cause the maximum blast damage to the average city type construction. An optimal air burst is one where you determine an altitude such that you would create maximum blast damage to the structures in the ground that you want to destroy. Hiroshima and Nagasaki would be typical air bursts; they were at about 1850 feet. As a rule there is no single optimum height of burst for someone to choose in regard to the blast effect anyway because it depends on the nature of the target you are trying to destroy. As a rule, the stronger the target the lower down you have to explode the bomb, and the weaker the target in the sense that you can knock it over with relatively low over pressure, you can increase the height of the burst because this mach effect tends to increase the area in which you could clobber the average wooden frame house or something like that. The air burst data that are presented about the effects of nuclear weapons that you usually find listed anywhere is for a typical air burst to create the maximum damage to the average city type construction.

Now let us take blast. The typical air burst raises hell with the largest amount of real estate as far as average city buildings are concerned. Still looking at blast, what about surface bursts? This affects less real estate because we use considerable energy of the bomb for digging this hole in the ground. But you have got very high over pressures close to the weapon and nearer to ground zero. This is the type of burst that you would select if you wanted to knock out a hardened IBCM base, something dug in deep. If you need a hundred pounds per square inch over pressure at the target, and then if you miss by a quarter of a mile or so with an air burst, you have missed it. But if you use a ground burst, and you miss your target by about a half a mile, you will still destroy it. So a surface burst substantially gives you tremendous over pressure close to the weapon but would fade away more rapidly as you go away from it.

The sub-surface burst affects the least amount of real estate because you are using more and more of the energy of the bomb to dig a bigger hole. It clobbers the hell out of anything in the immediate area, but it drops off very dramatically with distance. Essentially all you have done is dig a big hole and rupture the ground around it, but beyond this area everything is reasonably safe.

Now, let us take residual radiation fallout. With an air burst this forms very small particles which rise to heights very quickly so that the nuclear radiation really cannot reach the ground. The radiation emitted during this one minute or so that it has taken it to reach this altitude, is the initial radiation. The very fine dust that is formed by an air burst tends to get up high and fall very slowly to the earth. It gets distributed, more or less, around the world so that you have essentially no local fallout — no residual radiation in the sense in which we are using it here. So, perhaps the only way this will come down is if some rain or some snow comes through the cloud and brings it down to earth.

But in a surface shot the fire ball vaporizes a lot of earth and carries it into the air. This heavy stuff condenses out fairly rapidly. It consists of the soil (you can also consider this thing as vaporizing buildings, libraries, and so forth — people and so forth, in fact, if it shocks you, it is supposed to) and then this stuff comes falling back to earth in the immediate vicinity of ground zero. And this is how you get local fallout — the reason for the existence of this course. In a sub-surface shot the fallout is confined to a still smaller area that throws up a tremendous amount of dirt, but it comes right back to where it came from. So you have very intense radiation there but it is confined to a still smaller area. In a complete sub-surface shot where the fire ball does not get to the atmosphere at all, all the residual radiation and all "fallout" is confined, essentially, to within the hole.

Notice that you have got the same amount of radioactivity however you explode the bomb. The amount of radioacticity formed depends on the yield and what per cent of the energy came from fission (ignore any induced activity in the surface). It is just distributed differently. In a very high air burst, you tend to spread this stuff all over the world. Of course, it takes a little while for the winds to carry it, and it has some chance to decay before it eventually comes down. In a surface burst you spread it out over the real estate close to ground zero; in a sub-surface burst you confine it still more to the immediate area; and in a deep sub-surface burst it essentially all remains underground. So you have not changed the amount of radioactivity at all, you have just changed the way that you distribute it. For initial radiation there is essentially no difference in the amount of the initial amount of nuclear radiation formed by any of the three types of blast. The amount of radiation received by a target area is essentially the same for a surface burst or an air burst; however, the amount that reaches the target area is least of all for a sub-surface burst where most of it will be absorbed by the ground.

Now, for a world-wide fallout (this is essentially the opposite of local fallout) you maximize world fallout by exploding the weapon high in the air. If you shoot the stuff off here, it could fall in Siberia or South America, or France or wherever, and as you bring the weapon down closer to the ground, you deposit more and more of the stuff in your own back yard. So the Russians exploded their 50 megaton bomb high in the air because they did not want to louse up their own back yard.

Question: "How high up did they shoot?"

Answer: "I do not know how high up they shot. Calculations indicate a hundred magetaton bomb has a fire ball with a diameter of about eight miles, however, we did have some information from somebody in a previous class that, with this size weapon the fire ball did not have to touch the ground. The intense winds that came after the explosion swept up enough earth into the fire ball so they ended up getting local fallout anyway."

Let us summarize this in a short table.

TABLE OF RELATIVE EFFECTS OF AIR AND SURFACE BURSTS

	Air Burst	Surface Burst
Blast effect	Produces blast effect over largest area.	Less area effected than for air burst but with higher blast pressures closer to ground zero.
Thermal radiation effect	Produces most thermal radiation.	Produces about one-third as much as an air burst.
Radioactive cloud	Radioactive particles are small and rise quickly to great heights.	Heavily loaded with debris sucked up from ground and made radioactive. Does not rise as high as in air burst.
Residual nuclear radiation from fallout	Appears slowly and is distributed over a very great area such that it does not present an immediate danger to life, except if there is precipitation near the target area at the time of the burst.	Produces high radiation levels over a limited area soon after the burst.
Initial nuclear radiation	Same as surface burst.	Same as air burst.
World wide fallout	Produces more world fallout than a surface burst.	Produces less world wide fallout than an air burst.

Now I will give you an old concept which the Office of Civil Defense has discarded, but we will use it and refine it a little later. This is the old OCDM damage zone criteria. The "damage zone" approach to this blast problem defines the type of damage sustained by the average building in a city in and around ground zero. These average buildings are considered to be brick and wood frame houses, multi-story brick apartment houses, and one-story industrial buildings. This is the type of building that we were talking about — this type of construction. In Zone "A" it is considered that there is complete building destruction; for this type of destruction an over pressure of 7 pounds per square inch is required. In Zone "B" the buildings are so badly damaged that you really cannot use them for what they were intended. They are damaged so badly that you have to demolish then and rebuild them. This requires peak over pressures of 2 - 1/2 to 7 pounds per square inch. In Zone "C" the buildings are so badly damaged they must be vacated while repairs are being made. Major repairs are required.

Question: "What are the pressures required?"

Answer: "This is one and 1/2 to 2 pounds per square inch. This only gives you a rough idea of what the damage is. We will refine it later."

In Zone "D" some damage is incurred — doors blown off, windows broken, plaster shattered. But the buildings can be lived in while they are being repaired, and are usable as a building. And this is with over pressures of from 1 to 1-1/2.

Let us take a surface burst. And we will take Zones "A", "B", "C" and "D" for yields of 1, 50, and 100 megatons. Zone "A" goes from zero up to 2.3 miles for a 1 megaton. Zone "B" goes from 2.3 to 4.5 miles. Zone "C" goes from 4.5 to 6.5 miles. Zone "D" goes from 6.5 to 8.2. Do not take these decimal points as being that accurate.

Question: "What are you talking about this time? Are you talking about blast damage?"

Answer: "This is blast damage. This is the radius in miles".

Question: "You are not talking about heat destruction."

Answer: "No, I have not come to that at all. This is just blast — general blast."

So looking at this for 10 megatons, Zone "A" would go from zero up to 5 miles. Zone "B" from 5 to 9.7; Zone "C" from 9.7 to 14; and Zone "D" from 14 to 17.7. For a 50 megaton, Zone "A" goes from 0 to 8.5 miles; Zone "B" goes up to 16.5; Zone "C", 23.9; and Zone "D", 30.2. For a one hundred megaton, "A" goes up to 10.7 miles; Zone "B", 20.9. And I guess I made a mistake here. Zone "C" is up to 30.2, Zone "D" up to 38.2. We mentioned that the surface burst gave very high over pressures close to the target, but that you could affect a larger amount of real estate for the typical city building, (which is what we are talking about here) by using an air burst.

Let us take a typical air burst for the same yield weapons. Now Zone "A" goes up to 3.2 miles; Zone "B", 5.9; and Zone "C", 8; Zone "D",

10. For 10 megatons, Zone "A" goes up to 6.9 miles; "B", 12.7; "C", 13.2; "D", 21.5. (Do not have too much faith in these numbers, even though I am giving them to three Figure, I am doing it for my own benefit). 50 megatons, Zone "A", 11.5; Zone "B", 21.7, Zone "C", 28.9, Zone "D", 36.8. 100 megatons, Zone "A", 27.8; for Zone "B", 37.1; for Zone "C", 42.4; for Zone "D", 42.4. Multiple fires occur in Zones "A" and "B"; scattered fires in Zones "C" and "D".

TABLE OF BLAST EFFECTS
(old OCDM Zone damage)

Blast damage to brick and wood frame houses, multi-story apartment buildings, and one-story industrial buildings:

Type A Damage -	Complete destruction (requires greater than 7 psi).
Type B Damage -	Damaged beyond repair. For example, the front of a wood house is shattered so that the structure is for the most part collapsed (2.5 to 7 psi).
Type C Damage -	Major repairs required before it can be used for its intended purpose. For example, in a wood frame the wall framing is cracked, the roof badly damaged, and the interior partitions blown down (1.5 to 2.5 psi).
Type D Damage -	Light damage so that object or structure can be used with minor makeshift repairs or no repairs at all. Example: windows and doors blown in, and interior partitions cracked. (Requires from 1.0 to 1.5 psi).

BLAST DAMAGE BY SURFACE BURST - typical city buildings

(radii in miles)

	1 MT	10 MT	50 MT	100 MT
Zone A	0 - 2.3	0 - 5.0	0 - 8.5	0 - 10.7
Zone B	2.3 - 4.5	5 - 9.7	8.5 - 16.5	10.7- 20.9
Zone C	4.5 - 6.5	9.7 - 14.0	16.5 - 23.9	20.9- 30.2
Zone D	6.5 - 8.2	14.0 - 17.7	23.9 - 30.2	30.2- 38.2

BLAST DAMAGE BY AIR BURST - typical city buildings

(radii in miles)

	1 MT	10 MT	50 MT	100 MT
Zone A	0 - 3.2	0 - 6.9	0 - 11.5	0 - 14.8
Zone B	3.2 - 5.9	6.9 - 12.7	11.5 - 21.7	14.8- 27.8
Zone C	5.9 - 8.0	12.7 - 17.2	21.7 - 28.9	27.8- 37.1
Zone D	8.0 -10.0	17.2 - 21.5	28.9 - 36.8	37.1- 46.4

Multiple Fires - Zones A and B damage

Scattered Fires - Zones C and D damage

Looking at these figures, one might wonder why we would ever use a surface burst for blast since you get more damage by an air burst. This is because the over pressure criteria for Zone "A" is fairly low - 7 psi. If we had a higher criteria like 100 psi, the surface burst would be more effective.

The blast effect at a given distance from an explosion of a given yield depends on such factors as the type of burst (air or surface), the terrain, the building construction, and even meteorological conditions. For example, a massive blast resistant underground shelter located near ground zero may be only slightly damaged by an air burst, but vaporized by a surface burst. On the other hand, a surface burst utilizes considerable energy in forming a crater; hence, there is less energy available to cause damage at larger distances.

Most damage to humans from blast is due to collapsing buildings, flying building materials, and "translation" or "displacement" of the human body.

Now because of the variation in the structure of various items it is actually a little misleading to talk about a Zone "A" damage and then say that this applies to all the building that are in Zone "A" — they are all going to be completely demolished, independent of the type of building, and how old the construction is etc. So you can redefine this idea of "A", "B", "C", and "D", not into Zones, but into types of damage. There is a type A damage, which means that the item is completely demolished. You can define a type B damage where the thing is rendered useless for what it was intended to do. Then you can define a type C damage, where the item needs a kind of major overhauling to get it usable. You can define a type D damage where you can patch it up and it will still function. So, then you can talk about types of damage in regard to different features. For instance, take an automobile that is knocked over with perhaps singed upholstery, broken windows, banged up fenders.

If you can still get into the car, start it up, and drive it — this car has a type D damage. Take something like a window and you would have either type A damage or no damage at all. So we can actually take these things and draw radii for various types of damage; for telephone poles, or automobiles, or railroad cars, or things like this.

Now, if you look at page 247 of the Effects of Nuclear Weapons (or page 248 where the nomogram begins) then you will find some yield and distance relationships for the different types of structures and different types of damage. Take blast resistant reinforced concrete buildings. Notice the sb and ab on the column. By this time, you should be alert enough to realize they refer to a surface burst or an air burst. From the monogram you can determine the type of damage expected at various distances from different yield weapons. These have a similar monogram on pages 252 and 253. From these you can determine the different types of damage from various yields at different distances. In this way you can pin down the actual damage that would be expected, more accurately then with the old zone type of approach to the problem.

PART II

EFFECTS OF NUCLEAR WEAPONS

During the break I was asked about surface versus air bursts.

The graphs will show, better than any words I could possibly use, the effect of air versus surface burst on the blast.

Look at page 111 and you will see that the overpressure from a one-kiloton bomb goes up to 30 psi at a little less than .06 mile away from ground zero. On the other hand, if you go to page 109, taking the upper curve from surface burst, notice how the pressure climbs up very dramatically close to ground zero. Overpressures are much greater near ground zero, for a surface burst; but when you get further away from ground zero, you get slightly more overpressure from an air burst, because of the mach reflection which extends the distance to which the lower overpressures will reach. Any further questions of this?

Now, we get to the thermal effects which are caused by roughly 35 per cent of the bomb's energy which is liberated as infrared and ultraviolet light. This travels with the speed of light, but the radiation continues to be given off during the building of the fireball. Consequently, persons within the range of thermal damage have a short period of time to take some sort of protective action. The intensity of the thermal radiation on the ground depends on the bomb's size, distance from the bomb, and visibility conditions. It is assumed that visibility is reasonably good for these numbers I am going to put on the board.

Color has an influence on the amount of thermal energy absorbed. Some of the people who wore black kimonas, black clothes, or light clothes with dark embroidery or dark coloring on them got burned under the dark area of clothes. The dark colored area of clothes caught fire and the rest of it did not. So the color of the material has an influence on how much thermal radiation is absorbed.

Thermal radiation may be considered as traveling essentially in straight lines, although it does tend to scatter somewhat. Someone could set a flash bulb off in the hall and even though they aimed it in the other direction enough of the light would bounce around and come into this room so we would be aware someone took a picture in the hall. Thermal radiation does tend to scatter, but anything dense enough to cast a shadow will give some measure of protection.

Page 304 gives you some idea of the energies required to ignite fabrics. Page 299 and 298 list the skin burns, first, second, and third degree burns, caused by thermal radiation of various distances.

Incidentally, I should mention that there is a revised edition of the Effects of Nuclear Weapons which will be out very soon. It will be available for three dollars, I believe, from the Government Printing Office and for an extra dollar you can get a circular slide rule with which you can determine radii of blast damage, what overpressures you can get at certain distances, etc.

I am going to put a table on the board of thermal effects for various sized airbursts. Surface bursts will reduce these numbers about 30 per cent, that is to 2/3 of these values for the slant range.

This is the slant range in miles for first degree, second degree and third degree burns on bare skin under clear weather conditions. For 20-kiloton bombs, first degree burns, out to 2.4 miles; second degree, 1.6 miles; and third degree, 1.4 miles.

For one megaton, first degree burns out to 12 miles, second degree out to 9 miles, third degree out to 8 miles.

Ten megaton, first degree out to 27 miles, second degree 23 miles, third degree 21 miles.

Fifty megatons, first degree out to 70 miles, second degree out to fifty miles, third degree out to 42 miles.

One-hundred megatons, first degree out to 90 miles, second degree out to 65 miles, and third degree out to 58 miles.

Now, the next column I am going to put down will be the length of time for the arrival of one-third of the thermal energy. You will notice that on page 298 in the table for three different size weapons that it takes roughly three times as many calories per square centimeter for a third degree burn as a first degree burn. This makes it easy to remember, because one third of a third degree burn is a first degree burn!

How long does it take to get one-third of the thermal energy, which is independent of the distance, of course?

For twenty kilotons it is 0.17 seconds, a rather short time. It is usually stated that for the larger weapons there is some chance for evasive action because the thermal energy is given off over an appreciable length of time; so it is not all over in one big flash.

You might have a small chance to take cover. I wanted to see what length of time is available. Hence, this table. Therefore, in 0.17 seconds, one-third of the total thermal energy from a 20 kiloton has been received. This is too short a time to perform evasive action or take cover.

QUESTION: At what distance is this?

ANSWER: Any distance, it does not make any difference.

From a one megaton bomb, it takes 0.1 seconds for 1/3 of the total thermal energy to arrive. This is independent of the distance. It takes this long for the weapon to emit 1/3 the thermal radiation. So, if you could take cover in 0.1 second, you could reduce your thermal exposure to 1/3 of what it would have been if you remained in the open unprotected. If you were at the maximum distance from ground zero for a third degree burn (8 miles), you would have reduced it to a first degree burn.

For a ten megaton, 3.8 seconds; 50 megatons 8.5 seconds; 100 megatons 12 seconds. The numbers for the larger yields were obtained by extrapolation from data on lower yield weapons given in an OCDM publication. I am not sure how precise these figures are, but they should be in the right ball park.

For comparison, I will list the length of flash given previously in this lecture.

THERMAL EFFECTS

	Skin Burns (Slant Range)			Time for Arrival of 1/3 of Thermal Energy	Length Of Flash	Arrival of Blast Wave at 3rd° Burn Distance
	1st°	2nd°	3rd°			
20 KT	2.4	1.6	1.4	0.17 secs.	3 secs.	5.2 secs.
1 MT	12.	9.	8.	1.2	24	32
5 MT	24.	18.	15.	2.7	47	60
10 MT	27.	23.	21.	3.8	67	90
50 MT	70.	50.	42.	8.5	150	174
100 MT	90.	65.	58.	12.	213	238

In the last column, I have assumed that an individual is at a distance corresponding to a third degree burn, that is, 1.4 miles from a 20 kiloton, or eight miles from a 1 megaton, etc. Assume that a person has taken cover by ducking behind an opaque object, then he waits for the flash to recede, before dashing for cover from the on-coming blast wave. How much times does he have to take cover from the blast wave? That is, how long does it take the blast wave to arrive at the maximum distance at which a third degree skin could be expected?

At 1.4 miles from a twenty kiloton, the blast wave arrives in 5.2 seconds. One megaton, 32 seconds, 10 megatons 90 seconds; 50 megatons, 174 seconds, 100 megatons, 238 seconds. Unfortunately, at the distance I chose, the table does not give any excess time to leisurely seek out a blast shelter. However, this information is of use to civil defense directors, since by timing the length of flash, it is possible to estimate the yield. Timing the arrival of the blast is one method of estimating the distance from ground zero. Do you want the table giving probability of survival for zones around ground zero?

VOICE: Keep that a secret we would rather not know.

SOLARI: At least you see that at these distances, everything doen't happen at once. Perhaps you can do something to protect yourself.

QUESTION: Do you mean that with the bigger bombs it takes the heat a longer time to get to you?

ANSWER: No, the larger the weapon the longer is the period of time during which thermal radiation is emitted. Your skin has a chance to recover to some extent or to get rid of this heat energy. It, therefore, requires more calories per square centimeter to get a third degree burn from a yield weapon than a smaller yield one. I mentioned this before. On page 298 of ENW you will notice that to cause a given type of skin burn, more calories per square centimeter are required for a larger yield weapon. This is because of the longer length of time that the number of calories are spread over. For example, assume you were at the beach all day and got a mild sunburn. If you calculated how many calories per square centimeter you received, you would get a large number. If you absorbed that same amount of energy in a short period of time, say one tenth of a second, you would be burnt to a crisp. On a clear day you receive between one and two calories per square centimeter per minute from the sun.

The next item is initial nuclear radiation. This consists primarily of neutrons and gamma rays. The neutrons are released at the moment of detonation and for a few seconds afterward. The gamma rays come from the fission products. Some of the neutrons are captured in various material and the new atoms which are formed release a gamma ray at the time it is formed. Almost all of this radioactivity remains in the fire ball. As it rises high into the air, there is an increased distance between the radioactivity and the ground. The radiation intensity falls off to a low level in a minute or so, and then begins to rise as the fallout comes down. This permits the division into two categories, namely, the initial nuclear radiation (which is emitted in the first minute or so) and a residual, or delayed radiation, which is fallout.

The distance in miles from an air burst to get various doses of initial gamma radiation are given on page 354 ENW. Reading the graph we see that a dose of 300 roentgens of gamma rays from initial radiation are received 0.8 miles from a 20-kiloton; 1.6 miles from a 1-megaton; 2.1 miles from a 5-megaton; and 2.6 miles from a 20-megaton. A similar graph for neutron exposure can be found on page 366. The two are combined in the graph on page 372 which gives a total initial radiation dose of 300 rem at a distance of 181 miles from a 20-kiloton, 1.6 miles from a 1-megaton, 2.0 miles from a 5-megaton, and 2.5 miles from a 20 kiloton.

QUESTION: What is the slant range?

ANSWER: The slant range is the straight line distance between a point on the ground and the point at which the weapon is detonated.

For large yield weapons, the devastating effects of blast and thermal radiation by far outrange the hazards from initial nuclear radiation. The initial nuclear radiation is of concern primarily in hardened blast shelters which may be close to ground zero. It should be noted that initial gamma radiation is more penetrating than the residual gamma radiation. For example, if you compare the graphs on pages 357 and 403, you will notice that one inch of lead gives an attenuation factor of 3 for initial gamma radiation, but gives a factor of 10 for the delayed gamma radiation.

With these tables and graphs, you can if you wish take a given yield weapon and draw circles around ground zero corresponding to various blast overpressures, initial radiation levels, various types of skin burns, etc. Those of you who subscribe to McGraw Hill technical magazines probably saw such graphs presented in a recent issue which had a feature presentation on civil defense.

We now get to the final effect, namely, residual radiation or fallout. As mentioned before, this is the result of a surface or subsurface detonation. A surface burst pulverizes and vaporizes large masses of earth and lifts this material into the fireball. Radioactive material, primarily fission products created at the instant of explosion, plus some neutron-induced radioactivity in the soil (or water) under the explosion condenses on this soil and subsequently falls back to earth.

From the data released in the Operations Castle explosion of March 1, 1954, the following information was obtained. This was a surface shot estimated to be between 12 and 15 megatons. There was significant contamination of a cigar shaped zone about 220 miles long and from 20 to 40 miles wide. There was sufficient radiation in a down wind belt about 140 miles long and of varying widths up to 20 miles to threaten seriously the lives of all individuals who remained in the area for 36 hours and did not take any protective measures. The following figures are the total dose for the first 36-hour period:

10 miles downwind	5000 r
100 miles downwind	2300 r
110 miles downwind	2000 r
125 miles downwind	1000 r
140 miles downwind	800 r
220 miles downwind	400 r

The approximate time of the fallout arrival at the various distances downwind were as follows: 80 miles, 3 hours; 120 miles between 4 and 6 hours; 150 miles, 6.8 hours; and 310 miles, 22 hours. Notice that the size of the area contaminated with fallout tended to increase for the first day or so.

Studies were done at the Naval Radiological Defense Laboratories on fallout. One of these findings was that the time it takes from the first arrival of fallout to the maximum radiation level in roentgens per hour, is roughly equal to the time interval between the explosion and the arrival of the fallout. Thus, if fallout first arrives four hours after an explosion, fallout will continue to come down and the radiation levels will rise to a maximum in another four hours, that is, eight hours after a blast. This appears to be independent of weapon yield or distance from ground zero. There would appear to be no *a priori* reason to suspect this would be true.

Page 413 ENW gives dose rate contours from fallout at 1, 6, and 18 hours after a surface burst with a 15-mile per hour effective wind.

QUESTION: According to those numbers you have on the board, if a man were 150 miles downwind and unprotected he would definitely receive a lethal dose, wouldn't he?

ANSWER: Yes, he would.

QUESTION: Page 414 ENW shows the same thing. This is all concentrated downwind. There virtually is nothing beyond 10 miles upwind .... just over 300 roentgens....

ANSWER: I would say the 300 r total dose for 18 hours is just a little beyond 10 miles upwind. At least, that is how I would read the graph. However, you should not have any faith that the contour lines will look like this drawing in a real situation.

Page 413 gives dose rate contours at 1, 6, and 18 hours after a detonation, as we have said earlier. Notice the increase in contaminated area with increasing time. Page 414 gives the total accumulated dose at 1, 6, and 18 hours.

Page 419 gives an idealized one-hour reference dose rate contours for fallout after a 1-megaton surface burst with a 15 MPH effective wind. These contours are idealized in that the contours are smooth and symmetrical. This is not true in reality.

QUESTION: This shows fallout of 10 r/hr 320 miles away one hour after the blast ... is that right?

ANSWER: No. You are anticipating my talk. The fallout has not arrived 320 miles away in one hour. What they have done is to extrapolate the actual instrument readings of dose rate at that location, back to the one hour reference dose rate. This is what you have done in your problems.

This is a standard procedure in civil defense work. It may be a little confusing at first to look at this graph (p. 419) but as long as you understand the approach, it is rather simple.

A physics professor here at The University of Michigan once gave the students an assignment. We couldn't do the assigned problem so he did it in class. He wrote an equation on the board and we protested that this was not the right formula to use. It had been derived under conditions which differed from those in the assigned problem. He informed us that as long as we <u>knew</u> it was the wrong formula, we could substitute numbers in it and grind out the answer. As long as we did not take the results too seriously it was not a sin. However, if we did <u>not</u> know the formula was the wrong one to use, this would be a sin.

This graph (page 419) therefore must be interpreted correctly. The actual radiation levels have been extrapolated back to the one-hour reference value and then plotted. Except for the fact that you would not gain anything you could extrapolate back to the radiation levels which existed 24 hours before the bomb went off. As long as you know what you are doing, it is no sin. A one-second or one-minute reference dose rate could be used just as well as the one-hour reference level. However, it appears that fallout may not start for 20 to 30 minutes after a detonation. If it builds up to a maximum level in another 20 or 30 minutes, then the highest levels will start close to ground zero at about one hour.

The distribution of the fallout is highly dependent on the winds. If the wind velocity were very high, the fallout would arrive sooner downwind, but would be distributed over a larger area.

The only three cases that I know of, viz., the Japanese fishermen on the Lucky Dragon, the Marshallese Islanders, and two G.I.'s on a Pacific Island, the fallout was actually observed as it arrived. These were areas of lethal or near lethal doses. The visability of significant fallout in these cases led to the calculations by the U.S. Naval Radiological Defense Laboratory which developed the measure of fallout quantity associated with radiation intensity. Their studies of nuclear tests suggest that about 45 milligrams of fallout material per foot-squared corresponds to an H + 1 intensity of 1 r per hour. Thus, it is readily computed that nearly one ounce of fallout material per square foot is required for an H + 1 intensity of 1000 r per hour. One ounce of material per square foot is enough to see on a clean surface.

QUESTION: That is 1000 r per hour at H + 1 for one ounce per square foot? You say they saw it in these three cases?

ANSWER: These are the only cases that I know of. The G.I.'s and the Marshallese Islanders were evacuated. The fishermen went back to Japan. One of them died and I do not believe it was from fallout.

COMMENT: Art, the facts are fairly clear that this man died of hepatitis rather than fallout, and no one died on the Marshall Islands.

SOLARI: No, they were evacuated. To my knowledge, no one has been killed by fallout. The residents of Hiroshimo and Nagasaki were killed by blast, initial radiation, and thermal effects including fires. These were air bursts, so there was no local fallout.

QUESTION: Were we aware that there was or would be no fallout in Japan?

ANSWER: Yes, as I said, these were air bursts and the height of burst was presumably selected to maximize blast damage.

QUESTION: What about this one aircraft carrier that was washed down? These were apparently in a fallout region. They had their decks -- in fact the whole ship -- washed down with hoses apparently effectively with a spray. Could you apply that to a building?

ANSWER: I have not heard of it being done, but the principle should work. It would also tend to protect against thermal radiation. I do not know what you would use as a dependable water supply.

COMMENT: It would possibly all run down into the basement.

SOLARI: There are two items with regard to the effects of nuclear weapons which I have avoided until now. I am not trying to hide anything except perhaps my own ignorance. These involve thermal radiation. The first is a "fire storm" caused by a high yield explosion. The more I read about fire storms, the more confused I get. A fire storm, and I quote from ENW, page 548, is a "stationary mass fire, generally in urban build-up areas, generating strong in-rushing winds from all sides which keep the fires from spreading while adding fresh oxygen to increase their intensity."

The people opposed to civil defense efforts harp on the "fire storms" which they claim are inevitable. People in civil defense have little information on it. As a result, there is a dearth of factual information on the subject.

Fire storms are deliberately set to burn off wooded areas. A fire storm will remain confined as long as the embers and sparks which are thrown into the air do not ignite a new blaze. Apparently, any combustible material within a fire storm is fairly sure to be consumed. On the other hand a massive fire with a wind behind it can cover a larger area.

Having admitted my ignorance on that subject, I will turn to two other thermal effects. One is flash blindness or dazzle. This is caused by the bright light of the bomb. Remember it is thirty times as bright as the noonday sun to a person 60 miles away. This bright light causes a temporary and reversible dazzle or inability to see. Again, little information on this has been published. The most one gets is that it is a reversible effect, lasts for a short period of time, and the effects would be worse at night when your eyes are dark-adapted. This is about the sum and substance of what I have been able to find. I am sure there must be more information on it. The Air Force must be interested in this. Obviously, if you could fire a weapon off high in the air and blind every pilot for 30 or 60 miles around for one to ten or perhaps even 30 minutes, the Air Force would be interested in this. Of course, it is of interest to all, because if people can not see for several minutes, it will be difficult to perform any evasive action.

The other effect is retinal burns. This is a bizarre effect to me because distance provides no protection. I will modify this statement slightly in a moment. Distance alone does not protect you. The reason is that as you get further away, the energy that is received by the retina is decreased, but it is focussed on a smaller part of the retina so the amount of energy per square centimeter is the same.

At first this may be hard to understand, but let me give you an analogy. You have all taken photographs using a light meter. You can use your meter to take a reflected light reading off a person's face. You will use this to make a setting on your camera. Now, if you back off so as to increase the distance between you and your subject, you do not change the camera settings. You leave them alone. Why is this? After all the light landing on the film will be lessened as you back away, won't it? The reason is that the image on the film gets correspondingly smaller as I back away. The size obviously must decrease exactly as the light does. Hence, the light landing per square inch is the same.

Therefore, as far as retinal burns are concerned, these could occur out to great distances almost infinite distances except that the air and dust absorbs it.

QUESTION: You have to be looking at the bomb to get this?

ANSWER: Yes. Now, how serious this burn will be depends on the size of the burn and that particular area affected. I hope that the new edition of the Effects of Nuclear Weapons has more information on the subject.

QUESTION: Would these be similar to the burns you get from arc-welding?

ANSWER: I imagine so. Don't you get a dazzle from arc-welding.

QUESTION: Yes, but you can get blindness too.

QUESTION: These burns in the retina ... do they repair or heal themselves?

ANSWER: I am informed that they do not heal themselves. The damage is permanent. Any other questions?

VOICE: I have a couple of comments for what they are worth with respect to the fire storm. It takes a certain density of combustible material to support a fire storm and no where in Michigan is there this density of material.

ANSWER: I have heard this too, yet on the other hand my authority here at the University claims you can set a fire storm on one acre of forest.

VOICE: I don't think he could. A conflagration, perhaps, but not a fire storm.

ANSWER: No, it is a fire storm because he wants to confine the burning to a limited area. He admits it is a poor term. But I don't see why you could not have various sized fire storms.

VOICE: The other comment was this -- I was in Nevada in 1957. And we neophites put on the dark glasses and you could not see a darned thing under a normal light. But the natives, the guys who worked there did not wear any. They simply looked the other way and put their arms over their eyes. Their reasoning was they could get around and look at this darned thing quicker and see it better. And this is what they did.

QUESTION: They were still covered up?

ANSWER: Yes, but they uncovered quite quickly.

SOLARI: If you have five minutes I will go through one calculation and I will tell you frankly I don't know how good it is. In the congressional hearings I mentioned previously, they discuss a weapon exploding at very high altitudes, say 40 miles. The panel said a "pure inverse square law would apply" as it would be above the atmosphere. They mentioned the energy partition would be altered; so, perhaps 50 percent of the energy would appear as heat rather than 35 percent.

Let us take a 20-megaton bomb exploding 40 miles high. Now, one ton of TNT is equivalent to 10^9 calories (ENW p. 556) so 20 megatons equals 2×10^7 tons of TNT = 2×10^{16} calories. Assuming 50 percent thermal yield as in the hearings, so we take half of this, or 10^{16}

calories of heat emitted as our source. Now, one mile = 1.6×10^5 centimeters. If the height of the burst is 40 miles then the slant range "r" can be computed for any particular number of calories per square centimeter. I took five calories/cm^2, so $5 = \frac{10^{16}}{4\pi r^2}$. Solving for "r" we get 1.2×10^7 cm = 75 miles. Seventy-five miles is the slant range or the hypotenuse of a right triangle where the other two sides are the height of burst, and the distance (x) to ground zero along the surface of the earth.

So:

$$r^2 = 75^2 = 40^2 + x^2$$

$$x^2 = \sqrt{75^2 - 40^2} = 66 \text{ miles}$$

$$\text{area} = \pi x^2 = \pi(66)^2 = 13{,}700 \text{ square miles, which}$$

becomes compatible with its fallout area.

If we use a criteria of 10 calories/cm^2, the slant range (r) = 53 miles, and x = 34.8 miles. The area is $\pi(34.8)^2$ = 3600 square miles.

Equivalent Residual Dose Calculation*

Based on current scientific knowledge, and with very few exceptions, individuals will not become incapacitated or their ability to work be seriously affected if their exposures over a few days do not exceed 200 r. As the exposure over a few days increases beyond 200 r, the probability of radiation sickness requiring medical assistance rises rapidly -- the more the exposure the higher the incidence and the greater

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*Taken from notes by OCD. For background information see NCRP Rep. No. 29 "Exposure to Radiation in an Emergency" obtained from Section on Nuclear Medicine, Dept. of Pharmocology, Univ. of Chicago, Chi. 37, Ill. (0.50).

the severity of radiation sickness. Also, as the exposure increases the probability of death increases rapidly. If the dose exceeds 600 r most everyone so exposed will die.

The human body has recovery processes which are capable of repairing a major portion of the radiation injury except in cases where the dose is so great that death comes within a matter of days or a few weeks after the onset of exposure. Because of the existence of these recovery processes individuals are able to survive exposure to very large amounts of radiation when the exposure is distributed over long periods of time. The concept of the equivalent residual dose (ERD), previously called the effective biological dose, takes into consideration the recovery processes, and is used to allow for biological differences between exposures delivered during very short and very long periods of time. In situations where exposure occurs over a few days or less, the actual accumulated dose and ERD will be essentially the same. However, when exposure to radiation is spread over months or years the actual accumulated dose may be as much as five times the ERD. Under either circumstance the ERD is the controlling factor.

In evaluating the effect of damage from radiation exposure it may be considered that 10 percent of the exposure is irreparable; and that the body can repair about one-half of the remaining 90 percent in a month. The other half of the remaining 90 percent can be assumed to be repaired after about three additional months. Therefore, the ERD at any time is equal to 10 percent of the accumulated dose (the irreparable fraction of injury) plus the fraction of the balance of the accumulated dose which has not yet been repaired. It is assumed that recovery commences about four days after the onset of exposure and that radiation injury is repaired at the rate of 2.5 percent of the remaining injury per day. For all practical purposes this rate of recovery reduces the repairable damage to about zero by the end of four months postexposure.

The ERD can be expressed mathematically as:

$$(1) \quad ERD = 0.1D + 0.9D\ (0.975)^{t-4}$$

where D is the dose in a single day and t is the number of days from the time of exposure to the time at which the ERD is to be computed. (A table of powers of 0.975 is included as Attachment A.)

As an example, assume that a group of emergency workers had been exposed to 30 r each day for six consecutive days and to 20 r on the seventh day (exposure determined by dosimeter readings from a C V-740). Total exposure has been 200 r. About two weeks after the first day of exposure, this group is needed to carry out another emergency mission in a fallout area; and the CBR officer must compute their ERD at the end of fourteen days to determine whether they can be used without risk of serious radiation sickness. The computation, based upon Equation (1), is as follows:

No. 1 Day	No. 2 D Exposures	No. 3 $(0.975)^{t-4}$	No. 4 Value of $(0.975)^{t-4}$	No. 5 0.9D	No. 6 (#4 x #5) Not Yet Recovered	No. 7 Non-Re-Coverable 0.1D
1	30 r	$(0.975)^{10}$	0.776	27	20.9	3
2	30 r	$(\ \ )^{9}$	0.796	27	21.5	3
3	30 r	$(\ \ )^{8}$	0.816	27	22.0	3
4	30 r	$(\ \ )^{7}$	0.816	27	22.6	3
5	30 r	$(\ \ )^{6}$	0.859	27	23.2	3
6	30 r	$(\ \ )^{5}$	0.881	27	23.8	3
7	20 r	$(\ \ )^{4}$	0.904	18	16.3	2
	200 r				150.3	20

ERD at 14 days after start of exposure is the sum of column No. 6 and No. 7 of ERD = 150.3 + 20 or 170.3 r.

On the basis of this calculation it is apparent that, if essential, an additional dose of approximately 30 r might be tolerated on the fifteenth day. However, since the exposure of this group has been rather large it might be preferable to assign the task to another group with less exposure or if possible to postpone the operation for a while. This will take advantage of further radiation decay as well as additional biological repair.

As a further example, suppose that the CBR defense officer had to determine the ERD of the previously described emergency group 30 days after the start of their 7-day 200 r exposure rather than the ERD on the 15th day. The nonrecoverable portion of the 200 r dose remains 20 r. By applying the appropriate power of 0.975 to the remaining recoverable portion at 14 days (total of column 6, or 150.3 r) and adding it to the 20 r, the ERD at 14 days can readily be converted to the new ERD at 30 days from start of exposure. There are 30-14 or 16 days for additional recovery to take place. Therefore, ERD (at 30 days) = $20 + 150.3\ (0.975)^{16}$ or ERD = $20 + 150.3\ (0.667)$ or 120.2 r.

As a third example, if it should be necessary to estimate how much time must elapse before an additional specific dose could be reasonably accepted over a period of a few days, the calculation can be made. Assume that an emergency operation in a fallout area would involve an acute exposure of 100 r and it was decided to use the same group as in example 1 above, which had been exposed to 200 r during the first seven days. The CBR defense officer will make the computation to determine how much time will have to lapse after the fourteenth day of exposure before the additional planned 100 r of exposure can be undertaken without risk of serious radiation sickness. The nonrecoverable portion from the first seven days' exposure remains at 20 r.

The ERD at the end of the new mission will be made up of the following parts:

Nonrecoverable portion	20 r
New dose (planned)	100 r
Not yet recovered portion (similar to column No. 6)	X
Total	200 r

Obviously X must equal 80 r at the time when the additional planned exposure is undertaken. The column No. 6 value in the first example must be reduced by a factor of $\frac{80}{150.3}$ or 0.542, i.e., 0.542 must equal $(0.975)^Y$ where Y is the additional number of days required (in excess of 14) for recovery. Referring to the table of powers of 0.975, it is found that "t" would have to be about 25 additional days (beyond 14) before the planned 100 r short-time dose might be accepted without exceeding a 200 r ERD. Thus the operation under the assumed conditions could be planned for the 40th day subsequent to the initial exposure.

As a fourth example, assume that the CBR defense officer were required to determine the ERD of an emergency group at the end of 14 days if their daily doses as determined by personal dosimeters during the first week were: 95 r, 15 r, 50 r, 22 r, 10 r, 5 r, and 3 r -- again a first week total of 200 r. The computation would be as follows:

No. 1 Day	No. 2 D Exposures	No. 3 $(0.975)^{t-4}$	No. 4 $(0.975)^{t-4}$	No. 5 0.9D	No. 6 Not Yet Recovered	No. 7 Not-Re-Coverable 0.1D
1	95 r	$(0.975)^{10}$	0.776	85.5	66.4	9.5
2	15 r	$(\quad)^{9}$	0.796	13.5	11.7	1.5
3	50 r	$(\quad)^{8}$	0.816	45.0	36.7	5.0
4	22 5	$(\quad)^{7}$	0.837	19.8	16.6	2.2
5	10 r	$(\quad)^{6}$	0.859	9.0	7.7	1.0
6	5 r	$(\quad)^{5}$	0.881	4.5	4.0	0.5
7	3 r	$(\quad)^{4}$	0.904	2.7	2.4	0.3
	200 r			180.0	145.5	20.0

ERD (14 days after start of exposure) is the sum of column No. 6 and No. 7 totals or 165.5 r. It is to be noted that although the total dose during the first seven days was the same as in Example 1 the ERD in this example is approximately 5 r less. This is due to the fact that a larger fraction of the dose was during the early days of the first week and consequently there were longer periods for recovery from the major parts of the total dose.

Abbreviated methods can be used for obtaining close approximations. For instance, if the CBR defense officer had assumed that the seven-day exposure of the group in Example 1 had all occurred at mid-period or on the fourth day, the computation would be materially simplified so "t" would then be assumed to be 14 days -4 days or 10 days. Applying the formula in Equation (1)

$$\begin{aligned} \text{ERD} &= 0.1d + 0.9D\ (0.975)^{t-4} \\ \text{ERD} &= 20\ r + 180\ \ (0.975)^{10-4}\ r \\ \text{ERD} &= 20\ r + 180\ \ (0.859)\ r \\ \text{ERD} &= 20\ r + 154\ r = 174\ r \end{aligned}$$

While not exactly equal to the 170.3 r dose of Example 1, the percentage of error is small, $\frac{3.7}{170.3}$ x 100 or 2.2%. Thus, the abbreviated method is applicable. In application of the abbreviated method to the fourth example, estimating the assumed time of the single 200 r dose that would be representative of the daily doses, it should be noted that slightly more than half occurred by the end of the second day and it would be assumed that the separate doses would be equivalent to a single 200 r dose on the second day. Then "t" would be equal to 14-2 or 12 days. Computing the ERD for the single dose assumed to be equivalent to the several doses.

$$\text{ERD} = 20\ \text{r} + 180\ (0.975)^{12-4}\ \text{r}$$
$$\text{ERD} = 20\ \text{r} + 180\ (0.816)\ \text{r}$$
$$\text{ERD} = 20\ \text{r} + 147 \text{ or } 167\ \text{r}$$

This solution compared to the more precise calculation of Example 4 (165.5 r) again indicates close agreement, an error of slightly less than one per cent.

From the above example, it is apparent that for ease of computation, and without causing major error, it is feasible to consider the doses received over <u>a several day period</u> equivalent to a single dose equal to the total and received at the time that about half of the total dose was received. The ERD at "t" days later may then be computed by a single application of the fundamental Equation (1), and will be a close approximation of the ERD computed from separate daily doses.

Since field dosimetric measurement of radiation doses are likely to be subject to considerable error, the short-cut method presented above will be used for computing ERD of several exposures received in a period of one week or less when workloads make more detailed computation impractical.

In planning emergency survival and recovery operations the guiding principle should be to keep radiation exposures to the lowest practical levels.

Problems

1. The daily doses of an emergency operational group as measured by dosimeters were: 40 r, 10 r, 60 r, 15 r, 20 r, 30 r, and 25 r. Compute the ERD 24 days after the start of exposure. Do not use the abbreviated method for this problem. (Ans. ERD = 136.6)

2. Using the abbreviated method, recalculate the ERD at 24 days for the emergency operational group in problem 1 and calculate the percentage error. (Ans. 137).

3. When could the emergency operational group in problem 1 be exposed to an additional 125 r exposure assuming the mission is absolutely required. (Ans. 30 additional days or 54 days from start of exposure)

4. The daily exposures of an emergency operational group as measured by dosimeters were: 20 r, 6 r, 25 r, 8 r, 40 r, 16 r, 8 r. Use the abbreviated method to compute the ERD of this group 20 days and 50 days after start of exposure. (Ans. 94 r, 51 r)

5. The ERD of an emergency operational group 15 days after the start of their exposure was 135 r (irreparable dose = 18 r). This group is the only one available with a particular skill. How long before they can accept an additional exposure of 100 r (assume no exposure in the interim period). What is the maximum additional dose they could

accept if they entered a high radiation area 25 days after the start of their first exposure (assume 2 r exposure per day from 16 through 24 days and compute the ERD at the end of 24 days).

ATTACHMENT A

Powers of 0.975 (100%-2.5%)

For Use in Solution of the Equation

$$\mathrm{ERD} = 0.1\mathrm{D} \neq 0.9\mathrm{D}\ (0.975)^{t-4}$$

Power	Value	Power	Value
1	0.975	22	.573
2	0.951	24	.544
3	.927	26	.517
4	.904	28	.492
5	.881	30	.468
6	.859	32	.444
7	.837	34	.422
8	.816	36	.401
9	.796	38	.382
10	.776	40	.363
11	.757	45	.320
12	.738	50	.282
13	.719	55	.248
14	.701	60	.218
15	.694	65	.193
16	.667	70	.170
17	.650	80	.132
18	.634	90	.102
19	.618	100	.079
20	.602	110	.061
		120	.048

SHELTER CRITERIA

Glenn G. Mastin

The best protection factor will be useless if shelterees cannot survive the other hazards to living. This means other problems of environment must be considered beside the one of keeping out gamma rays.

By survival we do not simply mean to sustain life, except in a most desperate situation, but to bring people through in reasonably good physical condition. This does not imply, however, all the niceties will be provided.

Environmental engineering is not the most glamorous aspects of the problem, but is certainly an important aspect.

Environmental engineering maybe defined as those factors required to make a shelter habitable. Such criteria as: space, ventilation, water supply, sanitation, decontamination, electric power, potential hazards and many others must be considered before a shelter can be certified for a two-week occupancy period.

The objective of this period is to familiarize you with shelter evaluation criteria in a general way. Other speakers will consider many aspects in greater detail. Subsequently you will have an opportunity to apply the criteria to two different problems.

SOME DESIGN CRITERIA

TABLE I

PROTECTION REQUIRED AGAINST RADIATION

Dose, r (EBD)	10 MT Surface Burst Area Affected, mi^2	Required P_f, Dose/EBD, to limit EBD in protected area to 100r maximum
100-300	11,000	1-3
300-100	8,000	3-10
1000-3000	3,900	10-30
3000-10,000	1,800	30-100
> 10,000	300	> 100

The maximum effective biological dose (EBD) of 100r used in Table I is one which might cause some radiation sickness in some persons receiving it. Some might feel no ill effects at all. Also, it allows some margin for the additional exposure after leaving the shelter.

One can not say what the maximum dose will at any given place, but Table I indicates that a protection factor, P_f, of 100 will afford reasonable protection for large areas subject only to fallout radiation.

In the range where a higher protection factor is indicated a need for protection against fire and blast would also be likely. This possibility must be evaluated in each case.

TABLE II

SHELTER OR PROTECTION AGAINST

F/O[2,4]	Blast[3]	Fire[1]
	(F/O) (Fire)	(F/O)

1. Protection from heat and gases. House may collapse into basement in an hour or so. Temperature of 1800° may last 24 hours.

2. Survey is concerned primarily with fallout.

3. Technical Memorandum 61 - 1, 12/1/61. For family shelters, blast shelter 30 psi, semi-blast 5 psi.

4. For blast shelter dose from initial radiation limited to 20 rads.

Large areas subject to fallout radiation would probably not be endangered by thermal radiation or blast.

However, where protection against thermal radiation might be required, protection against fallout radiation would also be. Where protection against blast might be required, it would also be required against thermal and nuclear radiation. Furthermore, initial radiation may become a problem.

TABLE III

CRITERIA FOR VARIOUS OCCUPANCIES

	Home[1]	Community	Operational
Location			
Serve maximum number of persons		x	
Good Access	x	x	x
Mutual shielding	x	x	x
Protection, P_f	100	100	100-1000
Stay time	14d	14d	14d
Space (min.), net	10ft^2/per.(25ft^{2}min)	10ft^2/per.	
gross	12-15ft^2/per.	12-15ft^2/per.	
Volume (min.)	40ft^3/per.	65ft^3/per.	
Air (min.)	0-3CFM/per.	3CFM fresh 12CFM recirc.	
Ventilation			
Heat (max.)	85°ET	85°ET	75°ET
Toxicity	$O_2 \geq 14\%$	$CO_2 < 3\%$	
Heating			
Water (potable)	1/2g/per./d	1/2g/per./d	
Food			
Preparation	x	x	x
Serving	x	x	x
Storage	2ft^3/per./14d	2ft^3/per./14d	x
Storage			x
Ingress and egress	x	2/100	2/100
Loading time		x	
Decontamination showers, no.		1/200	1/200
Lighting	x	x	x
Variation			
Sleeping facilities, %cap.	x	50%	x
Sanitation			
Toilets	x	1WC/70per.	x
Lavatories	x	x	x
Sewage disposal	x	x	x
Trash disposal	x	x	x
Garbage disposal	x	x	x
Shelter cleaning materials		x	x
Fire protection requirements			
Mass fires			
Secondary fires			

TABLE III CONT'D

	Home[1]	Community	Operational
Radiation monitoring equipment			x
Communication - radio	x	x	x
Overpressure resistance			
Blast closure			
Hazards			
Gas seepage			
Flooding, sewer back-up			
Electrical			
Storage of dangerous materials			
Acoustics			
Noise from outside			
Fans			
Generators			
Effects on personnel			
Tools and materials			
Special purpose			
Emergency repairs			
Medical			
First aid supplies	x	x	x
Isolation		x	x
Morgue		x	x
Security			

x - of special importance

1 - defined as a shelter for use of a household group up to about ten persons.

Most of the criteria listed should be considered in planning any protected area. Those of particular importance have been indicated. For some recommended limits have been given.

Some criteria for an operational shelter will be a function of the operations to be performed. Since operational personnel might have functions to perform outside the shelter a higher degree of protection for such persons while in the shelter is indicated. Monitoring equipment will be needed to permit control of exposure for any who must go outside for any purpose.

Size, location and facilities will be determined by the functions to be performed.

In any shelter situation it may well be necessary to minimize facilities below those normally provided. Code requirements may have to be relaxed. Additional criteria for family shelters from Technical Memorandum 61-1, December 1, 1961:

Shelters of the outside underground or aboveground type designed for four or more occupants shall have mechanical air blowers. Smaller shelters may use movable or static head ventilators but in no case shall the vent pipe have an inside diameter of less than three inches.

Vent ports may be used for ventilating basement shelters. They shall provide at least 20 square inches of opening per person, but in no case less than 80 square inches in total.

Mechanical ventilation systems shall include air intake and exhaust vents and shall be capable of providing at least three cubic feet per minute of fresh outside air per shelter occupant. Mechanical blowers must be capable of being manually operable.

Engine generator sets for emergency power shall have separate vents and be heat-isolated from the main shelter chamber. Consideration must be given to the installation of engine generator sets and fuel tanks to minimize hazards from exhaust gases and fire.

In shelters offering resistance to blast, opening to the atmosphere shall be provided with appropriate devices to prevent a buildup of pressure within the shelter to no greater than 5 psi.

In shelters offering resistance to blast, the shielding required to adequately reduce the initial gamma and neutron radiation shall be calculated at the range of the design overpressure using methods approved by the Office of Civil Defense. At this range, the inside dose from initial radiation shall not exceed 20 rads.

SHELTER IN EXISTING AND NEW STRUCTURES[1]

General Requirements:

a. Location. Minimize the warning time required for persons to reach them from normal locations. Routes to shelters should not run through narrow passageways and should be clear of obstructions.

b. Capacity. A capacity for 50 to 100 persons is considered optimum.

c. Size. The provision of only standing or sitting room is inadequate for the anticipated length of occupancy.

d. Strength. The shelter should provide balanced protection against the blast and radiation effects anticipated.

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[1] "Personnel Protective Shelters" LCDR J.C. Hammer, CEC, USN, and LT A.F. Dill, CEC, USN, NAVDOCKS P-290, Studies in Atomic Defense Engrg.

e. Shielding. Adequate shielding from nuclear radiation should be provided to reduce the intensity of radiation within the shelter to allowable values.

f. Ventilation. Substantial protection does not require a high degree of ventilation protection and gasproofing. However, when the probability of mass fires is high (building density greater than about 20%), shelters may have to remain closed for periods as long as 15 hours. By pressurizing continuously, all minor leaks are outward.

g. Access. Preferably by at least two entrances provided with baffles against flying missiles and with reasonably airtight doors.

h. Communications. Two-way primary telephone and emergency self-powered radio communications should be provided with the station control center.

i. Facilities. See Criteria.

Characteristics of Potential Shelter Areas:

a. Fireproof steel or reinforced concrete buildings that are resistant to collapse, if possible.

b. Offer protection against blast, nuclear radiation, thermal radiation, flying glass and debris.

c. As far as possible from the outside, but still having ready access.

d. Structurally compact, if possible, with close spacing of columns and short-span floor beams.

e. Out of line with doors, windows, and hallways having exposure to the outside.

f. No unusually heavy concentrated loads on the floor directly above.

g. As free as possible of light furniture, free-standing lockers, suspended fixtures, combustible materials, equipment of any kind and utility piping.

Location of Potential Shelter Areas:

a. Interior corridors.

b. Basements. If close to utilities, may be dangerous in event they are damaged.

c. Elevator lobbies. May have direct connection with the outside.

d. Rest rooms.

e. Stairwells.

f. Chapels.

g. Schools.

h. Special structures. Tunnels, subways, etc.

i. Avoid open areas with long-span ceilings.

Existing Buildings:

a. Eliminate all suspended items from the ceiling which are potential missiles, such as lights, fans, etc.

b. Recess all lighting fixtures, or firmly fasten as flush as possible and provide with plastic face or cover.

c. Eliminate glass panels from doors, especially those opening into shelter areas.

d. Eliminate glass windows. They break under relatively small loads forming deadly missiles.

e. Add bracing and shoring to strengthen structural elements incorporated in shelter.

f. Baffle the entrances to reduce the danger of flying missiles.

g. Remove or safeguard portions of interior construction and fixtures which are likely to injure personnel.

h. Provide standby equipment for emergency lighting and ventilation.

i. Remove or otherwise safeguard against utilities which might be ruptured.

k. Provide readily accessible or automatic cut-off valves for utilities.

l. Provide facilities for occupany of several days.

m. Remove as much light funiture, stored material, and equipment of any kind as possible from the shelter area.

n. Reinforce ceilings and walls of the selected space, more to withstand cave-in and missiles than for the pressure itself.

o. Provide blast covers or automatic blast-closure devices for air conditioning and other openings into the shelter area.

New Buildings:

a. Provide special shelters in the corridors by designing the roof and walls to resist the blast pressure and withstand wracking and overturning.

b. Provide wall of reinforced concrete or of reinforced masonry.

c. Provide roof and floor slabs of reinforced concrete.

d. Provide shear walls between adjacent rooms as partitions to resist the lateral movement.

e. Provide shelters in basements because of the advantages of adaptability and radiation protection.

f. Provide shelters with covering reinforced concrete slab of sufficient strength to resist the blast pressure and the weight of falling debris. (100% of the weight of the first story, 80% of the weight of second story, and so on reducing by 20% for each additional story - with a minimum static design load of 500 psf.)

g. Provide interior shelters with walls designed for a minimum static load of 500 psf.

h. Provide shelter doors designed to withstand the same pressure as the walls.

i. Provide liberal bracing, connections which can carry a reversal of stress and of sufficient strength to develop the strength of connecting members, and continuity to improve the structural resistance of the shelter.

DESIGNS TO RESIST BLAST LOADING[1]

Blast Resistant Design:

There are three important characteristics of blast loads:

a. The far greater magnitude of the forces.

b. The horizontal nature of the forces.

c. The time characteristics of the load and their relation to those of the structure.

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[1] "Improvement of Conventional Designs to Resist Blast Loadings," LCDR J.G. Hammer, CEC, USN, and LT A.F. Dill, CEC, USN, Chapter 6, NAVDOCKS P-290, Studies in Atomic Defense Engineering.

To insure against structural failure there are two general requirements

a. Overall external stability against sliding or overturning.

b. Internal strength against local or general failure of members and frame.

Buildings of reinforced concrete frame construction might experience these effects:

a. Buckling and failure of the roof slab by lateral compression. This would be caused by the crushing pressure acting upon the sides of the structure.

b. A similar failure in the floor systems.

c. Cracking of concrete and overstressing of concrete and steel at haunches and connections. This would be a result of the tremendous force applied laterially.

d. Failure of columns by shearing action. This again would be a result of the lateral forces.

e. Failure of exterior walls, particulary on the side toward the blast.

f. Failure of floors where pressure did not equalize above and below.

g. Heavy damage to plaster, false ceilings, partititions, glass windows, etc.

Steel frame buildings might experience these effects:

a. Stripping of siding and roof material, or

b. Transfer of a large force to the frame, causing buildings to be pushed over bodily or to be left in a leaning position.

c. Buckling and collapse of columns because of a combination of lateral loads causing flexure and vertical loads causing axial compression.

d. Compression buckling of roof trusses caused by the load on the exposed side of the building.

e. Serious distortion of the steel members caused by fires of primary and secondary origin.

Timber frame buildings and housing night experience these effects:

a. Failure at comparatively low pressures at joints and connections.

b. Failure by wracking and twisting of frame.

c. Roofs, wall panels, and partititions failing by splintering or excessive fracturing.

d. Serious fires.

General recommendations for reinforced concrete construction:

a. All reinforcing steel should be extended to develop full continuity.

b. Negative steel should be provided for the full length of beams to develop the moment capacity of the columns and to resist reversed loadings.

c. Inasmuch as concrete when subjected to high blast forces may act as a brittle material, it is desirable to use reinforcing steel even in short projecting elements even though the expected unit shear value may be rather low and calculations indicate no steel required.

d. The use of diagonal bars is recommended across construction joints that have high shearing forces, so placed that shear forces put some bars in tension. When the possibility of reversal of loading exists an X system of diagonal bars should be used.

e. Joints should be designed with adequate strength to develop the strength of the connecting members.

f. Using solid concrete slabs supported by monolithic concrete exterior walls, fire walls, and fixed interior partitions, the entire structure acts as a column transmitting the local loads to the foundation by direct shear in the walls.

g. Partially solid walls at ends of a structure in addition to solid concrete fire walls and fixed partitions permits the use of light columns designed to carry vertical loads for the remainder of the framing.

h. Integral spandrel walls between bands of sash will act as flanges for the floors and also as vertical beams in causing parts of the structure to move and distribute the load as a unit in the vertical direction.

i. Solid concrete walls limited to stair openings, elevator shafts, and walls around plumbing and duct passages provide a structural core having a high degree of resistance at minimum additional construction costs.

j. The negative moment extending throughout the mid-length of slabs, beams, and girders due to the negative blast phase can be compensated for by welding of column rods at the splices, the anchoring of the roof to the columns, the use of vertical stirrups instead of bent rods since the latter are in, rather than across, the cracks which tend to form.

k. Beams or panels for blast resistant construction in general should be underreinforced and should contain compression steel. They should be overdesigned in shear.

General recommendations for steel construction:

a. Basic to the development of maximum shock load resistance is the full utilization of the plastic strength of steel.

b. Full continuity of construction is desirable for maximum plastic resistance.

c. Connections should be designed to develop the full plastic strength of the weakest connecting member.

d. Diagonal stiffeners can be used in corner connections to prevent large local angle change between connecting members due to undue shear yielding.

e. Continuous welded steel frame with heavy roof and fixed column bases has a maximum plastic resistance many times that of truss frame with lightweight roofing and pinned column bases.

f. Fixing the column bases increases lateral plastic resistance compared to pinned bases by approximately 100%.

g. Heavy roofing compared with lightweight roofing increases the continuous welded frame lateral resistance by about 100%.

h. Continuous welded frame instead of truss frame increases the lateral resistance by a factor of between 3 and 7.

i. In continuous welded frames the bending moments induced in the columns by the roof loads result in much heavier columns with corresponding increases in lateral resistance.

j. Steel wire strands attached on each side of the bend at the tops of exterior columns and anchored in the ground outside the building increases the lateral resistance.

General recommendation for wall construction:

a. Walls constructed of blocks, such as brick, terra cotta, concrete, and glass, are to be avoided as they are poor as blast resistant materials because the joining mortar is usually weak and brittle, the walls are generally poorly bonded to the building frame, and bending strength is lacking. Walls of these materials not only disintegrate under blast and fail to provide any protection but become dangerous missiles.

b. Integrally-poured reinforced concrete walls are not only excellent in providing protection to the contents of the building, but also in increasing the lateral resistance of the structure itself.

c. Walls of lightweight materials such as plain glass and sheet asbestos which readily shatter under blast will not transmit load to the frame and not form debris which will damage equipment. They would not be suitable for protecting personnel or delicate material and instruments.

d. Any type of metal covering is usually undesirable in that they transmit large loads to the frame before tearing loose and becoming dangerous missiles.

e. Resistant wall panels should be adequately designed and connected to carry the elastic rebound load superimposed on the negative load of the blast pressure.

Conclusions:

a. Provide sufficient structural resistance to all elements of the building thus insuring entire building remains intact without any structural failures, thereby attaining complete protection.

b. Provide protection only in certain sections within the building, such as corridors and basements, so constructing these sections as to provide protection despite collapse and damage to other portions of the structure.

c. Provide special shelter area within the building and improve the entire structure in an attempt to limit structural damage to a reasonable amount, thus keeping the structure usable immediately after the attack for emergency purposes and minimizing the repairs necessary to restore later for general use.

ENGINEERING IN PROTECTIVE STRUCTURES

J. R. Akerman

Introduction

As I understand our Civil Defense Program, the first and most important consideration in shelter design is the survival of the users. However, survival alone, if we define survival as merely retaining life, may not be enough. For a nation to recover from attack and endure, we must have individuals who have not only survived but who are capable of immediately taking up tasks of rebuilding, "cleaning up", retaliation, etc.

Ideas regarding the ability of a human being to perform tasks under adverse conditions have greatly changed during the last 20 to 25 years. Previously it was assumed that if one would try hard enough, any task could be accomplished, almost regardless of accompanying conditions. Now it is recognized that certain factors affect the efficiency of performance and that performance will always deteriorate in the presence of adverse conditions.

In the Shelter Program we must therefore focus our attention on the survival of the users but we must also take into account any conditions which will reduce performance effectiveness to too low a level. The cumulative effects of exposure to atmosphere with high CO_2 concentrations is an example.

While this is not a class in physiology, I think we can understand some of the shelter problems better if we make a brief review of some physiological reactions of humans who may be using the shelter.

PHYSIOLOGICAL ASPECTS

1. The human body is a very complicated chemical processing plant.

   a) Food taken in composed of carbohydrate, fat protein, etc.

   b) Food oxydizes, chemical reaction is basically (as far as ind. products are concerned) the same as burning in an oxygen atmosphere.

   c) Carbohydrate

   $C_6 H_{12} O_6 + 6 O_2 \rightarrow 6 CO_2 + 6 H_2O$

   Respiratory Quotient (RQ) $= CO_2/O_2 = 1$

   d) Fat

   $2 C_{51} H_{98} O_6 + 145 O_2 \rightarrow 102 CO_2 + 98 H_2O$

   R.Q = 102/145 = 0.7

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   e) Heat release is proportional to O_2 used with diet of average mix

   550 Btu for each 1# of O_2

2. Air volume vs O_2

   a) Air is 21% vol. O_2
   or 23% wt. O_2

   b) Recommended O_2 values net used
   (EM 1110 - 345 - 450 H + AC for Underground)
   0.85 $Ft.^3$ O_2/hr. per person
   4.05 $Ft.^3$ air per hour per person.
   NOTE: These values to sustain life.

3. Heat release

   a) Heat release is proportional to O_2 used with "average mix" diet

   550 Btu for 1# of O^2

b) Heat loss per "average" man depends on work done and what I choose to refer to as thermally related environment. The table below is in terms of E.T. about which more later.

E.T.	Loss Rest	Btu/hr Work
50	490	665
60	430	660
70	400	660
80	400	640
85	400	570
90	370	480

c) This includes SH and LH.

d) SH raises air temperature

$SH = Q\ \rho\ c\ (t_1 - t_2) = CFM\ (1.08)\ (t_1 - t_2)$
SH in Btu/hr.

4. Vapor release

a) LH is water vapor release and when given in BTU is heat extraction to condense.
It <u>does not</u> raise air temp.

1# water at 70° requires 1053.7 Btu to condense.
(at 212° - 970 Btu/#)

$\therefore LH = \#\ H_2O/hr \times 1053$ (1050 frequently used).

or in grains: $LH = \frac{GR}{7000}(1053)$

b) The water vapor loss per "average man" also varies with Temp.

T DB	Rest Btu/hr	#/hr	Work Btu/hr	#/hr
50	70	.067	120	.114
60	70	.067	200	.190
70	100	.095	310	.295
80	180	.171	450	.428
85	230	.219	530	.505
90	280	.267	600	.570
95	350	.333	690	.660

5. Heat Response

   a) We might say that man's response to his thermally related environment falls into 7 zones.

   b) Physiological reaction is not a continuous (linear) function. The mechanism in the 7 zones is physiologically different.

   c) Center zone is a neutral zone requiring no response.

   d) Next higher.

      1. Body dissipates additional heat by expanding blood vessels close to skin particularly in extremeties (hands and feet).

   e) Second higher.

      1. Sweating.

   f) Highest.

      1. Body unable to adapt.

      2. Long exposure - death.

   g) Next lower (than neutral).

      1. Blood vessels contract.

      2. Temperature drop in extremities.

   h) Second lower.

      1. Physical work - shivering.

   i) Lowest.

      1. Body cannot adapt.

      2. Unconsciousness.

      3. Death.

SHELTER STANDARDS

1. Space and Volume

   a) Based on a 14 day occupancy
   Minimum area is 10 Ft^2 per person
   Minimum volume is 65 Ft^3 per person
   Volume may have to be somewhat higher because of ventilation requirements

   (Guide for Architects and Engineers NP-10-2 page 10)

2. Temperature, maximum limit

   a) Highest permissible temperature for an extended period of time is 85°F ET

   b) Effective temperature is actually not a temperature but a number which is supposed to indicate a given sensation of warmth or coolness. At 100% relative humidity, in still air, the ET is the same as the dry bulb.

   c) History of ET
   (1) Limits of accuracy

   d) ET table

   e) Note that the ET of 85 corresponds to any of the following temperature humidity conditions:

Temp.	100	98	95	92-1/2	91	88-1/2	87	85
R.H.	30	40	50	60	70	80	90	100

3. Ventilation required

   The ventilation required when it is solely outside air is based on a number of considerations and the consideration which indicates the greatest air requirement is the one to use. The considerations are:

   a) Oxygen concentration in the air in the shelter.

   b) CO_2 concentration in the air in the shelter.

   c) The amount of heat removal required.

   d) The amount of moisture removal required.

4. Oxygen concentration

(Ref. OCDM-EN-60-2-RM Control of Shelter Environment)
Fig. 1

a) The minimum permissable concentration of oxygen in the air in the shelter is 14%. This is usually no problem.

b) Example: (Figure 1) With 500 Ft^3 per person and with absolutely no ventilation air, occupancy time to reach 14% O_2 is 40 hrs.

EFFECTIVE TEMPERATURES

Heading across, Relative Humidity in per cent

Heading down, (lines), Effective Temperatures

Values in table, Dry Bulb Temperature, degrees F.

ET \ R.H.	30	40	50	60	70	80	90
85	100	98	95	92-1/2	91	88-1/2	87
80	92-1/2	90-1/2	88	87	84	83	82
75	85	83	82	80	78	77-1/2	76-1/2
60	64	63	62-1/2	62-1/2	62	61-1/2	61
55	57-1/2	57	57	56-1/2	56-1/2	56	55-1/2

5. CO_2 Concentrations

(Ref. NP-10-2 Guide for Architects and Engineers)
Page 11

a) The reference above gives the maximum permissable CO_2 concentration as 3%.

b) This was in accord with tests run on limited occupancy time. (about 8 hours)

c) More recent tests indicate that a CO_2 concentration of 3% for 14 days exposure will give performance deterioration, will alter physiological functions and adaption of the body to these changes which continue for some time after return to normal concentrations.

d) Concentrations of 1.5% will not affect performance but will induce adaptive changes in physiological functioning which persist after return to normal atmosphere.

e) A concentration of not higher than 1.0% is recommended for no appreciable effect.

(Reference National Academy of Science -- Nat. Research Council Environmental Engineering in Protective Shelters.) Page 43 through 57.

VENTILATION FOR HEAT REMOVAL

1. Heat Capacity of Air.

   a) Specific heat of air at constant pressure is 0.24 Btu per pound per degree temperature rise F.

   b) Density of air at 70°F and 14.7 psia. (1 standard atmosphere) is 0.075 pounds per Ft^3.

   c) Heat to raise air temperature is:

   Heat = Q x sp. heat x density x temperature rise

   for Heat in Btu per hour and Q in CFM

   $$\text{Heat} = Q \times .24 \times .075 \times (t_1 - t_2)$$

   $$= 1.08\ Q\ (t_1 - t_2)$$

   d) Example:

   100 people
   500 Btu/hr. each
   400 SH - 100 LH
   Ventilation air at 80°F.

   Required: Air to hold shelter at 85°.

   e) Solution:

   100 x 400 = 40,000 Btu/hr.

   $$40{,}000 = 1.08 \times \text{CFM} \times 5^\circ$$

   $$\text{CFM} = \frac{40{,}000}{5.4} = 7.400 \text{ CFM or } 74 \text{ CFM/person.}$$

VENTILATION FOR MOISTURE REMOVAL

1. Moisture capacity of air.

   a) Air carries moisture like a sponge carries water.

   b) Amount given as $\#H_2O/\#_{Air}$

   Humidity Ratio or Specific Humidity

   c) Values from a psychrometric chart

   Example: 80° DB 50% RH - .011 $\#H_2O/\#_A$
   85° 60° - .0155

   d) Water Vapor removed by Air.

   $Wt_{H_2O} = Wt_{air} (W_1 - W_2)$

   W is specific Humidity

   or $Wt_{H_2O} = Q \times 60 \times .075 (W_1 - W_2)$

   $= 4.5 \times CFM (W_1 - W_2)$

   e) Example:

   100 people 100 Btu/hr LH each

   Ventilation air 80°F - 50%

   Required: Air to hold shelter at 85° and 60%.

   f) Solution:

   1. 100 Btu/hr = .095 #/hr/person
   $Wt_{H_2O} = 100 \times .095 = 9.5$ #/hr.

   2. $9.5 = 4.5 \times CFM (.0155 - .011)$
   $CFM = \frac{9.5}{4.5 \times .0045} = 470$ CFM
   or 4.7 CFM per person.

FILTERS

1. Fallout particles
    - a) Most particles are 10 microns or more in diameter
    - b) 1 Micron 1×10^{-6} meters

      1×10^{-4} cm

      4×10^{-5} inches
    - c) 10 Microns - .0004" 4/10,000 inch.
2. Settling velocity
    - a) About 1-1/2 ft. per minute
    - b) When air velocity less than this particles will not entrain.
3. Any standard air filter will take out 10 Micron solids.

CHEMICAL

EM 1110 - 345 - 450

Eng. and Dis. Heat + AC of Underground Inst.

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Also Outline Notes E. 350-18

Page 345 - 346.

PUBLIC UTILITIES*

The first requisite of shelter space is radiation protection adequate for survival of the occupants. This protection is a function of the structure itself. However, the occupants of a shelter will need other facilities and services if livability of the space and health of the group are to be maintained. What will be the problem? Simply stated, the problem will be one of insuring a shelter environment that is able to provide for minimum physiological and, to some extent, psychological needs of its occupants.

A great deal is taken for granted these days with our abundance of electricity, gas, water, public sewers, refuse collections, and similar facilities, utilities or services. An examination to assess the radiation protection of spaces for emergency shelter use must be accompanied by a critical evaluation of these public utilities that the community uses, or that normally service the potential shelter space, for the maintenance of livability. Their vulnerability must be appraised. Their availability under conditions requiring emergency use of the shelter space must be ascertained and stand-by, or substitute, facilities or services provided where deficiencies are found.

The shelter space environment must provide its occupants with certain essentials -- air, water, food, waste disposal and information. Under normal conditions in a community four broad categories of public

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* Lecture given by Joseph W. Price, P.E., as part of The University of Michigan Extension Service Course in Fallout-Shelter Analysis, October 1961 - May 1962.

services or utilities are available to assist in meeting these needs of people. We have electric power and gas. We have communications and transportation. We have water supply. We have sewerage and solid waste (refuse) collection and disposal. To evaluate the problem of maintaining livability in a potential shelter situation some procedure, or methodology, is necessary which utilizes certain basic principles that can be applied to the analysis of any situation.

First, there must be recognition of how these particular utilities are used each day in meeting these needs of a livable environment. Secondly, there must be an evaluation of the vulnerability of these utilities. Third, from an evaluation of vulnerabilities of public services will come a knowledge of the weak points and deficits as a base from which to develop alternate means for providing substitute services and facilities needed to maintain the shelter environment.

We depend upon our electric power and gas utilities to meet many of our general environmental needs. Lighting for an adequate visual environment, ventilation to maintain air hygiene and heating for comfort and health protection. We rely upon electric power for pumping our water and sewage. We use electricity and gas in refrigerating and preparing our food to protect health. Communications, the disemination of information, and transportation need electric power to some extent. Maintaining environmental livability within a shelter will require some dependable power.

Communications and transportation-wire or electronics systems for information, highway and rail for goods and services - are vital to individual and community life. We rely upon telephone and radio for essentially all of our primary information exchange. We rely upon highway and rail facilities, particularly in our urban areas, for the transportation of food, on a daily basis in many instances.

A public or privately operated, municipal-type water supply system provides for our daily needs by furnishing water to the community. Two kinds of water: that for dietary needs, which is the first and foremost because without this we cannot even survive; and that for sanitation requirements, or water used for personnel hygiene and as a vehicle for the removal of our wastes. Another use of public water supply is to assist in the maintenance of air hygiene. That is, it is used in air conditioning and air cooling.

Community sewerage facilities are essential to the maintenance of environmental health and livability in the urban community. Public sewers transport our liquid wastes out of the city. Sewage plants treat the wastes before final discharge to protect neighboring areas. A municipal collection system for refuse is a similar service operated on a regular basis to transport solid wastes (garbage and rubbish) out of the living area of the community for disposal. The control of rats and the protection of community health from several diseases associated with rodents depends upon sanitary collection and disposal of refuse.

This has been a brief review of a few of the important utilities and services and how they are used to maintain environmental livability under normal conditions. Let us next examine the reliability under a defense emergency of these same facilities and services. To begin a discussion of utility service vulnerability under nuclear attack there is need to first consider three general points.

First, since the majority of our population is "urban" most shelter space will be within a metropolitan area complex. Over 63% of our population lives in metropolitan areas. This does not mean that they are all within the central, or core, city, but also in the peripheral areas. Within this same metropolitan complex, we also find a great interdependency of one governmental unit on another for some utilities or services. As an example, our water supply today is more and more on a metropolitan basis. The City of Detroit water utility, which was originally only for the City of Detroit, now is extended beyond these corporate limits into Oakland and Macomb Counties in addition to Wayne County and planning studies on feasibility for extension into Washtenaw County and the City of Ann Arbor are being made at the present time. Electric utility service is most frequently from a single system within an entire metropolitan, and sometimes regional, area. There are, however, interconnections between systems that are not found between water supply systems. Even communities beyond metropolitan areas may depend upon electric power from generating plants within the metropolitan complex. As an example, the Detroit Edison electric system supplies power to Ann Arbor which is about 40 miles from Detroit. However, the power generation stations and much of the principle transmission system is within, or closer to, the center of the metropolitan area. This becomes most important when it is recognized that in a nuclear war emergency primary targets are going to be within these metropolitan complexes. We are faced with very definite probability of having much of our basic utility production capacity -- water supply, electric power, etc. -- in or proximate to target areas.

A second item of general importance will be the restrictions to movement of the people and supplies necessary to maintain utility services. Maintenance personnel will be facing the same hazards from fallout as the general public. Normal supply lines will be interrupted. The inability of a utility service to provide needed maintenance, or to obtain vital supplies, may curtail service in the absence of actual damage.

The third point of general concern may somewhat offset the first two. An appraisal must be made of the local civil defense planning or degree of preparedness. Questions must be answered as to how prepared the various utilities are for an emergency. Is fallout protection available so their key installations can be manned? Are vital supplies stockpiled? This is all part of Civil Defense planning, or degree of preparedness, which must be known for a realistic evaluation of the general problem of vulnerability. Some utility systems may be temporarily incapacitated, yet with good civil defense planning these may be brought back into use in a relatively short time. As an example, a community water supply that would be out of service with the failure of electric power service in the community might be kept in service with an independent source of power -- shelter protection for operating personnel and a supply of fuel. Perhaps the optimum goal would be to have each shelter completely equipped to operate independently of all community utilities and services. However, cost of such a program could be overwhelming. Adequate Civil Defense planning for an area can provide realistic safeguards, with an admitted element of assumed risk, that can reasonably assure continuance of some services on a community basis needed to maintain thelivability of shelter space.

Turning back to the four basic services and utilities, each must be examined individually for vulnerability. With electric power, it was mentioned earlier that many of our generation units are in key target areas, or may in themselves be targets -- such as large hydroelectric plants and dams -- even though located in isolated places. Electric power distribution and transmission systems are subject to blast damage beyond the area of immediate bombing where complete destruction would occur. Effects of the blast will progress to a considerable distance, knocking down poles, towers, etc. Attention is directed here to the text, "The Effects of Nuclear Weapons", pages 179 through 195 and the nomograms and bar charts on pages 252 through 255.

An evaluation of anticipated damage to the gas utility should be, at a maximum, restricted to above ground facilities, gas storage tanks, etc. Very little damage to underground facilities, pipe systems, would be anticipated in the areas where shelters are for fallout protection primarily. Where blast damage sufficient to disrupt underground piping occurs much of the shelter space selected primarily for fallout protection will also probably be destroyed or made uninhabitable.

We are dealing, at this time, with fallout; we are not protecting against extensive blast. So, generally speaking, our underground structures -- utilities lines, etc. -- are going to be little affected because they, and the immediate shelter space served, can be assumed beyond the area of heavy blast damage. Our concern will be primarily with the above ground structures and facilities regarding their vulnerability to wind pressures and drag in the outlying damage zones.

Most of our communications systems and facilities face the same limitations and damage problems as electric power. The reason is, of course, that they are dependent upon towers, poles, and wire lines, at least to some extent, which may be knocked down in many areas. In addition to the pole lines, there are switchboard systems with telephone communications. With the interdependency between urban areas, many of the central switchboard facilities are to be found closer to the center of the metropolitan community where damage will be more severe. Extensive telephone communication will be lost in many areas. Roads and highways will be subject to blocking by fallen buildings, by people, by vehicles, by many things. Our transportation system, as far as direct communication between persons or delivery of food and supplies, will be essentially nonexistant for some period of time.

We have a somewhat different problem in the vulnerability of water supply utility services. Here there may be another direct hazard from fallout itself in the contamination of surface water supplies. A water supply has three essential elements; production, treatment, and distribution. The weak link will be production for two reasons:

(1) Most pumping is primarily dependent upon power from public electric utilities which may be interrupted, and

(2) If the water source is a surface supply it may be contaminated by fall-out.

Ground water is not subject to fall-out hazards. Ground water will be an important reserve supply. Community Civil Defense planning might well start with programs to insure some ground water for emergency purposes. Even where communities may be dependent upon surface water as a primary source there is value in preserving any available wells that can be equipped with auxillary power to serve in an emergency. It may, in some instances, be possible to service an entire well field having multiple, individual wells, with an independent electric generating unit as a source of power or equip several wells with auxillary gasoline or diesel engine units.

In a fall-out emergency, ground water is our best and safest supply since surface waters will be contaminated with fall-out. Fortunately, much fall-out debris is not readily soluble. However, there will exist a hazard, although different than that of external exposure from intense gamma radiation. The problem of contamination of water or food is one that may arise from much lower levels of radio-activity where there are radio-active ions which may be assimilated by the body. Some of these materials are long-life isotopes which produce continuing radiation damage to the body when they become a part of body tissue. Hence, much lower levels of radio activity become significant in food or water that is to be ingested. Continuing surveillance of fall-out from bomb testing is now practiced to keep a careful watch of changing radiation levels in food and water. Milk, for instance, is checked for radioactive Strontium and radioactive Iodine. These materials are abosorbed into and actually become part of the body so low levels of radioactivity are of importance which would not present any particular external radiation hazard. Special techniques are available for doing this kind of monitoring, and Civil Defense agencies must be prepared to do a job of monitoring water, food, and milk for these low levels as well as determining direct gamma ray hazards.

In summary, the greatest protection for water in an emergency is the ground. The preservation or establishment of a ground water supply with independent power for pumping can furnish our dietary water needs. However, even surface water if it is contaminated and unsuitable for dietary purposes might still be very adequate for personal hygiene uses. Water with low levels of contamination that would be hazardous to ingest could be used for decontamination-showers, for hand-washing, for toilet flushing and these similar uses as long as adequate care was taken not to ingest a quantity of it.

In a nuclear attack emergency it seems quite probable that in many communities water treatment plants cannot be kept operating. There are, of course, varying degrees of treatment provided depending upon the community and the water source. Any, or all, of three things may be done to water in treatment plants. It may be clarified, it may be softened and it may be disinfected. All of these processes require some type of continuing supervision by operating personnel and all of them usually require some power from the electric utility system to keep pumps and other equipment operating. Vulnerability of electric utilities together with the curtailment of normal plant routines because personnel will need protection from fall-out will curtail water treatment plant operations. Open sedimentation basins may permit fall-out contamination of water in the plant.

It may be possible to provide through community civil defense measures some increased reliability of water treatment with auxillary power and fall-out protection so operating personnel may work. However, more elaborate treatment is usually needed for surface waters which in themselves may not be potable because of radioactive contamination not removable with normally used water treatment processes. There is a great likelihood for interrruption of community water service during and following any large scale attack. However, if the community uses ground water, since ground water ordinarily needs no clarification and in an emergency softening, if provided, could be abandoned, a minimum supply of water for potable purposes might be assured with a source of dependable power for pumping. Ground water has protection from fall-out contamination and in many instances bacteriological safety can also be relied upon even in the absence of disinfection.

Although water treatment processes are somewhat effective in fall-out removal, they are not going to remove all soluble material. In the event fall-out increases radiation levels in surface water by solution of radioactive ions the only effective treatment probably would be removal through an ion-exchange resin. Although additional research is needed in this area, it is not inconceivable that some type of ion-exchange unit might be installed in individual shelters to safeguard the drinking water supply from fall-out contamination where a surface water supply is used. This would only be effective where the rest of the community treatment process could be kept operating to provide clarification and disinfection.

The water distribution and storage system is much less vulnerable, or subject to damage, in areas where fall-out only is the principle problem. Reservoirs must be covered, but this has usually been done for finished water storage in the interest of protecting the water from bacterial contamination. In locations beyond the areas where extensive earth shock from a bomb might break buried water mains there is the problem of blast damage to some buildings which may damage water risers or piping within buildings. This can bring severe lose of pressure from extensive system leakage.

Within almost every community there is some type of liquid waste collection system either separate sanitary and storm, or combined, sewers with necessary pumping stations and in many instances a plant for treatment of sanitary sewage before disposal. In areas where shelters are primarily for fall-out protection - as distinguished from blast protection - damage to underground pipes of the sewerage system should be negligible. However, a few problems can arise with regard to sewers and shelter areas.

The most vulnerable points in a sewer system are the pumping stations. Many of our shelters will be in below-ground locations. If these same basement or sub-basement areas are dependent for drainage upon a sewer system which in turn, discharges through a pumping, or lift station, a hazard from sewers being sur-charged and actually backing-up into shelter areas exists if the pumps do not operate because of a power or pump failure. An evaluation of portions of the storm and sanitary sewer systems is needed beyond the building holding any prospective shelter space to insure its reliability in time of emergency and to be certain flooding of the shelter area from an overloaded sewer or pumping station failure will not occur.

Storm water flooding presents a threat of introducing radioactive material from surface fall-out accumulations into a shelter area. Many of our buildings have direct connections of roof conductors to storm sewers or to combined sewers. The matter of sewer and drain capacities may need be considered in such situations. If the outlet sewers in the vicinity are of inadequate capacity, and within the building floor drains exist that are connected, a situation could develop which might introduce fall-out residue into, or very close, to the shelter space during storms. Fall-out will be removed from the roof areas and from the ground surface by rainfall. In the event of a severe storm that may overtax a storm sewer system, this water carrying radio-active fall-out material, could flow back into a building and either into, or proximate with, space being used for shelter. Mention should also be made regarding the location of roof conductors with respect to shelter space. These pipes themselves may be a radiation hazard as fall-out is carried through them from removal of roof accumulations by water during periods of rainfall.

Community sewage treatment works will probably not be kept operating during a nuclear attack and subsequent fall-out situation. However, the degree of hazard to the public will be relatively minor when viewed as part of a total emergency situation. Sanitary sewage flow will be drastically reduced when the public must occupy shelters for survival. The water conservation and nuisance prevention reasons for pollution control will also not be meaningful or valid during the time of such an extreme survival emergency. At worst, the greatest impact should be a somewhat increased pollutional load upon any downstream use for water supply, which will be minor in the light of the probable fall-out hazard to that same supply.

Planning should be made, of course, to return sewage treatment plants to service during a post-attack, recovery period. However, if sewers can be utilized to remove wastes from shelter areas there is a health benefit to the public, people housed in these facilities, even though the sewage removed must then be discharged untreated into a ditch or stream during a temporary period of the emergency.

Any collection for solid wastes, garbage and refuse, that depends - as most do - upon collection personnel moving about freely, is not going to be operational. A method for handling and storing solid waste within each shelter will be needed to replace the municipal collection system.

In general, to maintain shelter livability the vulnerability of much of our public service and utility systems must be recognized and adequate substitution made or standby facilities provided. The primary objective of immediate survival through radiation protection must be supplemented to insure an environment in the shelter which meets other needs of livability so people who are going to use the shelter can, and will, remain in it. Since radiation is not discernible to the senses there is an unanswered question as to how much discomfort large groups of the public will endure in a shelter when the radiation hazards of the external environment may not be so readily apparent to them. The general population has been long accustomed to rather high standards of comfort far in excess of minimum survival needs. It is difficult to anticipate how people will react when they have been used to one thing and then are put in an entirely different environment. It seems reasonable to assume very real psychological as well as physical problems may develop. Anything that can be done in shelters to add livability that goes a little beyond what we really need as a minimum for survival may have real benefit in promoting group tolerance of a bad situation. There are, of course, obvious economic limitations in how much livability can be provided. I am aware of this, but I think we can do much with a little thought and good old "American ingenuity" to provide some things and some comfort that will be above simple physical survival requirements.

The analysis of any shelter space will include three things: (1) Assessement of the service reliability, or vulnerability of existing public utilities; (2) Selection of criteria which with shelter space and population data will define needs; and (3) Selection of alternate means for meeting these needs where public utilities and services are found unreliable. An outline of the public utilities and services vulnerability problem has already been given. It is understood that Shelter Criteria, at least of a tentative nature, have been suggested and time does not permit any further, detailed discussion at this point of the human physiological needs that form the basis for some of these standards, such as quantities of air for ventilation, quantity of water, etc.

It seems quite probable that in a great majority of cases each fall-out shelter will need to be constructed and equipped to maintain a livable environment with little, if any, dependency upon utility or other direct services from the community. This will create a need for space within the shelter, or nearby and accessible, for storage and possibly for mechanical equipment installation. Remembering again that intensity or radiation decreases with time (natural decay), and that short term human exposure is possible to levels of radiation much higher than can be tolerated for longer periods of time, space within a building having lower protection factors than necessary for the "core" of the shelter may be utilized to advantage. Storage of food, water, and wastes, or the installation of mechanical equipment could be made in such spaces so persons could spend most of the time within the maximum protection area but would make infrequent and short trips to obtain supplies, deposit material, or service equipment and return without significant hazard.

Intense use of limited shelter space will require careful consideration of ventilation and air supply needs to maintain air hygiene. Mechanical ventilation appears a most probable necessity which in turn requires a completely dependable power supply. Auxillary generation of electric power by an internal combustion engine seems a likely way of meeting this need where the electric utility service is vulnerable to any significant extent. The selection of suitable equipment will be a rather straight-forward engineering analysis of total power required, selection of unit, installation location etc. It is well to realize, however, that normal fuel deliveries will not be possible during the emergency period so adequate fuel storage will be needed. Attention must be given to the location of combustion air intakes and relative locations of exhaust outlets and fresh air intakes so new hazards are not created. The utilization of waste heat from combustion engines for heating water or portions of the shelter may add to the shelter livability or the disposal of the waste heat may in itself create a new problem to be solved.

Where the public water supply will be out of service water can be provided by storage or by an auxillary supply. "Canned" water could be utilized with containers that might be used for waste storage when empty. Tank storage within the building would be more desirable. Such a tank (s) should be large enough to carry the shelter population through the emergency period and must be capable of being isolated in a filled condition from the regular building distribution system at the start of the emergency. They should also be so integrated into the building piping system that a regular turn-over of water through them is maintained under normal building use. Sufficient elevation of the tank to maintain some pressure within the shelter area would be necessary if the stored water is to supply decontamination showers or toilets. However, storage beyond dietary requirements may not be feasible and another supply of non-potable water may be needed for these other uses.

Where electric power is available for pumping an auxillary well would seem the most positive way to provide adequate water in areas where ground water of suitable quality is reasonably available. A location for such a well must be available that is sufficiently isolated from sources of contamination to guarantee bacteriological safety, or disinfection must be included. Service piping should be so installed to permit periodic pump testing and emergency use but without creating a cross connection to the municipal supply which may violate plumbing and health codes. Removable sections of pipe that may be quickly coupled in place or multi-port valves can often be utilized so a stand-by well water supply can be readily connected to the water distribution system of the building when service from the municipal supply is stopped.

The criteria of suitability in disposal system for either liquid or solid wastes is primarily the protection of the public health and secondarily the freedom from immediate nuisance conditions. Two general systems seem possible for achieving these ends: (1) Immediate removal from the shelter; or (2) storage and later removal to a disposal point.

If flush toilets can be supplied with an adequate amount of water and connected to a reliable sewer this would be the optimum for excreta disposal since these human wastes are of the greatest health significance to the shelter occupants. Highest, dependable sanitary standards would be maintained more readily by the removal of these wastes from the immediate shelter environment. Even storm sewers would serve adequately as an outlet for temporary emergency use.

Although large quantities of garbage and rubbish would not be produced from the use of food concentrates in feeding the shelter population some containers and storage space should be provided as a precaution against rodents and vermin attraction. In other situations it may also be necessary to actually store human wastes in tight, leak-proof, containers until the end of the emergency period. Hypochlorites or other chemicals for odor control would, of course, be a necessity under such circumstances.

All food necessary for the emergency period must be stored within the shelter. Dietary requirements can be met by food concentrates which will maintain minimum nutrition levels. These require only a relatively small amount of dry storage space and water for mixing and serving.

An important psychological need of the shelter occupants will be for communication with their surrounding community. In addition, vital survival information regarding the Civil Defense situation must reach the persons in various shelter spaces. Radio will provide the most reliable link with the balance of the community and must be provided, at least for receiving information. Radio reception should be tested in shelter space and antennas installed as needed.

A fall-out shelter is essentially a small community. It must not only provide the shielding for protection of the community residents from external radiation hazard, but it must, in many instances, become a completely self contained community within which are located all the facilities and services to maintain a livable internal environment. Although the reliability of public utilities and services - electric power, water supply, waste disposal and communications - must be evaluated in each situation, it seems quite probable that little reliance can be placed upon them in most. Stand-by equipment and facilities to meet the environmental needs and maintain a suitable level of livability within each shelter, independently, will be needed in addition to the required shielding for the occupants that is provided by the structure.

SIMPLE STRUCTURES SHIELDING

Glenn G. Mastin

We are now ready to consider the application of shielding methodology to the determination of the protection afforded by geometry and barrier in specific situations, from gamma radiation from fission products contained in fallout.

The distribution of fallout will be variable depending on several factors. For analysis a uniform distribution is assumed on an infinite plane. Each particle of fallout is assumed to be an isotropic emitter of gamma rays, that is, emitting rays in all direction.

The intensity of radiation which might be expected at any given time or place cannot be known. The procedure is to determine what portion of the total radiation will reach a given point. The reciprocal of this amount is the protection factor for the given point. The actual radiation reaching this point would be a function of the actual degree of contamination which may vary over a wide range.

It is assumed that a radiation detector is located at the point of interest three feet above the ground surface or floor of the area under consideration. Various charts are based on this assumption.

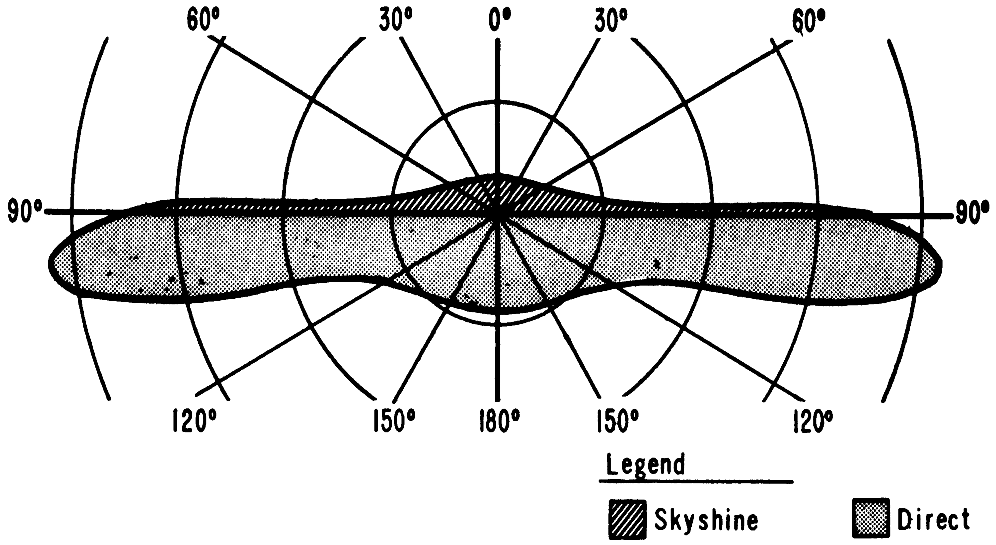
A completely unshielded detector would receive radiation from any direction. A 2Pi detector would be so shielded as to receive radiation through 180 degrees. A collimated detector is shielded to receive radiation through a very small angle, or essentially from one direction.

The intensity of radiation received from any single particle will reduce as its distance from the detector increases. A collimated detector with its axis perpendicular to the plane of contamination will "see" a small area. As the axis is rotated toward the horizon, while the particles from which radiation is received are farther away, the area "seen" is greater and the total radiation received remains fairly constant, Figure 1.

As the axis approaches the horizontal the effect of attenuation due to distance becomes important and the intensity drops off, blunting the limits of the diagram, Figure 1. As the axis of the 2Pi detector rotates above the horizon it would appear no radiation would be received since the shielding would be on the side of the contamination. In a vacuum this is true, but in air radiation backscattered in the air does reach the detector, though with greatly reduced intensity. This backscattered radiation is also referred to as albedo or skyshine.

Determination of the radiation reaching a detector must include radiation from above and below the detector plane, a plane through the detector parallel to the plane of contamination. Some radiation from below the detector plane will have been scattered in the air.

If an area were covered over by a membrane of nearly zero mass thickness such as a polyethylene film to catch the fallout which would otherwise fall on the ground, a 4Pi (spherical) detector mid height between the ground and overhead cover would receive the same total radiation as though positioned the same height above the uncovered ground. The contribution from the contamination overhead would be the same as from the same contamination on the same area of ground.



POLAR DIAGRAM (Detector 30 feet above contaminated plane)

Figure 1. Directional Distribution (Plane Case).

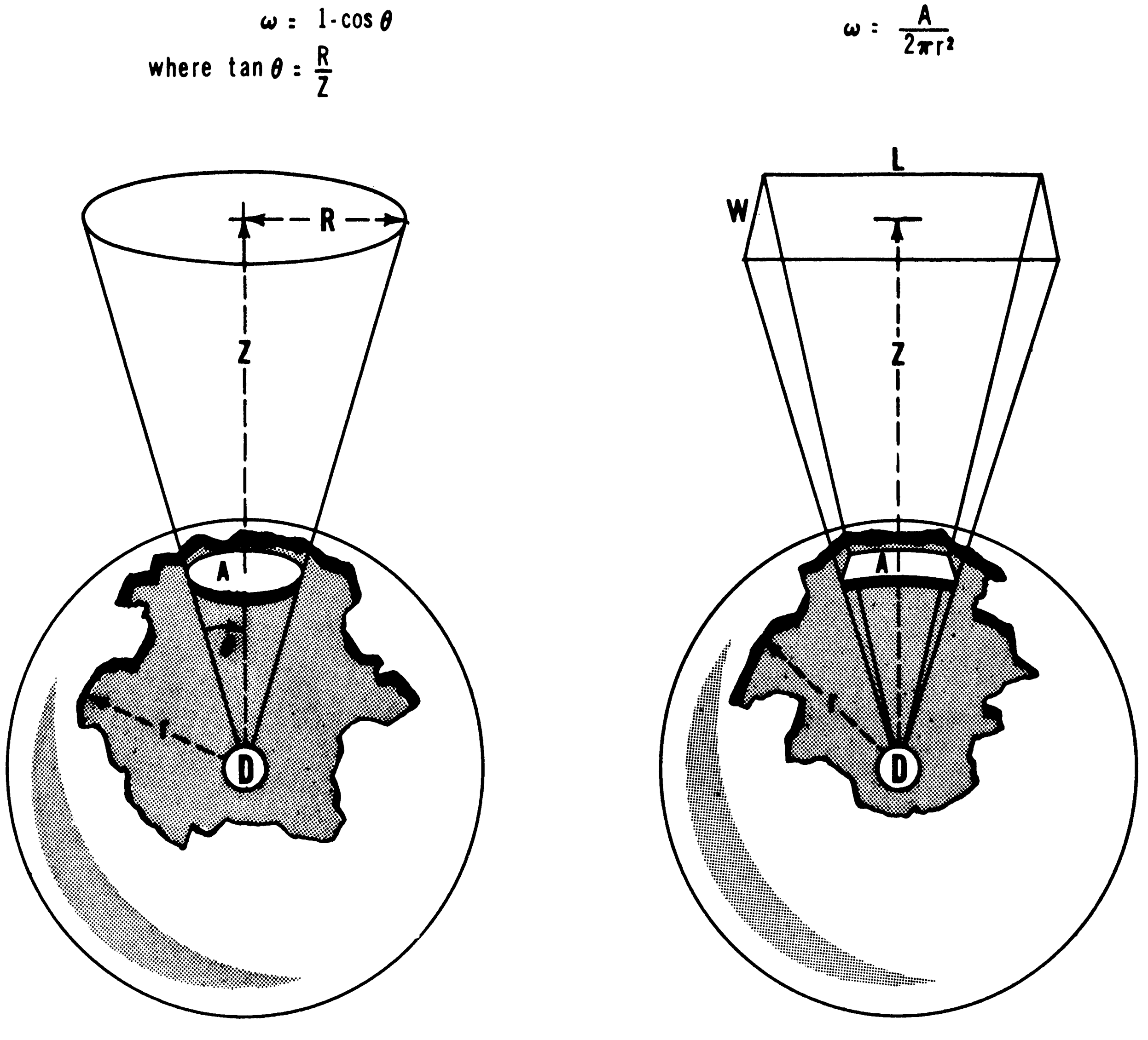
The cover above and the cleared area below are the bases of pyramids with their apexes at the detector. The angle at the detector is a solid angle and if the altitudes and bases are the same the solid angles are the same.

With a base of infinite area as an infinite contaminated plane it takes up the entire field of a 2Pi detector with its axis perpendicular to the plane. When a plane of finite area is involved as a roof or a cleared area it is necessary to know what portion of the field is taken up by the area.

In the situation assumed above the contaminated area above takes up the same portion of the field as the cleared area below. The solid angles at the detector are equal. If, however, the detector is not located at mid height the solid angles will not be the same and the portions of the field of the detector taken up by the area above will be different than for the area below. Thus the higher the overhead barrier above the detector the smaller the contribution of that much of the contamination. This is true even though there is not attenuation by the barrier.

It is necessary to be able to determine the solid angle fraction subtended at the detector by any area. Actually, it is more convenient to know what portion of the total solid angle at the detector is involved or the solid angle fraction, omega (ω), Figure 2.

For circular area, which forms the base of a right circular cone with its apex at the detector, ω equals $1 - \cos\theta$ where θ is the angle between the generators and the axis.



(A.) CIRCULAR AREA **(B.) RECTANGULAR AREA**

Figure 2. Solid Angle Fraction, ω.

The solution is not so simple for a rectangular area. Values of ω can be readily obtained from Figure 3 where the parameters are eccentricity ratio equal to the width of the area divided by the length and the normality ratio equal to twice the distance from detector to area divided by its length.

When a photon of a gamma ray impinges on a barrier it may pass through without interaction, be absorbed by interaction with electrons of the atoms in the barrier or be scattered in the barrier and emerge traveling in a different direction with lower energy. The probability of an interaction depends on the thickness and material of the barrier and energy of the rays.

The reduction factors for overhead barriers for combined effects of barrier attenuation and geometry are given in Figure 4 as a function of mass thickness and solid angle fraction. This is the roof contribution, C_o.

By reduction factor is meant the proportion of the total radiation impinging on the barrier which will reach the detector. Thinking of it as a transmission factor might be clearer. The mass thickness, X_o, is the sum of the mass thicknesses in pounds per square foot of all the horizontal barriers between the contamination and the detector.

In addition to the radiation from the contamination on the top surface of the barrier, skyshine, or backscatter, from the entire field will be impinging on the roof barrier. The amount getting through is a function of the mass thickness. Figure 5 gives a correction factor to be applied to the value from Figure 4.

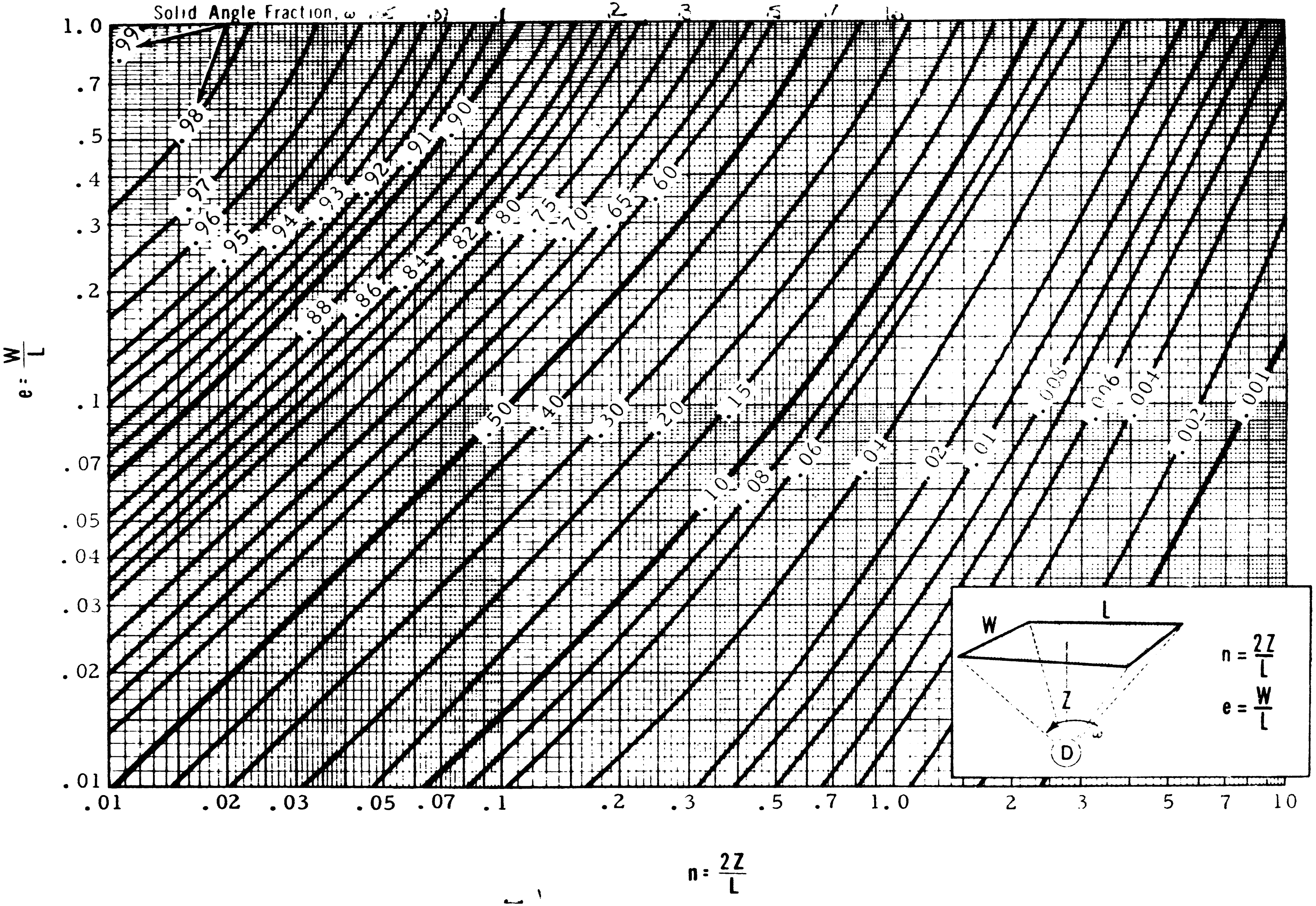
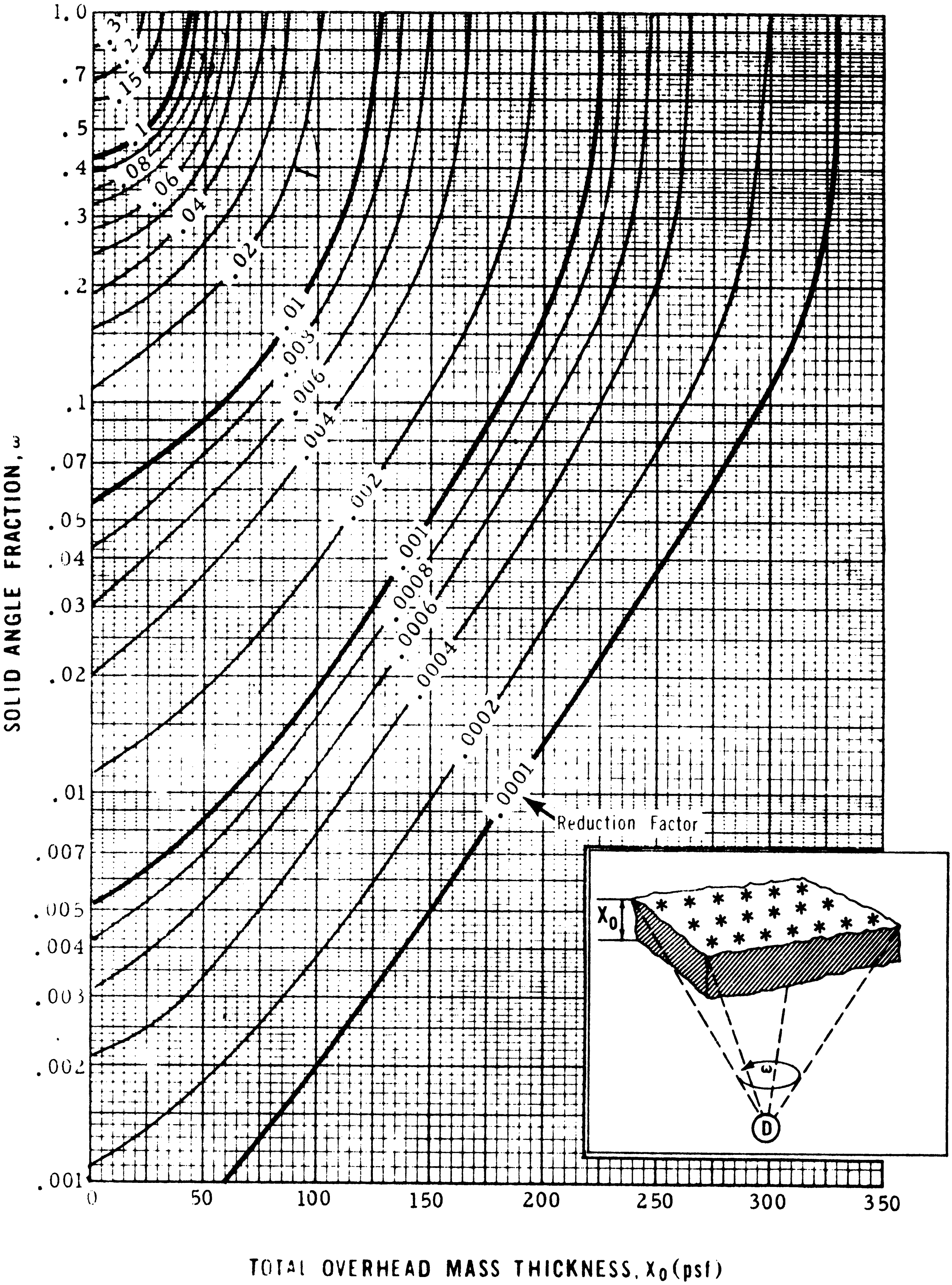


Figure 3. Solid Angle Fraction, ω.



note skysh[illegible]

Figure 4. Reduction Factors for Combined Shielding Effects, Roof Contribution, C_o.

(Reduction Factors for Combined Shielding Effects, Roof Contribution)

Overhead Mass Thickness, X_0 (psf)	Contaminated Roof	Decontaminated Roof
0	Use Chart 10	Use Chart 10
25	1.10	0.10
50	1.08	0.08
100	1.04	0.04
200	1.01	0.01

Figure 5. "Skyshine" Correction for Figure 4.

If the covered area is not enclosed, radiation from contamination outside the covered area will reach the detector through the remainder of the total solid angle fraction below the detector plane without absorption or scattering. Likewise skyshine will reach the detector through the remainder of the solid angle fraction above the plane.

While the solid angle fraction subtended at a detector by a radiating surface gives a good indication of the geometry shielding effect, it is more accurate to consider also the directional distribution associated with the radiating surface. The combined effect of both the solid angle fraction and the directional distribution is termed "directional response."

The directional response for an overhead contaminated plane is closely related to the mass thickness of the barrier, and directional response and barrier effect are combined in Figure 4.

In the case of a vertical barrier the radiating particles are not on the barrier, but on the ground surrounding the enclosure and detector. Since the angular distribution of radiation emerging from the inside of a wall is not well known, the directional response is calculated by an approximate method which considers the "non-wall-scattered" and "wall-scattered" radiation separately. The term "non-wall-scattered" refers to radiation which passes through the walls without interaction whether or not scattered in the air outside the wall. "Wall-scattered" refers to radiation scattered at least once in the walls of the structure.

Figure 6 indicates the relationship between the contaminated surface and the solid angle subtended at the detector for three separate cases of directional distribution:

(a) The direct case, G_d

(b) The skyshine case, G_a

(c) The scattered case, G_s

Figure 7 shows how the height of the detector is considered along with the solid angle fraction below the detector plane to determine the directional response, G_d.

Of the total radiation impinging on a wall when the upper and lower solid angle fractions are zero 90% is assumed to come from below the detector plane, G_d, and 10% from above, G_a, a total of 100%.

In this same situation it is assumed that of the total wall scattered radiation 50% will have been scattered in the wall below the detector plane and 50% in the wall above the detector plane, again a total of 100%.

If the walls are of zero mass thickness, no radiation will be scattered in the wall. With walls of infinite mass thickness all radiation will be scattered in the wall. Actual situations will tend toward the lower limit of mass thickness with glass walls taken as zero mass thickness for practical purposes. Thus, normally, some of the radiation reaching the detector will be wall-scattered radiation.

The amount of scatter is a function of the wall mass thickness. Figure 8 gives the fraction, S_w, of emergent radiation scattered in the wall. $1-S_w$ is, then, the fraction not scattered.

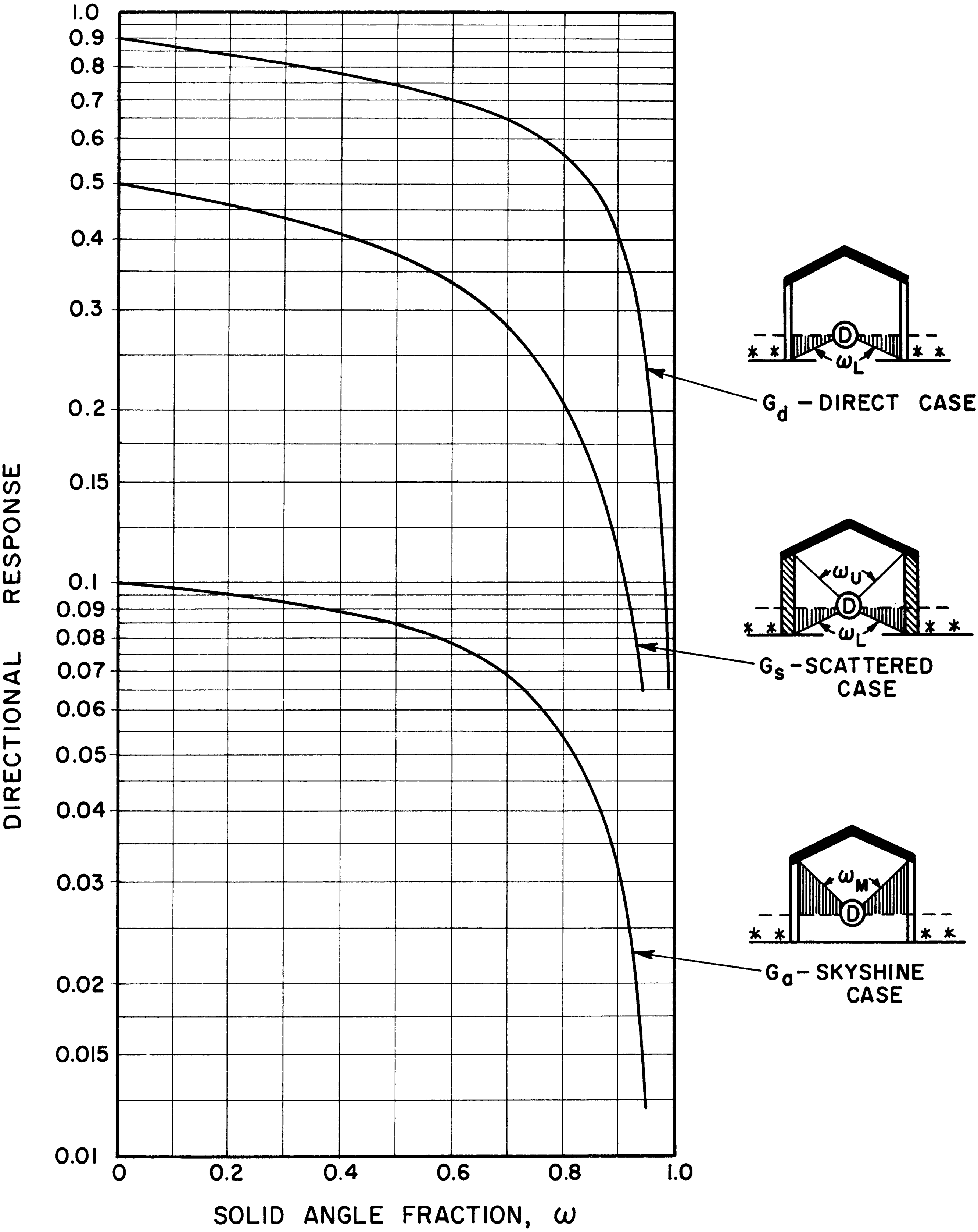


Figure 6. Directional Responses, Ground Contribution, G_d, G_s and G_o.

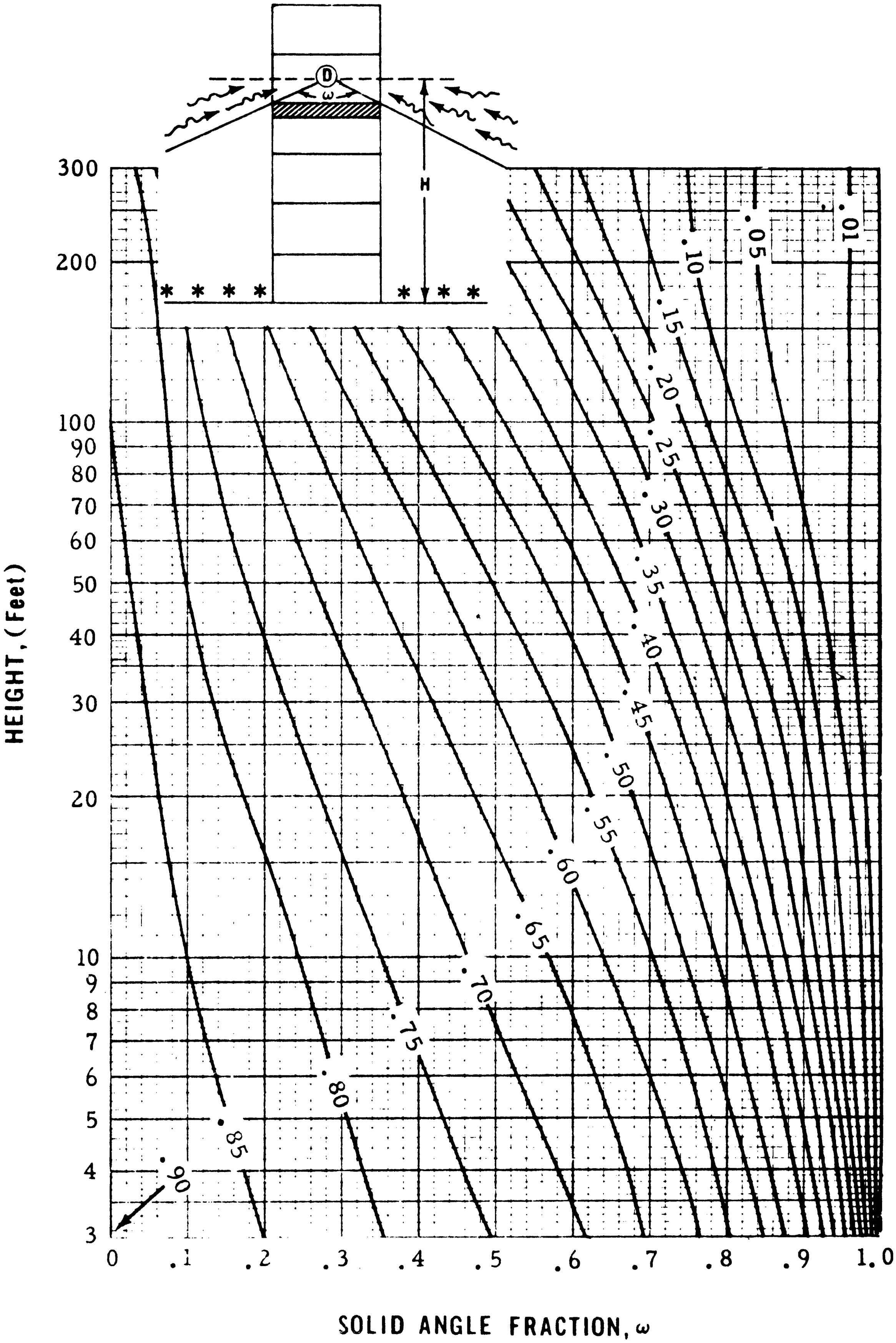


Figure 7. Directional Responses for Various Heights, G_d.

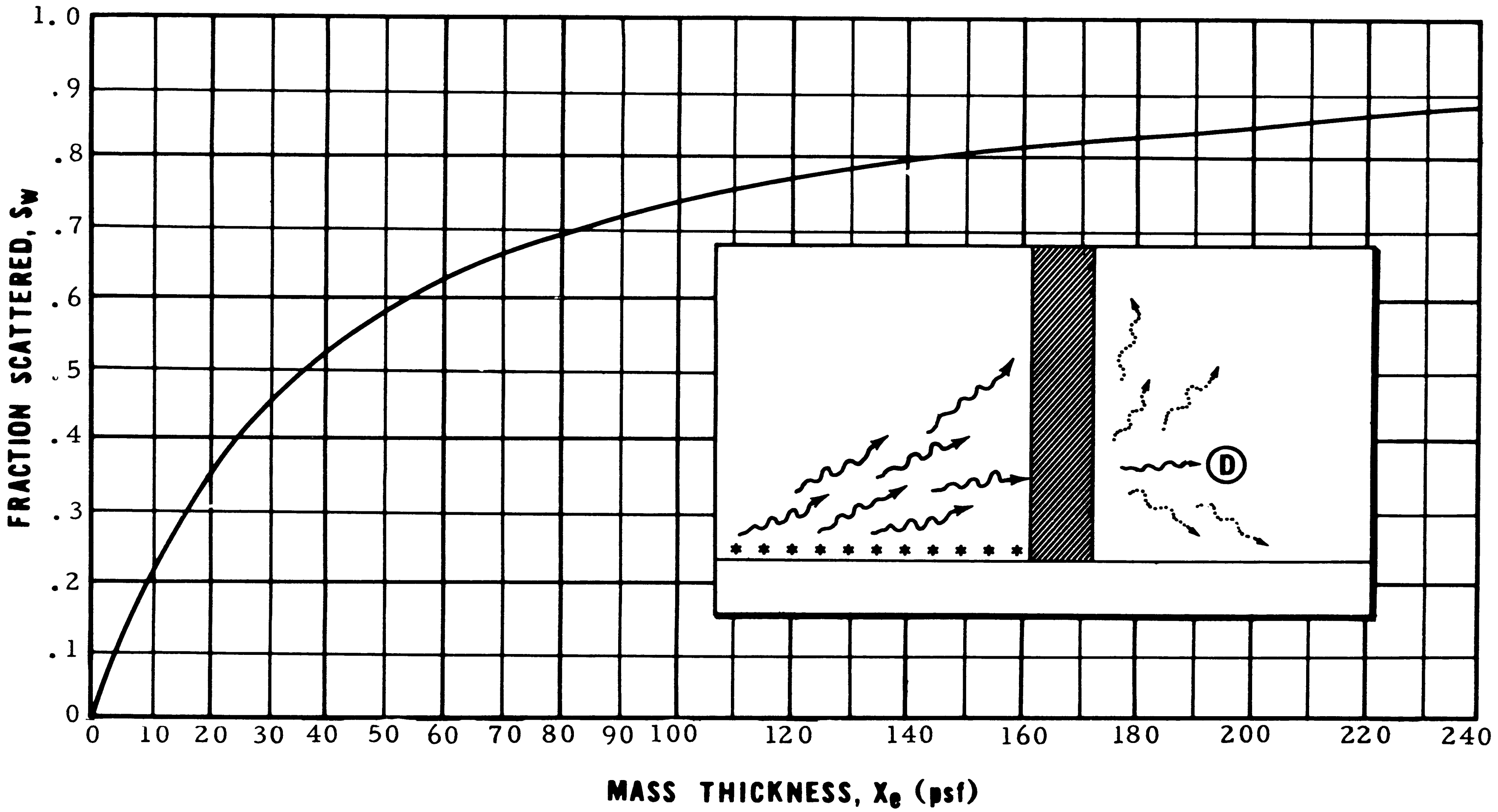


Figure 8. Fraction of Ermergent Radiation Scattered in Wall Barrier, S_w.

The directional responses G_d and G_a, are determined as for a wall of zero mass thickness and G_s is determined as for a wall of infinite mass thickness and then weighed in terms of S_w and $1-S_w$ for the actual wall mass.

As pointed out above some radiation is absorbed by the barrier. It is also attenuated by distance. Figure 9 gives the wall barrier reduction factor as a function of wall mass thickness and height of detector above the contaminated plane.

In the case of all scattered radiation the shape of the building is of importance. Radiation from particles in the angle formed by the wall lines extended can impinge on two walls and in each wall some will be scattered to the detector. It is thought that this will result in a build-up of scattered radiation reaching the detector above that received from the walls of very long narrow buildings. Figure 10 gives the shape factor, E, as a function of the eccentricity ratio, e, to be applied to the scattered geometry factor to correct for the shape of the building.

Thus far the discussion has assumed a contaminated plane of infinite extent in all directions. More typical, however, will be the case of strips of contamination of limited width, such as streets, alleys, parking lots, etc., on one or more sides. As shown subsequently in the example on mutual shielding the direct and sky-shine contributions can be easily handled. This is not the case for the wall scattered component and it is necessary to treat it differently.

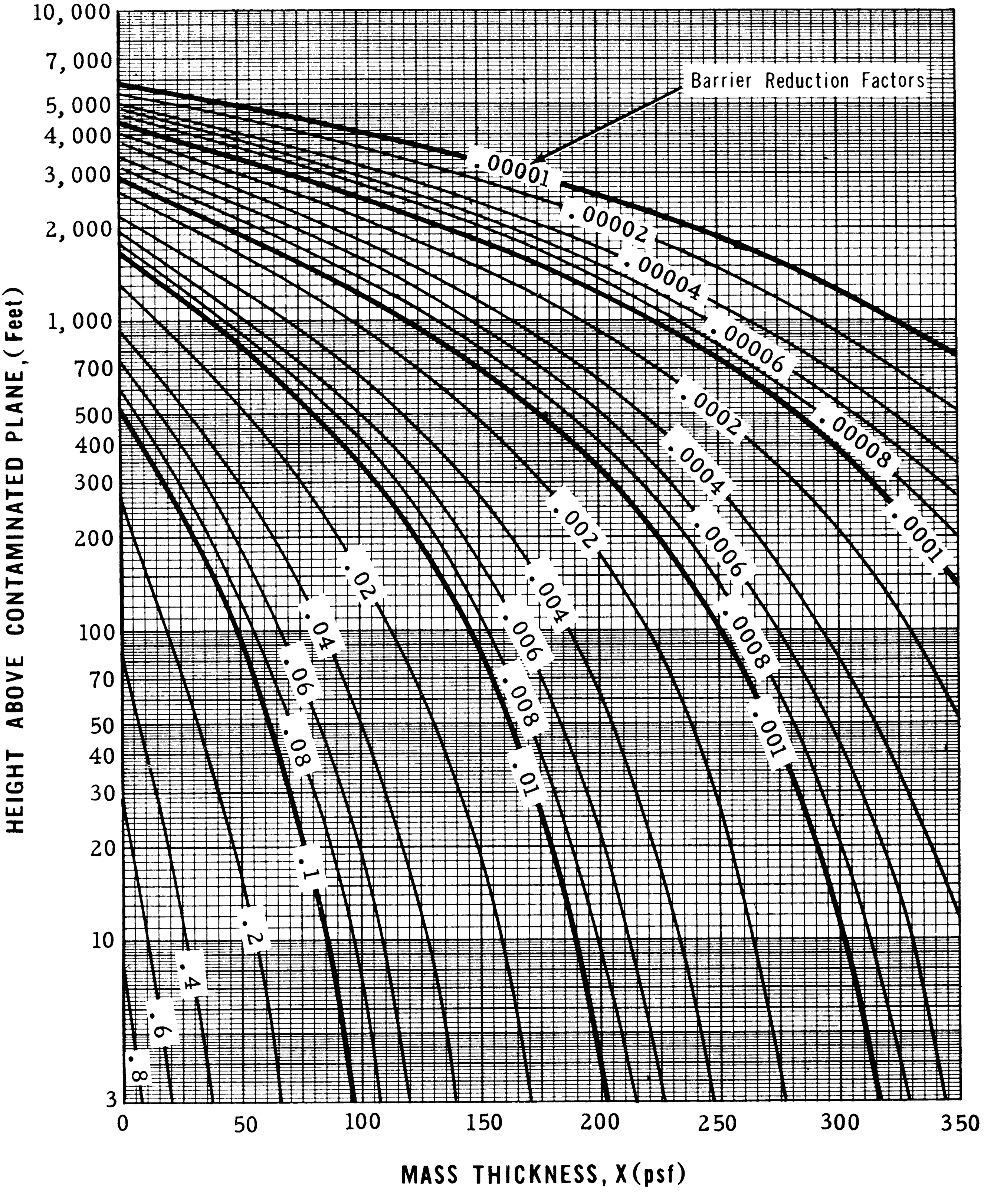


Figure 9. Wall Barrier Shielding Effects for Various Heights, B_W and B_e.

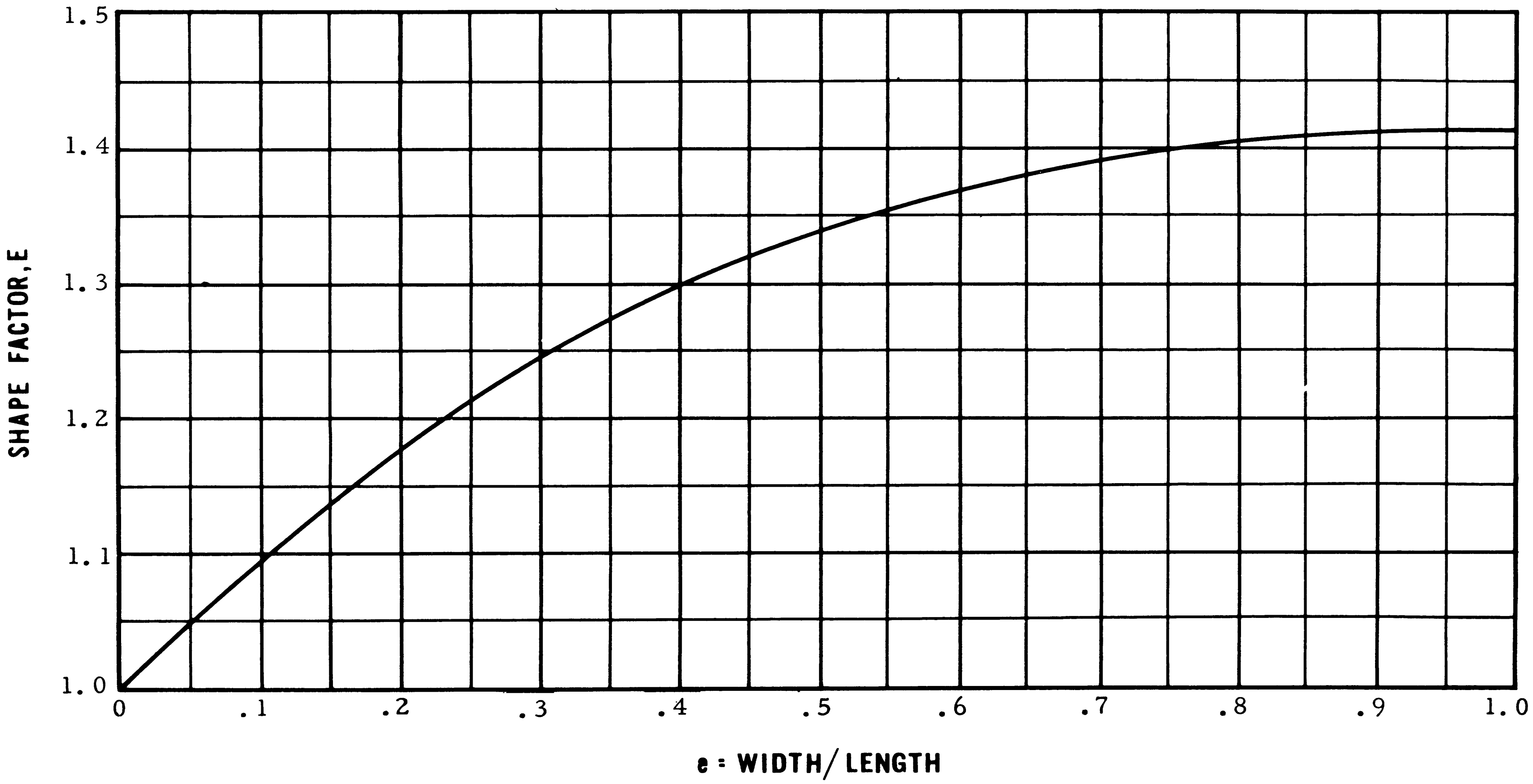


Figure 10. Shape Factor for Wall-Scattered Radiation, E.

Shape Factor for Wall-scattered Radiation, E

The scattered component reaching the detector will come from the entire area of the shielded wall as it would if not shielded, though the radiation impinging on the wall is from a strip of limited width. The effect is taken into account in the barrier reduction factor. Figure 11 shows the barrier reduction factor as a function of the wall mass thickness and ω_s. The solid angle fraction, ω_s, is a function of the width and length of the contaminated strip. The method of computation is shown in the example on mutual shielding.

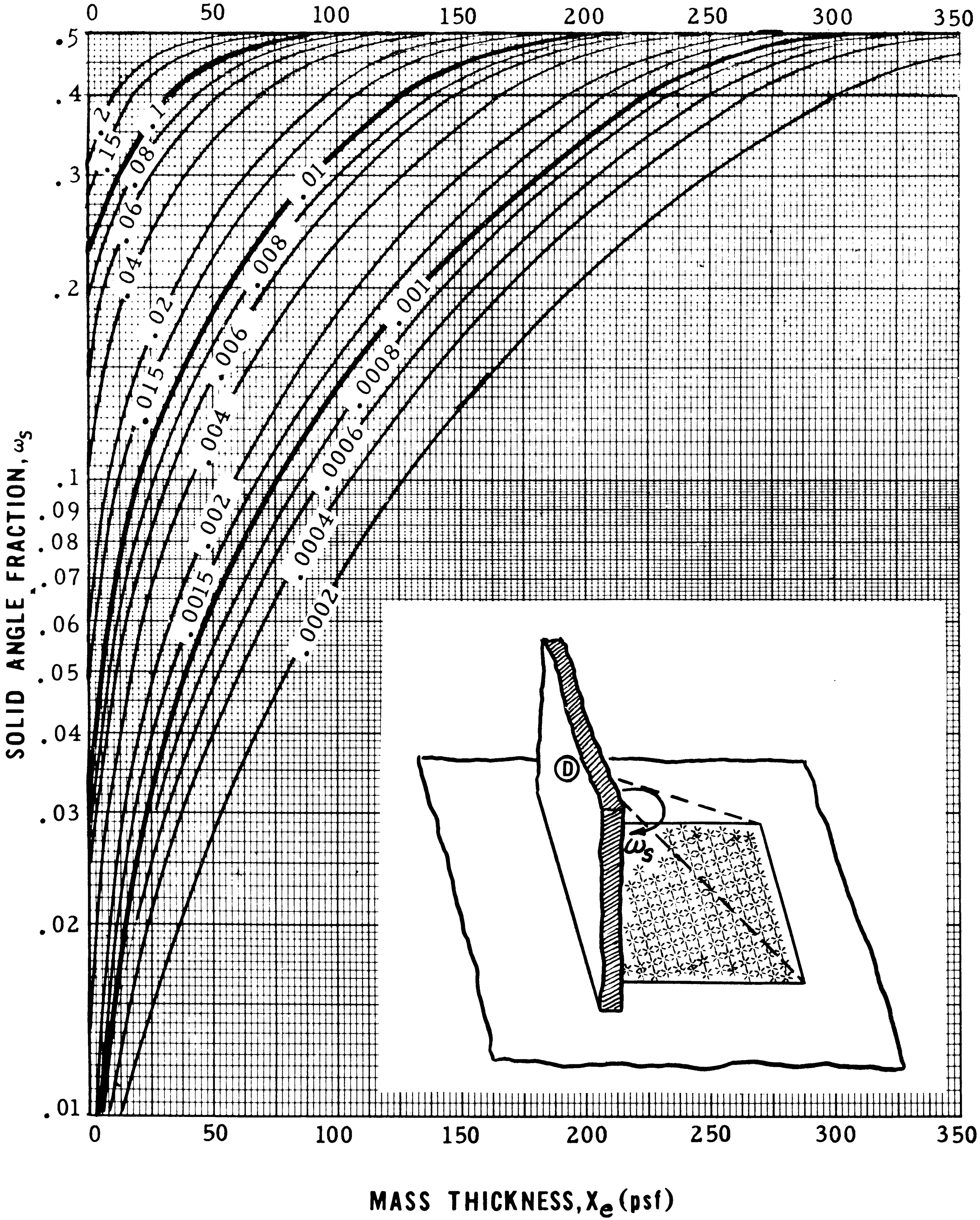
There are three basic barrier shielding effects shown in Figure 12. The energy spectrum of gamma radiation is assumed to be that from fission products at about one hour after weapon burst. It is assumed that the amount of attenuation by a given barrier depends only on its mass thickness and not on the chemical composition of the barrier material.

Case 1

Calculations are based on the assumption of infinite plane isotropic source and a point detector immersed in an infinite homogeneous medium and separated by a mass thickness X_o. In the case of radiation coming through the walls of the story below that in which the detector is located, the barrier reduction factor for the floor mass thickness X_f through which it must pass to reach the detector is taken from this case.

Case 2

Calculations apply to the penetration of radiation from a semi-infinite plane isotropic source on one side of a vertical



(values at ω = 0.5 taken from Figure 12, case 2.)

Figure 11. Barrier Reduction Factors for Wall-Scattered Radiation for Limited Strip of Contamination

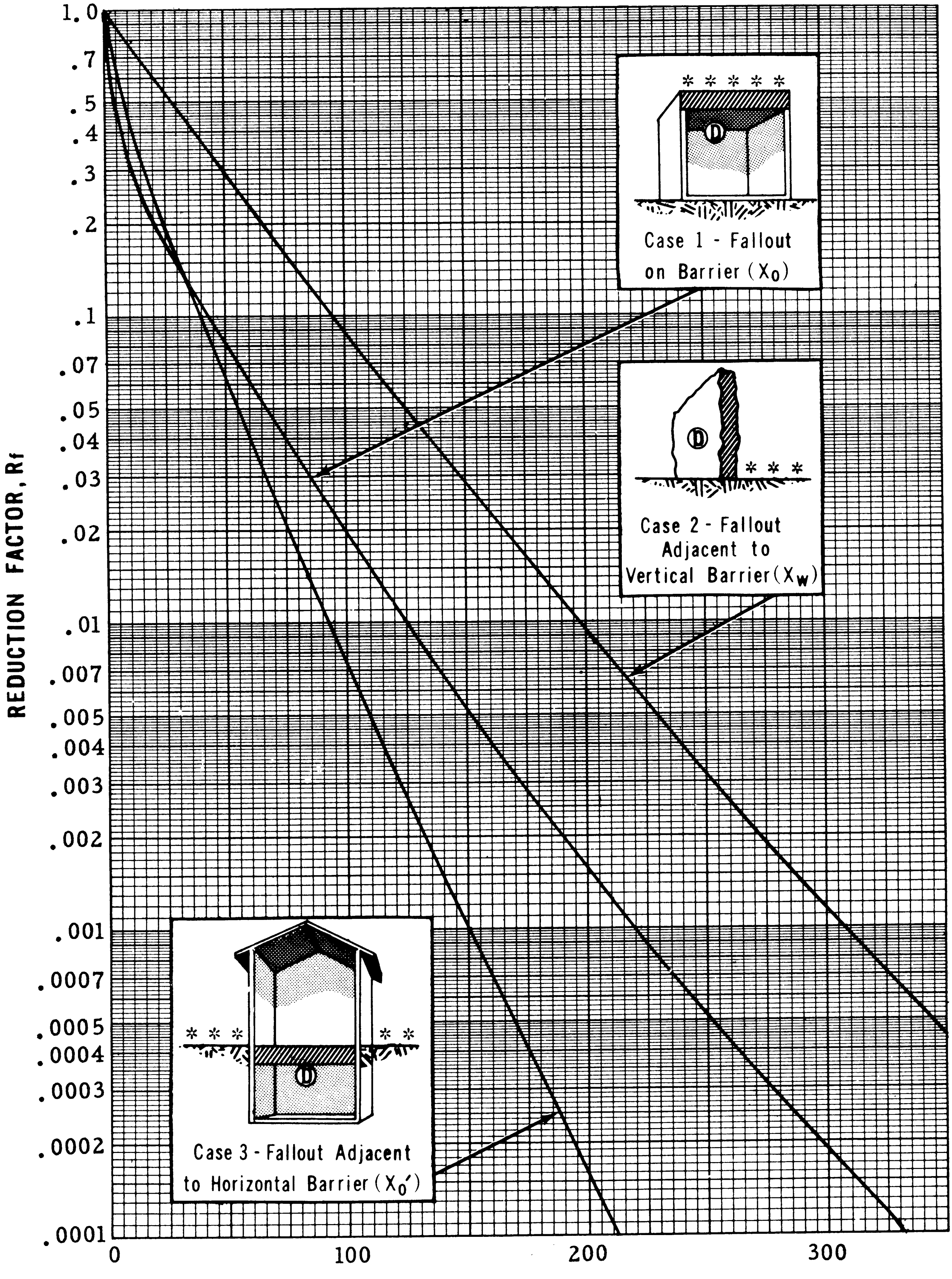


Figure 12. Barrier Shielding Effects (Plane Sources) B_o, B_w and B_o'

wall to a point detector on the other side, located three feet above the level of the source plane.

Case 3

Calculations apply to the attenuation of radiation backscattered from a plane isotropic source which emits only in a forward direction. In the case of radiation coming through the walls of the story above that in which the detector is located, the barrier reduction factor for the immediate overhead mass thickness X'_o through which it must pass to reach the detector is taken from this case.

The complexity of the equations which must be used to make shielding analysis is so great that analytical solutions are not appropriate. Instead it is necessary to make use of what is termed functional equations generally represented by graphical expressions. For example, consider case 1 of Figure 12 which graphically expresses barrier reduction factors as a function of mass thickness. In this particular case $B_o(X_o)$ has its values determined by the curve which graphically describes this function.

Many of the expressions are functions of two variables. For example, the barrier reduction factor for walls, a function of wall mass thickness and detector height above contaminated plane, is described by the expression $B_w(X_wH)$ which is graphically presented in Figure 9. This system of functional notation is useful since the various procedures for making a shielding analysis can be concisely described by them. Figure 13 summarizes the general procedures using functional equations.

Figure 13.

BASIC FUNCTIONAL EQUATIONS FOR SHIELDING ANALYSES

The following functional equations apply to rectangular structures with a roof of uniform construction and walls of uniform construction. They apply to structures located in a smooth, level, uniformly contaminated plane of infinite extent. The detector is assumed to be located at the center of the structure for equations (1) through (7); and, in addition, at sill level for equation (5). In general, $R_f = (1) + (5) + (6) + (7)$ and $P_f = 1 \div R_f$.

Roof Contribution:

$$(1) \quad C_o(\omega_o, X_o) + [C_o(\omega'_o, X_o) - C_o(\omega_o, X_o)] B_w(X_i, H_f)$$

Ground Contribution through adjacent walls, windowless case:

$$(2) \quad B_w(X_e, H) B_w(X_i, 3') G_g$$

$$\text{where } G_g = [G_s(\omega_\ell) + G_s(\omega_u)] S_w(X_e) E(e)$$

$$+ [G_d(\omega_\ell) + G_a(\omega_u)] [1 - S_w(X_e)]$$

Ground Contribution through ceiling, windowless case:

$$(3) \quad B_w(X_e, H_u) B_w(X_i, 3') B'_o(X'_o) G_g$$

$$\text{where } G_g = [G_s(\omega'_u) - G_s(\omega_u)] S_w(X_e) E(e)$$

$$+ [G_a(\omega'_u) - G_a(\omega_u)] [1 - S_w(X_e)]$$

Figure 13. Cont'd.

Ground Contribution through floor, windowless case:

(4) $B_w (X_e, H_\ell) B_w (X_i, 3') B_o (X_f) G_g$

where $G_g = [G_s (\omega'_\ell) - G_s (\omega_\ell)] S_w (X_e) E (e)$

$+ [G_d (\omega'_\ell, H) - G_d (\omega_\ell, H)] [1 - S_w (X_e)]$

Ground Contribution through adjacent walls, window case:

(5) $C_g + (C_a - C'_a) P_a$ or $C_g + (C_a - C'_a) Az_a$

where C_g is equation (2) above

and $C_a = B (X_i, 3') [G_a (\omega_a)] B_w (X_e = 0, H)$

and $C'_a = B_w (X_e, H) B_w (X_i, 3') [G_s (\omega_a) S_w (X_e) E (e) +$

$G_a (\omega'_a) [1 - S_w (X_e)]]$

Ground Contribution through ceiling, window case:

(6) $[C_g] (100\% - A_p) + [C'_g] A_p$

where C_g is equation (3) above with X_e

and C'_g is equation (3) above with $X_e = 0$ psf, i.e.

$B_w (X_i, 3') B'_o (X'_o) [G_a (\omega'_u) - G_a (\omega_u)] B_w (X_e = 0, H)$

Figure 13. Cont'd.

Ground Contribution through floor, window case:

(7) $[C_g]\ (100\% - A_p) + [C'_g]\ A_p$

where C_g is equation (4) above with X_e

and C'_g is equation (4) above with $X_e = 0$ psf, i.e.

$B_w\ (X_i,\ 3')\ B_o\ (X_f)\ [G_d\ (\omega'_\ell, H) - G_d\ (\omega_\ell, H)]\ B_w\ (X_e = 0,\ H)$

Ground Contribution through perpendicular passageways:

(8) a. 1st Corridor, $A_v\ (\omega_1)$

b. 2nd Corridor, $0.1\ \omega_2\ R_f$ (1st)

c. 3rd Corridor, $0.5\ \omega_3\ R_f$ (1st) R_f (2nd)

d. nth Corridor, $0.5\ \omega_n\ R_f$ (1st) R_f (2nd) R_f (3rd) ..... R_f (n-1)

Roof Contribution through shafts, including skyshine:

(9) Vertical shaft, $A_h\ (\omega_1) + A_a\ (\omega_1)$

For subsequent R_f's see equations (8)b, (8)c and (8)d above.

Figure 14.

LIST OF SYMBOLS

List of Symbols for Shielding Analysis

A	Area (sf).
A_a	Directional response for skyshine radiation through horizontal aperture.
A_h	Directional response for direct radiation through horizontal aperture.
A_p	Percent of apertures in wall relative to total wall area.
A_v	Directional response for direct and skyshine radiation through vertical aperture.
Az	Azimuthal sector
B	Barrier reduction factor for plane isotropic source.
B_e	Barrier reduction factor for exterior wall construction.
B_i	Barrier reduction factor for interior wall construction.
B_o	Barrier reduction factor for overhead construction.
B_o'	Barrier reduction factor for barrier immediately overhead.
B_w	Barrier reduction factor for wall construction.
B_{ws}	Barrier reduction factor for wall-scattered radiation (mutual shielding case only).
C_g	Reduction factor accounting for combined barrier and geometry shielding effects; ground contribution.
C_o	Reduction factor accounting for combined barrier and geometry shielding effects; overhead (roof) contribution.
D	Perpendicular distance between vertical plane and detector (ft).
e	Eccentricity ratio = W/L.
E	Shape correction factor for wall-scattered radiation.
F_e	Effective fetch (ft).
G	Geometry reduction factor

Figure 14. Cont'd.

LIST OF SYMBOLS

List of Symbols for Shielding Analysis

G_a	Directional response for skyshine radiation.
G_d	Directional response for direct radiation.
G_g	Geometry reduction factor for ground contamination.
G_s	Directional response for wall-scattered radiation.
H	Height of detector plane above contaminated plane (ft).
H_f	Fictitious height = 13Xo (ft). Also added height to account for ground roughness.
L	Length of structure (ft).
n	Normality ratio = 2Z/L.
P_a	Perimeter ratio of apertures.
P_f	Protection factor.
P_r	Perimeter ratio.
P_s	Barrier reduction factor for point isotropic source.
R_f	Reduction factor.
r_e	Effective radius (ft).
S_w	Percent of scattered radiation emergent from a wall barrier.
t	Barrier thickness (ft).
U	Unit weight of barrier (pcf).
W	Width of structure (ft).
W_c	Width of finite contaminated strip (ft).
X	Mass thickness (psf).
X_e	Mass thickness of exterior walls (psf).

Figure 14. Cont'd.

LIST OF SYMBOLS

List of Symbols for Shielding Analysis

X_f	Mass thickness of floor construction (psf).
X_i	Mass thickness of interior walls (psf).
X_o	Total overhead mass thickness (psf).
X'_o	Mass thickness of barrier immediately overhead (psf).
X_w	Wall mass thickness (psf).
Z	Perpendicular distance between horizontal plane and detector (ft).
ω_l (omega)	Solid angle fraction below detector plane.
ω_o (omega)	Solid angle fraction subtended by roof.
ω_s (omega)	Solid angle fraction below detector plane for mutual shielding cases.
ω_u (omega)	Solid angle fraction above detector plane.
ω_1, ω_2, etc.	Solid angle fraction in first, second, etc. leg of passageway or shaft.

The examples also use this functional notation. Since parenthesis are used in the functional equations to show the variables of which the value of interest is a function, brackets are used to set off a collection of terms.

Figure 14 is a list of symbols for shielding analysis.

Figure 15 and 16 illustrate the angles used in mutual shielding analysis.

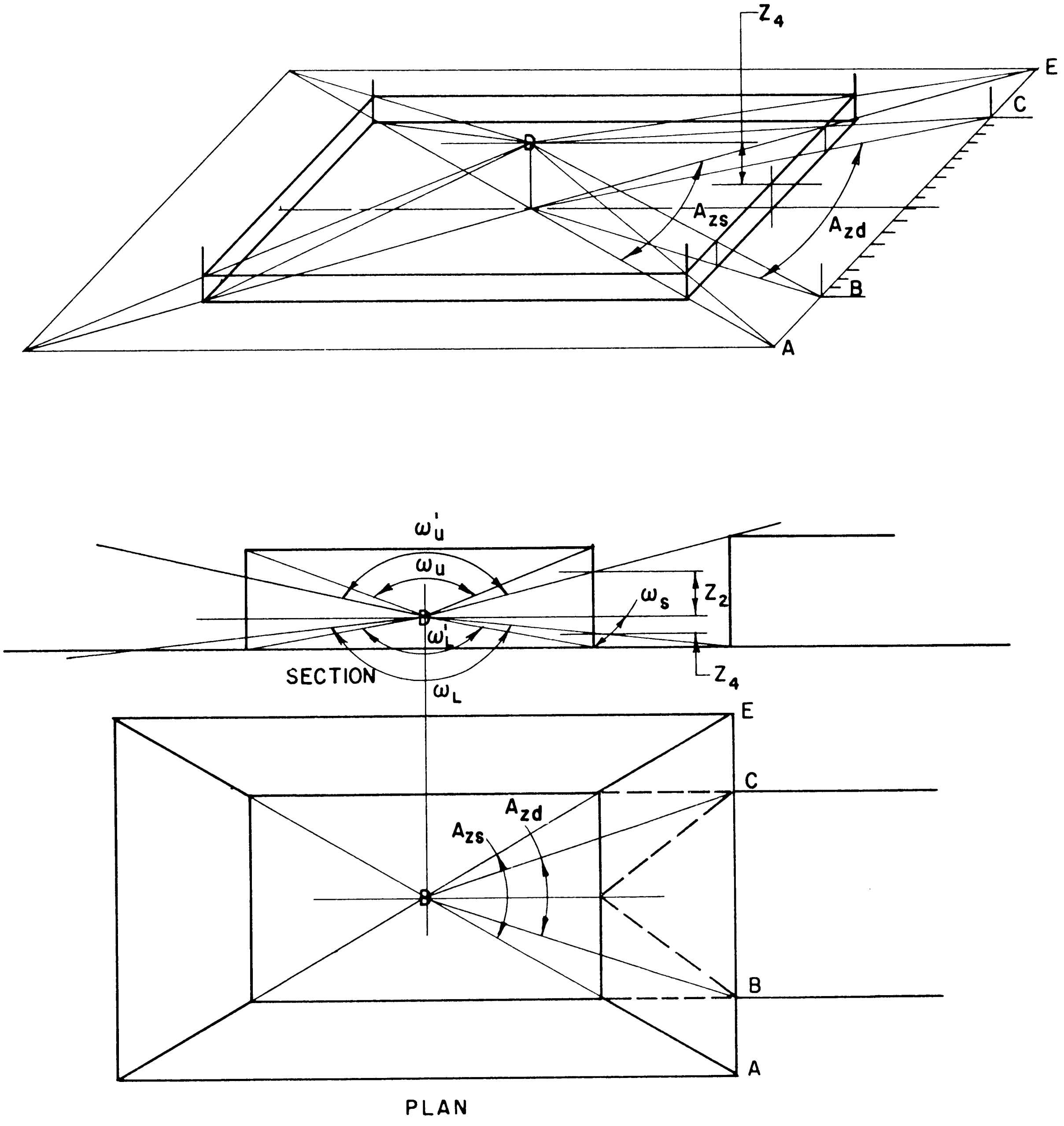
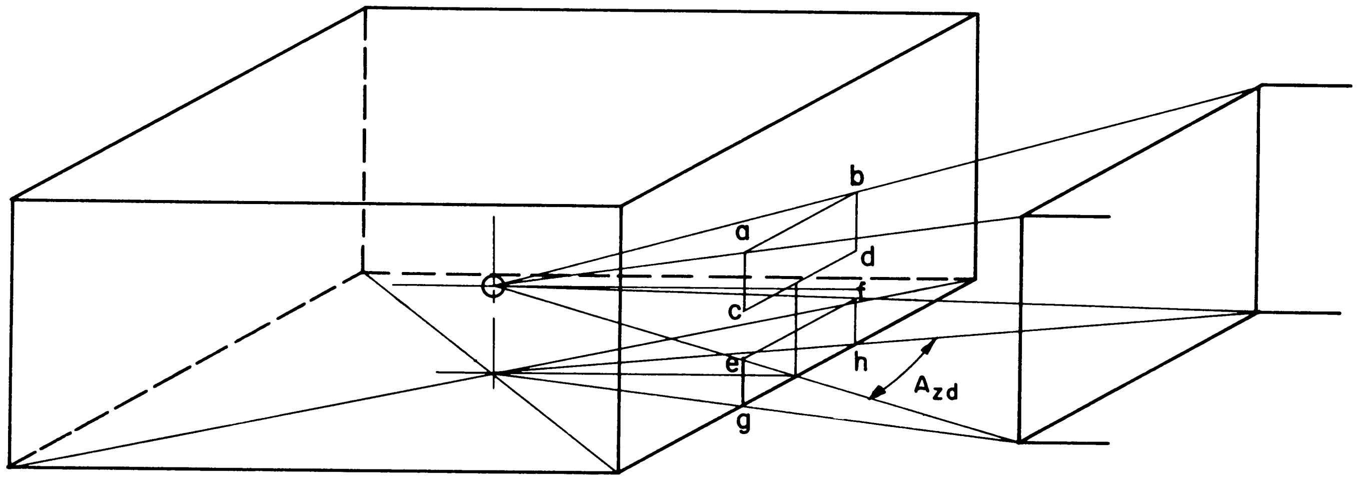
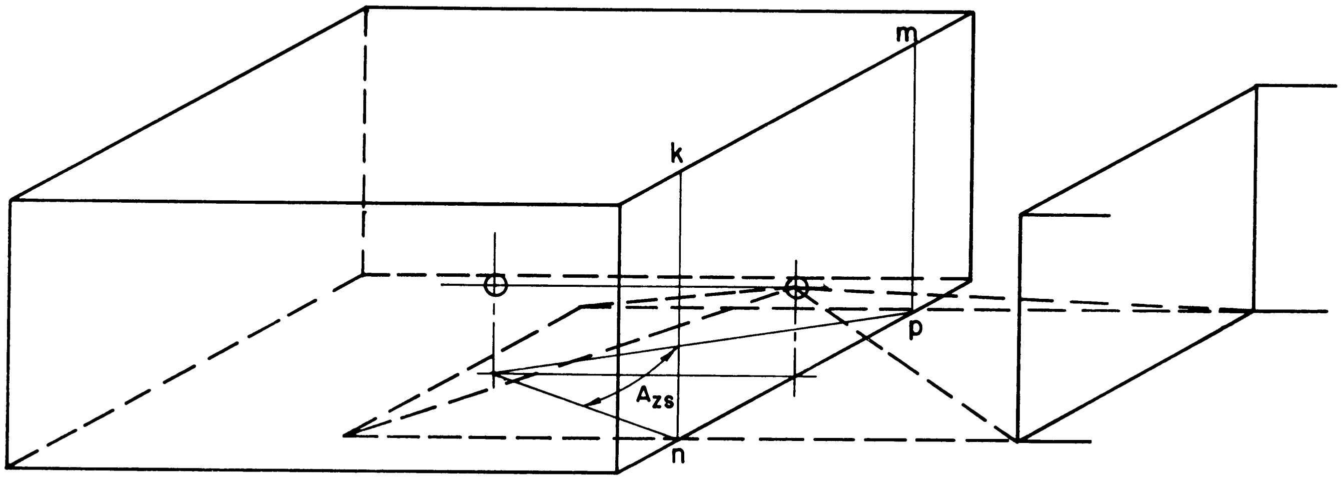


Figure 15. Mutual Shielding.



No skyshine through a, b, c, d.
No direct through c, d, e, f.
Direct through e, f, g, h from limited strip, only.



Pyramid with apex at O subtends solid angle fraction $2\omega_s$ at O.
1 July 61 edition of Manual puts O at detector height.
1 October 61 edition puts O at mid height of wall.

Figure 16.

EXAMPLES OF SIMPLE STRUCTURE SHIELDING

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Example No. 1 - This shows an overhead barrier and walls, such as glass, assumed zero mass thickness. The overhead, or roof, "takes up" 87% of the field of the detector above the detector plane. The radiation reaching the detector through the other 13% of the field is skyshine through the walls. There is no attenuation or scatter by the wall.

The cleared area below, while the same area as the roof, subtends a large angle at the detector, because it is closer to the detector. Direct radiation reaches the detector through 5.5% of its field.

Notice that the solid angles are referenced to a vertical axis.

Example No. 1A - The walls have mass thickness. 69% of the radiation reaching the detector has been scattered in the wall. Only 14.5% of the radiation impinging on the wall reaches the detector due to attenuation by the barrier.

Of the total radiation impinging on the structure 10.9% reaches the detector, whereas, in the previous example 37.8% reaches it.

Example No. 2 - Placing the structure in the ground effectively stops radiation through the walls. Now only 2.1% reaches the detector.

Example No. 3 - This shows how radiation through the walls of the story above that in which detector is located is handled.

Example No. 3A - This is a partially buried structure. The main difference between this and the previous example is that radiation through walls does not go through a horizontal barrier.

Example No. 4 - This shows how multiple horizontal barriers, floors are handled.

Example No. 5 - This shows how radiation through the walls of the story below that in which the detector is located is handled.

Example No. 6 - This shows how a continuous strip of windows in the wall of the story in which detector is located are handled. These walls are referred to as "adjacent" walls. Here the detector has been assumed at sill height. Exposure above a sill is undesirable due to the large direct component. There would be no attenuation by the window glass.

Example No. 7 - Here the windows are not continuous. Correction is made for the width of windows to wall perimeter, P_a. This is generally less accurate than use of azimuthal sector illustrated in Example No. 10.

Example No. 8 - This is a continuation of Example No. 6 to include the radiation from the walls of the story above and the story below. Here the ratio of the area of the apertures to the wall area is used. In this example the aperatures being continuous and 4 feet high in a 10 foot high wall the area of apertures is 40% of total wall area.

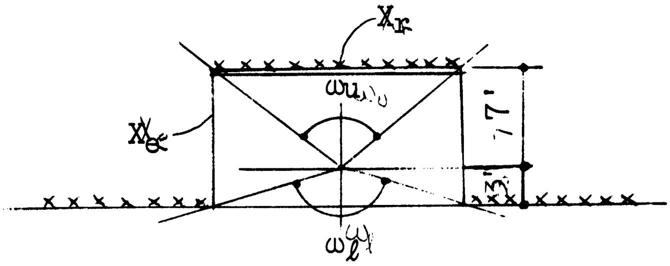
Example No. 9 - A structure with walls of different mass thickness. Here is introduced the concept of a fictitious building. This is a building having the characteristics of some part of the given structure. On the basis of perimeter ratio, P_r, or azimuthal sector, A_z, that portion of the contribution to the detector in the fictitious building appropriate to the given building is used.

Example No. 10 - This is an application of the use of azimuthal sector, A_z.

Example No. 11 - This is a building shielded on one side by another building 60 feet away, as across a street. In mutual shielding it is assumed the barrier is of such total mass thickness that radiation going through it to another building will be negligible.

Simple Structure Shielding

Example No. 1



X_r = 60 psf

X_e = 0 psf

Figure 4 ┌── Figure 6 ──┐

ω	W	L	Z	e=W/L	n=2Z/L	ω	G_d	G_s	G_a
ω_u	80'	140'	7	.57	.10	.87	----	.145	.039
ω_ℓ	80'	140'	3	.57	.043	.945	.275	.068	----

$\omega(n, e)$ Figure 3

$B_w(X_eH) = 1$ Figure 9

$S_w(X_e) = 0$ Figure 8

$E(e) = 1.36$ Figure 10

1. R_f (Roof) = $C_o(\omega_u X_o)$ where $\omega_u = .87$ & $X_o = 60$ psf $= X_r$

   = .06

   Correct for Skyshine - Figure 5 = 1.07

   R_f (Roof) = .06 x 1.07 = .064

2. R_f (Skyshine) = $C_a = G_a(\omega_u)\ B_w\ (X_e)[1 - S_w(X_e)]$

   R_f (Skyshine) = C_a = .039[1][1 - 0] = .039

3. R_f (Direct) = $C_d = G_d(\omega_\ell)\ B_w\ (X_e)[1 - S_w(X_e)]$

   R_f (Direct) = C_d = .275[1][1 - 0] = .275

4. R_f (Scatter) = C_s = $[G_s(\omega_u) + G_s(\omega_\ell)]B_w(X_e)\ S_w(X_e)\ E(e)$

   R_f (Scatter) = C_s = $[.145 + .068]\ 1\ [0]\ 1.36 = 0$

5. Total R_f = R_f (Roof) + R_f (Skyshine) + R_f (Direct)

   $.064 + .039 + .275$

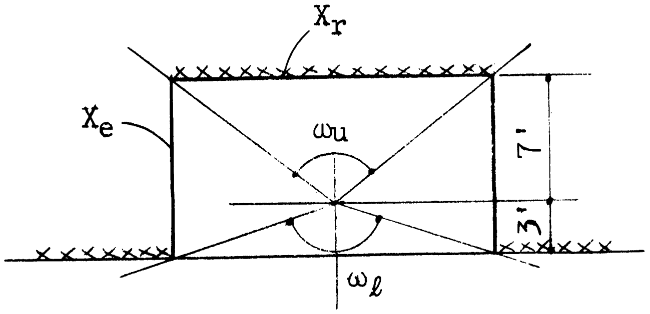
   $R_f = .378$

   $P_f = 1/R_f$

   $P_f = 2.65$

Simple Structure Shielding

Example No. 1A



X_r = 60 psf

X_e = 80 psf

From previous example:

		Figure 6	
	G_d	G_s	G_a
$\omega_u = .87$	---	.145	.039
$\omega_\ell = .945$	.275	.068	---

1. R_f (Roof) = $C_o(\omega_u X_o)$ Corrected for Skyshine

   $C_o = .064$

2. R_f (Skyshine) = C_a = $G_a(\omega_u)B_w(X_eH)[1 - S_w]$

   $C_a = .039[.15][1 - .69]$

   $C_a = .00181$

   H=3'
   $B_w(X_eH) = .15$ Fig. 12, Case 2 or Fig. 9

   $S_w(X_e) = .69$ Figure 8

   $E(e) = 1.36$ Figure 10

3. R_f (Direct) $= C_d = G_d(\omega_\ell) + B_w(X_eH)[1 - S_w]$

$C_d = .275[.15].31$

$C_d = .0128$

4. R_f (Scattered) $= C_s = [G_s(\omega_u) + G_s(\omega_\ell)]B_w(X_eH)S_w(X_e)E(e)$

$C_s = .030$

5. Total $R_f = C_o + C_a + C_d + C_s$

$R_f = .064 + .00181 + .0128 + .030$

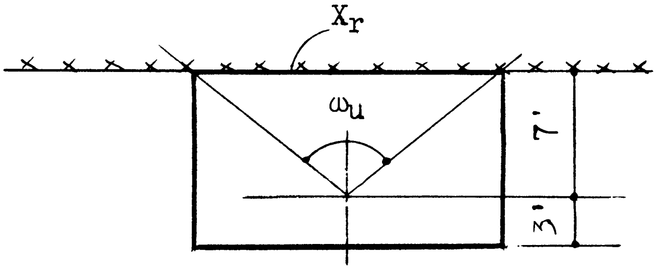
$R_f = .109$

6. $P_f = 1/R_f$

$P_f = 9.17$

Simple Structure Shielding

Example No. 2



$X_r = 60$ psf

$W = 80'$

$L = 140'$

$\omega_u = .87$ Figure 3 when $e = .57$ and $n = .10$

Figure 4 Figure 5

1. R_f (Roof) $= C_o(X_o\omega_u)$ [Correction Factor]

$.06\ [1.07]$

R_f (Roof) $= .064$

No Ground Contribution $B_w = 0$

2. $R_f = .064$ Note: Lip Effect Negligible

3. $P_f = 15.6$

If $X_o = 100$ psf

$C_o = .02[1.04]$

$C_o = .0208$

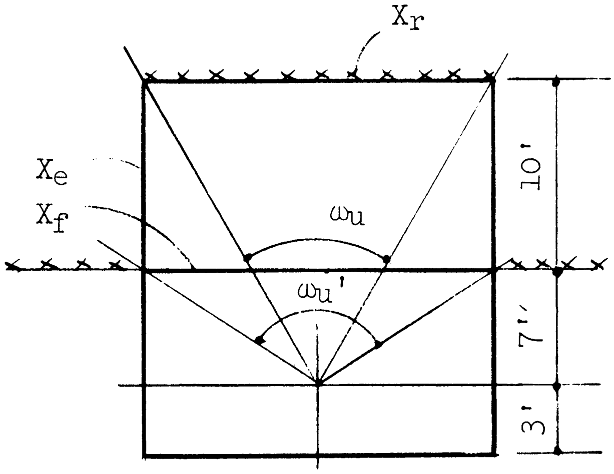
$R_f = .0208$

$P_f = 1/R_f$

$P_f = 48$

Simple Structure Shielding

Example No. 3



$X_r = 60$ psf

$X_f = 60$ psf

$X_e = 80$ psf

$X_0' =$ immediate overhead mass thickness

$X_0 =$ total overhead mass thickness

Figure 4 —— Figure 6

ω	W	L	Z	e=W/L	n=2Z/L	ω	G_d	G_a	G_s
ω_u	80'	140'	17'	.57	.24	.70	--	.069	.28
ω_u'	80'	140'	7'	.57	.10	.87	--	.039	.145

$\omega(n,e)$ Figure 3

$G_a(\omega)$ Figure 6 S_w Figure 8

$G_s(\omega)$ Figure 6 E Figure 10

Figure 4 Figure 5 (X_o)

1. R_f (Roof) = $C_o(X_o\ \omega_u)$ [Correction For Skyshine]

   .012[1.03]

   R_f (Roof) = .0124

   Figure 9 Figure 12

   H=5' Case 3

2. R_f (Skyshine) = $[G_a(\omega_u) - G_a(\omega_u')][1 - S_w]B_w(X_eH)\ B_o'(X_o')$

   [.069 - .039][1 - .69].14 [.04]

   R_f (Skyshine) = .0000521

3. R_f (Scatter) = $[G_s(\omega_u) - G_s(\omega_u')]S_wE\ B_w(X_eH)\ B_o'(X_o')$

   [.28 - .145].69[1.36].14 [.04]

   R_f (Scatter) = .000709

4. R_f (Total) = .0124 + .0000521 + .000709

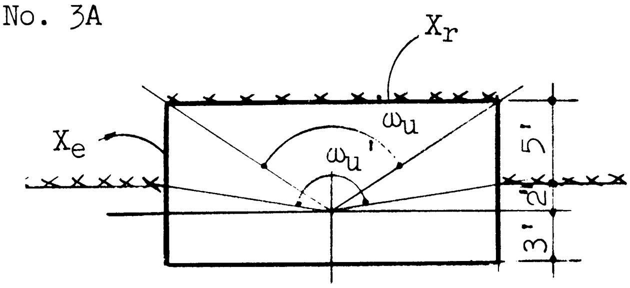
   R_f = .01316

5. $P_f = 1/R_f$

   P_f = 76.0

Simple Structure Shielding

Example No. 3A



X_r = 60 psf

X_e = 80 psf

ω	W	L	Z	e	n	ω	G_d	G_a	G_s
ω_u	80'	140'	7'	.57	.10	.87	--	.039	.145
ω_u'	80'	140'	2'	.57	.029	.965	--	.005	.05

$\omega(n,e)$ Figure 3

G_a Figure 6 —┐

— Lines Extended

G_s Figure 6 —┘

S_w = Figure 8

E = Figure 10

$B_w(X_e H)$ = .15 Figure 12, case 2 or
Figure 9
Use H = 3'

1. $C_o = C_o(X_o \omega_u)$ [Correction]

   $.06[1.07]$

   $C_o = .064$

2. $C_g = G_g B_w(X_e H)$

   Where $G_g = [G_s(\omega_u) - G_s(\omega_u')]S_w E + [G_a(\omega_u) - G_a(\omega_u')][1 - S_w]$

3. $G_g = [.145 - .05].69[1.36] + [.039 - .005][.31]$

   $G_g = .08915 + .01054 = .0997$

   $C_g = .0997[.15] = .01506$

4. $R_f = C_o + C_g$

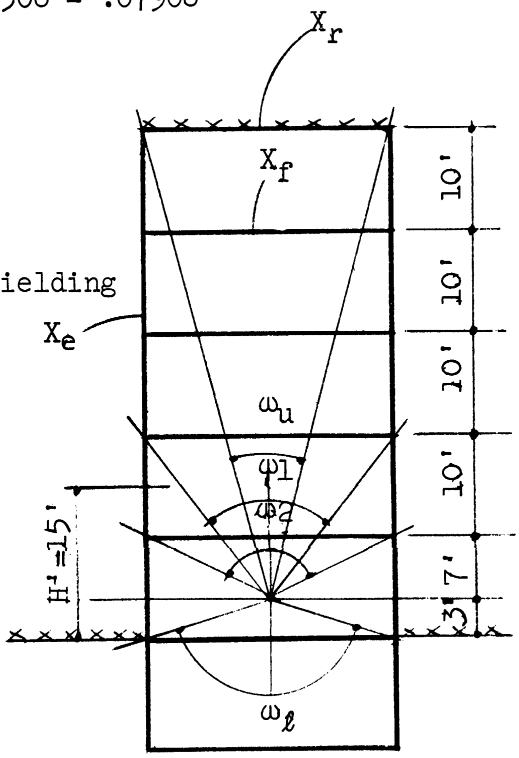
   $R_f = .064 + .01506 = .07906$

5. $P_f = 1/R_f$

   $P_f = 12.6$

Simple Structure Shielding

Example No.4



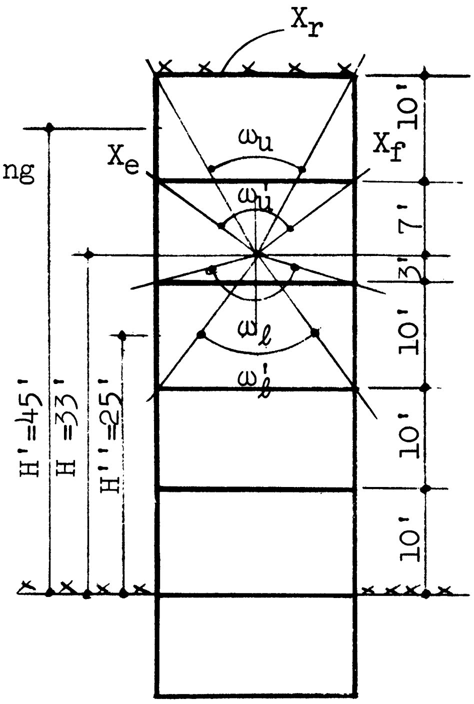
X_r = 60 psf

X_f = 60 psf

X_e = 80 psf

Simple Structure Shielding

Example No. 5



X_r = 60 psf

X_f = 60 psf

X_e = 80 psf

ω	W	L	Z	$e=\frac{W}{L}$	$n=\frac{2Z}{L}$	ω	G_d	G_s	G_a
ω_u	80'	140'	17	.57	.24	.70	---	.28	.069
ω_u'	80'	140'	7	.57	.10	.87	---	.145	.039
ω_ℓ	80'	140'	3	.57	.043	.945	.04	.068	----
ω_ℓ'	80'	140'	13	.57	.186	.76	.34	.245	----

Figure 7 H = 33'

Figure 4

Correction Factor = 1.03 = C. F.

1. R_f (roof) = $C_o(\omega_o X_o)$ [C. F]

$= .012[1.03]$

$C_o = .0124$

2. $C_g = C_g(\text{adjacent wall}) + C_g(\text{ceiling above}) + C_g(\text{floor below})$

3. Adjacent Wall

$C_g = G_g\, B_w(X_e,H)$

$=[[G_s(\omega_u') + G_s(\omega_\ell)]S_wE + [G_d(\omega_\ell) + G_a(\omega_u')][1-S_w]]B_w(X_e,H)$

$[[.145 + .068].69[1.36] + [.04 + .039].31].08$

$[.1999 + .0245].08$

ω	W	L	Z	e	$n = \frac{2z}{L}$	ω	G_d	G_s	G_a
ω_u	80'	140'	47	.57	.67	.36	----	----	----
ω_1	80'	140'	17	.57	.24	.70	----	.28	.069
ω_2	80'	140'	7'	.57	.10	.87	----	.145	.039
ω_ℓ	80'	140'	3'	.57	.043	.945	.275	.068	----

1. R_f (roof) $= C_o(\omega_u, X_o)$ Figure 4

   $C_o = .00018$ Skyshine correction negligible.

2. $C_g = G_g$ (adjacent walls) $[B_w(X_e,H)] + G_g$ (ceiling above)$[B_w(X_e,H)]B_o'(X_o')$

3. Adjacent walls

   $C_g = [[G_s(\omega_2) + G_s(\omega_1)]\ S_wE + [G_d(\omega_1) + G_a(\omega_2)][1 - S_w]]B_w(X_e,H)$

   From Example 1A (2, 3, 4)

   $C_d = .0128$

   $C_s = .030$

   $C_a = .00181$

   $\underline{C_g = .04461}$

4. Thru ceiling from walls of story above Figure 12, Case 3

   $C_g = [[G_s(\omega_1) - G_s(\omega_2)]S_wE + [G_a(\omega_1) - G_a(\omega_2)][1 - S_w]]B_w(X_e,H')\ \ B_e'(X_o')$

   $[.28 - .145].69[1.36] + [.069 - .039][.31]\ .1\ [.04]$

   $C_g = [.1267 + .0093]\ .004 = .000544$

5. $R_f = C_o + C_g(aw) + C_g(ca)$

   $R_f = .00018 + .04461 + .000544$

   $R_f = .04533$

6. $P_f = \frac{1}{R_f}$

   $P_f = 22.1$

$C_g = .01795$

4. Thru ceiling from walls of story above

$C_g = G_g\ B_w(X_e, H')$

$= [[G_s(\omega_u) - G_s(\omega_u')]S_w E + [G_a(\omega_u) - G_a(\omega_u')][1 - S_w]]B_w(X_e, H')\ B_o'(X_o')$

$[[.28 - .145].69[1.36] + [.069 - .039].31].07\ [.04]$

$[.1267 + .0093].0028$

$C_g = .000381$

5. Thru floor from walls of story below

$C_g = G_g\ B_w(X_e, H'')\ B_f'(X_f)$ Figure 12, Case 1

$= [[G_s(\omega_\ell') - G_s(\omega_\ell)]S_w E + [G_d(\omega_\ell') - G_d(\omega_\ell)][1 - S_w]]B_w(X_e, H'')\ B_f'(X_f)$

$= [[.245 - .068].69[1.36] + [.34 - .04].31].088[.06]$

$C_g = [.166 + .093].00528$

$.001367$

6. $R_f = \Sigma\ C_g + C_o$

$= .01795 + .000381 + .001367 + .0124$

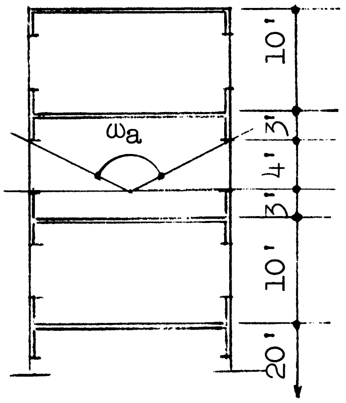
$R_f = .0321$

7. $P_f = \frac{1}{R_f}$

$P_f = 31.2$

Simple Structure Shielding

Example No. 6



Continuous Strip of Windows

$X_r = 60$ psf
$X_f = 60$ psf
$X_e = 80$ psf

Example No. 5 with windows.

ω	W	L	Z	e	n	ω
ω_a	80'	140'	4	.57	.057	.925

1. $C_o = .0124$

2. Adjacent Walls

$C'_g = C_g - C'_a + C_a$

$C_g = .01795$ previous example. Solid walls.

$C'_g = [[G_s(\omega_a)]S_wE + [G_a(\omega_a)][1 - S_w]]\ B_w(X_e,H)$ window plug

$= [[.084].69[1.36] + [.023].31].08$

$[.07883 + .00713].08$

$C'_a = .00688$ filled in plug

$C_a = [G_a(\omega_a)]\ B_w(X_e = 0,H)$ windows 'as is'

$= .023[.58]$

$C_a = .0133$

$C'_g = .01795 - .00688 + .0133$

$C'_g = .0244$

Simple Structure Shielding

Example No. 7

Example No. 5 with 3' x 4' H windows @ 12' - o" o.c. in adjacent wall

$C'_g = C_g - C'_a\ [P_a] + C_a\ [P_a]$ $P_a = 3/12 = .25$

$= .01795 - .00688[.25] + .0133[.25]$

$= .01795 - .00172 + .00335$

$C'_g = .0196$

Simple Structure Shielding

Example No. 8

Example No. 6 Continuous strip windows

1. Ceiling use area apertures / area wall = A_p (only for floors above and below).

$A_p = 0\%$ $C_g = .000381$ from Example No. 5, item 4

$A_p = 100\%$ $C_{g'} = [G_a(\omega_u) - G_a(\omega_u')]\ B_w(X_e - 0,H')\ B_o'(X_o')\ [1 - S_w]$

Figure 9 Figure 12 Case 3

$= [.069 - .039]\ .52[.04][1 - 0]$

$C_{g'} = .000624$

2. $A_p = 4/10 = .40$ or 40% of wall as windows.

3. $C_g' = C_g(1 - A_p) + C_{g'}\ (A_p)$

$C_g' = .000381\ [1 - .4] + .000624[.4]$

$C_g' = .000229 + .00025$

$C_g' = .000479$

4. Floor Below

$A_p = 0\%$ $C_g = .001367$ Figure 12, Case 1

$A_p = 100\%$ $C_{g'} = [G_d(\omega_1'\ H) - G_d(\omega_1\ H)][1-S_w]B_w(X_e - 0,H'')\ B_f(X_f)$

$= [.34 - .04][1 - 0].62[.06]$

$C_{g'} = .0112$

$C_g' = C_g[1 - A_p] + C_{g'}[A_p]$

$= .001367[.6] + .0112[.4]$

$C_g' = .0008202 + .00448$

$C_g' = .0053$

Apertures

$$R_f = C_o + \Sigma C'_g \qquad \textbf{Exp. No. 6}$$

$$= .0124 + .000479 + .0244 + .0053$$

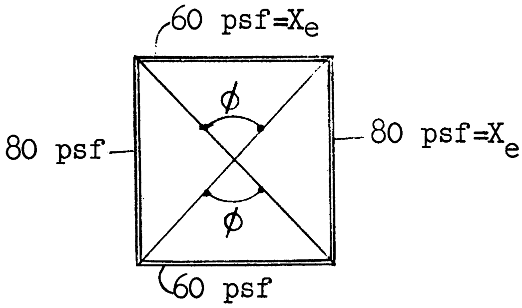
$$R_f = .04257$$

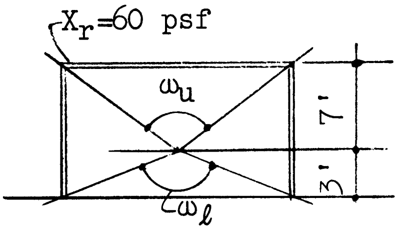
$$P_f = \frac{1}{R_f}$$

$$P_f = 23.5$$

Simple Structure Shielding

Example No. 9





Plan 100' x 100'

Assume Two Fictitious Buildings.
One with 60 psf walls
One with 80 psf walls

ω	W	L	Z	e	n	ω	G_d	G_s	G_a
ω_u	100'	100'	7'	1.0	.14	.885	----	.13	.036
ω_ℓ	100'	100'	3'	1.0	.06	.945	.275	.068	----

1. $C_o = C_o(\omega_u X_o)$ [skyshine correction]

$$= .06[1.07]$$

$$C_o = .064$$

2. $C_g = G_g \, B_w(X_e) \, P_r + G_g \, B_w(X_e) \, P_r$

3. $G_g = [.13 + .068].63[1.41] + [.275 + .036][1 - .63]$

$= .1759 + .1151$

$G_g = .291$

4. $G_g = [.13 + .068].69[1.41] + [.275 + .036][1 - .69]$

$= .1926 + .0964$

$G_g = .289$

5. $C_g = .291[.23].5 + .289[.15].5$

$C_g = .0335 + .0217 = .0552$

6. $R_f = .064 + .0552$

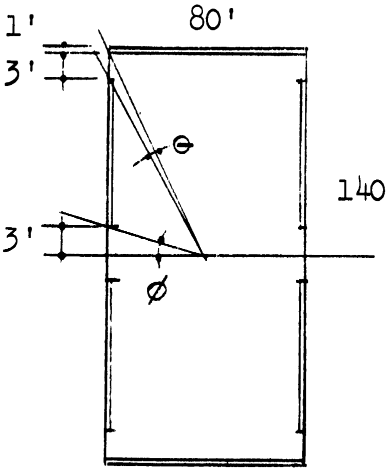
$R_f = .1192$

$P_f = \frac{1}{R}$

$P_f = 8.39$

Simple Structure Shielding

Example No. 10



Windows 3'W x 4'H

Plan

From Example 6

$$C'_g = C_g - C'_a[A_z] + C_a[A_z]$$

$$= .01795 - .00688[.06] + .0133[.06]$$

$$C'_g = .01795 - .000413 + .000798$$

$$C'_g = .0183$$

$\text{Tan } \theta_1 = \frac{69}{40} = 1.725$ $\qquad \theta_1 = 58.8°$

$\text{Tan } \theta_2 = \frac{66}{40} = 1.65$ $\qquad \theta_2 = 59.9°$ $\qquad 4\theta = 4.4°$

$\theta = 59.9 - 58.8$ $\qquad 4\phi = \underline{17.2}$

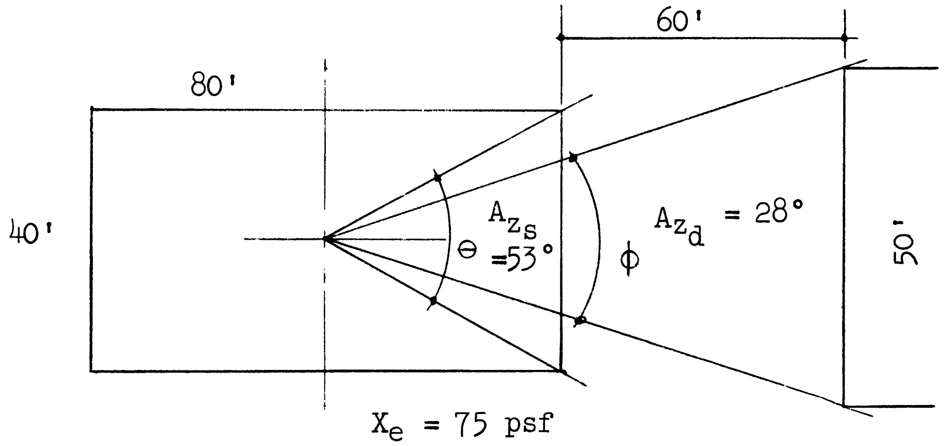
$\theta = 1.1°$ $\qquad 21.6°$

$\text{Tan } \phi = \frac{3}{40} = .075$

$\phi = 4.3°$ $\qquad A_z = \frac{21.6}{360} = .06$

Simple Structure Shielding

Example No. 11 Mutual Shielding. Engineering Manual, 1 July, 1961



$\text{Tan } \frac{\theta}{2} = \frac{20}{40} = .5$

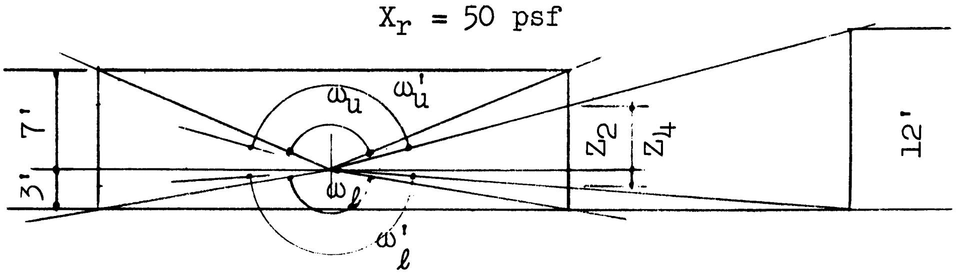
$\theta = 53°$

$\text{Tan } \frac{\phi}{2} = \frac{25}{100} = .25$

$\phi = 28°$

$X_e = 75$ psf

$X_r = 50$ psf



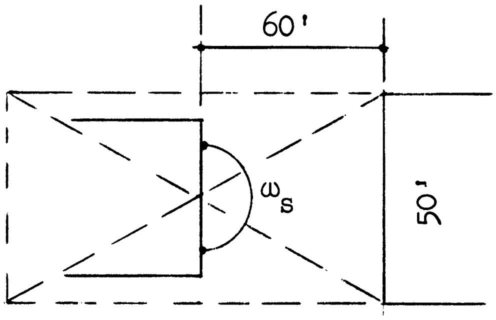
Two Azimuthal Considerations A_{z_s} and A_{z_d}

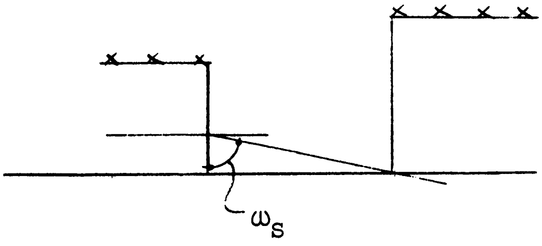
ω	W	L	Z	e	η n	ω	G_d	G_s	G_a
ω_u	40	80'	7	.5	.175	.76	---	.24	.061
ω'_u	40	80'	3.6	.5	.09	.875	---	---	.038
ω_1	40	80'	3	.5	.075	.895	.42	.12	----
ω'_1	40	80'	1.2	.5	.03	.96	.20	---	----
$2\omega_s$	50	120	3	.417	.05	.92			

$\omega_s = .46$

$z_2 = \frac{9}{100} \times 40 = 3.6$

$z_4 = \frac{3}{100} \times 40 = 1.2$





$B_w(X_e,H) = .16$

$S_w(X_e) = .68$

$E(e) = 1.34$

$B_{w_s}(\omega_s) = .06$ Figure 11

$A_{z_d} = 28/360 = .078[1 - A_{z_d}] = .922$

$A_{z_s} = 53/36 = .147[1 - A_{z_s}] = .853$

Unshielded:

$$C_{d_u} = [G_d(\omega_l,H) + G_a(\omega_u)]\, B_w(X_e,H)\, [1 - S_w(X_e)][1 - A_{z_d}]$$

$$[.42 + .061].16[.32].922 = .0227$$

$$C_{s_u} = [G_s(\omega_l) + G_s(\omega_u)]\, B_w(X_e,H)[S_w(X_e)\; E(e)][1 - A_{z_s}]$$

$$[.12 + .24]1.6[.68]1.34[.853] = .0448$$

Shielded:

$$C_{d_s} = [G_d(\omega_l,H) - G_d(\omega_l,H) + G_a(\omega_u) - G_a(\omega_u')]\, B_w(X_e,H)[1 - S_w]A_{z_d}$$

$$[.42 - .20 + .061 - .038].16[.32].078 = .00097$$

$$C_{s_s} = [G_s(\omega_l) + G_a(\omega_u)]\, B_{w_s}(X_e,\omega_s)\; S_w E\; A_{z_s}$$

$$[.12 + .24].06[.68]1.34[.147] = .00289$$

$$C_g = .0227 + .0448 + .00097 + .00289 = .07136$$

Roof:

$$C_o = .08[1.08] = .0864$$

$$R_f = .0864 + .07136 = .1578$$

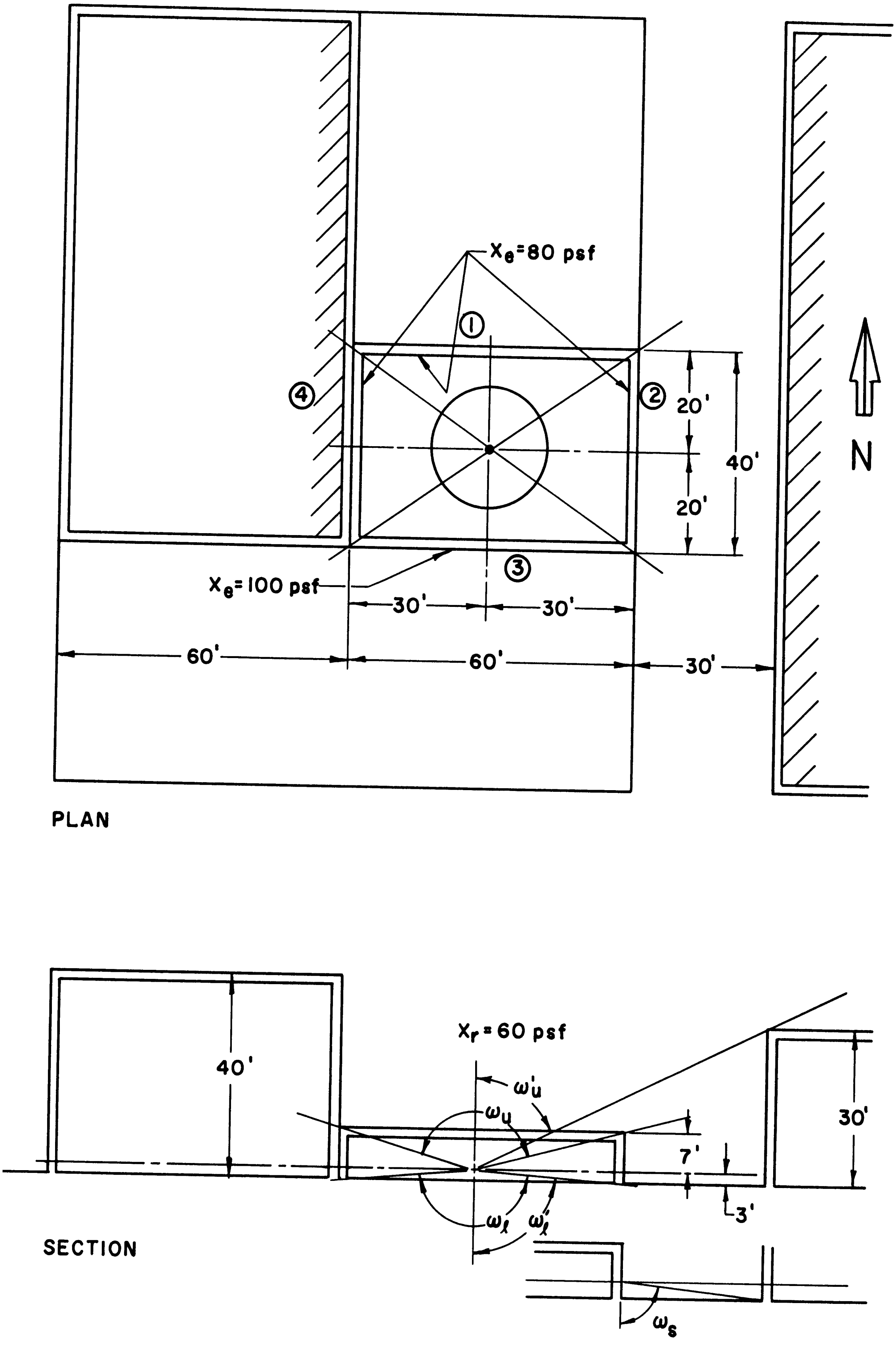
With no M_s

$$C_o = .0864$$

$$C_g = \underline{.0771}$$

$$R_f \quad .1635$$

SIMPLE STRUCTURE SHIELDING



Example No. 12. Neglect Shielding of North and South Walls by Extension of Shielding Buildings.

		W	L	Z	e	n	ω	G_d	G_s	G_a
①	ω_l	40	60	3	.67	.1	.89	.435	.125	----
①	ω_u	40	60	7	.67	.23	.75	----	.25	.062
②	ω_l	40	60	3	.67	.1	.89	.435	.125	----
②	ω_l'	40	60	1.5	.67	.05	.94	.300	----	----
②	ω_u	40	60	7	.67	.23	.75	----	.25	.062
②	ω_u'	40	60	---	---	---	---	----	----	----
②	$2\omega_s$	60	100	3	.60	.06	.925	----	----	----
②	ω_s	--	---	--	---	---	.463	----	----	----
③	ω_l	40	60	3	.67	.1	.89	.435	.125	----
③	ω_u	40	60	7	.67	.23	.75	----	.25	.062
④		no contribution								

1. Ground Contribution - wall ①

$[[G_d(\omega_\ell) + G_a(\omega_u)][1 - S_w] + [G_s(\omega_\ell) + G_s(\omega_u)]\ S_wE]\ B_w\ Z_{z2}$

$[[.435 + .062].31 + [.125 + .25].69[1.38]].15[.313]$

$[.154 + .357].15[.313] = .0240$

2. Ground Contribution - wall ② Completely shielded from skyshine. $A_{zd} = A_{zs}$

(a) $[G_d(\omega_\ell) - G_d(\omega_\ell')][1 - S_w]B_w\ A_{z1}$

$[.435 - .300].31[.15].187$

$[.135].31[.15].187 = .00117$

(b) $[G_s(\omega_\ell) + G_s(\omega_u)]S_wE\ B_{ws}\ A_{z1}$

$[.125 + .25].69[1.38].06[.187]$

$[.375].69[1.38].06[.187] = .000484$

3. Ground Contribution - wall ③

$[[G_d(\omega_\ell) + G_a(\omega_u)][1 - S_w] + [G_s(\omega_\ell) + G_s(\omega_u)]\ S_wE]\ B_wA_{z1}$

$[[.435 + .062].26 + [.125 + .25].74[1.38]].094[.313]$

$[.129 + .383].094[.313] = .0151$

4. Ground Contribution - wall ④ (none)

5. Total Ground Contribution

Step 1 + Step 2 + Step 3 + Step 4

$.0232 + [.00117 + .000484] + .0151 = .040$

6. Total Roof Contribution

$C_o(\omega_uX_o)$[Skyshine Correction]

$.055[1.07] = .0589$

7. Reduction Factor

Step 5 + Step 6

$.040 + .0589$

$R_f = .0989$

8. Protection Factor

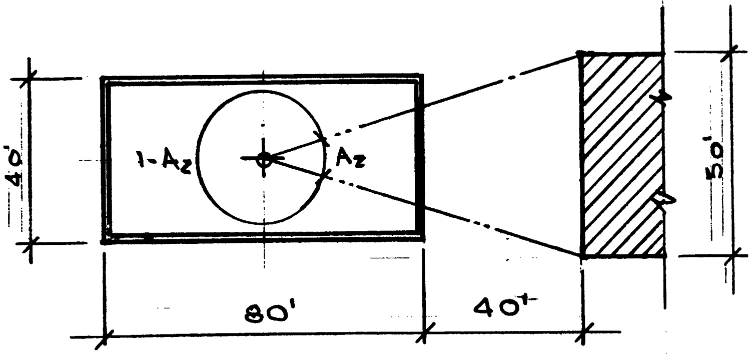
$R_f = 10.1$

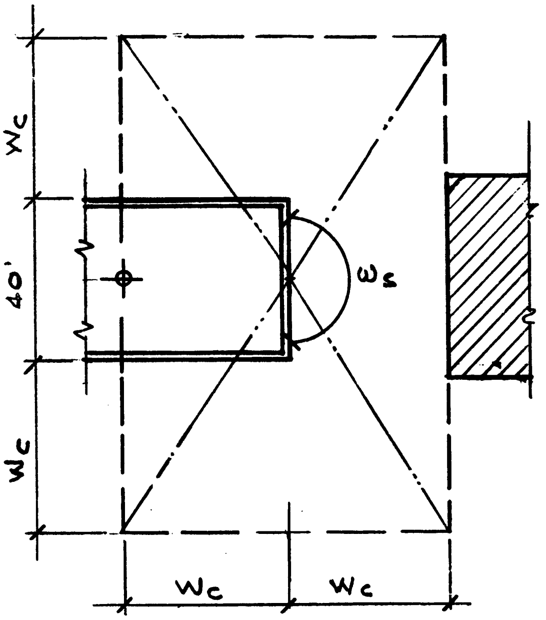
STRUCTURE SHIELDING ANALYSIS
Example No. 13
Mutual Shielding - Revised Method

Find P_f at the Center of the Building

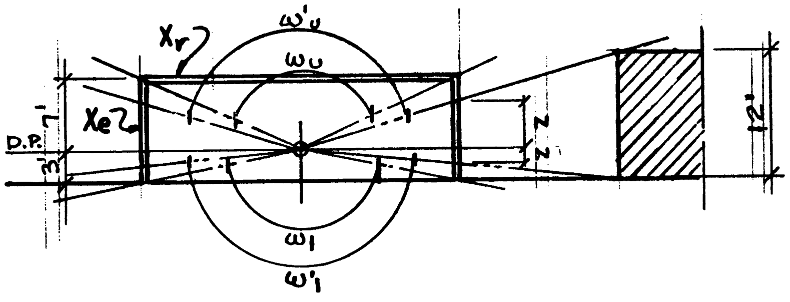
X_r = 50 psf

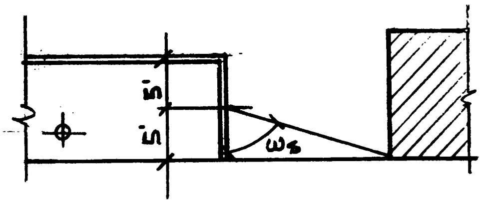
X_e = 75 psf





Plan





Section

ω	W	L	Z	e	n	ω	G_d	G_s	G_a
ω_1	40	80	3	.5	.075	.895	.42	.12	--
ω'_1			1.5		.0375	.95	.26	--	--
ω_u			7		.175	.76	--	.24	.061
ω'_u			4.5		.113	.84	--	--	.046
$2\omega_s$	80	120	5	.67	083	.905	ω_s	=	.453

$B_e(X_e,H)$ = .16

$S_w(X_e)$ = .68

$E(e)$ = 1.34

$B_{ws}(\omega_s,X_e)$ = .06

$$A_z = \frac{34.7}{360} = .0965$$

$$\text{Tau}\ \frac{\theta}{2} = \frac{12.5}{40}$$

θ = 34.7

$1 - A_z$ = .9035

Roof Contribution

$C_o = C_o(\omega_u, X_o)$

$C_o = \underline{.08}$

Ground Contribution Example 13-2

Unshielded

$$C_g = \left[[G_s(\omega_l)+G_s(\omega_u)] S_w(X_e) \ E + [G_d(\omega_l, H)+G_a(\omega_u)][1 - S_w(X_e)] \right] B_e(X_e,H)[1-A_z]$$

$$C_g = \left[[.12+.24] \ .68 \ [1.34] + [.42+.061][1-.68] \right] .16 \ [.904]$$

$$[.328 + .154] \ .145 = \underline{.07}$$

Shielded (Non-wall Scattered)

$$C_g = \left[[G_d(\omega_l,H)-G_d(\omega'_l,H)+G_a(\omega_u)-G_a(\omega'_u)][1-S_w(X_e)] \right] B_e(X_e,H) \ A_z$$

$$C_g = \left[[.42-.26 + .061-.046][1-.68] \right] .16 \ [.0965][.056] \ .0154 = \underline{.00086}$$

Shielded (Wall Scattered)

$$C_g = [G_s(\omega_l)+G_s(\omega_u)] \ S_w(X_e) \ E \ B_{ws}(\omega_s,X_e) \ A_z$$

$$C_g = [.12 + .24] \ .68 \ [1.34] \ .06 \ [.0965] = \underline{.0019}$$

$$R_f = C_o+C_g+C_g+C_g$$

$$R_f = .08 + .07 + .00086 + .0019 = \underline{.153}$$

$$P_f = \frac{1}{R_f} = \underline{\underline{6.53}}$$

$$.08 + .061 + .00075 + .0019 = .144$$

$$P_f = 6.93$$

PASSAGEWAYS AND SHAFTS

Robert W. Kindig
Glenn G. Mastin

Passageways

A horizontal passageway may be associated with a ground floor entrance to a shelter area. If passageways walls are of about the same mass thickness as the exterior walls, a detector in the passageway would receive radiation which comes principally down the passageway itself. For this special case a directional response, A_v, has been developed and is graphically shown as case 2, Figure 1. The use of this curve is illustrated in Example No. 1. First, calculate the solid angle fraction, ω, subtended at the detector by the entranceway opening. Note that here the angle is reference to a horizontal axis perpendicular to the geometric center of the opening.

For subsequent changes in direction it is necessary to use solid angle fractions directly as multipliers, since the directional response in this case is not well defined. Experimental results indicate that the solid angle fraction subtended at a detector in the second leg of an L shaped corridor should be reduced by a factor of .1 to account for the diffusion of the radiation as it scatters around the first right angle turn. In subsequent 90° turns in the passageway the solid angle fraction should be reduced by a factor of .5.

The above calculations refer to the contribution through the entranceway alone and must be added to the ground and roof contributions

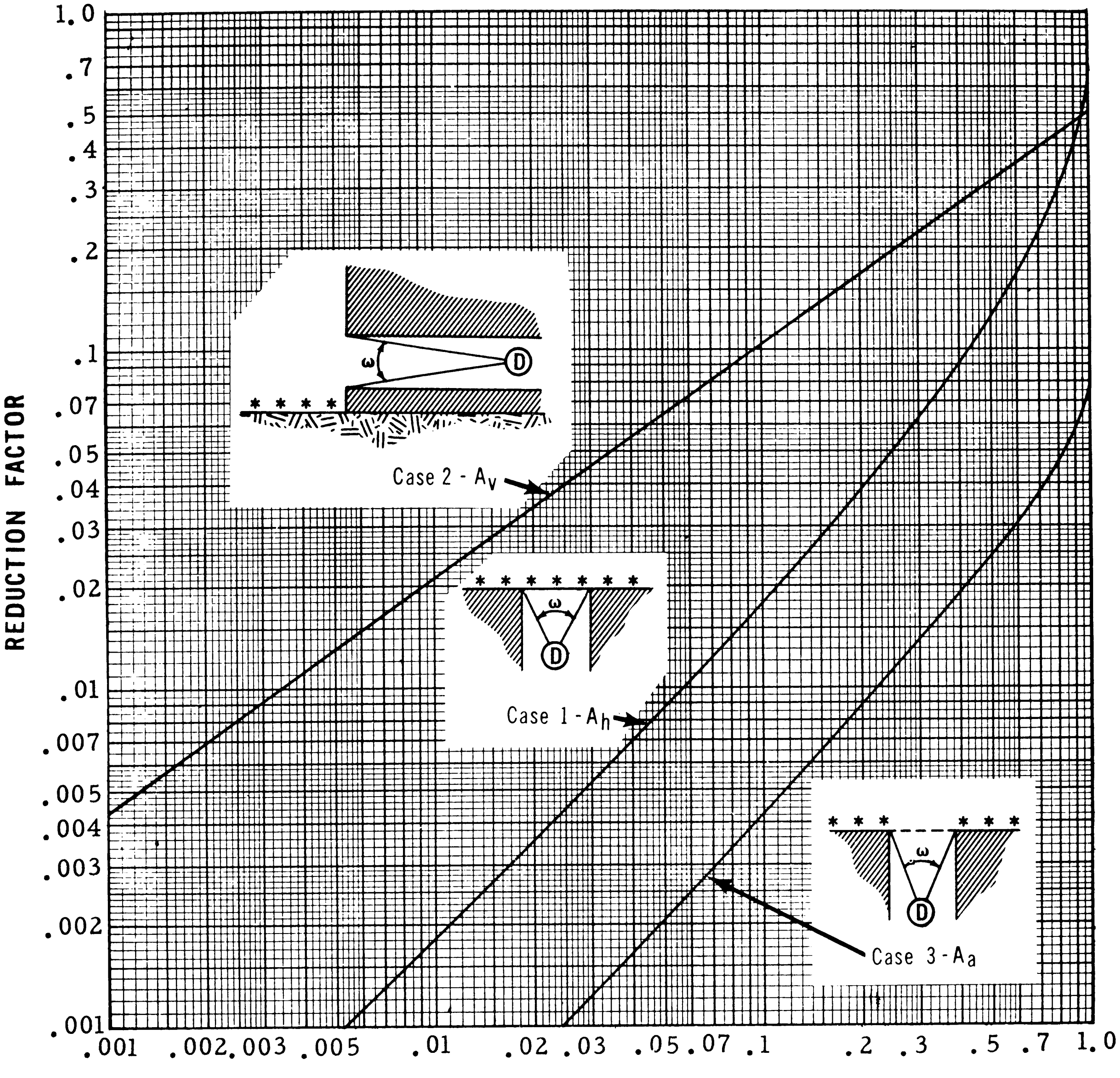


Figure 1. Reduction Factor for Passageways and Shafts.

to find the total reduction factor at the detector. These calculations assume the mass thickness of the entrance door to be close to zero.

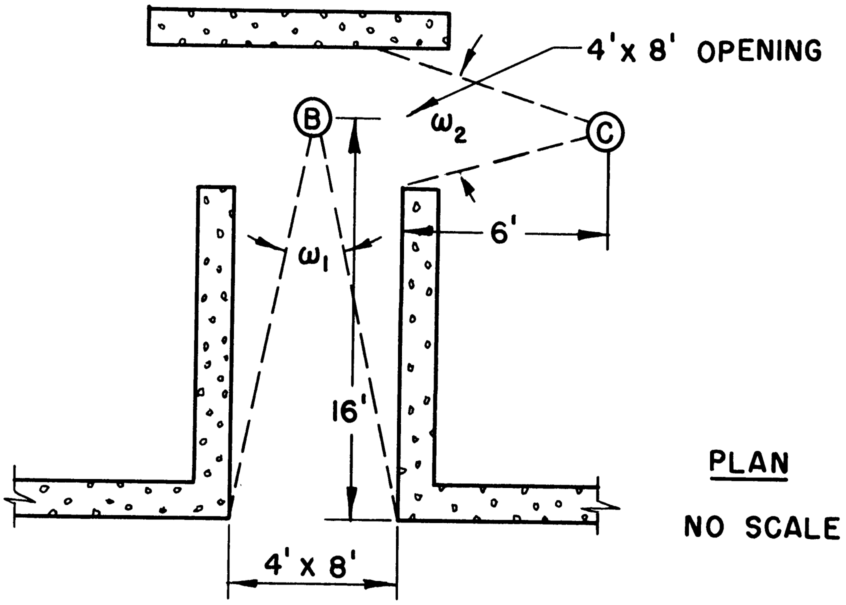
Shafts

Sometimes shelter entranceways are vertical shafts or shelter areas are otherwise associated with shafts. It is necessary to have directional responses for two special cases. For directional response, A_h, it is assumed that the shaft is covered with a material of zero mass thickness, on which fallout is uniformly distributed, and there is no skyshine contribution into the shaft. The second case, A_a, assumes only skyshine.

The application of these responses is illustrated in Example No. 2. Compute the solid angle fraction subtended at a detector on an axis perpendicular to the geometric center of the shaft opening and add A_h, Case 1, Figure 1, and A_a, Case 3, Figure 1, to any other roof and ground contribution to find the reduction factor at the detector. If it is assumed that fallout will not remain on the shaft cover, only the skyshine directional response needs to be considered. For corridors or passageways leading from a vertical shaft the procedure of Example No. 1 is used.

Passageways and Shafts

Example No. 1 - Contribution from entrance, only.



Find: R_f at Ⓒ

First Find R_f at Ⓑ

$e_1 = \frac{W}{L} = .5$ $n_1 = \frac{2Z}{L} = 4$ $\omega_1 = .019$ Figure 3[1.]

R_f at Ⓑ $= A_v\ (\omega_1) = .0325$ (Case 2, Figure 1)

Next Find R_f at Ⓒ

$e_2 = \frac{W}{L} = .5$ $n_2 = \frac{2Z}{L} = 1.5$ $\omega_2 = .12$ Figure 3[1.]

R_f at Ⓒ $= R_f$ at Ⓑ $\times\ \omega_2 \times F_s{}^* = .0325 \times .12 \times .1$

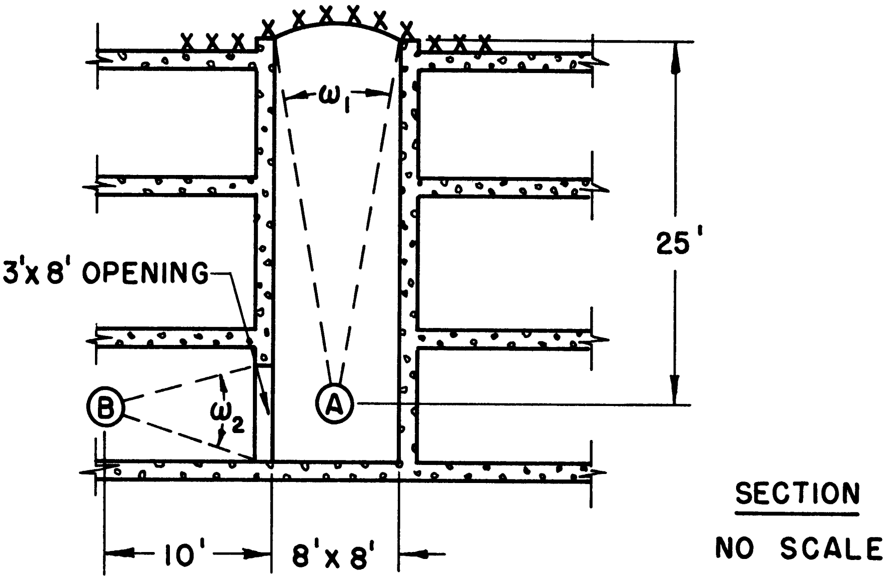
$= .00039$ ans.

[1.] See section on Simple Structure Shielding.

*F_s = scatter factor in passageways
= .1 for 1st right angle turn
= .5 for each right angle turn thereafter.

Passageways and Shafts

Example No. 2 - Contribution from skylight, only.



Find: R_f at Ⓑ

First Find R_f at Ⓐ

$e_1 = \frac{W}{L} = 1$ $n_1 = \frac{2Z}{L} = 6.25$ $\omega_1 = .014$ Figure 3[1.]

R_f at Ⓐ $= A_h (\omega_1) + A_a(\omega_1) = .0025 + .0006$ Case 1 + Case 3; Figure 1

Next Find R_f at Ⓑ

$e_2 = \frac{W}{L} = .43$ $n_2 = \frac{2Z}{L} = 2.86$ $\omega_2 = .031$ Figure 3[1.]

R_f at Ⓑ $= R_f$ at Ⓐ $\times \omega_2 \times F_s = .0031 \times .031 \times .1$

$= .0000096$ ans.

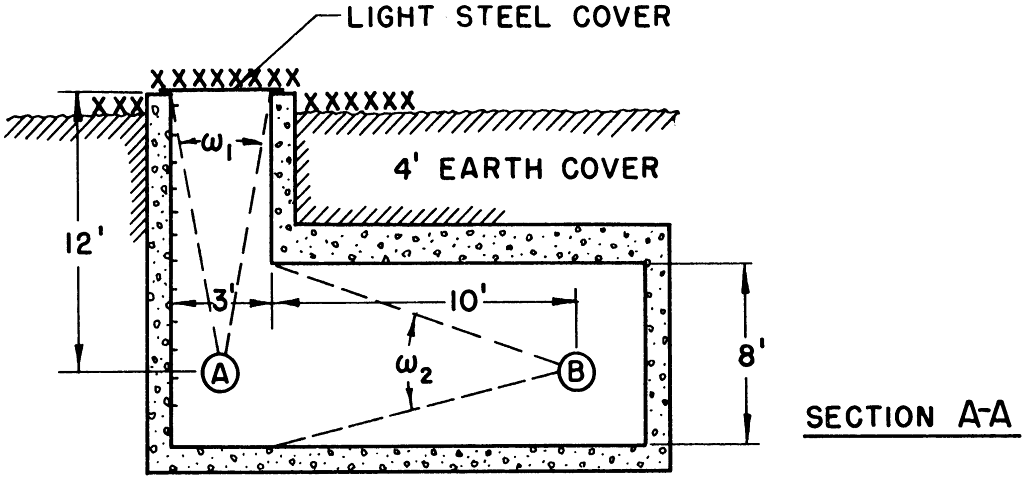
[1.] See section on Simple Structure Shielding.

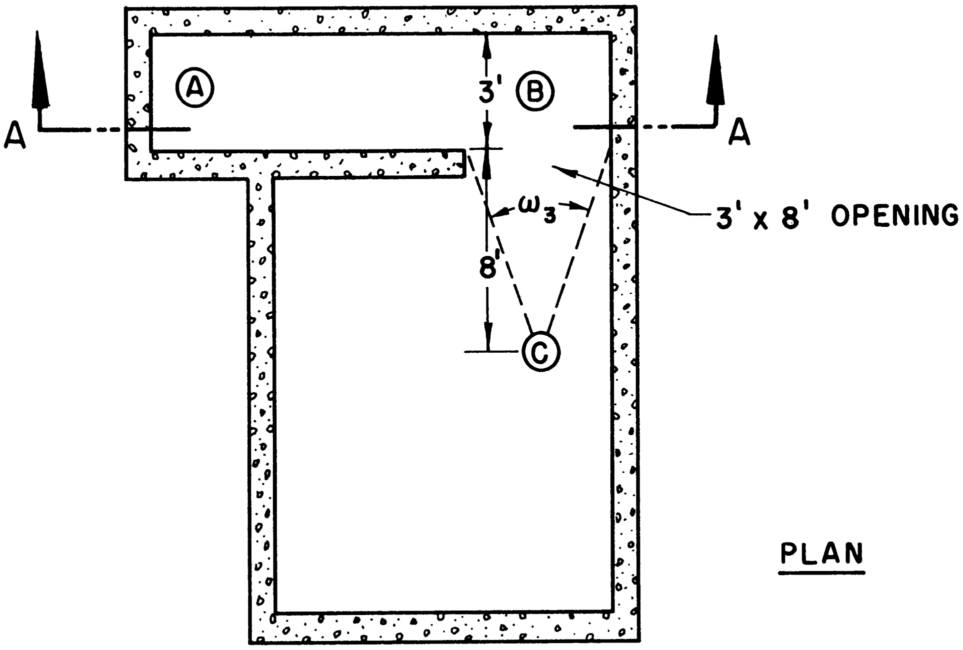
NOTE:

IF SKYLIGHT WAS INSTEAD A CONCRETE SLAB OF SAY 50 PSF MASS THICKNESS, TO FIND R_f AT Ⓐ YOU WOULD USE ω_1 IN FIGURE 4[1.] AND CORRECT THE REDUCTION FACTOR FOR SKYSHINE WITH FIGURE 5[1.] .

Passageways and Shafts

Example No. 3 - Contribution from shaft, only.





Find: $\omega_1 = .039$ $e_1 = 1$ $n_1 = 4$

$\omega_2 = .042$ $e_2 = .38$ $n_2 = 2.25$

$\omega_3 = .05$ $e_3 = .38$ $n_2 = 2$

R_f at Ⓐ = .0068 + .0016

R_f at Ⓑ = .008,4 x .042 x .1 = .000,035

R_f at Ⓒ = .000,035 x .05 x .5 = .000,000,88

COMPARTMENTALIZED STRUCTURES

Harold W. Himes
and
Glenn G. Mastin

As a transition from simple structures to compartmentalized structures we will discuss the handling of situations where the detector is not at the geometric center of the structure in plan.

In simple structures shielding use was made of a fictitious building. The same is done for off-center detector locations. In Figure 3[1] of the section on simple structure shielding the solid angle fraction is referenced to an axis perpendicular to the center of the area. Thus it is necessary to assume fictitious buildings with the detector at the center. With the detector off center in one direction two buildings will be required. The reduction factor for the given building will equal the sum of one-half of the reduction factor of each of the fictitious buildings.

With the detector off center in two directions four buildings will be required. The reduction factor for the given building will equal the sum of one-quarter of the reduction factor of each of the four buildings.

Example No. 1 shows the application of this procedure.

Consider now the situation where the radiation from fallout on the roof does not all pass through the same barrier getting to the detector. This might be due to difference in mass thickness of the horizontal barrier, or interior partitions, or both.

---

[1] Figures referred to will be found in section on Simple Structure Shielding.

Assume for simplicity a symmetrical detector position and a portion of the roof centered over the detector which has a different mass thickness than the remainder, or periphery. If the solid angle fraction subtended by the entire area is used with the mass thickness of the peripheral to determine C_o, the portion of roof having a different mass thickness will have been included. Its contribution can be eliminated by subtracting C_o as a function of the solid angle fraction subtended by the smaller area and the mass thickness of the periphery. Now add in C_o as a function of the smaller solid angle fraction and the mass thickness of the smaller area.

When the detector is located in a core area formed by interior partitions, radiation through the peripheral roof area outside the core must pass through the partition. The same is true for radiation through the exterior walls. In either case there is a further barrier attenuation by the interior partition.

To account for the barrier effect of the interior partition on the ground contribution through the exterior walls multiply by B_i, Figure 12 Case 2. The correction for height above the contamination is included in B_e and is not included in B_i.

Figure 9 gives the wall barrier factor as a function of the wall mass thickness and the height of the wall above the contaminated plane. In the case of contamination on the roof the radiation does not go any appreciable distance through air before impinging on the interior partition, but the effect of passing through the overhead barrier is the same as passing through an equivalent mass thickness of air equal to $13X_o$. $13X_o$ is called a fictitious height, H_f, and is used as the height in entering the chart of Figure 9 to determine the barrier factor for the interior partition. Since barrier effect, only, is needed the effect of height is factored out by use of the ratio $B_i(X_i H_f)/B_i(0\text{-psf } H_f)$. See Example No. 2, Item 7.

The size and shape of the core do not effect the ground contribution since it must pass through the interior partition where ever located between detector and exterior wall. They do effect the roof contribution, since only the contribution from the area outside the core has to pass through the partition.

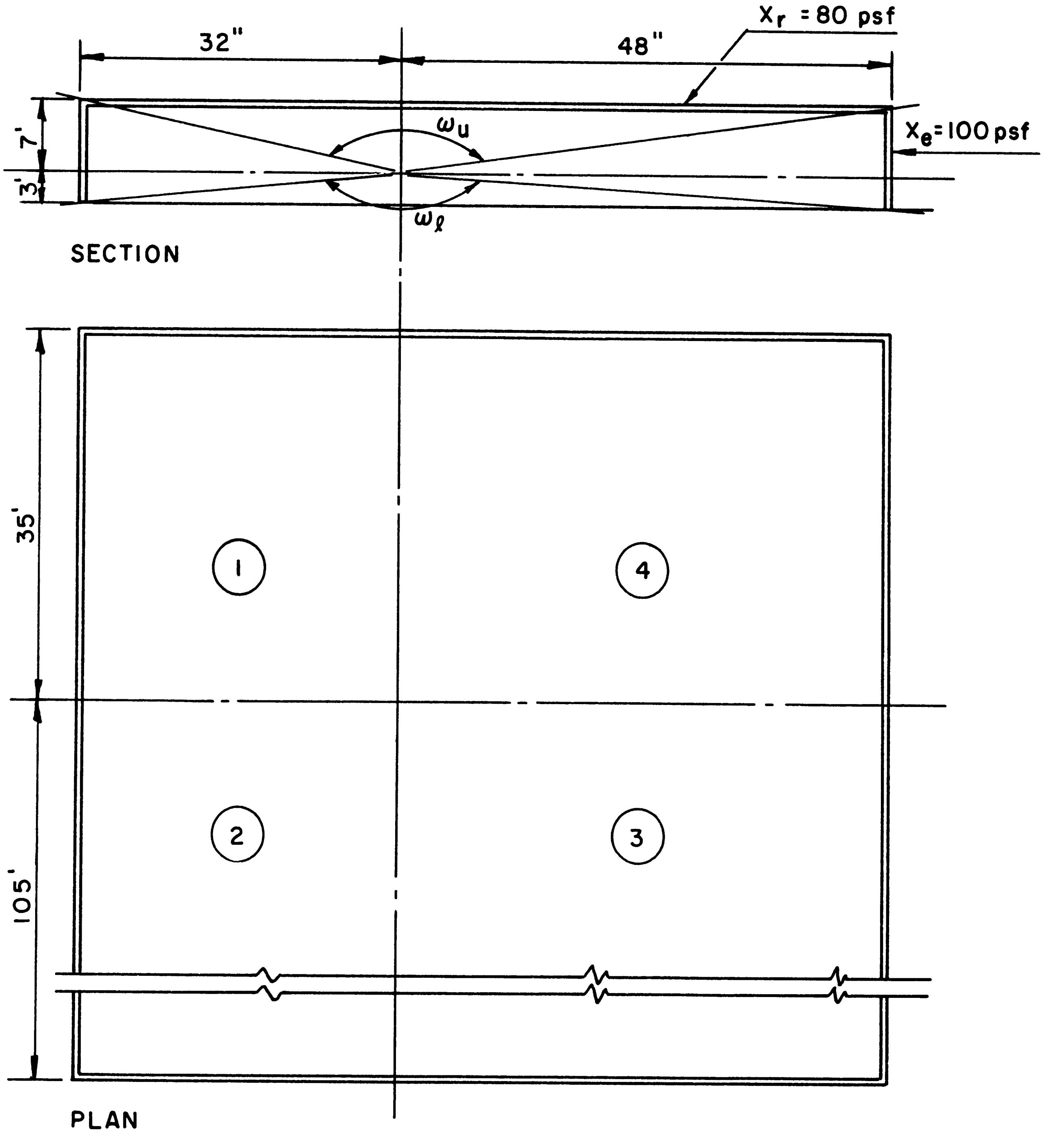
Example No. 3 has an off center partition across the building with the detector assumed against the partition on the side of the smaller area. All the wall and roof contribution of the larger area will go through the partition to reach the detector.

The actual contribution of each fictitious building to the detector is one-half the total contribution to the detector in each fictitious building.

Example No. 4 has the detector off center in one direction five feet from a partition across the building. Now, not all the ground and roof contribution from the left side passes through the partition, only that portion through $A_z = .46$.

Example No. 5 is a comprehensive problem given as a week end problem at the end of the first week. Since the detector is off center only on one axis, only two fictitious buildings are required, but various portions of the walls of each must be treated separately. The solution is more detailed than would normally be required.

Example No. 1-1 - Position Variations



Example No. 1-2

		W	L	Z	e	n	ω	G_d	G_s	G_a	E	C_o	
①	ω_u	64	70	7	.92	.2	.81	-	.205	.052	1.41	.035	
①	ω_ℓ	64	70	3	.92	.086	.915	.38	.10	-	1.41	-	$B_e = .094$
②	ω_u	64	210	7	.305	.067	.86	-	.155	.042	1.25	.035	$S_w = .74$
②	ω_ℓ	64	210	3	.305	.0285	.94	.30	.073	-	1.25	-	
③	ω_u	96	210	7	.466	.067	.90	-	.115	.032	1.33	.035	
③	ω_ℓ	96	210	3	.466	.0285	.96	.22	.055	-	1.33	-	
④	ω_u	70	96	7	.73	.148	.84	-	.175	.046	1.39	.035	
④	ω_ℓ	70	96	3	.73	.063	.93	.34	.080	-	1.39	-	

1. Non-Wall Scattered Geometry Factor

$$1/4[G_a\textcircled{1} + G_a\textcircled{2} + G_a\textcircled{3} + G_a\textcircled{4} + G_d\textcircled{1} + G_d\textcircled{2} + G_d\textcircled{3} + G_d\textcircled{4}][1 - S_w]$$

$$1/4[.052 + .042 + .032 + .046 + .38 + .30 + .22 + .34]\ .26 = .092$$

2. Wall Scattered Geometry Factor

$$1/4\{[G_s(\omega_u)\textcircled{1} + G_s(\omega_\ell)\textcircled{1}]E + [G_s(\omega_u)\textcircled{2} + G_s(\omega_\ell)\textcircled{2}]E + [G_s(\omega_u)\textcircled{3} + G_s(\omega_\ell)\textcircled{3}]E + [G_s(\omega_u)\textcircled{4} + G_s(\omega_\ell)\textcircled{4}]E\}S_w$$

$$1/4\{[.205 + .10]\ 1.41 + [.155 + .073]\ 1.25 + [.115 + .055]\ 1.33 + [.175 + .080]\ 1.39\}\ .74 = 0.239$$

3. Total Ground Contribution

$$C_g = [\text{Step 1} + \text{Step 2}]\ B_w$$

$$[.092 + .239]\ .094 = .0311$$

4. Total Roof Contribution

$$C_o = \underline{1}/4[C_o(\omega_u)\textcircled{1} + C_o(\omega_u)\textcircled{2} + C_o(\omega_u)\textcircled{3} + C_o(\omega_u)\textcircled{4}]$$

[Skyshine Correction]

$$= .035[1.06] = .0371$$

5. Reduction Factor

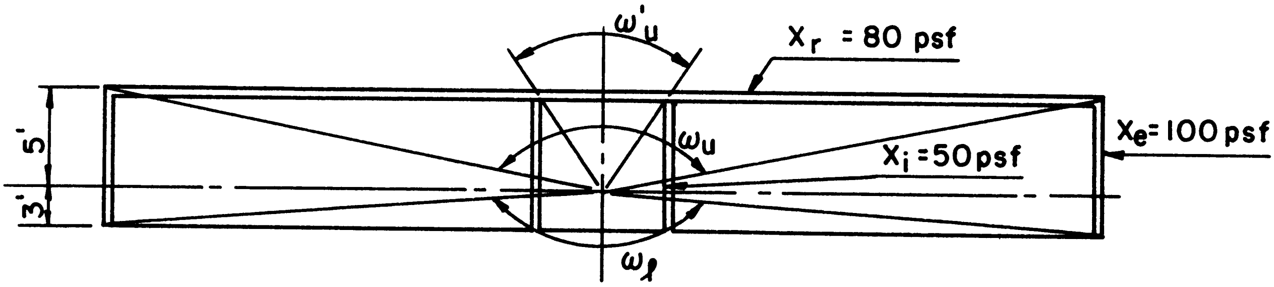
$$R_f = C_g + C_o$$

$$= .0311 + .0371 = .0682$$

6. Protection Factor

$$P_f = \frac{1}{R_f} = \frac{1}{.0682} = 14.7$$

Example No. 2-1 Parallel Interior Partitions (Core Situation)
Core and Detector Centered in Large Area



	W	L	e	n	ω	G_d	G_s	G_a	
ω_ℓ	80	140	.57	.043	.945	.275	.068	-	$B_w(X_eH) = .094$
ω_u	80	140	.57	.10	.87	-	.145	.039	$S_w(X_e) = .74$
ω'_u	10	10	1	.60	.53	-	-	-	$E(.57) = 1.36$
									$H_f = 13[80] = 1040'$
									$B_i(X_i\ 3') = .3$
									$B_i(X_iH_f) = .006$
									$B_i(0\text{-psf},H_f) = .03$

1. Wall Scattered Contribution

$$G_g = [G_s(\omega_u) + G_s(\omega_\ell)]S_wE$$

$$[.145 + .068]\ .74[1.36] = .214$$

2. Non-Wall Scattered Contribution

$$G_g = [G_a(\omega_u) + G_d(\omega_\ell)][1 - S_w]$$

$$[.039 + .275]\ .26 = .0816$$

3. Total Ground Contribution (No Interior Partitions)

$$C_g = [(1) + (2)]\ B_w(X_eH)$$

$$[.214 + .0816]\ .094 = .0278$$

4. Ground Contribution (Parallel Interior Partitions)

$$C_g(G_gB_wB_i) = C_g(G_gB_w)B_i(X_i3')(C_g \text{ is from Step 3 above})$$

$$.0278[.3] = .00834$$

5. Roof Contribution for Entire Building

$$C_o(\omega_uX_o)[\text{Skyshine Correction}]$$

$$.035[1.06] = .0371$$

6. Roof Contribution for Core Area

$$C_o(\omega_u'X_o)[\text{Skyshine Correction}] = .03[1.06] = .0318$$

Note the large part of the roof contribution which comes from the roof of the core area.

7. Peripheral Roof Area

$$C_o = [C_o(\omega_uX_o - C_o(\omega_u'X_o)]\ \frac{B_i(X_iH_f)}{B_i(0\text{-psf } H_f)}\ [\text{Skyshine Correction}]$$

$$[.035 - .030]\ \frac{.006}{.03}[1.06] = [.005]\ .2\ [1.06] = .00106$$

8. Reduction Factor

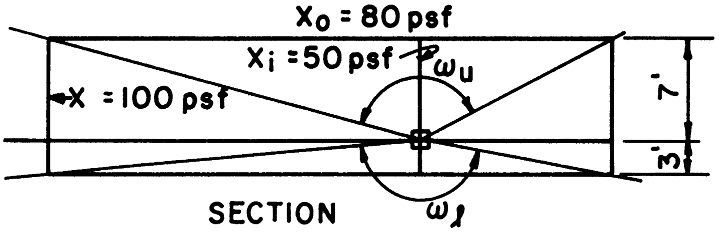
$$R_f = C_g + \sum C_o$$

$$= .00834 + .0318 + .00106 = .0412$$

9. Protection Factor

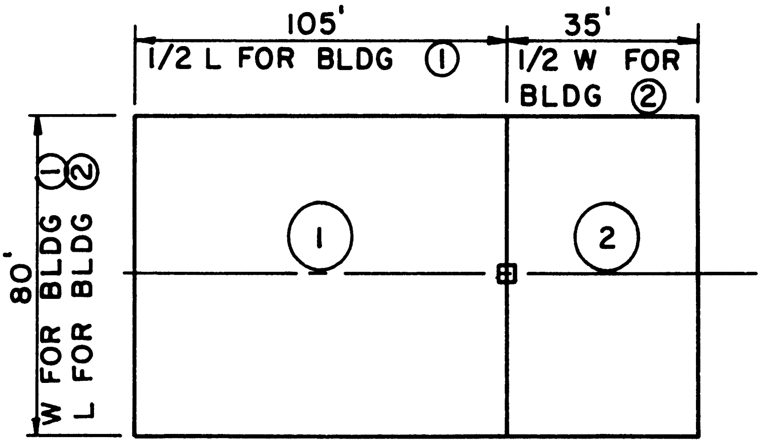
$$P_f = \frac{1}{R_f} = 24.3$$

Example No. 3-1 Off Center Detector Next to Partition



SECTION

The detector being off center along one axis, two fictitious buildings are required. The detection is against the partition in Bldg 2.



PLAN

$B_w(X_\ell H) = .094$

$S_w(X_\ell) = .74$

$H_\ell = 13[80] = 1040'$

$B_i(X_i 3') = .3$

$B_i(X_i H_f) = .006$

$B_i(0\text{-psf}, H_f) = .03$

		W	L	Z	e	n	ω	G_d	G_s	G_a	E
①	ω_u	80	210	7	.38	.067	.885	-	.13	.036	1.29
1	ω_ℓ	80	210	3	.38	.029	.95	.26	.063	-	1.29
2	ω_u	70	80	7	.88	.175	.83	-	.185	.049	1.41
2	ω_ℓ	70	80	3	.88	.075	.925	.35	.08	-	1.41

1. Ground Contribution - Bldg. 1

$$C_{g1} = 1/2\{[G_a(\omega_u) + G_d(\omega_1 H)][1-S_w(X_e)] + [G_s(\omega_u) + G_s(\omega_1)]E(e)S_w(X_e)\} B_w(X_e H)B_i(X_i 3')$$

$$1\ 2\{[.036 + .26][.26] + [.13 + .063]\ 1.29[.74]\ .094[.3] = .00368$$

2. Ground Contribution - Bldg. ②

$$C_{g2} = 1/2\{[G_a(\omega_u) + G_d(\omega_1 H)][1-S_w(X_e)] + [G_s(\omega_u) + G_s(\omega_1)]\ E(e)S_w(X_e)\}\ B_w(X_e H)$$

$$1/2\{[.049 + .35]\ .26 + [.185 + .08]\ 1.41\ [.74]\ .094 = .0178$$

3. Total Ground Contribution

$$C_g = C_{g1} + C_{g2} = .00368 + .0178 = .02148$$

4. Roof Contribution - Bldg. ①

$$C_{o1} = 1/2\ C_o(\omega_u X_o)B_i(X_i H_f)/B_i(X_i = CH_f)[\text{Skyshine Correction}]$$

$$1/2[.036]\ .006/.03[1.06] = .0038$$

5. Roof Contribution - Bldg. ②

$$C_{o2} = 1/2\ C_o\ (\omega_u X_o)[\text{Skyshine Correction}]$$

$$1/2[.035]\ 1.06 = .0186$$

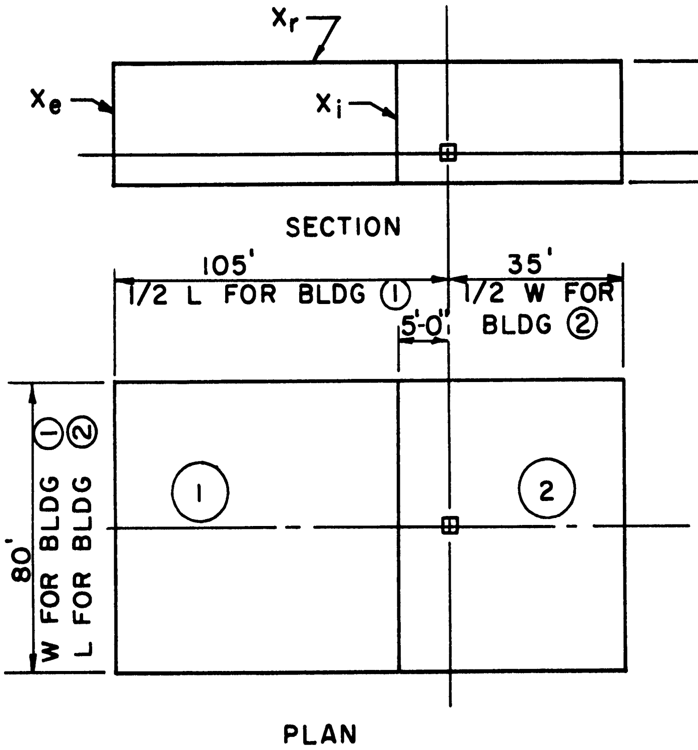
6. Total Roof Contribution

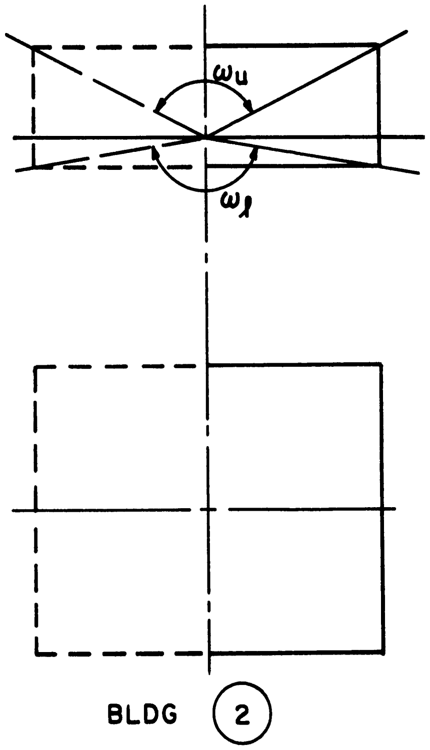
$$C_o = C_{o1} + C_{o2} = .0038 + .0186 = .0224$$

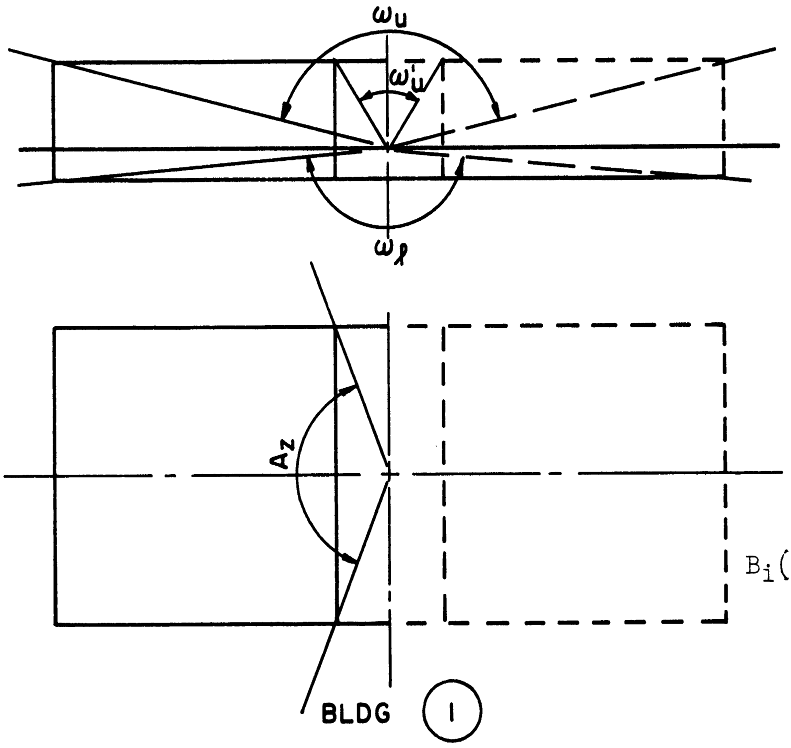
7. $R_f = C_g + C_o = .02148 + .0224 = .0439$

8. $P_f = 1/R_f = 22.8$

Example No. 4-1 Off Center Detector Away From Partition







$X_o = X_r = 80\text{psf}$

$X_e = 100\text{psf}$

$X_i = 50\text{psf}$

$B_w(X_eH) = .094$

$S_w(X_e) = .74$

$H_f = 1040'$

$B_i(X_i3') = .3$

$B_i(X_iH_f) = .006$

$B_i(0\text{-psf}, H_f) = .03$

$A_z = .46$

Bldg.	ω	W	L	Z	e	n	ω	G_d	G_s	G_a	E
①	ω_u	80	210	7	.38	.067	.885	-	.13	.036	1.29
①	ω_u'	10	80	7	.125	.175	.39	-	-	-	-
①	ω_l	80	210	3	.38	.029	.95	.26	.063	-	1.29
②	ω_u	70	80	7	.88	.175	.83	-	.185	.049	1.41
②	ω_l	70	80	3	.88	.075	.925	.35	.08	-	1.41

1. Ground Contribution - Bldg. ①

$$G_{g1} = .46\{[.036+.26][.26]+[.13+.063]1.29[.74]\}\ .094[.3] = .00338$$

$$.04\{[.036+.26][.26]+[.13+.063]1.29[.74]\}\ .094 = \underline{.00049}$$

$$.00387$$

2. Ground Contribution - Bldg. ②

Same as Bldg. ② Example No. 3 .0178

3. Roof Contribution - Bldg. ①

$$C_{o1} = 1/2\left\{C_o(\omega_u' X_o)+[C_o(\omega_u X_o)-C_o(\omega_u' X_o)] \cdot \frac{B_i(X_i H_f)}{B_i(0\text{-psf}, H_f)}\right\}[\text{Skyshine Correction}]$$

$$1/2\{.025+[.036-.025][.006/.03]\}\ 1.06 = .0144$$

4. Roof Contribution - Bldg. ②

Same as Bldg. ② Example No. 3

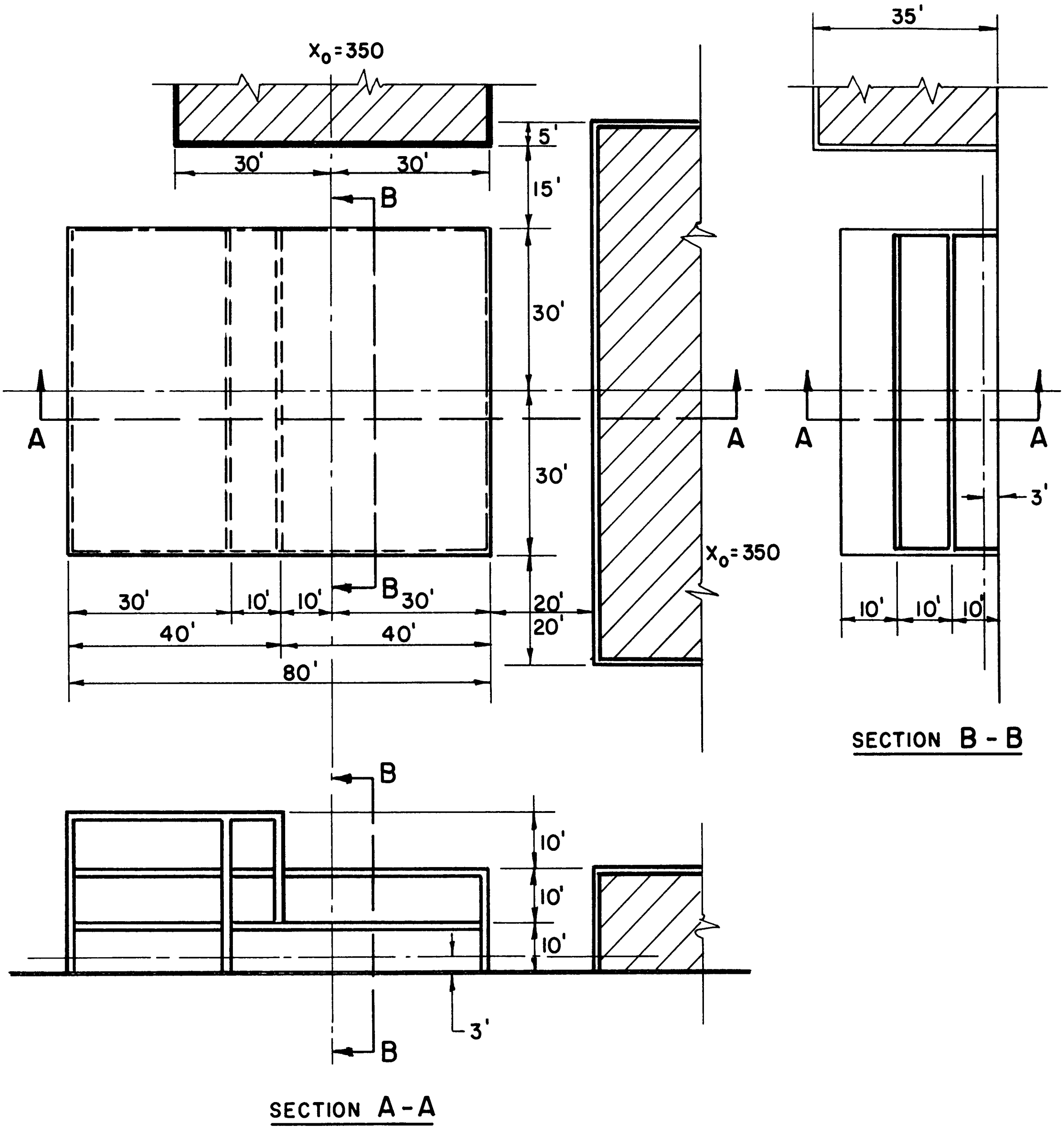
$C_{o2} = .0186$

5. $R_f = .00387 + .0178 + .0144 + .0186 = .0547$

6. $P_f = 18.3$

Note the reduction in protection factor due to moving partition five feet from detector.

Example No. 5-1 - Comprehensive



X_r = 50 psf

X_e = 80 psf

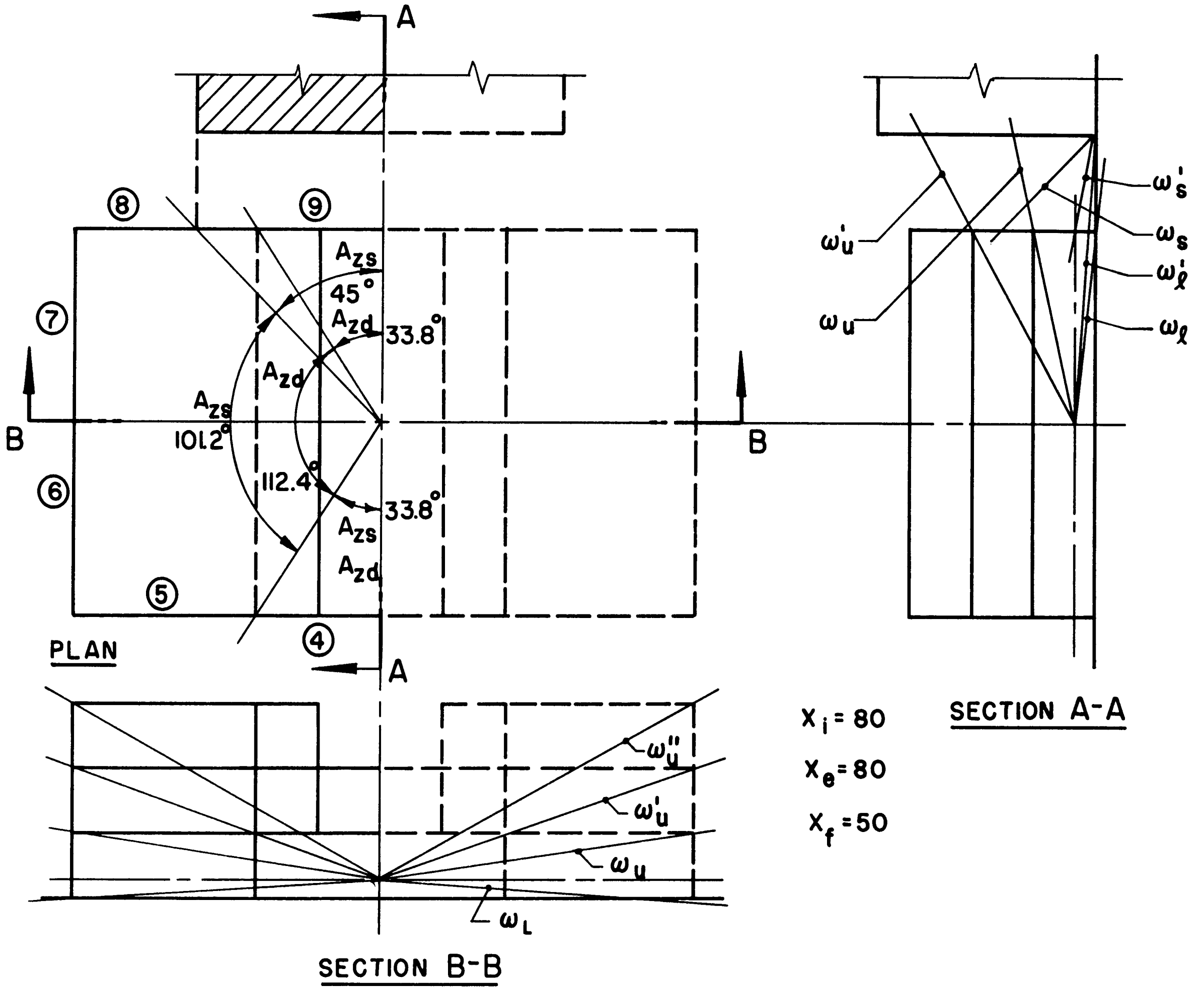
X_i = 80 psf

X_f = 50 psf

GROUND CONTRIBUTION

SITUATION A - WALLS - 4 - 5 - 6 - 7 - 8 - 9

EXP. NO. 5 - 2



$X_i = 80$

$X_e = 80$

$X_f = 50$

		W	L	Z	e	n	ω	G_d	G_s	G_a	Z_{zd}	A_{zs}
5-8	ω_ℓ	60	100	3	.6	.06	.925	.35	.085	----	.312	.281
	ω_u	60	100	7	.6	.14	.83	---	.185	.048	----	----
	ω'_u	60	100	17	.6	.34	.62	---	.325	.077	----	----
4	ω_ℓ	60	100	3	.6	.06	.925	.35	.085	----	.094	.094
	ω_u	60	100	7	.6	.14	.83	---	.185	.048	----	----
	ω'_u	60	100	17	.6	.34	.62	---	.325	.077	----	----
9	ω_ℓ	60	100	3	.6	.06	.925	.35	.085	----	.094	.125
	ω'_ℓ	60	100	2	.6	.04	.95	.26	----	----	----	----
	ω_u	60	100	7	.6	.14	.83	---	.185	.048	----	----
	ω'_u	60	100	17	.6	.34	.62	---	.325	.077	----	----
	$2\omega_s$	30	60	3	.5	.1	.86	ω_s =	.43	----	----	----
	$2\omega'_s$	30	60	15	.5	.5	.43	ω_s =	.215	----	----	----

$B_w(X_e3')$(Figure 9) = .15

$B_i(X_i3')$(Figure 9) = .15

$S_w(X_e)$(Figure 8) = .69

$[1 - S_w] = .31$

$E(e)$(Figure 10) = 1.37

$B'_w(X_e15')$(Figure 9) = .1

$B'_o(X'_o)$(Figure 12, Case 3) = .063

$B_{ws}(X_e\omega_s)$(Figure 11) = .04

$B'_{ws}(X_e\omega'_s)$(Figure 11) = .006

1. Ground Contribution (Adjacent Walls - 5 - 6 - 7 - 8)
   All radiation impinges on interior partition. The scattered component from part of Wall 8 is from a limited strip, i.e., $A_{zs} \neq A_{zd}$, and is included in 4.(b).

(a) $C_{gd} = [G_d(\omega_\ell) + G_a(\omega_u)][1 - S_w(X_e)]\ B_w(X_eH)\ B_i(X_i3')\ A_{zd}$

$[.35 + .048].31[.15].15[.312] = .000866$

(b) $C_{gs} = [G_s(\omega_\ell) + G_s(\omega_u)]\ S_w(X_e)E(e)\ B_w(X_eH)\ B_i(X_i3')A_{zs}$

$[.085 + .185].69[1.37].15[.15].281 = .001614$

(c) C_g = Step (a) + Step (b) = .000866 + .001614 = .002480

2. Ground Contribution (Adjacent Wall - 4)
Radiation through this wall does not impinge on interior partition

$C_g = [[G_d(\omega_\ell) + G_a(\omega_u)][1 - S_w(X_e)] + [G_s(\omega_\ell) + G_s(\omega_u)]\ S_w(X_e)E(e)]B_w(X_eH)A_z$

$[[.35 + .048].31 + [.085 + .185].69[1.37]].15[.094] = .005338$

3. Ground Contribution (Floor Above - Walls - 4 - 5 - 6 - 7 - 8)
See comment under 1 above. A small portion of radiation through walls 5 and 8 will impinge on two partitions. Part through wall 4 (and 9) will not impinge on a partition. One partition is assumed for all.

(a) $C_{gd} = [G_a(\omega_u') - G_a(\omega_u)][1 - S_w(X_e)]B_w'\ (X_e15')B_i(X_i3')B_o'(X_o')A_{zd}$

$[.077 - .048].31[.1].15[.063][.312 + .094] = .0000035$

(b) $C_{gs} = [G_s(\omega_u') - G_s(\omega_u)]S_w(X_e)E(e)B_w'(X_e15')B_i(X_i3')B_o'(X_o')A_{zs}$

$[.325 - .185].69[1.37].1[.15].063[.281 + .094] = .0000469$

(c) C_g = Step (a) + Step (b) = .0000035 + .0000469 = .0000504

4. Ground Contribution (Adjacent Wall - 9) (No Skyshine)
The direct and scattered components are from a limited strip.

(a) $C_{gd} = [G_d(\omega_\ell) - G_d(\omega_\ell')]\ B_w(X_e3')[1 - S_w(X_e)]A_{zd}$

$[.35 - .26].15[.31].094 = .000393$

(b) $C_{gs} = [G_s(\omega_\ell) + G_s(\omega_u)]\ B_{ws}(\omega_s X_e)\ S_w(X_e)\ E\ (e)\ A_{zs}$

$[.085 + .185].04[.69]1.37[.125] = .00128$

Approximately one-quarter ($A_z = .031$) impinges on a partition. The barrier effect has not been included.

(c) C_g = Step (a) + Step (b) = .000393 + .00128 = .001673

5. Ground Contribution (Floor Above)(No Skyshine)(Wall - 9)

$C_s = [G_s(\omega_u') - G_s(\omega_u)]\ B_{ws}'\ (\omega_s')\ B_i'(X_i 3')B_o'(X_o')\ S_w(X_e)E(e)A_{zs}$

$[.325 - .185].006[.15].063[.69]1.37[.125] = .0000009$

A small portion impinges on two partitions and a small portion on no partition. The barrier effect of one partition has been assumed for all.

6. Total Ground Contribution (Situation A)

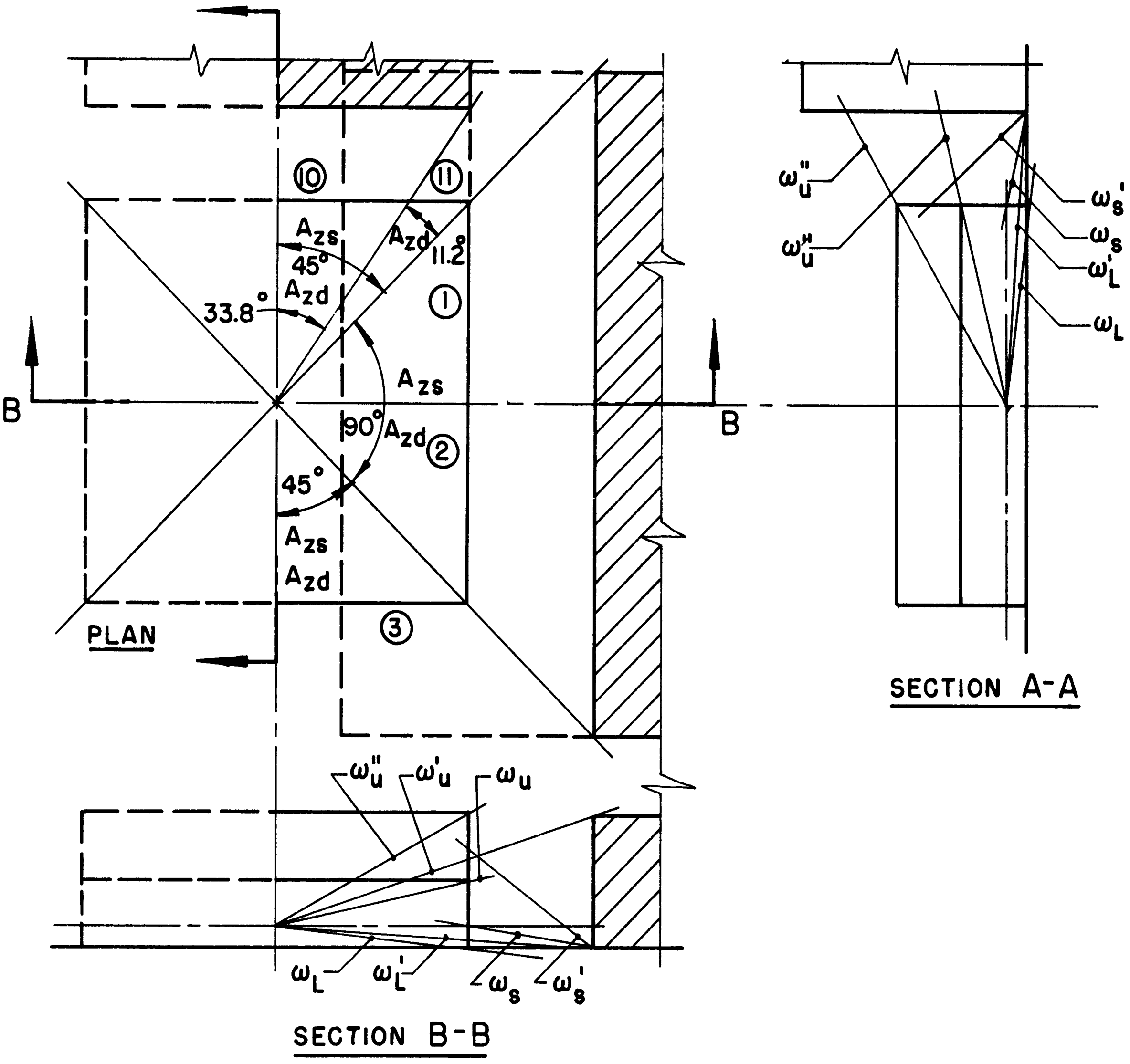
1(c) + 2 + 3(c) + 4(c) + 5 = .00248 + .005338 + .001673 + negligible =

.00949

GROUND CONTRIBUTION

SITUATION B - WALLS-1-2-3-10-11

EXP. NO. 5-5



Example No. 5-7

		W	L	Z	e	n	ω	G_d	G_s	G_a	A_{zd}	A_{zs}
	ω_ℓ	60	60	3	1	.1	.905	.4	.11	----	.25	.25
	ω'_ℓ	60	60	1.8	1	.06	.945	.28	---	----	---	---
	ω_u	60	60	7	1	.233	.79	---	.22	----	---	---
1-2	ω'_u	60	60	10.2	1	.34	.71	---	---	.067	---	---
	ω''_u	60	60	17	1	.567	.55	---	.36	.083	---	---
	$2\omega_s$	40	100	3	.4	.06	.90	ω_s	=	.45	B_{ws}	=.06
	$2\omega'_s$	40	100	15	.4	.30	.56	ω'_s	=	.28	B'_{ws}	=.01
	ω_ℓ	60	60	3	1	.1	.905	.4	.11	----	.156	.125
3-11	ω_u	60	60	7	1	.233	.79	---	.22	.056	----	---
	ω''_u	60	60	17	1	.567	.55	---	.36	.083	----	---
	ω_ℓ	60	60	3	1	.1	.905	.4	.11	----	.094	.125
	ω'_ℓ	60	60	2	1	.067	.936	.32	---	----	----	---
	ω_u	60	60	7	1	.233	.79	---	.22	----	----	---
	ω''_u	60	60	17	1	.567	.55	---	.36	----	----	---
	$2\omega_s$	30	60	3	.5	.1	.86	ω_s	=	.43	B_{ws}	= .05
	$2\omega'_s$	30	60	15	.5	.5	.43	ω_s	=	.215	B'_{ws}	= .005

$B_w(X_e3')$(Figure 9) = .15

$S_w(X_e)$(Figure 8) = .69

$[1 - S_w] = .31$

E(e)(Figure 10) = 1.41

$B'_w(X_e15')$(Figure 9) = .1

$B'_o(X'_o)$(Figure 12, Case 3) = .063

Ground Contribution Continued. Situation B

1. Ground Contribution (Adjacent Walls - 11 - 3)

(a) $C_{gd} = [G_d(\omega_\ell) + G_a(\omega_u)][1 - S_w(X_e)]\, B_w(X_eH)A_{zd}$ (Walls - 11 - 3)

[.4 + .056].31[.15].156 = .00331

(b) $C_{gs} = [G_s(\omega_\ell) + G_s(\omega_u)]\, S_w(X_e)E(e)B_w(X_eH)A_{zs}$ (Wall - 3)

[.11 + .22].69[1.41].15[.125] = .00602

(c) C_g = Step (a) + Step (b) = .00331 + .00602 = .00933

2. Ground Contribution (Floor Above - Walls - 11 - 3)

(a) $C_{gd} = [G_a(\omega_u'') - G_a(\omega_u)][1 - S_w(X_e)]B_w'(X_eH)B_o'(X_o')A_{zd}$ (Walls - 11 - 3)

[.083 - .056].31[.1].063[.156] = .000008

(b) $C_{gs} = [G_s(\omega_u'') - G_s(\omega_u)]S_w(X_e)E(e)B_w'(X_eH)B_o'(X_o')A_{zs}$ (Wall - 3)

[.36 - .22].69[1.41].1[.063].125 = .000107

(c) C_g = Step (a) + Step (b) = .000008 + .000107 = .000115

3. Ground Contribution (Adjacent Walls - 1 - 2)(No Skyshine)

$C_g = [[G_d(\omega_\ell) - G_d(\omega_\ell')]B_w(X_e 3')[1 - S_w(X_e)]$

[[.4 - .28].15[.31]

$+[G_s(\omega_\ell) + G_s(\omega_u)]B_{ws}(\omega_s X_e)S_w(X_e)E(e)]A_z$

+[.11 + .22].06[.69]1.41].25 = .00621

4. Ground Contribution (Floor Above)(Some Skyshine)(Walls - 1 - 2)

$C_g = [[G_s(\omega_u') - G_s(\omega_u)]B_{ws}'\ (\omega_s')B_o'(X_o')S_w(X_e)E(e)$

[[.36 - .22].01[.063].69[1.41]

$+[G_a(\omega''_u) - G_a(\omega'_u)]B_w(X_eH)[1 - S_w(X_e)]B'_o(X'_o)]A_z$

$+[.083 - .067].1[.31].063].25 = .0000293$

5. Ground Contribution (Adjacent Wall - 10)(No Skyshine)

(a) $C_{gd} = [G_d(\omega_\ell) - G_d(\omega'_\ell)]B_w(X_e3')[1 - S_w(X_e)]A_{zd}$ (Wall - 10)

$[.4 - .32].15[.31].094 = .000350$

(b) $C_{gs} = [G_s(\omega_\ell) + G_s(\omega_u)]B_{ws}(\omega_s X_e)S_w(X_e)E(e)A_{zs}$ (Walls - 10 - 11)

$[.11 + .22].05[.69]1.41[.125] = .00201$

(c) C_g = Step (a) + Step (b) = .00035 + .00201 = .00236

6. Ground Contribution (Floor Above)(No Skyshine)(Wall - 10)

$C_g = [G_s(\omega''_u) - G_s(\omega_u)]B'_{ws}(\omega'_s)B'_o(X'_o)S_w(X_e)E(e)A_{zs}$ (Wall - 10 - 11)

$[.36 - .22].005[.063].69[1.41].125 = .000005$

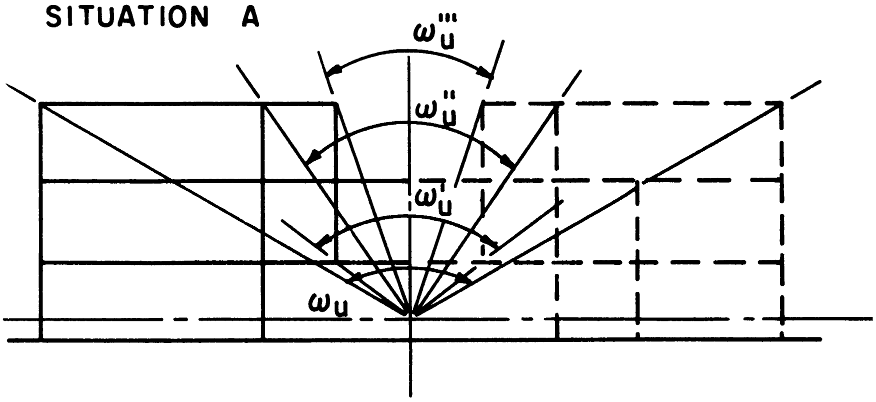
7. Total Ground Contribution (Situation B)

1(c) + 2 (c) + 3 + 4 + 5(c) + 6 =

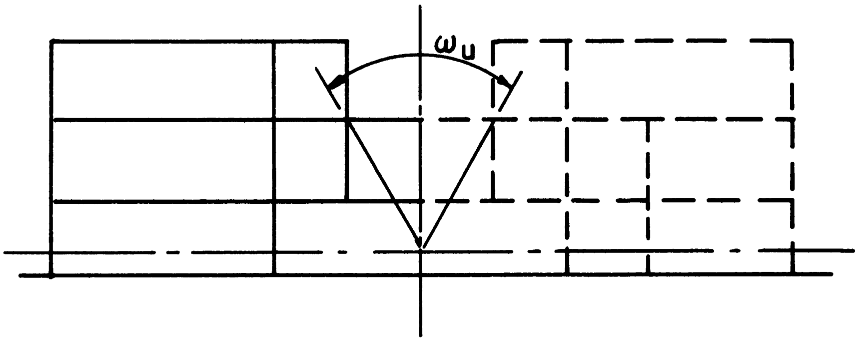
.00933 + .000115 + .00621 + .0000293 + .00236 + .000005 = .01805

Roof Contribution

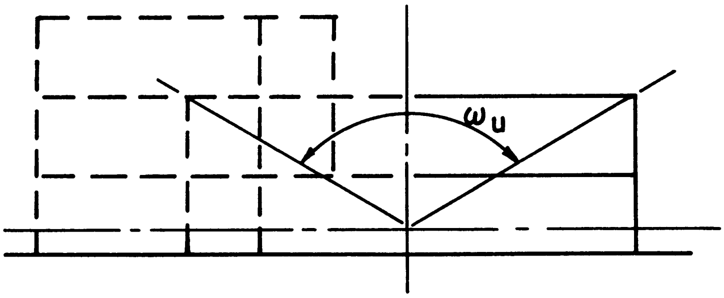
SITUATION A



SITUATION B



SITUATION C



Example No. 5-11

	W	L	Z	e	n	ω	X_o	C_o	H_f	X_i	$B_i(X_i H_f)$	$B_i(0,H_f)$
ω_u Ⓐ	60	100	27	.6	.54	.45	150	.005	1950	80	.00055	.006
ω'_u Ⓐ	60	77.2	27	.78	.70	.41	150	.005	1950	160	.0007	.006
ω''_u Ⓐ	40	60	27	.67	.90	.30	150	.0043	1950	80	.00055	.006
ω''' Ⓐ	20	60	27	.33	.90	.17	(150)	.003	----	--	------	----
ω_u Ⓑ	20	60	17	.33	.567	.30	100	.013	----	--	------	----
ω_u Ⓒ	60	60	17	1	.567	.55	100	.018	----	--	------	----

X_i = 80 psf $H_f = 13X_o$ C_o(Figure 4)

Ⓐ $C_o = \frac{1}{2}[C_o(\omega_u X_o) - C_o(\omega'_u X_o)] \dfrac{B_i(X_i H_f)}{B_i(0 \text{ psf } H_f)}$

Negligible

$+ \frac{1}{2}[C\ (\omega'_u X_o) - C_o(\omega''_u X_o)] \dfrac{B_i(X_i H_f)}{B_i(0 \text{ psf } H_f)}$

$$\frac{1}{2}[.005 - .0043] \frac{.00007}{.006} = .000004$$

$+ \frac{1}{2}[C\ (\omega''_u X_o) - C_o(\omega'''_u X_o)] \dfrac{B_i(X_i H_f)}{B_i(0 \text{ psf } H_f)}$

$$\frac{1}{2}[.0043 - .003] \frac{.00055}{.006} = .00006$$

Ⓑ $C_o = \frac{1}{2} C_o(\omega_u X_o) = \frac{1}{2}[.013] = .0065$

Ⓒ $C_{\underline{o}} = \frac{1}{2} C_o\ (\omega\ X\ ) = \frac{1}{2}[.018] = .009$

Total C_o = Ⓐ + Ⓑ + Ⓒ = .000064 + .0065 + .009 = .0156

Total R_f = 6.(p.5) + 7.(p.9) + Total C_o(p.11)

.00949 + .01805 + .0156 = .04314

$P_f = 23.2$

SPECIAL SHIELDING PROBLEMS

Glenn G. Mastin

Shielding calculations assume a uniformly contaminated, smooth infinite plane. It is necessary to account for the effects of terrain and ground roughness.

Obviously, a detector will be at least partially shielded from radiation from particles in depressions in the ground. The greater the depth of depression the greater the degree of shielding. One method of taking this shielding into account is to assume an increased height of the detector above the contamination in determining the wall barrier reduction factor.

Condition	Fictitious Height*(Feet)
Smooth Plane	0
Paved Areas	0-5
Lawns	5-10
Gravelled Areas	10-20
Ordinary Plowed Field	20-40
Deeply Plowed Field	40-60

* To add to actual detector height for use with wall-barrier curves.

Figure 1. Fictitious Heights for Various Ground Roughness Conditions.

The shielding problem associated with filters (or plenum chambers) is to properly isolate them from the occupied portions of the shelter. Figure 2 gives some general guidance as to minimum thicknesses of shielding barriers between filter rooms (or plenum chambers) and occupied areas. Apertures in these barriers must be appropriately baffled.

In Figure 2 a protected opening is an air intake with a vertical face which is hooded in such a manner as to force incoming air paths to change their direction at least 90 degrees before reaching the opening. In both protected and unprotected cases the intake velocities should be kept below 2000 fpm.

Air Intake, cfm	Protected Opening	Unprotected Opening
100	nil	50 psf
300	nil	100 psf
1000	50 psf	150 psf
3000	100 psf	200 psf
10000	150 psf	250 psf

Figure 2. Mass Thickness Requirements for Filter Rooms.

Particles of fallout which have been deposited on turfted areas do not tend to drift, but a building located in a parking lot could be expected to have a "pile-up" of fallout particles on its windward side. To estimate the influence of this pile-up on a protection factor, it is necessary to know its relative source concentration. This concentration can be related to the effective "fetch" of the paved area, that is, the distance of the outer edge of the pavement from the wall of the building. For above ground detector positions the reduction factor accounting for pile-up along a given wall is:

$$R_f \text{ (for sector } A_z) = 0.18\, P_s(X_e) F_e \frac{A_z}{r_e}$$

where $P_s(X_e)$ is the barrier reduction factor for a point isotropic source, Figure 3.
F_e is the effective fetch
A_z is the azimuthal sector
r_e is the perpendicular distance from the detector to the given wall

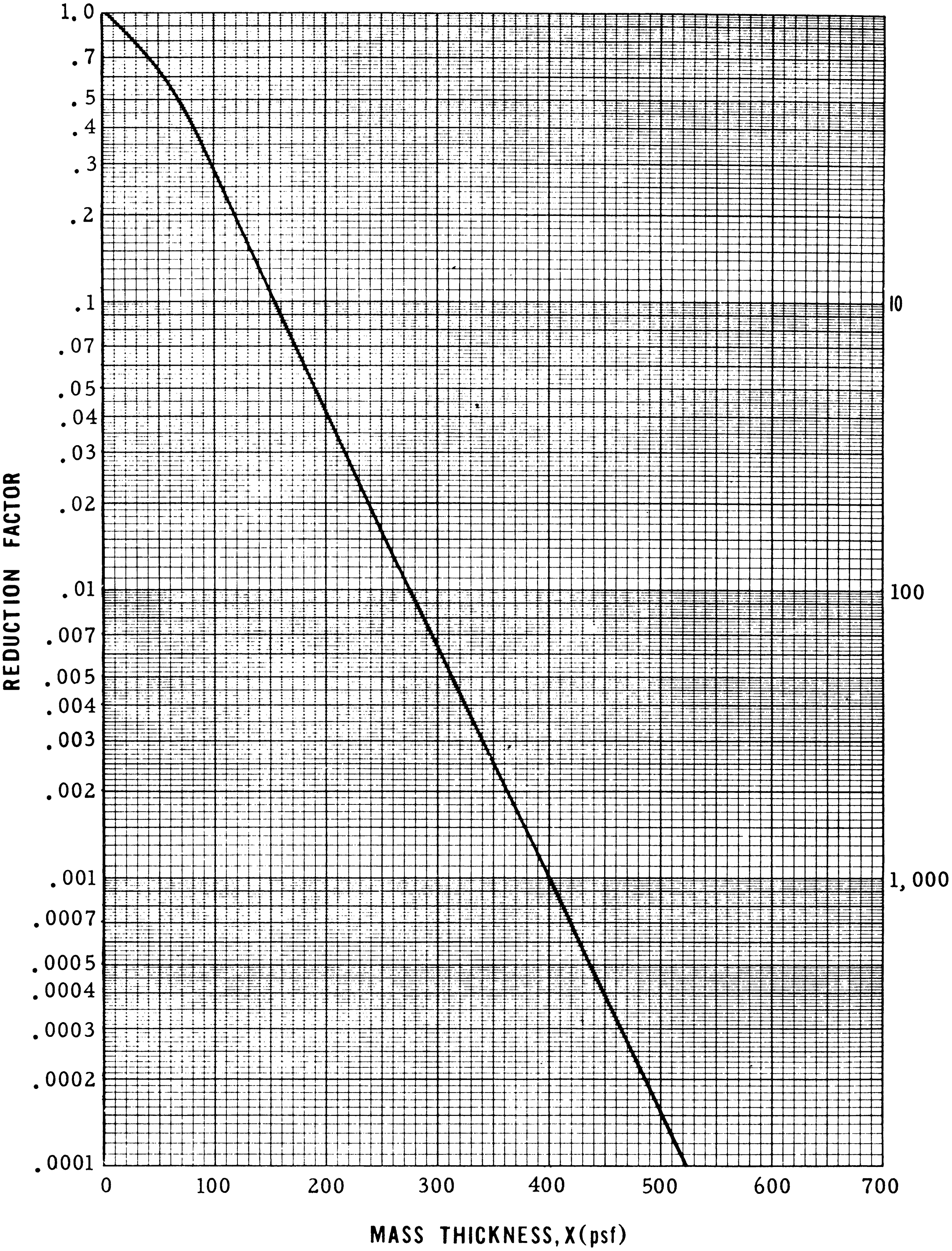


Figure 3. Barrier Shielding Effects (Point Source).

For a below ground detector the equivalent reduction factor is given by the following:

$$R \text{ (for sector } A_Z) = \frac{12\omega(1-\omega)(2-\omega)}{U\ Z} B_W(X_e)F_eA_Z$$

The parameters are shown in Figure 4 or given above.

Pile-up would be assumed on one (or possibly two) sides, only. Unless the fetch is very great, account must be taken of the contamination beyond.

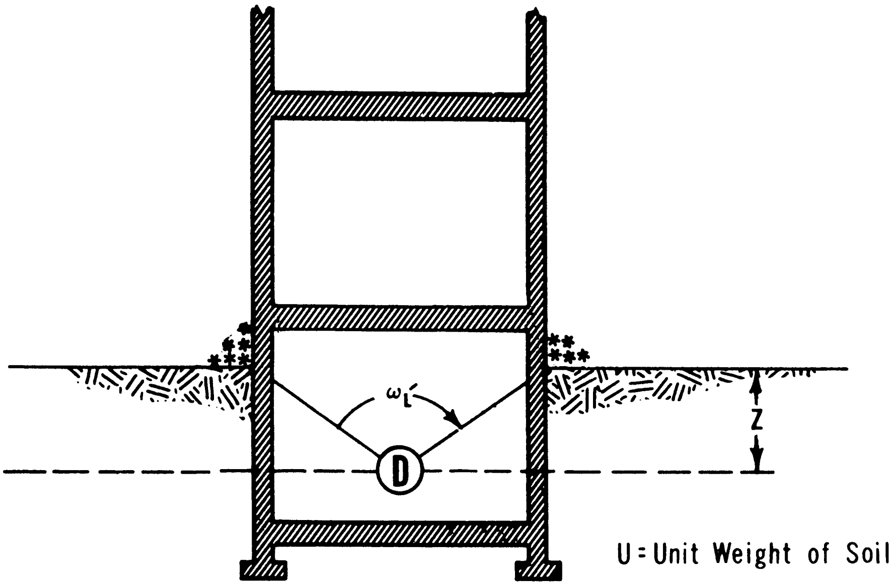


Figure 4. Fallout Particle Pile-Up on Foundation Walls.

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