# AN ANALYSIS OF CIVIL DEFENSE HAZARDS BEING CREATED BY EMPLACEMENT OF INTERCONTINTENTAL BALLISTIC MISSILES NEAR TUCSON

JAMES E. McDONALD

INSTITUTE OF ATMOSPHERIC PHYSICS, THE UNIVERSITY OF ARIZONA

INTRODUCTION. — This paper will summarize the principal results of a study of the civil defense implications of the deployment near Tucson of eighteen Titan ICBM's (intercontinental ballistic missiles). The Titan is a U. S. Air Force weapon of 8000-10,000-mile range with a multimegaton nuclear warhead which, along with the similar Atlas, will form the heavy-caliber part of America's retaliatory missile force in a few years. Implementing our strategic policy of deterrence of war through threat of massive retaliation, the function of these weapons is to ride out the first few minutes of any future enemy attack on the United States in order to carry to the enemy's homeland devastating retaliation. Credibility of such a deterrence function demands that the ICBM's be emplaced in heavily reinforced or "hardened" underground launching tubes capable of withstanding very high blast overpressures from near misses during the initial minute or so of the nuclear war they are intended to forestall. In turn, hardening our sites forces a would-be nuclear attacker to dispatch against these sites an extremely intense salvo of his own multimegaton missiles in hope of wiping out so large a national fraction of our retaliatory missiles as to render tolerable their counter-blow to his own homeland. Out of these rather simple strategic considerations will arise Tucson's horrendous civil defense hazards by the estimated 1964 completion date of the Titan base. It is the thesis of this paper that failure to locate *all* of those eighteen Titan sites well *downwind* of (east and southeast of) Tucson's 225,000 residents will reduce survival chances for this entire unprotected population essentially to zero. If unchallenged on scientific grounds, this analysis will fill a serious information-gap for Tucson citizens who have never been given by the Air Force or other agencies any inkling of the magnitude of the hazards they will contfront when these sites become operational a few years from now. Or, if the following should contain any substantial errors of hazard prediction, then clarification and correction of such errors by technically documented official statements will serve the very important end of giving Tucson citizens an adequate estimate of the dangers they must anticipate in coming years.

TARGETING PROBABILITIES. — In Figure 1 the numbered crosses mark the planned locations of the eighteen Titan launcher sites. At the date of this writing initial excavation work has been begun at sixteen of the eighteen, with perhaps the most dangerous one of the entire group, Site 11, being the

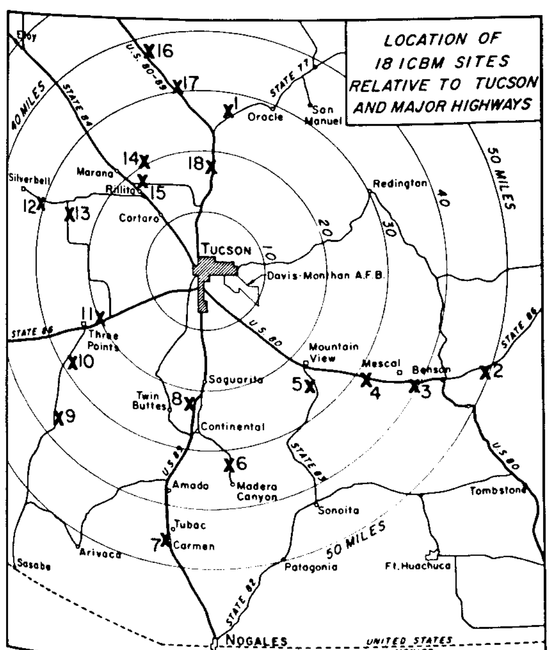



Figure 1.—Site map.

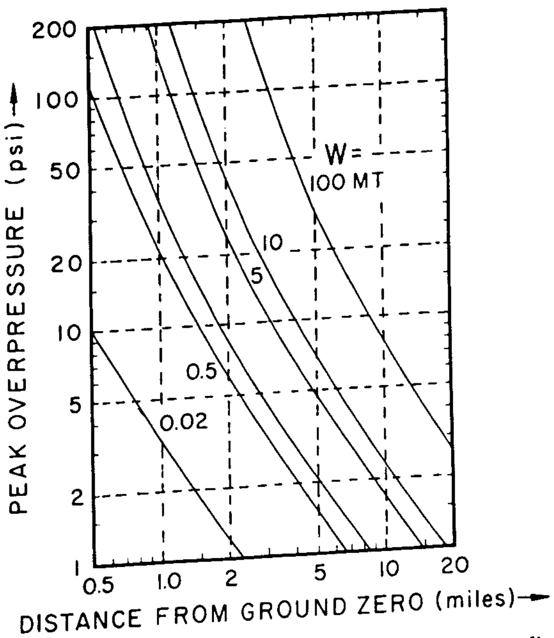



Figure 2.—Dependence of peak blast overpressure on radius and weapon yield.

one begun first and now in the most advanced state of construction. Number 2, the least dangerous, has to the writer's knowledge, not yet been begun at time of writing (March 1961).

Each one of the eighteen launcher sites shown in Figure 1 is, by design, a ballistically separate target, hardened to withstand 100 psi (pounds per square inch) blast overpressure. Recent military statements (e.g., those of Gen. T. S. Power, SAC commander, Feb. 15, 1960 issue, *Missiles and Rockets*) indicate that an over-all knockout probability of at least 95 percent is the lowest knockout percentage a would-be attacker could dare accept in view of the total number of such ICBM's we will have on station by the operational date of the Tucson Titans. With this figure plus the required 100 psi overpressure, it becomes a straightforward probability computation (Morse and Kimball, 1954, p. 112) to determine how many missiles of specified warhead megatonnage and ballistic accuracy an enemy must fire against *each* site to accomplish "successful" attack. This computation involves the known relation (U. S. Dept. of Defense, 1957) between the megatonnage of a surface burst and the radial distance from ground zero out to which any given blast overpressure is *exceeded*. In Figure 2, this relationship is displayed for surface bursts ranging from weapon yield W=20 KT (nominal atomic bomb of Hiroshima-Nagaski type) to 100 MT.

The ballistician's standard figure of merit for accuracy, the *circular probable error* (curiously designated as CEP) is defined as the radius of that circle, concentric with ground zero, within which *half* of a large sample of test-shots fall. Whereas it had seemed somewhat over-optimistic that acceleration of our ICBM program in 1954 was tied to a hope of a five-mile CEP, actual guidance developments have subsequently given us Atlas CEP's under three miles, and there seems to be fairly general agreement that Russian CEP's will go to or below *one mile* by about 1963 (U. S. Congress, 1960). Some military observers (Gettings, 1960) forecast 0.5-mile CEP's in 1965 Russian ICBM systems. This guidance progress actually renders obsolescent as a deterrent the 100 psi ICBM launchers of the Tucson Titan type even as construction is barely begun, a circumstance which makes this writer wonder why Tucson must accept such dire civil defense hazards in the first place. Thus, the Air Force's Lt. General Bernard Schriever (quoted in April, 1960 *Astronautics*, p. 11) has noted that "when ICBM accuracy gets down to one mile, the 100-psi-protected missile will be 'pretty much finished.'" To counter this accuracy trend, newer missile systems (e.g., Air Force Minuteman) are reportedly to be hardened to 300 psi. Now if the Tucson hardening stays at 100 psi, the predicted CEP reduction augurs diminished attack megatonnage and consequent mitigation of civil defense hazards (along with cancellation of much of the deterrence value of the Titans); but if design changes are introduced to boost the hardening to, say, 200 psi or more, Tucson will face just as severe hazards as will now be summarized on the assumption of 100 psi hardening.

In Table 1 are shown the results of a series of probability calculations which the writer has made on the basis just outlined. The figures in the body of the table show (rounded to nearest integer) the number of enemy missiles of specified CEP and warhead megatonnage that must be fired against *each* Tucson site as part of a 95-percent-probability salvo from a nuclear aggressor. Note that with CEP's as high as five miles, so absurdly high an attack must be mounted as to rule out nuclear aggression on the simple ground that it would be economically out of reach of a would-be aggressor. Even at two miles, the national total remains prohibitively expensive to an attacker. But when, as predicted for perhaps 1963, system CEP's fall to one mile, nuclear attack on the United States' Atlas and Titan missiles becomes economically and militarily possible. With 0.5 mile CEP's credibility of deterrence vanishes for 100 psi sites, as noted in Gen. Shriever's quoted remarks.

Table 1. Numbers of missiles required for 95 per cent knockout of 100 psi targets.

| C.E.P. (miles) | Warhead megatonnage W 1 | 5 | 10 | 20 |
|---|---|---|---|---|
| 0.5 | 2 | 1 | 1 | 1 |
| 1 | 10 | 4 | 2 | 1 |
| 2 | 38 | 14 | 8 | 5 |
| 5 | 250 | 82 | 48 | 34 |

Our Titan has been reported to have a warhead of 7 MT, the Atlas 4 MT, Minuteman and Polaris about 1 MT; Russia is believed to have an 8 MT warhead. It seems plausible to assume that an attack on the Titans might involve 5 to 10 MT warheads, whence Table 1 shows that, in both cases, 20 MT would be the total *per site*. For, say, 300 such sites when the nationwide Atlas-Titan program is completed, a 6000 MT attack could neutralize that part of our retaliatory machinery. Since our own nuclear stockpile has been reported as about 30,000 MT, we cannot regard such a level of attack as at all out of the question. By operational date of the Titans other superior retaliatory weapons may be in existence, raising to considerably higher levels the total requirements for successful attack on our country; but this will not alter the arithmetic of attack on the Tucson area, since as long as the Titans are operational here they will constitute a highest-priority target that an enemy must seek to obliterate in the first crucial minutes of World War III. That being our concern here, we can ignore the larger strategic questions influencing prospects for such a war, and proceed on the assumption that, if attacked in the foreseeable future, *the Tucson Titans would draw 18 times 20 MT, or an areal total of 360 MT. All* World War II aerial bombardment campaigns carried out by *all* combatant forces in *all* theatres of war totaled about 3 MT (five megatons of total bomb weight,



of which only about half was TNT as di
from casing steel); war-making has u
quantum jump.

A corollary implication must be stress
course of extensive but unsuccessful loc
secure public hearings in which technical
to the planned Titan deployment patter
answered by qualified Air Force weapo
many Tucson citizens and at least one Ai
cial have intimated to the writer that
entirely downwind siting was a quibble
the likelihood that stray enemy missiles
on *all* sides of Tucson *regardless* of wh
the community these targets lay at time o
attack. Now, given the CEP of a weapon
is easy to compute the fraction of all i
siles that must be expected to land with
greater than any specified amount, and T
marizes a set of such calculations for
Note that even with a two-mile CEP only
of a large salvo will err by more than five
with a one-mile CEP, the probability of
than five miles has fallen to *one in ten*
stray-missile objection to a downwind s
categorically ruled out by the kind of C
now available, let alone with the kind
characteristic in 1964.

Table 2. The stray-missile problem. (Table
fraction of a salvo having more tha
radial error.)

| C.E.P. (miles) | Radial error (miles) 1 | 2 | 5 | 1 |
|---|---|---|---|---|
| 1 | 0.50 | 0.06 | $10^{-7}$ | |
| 2 | 0.84 | 0.50 | 0.01 | 1 |
| 5 | 0.97 | 0.89 | 0.50 | ( |

It should be made clear to the rea
*surface bursts* (as contrasted with *air* b
considered here. To attain the very hi
pressures required for successful attack
sites it is necessary to employ surface
shock-reflection by the ground adva
creases by a factor of two or more th
pressure rise at the shock front (M
surface burst leads to crater-formati
quent entrainment into the fireball o
of soil and rock (something like a m
a 10 MT detonation) which, after
recondensing, forms the vehicle for
much of the fission products in a
(formation of so-called *local fallout*
an attack on Davis-Monthan AFB or
hardened SAC retaliatory bomber bas
accomplished through use of air bu
pressure of only 3 psi suffice to rende
unflyable and since it is a quirk of the
hydrodynamical laws that such low o
produced out to greater radial distan
than in surface bursts. A 1 MT op
delivers 3 psi to more than five miles

of which only about half was TNT as distinguished from casing steel); war-making has undergone a quantum jump.

A corollary implication must be stressed. In the course of extensive but unsuccessful local effort to secure public hearings in which technical objections to the planned Titan deployment pattern might be answered by qualified Air Force weapons experts, many Tucson citizens and at least one Air Force official have intimated to the writer that a plea for entirely downwind siting was a quibble in view of the likelihood that stray enemy missiles would land on *all* sides of Tucson *regardless* of which side of the community these targets lay at time of any future attack. Now, given the CEP of a weapons system, it is easy to compute the fraction of all inbound missiles that must be expected to land with radial errors greater than any specified amount, and Table 2 summarizes a set of such calculations for three CEP's. Note that even with a two-mile CEP only one percent of a large salvo will err by more than five miles, while with a one-mile CEP, the probability of error greater than five miles has fallen to *one in ten million.* The stray-missile objection to a downwind siting plea is categorically ruled out by the kind of CEP's that are now available, let alone with the kind that will be characteristic in 1964.

Table 2. The stray-missile problem. (Table entries show fraction of a salvo having more than the specified radial error.)

| C.E.P. (miles) | Radial error (miles) 1 | 2 | 5 | 10 | 15 |
|---|---|---|---|---|---|
| 1 | 0.50 | 0.06 | $10^{-7}$ | | |
| 2 | 0.84 | 0.50 | 0.01 | $10^{-7}$ | |
| 5 | 0.97 | 0.89 | 0.50 | 0.06 | 0.002 |

It should be made clear to the reader that only *surface bursts* (as contrasted with *air* bursts) need be considered here. To attain the very high blast overpressures required for successful attack on hardened sites it is necessary to employ surface detonation, for shock-reflection by the ground advantageously increases by a factor of two or more the intensity of pressure rise at the shock front (Mach effect). A surface burst leads to crater-formation and consequent entrainment into the fireball of a large mass of soil and rock (something like a million tons for a 10 MT detonation) which, after vaporizing and recondensing, forms the vehicle for bringing down much of the fission products in a very short time (formation of so-called *local fallout*). By contrast, an attack on Davis-Monthan AFB or any other unhardened SAC retaliatory bomber base might be best accomplished through use of air bursts, since overpressure of only 3 psi suffice to render parked aircraft unflyable and since it is a quirk of the relevant shock-hydrodynamical laws that such low overpressures are produced out to greater radial distances in air bursts than in surface bursts. A 1 MT optimum air burst delivers 3 psi to more than five miles, while a 1 MT surface burst delivers the same pressure only to three miles. Hence, in view of recent guidance break-throughs, Davis-Monthan alone might have brought only one or two megatons to the Tucson area by 1964 if still a bomber base by then (B-47 phase-out by about 1962 makes even this target value unlikely).

Even if Davis-Monthan remained, say, a 5 MT surface-burst target beyond 1964, the Titans will remain overwhelmingly the chief civil defense hazard to Tucsonans — in contrast to Air Force press assurances that the Titans would not represent any additional hazard to Tucson.

While comparing surface *versus* air bursts, one other serious piece of misinformation given Tucsonans demands clarification. In an important television talk made by a local Air Force spokesman during the height of protests against upwind siting, it was suggested that all of the emphasis on fallout dangers was rather overdone inasmuch as no Japanese at Hiroshima or Nagasaki were killed by fallout. This true but wholly irrelevant statement was based on the fact that the Japanese 20 KT attacks were both *air bursts*!

Finally, the above targeting analysis permits preliminary comment on the important question of whether attack on the Titans would wipe out Tucson as a result of blast effects. Typical houses do not collapse until about 5 psi is exceeded, and only window breakage and comparatively minor structural damage occurs beyond 1 psi.

From joint study of Figures 1 and 2 and consideration of the stray-missile results cited above, one sees that *negligible blast destruction in Tucson will result from attack on the Titans.* Similarly, thermal radiation effects will be of only marginal concern in Tucson itself. This confirms as essentially correct an Air Force statement to the effect that the deployment would involve "relatively minor additional blast, thermal, and prompt radiation effects on the base and on Tucson." However, omission of any mention o the tremendous increase in fallout hazards rendere this true statement a most objectionably decepti one to lay before a trusting but technically u informed citizen. Identical phraseology was used i Air Force reassurances in other ICBM-base cities.

INTERACTION EFFECTS. — All nuclear te explosions and all published data derived therefro known to the writer involve effects of detonation c *single* weapons, but Tucson's forthcoming civil de fense hazards will be dependent upon physical proc esses set in motion by detonation of, say, 36 10-MT weapons or 72 5-MT weapons within a 50-mile radius of the city (Figure 1). Here and throughout the following the single case of 36 10-MT weapons will be considered.

Within what time-spread must an attacker program his salvo to arrive on our country? Clearly, all must arrive within the *shortest* reaction time of all our retaliatory devices. The Titan II which is to be used in Tucson will feature storable-liquid propellant and all-inertial guidance, permitting it to be fired from within the launch-tube itself without either fuel-up or elevator delays. Reportedly, these features reduce its alert-to-firing reaction time to about one minute. It is easy to see that this requires that the enemy's attack-programming confine *all* arrival times, not only here in Tucson but in *all* other Titan II and Atlas F launch-areas (e.g., Wichita, Little Rock, Rome-Utica, Salina, Lincoln, Altus, Roswell, Abilene, and Plattsburg) to within *no more than a minute.* A slightly more leisurely pace could be used in attacking Titan I and Atlas D or E launch areas, where the salvo might be spread over several minutes if tactically desirable since these sites will have appreciably longer reaction times. Contrary to some citizens' notions, Tucson's evident vulnerability to attack from ballistic missile submarines lying off Southern California in no way alters the above programming requirements faced by an enemy. Hence we must ask how the nearly-simultaneous detonation of 36 multimegaton weapons near Tucson may affect civil defense hazards.

First, many bizarre Mach interactions are certain to occur where adjacent shock waves intersect. A glance at Figure 1 shows, however, that most of the loci of shock collisions will occur in uninhabited desert, so the resultant overpressure increases are of little civil defense concern. That they will occur over a few small communities such as Benson or Marana is not really of any additional interest, since Titans have been located so near these and a number of other small towns as to insure complete blast-destruction accompanied by fireball ignition of all combustible materials; Mach effects only yield overkill there. (Construction of conventional shelters in these and other small communities near the Titan sites seems wholly futile, yet to the writer's knowledge neither Air Force nor civil defense officials have yet given the citizens concerned any hint of this.)

But a second type of interaction, that involving the stratospheric mushroom clouds formed by the explosions, is of very great civil defense interest, in the writer's opinion. The Rand studies (Kellogg, Rapp, and Greenfield, 1957) indicate that an *isolated* 10 MT detonation produces a mushroom cloud extending from about 55 to 105 kft (kilofeet, or thousands of feet). After stabilization (10-15 min) its radius is approximately 25 miles, the contaminated portion having a radius of about 17 miles. If, as a first approximation, we plot circles of contaminated radius 17 miles concentric with each Titan site, we obtain the *schematic* overlap pattern of Figure 3. On the average there then exists about a threefold overlap at points within the heavily shaded envelope. Does this mean that the density of fission products will average about three times that for an isolated 10 MT cloud (or, more accurately, *six* times, since each site is assumed to be hit with two weapons)? No; and this for the following reasons.

The fission products are intermixed with the air pumped into the cloud through the stem and distributed radially by the vortical circulations in the cloud's interior (Kellogg *et al.*, 1957). The total mass of air injected into the stratosphere over Tucson by 36 explosions will be very nearly 36 times that injected by one explosion, and this huge mass of

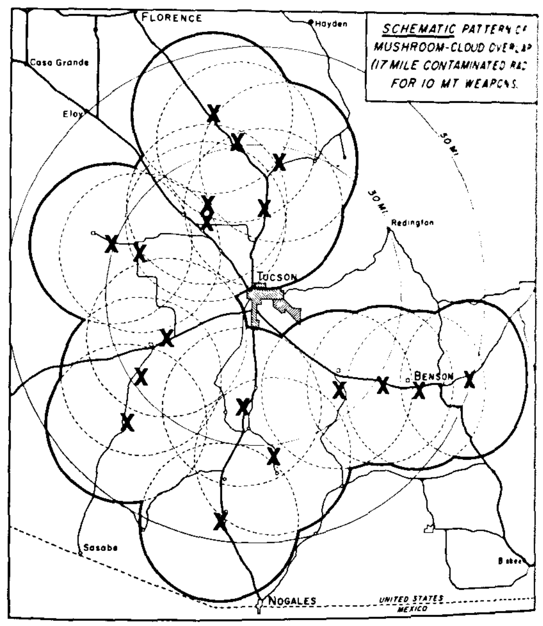



Figure 3.—Schematic overlap pattern.

air can only be accommodated by vertical or horizontal expansion of the composite mushroom cloud.

The great static stability of the base of the ozonosphere precludes appreciable vertical penetration beyond altitudes reached by an isolated 10 MT mushroom cloud. In addition, the mere fact that the pressure is so low there means that only a slight *mass* increment can be accommodated even by an appreciable rise of cloud-top altitude. For example, the pressure-thickness of the 55-105 kft layer occupied by an isolated 10 MT cloud is about 85 mb while that of the next 50 kft is only about 7 mb. Hence even a *doubling* of cloud thickness could accommodate a mere 7/85 or 8 percent mass increment per unit horizontal area of cloud, yet a doubling of thickness seems statically quite out of question. It appears that we may completely ignore thickness changes, whence we comput a *composite cloud radius* of about 150 miles, of which about 100 miles will be radioactively contaminated in the case of our hypothesized 360 MT attack (square-root scaling will hold). If an isolated cloud spreads out above the tropopause to 25 miles in about 10 minutes, the above expansion might be accomplished in a time of about an hour, although the writer does not yet see any firm basis for making any precise



estimate of this rate, and there are a num
interesting hydrodynamic questions pos
conception of the composite cloud that
considered here. We shall see that the gr
tal expansion just described markedly
Tucson fallout hazards.

DISTURBED AIRFLOW EFFECTS.
portant question which this section w
answer is another question peculiar to th
megatonnage that ICBM-base cities such
will face. Will the enormous total releas
so derange the local airflow that the la
essentially unrelated to pre-attack syn
tions? This proves to be an extremely
question from the standpoint of both
meteorology, but the very novelty of
precludes a really firm negative or affirm
at this time. Until quite recently it h
writer's conviction, as it has been that of
as Machta (U .S. Congress, 1959, p.
negative answer was to be given. How
made some progress in understanding se
tant details of the energy conversion
writer now leans toward the view that
first crucial hour or two after attack, fa
significantly affected by thermally induce
circulations in the lower troposphere.

Since the energy equivalent of one
TNT) is 4.2 × $10^{22}$ ergs, the total
is here 1.3 × $10^{25}$ ergs (equal to almos
of the kinetic energy of the entire gl
tion). Of this total, about 50 percent go
energy, about 35 percent into fireball
percent into residual nuclear radiation of
5 percent into the initial nuclear radia
during the first minute of the fireball's
Dept. of Defense, 1957). Of the last
nents, we may ignore the residual nuc
energy as being released too slowly t
meteorological concern (though of
human concern since it constitutes by
est killing agent of nuclear attack), but
of initial nuclear radiation may be con
degraded almost immediately to heat.

In an analysis which cannot be deta
will be published elsewhere, the write
ined the rate of conversion of blast ene
through the mechanism of non-isen
wave dissipation processes. The result
lish that substantially *all* of the blast
ever into thermal energy by the time th
has propagated out to where its peak
have fallen to below 1 psi. Figure 2 s
latter limit is reached at radial distar
miles from ground zero for weapons
required for attack on the Tucson site
heating is so related to peak overpressu
a pattern of quasi-hemispheric isothe
centered on the 36 impact points, with
heating decreasing radially outward

he fission products are intermixed with the air ped into the cloud through the stem and dis- ted radially by the vortical circulations in the d's interior (Kellogg *et al.*, 1957). The total of air injected into the stratosphere over Tucson 6 explosions will be very nearly 36 times that ted by one explosion, and this huge mass of

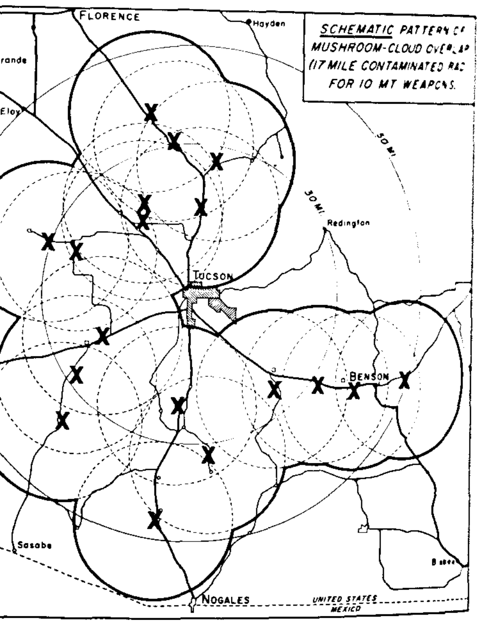



Figure 3.—Schematic overlap pattern.

n only be accommodated by vertical or hori- expansion of the composite mushroom cloud.

reat static stability of the base of the ozonos- precludes appreciable vertical penetration be- ltitudes reached by an isolated 10 MT mush- cloud. In addition, the mere fact that the e is so low there means that only a slight ncrement can be accommodated even by an able rise of cloud-top altitude. For example, essure-thickness of the 55-105 kft layer occu- y an isolated 10 MT cloud is about 85 mb that of the next 50 kft is only about 7 mb. even a *doubling* of cloud thickness could nodate a mere 7/85 or 8 percent mass incre- er unit horizontal area of cloud, yet a dou- f thickness seems statically quite out of ques- t appears that we may completely ignore ss changes, whence we comput a *composite adius* of about 150 miles, of which about 100 vill be radioactively contaminated in the case hypothesized 360 MT attack (square-root will hold). If an isolated cloud spreads out he tropopause to 25 miles in about 10 min- e above expansion might be accomplished in of about an hour, although the writer does see any firm basis for making any precise



estimate of this rate, and there are a number of other interesting hydrodynamic questions posed by this conception of the composite cloud that cannot be considered here. We shall see that the great horizontal expansion just described markedly influences Tucson fallout hazards.

DISTURBED AIRFLOW EFFECTS. — The important question which this section will seek to answer is another question peculiar to the ultra-high megatonnage that ICBM-base cities such as Tucson will face. Will the enormous total release of energy so derange the local airflow that the latter will be essentially unrelated to pre-attack synoptic conditions? This proves to be an extremely interesting question from the standpoint of both physics and meteorology, but the very novelty of the problem precludes a really firm negative or affirmative answer at this time. Until quite recently it has been the writer's conviction, as it has been that of others such as Machta (U .S. Congress, 1959, p. 127), that a negative answer was to be given. However, having made some progress in understanding several important details of the energy conversion process, the writer now leans toward the view that during the first crucial hour or two after attack, fallout may be significantly affected by thermally induced convergent circulations in the lower troposphere.

Since the energy equivalent of one megaton (of TNT) is $4.2 \times 10^{22}$ ergs, the total attack energy is here $1.3 \times 10^{25}$ ergs (equal to almost one percent of the kinetic energy of the entire global circulation). Of this total, about 50 percent goes into blast energy, about 35 percent into fireball radiation, 10 percent into residual nuclear radiation of fallout, and 5 percent into the initial nuclear radiation emitted during the first minute of the fireball's life (U. S. Dept. of Defense, 1957). Of the last two components, we may ignore the residual nuclear radiation energy as being released too slowly to be of any meteorological concern (though of the greatest human concern since it constitutes by far the greatest killing agent of nuclear attack), but the 5 percent of initial nuclear radiation may be considered to be degraded almost immediately to heat.

In an analysis which cannot be detailed here but will be published elsewhere, the writer has examined the rate of conversion of blast energy into heat through the mechanism of non-isentropic shock-wave dissipation processes. The result was to establish that substantially *all* of the blast energy goes over into thermal energy by the time the shock front has propagated out to where its peak overpressures have fallen to below 1 psi. Figure 2 shows that the latter limit is reached at radial distances of 15-20 miles from ground zero for weapons of the yield required for attack on the Tucson sites. The shock heating is so related to peak overpressure as to yield a pattern of quasi-hemispheric isothermal surfaces centered on the 36 impact points, with the degree of heating decreasing radially outward from ground zero. To indicate magnitudes, it may be noted that a 10 MT detonation will produce *residual* shock heating of about 80°C at two miles out from ground zero, while at four miles radius the heating is still over 8°C. The residual heating does not fall below 1°C until one goes out about nine miles from ground zero.

Turning to the disposition of the 35 per cent of weapon energy that goes into thermal radiation, we note that the composite absorption half-length for all wavelengths and stages of emission is put at about 10 miles in air of 10-mile visibility and 10 gm/m$^3$ absolute humidity (U. S. Dept. of Defense, 1957), so under typical Arizona conditions, we must expect absorption half-lengths substantially greater than 10 miles. Inasmuch as our concern in this section is with the total conversion to heat energy within some rather large cylinder concentric with Tucson and of radius of the order of at least 50-60 miles, it seems quite conservative and accurate enough for present purposes, to treat the effective mean optical path-length lying interior to our cylinder of interest as equal to about one absorption half-length, giving one-half absorption of the 35 percent of weapon energy emitted as thermal radiation.

In all, then, we have perhaps $0.50 + 0.17 + 0.05 = 0.72$, or about 70 *percent of the total weapon energy, or* $9 \times 10^{24}$ *ergs, converted into heat within a minute or two after the enemy salvo arrives.*

An inevitable secondary energy source of possible meteorological importance will be the scattered *fires* ignited by fireball radiations (cf. McDonald, 1959). Using the ignition threshold of coarse grasses and similar vegetation (15-20 cal/cm$^2$ for a multimegaton fireball) we find that each 10 MT fireball will ignite the surrounding vegetation out to about 10 miles from ground zero. Botanical data suggest that grass and shrub cover the desert floors in southern Arizona will not exceed about 500 lb/acre dry weight which, calculated as cellulose, gives a release of heat of combustion at the rate of about $8 \times 10^{8}$ erg/cm$^2$. Substantial portions of the Catalina Mountain forests will burst into flame from the fireballs at Site 18, those of the Santa Ritas will be ignited by Sites 6 and 7, and at least the southern flanks of the Rincons by Sites 4 and 5, with the Whetstones, Sierritas, and Tortolitas also ignited but only capable of smaller heat release because of thinner forests. Density of combustible material in the coniferous summits of the first three of these montane forests is perhaps 200,000 lb/acre (some 400 times greater than that of the desert floor). From rough planimetry, the total *ignitible* high forest area is found to be only about 2 per cent of the area comprised by eighteen 10-mile-radius circles concentric with the Titan sites (double irradiation by two 10 MT bursts at each site does not alter the fact that combustion can yield energy only once), but this still leaves the montane forests as the greater heat source in the ratio of about $0.02(400) = 8$. We find about $1.2 \times 10^{23}$ ergs from desert-floor fires and about $10^{24}$ ergs from montane forest fires. Comparing with the earlier estimate of direct heating of $9 \times 10^{24}$ ergs, we see that the fire-heating is only about 10 per cent as large. Thus fires cannot greatly add to the all-important *initial* circulations; but the very fact that the release of the combustion energy will extend over many hours tends to be disadvantageous to Tucson in that it will comprise a persistent even if weak heat source centered roughly on the city (when viewed from the large-scale convergence flows we are here concerned with) and hence aggravates the focussing of fallout effects on the Tucson area.

So far we have found that some $9 \times 10^{24}$ ergs of almost immediate heat energy will be put into the area roughly identical with that depicted in Figure 1, but not all of this will manifest itself as kinetic energy of organized motion. We next need some estimate of efficiency of this conversion process. It is known to be rather low under normal atmospheric conditions, roughly *1 to 10 per cent* (Miller, 1951). The writer finds that the classical Margules undercutting analysis (Haurwitz, 1941, p. 251) involves only about a *2 per cent* efficiency of conversion from initial *differences* of potential and internal energy into organized kinetic energy. Palmen and Riehl (1957) found about a *3 per cent* conversion from latent heat into kinetic energy in hurricanes. But reasoning broadly from Carnot's principle (viewing the process as that of a large heat engine), we sense that the abnormally large temperature differences between the heated air and the unheated air surrounding the ring of Titans must inevitably lead to higher Carnot efficiencies than those characteristic of typical meteorological systems. Hence we may take the upper limit suggested by Miller, *10 per cent*, as a likely value for our present case. This means that $9 \times 10^{23}$ ergs of organized kinetic energy may be expected to result from our 360 MT attack. The general nature of the resultant circulations seems clear: There will shortly develop a widespread convergent influx in the lower troposphere, with air moving radially inward from all sides toward the centroid of the heat sources, the city itself.

Will all this represent a discernible derangement of the natural airflow controlled by the pre-attack synoptic situation over southern Arizona? The question may be rephrased somewhat loosely, but in a form permitting quantitative evaluation, as follows: Will $9 \times 10^{23}$ ergs of organized kinetic energy be large or small compared to the pre-attack kinetic energy in a cylinder centered on Tucson and of radius great enough to represent the block of the atmosphere that will deliver fallout to the city? There are admittedly many uncertainties in even this simpler question. Weighing several factors, the writer feels one must take as the cylinder of concern one whose radius is at least 100 miles. This is not only the final radius of the composite stratospheric contaminated region but is also the order of magnitude of the radius from which influx might be expected to occur within the time of an hour or two at plausilbe speeds, and is, finally, also the radius from which a mass of air equal to the *total* mass of mushroom-cloud air could be drawn if the influx were confined to the lowest 10,000 ft of the atmosphere, and the latter seems to the writer to be a reasonable first guess. If, then, we consider a cylinder of 100 mile radius extending from ground to the top of the atmosphere and having the reasonable columnar-mean pre-attack wind speed of 15 m/sec, we find its total kinetic energy to be about $9 \times 10^{23}$ ergs, just the value of the estimated increment of kinetic energy itself. It is, of course, entirely by chance that these two energy estimates have come out identical, but what we seem to have found is that *the energy of the induced circulations are neither small nor large compared to the relevant pre-attack atmospheric kinetic energy.*

Hence we can neither ignore these induced convergent circulations nor base all of the Tucson fallout analysis on their effects, a finding that renders quantitative radiological estimates less certain, but which *qualitatively* implies that the fallout hazards will tend to be *more serious* than would be the case if this convergence were negligible. Because Tucson is so nearly centroidal to the 36 burst points there will be such a superposition of shock-heating and radiative heating contributions there that, notwithstanding the minimal displacement of about 20 miles to the ring of Titans, the city itself will almost certainly be the effective goal of the inflowing afterwinds during the hour or so in which those will still be blowing. If this influx is, as suggested above, limited to about the lowest 10,000 feet of the atmosphere, it will *not* eliminate all concern for pre-attack tropospheric wind patterns (and hence will not here eliminate all interest in fallout-wind climatology of the type to be discussed below), but will clearly bring in some additional stratospheric fallout to Tucson and, *far more important*, will tend to bring to the city a very significant additional amount of *stem fallout*. Stem fallout is important in the Tucson survival picture because it tends to consist chiefly of large, fast-falling particles that bring to ground the gamma emitters early in their decay lives and build the intense fallout fields which all published fallout calculations show as centered just downwind of ground zero (several stem diameters, according to the Rand studies, and hence just about the distance of Tucson from sites such as 8, 11, 13, 15, 18).

Before turning next to fallout climatology, we should carefully note that were the centroid of the Titan deployment pattern not Tucson itself but a point near, say, the Whetstone Mountains 10 to 15 miles south of Sites 3 and 4, thermally induced afterwinds would have acted in such a way as to *minimize* fallout on the city by enhancing blow-over (rather than blow-in). The Air Force's practice of deploying ICBM launchers roughly in a ring con-



centric with base cities (Tucson, Wic
Spokane, Topeka, etc.) makes for co
muting of operating personnel but se
when analyzed from a civil defense st

TUCSON FALLOUT CLIMATOL
the writer undertook a statistical stud
larly-reported fallout-wind computati
"UF reports") which the U. S. Weat
made twice daily at Tucson and at ab
U. S. cities in the past few years, he
to find no national agency compiling
even maintaining punchcard files of
able reports. Fortunately, the Tucson
Weather Bureau had an unofficial 1
years' data; the rest had to be extracte
film copies of original teletype shee
sample (Nov. 1, 1956 to Oct. 30, 19
1350 daily UF reports was finally ass
ple large enough to yield reasonabl
stability. Data for all five standard
levels, 10, 20, 40, 60, and 80 kft
tabulated in a variety of ways to
relevant to evaluating civil defense
ated with upwind ICBM siting.

Fallout drift directions. — In Figu
the four-year-mean azimuthal distrib
regard to drift *distance*, for the five
(the 10 and 20 kft UF data are n
garded as of almost no civil defe

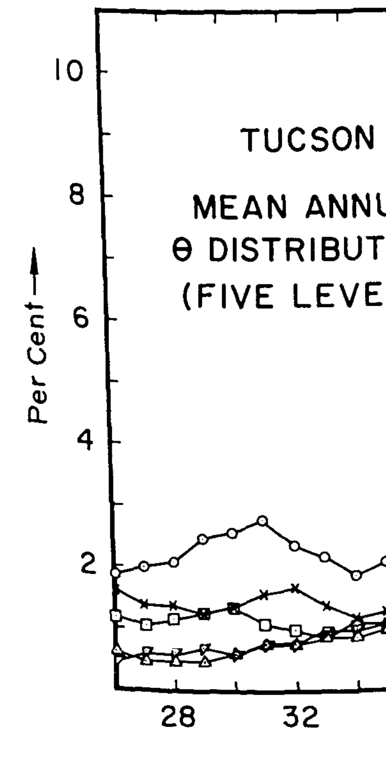



Figure 4

e of the radius from which influx might be ex-
ted to occur within the time of an hour or two
plausilbe speeds, and is. finally, also the radius
m which a mass of air equal to the *total* mass
mushroom-cloud air could be drawn if the influx
e confined to the lowest 10,000 ft of the atmos-
re, and the latter seems to the writer to be a
onable first guess. If, then, we consider a cylinder
100 mile radius extending from ground to the
of the atmosphere and having the reasonable
mnar-mean pre-attack wind speed of 15 m/sec,
find its total kinetic energy to be about 9 X 10
, just the value of the estimated increment of
tic energy itself. It is, of course, entirely by
ce that these two energy estimates have come
identical, but what we seem to have found is
*the energy of the induced circulations are neither*
*l nor large compared to the relevant pre-attack*
*spheric kinetic energy.*

ence we can neither ignore these induced con-
ent circulations nor base all of the Tucson fall-
analysis on their effects, a finding that renders
titative radiological estimates less certain, but
*qualitatively* implies that the fallout hazards
tend to be *more serious* than would be the case
s convergence were negligible. Because Tucson
nearly centroidal to the 36 burst points there
be such a superposition of shock-heating and
ive heating contributions there that, notwith-
ing the minimal displacement of about 20 miles
ring of Titans, the city itself will almost cer-
be the effective goal of the inflowing after-
during the hour or so in which those will
e blowing. If this influx is, as suggested above,
d to about the lowest 10,000 feet of the atmos-
it will *not* eliminate all concern for pre-attack
pheric wind patterns (and hence will not here
ate all interest in fallout-wind climatology of
pe to be discussed below), but will clearly
in some additional stratospheric fallout to
and, *far more important*, will tend to bring
city a very significant additional amount of
*allout.* Stem fallout is important in the Tucson
l picture because it tends to consist chiefly of
fast-falling particles that bring to ground the
emitters early in their decay lives and build
ense fallout fields which all published fallout
ions show as centered just downwind of
zero (several stem diameters, according to
nd studies, and hence just about the distance
on from sites such as 8, 11, 13, 15, 18).

re turning next to fallout climatology, we
carefully note that were the centroid of the
leployment pattern not Tucson itself but a
ear, say, the Whetstone Mountains 10 to 15
outh of Sites 3 and 4, thermally induced
ds would have acted in such a way as to
*e* fallout on the city by enhancing blow-over
than blow-in). The Air Force's practice of
g ICBM launchers roughly in a ring con-



centric with base cities (Tucson, Wichita, Lincoln, Spokane, Topeka, etc.) makes for convenient commuting of operating personnel but seems disastrous when analyzed from a civil defense standpoint.

TUCSON FALLOUT CLIMATOLOGY.—When the writer undertook a statistical study of the regularly-reported fallout-wind computations (so-called "UF reports") which the U. S. Weather Bureau has made twice daily at Tucson and at about fifty other U. S. cities in the past few years, he was dismayed to find no national agency compiling such data nor *even maintaining punchcard files* of these invaluable reports. Fortunately, the Tucson office of the Weather Bureau had an unofficial log for several years' data; the rest had to be extracted from microfilm copies of original teletype sheets. A four-year sample (Nov. 1, 1956 to Oct. 30, 1960) comprising 1350 daily UF reports was finally assembled, a sample large enough to yield reasonable climatological stability. Data for all five standard UF reporting levels, 10, 20, 40, 60, and 80 kft (kilofeet) were tabulated in a variety of ways to obtain statistics relevant to evaluating civil defense hazards associated with upwind ICBM siting.

Fallout drift directions. — In Figure 4 are shown the four-year-mean azimuthal distributions, without regard to drift *distance*, for the five levels of origin (the 10 and 20 kft UF data are now generally regarded as of almost no civil defense interest, because even in the stem, most of the available fission products begin their descent from the *upper* levels near 40 kft). The azimuth angle $\Theta$ indicates the compass point, in tens of degrees, *toward* which particles drift in descending to earth from the given level. Thus, $\Theta = 9$ means drift *towards* azimuth 90°, i.e., towards the east. Because almost all of the $\Theta$ distributions are roughly symmetric about the east point (influence of the prevailing "westerlies" aloft), the abscissa scale of Figures 4 and following have been centered at about $\Theta = 9$. The ordinate gives per cent of cases per ten degrees of $\Theta$, i.e., the sum of all 36 ordinates for any one curve is 100 per cent. To eliminate some of the small and climatologically meaningless irregularities in the curves, a 30° unweighted running mean frequency is what is actually plotted here and in subsequent figures, thus the ordinate at $\Theta = 9$ is really the mean of the raw frequencies at 8, 9, and 10.

Which of these five curves is of greatest importance in predicting Tucson's fallout hazards? To answer this, one must consider the vertical distribution of fission products in a mushroom cloud. The Rand model (Kellogg *et al.*, 1957) puts about 10 per cent in the stem, and the remaining 90 per cent is distributed with *constant mass-mixing-ratio* through the stratospheric cloud. The Rand curves show the latter as lying in the layer 50-75 kft for a 1 MT explosion, and in the 55-105 kft layer for a 10 MT

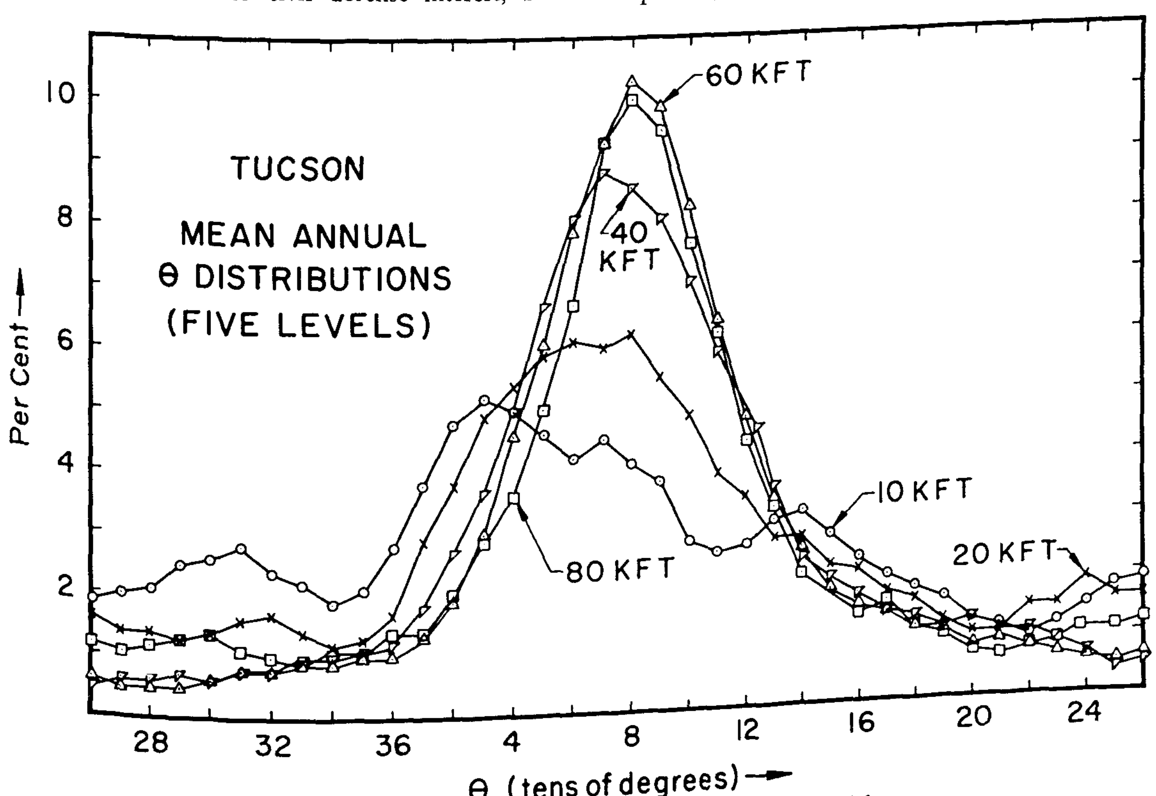



Figure 4.—Mean annual Tucson fallout drift directions for 60 kft.

explosion. Constancy of the mixing-ratio of air and fission products implies a rapid exponential decrease of contamination from base to top; hence even in the case of a 10 MT burst the center of gravity of the debris is found not much above the 60 kft level. The radiological importance of the lowest levels of the cloud is enhanced by the simple fact that times of descent will be minimal from the lowest layers and in-air decay of the activity will be that much less for particles originating near the cloud base. For these reasons, and because 10 MT bursts seem more probable than 1 MT bursts on grounds elaborated above, it follows that *the single level that is by far the best predictor of fallout drift patterns is the 60 kft level.* Figure 4 shows that the $\Theta$ distributions for 40, 60, and 80 kft are so similar that the 60 kft curve is itself a quite good predictor of 40 or 80 kft drift climatology, in any event.

To check this latter point more thoroughly the absolute value of $\Theta$ differences between concurrent reports for the 40-60 and the 60-80 kft intervals were computed and ranked. These are effectively "fallout wind shear" values. To disclose the seasonal dependence of such shears, January and February were lumped into one ranking while July and August formed a second array. For the 40-60 kft layer, the two winter months yielded a median shear of only 6°. (This and the other shears were obtained by interpolation between the ten-degree $\Theta$ values actually reported. That a median shear could come out as low as 6° results from the very high frequency of *zero* reported shear between the adjacent levels of origin.) Even at the 90th percentile, the 40-60 kft winter shear was only 14°. In summer (July-August) the median was again 6°, the 90th percentile 22° for this same layer. The 60-80 kft layer gave 2° and 7° as the median and 90th percentile winter shears, and 20° and 55° for the corresponding summer shears. These shears are all negligibly small, by civil defense prediction standards, except perhaps for the summer 60-80 kft shears. But even in the latter case a median shear of 20° still leaves the 60 kft UF data a quite good predictor, and it should be stressed that this is a peculiarity

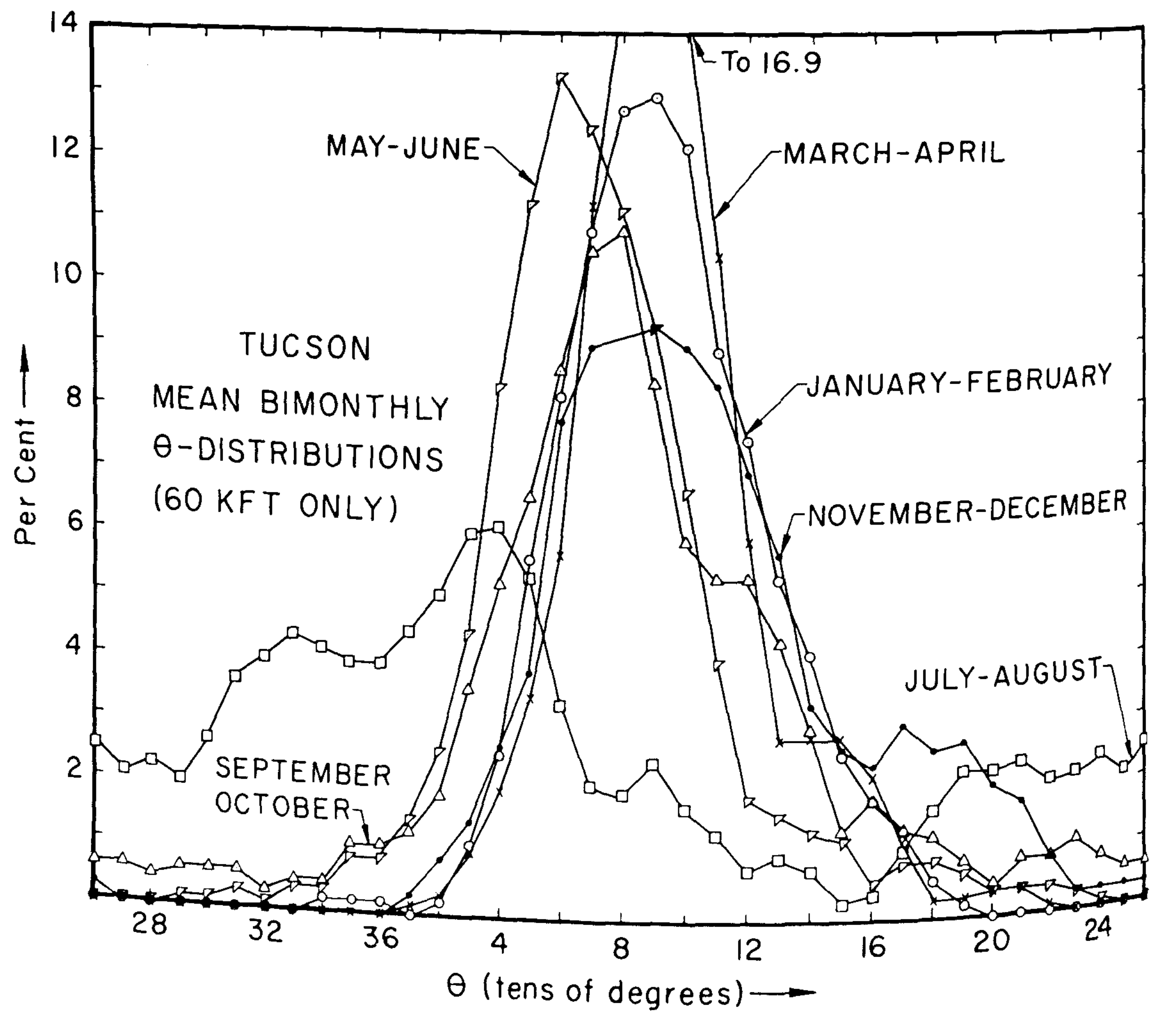
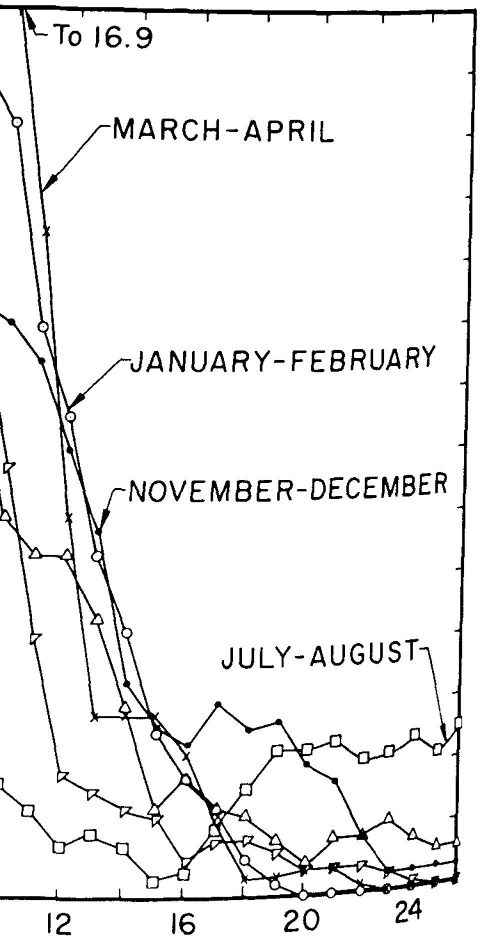



Figure 5.—Bimonthly 60 kft fallout directions.

llout wind shear" values. To disclose the sea-
al dependence of such shears, January and Feb-
ry were lumped into one ranking while July and
gust formed a second array. For the 40-60 kft
er, the two winter months yielded a median shear
only 6°. (This and the other shears were obtained
interpolation between the ten-degree Θ values
ually reported. That a median shear could come
as low as 6° results from the very high fre-
ncy of *zero* reported shear between the adjacent
els of origin.) Even at the 90th percentile, the
60 kft winter shear was only 14°. In summer
ly-August) the median was again 6°, the 90th
centile 22° for this same layer. The 60-80 kft
r gave 2° and 7° as the median and 90th per-
ile winter shears, and 20° and 55° for the cor-
onding summer shears. These shears are all
igibly small, by civil defense prediction stand-
, except perhaps for the summer 60-80 kft shears.
even in the latter case a median shear of 20°
leaves the 60 kft UF data a quite good predictor.
it should be stressed that this is a peculiarity




ıt directions.



of just the July-August rainy season and *not* a characteristic of the summer half-year, as will be clarified below. The conclusion is evident: *Use of only the 60 kft UF data will give very reliable over-all estimates of fallout climatology for civil defense purposes.*

To reveal the degree of *seasonal variation* in fallout drift directions, the 60 kft data were subdivided into six *bimonthly* groups and corresponding Θ distributions were recomputed for each. Figure 5 shows the results, the most important implication of which is this: With the exception of the two months of July and August, there is only very slight month-to-month change in the distribution curves. This point deserves emphasis because one of the most misleading statements made in defense of the projected siting pattern dealt with an alleged major summertime reversal of flow at high levels. This reversal is, to repeat, limited almost entirely to July and August and shifts the mode less than 90 degrees. Furthermore, the July-August shift is strongest not at 60 kft, the level of greatest fallout prediction value, but *at higher levels where it makes little difference*. Thus, in Figure 6 are shown just the July-August data, but for 40 and 80 kft as well as 60 kft, and from these it may be seen that the only really market monsoonal shift (to a Θ mode at 300 degrees) occurs at the 80 kft level. Even for 10 MT explosions, only a small fraction of the total effective ground-level gamma dosage is contributed by fallout originating at levels as high as 80 kft, and for the particular case of Tucson, blowover of virtually all 80 kft debris is assured despite upwind mushroom cloud expansion resulting from vortex interactions. Hence the suggestion that high-level summertime wind reversals nullify the advantage of restricting all sites to the east or southeast of Tucson was a quite serious distortion of the facts. Actually there is nothing meteorologically surprising about the result shown in Figures 4 and 5. That very severe danger of fallout would accompany construction of fixed-base ICBM launchers on the generally *west* side of any city should have been obvious to the Air Force from the start. Figures 4 and 5 merely document the meteorologically obvious.

Fallout drift distances. — In Figure 7 are displayed some results for the four-year distribution of fallout drift distances, D, as conventionally expressed in Weather Bureau practice, namely as distances (in miles) to which fallout originating at a given level would drift *if* it required exactly *three hours* to fall to the ground. Use of three hours is basically arbitrary, but it does vaguely indicate the distance out to which heavy fallout occurs. (For any given level of origin there is, of course, only a single particle radius for which the descent time happens to be three hours, this being 80 microns for 60 kft assuming a density of 2.5 g/cm³. However, all other particles originating from the same level will undergo a total drift directly proportional to these standard three-hour drifts, the factor of proportionality being the quotient of that particle's actual fall-time divided by three hours. Hence such D's are easily applied to *all* particle sizes.) The median and the 90th percentile values of D for the 60 kft level of origin are plotted as a function of Θ in Figure 7 in order to reveal the extent to which D depends on vector resultant wind direction in the 0-60 kft layer. A quite marked azimuthal dependency emerges; by far the greatest drifts occur under conditions when the flow is broadly toward the east. This is also the sector for which the directional frequencies are them-

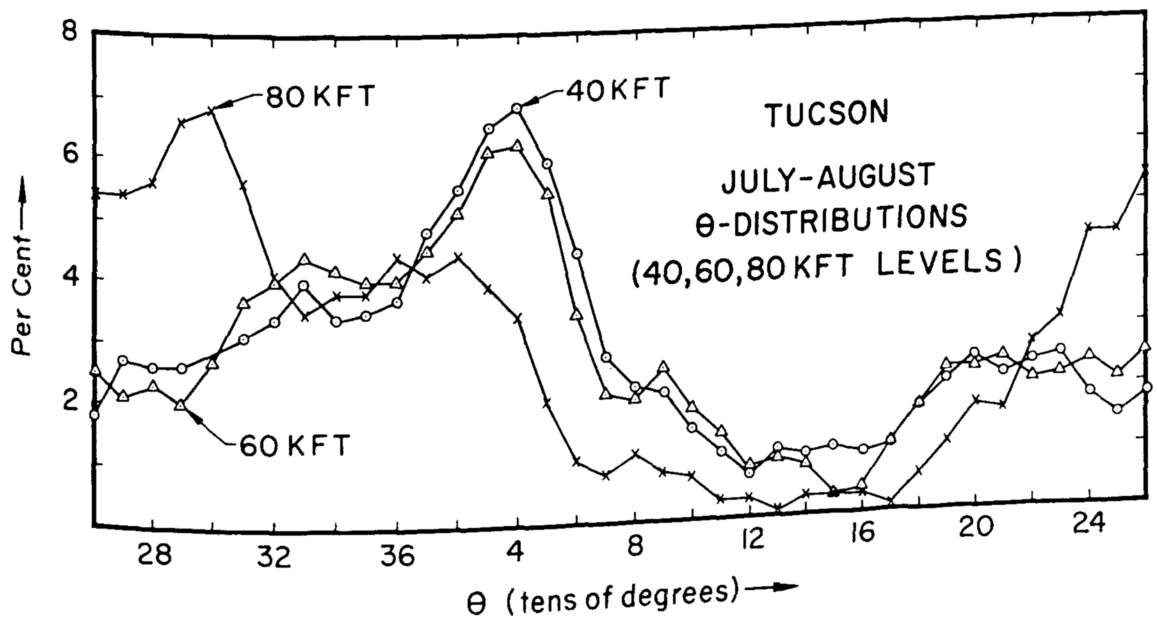



Figure 6.—July-August directions for three levels.

selves maximal, as shown by the dashed curve of Θ frequencies. (No 30-degree smoothing was applied to either the D or the Θ data plotted in this one figure. Thus, comparison of the Θ curve of Figure 7 with the 60 kft curve of Figure 4 will afford the reader a direct measure of the slight degree to which the smoothing used earlier alters the distributions.) We see that median D values of about 100 miles characterize the sector of peak directional frequency, while only about 10 per cent of all cases exhibit D's in excess of 200 miles for this same sector.

To show salient features of Tucson's D distributions for the other two UF levels of chief interest, 40 and 80 kft, as well as to show more detail for the 60 kft D's in just the sector of peak Θ frequency, Figure 8 was prepared. Here all cases for which Θ lay in the 90-degree sector centered on Θ = 90°, i.e., the sector from 45 to 135° azimuth, were lumped together, their D's ranked, and the cumulative percentages computed. This was done separately for each one of the three levels shown. There is not a very large difference between D's for the three levels, but the prevailingly light winds in the 60-80 kft layer do lower the 80 kft D's slightly below the values found for the 40 and 60 kft levels. Both the latter tend to be dominated by the jet-level maximum of the westerlies. The data of Figure 8 are very relevant for over all Tucson civil defense hazard assessments since the sector depicted in the figure embraces about two-thirds of all days out of the year (specifically, the 60 kft curve of Figure 8 represents a subsample of 912 observations out of the 1350 four-year total).

CIVIL DEFENSE HAZARDS. — On the basis of the principles and physical data summarized above, an attempt will now be made to predict the civil defense hazards that will have been created at Tucson if the Titan complex is carried to completion without any changes in the deployment pattern of Figure 1.

Blast hazards. — As has been pointed out above, the deployment pattern of Figure 1 does appear to rule out blast damage from enemy attack on the Titans as a significant civil defense hazard in Tucson. Even allowing for a ballistic error of three miles toward the side nearest Tucson at Site 15 (site closest to the city), a margin of 15 miles would exist between ground zero and the nearest edge of the city. Figure 2 shows that at 15 miles from a 10 MT surface burst the peak overpressure as the shock wave passes is only about 1.3 psi. On the other hand, considering all of the city, Figures 1 and 2 jointly show that 1.0 psi is a good measure of the *least* overpressure to be expected in any residential area when all sites are taken into account; so prediction of blast effects is limited to consideration of the narrow pressure range 1.0 - 1.3 psi. The 5 psi threshold for house collapse, cited earlier, implies that all Tucson houses will remain standing, but the

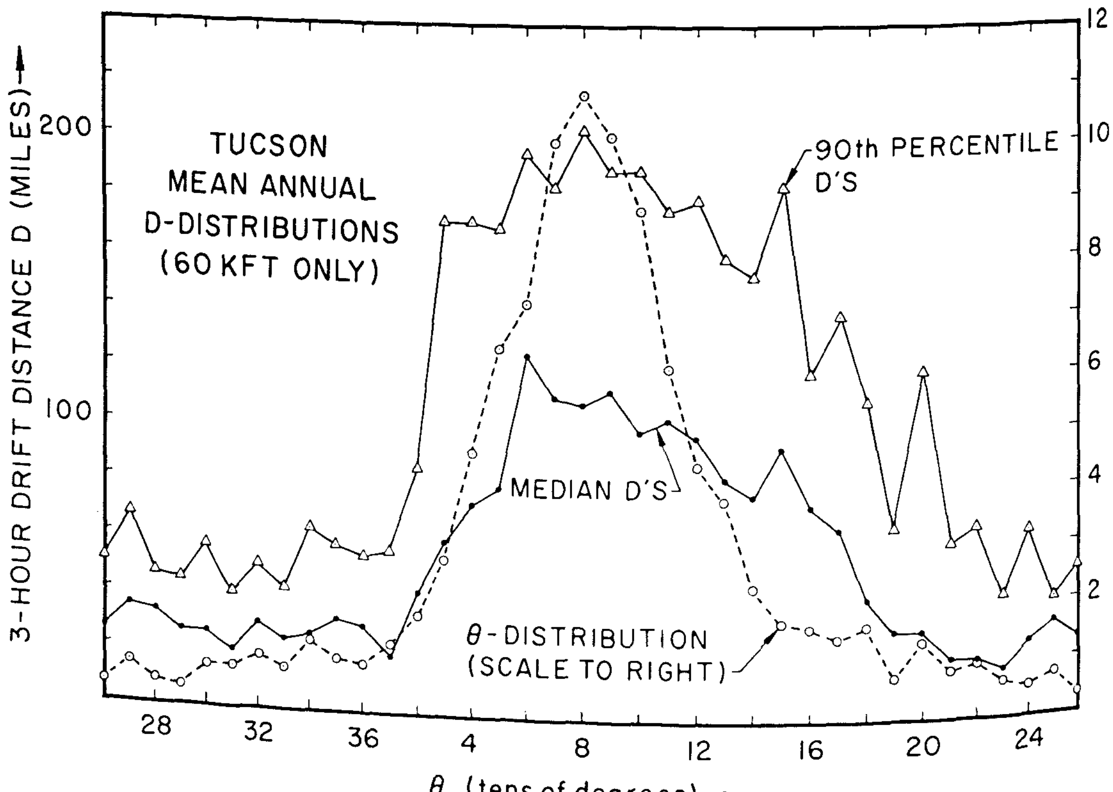
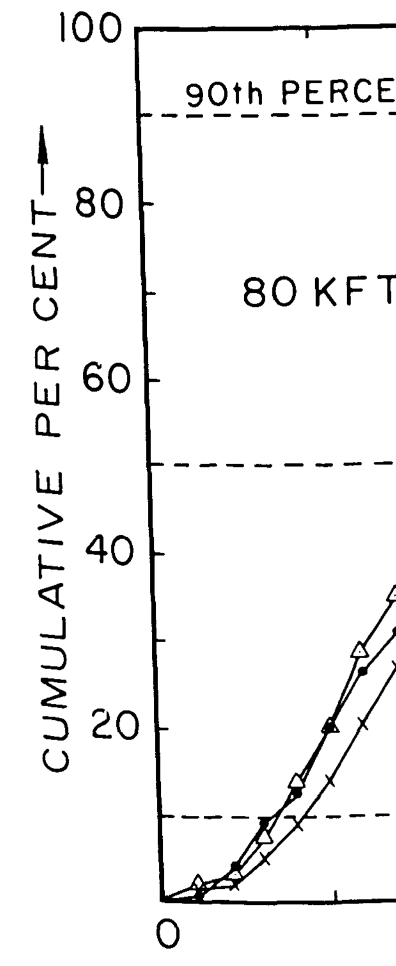



Figure 7.—Three-hour drift distance distribution data.



threshold for window breakage, 0.5 -
Dept. of Defense, 1957, p. 232) imp
all windows in all Tucson houses and
be blown in. The latter raises the q
sonnel injury from flying glass (a m
bodily injury in many blast situatic
studies by White (U. S. Congress, 1
provide prediction data thereon. V
acceleration of a 10 gm glass fragm
of 115 ft/sec in a distance of 10 ft
tration threshold, based on laborat
which glass missiles were fired into c
Collateral studies revealed that 2.2
is required to yield this acceleration
flying glass need not be expected
cause of injury in Tucson from attack
Similarly, White's data show that n
begin to be a source of injury only a
and direct bodily displacement, in w
himself becomes the missile, is qu
beyond about 2 psi. Finally, eardru

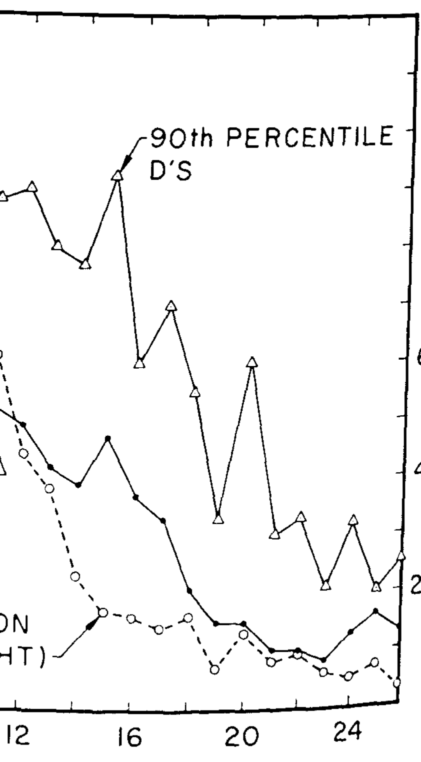



F

picted in the figure embraces about two-thirds of days out of the year (specifically, the 60 kft curve Figure 8 represents a subsample of 912 observa- ns out of the 1350 four-year total).

CIVIL DEFENSE HAZARDS. — On the basis of principles and physical data summarized above, attempt will now be made to predict the civil ense hazards that will have been created at Tucson he Titan complex is carried to completion without changes in the deployment pattern of Figure 1

Blast hazards. — As has been pointed out above, deployment pattern of Figure 1 does appear to out blast damage from enemy attack on the ins as a significant civil defense hazard in Tucson. n allowing for a ballistic error of three miles ard the side nearest Tucson at Site 15 (site est to the city), a margin of 15 miles would t between ground zero and the nearest edge of city. Figure 2 shows that at 15 miles from a MT surface burst the peak overpressure as the k wave passes is only about 1.3 psi. On the r hand, considering all of the city, Figures 1 2 jointly show that 1.0 psi is a good measure ne *least* overpressure to be expected in any resi- ial area when all sites are taken into account; rediction of blast effects is limited to considera- of the narrow pressure range 1.0 - 1.3 psi. The 5 hreshold for house collapse, cited earlier, implies all Tucson houses will remain standing, but the




istribution data.



threshold for window breakage, 0.5 - 1.0 psi (U. S. Dept. of Defense, 1957, p. 232) implies that nearly all windows in all Tucson houses and buildings will be blown in. The latter raises the question of personnel injury from flying glass (a major source of bodily injury in many blast situations). Extensive studies by White (U. S. Congress, 1959, 313-361) provide prediction data thereon. White proposes acceleration of a 10 gm glass fragment to a speed of 115 ft/sec in a distance of 10 ft as a body-penetration threshold, based on laboratory studies in which glass missiles were fired into dogs' abdomens. Collateral studies revealed that 2.2 psi overpressure is required to yield this acceleration criterion. Hence flying glass need not be expected to be a major cause of injury in Tucson from attack on the Titans. Similarly, White's data show that masonry missiles begin to be a source of injury only at about 2.1 psi; and direct bodily displacement, in which the person himself becomes the missile, is quite unimportant beyond about 2 psi. Finally, eardrums rupture only above 2.5 psi, whence this is also no problem. Mach interactions between shock waves intersecting over the city *might* bring some of the above effects into marginal importance; but, in general, blast effects are not of serious concern.

Thermal radiation hazards. — Thermal radiation effects from fireballs rising over the Titan sites will also be of only secondary importance, though more serious than blast effects. A 10 MT fireball at Site 15 will deliver about 12 cal/cm$^2$ to the *extreme northwest edge of the city*. This is above the ignition threshold of only a few combustible materials such as oily rags and crumpled newspapers, and hence cannot be expected to cause more than widely scattered small fires within Tucson itself. Tucson will of course be ringed with fires concentric with all of the Titan sites and extending out to perhaps 10 miles from each impact point, but it is well known that the desert vegetation in southern Arizona cannot "carry a fire," so there is probably little need to fear spread into the city itself from any of the 18 outlying

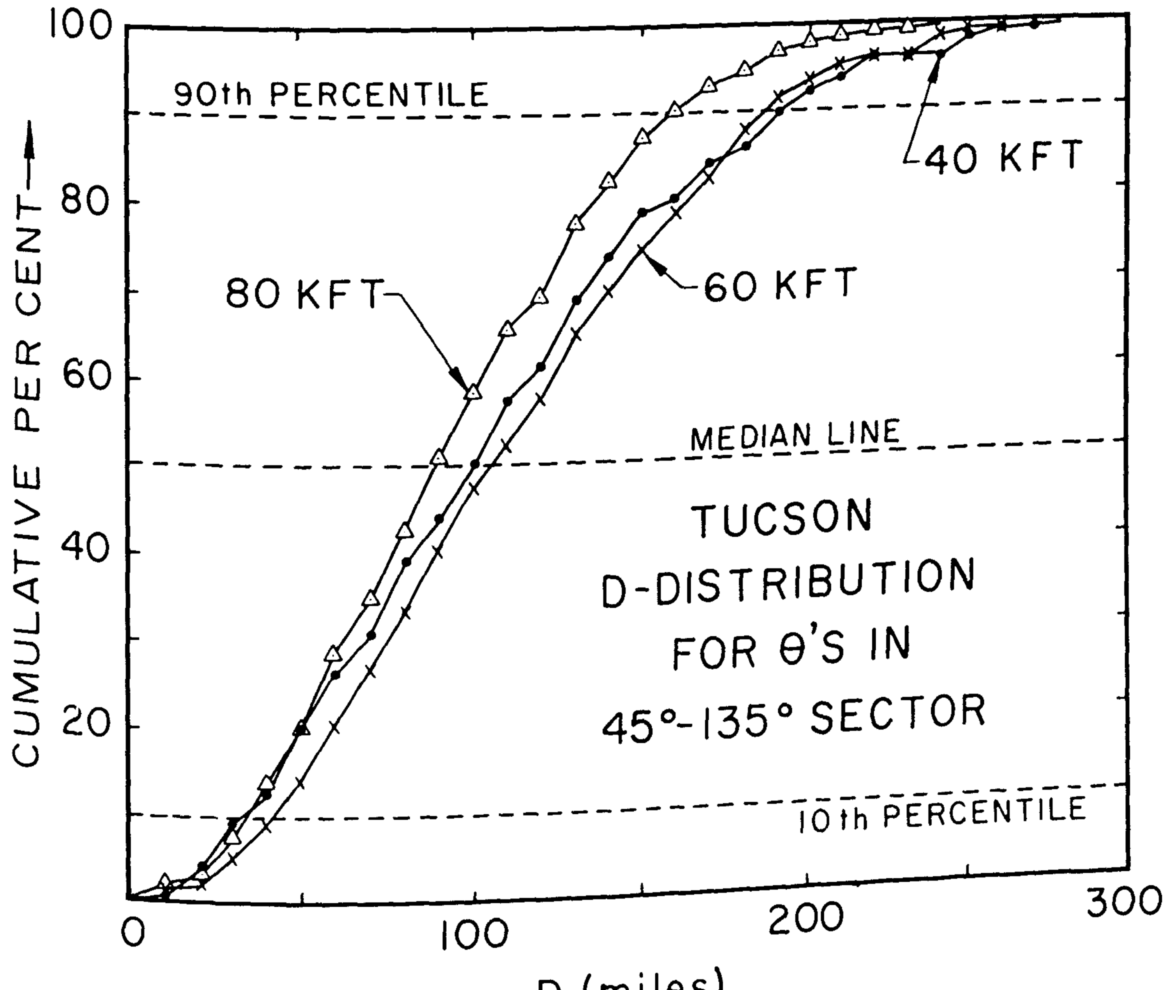



Figure 8.—Cumulative percentage distributions for D.

fire areas. (Presence of convergent afterwinds may aggravate the danger of fires invading the city, and this may warrant further study in the future; but the writer's present view is that even the minimal five miles of unignited desert vegetation between Site 15 and the northwest edge of the city would form an unbridgable gap for entry of fire.) Some fires might be caused by the additivity effects described below, but these will be confined to northwest Tucson only.

Thermal radiation from fireballs can also produce severe flash-burning of exposed human skin. One wonders if any hidden meaning inheres in the fact that the pig has proved most similar to man with respect to skin response to such flash effects and has become the preferred laboratory stand-in till man takes the stage. At any rate, 11 cal/cm$^2$ is the predicted threshold of third-degree human skin burns from multimegaton fireballs, so our question is that of whether the siting pattern implies irradiation in central Tucson above the 11 cal/cm$^2$ level. An *isolated* 10 MT fireball delivers only about 5-6 cal/cm$^2$ at a distance of about 20 miles from a *surface* burst, in standard air (just under second-degree limit of 7 cal/cm$^2$). Since 20 miles is representative of the minimal distance from the city to the nearest sites, it would appear that no severe flash-burning could occur in central Tucson itself; and this is what the Air Force has told Tucsonans. This conclusion, however, appears to overlook statistics of arrival-times of the missiles comprising an attack salvo, a point which will now be examined briefly.

If two detonations happen to occur sufficiently close together, both geographically and temporally, the radiation effects may become simply additive. The geographic restriction reflects the requirement that the rays from the two fireballs must strike roughly the same portion of the total surface of an object or exposed person to be additive in their effects. That a temporal restriction enters is due to the combined implications of first the fairly rapid rise and fall of fireball luminosity and second the thermal response characteristic of an object exposed to irradiation spread over a finite time interval. A 10 MT fireball reaches its peak emission intensity approximately 3 seconds after the instant of detonation, with 50 per cent of its total output achieved within the subsequent 4 seconds (i.e., by 7 seconds after detonation) and 80 per cent by 30 seconds after detonation. It seems a fairly realistic assumption to assert that if two nearby detonations take place within about *five seconds* of each other, their thermal pulses will produce peak heating in irradiated objects at times sufficiently close together that ignition or skin-burning effects may be estimated by simple *addition* of the two separate radiation loads. That is, we may assume, as a fair approximation to an actually quite complex process, that two nearby 10 MT surface bursts 20 miles from Tucson that happen to occur within 5 sec of each other will deliver about 10-12 cal/cm$^2$ on objects in central Tucson.

The probability distribution of missile arrival times will follow a Poisson law whose defining parameter (variance = mean) can be specified rather realistically for an attack on the Tucson Titans. The requirement, elaborated earlier, that all attack missiles be programmed to hit the Tucson area within a total time-span of about one minute is the governing factor. Inspection of Figure 1 suggests that additivity of irradiation might occur best from hits on Sites 13, 14, 15, and 18, since rays therefrom will strike Tucson objects from nearly the same direction. In the interests of conservatism, however, suppose we consider only *three* nearby sites, say, 14, 15, and 18 (or 13, 14, 15, though not *both* trios at one time, for that would be invalid). Such a trio of sites will, on our attack hypothesis, receive a total of six enemy missiles spread over about one minute, a mean arrival rate of one per 10 seconds, or if we use 5 seconds as the time-unit based on the additivity criterion given above, 0.5 per time-unit. We have 12 of these time-units to be randomly filled with events having a mean occurrence rate of 0.5 per time-unit; whence we find from appropriate computations based on the Poisson distribution (rounding off computed frequencies to nearest integral values) that we may anticipate *seven* of our 5-second time-units to contain *no* hits on our trio of targets, *four* of them to contain just one hit per time-unit, and *one* to contain two hits per time-unit. The last is our case of interest. It implies that we must, on probability grounds, reckon with at least one space-time coincidence of detonations such that Tucson objects will be irradiated from a northwesterly direction with an effective radiative load of 10-12 cal/cm$^2$. This is the third-degree-burn threshold, so it appears that the deployment pattern has not actually eliminated thermal radiation burns within the city, after all. To be sure, the above probability argument contains a number of simplifications designed to reduce a complex problem to a form in which some kind of quantitative estimate of burn hazards can be made, but the writer feels that it is probably based on a slightly conservative set of assumptions (not the least of which is the unusual clarity of the air over southern Arizona which implies lower attenuation than that assumed in the radiation reference here used (U. S. Dept. of Defense, 1957). The conclusion is that third-degree burns of all personnel exposed towards the northwest will constitute a part of the over-all civil-defense hazard created by the Titan deployment. Shall one term this a *serious* increase? No, for unpleasant as it seems, it is a minor difficulty when measured against the hazards of fallout to be considered below. But there remains one more odd fireball-hazard to be considered in the next paragraph.

In Tucson there will be extremely high probability of injury from another little-known radiative effect of nuclear attack — *retinal burns* in the eyes of persons who look toward the fireball. With an array of several dozen fireballs bursting into luminosity in

The probability distribution of missile arrival imes will follow a Poisson law whose defining parameter (variance = mean) can be specified rather ealistically for an attack on the Tucson Titans. The equirement, elaborated earlier, that all attack mis- les be programmed to hit the Tucson area within total time-span of about one minute is the govern- g factor. Inspection of Figure 1 suggests that dditivity of irradiation might occur best from hits n Sites 13, 14, 15, and 18, since rays therefrom will rike Tucson objects from nearly the same direc- on. In the interests of conservatism, however, sup- se we consider only *three* nearby sites, say. 14, 15, d 18 (or 13, 14, 15, though not *both* trios at one ne, for that would be invalid). Such a trio of es will, on our attack hypothesis, receive a total of enemy missiles spread over about one minute, a an arrival rate of one per 10 seconds, or if we 5 seconds as the time-unit based on the additivity erion given above, 0.5 per time-unit. We have of these time-units to be randomly filled with nts having a mean occurrence rate of 0.5 per e-unit; whence we find from appropriate computa- s based on the Poisson distribution (rounding off puted frequencies to nearest integral values) we may anticipate *seven* of our 5-second time- s to contain *no* hits on our trio of targets, *four* hem to contain just one hit per time-unit, and to contain two hits per time-unit. The last is our of interest. It implies that we must, on prob- y grounds, reckon with at least one space-time idence of detonations such that Tucson objects be irradiated from a northwesterly direction with fective radiative load of 10-12 cal/cm$^2$. This is hird-degree-burn threshold, so it appears that eployment pattern has not actually eliminated al radiation burns within the city, after all. To re, the above probability argument contains a er of simplifications designed to reduce a com- problem to a form in which some kind of tative estimate of burn hazards can be made. e writer feels that it is probably based on a y conservative set of assumptions (not the f which is the unusual clarity of the air over n Arizona which implies lower attenuation hat assumed in the radiation reference here U. S. Dept. of Defense, 1957). The conclu- that third-degree burns of all personnel ex- owards the northwest will constitute a part of r-all civil-defense hazard created by the Titan nent. Shall one term this a *serious* increase? unpleasant as it seems, it is a minor difficulty easured against the hazards of fallout to be ed below. But there remains one more odd hazard to be considered in the next paragraph.

cson there will be extremely high probability y from another little-known radiative effect ar attack — *retinal burns* in the eyes of per- o look toward the fireball. With an array of dozen fireballs bursting into luminosity in



quick succession all around the city, the chance that Tucsonans out of doors at moment of attack will glance towards at least one fireball seems very high. Tests performed with rabbits show that severe retinal lesions can be produced out to many tens of miles from ground zero (U. S. Congress, 1959, pp. 243-250). Although the human blink-reflex of 0.15 sec is slightly faster than the rabbit's 0.25 sec, the comparatively short optical paths from eye to fireball in the Tucson case insures widespread retinal damage. By a familiar optical principle, the *intensity* of irradiation of the retina is independent of distance if we ignore absorption and scattering. However, the *area* of irradiation varies inversely as the square of the eye-fireball distance. Even at 20 miles, a fireball need have a diameter of only 1500 ft to subtend an angle of 0.9° at the retina, the angular extent of the foveal region of clear central vision. But a 10 MT fireball attains a *maximum* diameter of about ten times that limit, so complete foveal blinding seems assured for any Tucsonan who should look toward any *one* of fifteen or twenty of the nearest fireballs.

Initial nuclear radiation hazard. — This hazard is completely negligible in view of the comparatively short absorption lengths for even the most energetic gamma radiations (order of a thousand feet). Thus, with the principal exception of the retinal lesion problem and the secondary exception of third-degree burns from additivity effects, it is essentially correct to say that the civil defense hazards of blast, thermal radiation, and initial nuclear radiation are not "seriously" increased by the Titan deployment. But the *fourth* main category of civil defense hazard, that of the radiological effects of local fallout, is an entirely different matter, to which we may next turn. Its seriousness makes all of the above, including retinal damage and skin-burning, pale into insignificance for the Tucsonan. (Indeed, the fallout hazards being *total*, one can only ask why the Titans were put far enough out of town to suppress the *secondary* hazards. Why, unless fallout was simply overlooked from the start of the ICBM siting program.)

Radiological hazards. — Figure 8 implies that with UF winds at the 90th percentile level, a radial drift distance of 75 miles could be covered in an hour. From data (McDonald, 1960) on velocities of fallout particles one finds that a one-hour descent time from 60 kft is associated with a particle radius of about 250 microns (density 2.5 g/cm$^3$). For median UF winds in the 0-60 kft layer, Figure 8 shows that this 75 miles of drift would require about 2.2 hours, which is the 60 kft fall-time for particles of radius 125 microns. Submedian UF winds will bring into play correspondingly smaller fallout particles, and hence a greater total fraction of the fission debris. These considerations bring us to the greatest single uncertainty in estimating the effects of local fallout from nuclear attack — the distribution of activity with respect to fallout particle size.

Even for the conditions pertaining to test detonations of nuclear weapons there is an evident lack of conclusive data on size distributions, but, still more pertinent there is the fact that there has never been a multimegaton surface burst on silicaceous (as distinguished from calcareous) terrain. Such data as exist have been summarized (Kellogg, Rapp, and Greenfield, 1957) in the form of two model distributions, the Rand and the NRDL (Naval Radiological Defense Laboratory) distributions. They differ somewhat: the NRDL curve shows a larger fraction of activity on the larger particles than does the Rand curve. All of the high-yield fallout data have been obtained from Pacific Bomb Test Range detonations where the calcareous atoll material blasted into the fireball formed almost all of the fallout particles. Now CaO condenses at a temperature of about 2850°C, while SiO condenses at about 2250°C; furthermore the temperature spread between melting and boiling points is about twice as great for SiO as for CaO. The writer feels that both circumstances should, on cloud physics principles, tend to produce relatively more large particles in a detonation over silicaceous continental soil than in a burst over a calcareous atoll, so it seems possible that even the NRDL distribution underestimates the importance of the large fallout particles. Hence the NRDL data will be regarded here as more likely to be correct for an attack on Tucson. It bears reemphasis, however, that this uncertainty as to the correct size-activity distribution curve is a major gap in our knowledge of what to expect from attack on our continental targets.

Both models cited put about 90 per cent of the total fission products onto large particles distributed through the mushroom cloud, the remaining 10 per cent going to the stem. In the mushroom itself, the NRDL distribution has about 10 per cent of all fission products on particles of radius in excess of 250 microns. Assuming weapons of 50 per cent fission, 50 per cent fusion yield, and spreading this over our disc of 75 mile radius gives an areal density of debris equivalent to 10 KT/mi$^2$ *in the cloud*. If we take the 10 per cent of this residing on particles of radius greater than 250 microns, and treat the latter as if all lay at 60 kft (some will be lower, some higher, but this simplification is not seriously in error because of the constancy of the mass mixing ratio), then we may think crudely in terms of a fallout field equivalent to 1 KT/mi$^2$ deposited as a circle of 75 mile radius, but centered just 75 miles *downwind* of Tucson, and arriving at the ground one hour after attack. By construction, the city will lie on the upwind edge of this field. Since we have used UF winds at the 90th percentile level, this is proposed as a good measure of the *minimum intensity field Tucson may expect from an attack on the Titans*. The winds might be lighter, bringing in additional fallout from smaller particles of the total distribution, the afterwind convergence will augment this to an extent that may be very high, the NRDL distribution may underestimate the relative importance of large particles in surface bursts over siliceous soils, and finally, the very serious contribution from *stem fallout* has yet to be allowed for. But even this minimum intensity will now be shown sufficient to lethally irradiate everyone in Tucson and vicinity in a matter of hours, assuming no citywide program of construction of radiation shelters.

In a variety of Congressional testimony over the past few years, Lapp has stressed that officially published data on gamma intensities from fallout are too low, his estimate being that they were too low by at least a factor of *two*. This point seems finally to have been clarified (U. S. Congress, 1960, Appendix VII), with the result that the corrections in the initial dosage rates are even *higher* than Lapp had suggested. In contrast to a 1-hour reference dose rate of 1260 r/hr per KT/mi² as previously published (U. S. Department of Defense, 1957), the now accepted value is 2750 r/hr per KT/mi². Lapp had conservatively used a figure of 2000 in his computations of fallout hazards summarized in the cited Congressional document. We may use Lapp's dosage results by increasing his dosages in the correction ratio 2750/2000, followed by adjustment for the number of kilotons per square mile (here one *versus* his two), giving an over-all correction factor of 0.69. In this way, we obtain as the integrated whole-body gamma dosage for an unsheltered person in our minimal 1 KT/mi² fallout field due just to the upper tail of the particle-distribution curve a value of *3500 r from the first to the fifth hour* after attack (the first hour being required to bring the particles in question down to the ground). The accepted median lethal human gamma dose is 450 r. Thus five hours after attack, and for the above minimal conditions, every unsheltered Tucsonan would have received *eight times the median lethal dose (and about six times the 100 per cent lethal dose of roughly 600 r)*. When, then, we make even qualitative allowance for the adverse effect of convergent afterwinds, stem fallout, and strong likelihood of winds well under the 90th percentile level we conclude that radiological death is a certainty for unsheltered Tucsonans if the Titans are ever attacked.

The further aggravation of the survival hazards resulting from *stem fallout* must be considered briefly. Published information as to stem sizes suggests radii ranging from 10 miles down to about 3 miles, so 5 miles will here be taken as reasonable. If about 10 per cent of all the fission debris is in such stems, centered on the targets shown in Figure 1, then the very large stem particle sizes involved will lay down a very intense additional gamma-emitting field in about the first hour that will be a further Tucson radiological hazard. Thermally-induced low-level convergence towards the city in the first hour or so after an attack would be especially effective in concentrating stem fallout on Tucson regardless of pre-attack winds, since there will be a relatively larger fraction of the total fall-distance strongly influenced by the convergence in the case of stem fallout from a mean altitude of perhaps 40 kft than in the case of stratospheric fallout from a mean altitude of about 60 kft, and also because most of the fall-time for stem fallout will overlap the initial period of significant convergence. If one assumed, as an unfortunately plausible model, the roughly 10 per cent of fission debris residing in each stem near just Sites 5, 8, 11, 13, 15, and 18 formed discoidal fallout fields that were swept into overlap with Tucson, we would have 10 per cent of $6 \times 2 \times 10$ MT $=$ 12 MT of total yield or 6 MT assuming weapons of only 50 per cent fusion yield. Each disc would have an area of 80 mi², and if Tucson received convergent overlap effects from all the stem discs the fallout field would have a density of 75 KT/mi² in the city. Even if one then said implausibly that such a model might be too high by a factor of as much as ten, the 1-hr dosage rate in the city would still be about 20,000 r/hr! The reader familiar with all the complexities of the fallout process will recognize that it is difficult to sharpen the above estimating scheme, but he will also recognize that unprecedented post-attack gamma dosage rates are certain to result from thermal convergence of the stem fallout from the ring of bursts surrounding Tucson and other ICBM-base cities that are being ringed with hard Atlas or Titan launchers.

The statistical implications of pre-attack UF winds are also extremely serious with respect to stem fallout: Using the four-year 40 kft data for Tucson and assuming a five-mile effective stem radius (and now *ignoring* thermal convergence), one finds a 26 per cent probability of stem fallout on Tucson from Site 11, and 18 per cent probability from Site 13, and 8 per cent for Site 15. The joint probability of 40 kft stem fallout from *one or another* of Sites 5, 8, 11, 13, 15, or 18 *totals 63 per cent*. It is of great interest to note that Site 5 contributes a mere 1.6 per cent to that 63 per cent, showing once again how much less hazard could have been imposed on Tucson if all Titans had been deployed east and southeast of the city. Indeed, on the basis of the 40 kft UF statistics, one finds that stems might be arrayed in the *entire quadrant* lying between directions east and south from Tucson with only a probability of 8 per cent that pre-attack winds could carry stem fallout onto the city. And, to repeat the important implications of thermal convergence, such a deployment pattern would have yielded the extremely favorable by-product of allowing thermal convergence to oppose even the low-probability winds from the southeasterly sector, thereby suppressing stem fallout to a danger level well under 8 per cent!

Prospects for shelter or evacuation. — On the basis of all of the above we infer a bare-minimum fallout field of density 1 KT/mi², and an indefinite maximum ranging into many tens of kilotons of fission debris per square mile. Let us assume 10 KT/mi² as the likely Tucson level (2 KT/mi² is commonly used



as the peak density for even ordina
official analyses). Using the recently
rate data cited earlier, and asking h
of time would have to elapse aft
personnel could move about above
*subsequently* accumulating a media
450 r in a time of the order of a
the answer to be about *three mon*
gence after three months would still
to almost exactly 450 r during th
(fourth post-attack month).

The long sheltering time req
residual radiological effects of the t
that would hit the Tucson area in
war has not been officially clarifie
*immediately* in fairness to the p
some of whom are using persona
fallout shelters on the publicized
weeks sheltering period will prom
an Air Force spokesman recently
blage of Tucson school officials t
keep the children in the inside
houses as a civil defense measure -
lem were on the time-scale of a sn
A mere two-week post-attack shelte
will not apply after completion o
It is unattractive enough to contem
stay underground, but a stay of tw
poses the most severe psychologic
tical problems.

Furthermore, formidable *econo*
in the way of construction of ade
if a federally-financed program we
With initial ground-level dosage
many thousands or even ten thous
per hour, survival will demand she
tors of no less than 1000. Even i
homes have basements, shelterin
cannot readily be accomplished by
tion of an enclave in the basement
than one per cent of Tucson hom
so mass shelters or the more expen
will have to be specially built.
defense studies (U. S. Congress,
even mass shelters cost about $20
family shelters run about twice t
shelter all 225,000 Tucsonans aga
hazards created by the Titan de
expected to cost $50-100 millio
even a bit greater cost than the
Titan base itself!

The USNRDL experimental m
Congress, 1960, 497-515) "is a b
arch structure, 25 ft wide by 48
that used by the Navy as an
magazine, that is furnished and
tain the life and basic health of
period of approximately 14 days.
sibility that such congestion migh
intolerable for two or three mo

ne total fall-distance strongly influenced by the ergence in the case of stem fallout from a mean ide of perhaps 40 kft than in the case of strato- ric fallout from a mean altitude of about 60 kft, also because most of the fall-time for stem fallout overlap the initial period of significant con- ence. If one assumed, as an unfortunately plausi- model, the roughly 10 per cent of fission debris ng in each stem near just Sites 5, 8, 11, 13, 15, 8 formed discoidal fallout fields that were swept overlap with Tucson, we would have 10 per cent $\times 2 \times 10$ MT = 12 MT of total yield or 6 MT ing weapons of only 50 per cent fusion yield. disc would have an area of 80 mi$^2$, and if n received convergent overlap effects from all em discs the fallout field would have a density KT/mi$^2$ in the city. Even if one then said usibly that such a model *might* be too high by or of as much as ten, the 1-hr dosage rate in y would still be about 20,000 r/hr! The reader ar with all the complexities of the fallout s will recognize that it is difficult to sharpen ove estimating scheme, but he will also recog- hat unprecedented post-attack gamma dosage re certain to result from thermal convergence stem fallout from the ring of bursts surround- cson and other ICBM-base cities that are being with hard Atlas or Titan launchers.

statistical implications of pre-attack UF winds o extremely serious with respect to stem fall- Jsing the four-year 40 kft data for Tucson and ng a five-mile effective stem radius (and now *g* thermal convergence), one finds a 26 per robability of stem fallout on Tucson from , and 18 per cent probability from Site 13. per cent for Site 15. The joint probability of stem fallout from *one or another* of Sites 5, 13, 15, or 18 *totals 63 per cent.* It is of great to note that Site 5 contributes a mere 1.6 per that 63 per cent, showing once again how ess hazard could have been imposed on Tucson Titans had been deployed east and southeast city. Indeed, on the basis of the 40 kft UF s, one finds that stems might be arrayed in *tire quadrant* lying between directions east uth from Tucson with only a probability of cent that pre-attack winds could carry stem onto the city. And, to repeat the important tions of thermal convergence, such a deploy- attern would have yielded the extremely le by-product of allowing thermal convergence se even the low-probability winds from the sterly sector, thereby suppressing stem fallout nger level well under 8 per cent!

*ects for shelter or evacuation.* — On the basis f the above we infer a bare-minimum fallout density 1 KT/mi$^2$, and an indefinite max- anging into many tens of kilotons of fission er square mile. Let us assume 10 KT/mi$^2$ as y Tucson level (2 KT/mi$^2$ is commonly used



as the peak density for even ordinary target areas in official analyses). Using the recently revised dosage-rate data cited earlier, and asking how long a period of time would have to elapse after attack before personnel could move about above-ground without *subsequently* accumulating a median-lethal dose of 450 r in a time of the order of a month, we find the answer to be about *three months*, since emergence after three months would still expose personnel to almost exactly 450 r during the ensuing month (fourth post-attack month).

The long sheltering time required to survive residual radiological effects of the tremendous attack that would hit the Tucson area in event of nuclear war has not been officially clarified, but should be *immediately* in fairness to the people of Tucson, some of whom are using personal funds to build fallout shelters on the publicized basis that a two-weeks sheltering period will promise survival. And an Air Force spokesman recently urged an assemblage of Tucson school officials to make plans to keep the children in the inside rooms of schoolhouses as a civil defense measure — as if the problem were on the time-scale of a snowed-in weekend. A mere two-week post-attack sheltering period simply will not apply after completion of the Titan base. It is unattractive enough to contemplate a two-weeks stay underground, but a stay of two or three months poses the most severe psychological and even logistical problems.

Furthermore, formidable *economic* barriers stand in the way of construction of adequate shelters even if a federally-financed program were offered Tucson. With initial ground-level dosage rates of the order many thousands or even ten thousands of roentgens per hour, survival will demand shelter protection factors of no less than 1000. Even in regions where all homes have basements, sheltering to that degree cannot readily be accomplished by low-cost construction of an enclave in the basement. Furthermore, less than one per cent of Tucson homes have basements, so mass shelters or the more expensive family shelters will have to be specially built. A variety of civil defense studies (U. S. Congress, 1960) show that even mass shelters cost about \$200 per capita, while family shelters run about twice that rate. Hence to shelter all 225,000 Tucsonans against the radiological hazards created by the Titan deployment must be expected to cost \$50-100 millions, the same as or even a bit greater cost than the direct cost of the Titan base itself!

The USNRDL experimental mass shelter (U. S. Congress, 1960, 497-515) "is a buried flexible-steel-arch structure, 25 ft wide by 48 ft long, similar to that used by the Navy as an ammunition storage magazine, that is furnished and equipped to maintain the life and basic health of 100 people for a period of approximately 14 days." Ignoring the possibility that such congestion might be psychologically intolerable for two or three months rather than 14 days, we see that it would take 2250 of these USNRDL-type shelters to counter the Titan hazards. On an average, there will be about 100 Tucsonans per two city blocks, so we must envisage a construction program that would bury one of these on every other block throughout Tucson. (One would have only about a half-hour to take shelter, so they must be widely distributed, of course.) Unless one sees prospect of Tucsonans themselves subscribing some \$50 millions for this means of countering the new civil defense burdens that are being placed upon them, it becomes a question of whether federal expenditure on that scale can be anticipated to make adjustment for a weapons deployment program that has thus far appeared to be unjustifiable. The entire history of civil defense efforts makes the latter solution seem only remotely possible, unfortunately.

Nor is immediate post-attack evacuation an available alternative. Overlooking the well-known difficulties inherent in orderly evacuation of even a few thousands of people, we need only examine Figure 1 to find a reason why *no one* will be able to leave Tucson after attack is over. Most of the Titan sites are within about 1000-2000 ft from the major highways on which most of the eighteen have been located. Crater radius for a 10 MT surface burst is almost 1500 ft, and the intensely contaminated lip formed by throwout from the crater extends about the same distance beyond the crater itself. Additional driftout and stem fallout will form an intolerably contaminated halo still further out around each site, the over-all implication of all these effects being *to block every highway joining Tucson with other nearby communities.* There are, for local mountain topography reasons, only *five* such highways, and Titan sites are to be put near every one. Note particularly how Site 5 precludes escape via the Sonoita road (State 83), how Site 11 rules out escape to Ajo by way of State 86, and Sites 1 and 18 block escape via Hayden. In several of these cases, merely shifting the site a few miles could have left a route open. Site 15 might seem far enough from the Casa Grande Highway (State 84) to leave that road uncut, but even that highway is almost certain to be so debris-strewn as to preclude escape at a rate fast enough to avoid lethal irradiation of any would-be evacuators attempting that route. Even afoot or on horseback, one could not get out from under the fallout fast enough to survive, even if fires happened to leave any such routes open between sites. Briefly, *no one will escape, and no one will survive* — unless an unparalleled and very costly program of construction of underground radiation shelters is undertaken in Tucson immediately.

CONCLUSIONS. — A far simpler, far less costly, far more sensible solution seems to be this: Abandon all upwind sites, relocating the entire complex well to the southeast of Tucson, where these terrible hazards will not confront Tucson's 225,000 inhabitants. There is space available to the east and southeast of the city, and contrary to the impression that the Air Force has sought to leave in the minds of Tucsonans, no technically supported arguments have yet been advanced to show that such a shift is out of question. Consider the following points:

(1) "Stray missiles" do not at all eliminate the advantages of easterly (downwind) siting, as shown above.

(2) Davis-Monthan AFB is, because of remarkable recent improvements in missile accuracies, rapidly becoming a very low megatonnage target. Furthermore, phase-out of the B-47 program is now imminent. Even if it became a B-52 dispersal base its megatonnage rating would remain low enough that it would not insure total extinction for all Tucsonans as do the Titan sites in event of attack. And even the B-52 is due for phase-out in the middle or late 1960's whereas the Atlas-Titan sites have been repeatedly ascribed operational lifetimes of 10-15 years in Congressional testimony.

(3) One local Air Force spokesman, replying to the suggestion that a number of launchers could be put in the sparsely populated San Pedro River valley, insisted that the water table was too high there, while a Washington, D. C., Air Force spokesman said the water table was too low there. Data on well-depths discount both claims. When challenged on the latter grounds the local Air Force spokesman switched to the claim that the mountains rise too abruptly along the San Pedro to permit site-construction there — a most curious argument in the view of anyone familiar with the area in question.

(4) Tucson was described, utterly erroneously, as being in just as much radiological danger from fallout drifting over from attack on the Los Angeles area as from Titan-assault fallout. Even after this writer communicated to the Air Force data clearly showing the meteorological and radiological absurdity of the claim, the argument was officially repeated and accordingly publicized in the Tucson press.

(5) Lack of any deaths from fallout in Hiroshima and Nagasaki was offered by way of allaying fears of fallout hazards, a true statement which perhaps not one in a thousand laymen would recognize as the patently deceptive argument that it is.

(6) Again, the meteorologically correct statement that easterly flow occurs during about five months out of the year from 65 to 90 kft was cited and was probably accepted by most televiewers as nullifying any plea for downwind siting, yet is quite irrelevant, as shown above.

(7) Assurances emanated from several Air Force offices to the effect that locating all Titan sites at least 20 miles away from the city removed all danger from "blast, thermal radiation, and initial nuclear radiation," another true (or nearly true) statement which the average citizen is scientifically incapable of detecting as utterly specious in that it lists only the first three and least serious of the *four* principal killing agents of nuclear war — casually omitting the real decimator, local fallout.

(8) One member of the Arizona Congressional delegation passed on via television this "justification" he had personally received from the Air Force: A "brain center" for the whole Titan complex was going to be put at Davis-Monthan AFB and an attacker would then surely hit the "brain center" with at least 10 MT, wiping out so much of Tucson as to render siting arguments unimportant. *If* many tens of millions of dollars are being spent to deploy 18 targets so widely that no one enemy missile can wipe out any two sites, whereas a hit on some communications post at Davis-Monthan could neutralize the whole Titan complex, the entire project is nonsensical.

(9) Another member of the Arizona Congressional delegation never approached any closer to the awesome issues at stake than to give repeated assurances that the Titans were to be put in strongly-built underground emplacements such that there will be no significant chance that they might accidentally explode and injure anyone in Tucson.

(10) Perhaps most pernicious of all arguments against downwind siting was that based on an idea which has been built up in the minds of not only Tucsonans but also in the minds of all too many other Americans in recent years, namely the idea that if nuclear war should come "no one will survive." Of course, if it were true that no one could survive, all we could hope to do in a purely military way is to put more and more national resources into retaliatory machinery to try to forestall that awful event; and in so doing we need not worry about the side of a city on which we emplace our Atlas or our Titan missiles. This "all or none" viewpoint has been most cogently rebutted in recent years by Herman Kahn, and yet involves so seemingly callous a toting-up of "merely" many tens of millions of deaths that it is not accepted by the public, whence arises a most peculiar and subtle danger. This is not the place to analyze the dread balance-sheets of nuclear attack, but it is the place to assert that no technically supported case has ever yet been offered by the Air Force to show that even with entirely downwind Titan sites all Tucson is doomed in event of World War III.

The list of "justifications" for ignoring downwind siting could be extended. The above should suffice to suggest that in the very profusion of specious or simply erroneous "justifications" that have appeared from a variety of official sources one sees grounds for suspecting that there must not be any real justification for insisting on the extremely hazardous Titan deployment pattern of Figure 1.

In all, the preceding analysis is offered as an



attempt to assess quantitatively th
implications of the deployment that
in final form in July, 1960 and tha
November, 1960. If it contains subs
hazard-prediction, the writer earne

GITTINGS, H., 1960. Mobility adds to
Missiles and Rockets, 7, No. 12:26-

HAURWITZ, B., 1941. Dynamic meteor
McGraw-Hill, 365 pp.

KELLOGG, W. W., R. R. RAPP, and S
1957. Close-in fallout. J. Meteor.

McDONALD, J. E., 1959. An analysis c
attacks on Tucson and Phoenix.
1:41-52.

———, 1960. Rates of descent of fa
thermonuclear explosions. J. Meteo

MILLER, J. E., 1951. Energy equations.
Meteorology. Boston, Am. Meteor.

ich the average citizen is scientifically incapable of
ecting as utterly specious in that it lists only the
three and least serious of the *four* principal kill-
agents of nuclear war — casually omitting the
decimator, local fallout.

8) One member of the Arizona Congressional
gation passed on via television this "justification"
had personally received from the Air Force: A
in center" for the whole Titan complex was
g to be put at Davis-Monthan AFB and an
ker would then surely hit the "brain center"
at least 10 MT, wiping out so much of Tucson
render siting arguments unimportant. *If* many
of millions of dollars are being spent to deploy
argets so widely that no one enemy missile can
out any two sites, whereas a hit on some com-
ications post at Davis-Monthan could neutralize
whole Titan complex, the entire project is
ensical.

) Another member of the Arizona Congres-
l delegation never approached any closer to the
ome issues at stake than to give repeated assur-
that the Titans were to be put in strongly-
underground emplacements such that there will
significant chance that they might accidentally
de and injure anyone in Tucson.

)) Perhaps most pernicious of all arguments
st downwind siting was that based on an idea
has been built up in the minds of not only
nans but also in the minds of all too many
Americans in recent years, namely the idea that
clear war should come "no one will survive."
urse, if it were true that no one could survive,
could hope to do in a purely military way is
more and more national resources into retalia-
achinery to try to forestall that awful event;
so doing we need not worry about the side of
on which we emplace our Atlas or our Titan
s. This "all or none" viewpoint has been most
y rebutted in recent years by Herman Kahn,
t involves so seemingly callous a toting-up of
y" many tens of millions of deaths that it is
cepted by the public, whence arises a most
r and subtle danger. This is not the place to
the dread balance-sheets of nuclear attack,
s the place to assert that no technically sup-
case has ever yet been offered by the Air
o show that even with entirely downwind
ites all Tucson is doomed in event of World
I.

ist of "justifications" for ignoring downwind
ould be extended. The above should suffice to
that in the very profusion of specious or
erroneous "justifications" that have appeared
variety of official sources one sees grounds
ecting that there must not be any real justi-
for insisting on the extremely hazardous
eployment pattern of Figure 1.

l, the preceding analysis is offered as an



attempt to assess quantitatively the civil defense implications of the deployment that was announced in final form in July, 1960 and that was begun in November, 1960. If it contains substantial errors of hazard-prediction, the writer earnestly hopes that official rebuttal will be made quickly and *in the fullest scientific detail.* Failure to do so must be interpreted as inability to do so, for accurate public information on these coming hazards is the least the authorities now owe the Tucson citizen.

## LITERATURE CITED

GITTINGS, H., 1960. Mobility adds to support problems. Missiles and Rockets, 7, No. 12:26-28.

HAURWITZ, B., 1941. Dynamic meteorology. New York, McGraw-Hill, 365 pp.

KELLOGG, W. W., R. R. RAPP, and S. M. GGEENFIELD, 1957. Close-in fallout. J. Meteor. 14:1-8.

McDONALD, J. E., 1959. An analysis of effects of nuclear attacks on Tucson and Phoenix. J. Ariz. Acad. Sci. 1:41-52.

———, 1960. Rates of descent of fallout particles from thermonuclear explosions. J. Meteor. 17:380-381.

MILLER, J. E., 1951. Energy equations. In Compendium of Meteorology. Boston, Am. Meteor. Soc., 1334 pp.

MORSE, P. M., and G. E. KIMBALL, 1954. Methods of operational research. New York, Wiley, 158 pp.

PALMEN, E. and H. RIEHL, 1957. Budget of angular momentum and energy in typical cyclones. J. Meteor. 14:150-159.

U. S. DEPT. OF DEFENSE, 1957. Effects of nuclear weapons. Washington, U. S. Govt. Print. Off., 579 pp.

U. S. CONGRESS, 1959. Biological and environmental effects of nuclear war. Hearings before the Special Subcomm. on Radiation, Joint Comm. At. Energy, 86th Congress, 1st session, Washington, U. S. Govt. Print. Off., 966 pp.

U. S. CONGRESS, 1960. Civil defense. Hearings before a Subcomm. of the Comm. on Govt. Operations, House of Rep., 86th Congress, 2d session, Washington, U. S. Govt. Print. Off., 573 pp.