RESPONSE TO DCPA QUESTIONS ON FALLOUT

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Prepared by Subcommittee on Fallout
Advisory Committee on Civil Defense
National Academy of Sciences
with Notes and Comments by J.C.Greene, DCPA

PREFACE

The May 1973 report of the Advisory Committee on Civil Defense of the National Academy of Sciences (ACCD/NAS), which discusses various aspects of the fallout hazard, is considered to be of sufficient importance to warrant further distribution. For this reason, and with the ACCD/NAS concurrence, this report is herein reissued in the format of a DCPA Research Report. There is a further advantage in that an opportunity is provided for the addition of notes and comments to help define the implications of the report.

These notes and comments by Jack C. Greene of DCPA, listed by chapter, appear as Part II of this Research Report. Part I is the ACCD Subcommittee document in its original form.

SOME ASPECTS OF FALLOUT OF CONCERN TO CIVIL DEFENSE

May 1973

Subcommittee on Fallout
Advisory Committee on Civil Defense

NATIONAL ACADEMY OF SCIENCES

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A report of the ad hoc Subcommittee on Fallout
Advisory Committee on Civil Defense

NOTICE

The work of the Advisory Committee on Civil Defense is approved by the Governing Board of the National Research Council, acting in behalf of the National Academy of Sciences. Such approval reflects the Board's judgment that the work of the Committee is of national importance and appropriate with respect to both the purposes and resources of the National Research Council.

The members of the Subcommittee selected to prepare this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. Responsibility for the detailed aspects of this report rests with the Advisory Committee on Civil Defense.

Each report issuing from a committee of the National Research Council is reviewed by an independent group of qualified individuals according to procedures established and monitored by the Report Review Committee of the National Academy of Sciences. Distribution of the report is approved, by the President of the Academy, upon satisfactory completion of the review process.

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CHAPTER 1

THE PORTION OF ACTIVITY DEPOSITED IN LOCAL FALLOUT

A typical deterministic fallout-prediction system is based upon a forecast of climatological winds and a postulated (or calculated) initial distribution of radioactivity on particles of various sizes located at various positions within a radioactive cloud.[1] The amount and kinds of radioactivity postulated depend on the yield of the nuclear explosion, its fission-fusion ratio, the type of fissionable material used, and the kinds of induced activities produced. The height and other dimensions of the cloud depend on the yield and on ambient atmospheric conditions, particularly on the variation of temperature and relative humidity above the ground. During their fall the radioactive particles move laterally under the influence of the wind field. If the above factors are properly accounted for, one can predict levels of deposition of radioactivity on the ground, from which radiation exposure rates can be derived. DCPA and hence this paper is concerned primarily with surface and near-surface bursts. Possibly important perturbations, which will be taken up later, are small changes in the height of burst (Chapter 2), the chemical and physical properties of the soil or other substrate over which the explosion takes place (Chapter 3), and the influence of adjacent, nearly simultaneous bursts (Chapter 8).

A central problem in fallout prediction is that of relating radiation exposure rates at various locations to the yield of the detonation that produced the fallout. Sophisticated models can, at least in principle, rigorously compute this relation nuclide by nuclide for each point on the ground, subject to the accuracy of the fission-product data base, the assumed relation between radioactivity and particle size, and available wind and weather information. Simpler models, however, predict only the gross deposition of mixed-fission products. Any model implies, and one of the models used by DCPA explicitly uses, an empirical factor called the K-factor* to relate deposition to radiation intensity. In the literature, this term has referred to at least two different but related things: (1) the ratio of exposure rate measured at a particular place in the fallout field to the density of deposition of radioactivity there; and (2) an integrated, weighted average of this ratio over the "local" fallout field. The confusion caused by the various uses of the concept has been well reviewed by Rapp[2] and Cane.[3] The customary unit for K-factors is R/hr per kt/mi^2 at H + 1 hour. Since this is a rather unwieldy unit, we shall not repeat it hereafter.

An idealized limit of the K-factor corresponds to unfractionated fission products uniformly spread over a smooth ideal plane, and measured with an ideal detector 3 feet above the plane. This limit, here called K_o, varies depending on what particular fission process is being considered. According to Tompkins,[4] K_o = 3067 for U-235 fissioned by

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*Also called the Normalization Factor, the Magic Number, and the Exposure Rate Conversion Factor.

Some Aspects of Fallout of Concern to Civil Defense

In October 1971, the Research Directorate of the Office of Civil Defense, now the Defense Civil Preparedness Agency (DCPA), posed questions on eight aspects of fallout of interest to civil defense. They were sent to the Fallout Subcommittee of the Advisory Committee on Civil Defense in the form given in Appendix A. These topics encompass problems of the basic constraints used in fallout prediction, various perturbations on the standard surface-burst problem, the direct detection of heavy fallout without instruments, and the feasibility of extrapolating predictions on an operational basis. The Subcommittee itself and working groups of the Subcommittee have attempted to answer questions on these topics, several of which were rephrased in interaction and by agreement with DCPA representatives. The results of these deliberations are the subject matter of this report.

May 1973

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Melvin L. Merritt (Chairman)
Eric T. Clarke
Frank D. Cluff
Robert E. Heft
Carl F. Miller
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neutrons with a fission spectrum, and for Pu-239, similarly fissioned, $K_o = 2692$. From these and other values determined in the same manner, we conclude that 2900 is a good estimate of K_o for most applications.

The detonation products are not, of course, deposited uniformly. The ratio of exposure rate to deposition density has been observed to vary from point to point within the fallout field,[5] tending to increase with increasing distance downwind from ground zero. This observation is consistent with the concensus that radiochemical fractionation causes this ratio to decrease with increasing particle size.[6] This problem has been customarily circumvented by using what amounts to an average of this ratio over the region of "local" fallout, where "local" was defined at the convenience of the author. This local averaged K-factor we call K_1. Since local fallout (however defined) represents deposition of only a fraction of the total radioactivity produced by the detonation that produced the fallout, the ratio K_1/K_o has been referred to as the fraction of the activity deposited in the local fallout, or simply "fraction down." However, DCPA wants K_1, as well as the ratio.

Two additional factors degrade the apparent value of the K-factor. Shielding by small-scale irregularities of terrain leads to a reduction in K_1 of about 25% and measuring instruments used in the past have had built-in self-shielding factors that led to another reduction of about 25%. So-called measured values of the K-factor in the literature are nearly always this doubly degraded K-factor, here called K_2.

The numerical value of K_1 or K_2 depends on the definition of local fallout. Three definitions have been used: (1) all deposition out to the distance traveled by particles of a given size, say 45μ, which fall from the top of the nuclear cloud, (2) fallout deposited up to a given time, say H + 24 hours, and (3) the region within a given fallout contour, say 0.5 R/hr at H + 1 hour. None of these leads to a K-factor completely independent of yield and meteorology, although the first comes closest. We focus here on the third which appears to be the most significant in fallout prediction systems used by DCPA.

Empirical determinations of the K-factor make use of the intensity area integral; thus

$$K_2 = \frac{1}{W_f} \int_0^{A_1} I dA$$

where A is the area (mi^2) within the contour of intensity I (R/hr extrapolated from measurements back to H + 1 hour), W_f is the yield due to fission (kt), and A_1 is the area within the largest and least intense contour used.

Problems in using this procedure have been particularly difficult very close to ground zero and very far away from it. At close-in locations, physical factors have often prevented the installation of recording instruments, and high radiation levels have denied entry for standard methods of measurement until decay and weathering have greatly decreased the levels of radiation. Airplane and helicopter measurements over such areas have not been reliable. Often, however, because the area within the innermost measured contour is small, the resultant K-factor has not been sensitive to the estimates needed in lieu of measurements within that contour.

At great distances, the reliability of measurements is reduced because intensities are small, approaching background levels. Unfortunately their contribution to the integral can be large because of the large areas involved. Properly, A_1 (or rather the value of $I(A_1)$) should be determined by the definition of local fallout. The tendency of many investigators to carry out the integration to the limit of reliability of the data results in an implicit definition of local fallout that varies from shot to shot and makes intercomparison of results difficult.

A number of empirical values of K_2 are listed in Table 1. (We cannot guarantee that these data do meet the criterion of consistent integration limits.) All the fallout patterns from which these data were obtained are uncertain to some degree. The Subcommittee believes that the best near-surface-burst data on this list are those from Johnie Boy, Buffalo 2, Zuni, Tewa, and Jangle Surface. Taking a mean of those average values, we get

$$K_2 \simeq 1090.$$

This mean represents average field-roughness conditions, and instruments as used in the past. In DCPA use, a K-factor is required which does not include corrections for surface roughness or instrument response, which is to say K_1. Since $K_1 = 16/9\ K_2$, the result is

$$K_1 \simeq 1930.$$

The Subcommittee recommends that DCPA use this value of K_1.

TABLE 1. SOME CALCULATED K-VALUES FROM WEAPON TESTS

(Based on field measurements that include terrain roughness effects, and which were not corrected for instrument response.)

			K_2				
Item	Yield	Scaled Height of Burst (λ)	Heffter	Miller	DASA	Tompkins	Average
	kt	$(ft/kt^{1/3})$*					
Ess	1.2	-61.3		1340	1250		1300
Jangle U	1.2	-16		1710	2170**		1710
Johnie Boy	0.5	- 2.4	1700**	930	1800**	1410	1170
Coulomb C	0.5	0		390	290		340
Buffalo 2		0	880	1080			980
Bravo	15 Mt	0.4	960	610	2080**		785
Zuni	3.53Mt	0.6		1340	960		1150
Tewa	5.01Mt	0.9		900	940		920
Koon	110	2.6		530	725		630
Jangle S	1.2	3.3	1300	1130	1620**		1215
Coulumb B	0.3	4.4	350	250	330		310
Smallboy	low	8.5	480	700***		490	560
Little Feller II	low	10.7	160	450	175	135	230
Little Feller I	low	11.4	190	175	255	133	190
Trinity	19	35		645	740		690
Simon	43	84		360			360
Harry	32	94		520	450		485
Badger	23	103		235	245		240
Nancy	24	104		140	175		155
Annie	16	117		150			150
Humboldt	7.8t	126		415	265		340
Tumbler-Snapper 5	12	129		235			235
Tumbler-Snapper 6	11	133		185	185		185
Met	22	142		155			155
Turk	43	142		235			235

Heffter -- private communication
Miller -- reference 8
DASA -- reference 9
Tompkins -- derived from "fraction down" given in Reference 10. Integrations to 0.5 R/hr except Johnie Boy to 1.0 R/hr.

* The scaled height of burst (λ) is determined by dividing the actual height of burst in feet by the cube root of the total yield in kilotons.

** Value $\gtrsim (0.75)^2 \times 2900$: not included in average.

*** Reduced from Miller's original 990 by excluding data at distances beyond the 0.5 R/hr contour.

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CHAPTER 2

EFFECTS OF SMALL CHANGES IN BURST HEIGHT ON THE AMOUNT OF LOCAL FALLOUT

Data from weapons tests show that radiation-intensity levels of local fallout decrease as the height of burst increases. An estimate of the magnitude of this decrease is of interest to DCPA since detonations in a nuclear attack may occur on contact with urban structures or even in trees. Such heights of burst will, however, be small when scaled from megaton-yield weapons. Taking a one-megaton burst as an example, the scaled height of burst ranges from $\lambda = 12$ (ft/kt$^{1/3}$)* for a tall tree or a ten-story building to $\lambda = 50$ for a 40-story building.

It is well known that the amount of local fallout is very low, almost insignificant, when the height of burst is greater than about a fireball radius, i.e., $\lambda = 180$[1], (except when the burst takes place on a tower.[2,3]). In such detonations, the soil or dust swept up by rising fireball either does not reach the fireball or enters it only after most of the radionuclides have condensed. In this case the small amount of local fallout depends primarily on the mass of the warhead assembly. The bulk of the radionuclides is carried by very small particles which do not fall to the ground fast enough to contribute to local fallout.

For detonations at small heights of burst, the coupling of energy to and the interaction of the fireball with the ground apparently decreases rapidly as the height increases, as manifested in the rapid decrease in crater volume. The particle-size distribution is also shifted to smaller sizes.

In the absence of a theoretical foundation for describing these effects quantitatively, one must take recourse in observation. Table 1 (Chapter 1) lists some K-factors (K_2) derived from intensity-area integrals by a number of investigators, with data from bursts beyond the altitude range of immediate concern included for perspective. The averages have been plotted in Figures 1 and 2, along with the spread in various investigators' interpretations. The mode of support of each burst is indicated as a basis for interpretation. Most of these bursts were over dry desert soil at the Nevada Test Site (NTS) and in the low kiloton range. Thus these data are intercomparable. Also shown are K-factors from a number of megaton bursts; although these fallout patterns are much less well known due to the difficulties of obtaining and interpreting data over water, it is comforting to see that their resultant K-factors are consistent with those from NTS shots.

In Figure 2, which extends the field of view to greater heights of burst, the horizontal part of line B represents the mean K-factor

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*See first footnote on Table 1.

(K_2 = 220) for 30 tower shots with $\lambda \geq 100$. The horizontal part of line A represents the mean K-factor (K_2 = 25) of 40 airbursts. There is a substantial difference between detonations on steel towers and those that are air burst. We consider a burst on a building to be comparable to a burst on a massive steel or concrete tower; similarly a treetop burst is comparable to an airburst. The most critical point for establishing the dependence of K-factor on building height appears to be the Trinity shot, analogous to one megaton on a 30-story building. If wooden towers can be considered analogous to treetop-burst conditions, several points in the two figures are analogous to treetop bursts. The only well-established ones are those for Smallboy and the two Little Fellers. For lower elevations we have Koon, whose suspension does not fit these categories, and Coulomb B, burst on a wooden tower but with a poorly documented fallout pattern.

For air and treetop bursts, the Subcommittee recommends using line A in Figures 1 and 2, which amounts to a factor of about 0.45 for a scaled burst height, λ, of 10. This is uncertain to the extent represented by the spread in the Small Boy data.

As for bursts on buildings, the available data indicate that line B should be used, which is to say a height-of-burst correction of only 0.87 at a scaled height of burst of λ = 10. This effect cannot reduce the K-factor below about 220 no matter how tall the building. As in Chapter 1, DCPA needs a K-factor (K_1) that does not reflect reductions for instrument response or ground roughness. On this basis, the minimum K-factor (K_1) for bursts on buildings is about 390.

Figure 1 Empirical *K*-factors (K_2) for detonations at various heights of burst and on various supports.

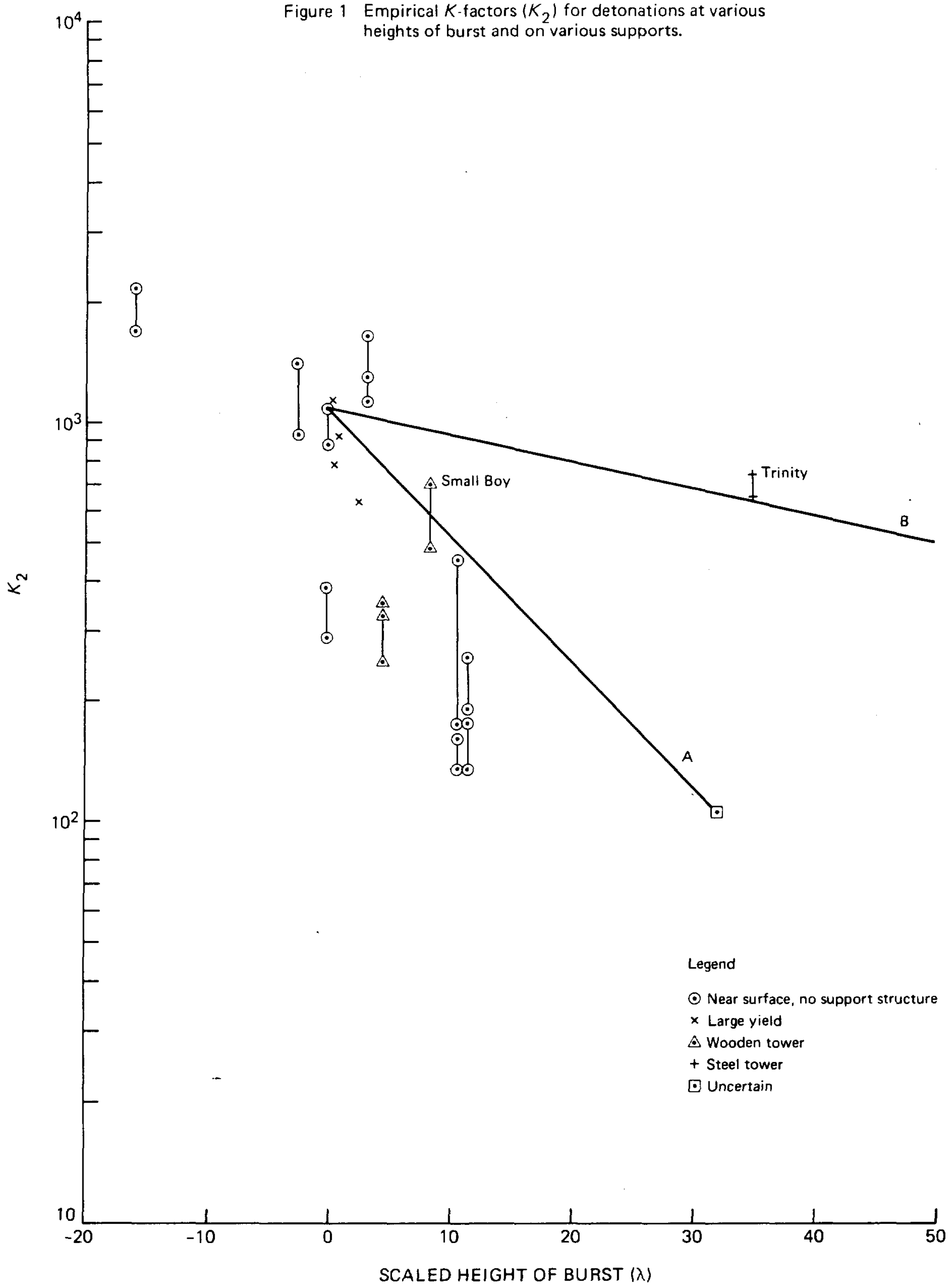
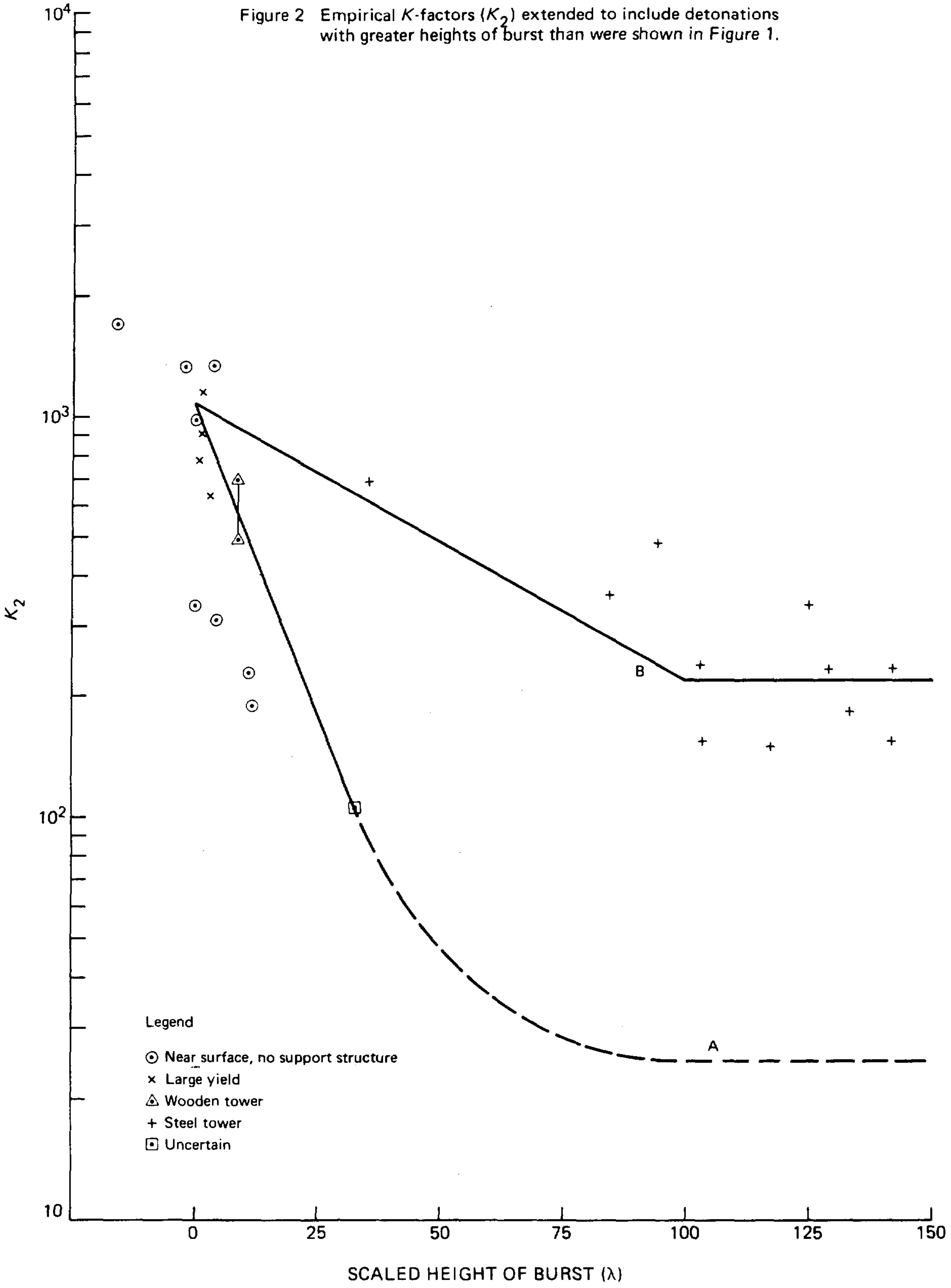


Figure 2 Empirical K-factors (K_2) extended to include detonations with greater heights of burst than were shown in Figure 1.



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CHAPTER 3

EFFECTS OF SOIL TYPE AND BUILDING MATERIAL ON THE PORTION OF RADIOACTIVITY DEPOSITED IN LOCAL FALLOUT

The effects of soil type and building material on the amount and levels of radioactivity deposited in local fallout are of three types: (1) induced activities can enhance the radiation levels over those of fission products alone, and can change the shape of the decay curve; (2) the substrate material can influence fractionation effects among the fission products through variation of melting and vaporization temperatures and chemical reactivity with the various radionuclides; and (3) differences in particle size, density, and other physical properties of the soil or matrix material can influence specific activity/particle-size distributions and hence fall-rate variables.

U. S. experience and hence data are limited to three substrates: Nevada dry desert alluvium, wet coral rock and sand, and sea water. In addition there is the experience with tower bursts (mostly steel, but occasionally of aluminum or wood) referred to in Chapter 2. Comparative analyses of the data are difficult because detonations on coral have generally been larger in yield than those over Nevada soil; the larger yield detonations were also in tropical atmospheres having much higher humidity and other differences from temperate-zone atmospheres.

Extensive work in the days of atmospheric testing [1-5] indicated that the principal soil constituents that influence the production of induced activities are sodium, aluminum, iron, and manganese contained in the soil (these being the principal elements activated by bomb neutrons), and the water content of the soil (a non-activated competitor for neutrons). The longer-lived of the first two induced activities, Na-24, has a half life of only 15 hours, so it significantly affects decay only up to about 4 days after the detonation. It has, however, a penetrating component of radiation that makes its presence important while it does last. At later times, Fe-59 and Mn-54 may be found in relatively large amounts in fallout from large-yield detonations. In general, soil-activation products are not important contributors to local fallout except for weapons with very low fission-fusion ratios.

With respect to the effects of soil type or substrate, no definitive sets of data are available for comparing gross radioactivity/particle-size distributions of the fallout from comparable detonations on dry desert soil and wet coral. In principle, the fallout from detonations over deep water or over wet substrates such as coral should have a smaller K-factor (K_2) than fallout from detonations on dry soil, since the radionuclides would be carried initially by smaller particles and by particles with variable fall rates due to evaporation and condensation of water. However, as Table 2 shows, there is insufficient evidence from the test program to support a conclusion concerning how K-factors vary with depth of water.

A similar effect should result from detonations over very hard substrates such as rock because of the tendency toward the production of smaller particles, with, perhaps, higher specific activities. The crater volume from a near-surface detonation is not considered a good indicator of the value of K_2, although both crater volume and K_2 decrease (and the average specific activity increases) with increased height of burst.

Under these circumstances, the Subcommittee recommends that DCPA assume for all practical purposes that no soil or substrate effect exists. If there is such an effect, the common soils in the country, being wetter than dry desert alluvium, should yield slightly lower K_2's and thus this recommendation will produce conservative results.

TABLE 2. K-FACTORS (K_2) FOR WATER AND WET CORAL BURSTS

Shot	Yield Mt	Water Depth ft	K_2(Miller)[6]	K_2(DASA)	K_2(Average)
Bravo	15	0	610	2080*	785**
Zuni	3.5	0	1340	960	1150
Koon	0.11	0	530	725	630
Tewa	5.01	25.6	900	940	920
Flathead		136	710	670	690
Nectar		155	410	540	475
Yankee		160	760	940	850

* Value exceeds $(0.75)^2 \times 2900$: not included in average.

** Reflects Heffter's 960; see Table 1.

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CHAPTER 4

THE RADIOIODINE PROBLEM -- INHALATION

The discovery a decade later of severely damaged thyroids in those Marshallese who were exposed as children to the fallout from the March 1, 1954, BRAVO shot, in two instances amounting to complete ablation, and almost surely due to radioiodine,[1, 2] raised the question of the pathway by which that exposure occurred. In earlier analyses, it was generally assumed that ingestion through food and drinking water was the principal pathway, and not inhalation.[3] Direct data on the thyroid exposure were not available, partly because the problem was not appreciated then, and partly because gamma spectral analysis was in its infancy. Direct measurement of thyroid burden was not possible as it is today. On the other hand, it is readily demonstrable that there were massive external and internal exposures to a wide mix of fission products, including the radioiodines.[4]

The severity of the thyroid damage suffered by the Marshallese has raised the specter of a possible neglected but important danger from radioiodine in fallout particles. It also became important to investigate the possible routes of entry--ingestion or inhalation. This has led to recent studies by Cole[5] and Norman[6] on the threat of inhalation of radioiodine.

In the fission process, the iodine radionuclides (I-131, 132, 133 and 135) are mainly produced as decay products of the precursor nuclides of Sb and Te. Although these precursors are less volatile than iodine itself, almost all the iodine radionuclides would be expected to condense late in the temperature history of the nuclear cloud and thus on the surface of the fallout particles. This tendency for surface condensation would make the radioiodines liable to leaching and later assimilation by plants and animals. In addition, significant volatilization of iodine takes place in the evaporation of water solutions of iodide, and when moist warm air is passed over iodine-coated, pseudo-fallout particles. This effect can be orders of magnitude greater on coral (carbonate) than on siliceous particles.[6]

Cole found one set of circumstances in which he concluded that inhalation of radioiodine would be a real and significant hazard following nuclear attack: where people are in a fallout shelter near the most intense part of a fallout field,* and there is appreciable standing water near the shelter ventilator intakes, and an extended thermal inversion. Fallout in rain he excluded because rain seldom occurs in coincidence with a strong inversion.

Examination of data from atmospheric tests does not yield a basis for clear-cut conclusions about the hazard of iodine inhalation. The

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*Because iodine is usually fractionated out of the larger particles that fall in the intense part of the fallout field, these circumstances are generally limited to overlapping fallout fields.

Japanese fishermen exposed to BRAVO fallout were found to have had about 7 times as much external as thyroid exposure.[7] They had lived with the external exposure for two weeks during their return to their home port, but probably avoided all but ingestion exposure to iodine. At the Sedan cratering explosion, one man remained in the open without facemask protection during cloud passage. His resultant thyroid exposure was slightly more than his external gamma exposure.[8] He thus had exposure to inhaled iodine, but avoided subsequent external exposure; his experience is evidence that the inhalation danger is real during cloud passage. Also on Sedan there were three air samplers in the fallout field that were changed often enough to distinguish cloud-passage iodine from later volatized iodine; the results showed that there was no more than 10 percent as much volatilized as cloud-passage iodine.[9] This observation does not answer the concern about volatilization because it was made in dry, not wet, circumstances.

Dr. Conard, the medical doctor in charge of the study of the effects of the BRAVO fallout on the Rongelap people, points out that data are lacking as to the importance of the inhalation process at Rongelap. His opinion is that, under those particular circumstances, ingestion and not inhalation probably was the process that produced most of their thyroid dose.[10,11] Thus the Marshallese evidence neither establishes or denies an inhalation threat.

The opinion of the Subcommittee is that inhalation is far less of a threat than ingestion, and does not justify countermeasures such as filters in the ventilating systems of shelters.

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CHAPTER 5

DETECTION OF FALLOUT BY THE PHYSICAL SENSES

The DCPA is concerned about advice to be given to people living in isolated or thinly populated areas who do not have the help of radiation measuring instruments to guide their actions in cases of possible fallout following nuclear attack. It is quite important that these people have as much time as possible to bring stock into barns and supply them with water and feed, to protect equipment from the elements, and to gather water and supplies for themselves and their families.

There is evidence that much if not all heavy fallout observed during atmospheric nuclear tests was visible as individual particles falling and striking objects, or as deposits accumulated on the surfaces of various objects.[1,2] Similar particulate fallout from volcanoes in similar quantities has been visible.[3,4]

For persons exposed to the particulate fallout from volcanoes, the forehead and nose are the most sensitive detectors of falling particles. At a stage of rapid accumulation of particles or under windy conditions, the presence of the airborne particles may be detected by irritation of the eyes or a gritty sensation on the lips and between the teeth. Usually at that stage of deposition the forehead will feel like sandpaper to the touch of the hand. The gritty sensation will also be felt on the hands and on bared arms. In rain, volcanic fallout has been observed on an automobile windshield behind the sweep of the wiper.

The DCPA might issue guidance to isolated individuals along these lines:

> "If you are within one or two hundred miles of an explosion, you will know the country has been under attack by seeing flashes and, even if clouds intervene, by hearing shock waves, and you can confirm what has happened by listening to the radio. You will want to protect yourself and your family from fallout by going to the basement or to your storm celler, if you have one; however, fallout travels with the wind and will not arrive right away. Indeed, it may be several hours (or never) before fallout reaches you, and you probably will have time to protect your stock and equipment, and bring supplies into your own shelter. Probably you do not have a radiation-measuring instrument (if you do you can work outside until the instrument reads 0.5 R/hr), but heavy fallout can still be detected by one of these several clues:
>
> 1. Seeing fallout particles, fine, soil-colored, some fused, bouncing upon or hitting a solid object, particularly visible on shining surfaces such as the hood or top of a car or truck. A white board or piece of white paper on a flat surface may serve as a visual detecting device.

2. Seeing a dust cloud or general haze in the sky not associated with a dust storm.

3. Feeling particles striking the nose or forehead or collecting on the hands and arms or in the eyes or between the teeth.

4. In the rain, after turning on the windshield wiper of your car, seeing fallout particles in raindrops slide downward on the glass and pile up at the edge of the wiper stroke, like dust or snow. The particles generally move readily like sand, rather than tending to smear and stick to the glass like fine dust."

It is reasonable to assume that life-threatening radiation exposures will be evident in such ways, as illustrated by this calculation:

A K-factor of 2000 is equivalent to 4×10^{-13} (R/hr)/(fissions/sq ft). Typical specific activities of fallout particles are 5×10^{14} fissions/gram of fallout; thus for each R/hr at 1 hour exposure rate produced, 5 milligrams of particles would be deposited per sq ft of area. This amount of fallout would be clearly visible.

According to DCPA's Nuclear Emergency Operations Plan (NEOP), the threshold of short-term radiobiological injury (defined as no medical care required) is an exposure of 150R in one week or less. For an effective fallout-arrival time of one hour after detonation, such an exposure would occur in an open-field location where the fallout contour would be about 50 R/hr at 1 hr. If the fallout-arrival time were 4 hours after detonation, the corresponding fallout contour would be about 75 R/hr at 1 hour. The total weight deposited would, according to the above data, be about 1/4 gram per square foot for the 1-hour arrival time and about 3/8 gram per square foot for the 4-hour arrival time. Such amounts of fallout particles, depositing on a clean surface over a period of an hour should be readily visible. Much smaller amounts of volcanic fallout were visually detected on streets, roofs, and macadam roads in Costa Rica.[3,4]

Use of such advice is necessarily a calculated risk. The Subcommittee is quite willing to agree that if a person can detect fallout, he should go to shelter. The reverse statement, that a person is safe if he cannot see or feel fallout, has loopholes the importance of which the Subcommittee has not evaluated, but which enter into the calculation of that risk. First, the advice, even when it is sound and is followed, exposes the individual to some increment of exposure beyond that which he would get if he goes to shelter as soon as he learns of an attack. Second, the advice may not be fully understood or trusted or properly followed. Third, these detection indices break down in a naturally dusty area such as the western great plains during the summer, or in the mountain states. Fourth, the fallout-detection indices are not very good when it is raining. Rainout brings down fine particles as well as the large ones postulated in the example given. Even for the larger particles, detection under raining and cloudy conditions would be more difficult than under dry and clear conditions.

The Subcommittee reemphasizes that the implementation of such advice is a calculated risk, probably justified where instruments for detecting radiation are not available. Visible and tactile indices of fallout would provide valuable warning of danger, but any real control of radiation exposure must depend on instruments.

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CHAPTER 6

FEASIBILITY OF DEVELOPING FALLOUT-PREDICTION TECHNIQUES FOR OPERATIONAL APPLICATION

A number of fallout-prediction systems have been developed in response to a variety of needs.[1] These are widely used in damage assessment and training exercises, in scientific, engineering, and military studies, and in the prediction of fallout during the conduct of nuclear tests. The general aspects of such prediction systems is that they predict fallout patterns before the fact, using assumed or known yields, heights of burst, locations, and winds. None of them use reports of fallout intensity as a basis for fallout predictions at locations further downwind. Civil defense can use existing prediction systems only in planning and not operationally, since these systems require the inherently unknowable details of the enemy's plans for attack, and their accuracy is limited by uncertainties in weather parameters. What civil-defense authorities can hope to do operationally during and after the attack is to give the best possible advice to the population on where the fallout is, where it will go, when it will get there and at what levels, and where to move to--if that is a viable alternative. The kind of prediction system needed to do these things is quite different from existing systems.

In an effort to meet this need, a monitoring and prediction method based on observation of the unfolding fallout event was developed and tested by the Research Directorate of DCPA in the undocumented RESEX I exercise. The method utilized available weather data and techniques to predict the fallout sector once the location and general magnitude of detonation were established. Information on certain fallout parameters--time when the exposure rate became 0.5 R/hr, time of peak exposure rate, time when exposure rate exceeded or decreased to 50 R/hr, etc,-- were reported by operating areas to higher headquarters (county, state, and regional EOC's) where the data were plotted and extrapolated in time and distance to provide warning and the same fallout parameters for locations farther downwind.

The existence of the RESEX 1 exercise shows that a real-time extrapolative prediction of fallout is to some extent feasible. However, there is a question whether such a system could be made to work in the attack situation, what with its critical dependence on the ability to receive data from the field and to disseminate information back. The questions have not been resolved to the Subcommittee's satisfaction. Nevertheless, it is self-evident that a system using current and real data is preferable to before-the-fact prediction.

REFERENCES -- Chapter 6

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CHAPTER 7

RADIOACTIVITY OF CRATERS OF MULTI-MEGATON EXPLOSIONS

There are a number of considerations that make a general knowledge of close-in fallout levels desirable. They include the need to rescue and evacuate people from badly damaged central areas; the need to fight fire there lest it spread into otherwise habitable areas and there destroy precious resources of people, food, and equipment; and even the possible use of the crater itself as a ready-made trash dump during subsequent cleanup.

Knowledge of crater exposure levels, though poor, is sufficient to answer the question for civil-defense planning: radiation-exposure rates in and near surface-burst nuclear craters will be in the order of 10^4R/hr at 1 hour, and fallout there will be substantially complete in 20-30 minutes.[1,2] (Actual data vary from 3000 to 40,000 R/hr.) Any such level precludes the use of the crater and approaches to it for times like weeks, even on an emergency basis.

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CHAPTER 8

INTERACTION OF SIMULTANEOUS SURFACE BURSTS

Circumstances have arisen leading to concern over how the effects of multiple bursts would differ from those of single bursts. For example, multiple reentry vehicles, row-charge atomic demolition munitions, and barrages from nuclear artillery provide scenarios for the occurrence of multiple bursts nearly simultaneous in time and space.

The United States has no experience with multiple bursts in the atmosphere. Under the Limited Nuclear Test Ban Treaty, the only recourse is to theoretical analysis and laboratory modeling. Theoretical analysis is both mathematically and computationally difficult, involving aerodynamic and thermodynamic modeling of complex flow fields and interacting forces in time and space. Laboratory modeling, while of some use in confirming theoretical analysis, suffers from experimental difficulties and inadequate representation of real-world phenomena.

An essential element for theoretical analysis of possible multiple-burst interactions is a vortex model of the rising nuclear-debris cloud. Work in this area is being performed by Major Dan Matuska at the Air Force Weapons Laboratory (AFWL), using the Shell Oil code, Dr. William Layson at Science Applications, Incorporated, using LADUST, WEDUST, DUSTEN, and VORDUM models, and Dr. Timothy Fohl, formerly at Mt. Auburn Research Associates (MARA), using a buoyant vortex ring model.

As yet, very little work has been reported on the actual interactions between the rising nuclear-debris clouds from multiple bursts. Independent efforts in this area have been performed by MARA and are being performed by AFWL. Preliminary results from MARA for simultaneous, space-separated, equal-sized nuclear bursts on the same horizontal surface indicate that the bursts will interact if separated by an initial center-to-center distance of less than five fireball diameters.[1] This interaction results in the clouds merging to form a single cloud which will rise to a stabilization height that is markedly less than the stabilization height to be expected from the individual clouds if they had not interacted. A MARA example for the side-by-side collision of two 13.5 MT clouds indicates a center height of the combined cloud of 14-19 km, whereas the center height of a single cloud would be $\simeq$ 25 km.

The results so far are necessarily preliminary and leave unanswered, even on a model scale, questions of bursts of non-equal yields, or not-quite-simultaneous bursts, or bursts not at the same height, or combinations of these. The results do indicate how far apart bursts must be to be considered independent and non-interacting. For purposes of making hypothetical-attack studies, the Subcommittee recommends that megaton bursts more than 700 $W^{1/3}$ ft apart (7000 ft for 1 MT) be treated as individual events where fallout patterns are simply superimposed. Events closer than this that are separated in time by more than 10 minutes may also be treated as independent bursts. For the exceptions, local fallout will be much increased.

REFERENCES -- Chapter 8

1. Fohl, T., and A. D. Ealay. Vortex Ring Model of Single and Multiple Cloud Rise, MARA report, October, 1972, DNA-2945 F (CFRD).

UNRESOLVED QUESTIONS ON FALLOUT OF INTEREST TO OCD

1. The portion of activity deposited in local fallout.
2. Effects on (1) of small changes in burst height.
3. Effects of soil type and building material on (1) above.
4. The radioiodine problem (inhalation).
5. Detection of fallout directly by the physical senses.
6. Feasibility of developing fallout prediction techniques for operational applications.
7. Radioactivity of craters of multi-megaton explosions.
8. Interaction of simultaneous surface bursts.

APPENDIX A

PART II

NOTES AND COMMENTS

ABOUT THE SUBCOMMITTEE MEMBERSHIP

The amount of research effort aimed at an improvement in understanding of the fallout radiation hazards that would be associated with nuclear war has steadily declined since the signing of the test ban treaty terminated the atmospheric weapons test program. Among the reasons why this has occurred are:

1. A general tightening of research budgets for defense purposes;

2. The difficulties and costs associated with doing meaningful research in the absence of an atmospheric weapons test program;

3. The practical limitations in the amount and reliability of reference fallout data from past atmospheric weapons tests.

As a consequence, the number of scientific and technical personnel active in this area of investigation also has declined markedly. In particular, the relatively small group of people with field-test experience continues to grow ever smaller.

The membership of this ACCD/NAS Fallout Subcommittee was carefully drawn so as to include a good sample of those people who have actual field-test experience and/or commensurate experience in other types of fallout research.

In the belief that many readers of this document would appreciate knowing something about the "credentials" of the individual Subcommittee members, the very brief summary of their backgrounds which appears below was prepared.

> Melvin L. Merritt received his Ph.D. in physics from the California Institute of Technology in 1950. Since then he has been with the Sandia Laboratories, an AEC prime contractor in Albuquerque. He has participated in most of the U.S. nuclear test programs since, having had responsibilities for fallout and thermal predictions on atmospheric tests before 1962, and for ground shock predictions and effects on underground tests since. He was Effects Evaluation Scientist responsible for all safety activities on the Milrow and Cannikin tests on Amchitka.

His technical interests continue to relate to the safety of nuclear explosions and their effects on man, his structures, and his environment.

Eric T. Clarke received his Ph.D. in nuclear physics at MIT in 1944. In 1949 he participated in a program for long-range detection of nuclear explosions that succeeded in identifying the first Russian detonation through fallout analysis. From 1956 to 1967 he was in charge of, or closely associated with, various research studies performed by Technical Operations, Inc. for the predecessors of the Defense Nuclear Agency and the Defense Civil Preparedness Agency to determine the probable deposition and the radiation characteristics of fallout. He helped to organize a weapons effects group for, and in 1966 was the chairman of, the American Nuclear Society's Shielding Division.

Frank Cluff joined the Weather Bureau in 1946 as a Weather Observer. He continued in that employment for over 20 years, except for time out to obtain a B.S. degree in 1950 and an M.S. degree in 1956, both in meteorology at the University of Utah. In 1967 he joined the AEC, becoming Deputy Test Manager at the AEC's Nevada Test Site. He is now retired.

Robert E. Heft received his Ph.D. in physical chemistry at the University of Chicago in 1953. He has engaged in research concerning the physical and chemical properties of the particle populations generated by nuclear detonations. He was with the Air Force Technical Application Center until 1963 and since that time has been with the bio-environmental group at Lawrence Livermore Laboratory.

Carl F. Miller received his M.S. in physical chemistry from the University of California at Berkeley in 1948 and his Ph.D. from Iowa State University at Ames in 1951. He has been concerned with research on the formation, distribution, and deposition of fallout and the hazards due to the radiations therefrom as well as on various civil defense coutermeasures to provide protection against these hazards. He participated in research projects covering several nuclear weapon field-test operations at the Nevada Test Site and at the Pacific Proving Grounds in the period of 1952 to 1962. These activities and research on civil defense subjects were performed while Dr. Miller was employed by the U.S. Naval Radiological Defense Laboratory, the Office of Civil Defense (as an Assistant Research Director), and the Stanford Research Institute; Dr. Miller is presently a staff member of The Dikewood Corporation.

R. Robert Rapp served as a Naval Aerologist from 1942 to 1946. He subsequently attended UCLA and worked in the Short Range Forecast Development Section of the USWB. From 1949 to 1952 he attended NYU where he received his Ph.D. From 1952 to the present he has been with the Rand Corporation where he has worked on problems of radioactive fallout, weather and climate modification, the uses and benefits of weather information and other projects involving environmental effects on military operations.

Lewis V. Spencer received his Ph.D. in physics from Northwestern University in 1948. He has been engaged in studies of the transport of gamma rays, electrons, and neutrons, and in shielding and dosimetry applications of these transport studies with the National Bureau of Standards (NBS) since that time. Dr. Spencer was one of the primary developers of the fallout shielding technology currently used in national shelter inventory studies. He has been a member of the Advisory Committee on Civil Defense (ACCD) of the National Academy of Sciences since 1958, and has been chairman of the ACCD since 1966.

Robert C. Tompkins received his B.S. in chemistry from the Ohio State University in 1944 and took some graduate courses at the University of Chicago in 1946-48. Now with the U.S. Army Ballistic Research Laboratories (BRL), he was employed by the U.S. Army Nuclear Defense Laboratory and its predecessors from 1949 until that organization's absorption into BRL in 1970. During most of that period he was engaged in research in fallout prediction and characterization of fallout particles. Mr. Tompkins participated in fallout-related projects at six U.S. atmospheric nuclear test operations in Nevada and the Pacific between 1951 and 1962.

Gilbert J. Ferber received his M.S. in meteorology at New York University in 1958. He has been engaged in research concerning atmospheric dispersion and deposition of radioactivity and other pollutants with the Air Resources Laboratories, National Oceanic and Atmospheric Administration (NOAA) and its predecessor organizations since 1955. Mr. Ferber was also a participant, with fallout prediction responsibilities, in all U.S. atmospheric nuclear test operations in Nevada and the Pacific from 1957 through 1962.

Jack C. Greene received his B.S. in electrical engineering from MIT in 1947 and his Masters in engineering administration from the George Washington University in 1970. He served with the Manhattan District at Oak Ridge during WWII after which he was a member of the AEC's Radiation Instrument Branch until joining the then newly created civil defense agency in 1951. Since that time Mr. Greene has been associated with civil defense related technical and scientific activities including radiological instrument development, nuclear weapons test programs and other research. From 1962 through 1973 he headed the Postattack Research Division which included responsibility for civil defense fallout studies. Currently Mr. Greene is DCPA's Deputy Assistant Director for Research.

Jerome L. Heffter received his M.S. degree in meteorology at MIT in 1960. He is presently a research meteorologist with the Air Resources Laboratories, NOAA, and is engaged in modeling atmospheric transport and dispersion of pollutants on local, regional and global scales. Mr. Heffter has been involved in fallout prediction research since 1960 and in U.S. nuclear test operations (atmospheric and underground) since 1962.

John C. Phillips is the Defense Nuclear Agency's fallout project officer. Captain Phillips is a U.S. Army Ordnance Corps officer and has been with Headquarters, DNA, since October 1971. Captain Phillips received his M.S. in nuclear engineering from Purdue University in 1967.

Richard Park received a B.S. in Mechanical Engineering from Yale University in 1931. In 1958, after 11 years in the Office of the Secretary of Defense with the Research and Development Board and the other agencies that preceded the Director, Defense Research and Engineering, he joined the staff of the National Academy of Sciences where his primary assignment has been as Technical Director of the Advisory Committee on Civil Defense.

Although Dr. David Bensen of DCPA was not a "formal" member of the Subcommittee, he attended several of the meetings and was responsible for the preparation of certain background material to serve as input for committee discussion and deliberation. His very substantial contribution is acknowledged with thanks. Also the help of Mr. Costa Telegadas, a colleague of Mr. Ferber and Mr. Heffter at NOAA, is gratefully acknowledged.

CHAPTER 1 - THE PORTION OF ACTIVITY DEPOSITED IN LOCAL FALLOUT

1. In recent years there has been some concern that DCPA (and other) estimates of the fallout hazard that would be associated with a nuclear war may be excessively high. The basis for this concern was that the fallout models used in calculating this hazard were thought to seriously over-predict the amount of the radioactivity deposited in local fallout. According to the discussions of Chapter 1, this concern is not justified. Specifically, the K-factor value of 2000 (R/hr)/(kt/sq mile), which has been in general usage, varies from the figure of 1930 recommended in the report by the Subcommittee by a small percentage.

2. Past procedures for accounting for reduction in the ambient radiation levels attributable to ground roughness (unevenness in terrain features) have been either: (1) in effect reducing the amount of radioactivity (and consequently R/hr at any given time) assumed to be associated with a particular weapon's fallout pattern; or (2) assuming that personnel or other objects of interest, such as crops or livestock, receive some protection because of this ground roughness. Although the net result of either method of treatment is the same, logically the latter procedure is preferable since patently ground roughness would have little if any effect on the amount of activity deposited per unit area. By accepting the recommendations of Chapter 1, i.e., that a K-factor of 1930 be used in damage assessment models, then implicity, procedure Number 2 for accounting for ground roughness effects is to be used.

This means, however, that when damage assessment of nuclear radiation effects from a hypothetical attack on personnel or things in the open is performed, an allowance for ground roughness protection must be made. Unless a specific evaluation of this ground roughness for the condition of interest is available, an average PF of 4/3 should be assumed.

3. The monitoring instruments of DCPA correctly read (assuming proper calibration of course) the ambient dose rates, and no instrument correction factor (as was necessary for older instrument designs) is required. (The test data on which the Subcommittee's recommendations were based largely came from these old instruments and have been adjusted, by using a multiplying factor of 4/3, to eliminate the instrument response factor.)

4. For the K-factor 1930 to apply, the detonation condition assumed is that of a true ground burst. That is, it is assumed that the incoming nuclear warhead does not detonate until it touches the ground.

CHAPTER 2 - EFFECTS OF SMALL CHANGES IN BURST HEIGHT ON THE AMOUNT OF LOCAL FALLOUT

1. When fallout models are used in hypothetical nuclear war studies, the weapons usually are assumed to detonate either as true air bursts, in which case no local fallout is assumed; or as true surface bursts, in which case about two-thirds of the total amount of radioactivity, as normalized to one hour after the detonation, is assumed to be deposited in local fallout. In an actual attack on a city some incoming enemy weapons are likely to impact on a building rather than directly on the ground, especially if they arrive along a non-vertical pathway such as one that would be followed by an incoming ICBM. If such weapons are fuzed to detonate on contact, the detonations therefore could occur some distance above the ground. Presumably for this reason, the amount of radioactivity in local fallout would be reduced compared to that of a true surface burst of the same type weapon. The material of Chapter 2 can be used to estimate how much the local fallout would be reduced due to this "height-of-burst" effect.

2. If Curve B of Figure 2 of the Fallout Subcommittee's report applies to the building height <u>vs</u> local fallout production phenomena as suggested in the report, an equation can be derived which, when corrected for ground roughness and instrument response, is as follows:

a. $K_1 = e^{7.565 - 1.599 \times 10^{-2} \lambda}$ (R/hr)/(kt/sq mi) at 1 hour where:

- λ = scaled height of burst = $h/w^{1/3}$
  - h is height in feet of building where detonation occurs
  - w is in kilotons of total yield
- λ is any positive value equal to or less than 100
- for λ values greater than 100, the K_1 value for $\lambda = 100$ applies.

b. To illustrate, assume that h = 400 feet (i.e., about a 40-story building) and that the total yield, all of which is due to fission, is 1-MT. Then $\lambda = 400/\sqrt[3]{1000} = 40$. In which case

$$K_1 = e^{6.925} = 1017 \text{ (R/hr)/(kt/sq mi)}.$$

This predicts that the local fallout from a 1-MT fission yield detonation on a 400-foot building would be about one half (1017/1930) the level that would be produced by the same weapon if detonated as a true ground burst.

c. If only a part of the total yield comes from fission, then a factor to account for the fission fraction is needed; in which case the equation for K would become $K = fK_1$, where f = fission fraction.

d. Thus, the value of K to be used in a fallout model such as WSEG-10 is

$$K = fe^{7.565 - 1.599 \times 10^{-2} \lambda}$$

with the symbols defined as above.

e. A curve of percentage of local fallout for various values of λ compared to the fallout from a true ground burst is shown below.

REDUCTION OF LOCAL FALLOUT WITH SCALED HEIGHT OF BURST

CHAPTER 3 - EFFECTS OF SOIL TYPE AND BUILDING MATERIAL ON THE PORTION OF RADIOACTIVITY DEPOSITED IN LOCAL FALLOUT

With the cessation of U.S. atmospheric tests, and in particular, test detonations on or near the surface of the ground, there seems to be little promise of learning just how much difference various types of soil or other materials over which the detonation occurs would make with respect to the amount of radioactivity deposited in local fallout. The recognition, however, that current fallout prediction models probably somewhat overpredict radiation levels, is important. It provides one more reason why, in a nuclear war contingency, people should be urged to take the best available shelter and to improve whatever radiation protection they may have even though some standardized protection factor (say PF 40) cannot be achieved.

CHAPTER 4 - THE RADIOIODINE PROBLEM--INHALATION

1. There is an insufficient basis for ruling out the threat of thyroid damage attributable to inhaled radioiodine vapor released in local fallout, even though it is the consensus of the ACCD/NAS Fallout Subcommittee and many others that the radioiodine inhalation threat is relatively minor compared to the ingestion threat.

2. However, there is little question that the danger of thyroid damage due to ingestion of radioiodine is significant and requires protective measures. The principal and probably only important ways by which radioiodine could be ingested are through drinking contaminated water or contaminated fresh milk. Thus, protection against ingestion could be achieved by avoiding water from open reservoirs, cisterns, and the like, where fallout has been deposited, and by keeping milk cattle from grazing on contaminated pasture or not using their milk if they do.

3. A third means of protecting the thyroid against ingested (and/or inhaled) radioiodine is through prophylaxis, i.e., using pre-administered stable compounds of iodine such as potassium iodide tablets to block the uptake by the thyroid of the radioactive iodine.

4. There could be radioiodine hazards to the U.S. population associated with a nuclear war even though the war did not directly involve the U.S., i.e., the so-called world-wide fallout that would result from an overseas nuclear exchange between, say, China and Russia. Also, there could be a radioiodine hazard due to an accidental release of radioactivity from a nuclear reactor accident.

5. It seems obvious that any national system designed to provide radioiodine protection should take into account the various possible threats, and it is equally obvious that the nature of the system may change depending on which threats are to be covered. Therefore, a final recommendation about the nature of the national protective system should await the conclusion of current studies of the problem.

CHAPTER 5 - DETECTION OF FALLOUT BY THE PHYSICAL SENSES

With the current limited availability of radiation detection instruments, especially in rural areas, wider publicity needs to be given to the statement in Chapter 5 of the report concerning the detection of radioactive fallout in dangerous quantities by an alert individual relying solely on his physical senses. It is important to note that this detection capability applies only to local fallout, and not to fallout from a Sino-Soviet exchange or from a nuclear reactor accident. (See the comments on Chapter 4.)

CHAPTER 6 - FEASIBILITY OF DEVELOPING FALLOUT-PREDICTION TECHNIQUES FOR OPERATIONAL APPLICATION

1. The Subcommittee states that "civil defense can use existing prediction systems only in planning and not operationally..."(underlining added).

2. It is important to understand that the prediction systems referred to in the report are for predicting what the dose rates (R/hr) or total doses will be at a particular time and at a particular place. "Prediction" as used here does not refer to estimating "time of arrival" of fallout (if it arrives) since such estimates would depend primarily on wind speeds which could be determined with considerable reliability.

3. Also, it is important to understand what is meant by "prediction techniques for operational application." Specifically, this term is used to describe the prediction after an enemy weapon actually has been detonated of fallout radiation dose rates at various times and at various locations. Thus, the Subcommittee's concern about use of existing prediction systems does not refer to civil defense operations such as pre-attack evacuation of cities, or calculations of risks based on studies of hypothetical attacks, or the like.

4. Even if an operational prediction scheme based on an extrapolation technique is developed, careful examination of the types of protective actions that might be taken based on the predictions is needed. This should include a careful analysis of the probable benefits in terms of the net expected lives saved or lost, and doses reduced or increased.

5. In any case, a policy which calls for the movement of people out of a predicted path of fallout, especially if they have been crowded into some NFSS-identified facility or other protected location, seems questionable. This is due to at least four factors: (1) inherent uncertainties of the predictions, as discussed above; (2) uncertainties about dependable communications; (3) the inherent difficulties of moving large numbers of people under unrehearsed and highly stressful conditions in a short period of time; and (4) moving them in a direction and for a distance not definitely known until the signal from the detection system has been received.

CHAPTER 7 - RADIOACTIVITY OF CRATERS OF MULTI-MEGATON EXPLOSIONS

1. The information in this chapter is about the very high radiation levels to be expected in craters; it need have little practical impact on current civil defense planning. It has been recognized that emergency actions near the crater (such as rescue or firefighting) would be futile in any case because of the severity of the destruction that would have occurred so close in to ground zero. In other words, there would be no surviving people to be rescued or standing structures to be saved from fires.

2. It is noted that the craters, which might have been considered for burial grounds or repositories for debris and other material damaged beyond repair by the blast, because of the high levels of radioactivity should not be counted on for such use, at least in the early months following the detonation.

3. Although mostly academic, also it is noted that the intensely radioactive crater areas are not shown or accounted for in conventional fallout prediction models, nor do they show up in national depictions of the fallout conditions associated with hypothetical nuclear attack studies.

CHAPTER 8 - INTERACTION OF SIMULTANEOUS SURFACE BURSTS

1. The situation discussed in this chapter is the only one in the report which, in effect, could mean that current assessments of the local fallout hazard may not be conservative, i.e., that current methods under certain circumstances predict less local fallout than actually could occur. If two or more nuclear weapons were to be detonated closely in time and space, causing the resulting cloud height to be severely limited, the expected radiation levels in the local fallout pattern could be substantially increased compared to those predicted by DCPA (and other) fallout prediction models. Currently assumed characteristics of the nuclear arsenal of any potential U.S. adversary in a nuclear war are such that near-simultaneous, closely spaced nuclear bursts seem unlikely. Multi-reentry vehicles are not thought to be part of such a potential enemy's current arsenal. If and when such weapons become available for use against us, the probability of such simultaneous-burst circumstances, and thus an enhanced fallout radiation threat, could increase.

2. It is noted that the above assessment is, as pointed out in the report, based on preliminary and inadequate data. Questions of bursts of non-equal yields, or that are not quite simultaneously detonated, have not been answered. Thus, the increased threat of local fallout resulting from interactions of nearby simultaneous bursts is far from having been established.