~~RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1946~~

[redacted]

Copy 99

U.S. AIR FORCE Project RAND

A STUDY OF COMPLEX TARGETS MOSCOW, DAYTON, AND GENEVA STEEL

November 15, 1954

R-272

[redacted]

~~RAND WASHINGTON OFFICE~~

SEE INSIDE COVER FOR DISTRIBUTION RESTRICTIONS

[redacted] OF TRANSMITTAL ON HAND

[redacted] FROM W/O Lib. 7-2-71

The RAND Corporation

1700 MAIN ST. • SANTA MONICA • CALIFORNIA

R-272 C

DISTRIBUTION RESTRICTIONS

Not suitable for distribution to foreign governments or foreign nationals.

Not suitable for distribution to industrial contractors or commercial organizations.

Not suitable for distribution by the Armed Services Technical Information Agency (ASTIA), Authority AFR 205-43.

~~RESTRICTED DATA~~
~~ATOMIC ENERGY ACT OF 1946~~

UNCLASSIFIED

PROJECT RAND

Contract No. AF 33(038)-6413

A STUDY OF COMPLEX TARGETS MOSCOW, DAYTON, AND GENEVA STEEL

Olaf Helmer, Norman Dalkey,
and Frederick B. Thompson

November 15, 1954

R-272

COPY NO. 99

The RAND Corporation
1700 MAIN ST. • SANTA MONICA • CALIFORNIA

~~SECRET~~

SUMMARY

This report is a compendium of facts concerning urban and industrial vulnerability to atomic bombing. The analysis is based on an examination of three specific targets, i.e., the cities of Moscow and Dayton and the Geneva Steel Plant. The tabulations and graphs presented here may be of aid to the planner in such areas as civil and industrial defense, strategic targeting, strategic reconnaissance and intelligence, and long-range Air Force planning as reflected in weapon and delivery system specifications.

CONTENTS

INTRODUCTION

This report presents a compendium of facts gained from a study of urban and industrial vulnerability and states some general conclusions regarding both offensive and defensive planning.* It is hoped that the facts assembled here will provide guidance to decision-makers in such areas as civil and industrial defense, targeting, intelligence and reconnaissance requirements, and long-range Air Force planning as reflected in weapon and delivery system specifications.

An indication of the methods used is given to provide a rational basis for the application of a similar methodology to the analysis—either offensive or defensive—of target entities other than those specifically studied here.

Three specific targets have been considered: a medium-sized city, a large city, and an industrial installation. For the latter, the U.S. Steel Plant at Geneva was chosen; and for the cities, Dayton, Ohio, and Moscow, respectively.

Because of the availability of high-speed computing machines, our study, compared with earlier studies of such targets carried out by others, has been able to introduce for the first time a great deal more detail into the analysis. Each of the targets was, in fact, divided into a large number of parts; the effect on each of these sections by each of the bombs dropped was then recorded; and the over-all damage to the target was estimated by a process of integration over all of these sections. Altogether, the results of about 25,000 bomb drops were computed; these drops were both single and multiple and comprised a whole spectrum of yields and bombing errors.

What types of questions may the results of this study be expected to answer? These might include: Just how big a bomb is needed to take out a given city? How does damage vary with bomb size, number of bombs, height of burst, and aiming error? What difference does it make if bombs are aimed at population or at industry? How much can casualties be reduced through warning and shelters? For what type of target is an air burst preferable to a ground burst, and vice versa? How sensitive are the results to faulty target intelligence and

*Thanks are due to Mark Peter, Jr., for basic estimates of structural vulnerabilities, to Marvin Hoffenberg for capital cost estimates for the industries of Dayton and Moscow, to Bob Rumsey and Pat Haverty for being effective intermediaries between the authors and the IBM 701 computer, and to Marian Centers for a variety of contributions too numerous to list.

erroneous vulnerability assumptions? This list could be continued, but these examples should suffice to indicate the type of information this study can be expected to provide.

The reader should not expect, on the other hand, to find out how the predicted mortalities will affect the continued operation of an urban community or how the predicted capital destruction will affect the continued operation of the national economy. An analysis of such over-all consequences, taking into consideration the interaction of a multitude of bombing effects and the cumulative disruption of the life of the nation, may be undertaken in the future.

UNCLASSIFIED

UNCLASSIFIED

RELIABILITY

A few words should be said regarding the reliability of our results. There are so many basic uncertainties involved, especially with regard to the accuracy of target intelligence and the vulnerability assumptions, that it has often been suggested that this is an area in which reliable prediction of the outcome is well-nigh impossible. We have been well aware of these uncertainties throughout this study, and we have made a special effort to find out how sensitively the results depend on the accuracy of the basic assumptions. What we found has been rather encouraging. For instance, if the assumptions on physical vulnerability are changed throughout by either raising or lowering the overpressure requirements for any given kind of damage by as much as 20 per cent, the over-all damage does not change by more than 9 per cent. The same may be said if our target intelligence involves a comparable error, i.e., if the distribution of population and industry is in error by some comparable amount. It turns out that even for so large an error in basic inputs, the amount by which the estimated outcome might be in error is, at most, of the same order of magnitude as the amount by which it is apt to be in error due to such operational factors as bombing errors, variations in yield, and errors in burst height. We therefore feel justified in claiming that our results, in spite of possible errors in basic assumptions, are reasonably correct, by which is meant that they are accurate to one and possibly two, but certainly not three, significant figures. Moreover, we believe that the results for other targets of similar configuration would not be far different.

UNCLASSIFIED

METHODOLOGY

A major difficulty in analyzing complex targets, such as cities or large industrial installations, is their lack of homogeneity. In a city, large and small industries intermingle, in no mathematically neat pattern, with commercial and residential structures. Population is distributed in an irregular, if not entirely haphazard, fashion, wide-open spaces being juxtaposed to densely crowded blocks. These many diverse elements of such a complex target respond in very different ways to the destructive forces of a bomb.

To deal with this complexity, we dissected the target into subregions so that each section formed a homogeneous unit. For Moscow, there were 1400 such divisions, none being larger than about ½ n mi on a side. The sections were located on a standard coordinate grid, so that it was a simple calculation to find the distance from any point in the target area to the center of any one of the sections. For the city studies, each section was characterized by five quantities: population, number of dwelling units, square feet of industrial roof cover, an index of industrial capital, and predominant building type. In the case of the U.S. Steel Plant at Geneva, Utah, each major production unit was considered a section and was characterized by the total cost of above-ground construction, which was further broken down into cost of labor, structural steel, refractory brick, electrical equipment, and machinery; in addition, the total time for above-ground construction was determined.

To calculate the expected damage from a single bomb with a given designated ground zero (DGZ) and bombing error (circular probable error, or CEP), a random sample of ground zeros, distributed with the proper CEP about the given DGZ, was selected. In most cases, a sample of 200 ground zeros was used. For each ground zero, the damage to any particular section was determined as a function of the size of the bomb, height of burst, the type of structure in the section, and the distance from the ground zero. For the city studies, damage was expressed in terms of population killed, dwelling units destroyed, and two measures of industrial damage, namely, industrial structures and industrial capital destroyed. The distinction between the two is that industrial capital included machinery and equipment, a much tougher target than structures alone.

... addition, to furnish a comparison with more conventional methods of calculating damage, the square feet of industrial roof cover destroyed was computed on a "cookie-cutter" basis. In the case of the U.S. Steel Plant study, damage was calculated in terms of the five capital indices mentioned in the preceding paragraph. The damage functions on which these calculations were based are given in the Appendix, pages 21–28.

The influence of the drag effect was taken into account in scaling for various bomb sizes. A uniform 0.37th-power scaling law was employed for all of the indices.

This series of computations furnishes the damage to one subsection from a bomb landing at a given ground zero. To determine the damage to the entire target area, the damage to each of the sections was summed over the target, and to determine the expected damage for a given bomb size, DGZ, and height of burst, the damage was averaged over the sample of ground zeros.

For the case of more than one bomb on target, a similar procedure was followed, in which the percent damage for each succeeding bomb was applied to the capital or population remaining in each section.

For the two cities, Moscow and Dayton, the calculations described above were run for six bomb sizes ranging from 100 KT to 25 MT, for five bombing errors ranging from a ½-n-mi to an 8-n-mi CEP, for a number of bombs on target ranging from 1 to 10, and for two different heights of burst, a ground burst and a 600-ft 1-KT equivalent. The same spectrum of cases was considered in the case of the U.S. Steel Plant, except that the number of bombs on target was confined to one and that the influence of the angle of the blast was taken into account, the assumption being that a sideways blast was about 1.8 times as effective as an end-on blast; for intermediate angles it was assumed that the effectiveness of the blast was $\sin\theta + 1.8\cos\theta$ times the effectiveness of an end-on blast, where θ ranges from 0° for a sideways blast to 90° for an end-on blast.

A summary of the basic data for the three targets is given in the Appendix, pages 31–37.

The U.S. Steel Plant is an intermediate-sized mill turning out about 1,500,000 tons of steel per year. It was constructed during the last war and is somewhat more spread out and rugged in construction than the average steel mill of its size.

The target which we have called Moscow is in reality the Moscow metropolitan area. The region involved covers more than 700 sq mi and is much larger than the city of Moscow proper. The percent damage figures quoted refer to this large area and not just to the city of Moscow. A glance at the regional breakdown (Appendix, page 35) will show that the population is highly concentrated around the Kremlin, which is at the center of the map. In fact, a region 4 mi on a side centered on the Kremlin includes 42 per cent of the population. Industry is less concentrated. Some of the largest plants are on the very fringes of the area. Nevertheless, one region to the east of the Kremlin and 4 mi on a side contains more than 25 per cent of the industrial capital of the entire area.

The city of Dayton is a medium-sized industrial city having a population of about 300,000. It is considered nineteenth in the list of American industrial cities. The regional breakdown (Appendix, page 33) shows that population is not nearly so heavily concentrated as it is in Moscow and that industry is more uniformly suffused throughout the city.

Highly useful tools in analyzing targets such as these are equidamage maps (Appendix, pages 68 and 69 and 89–92); they give a picture of the damage to the entire target resulting from a bomb falling at any point within the target. The contour lines are to be interpreted in the following way: A bomb falling at any point on a contour line does the same amount of damage (namely, the percentage indicated at that contour) to the *entire* target as a similar bomb falling at any other point on that contour. If the bomb falls outside the contour, it does less damage; if inside, it does more. The contour lines are obviously helpful in determining the optimal ground zero for a single bomb.

If one wishes to maximize a particular index, it is interesting to note that for almost all cases, and for bomb sizes greater than 500 KT, the contour lines closely approximate a set of concentric circles. This would indicate that for hasty computation of aggregate indices, such as total capital destroyed or total mortalities, the complex target can be closely approximated by a model consisting of a point target having a damage function falling off smoothly from some point of maximum damage. Of course, this function will depend on the size and shape of the target as well as on the types of structures within the target.

The mortalities due to fallout, which are incorporated in the tables on pages 44 and 50 of the Appendix, were based on the following assumptions: (1) the fallout pattern is circular about the ground zero, with a diameter equal to the crosswind diameter found experimentally (this assumption approximates the actual hot spot around ground zero but neglects the secondary hot spot farther out); (2) personnel remains exposed virtually without protection for 8 hr; (3) fallout occurs 40 min after bomb burst. A more careful analysis of fallout effects has recently been completed at RAND.*

* S. M. Greenfield, W. W. Kellogg, F. J. Krieger, and R. Rapp, "Transport and Early Deposition of Radioactive Debris from Atomic Explosions: Project Aureole," The RAND Corporation, Report R-265-AEC, July 1, 1954 (Secret—Restricted Data; Limited Distribution).

DISCUSSION OF THE RESULTS

The results of this study are recorded in detail in the Appendix. It is difficult to single out any major conclusions. In fact, the purpose of this effort, as emphasized before, was not viewed primarily as aiming for any conclusions. The following comments on, and "sample conclusions" from, our results are offered merely to point up some of the potential uses of this material and to emphasize certain factors which seem to be of special interest.

YIELD REQUIREMENTS

The yield required to take out a city such as Moscow with a single aircraft-delivered bomb is no greater than 10 MT, in the sense that a 10-MT ground burst delivered with a ½-n-mi CEP or less can be expected to destroy about half the city's capital assets and to kill two-thirds of its people (Appendix, page 44); not counting the effects of radioactive fallout; of the remaining third, most would be either killed by fallout or seriously injured. To achieve a similar effect with a missile delivery system having, say, a 1-MT warhead and a 3-n-mi CEP, it would be necessary to deliver about 10 such missiles.

For a city of the size of Dayton, similar percentage losses could be expected from a single 1-MT aircraft-delivered bomb or from four 1-MT missile-delivered bombs having a 3-n-mi CEP.

In assessing the implications of a 50 per cent destruction of the capital assets of these cities, it is well to keep in mind the severity of the capital-destruction index used here, which includes machinery and equipment. Thus, collapse of an industrial building is associated with only two-thirds destruction of the capital involved in building and equipment.

It may also be noted that the effect of what we now consider a small bomb, having a yield of 100 KT, when dropped on the center of a city as densely populated as Moscow, is perhaps greater than might be expected. It is likely to kill about a half a million people.

DIMINISHING RETURNS

Once a certain yield or a certain number of bombs has been reached, the additional damage obtainable from an increased yield or an increased number of bombs diminishes rapidly. This is exemplified clearly by the curves on pages 70 and 71 and pages 94 and 95 of the Appendix. Thus, if we examine the Moscow case discussed above, we find that the aircraft-delivered 10-MT bomb, compared with an 8 MT, does only slightly better, producing 68 instead of 65 per cent mortalities and 50 instead of 45 per cent capital destruction. Similarly, in the missile-delivery case, if 10 instead of 8 bombs of 1 MT each are delivered, mortalities increase from 59 to 65 per cent and capital destruction increases from 47 to 52 per cent.

DAMAGE TO POPULATION

In interpreting the examples of mortality figures given above, the reader should keep in mind, on the one hand, that they refer to the case of an attack without warning, and on the other, that fallout will kill additional people and that many of the survivors will be seriously injured.

In the case of Moscow we also considered two degrees of warning—one for short warning and one for long. In the case of short warning, people were assumed to seek shelter in the basement or, at least, to go to other relatively safe parts of their building. People on the street were allowed to go into the nearest building. In the case of long warning, people were allowed to move as far as 1 mi from their place of residence to seek better shelter, such as the basement of a more blast-resistant structure. Also, 5000 people were funneled through each subway entrance. Altogether, about 1,000,000 people were moved from one building type to another which might offer better protection. (More people could have been moved within the 1-mi limitation had more shelters been available.) The number of lives saved in the long-warning case increased about 6 per cent, more or less independently of the yield of the bomb, and increased about half that amount for the short-warning case. These are small percentages, yet represent very sizable absolute numbers of people. The short-warning case was also run for Dayton and showed similar and slightly improved survival results. (See Appendix, page 113.)*

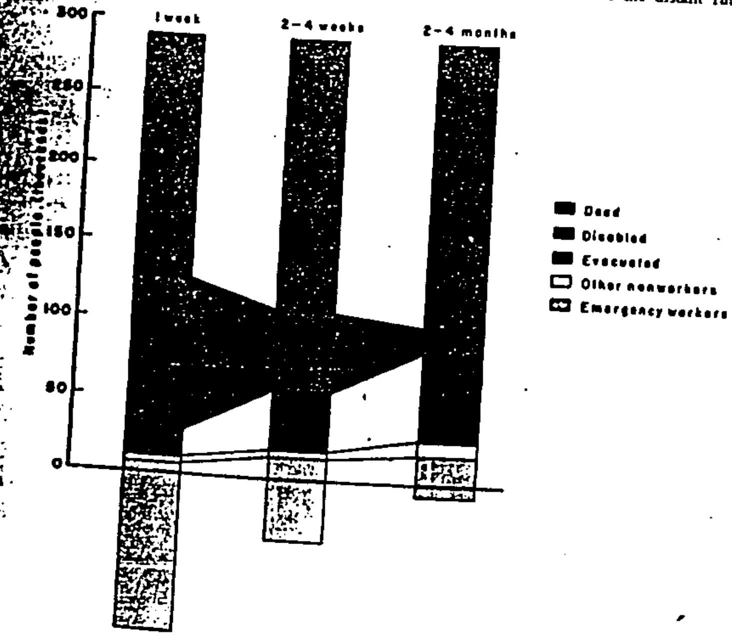
DAMAGE TO INDUSTRY

Depending on the over-all bombing strategy, the interest in industrial damage may be centered on the fate of specific plants or on over-all capital destruction.

*A more telling description of the effects of high-percentage population kills on the life of a city is given by the following bar diagram based on an analysis suggested by Dr. Paul Johnstone of the

Our results throw some light on means to obtain either of these objectives. With regard to the effect of bombing individual plants, the tabulated results on the Geneva Steel Plant (Appendix, page 54) speak fairly well for themselves. However, two comments may be made. First, while the *methods* are directly applicable to other plants, the *results* are not, because a steel plant, by virtue of its size and construction, is a much tougher target than the average industrial installation, and any attempt at extrapolation must take this into account. Secondly, the recuperation time, which—as might be expected—always dominates the capital destruction, should be interpreted as the time which would be required for recuperation if one could go to work immediately after the blast with all the needed resources of the economy intact. Of course, site contamination, widespread damage to adjacent housing and population, and the fact that

Deputy Directorate for Targets. The chart predicts the effects over several months of a 1-MT attack on the unwarned city of Dayton and shows that many months would be required before the city could look after its own emergency services, with industrial rehabilitation in the distant future:



that "minimum recuperation times" have little chance of being met. Nevertheless, the stated recuperation time gives a picture of what it would take to get the plant back into operation, once resources could be poured into that task.

With regard to over-all damage to industrial capital, the differential effects of various numbers and sizes of bombs can be seen from the graphs on pages 108 and 109 of the Appendix and, in the case of Moscow, from the maps on pages 34 and 41–43 of the Appendix.

COMPARATIVE DAMAGE TO POPULATION, HOUSING, AND INDUSTRY

Damage to dwelling units and mortalities are not only highly correlated (see charts on extreme right of page 116 of the Appendix), but destruction of dwellings is always slightly in excess of mortalities. (Note, however, that the mortality figures used here do not include deaths from fallout.) There is, naturally, much less correlation between mortalities and capital destruction (see charts on extreme left of page 116). In the case of Moscow, for instance, the contour lines for mortalities (Appendix, page 68) and capital destruction (page 89) are centered on points several miles apart, so that it makes quite a difference whether a bomb is aimed at population or at industry. For example, a 1-MT bomb dropped on the center of population will kill about 26 per cent of the population but will destroy only about 12 per cent of industrial capital. A bomb of this yield dropped on the center of industry, while killing only 20 per cent of the population, will destroy about 30 per cent of capital.

EFFECT OF GROUND ZERO AND CEP

Our results seem to indicate that, even for large bombs, the location of ground zero and the expected bombing error have a greater influence on the outcome of a strike than is generally expected. For example, in Moscow, in the case of long warning, a 5-MT bomb having a ½-n-mi CEP is expected to kill 54 per cent of the population. A similar bomb having a 3-n-mi CEP is expected to kill only 34 per cent of the population. The same is true to an even greater degree for a smaller city such as Dayton. Multidrops do not change the situation. For example, four 1-MT bombs having a ½-n-mi CEP are expected to destroy 83 per cent of Dayton's capital assets, while similar bombs having a 3-n-mi CEP destroy only 55 per cent on the average.

The curves on page 110 of the Appendix gave a slight spurious advantage to the air burst with respect to mortalities—spurious because again the additional fallout fatalities (which are significant for ground burst only) have been neglected. For capital, the ground burst dominates eventually, but, for as large a city as Moscow, not until a yield of about 17 MT has been reached. The reason is that the payoff here is in terms of over-all capital destruction in a widespread but rather soft target. This contrasts sharply with an attack upon a steel mill (page 111), where the ground burst is dominant throughout.

COST OF CONFIDENCE

In carrying out a bombing strike it may be important not only to achieve a certain effect *on the average* but to be reasonably sure that *in fact* a certain damage level has been achieved. To assess the value of special reconnaissance operations, the planner will have to know what damage level he can expect with, say, 90 per cent confidence (in the sense that in 90 out of 100 similar strikes at least that much damage would be achieved). Our results show (Appendix, page 106) that in attacks against cities, the damage on which one may count with 90 per cent confidence is not much lower than the average (or expected) damage, unless the CEP is excessively large. Hence, if the attack is aimed at destruction of population or housing or generalized capital, it will rarely pay to engage in costly reconnaissance operations. On the other hand, as shown by the graphs on page 107, the variance of the outcome of a strike against an individual plant is so high that the damage which one may expect with 90 per cent confidence is quite considerably below the average damage. Thus, the reconnaissance requirements depend essentially on the specific mission of the attack.

SUPER BOMBS

Although it would appear from the figures presented here that yields of 25 MT and under suffice to carry out the more commonly envisaged bombing missions, we have included, on page 129 of the Appendix, some graphs showing expected results on Moscow of dropping bombs having yields up to 1000 MT. If, for instance, a 1000-MT bomb were dropped at the uranium refinery at Noginsk, which is 25 mi from Moscow, we would gain as bonus damage the destruction of about 50 per cent of Moscow.

UNCLASSIFIED

APPENDIX

UNCLASSIFIED

UNCLASSIFIED

VULNERABILITY ASSUMPTIONS

UNCLASSIFIED

UNCLASSIFIED

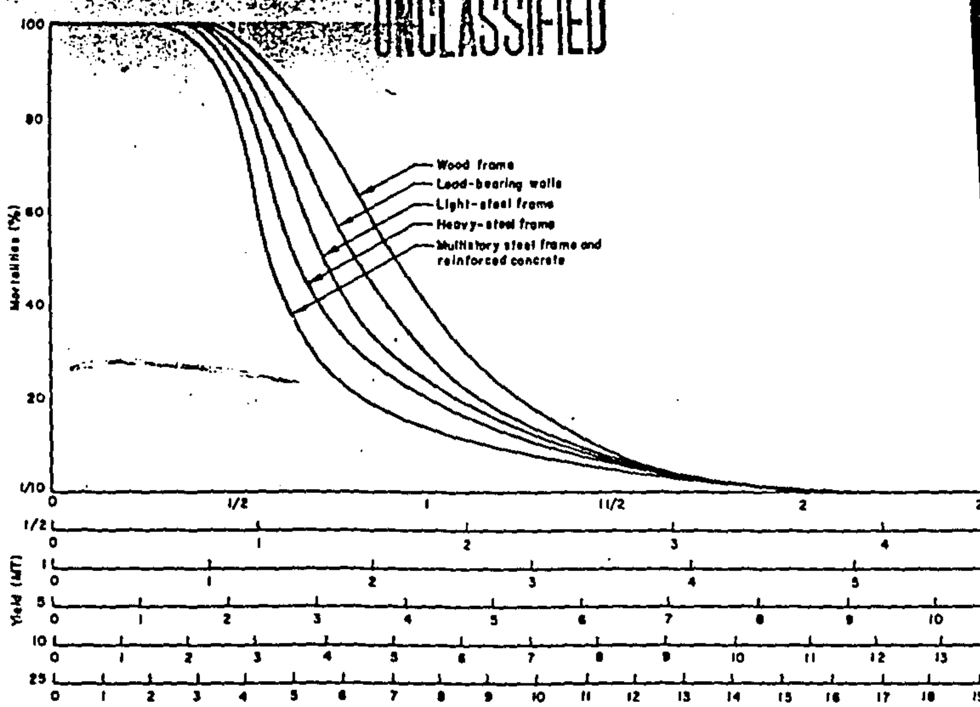


Fig. 1—Mortalities vs distance, by building type: ground burst, unwarned

UNCLASSIFIED

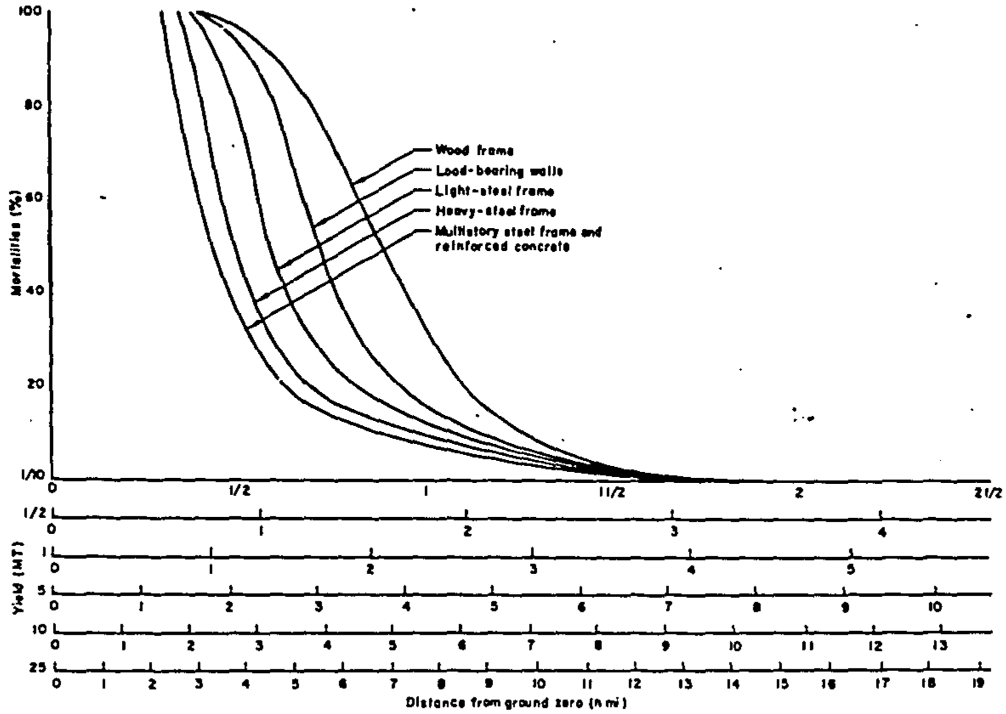


Fig. 2—Mortalities vs distance, by building type: ground burst, warned

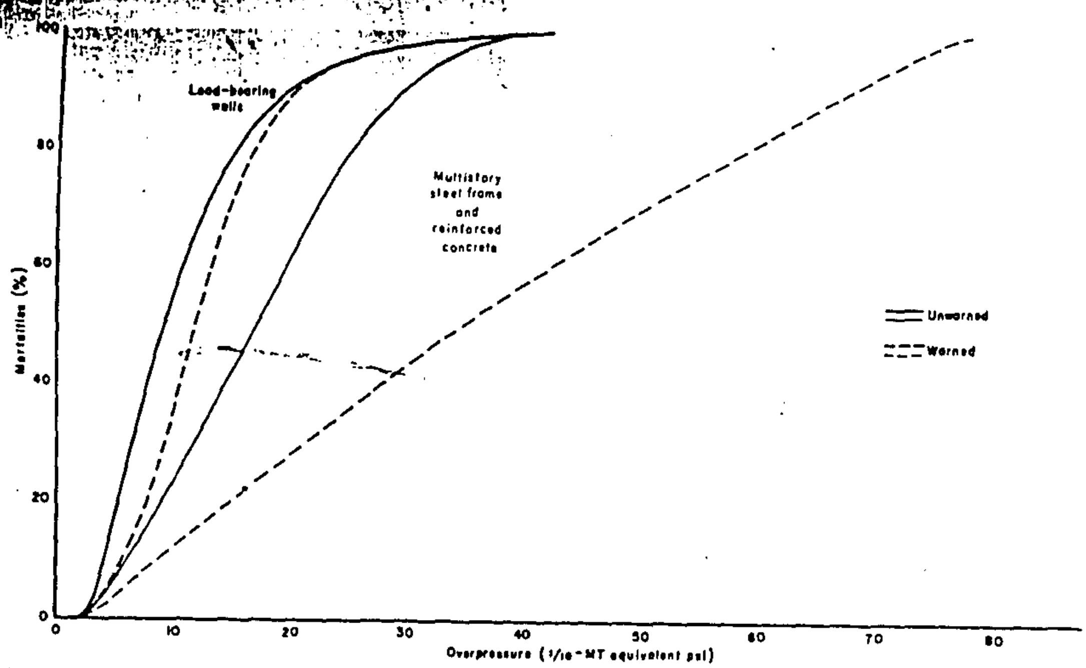


Fig. 3—Mortalities vs overpressure: comparison of warned and unwarned cases

UNCLASSIFIED

Table 1

LETHAL RADII* FOR COLLAPSE OF INDUSTRIAL ROOF COVER AND FOR MORTALITIES DUE TO FALLOUT RADIATION
(In nautical miles)

Type of Burst	Type of Damage	Type of Structure	Bomb Yield (MT) 1/10	1/2	1	5	10	25
Ground burst	Collapse of industrial roof cover	Wood frame	1.18	2.22	2.77	5.20	6.48	9.10
		Load-bearing walls	0.91	1.71	2.13	4.01	5.00	7.02
		Light-steel frame	0.73	1.37	1.71	3.22	4.01	5.63
		Heavy-steel frame	0.61	1.14	1.43	2.69	3.35	4.70
		Multistory steel frame	0.53	1.00	1.24	2.33	2.91	4.09
	Mortalities due to fallout	....	1.20	2.55	3.55	7.75	10.90	17.00
Air burst (600-ft 1-KT equivalent)	Collapse of industrial roof cover	Wood frame	1.50	2.82	3.52	6.61	8.24	11.57
		Load-bearing walls	1.14	2.14	2.67	5.02	6.26	8.79
		Light-steel frame	0.75	1.41	1.76	3.30	4.12	5.78
		Heavy-steel frame	0.45	0.85	1.05	1.98	2.47	3.47
		Multistory steel frame	0.35	0.66	0.82	1.54	1.92	2.70

*These "cookie-cutter" radii were used in the calculation of P^* and RC in Tables 4 and 6.

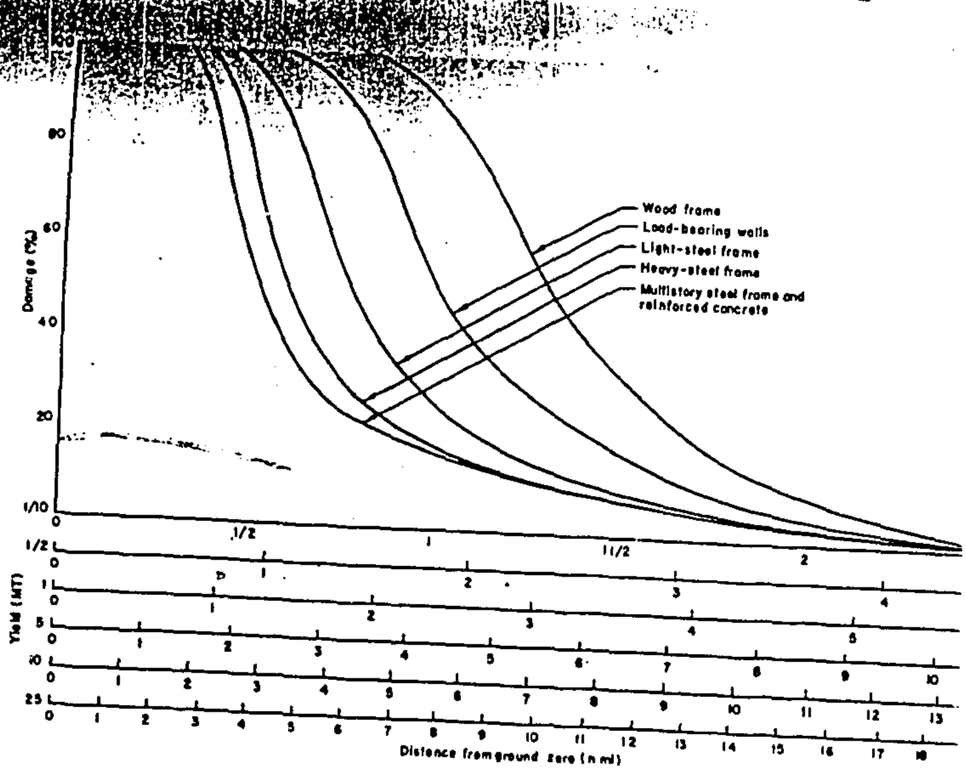


Fig. 4—Damage to structures vs distance, by building type; ground burst

UNCLASSIFIED

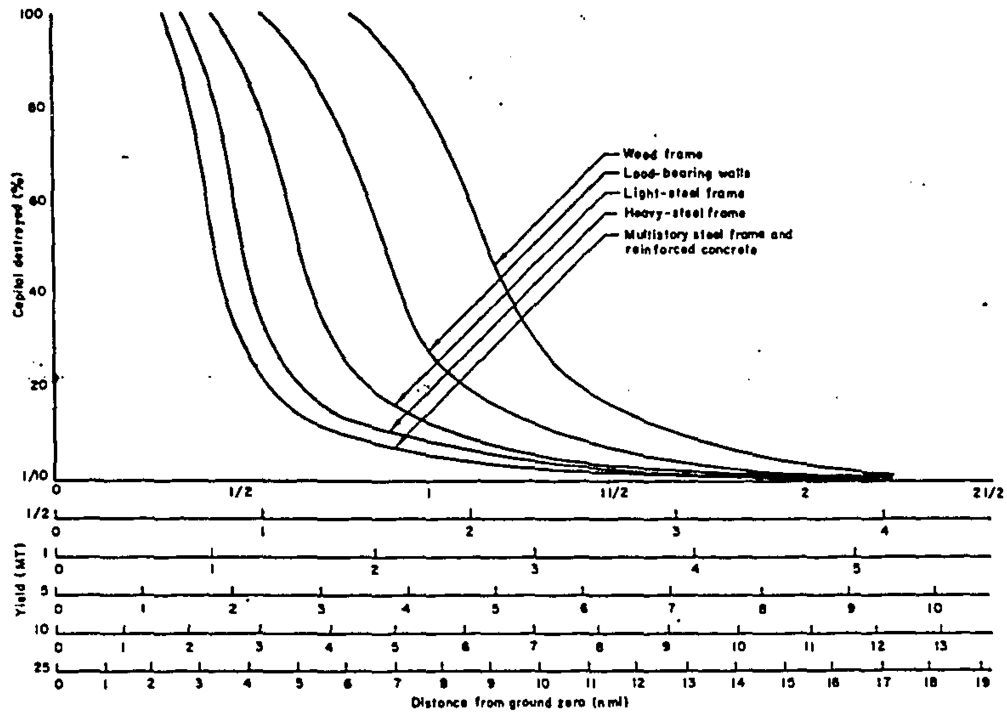


Fig. 5—Capital destroyed vs distance, by building type; ground burst

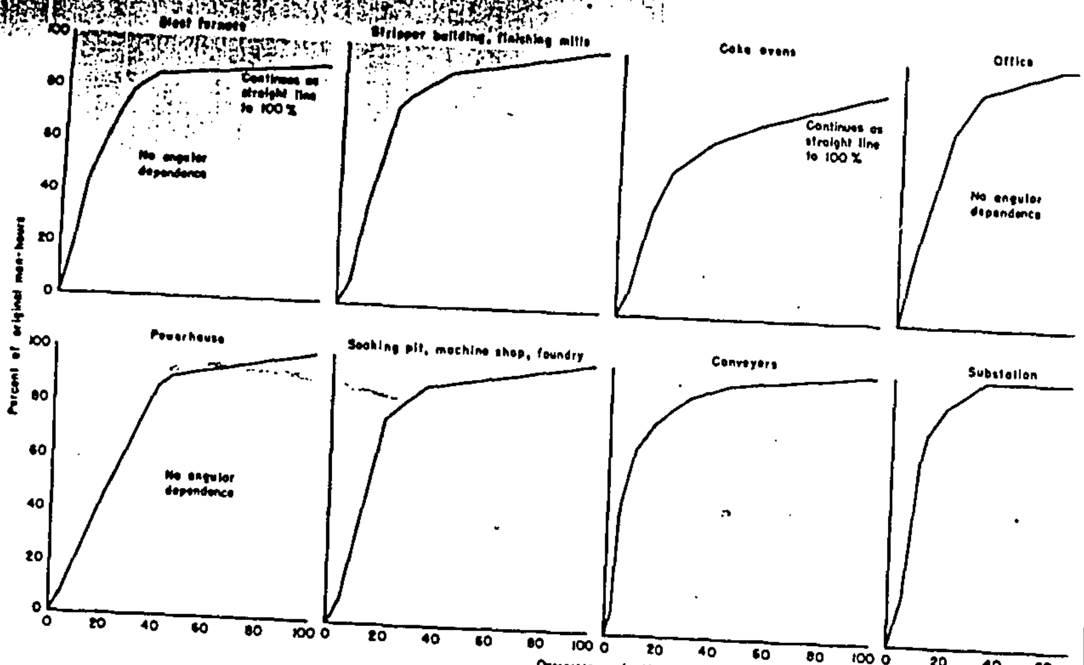


Fig. 6—Industrial vulnerability curves for Geneva Steel Plant, showing man-hours required for replacement vs overpress[u]
by plant component

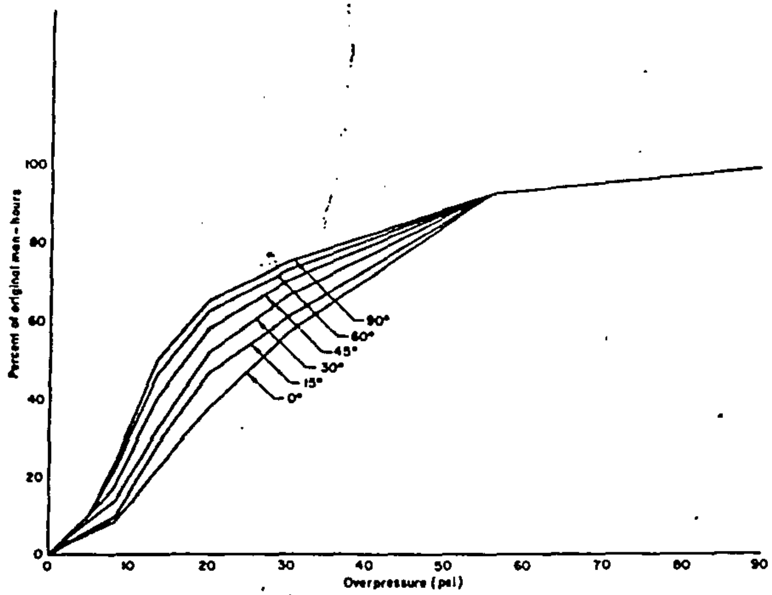


Fig. 7—Example of vulnerability curve for Geneva Steel Plant, showing dependence on angle of incidence: open hearth

BASIC TARGET INPUT DATA

UNCLASSIFIED

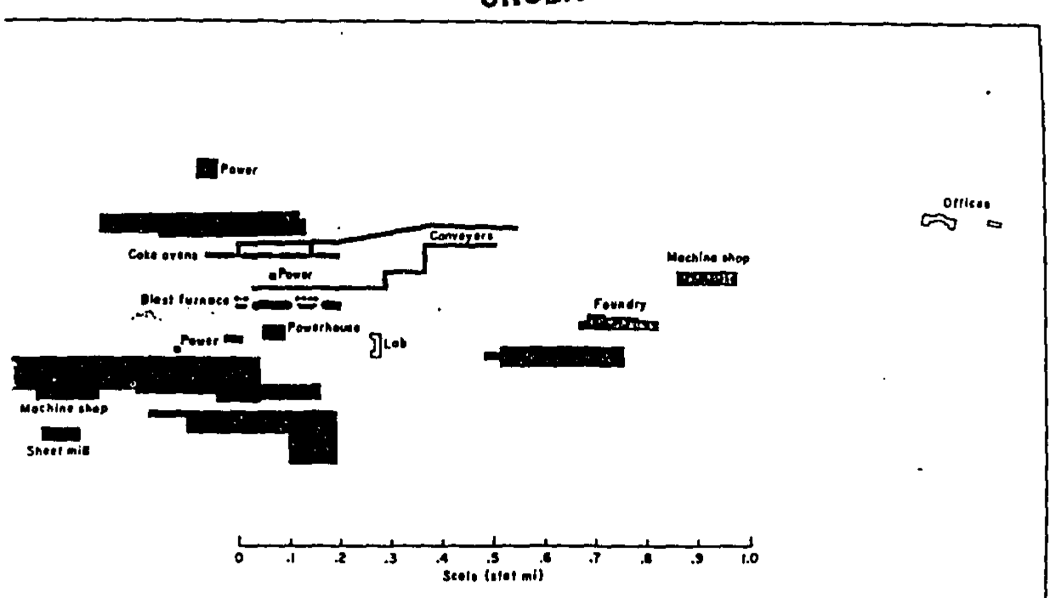
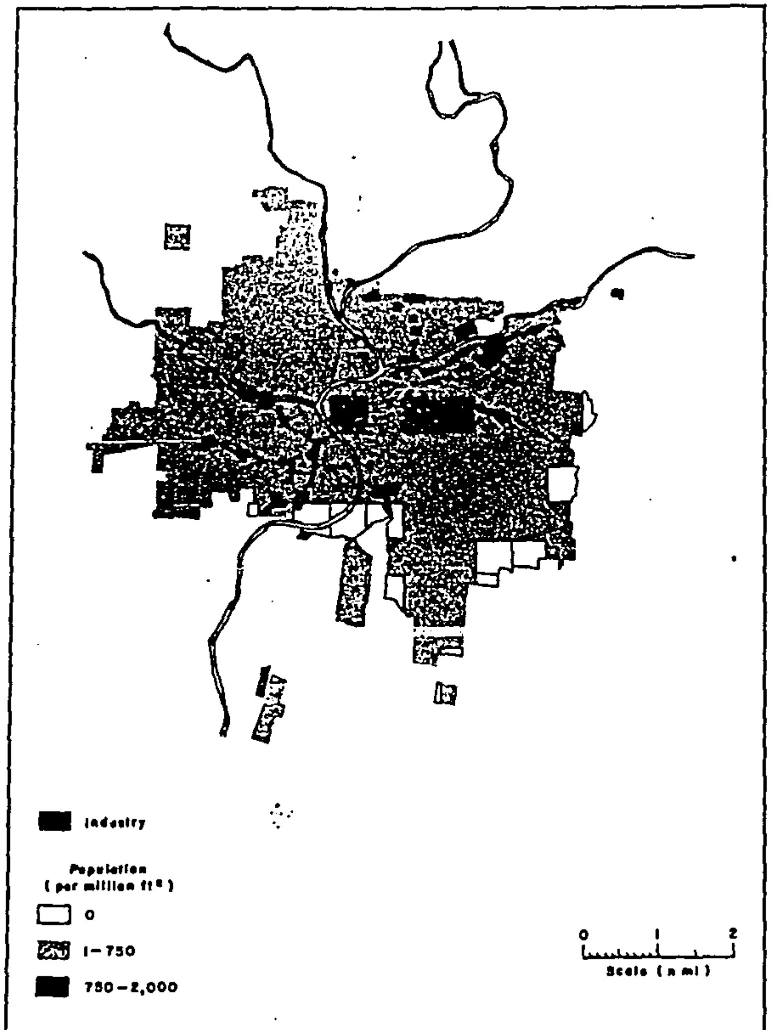


Fig. 8—Map of Geneva Steel Plant

RESTRICTED DATA—ATOMIC



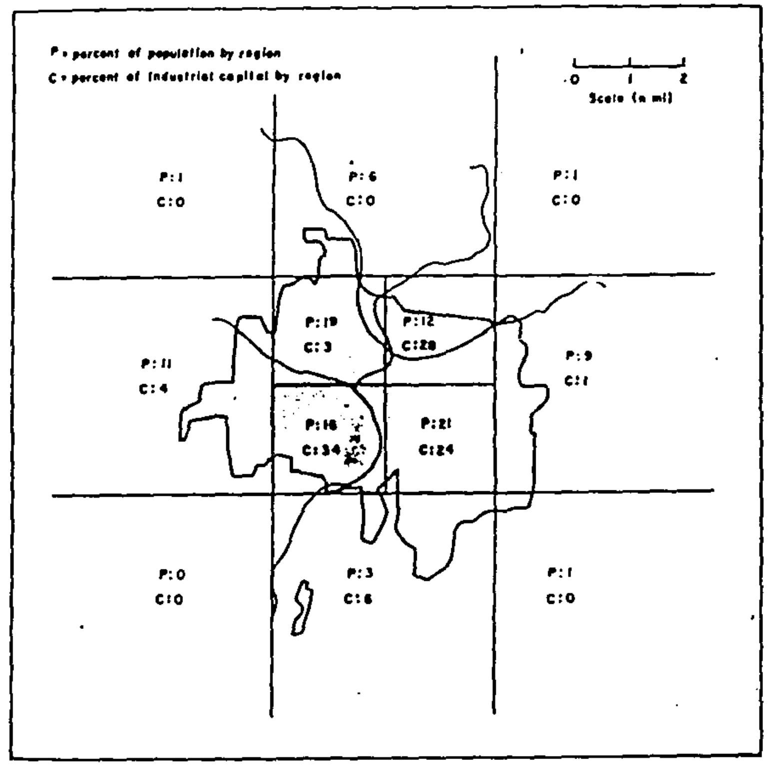


Fig. 10—Map of Dayton, showing gross distribution of population and industrial capital

Table 2

POPULATION AND CAPITAL DISTRIBUTION BY BUILDING TYPE FOR MOSCOW AND DAYTON

pe of Structure	Moscow*						Dayton			
	Population (in thousands)				Capital ($ million)		Population (in thousands)		Capital ($ million)	
	Unwarned		Long Warning							
d frame	1400	28%	667	13%	125	4%	244	84%	3	⅔%
l-bearing wall	3322	66%	3667	73%	1572†	50%	36	12½%	67	15%
t-steel frame	109	2%	109	2%	884	28½%	9	3%	222	49%
vy-steel frame	27	½%	27	½%	311	10%	0	.....	0	.....
tistory	169	3½%	558	11½%	232	7½%	1	½%	160	35½%
OTAL	5028	.....	5028	......	3124	......	290	......	452	......

*Data based on target mosaics prepared by the Air Research Division of The Library of Congress (monitored by the Deputy Directorate of gets, Department of the Air Force).
†Includes oil refinery and other "soft" industrial targets.

Table 3

CAPITAL COSTS OF ABOVE-GROUND CONSTRUCTION AND MINIMAL CONSTRUCTION TIME FOR PLANT COMPONENTS OF GENEVA STEEL*

(Costs in units of $10,000; time in months)

Component	Labor	Structural Steel	Brick	Electrical Equipment	Machinery	Total Cost	Construction Time
st furnaces	1,296	100	135	113	540	2,184	15
erhouse	800	50	...	500	870	2,220	12
n hearth	1,800	225	227	113	950	3,315	13
pper	90	18	...	5	24	137	7
king pit	240	15	35	13	50	351	8
oming mill	474	31	15	434	590	1,544	11
te mill	492	27	31	253	380	1,183	13
p mill	3,553	328	45	3,169	2,009	9,104	12
e ovens	1,380	69	156	102	370	2,077	16
l conveyors	570	55	...	110	440	1,175	6
conveyors	300	19	...	40	300	659	7
ndry	156	22	...	37	150	365	5
chant mill	354	26	...	298	439	1,117	12
chine shop	270	38	...	35	173	516	7
ices	24	4	...	5	.....	33	7
auster and booster uilding	120	15	...	35	140	310	6
station	60	3	...	80	.....	143	6
TOTAL	11,979	1,045	642	5,342	7,425	26,433	..

NOTE: Recuperation costs were computed according to the following formula: Recuperation Cost = D (Labor) + D^2 (Structural Steel + Brick) D^4 (Electrical Equipment + Machinery), where D is the damage measured by the percentage of original man-hours necessary (compare charts page 27). This formula, as well as recuperation-time estimates used in this study, is based on material supplied by the staff of the Geneva l Plant.

*See S. M. Marshall, "A Review of the Steel Industry of the United States," The RAND Corporation, Research Memorandum RM-1091, April 1953.

UNCLASSIFIED

~~SECRET~~
~~RESTRICTED DATA — ATOMIC ENERGY ACT — 1946~~

SUMMARY TABULATIONS AND MAPS

UNCLASSIFIED

UNCLASSIFIED

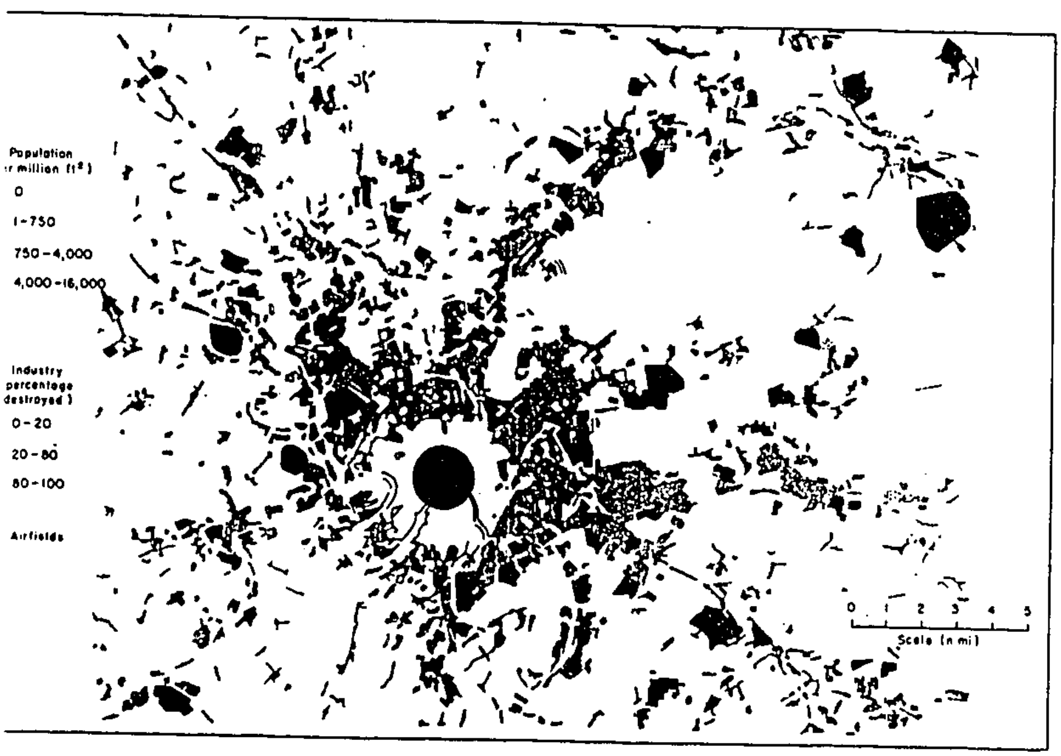


Fig. 13—Map of Moscow, showing damage from one 5-MT bomb

RESTRICTED DATA—ATOMIC ENERGY ACT—1946
SECRET

UNCLASSIFIED

UNCLASSIFIED

SECRET
RESTRICTED DATA — ATOMIC ENERGY ACT 1946

Fig. 14—Map of Moscow, showing damage from one 10-MT bomb

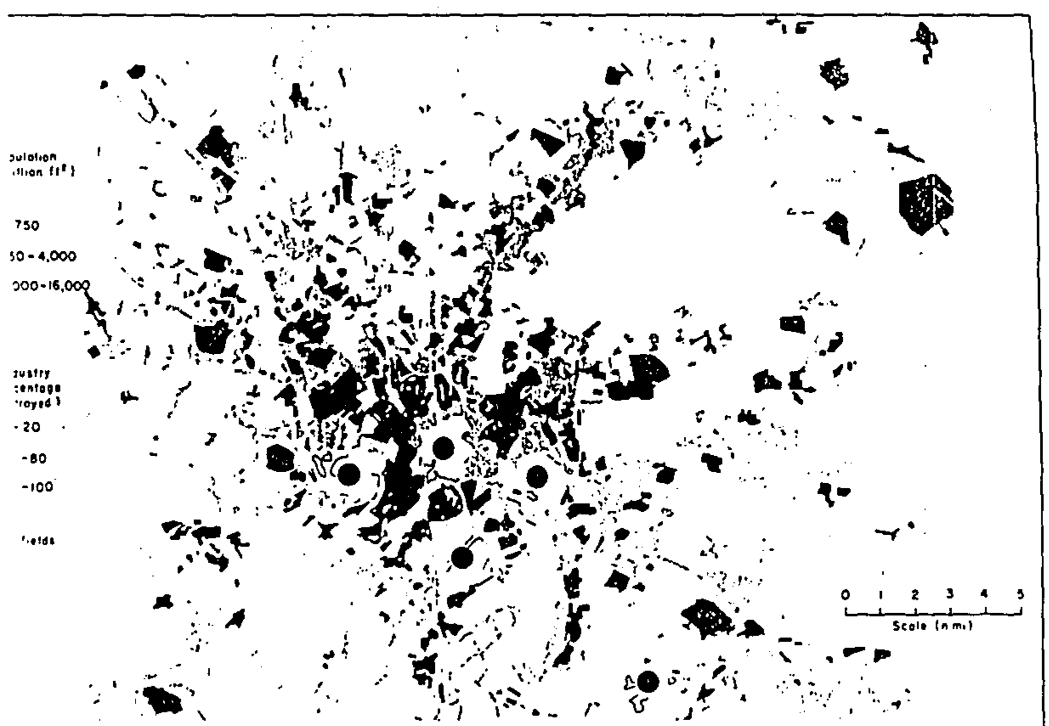


Fig. 15—Map of Moscow, showing damage from five ½-MT bombs

RESTRICTED DATA — ATOMIC ENERGY ACT 1946
SECRET

UNCLASSIFIED

Table 4

MOSCOW: SUMMARY TABULATION OF SINGLE BOMB DROPS, GROUND BURST, UNW[illegible]
AIMING POINT—KREMLIN

(In percent)

P — population killed (excluding fallout)
*P** — population killed (including fallout)
D — dwelling units destroyed

RC — industrial roof cover destroyed
I — industrial structures destroyed
C — industrial capital destroyed

		½-n-mi CEP				1-n-mi CEP			
		Expected Damage	σ	50% Level	90% Level	Expected Damage	σ	50% Level	90% Level
⅒ MT	*P*	9	1	10	9	9	2	9	[illegible]
	*P**	16	2	17	15	15	3	14	[illegible]
	D	14	1	15	13	13	2	14	[illegible]
	RC	1	1	1	0	1	1	1	[illegible]
	I	2	1	2	1	3	1	2	[illegible]
	C	1	1	1	1	2	1	1	[illegible]
½ MT	*P*	26	2	27	23	23	4	24	[illegible]
	*P**	46	2	47	42	43	5	44	[illegible]
	D	35	2	36	31	32	4	33	[illegible]
	RC	4	2	4	3	5	2	4	[illegible]
	I	10	1	10	9	11	2	10	[illegible]
	C	7	1	6	5	7	2	6	[illegible]
1 MT	*P*	36	2	36	33	33	4	34	[illegible]
	*P**	58	2	59	56	57	3	57	[illegible]
	D	46	2	46	43	43	4	44	[illegible]
	RC	8	2	9	7	9	3	8	[illegible]
	I	19	2	18	16	18	3	18	[illegible]
	C	12	1	12	11	12	2	12	[illegible]
5 MT	*P*	59	1	60	57	57	3	59	[illegible]
	*P**	82	1	82	82	82	1	82	[illegible]
	D	68	1	68	66	67	2	68	[illegible]
	RC	35	5	36	28	34	7	35	[illegible]
	I	45	3	45	41	44	4	44	[illegible]
	C	35	3	35	32	34	5	34	[illegible]
10 MT	*P*	68	1	69	68	67	2	68	[illegible]
	*P**	90	0	91	90	90	1	90	90
	D	77	1	78	77	76	2	77	73
	RC	55	4	58	50	52	7	54	43
	I	59	3	60	56	57	4	58	52
	C	50	3	52	46	49	5	49	42
25 MT	*P*	79	1	79	78	79	1	79	78
	*P**	99	0	99	98	99	1	99	98
	D	87	0	87	87	87	1	87	86
	RC	72	1	73	72	71	2	72	68
	I	74	1	74	72	73	2	74	70
	C	68	2	68	65	66	4	68	62

		2-n-mi CEP				4-n-mi CEP				8-n-mi CEP			
		Expected Damage	σ	50% Level	90% Level	Expected Damage	σ	50% Level	90% Level	Expected Damage	σ	50% Level	90% Level
⅒ MT	*P*	9	3	5	1	2	3	1	0	1	2	0	0
	*P**	8	6	7	1	4	5	2	0	1	3	0	0
	D	8	5	7	2	4	4	2	0	1	3	0	0
	RC	2	2	1	0	1	2	1	0	1	1	0	0
	I	3	2	3	1	2	2	2	0	1	2	0	0
	C	2	2	2	1	2	2	1	0	1	1	0	0
½ MT	*P*	16	8	16	5	8	8	5	1	3	5	1	0
	*P**	30	13	32	9	16	14	8	2	6	10	1	0
	D	22	10	23	8	12	10	8	2	4	7	1	0
	RC	6	4	5	3	4	4	3	0	2	3	1	0
	I	10	4	9	6	7	5	6	1	3	4	1	0
	C	7	3	7	4	5	4	4	1	2	3	1	0
1 MT	*P*	22	10	23	8	12	10	9	2	5	8	1	0
	*P**	45	14	50	22	27	20	22	3	10	16	1	0
	D	30	12	32	14	18	14	14	3	7	11	2	0
	RC	9	5	8	5	7	6	6	1	5	5	1	0
	I	16	6	16	9	11	7	10	2	5	7	2	0
	C	11	5	11	6	8	6	8	1	4	5	1	0
5 MT	*P*	48	11	51	33	31	17	30	9	14	16	5	0
	*P**	80	3	82	78	71	16	78	50	37	32	30	1
	D	60	10	64	47	43	19	45	7	20	21	11	1
	RC	30	9	30	18	20	12	19	5	9	11	4	0
	I	39	8	41	28	29	13	30	13	14	14	8	0
	C	31	7	32	20	22	11	22	8	11	13	6	0
10 MT	*P*	60	10	64	48	44	18	46	19	21	21	12	1
	*P**	90	2	90	88	87	6	89	82	58	33	73	4
	D	72	7	74	63	57	18	63	30	29	25	22	2
	RC	45	10	46	29	31	15	31	11	12	16	6	0
	I	32	8	54	40	41	14	43	23	22	18	16	1
	C	43	8	45	31	33	13	33	15	16	16	10	1
25 MT	*P*	75	6	77	68	62	16	68	37	34	26	28	3
	*P**	[illegible]	1	[illegible]	97	97	2	98	94	87	20	94	70
	D	[illegible]	4	[illegible]	[illegible]	75	13	81	58	47	28	45	8
	RC	[illegible]	9	[illegible]	[illegible]	51	17	54	28	26	23	18	1
	I	[illegible]	[illegible]	[illegible]	[illegible]	59	13	62	36	33	23	34	7

Table 5

MOSCOW: SUMMARY TABULATION OF MULTIPLE BOMB DROPS, GROUND BURST, UNWARNED

(In percent)

P — population killed (excluding fallout)
D — dwelling units destroyed
C — industrial capital destroyed

CEP		½ n mi					1 n mi				
Number of Bombs		2	4	6	8	10	2	4	6	8	10
1/10 MT	P	11	16	20	24	27	11	16	20	23	[illegible]
	D	17	22	27	31	35	16	22	27	31	[illegible]
	C	9	16	23	29	32	8	14	18	21	[illegible]
½ MT	P	31	40	48	54	58	30	41	49	55	[illegible]
	D	40	50	58	64	67	39	50	58	63	[illegible]
	C	20	34	45	53	57	23	33	41	47	[illegible]
1 MT	P	44	54	61	67	71	41	52	60	66	[illegible]
	D	51	61	68	74	77	50	61	69	74	[illegible]
	C	30	46	57	65	68	28	42	51	58	[illegible]
5 MT	P	68	77	83	86	88	67	76	82	85	87
	D	76	83	88	91	93	75	82	86	89	[illegible]
	C	52	68	78	84	87	54	67	75	81	[illegible]
10 MT	P	76	85	90	94	96	74	84	89	93	[illegible]
	D	83	90	94	97	99	82	89	93	96	[illegible]
	C	64	77	85	90	92	65	77	84	89	[illegible]
25 MT	P	86	93	97	99	100	86	93	97	99	100
	D	92	97	99	100	100	92	97	99	100	100
	C	78	86	93	97	98	78	86	92	96	98

CEP		2 n mi					4 n mi				
Number of Bombs		2	4	6	8	10	2	4	6	8	10
1/10 MT	P	8	14	20	25	30	4	9	14	18	22
	D	11	18	25	31	37	7	14	20	26	31
	C	6	11	15	19	22	3	6	9	12	15
½ MT	P	21	33	42	50	56	13	24	35	44	52
	D	29	43	53	60	65	17	28	37	46	53
	C	15	26	33	40	45	10	19	26	32	36
1 MT	P	31	45	53	59	64	21	38	49	58	64
	D	43	55	63	70	75	28	48	61	70	75
	C	24	36	44	49	53	14	26	36	44	49
5 MT	P	61	73	80	84	86	46	70	79	84	86
	D	70	80	[illegible]	89	92	61	79	87	90	92
	C	49	61	[illegible]	74	79	38	56	66	72	75
10 MT	P	69	82	88	91	93	60	80	87	90	92
	D	78	87	92	95	96	71	87	92	94	96
	C	60	73	79	83	86	52	68	76	81	84
25 MT	P	85	92	96	98	99	78	91	96	98	99
	D	90	95	98	100	100	86	95	98	99	100
	C	76	85	91	95	97	69	82	88	92	94

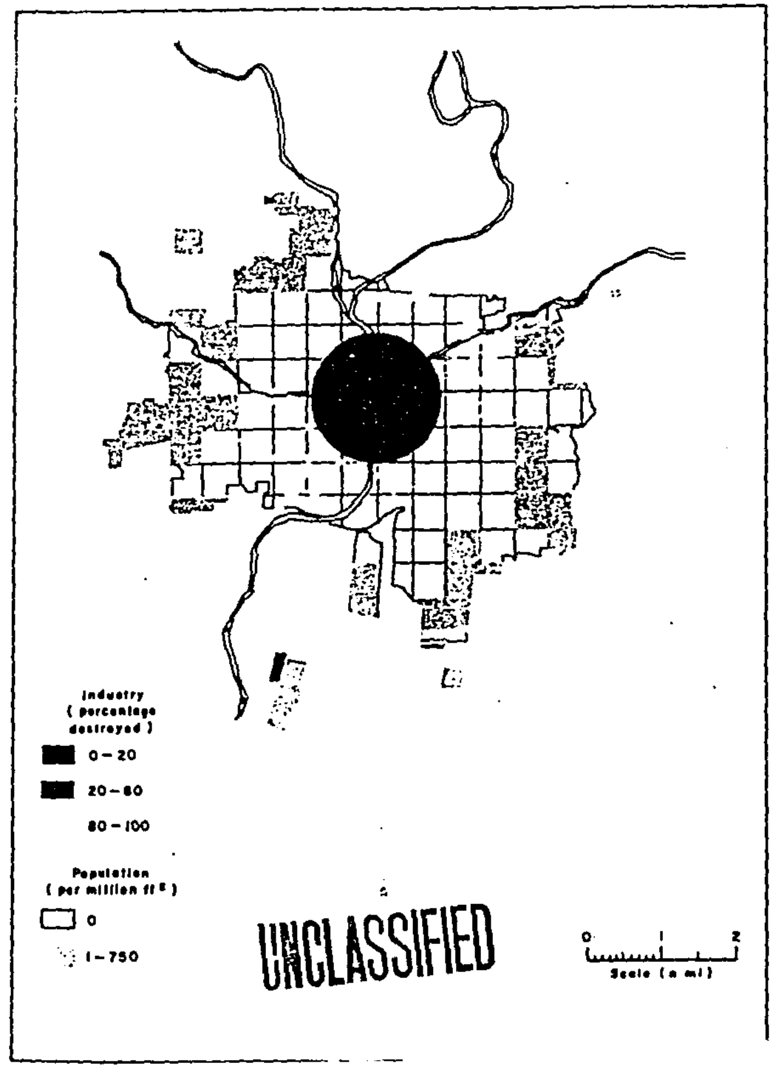

Industry
(percentage destroyed)
0 – 20
20 – 80
80 – 100
Population
(per million ft²)
0
1 – 750
0
1
2
Scale (n mi)

Table 7

DAYTON: SUMMARY TABULATION OF MULTIPLE BOMB DROPS, GROUND BURST, UNWARNED

(In percent)

P — population killed (excluding fallout)
D — dwelling units destroyed
C — industrial capital destroyed

CEP		½ n mi					1 n mi				
Number of Bombs		2	4	6	8	10	2	4	6	8	[illegible]
1/10 MT	*P*	25	42	55	66	70	26	41	54	64	[illegible]
	D	41	59	70	78	83	42	60	73	80	[illegible]
	C	31	49	57	62	66	22	36	47	53	[illegible]
½ MT	*P*	60	80	90	94	96	62	80	89	93	[illegible]
	D	81	93	98	99	100	82	93	97	98	[illegible]
	C	57	75	84	89	93	50	66	76	82	[illegible]
1 MT	*P*	80	95	98	99	100	80	91	96	98	99
	D	94	99	100	100	100	94	99	100	100	100
	C	72	83	90	95	96	63	75	85	91	[illegible]
5 MT	*P*	97	100	100	100	100	99	100	100	100	100
	D	100	100	100	100	100	100	100	100	100	100
	C	91	96	99	100	100	89	97	99	100	[illegible]
10 MT	*P*	100	100	100	100	100	100	100	100	100	100
	D	100	100	100	100	100	100	100	100	100	100
	C	99	100	100	100	100	98	100	100	100	100
25 MT	*P*	...	...	...	...	...	...	...	...	...	...
	D	...	...	...	...	...	...	...	...	...	...
	C	...	...	...	...	...	...	...	...	...	...

CEP		2 n mi					4 n mi				
Number of Bombs		2	4	6	8	10	2	4	6	8	10
1/10 MT	*P*	15	30	41	50	56	4	14	22	29	35
	D	26	47	60	70	76	8	22	33	45	54
	C	13	23	31	37	42	4	9	13	17	20
½ MT	*P*	41	67	81	89	93	17	34	49	65	75
	D	61	86	95	98	99	30	53	71	86	93
	C	32	52	63	70	76	10	20	29	40	45
1 MT	*P*	57	83	94	97	99	25	54	71	83	91
	D	77	95	99	100	100	43	76	89	94	98
	C	44	66	76	82	86	18	36	49	59	66
5 MT	*P*	93	99	100	100	100	66	94	99	100	100
	D	99	100	100	100	100	86	99	100	100	100
	C	78	92	98	99	99	42	71	83	89	93
10 MT	*P*	98	100	100	100	100	82	99	100	100	100
	D	100	100	100	100	100	96	100	100	100	100
	C	89	98	99	100	100	54	84	93	96	98
25 MT	*P*	...	...	...	...	...	96	100	100	100	100
	D	...	...	...	...	...	100	100	100	100	100
	C	...	...	...	...	...	73	95	98	99	100

Table 8

GENEVA STEEL PLANT: SUMMARY TABULATION OF SINGLE BOMB DROPS, GROUND AND AIR BURSTS

(Percentage of total required for reconstruction)

Item	Ground Burst			Air Burst*		
	1500-ft CEP	3000-ft CEP	6000-ft CEP	1500-ft CEP	3000-ft CEP	6000-ft CEP
Man-hours	78	56	31	65	49	30
Structural steel	63	40	18	45	30	15
Brick	63	39	15	41	27	12
Electrical equipment	61	32	14	36	20	9
Machinery	61	33	13	35	19	8
Total	69	43	22	49	34	18
Recuperation time	81	64	40	71	57	36
Man-hours	98	91	65	83	76	57
Structural steel	96	84	51	70	60	38
Brick	96	81	49	60	52	33
Electrical equipment	98	82	42	64	49	25
Machinery	96	80	42	58	45	24
Total	97	85	53	71	60	40
Recuperation time	99	94	71	85	80	62
Man-hours	..	100	94	..	86	80
Structural steel	..	99	91	..	76	67
Brick	..	99	87	..	65	57
Electrical equipment	..	100	89	..	67	55
Machinery	..	99	87	..	62	51
Total	..	100	91	..	75	66
Recuperation time	..	100	97	..	87	83

:0-ft 1-KT equivalent.

RESULTS ON MORTALITIES

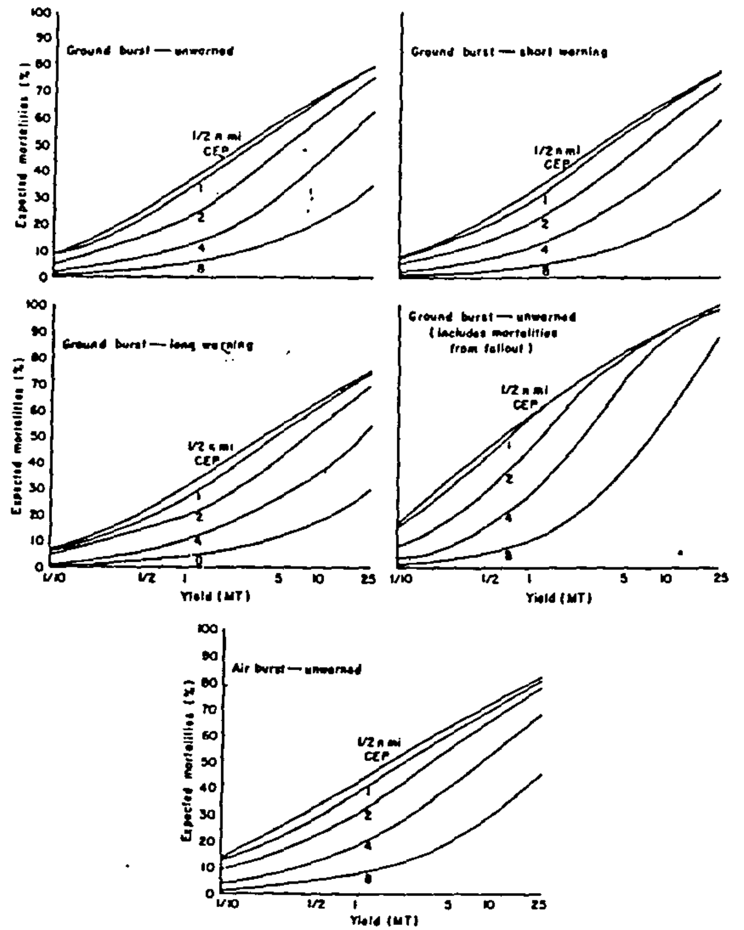


Fig. 17—Moscow: mortalities vs yield, by CEP; single bomb drop; DGZ—Kremlin

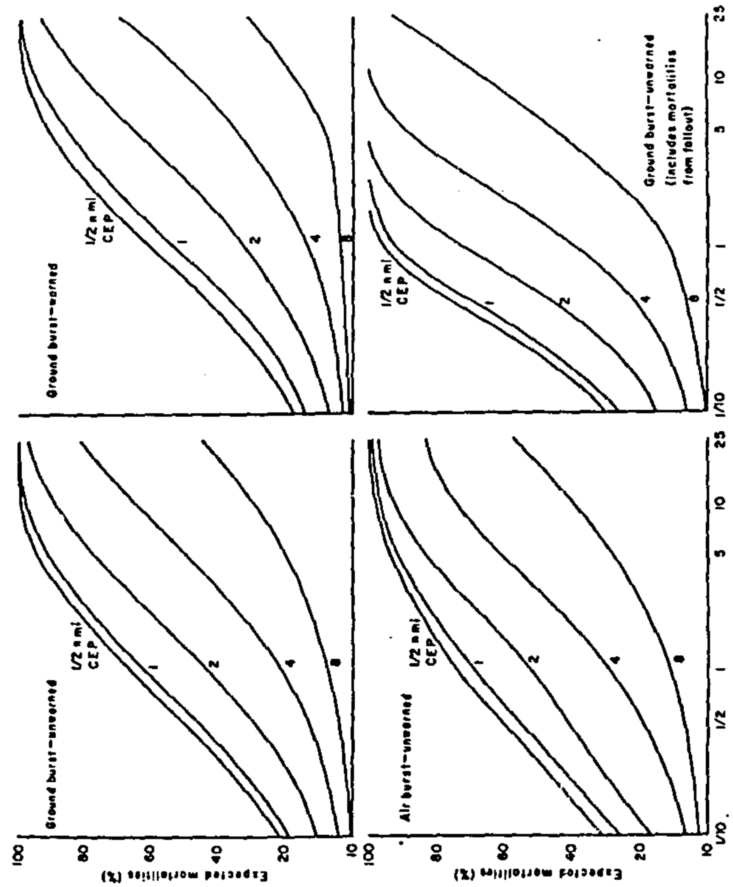


Fig. 18—Dayton: mortalities vs yield, by CEP; single bomb drop; DGZ—city center

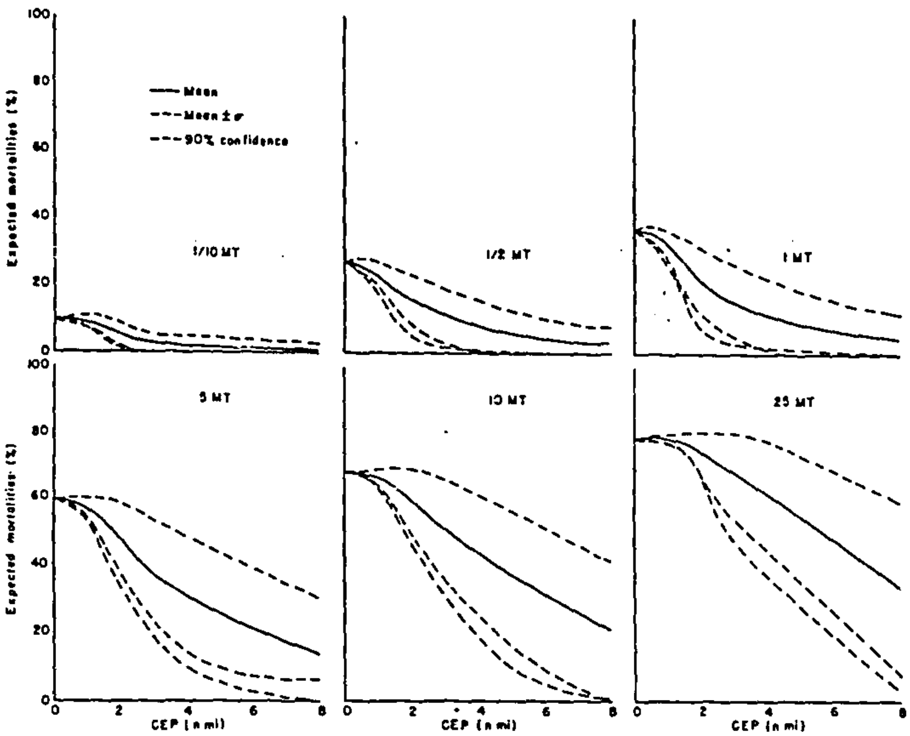


Fig. 19—Moscow: mortalities vs CEP, showing standard deviation and 90 per cent confidence; ground burst, unwarned; DGZ—Kremlin

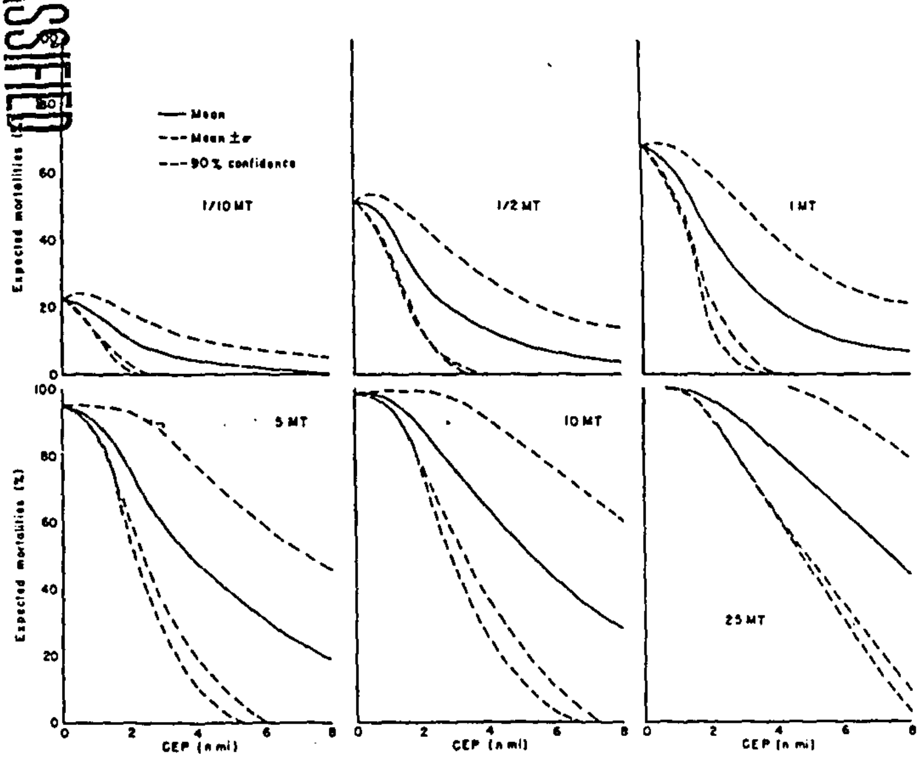


Fig. 20—Dayton: mortalities vs CEP, showing standard deviation and 90 per cent confidence; ground burst, unwarned; DGZ—city center

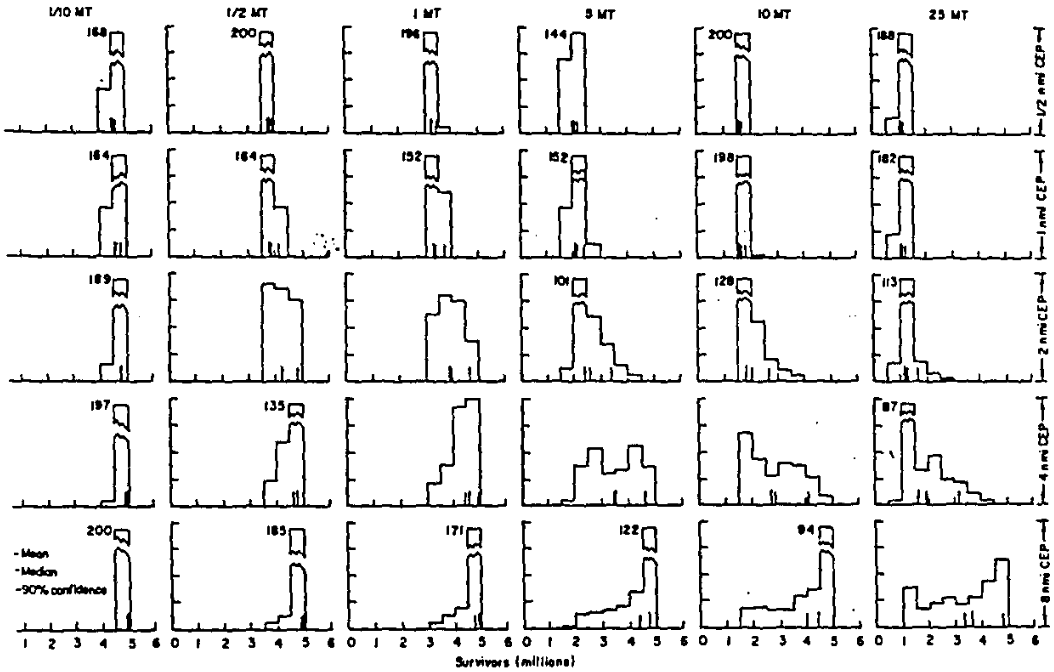


Fig. 21—Moscow: frequency distributions for 200 single bomb drops; survivors

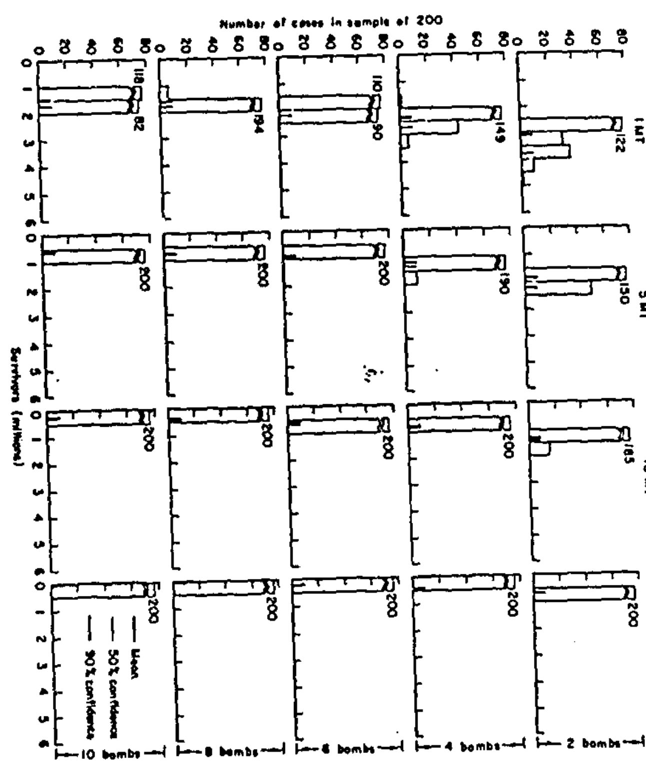


Fig. 22a—Moscow: frequency distributions for 200 multidrops, 1-n-mi CEP; survivors

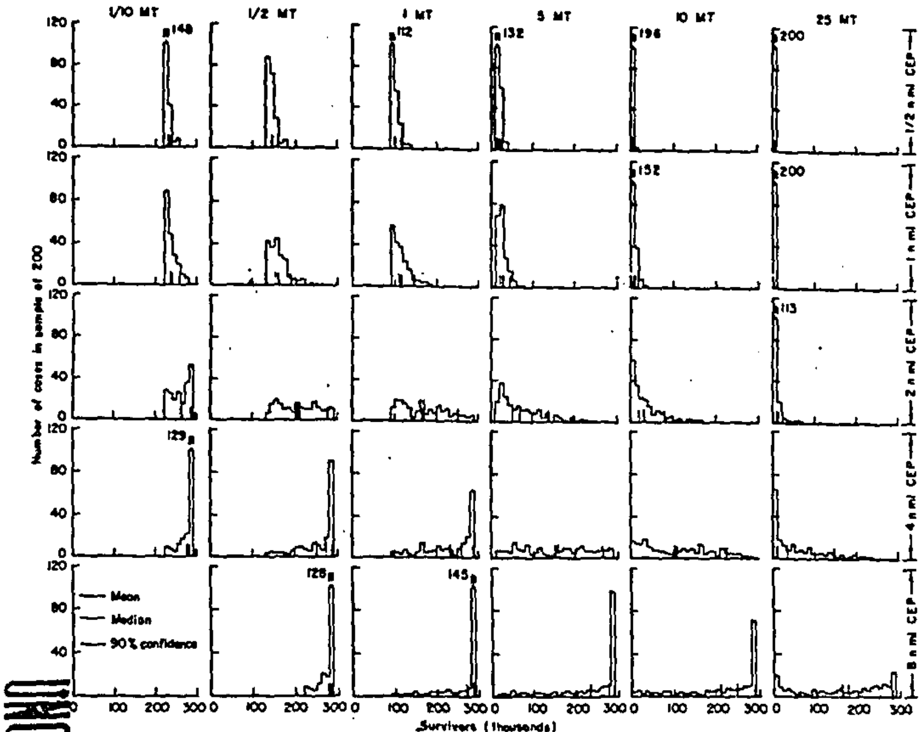


Fig. 23—Dayton: frequency distributions for 200 single bomb drops; survivors

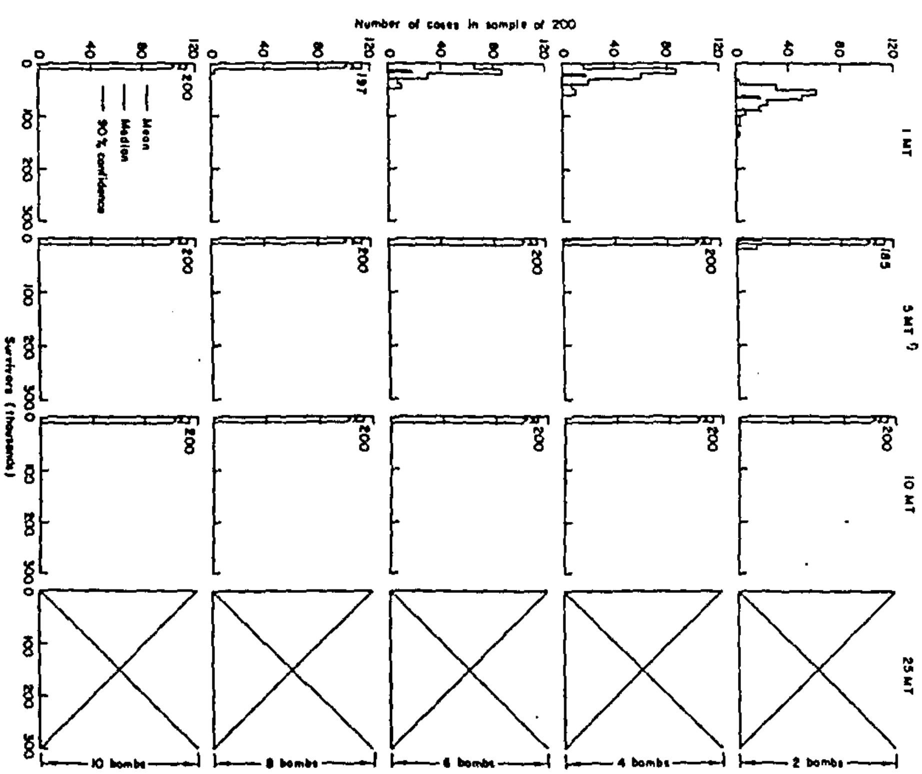


Fig. 24a—Dayton: frequency distributions for 200 multidrops, 1-n-mi CEP; survivors

UNCLASSIFIED

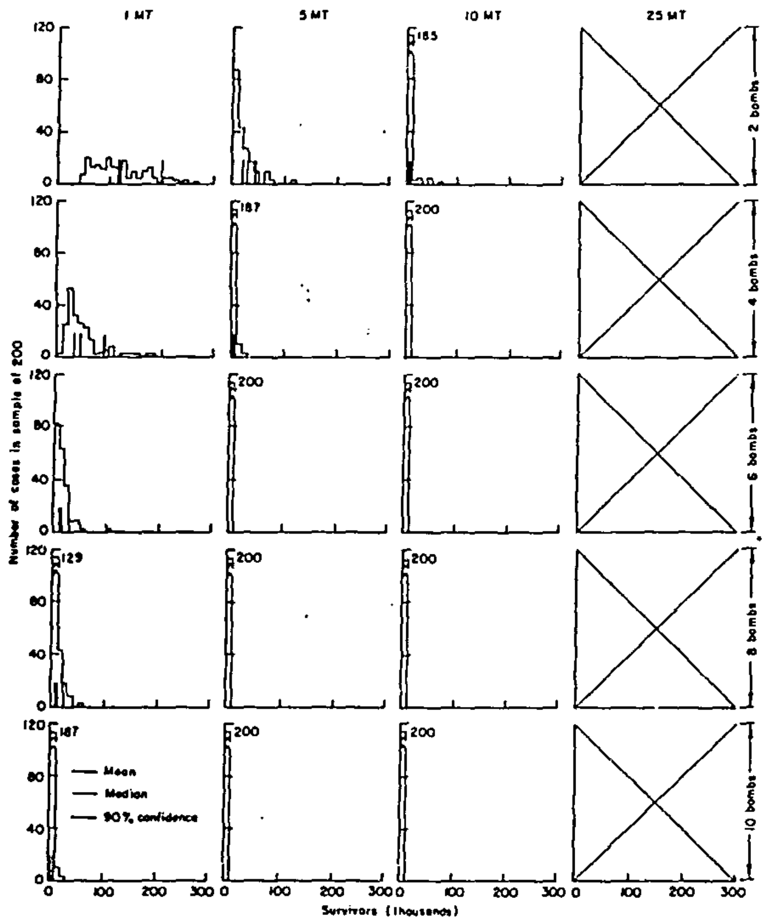
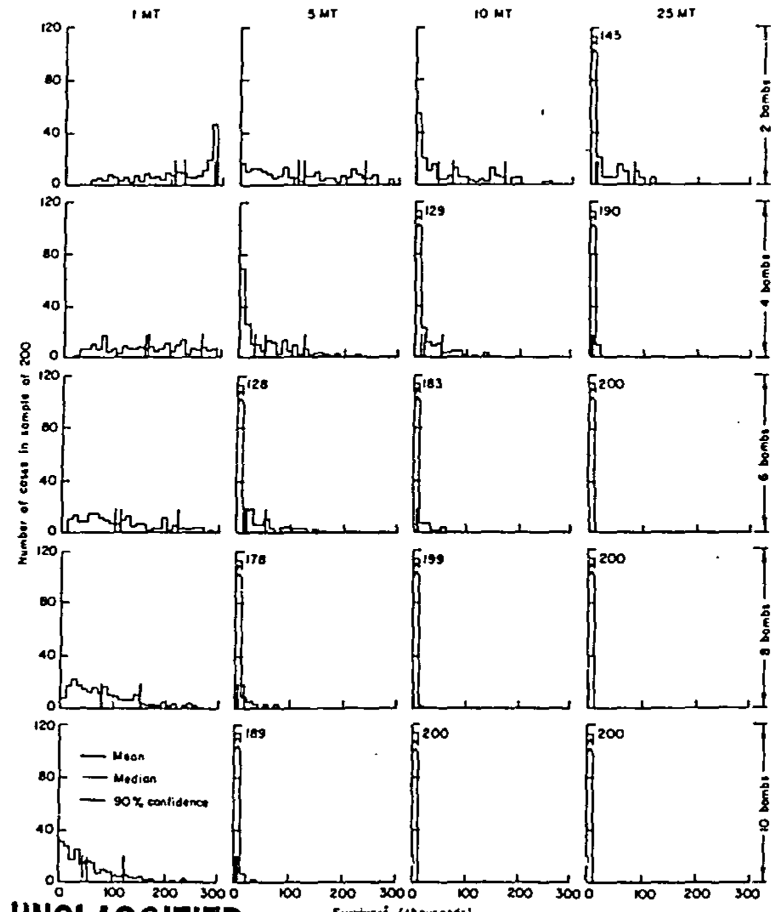


Fig. 24b—Dayton: frequency distributions for 200 multidrops, 2-n-mi CEP; survivors



UNCLASSIFIED

Fig. 24c—Dayton: frequency distributions for 200 multidrops, 5-n-mi CEP; survivors

UNCLASSIFIED

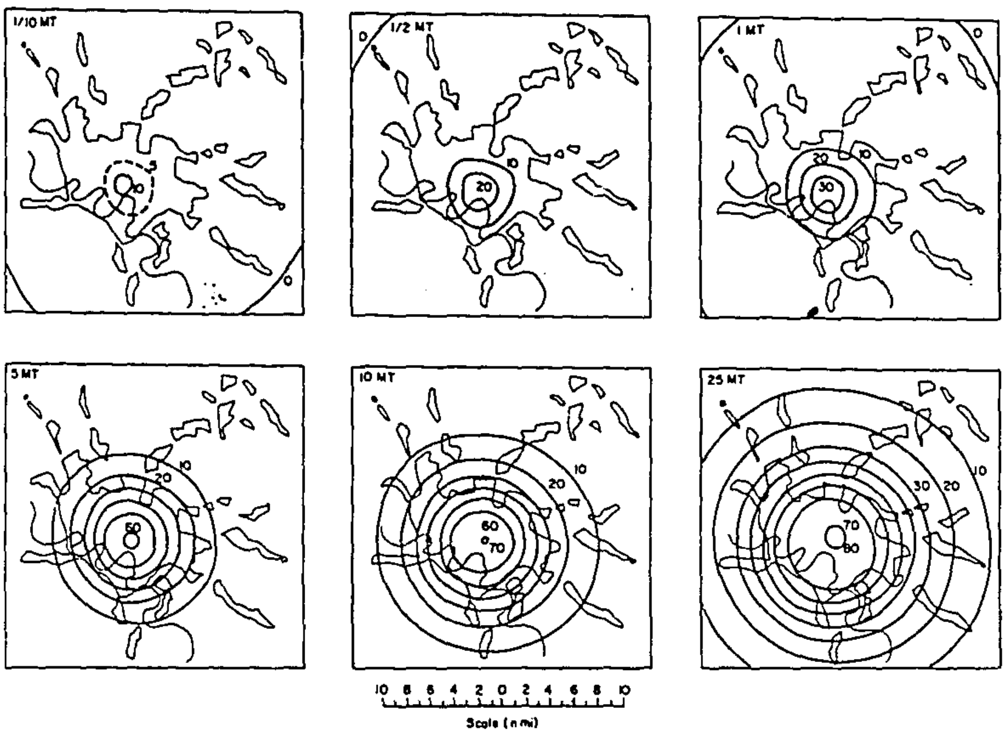


Fig. 25—Moscow: contours of GZ's producing equal mortalities (percent)

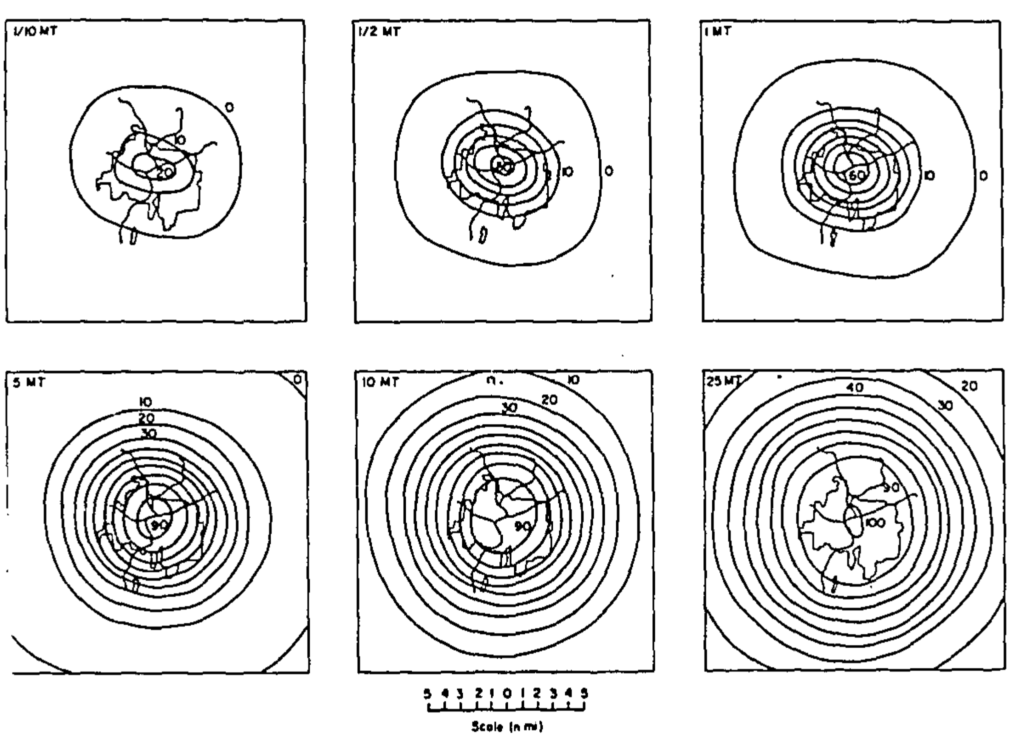


Fig. 26—Dayton: contours of GZ's producing equal mortalities (percent)

UNCLASSIFIED

UNCLASSIFIED

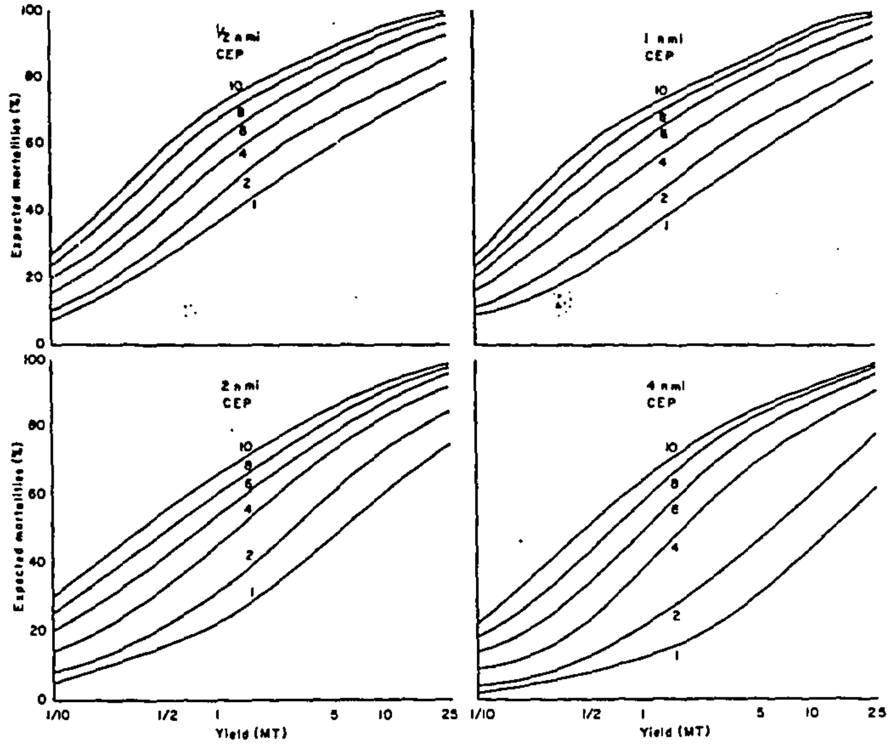


Fig. 27—Moscow: mortalities vs yield, by number of bombs; unwarned (numbers on curves show number of bombs)

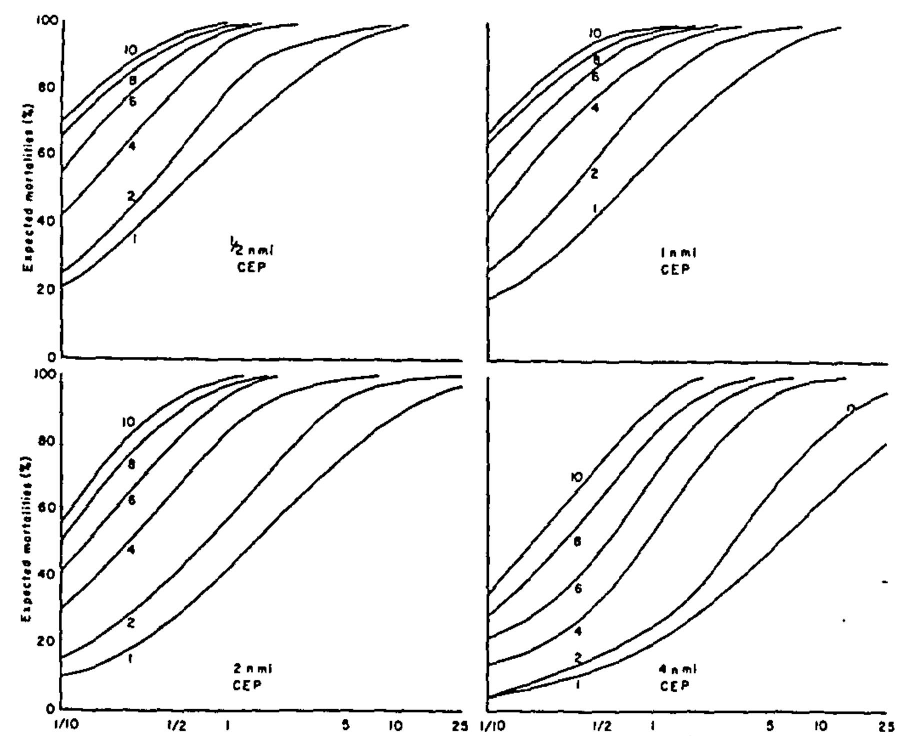


Fig. 28—Dayton: mortalities vs yield, by number of bombs; unwarned (numbers on curves show number of bombs)

UNCLASSIFIED

UNCLASSIFIED

~~SECRET~~
~~RESTRICTED DATA—ATOMIC ENERGY ACT 1946~~

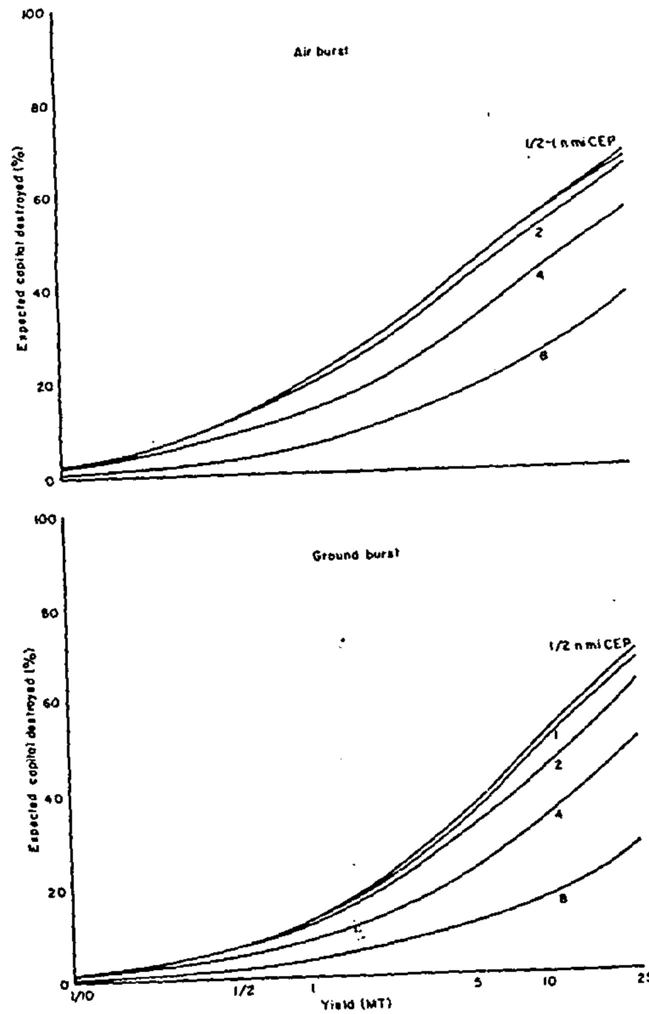
RESULTS ON CAPITAL DESTRUCTION

UNCLASSIFIED

UNCLASSIFIED

SECRET

RESTRICTED ... ACT 1946



UNCLASSIFIED

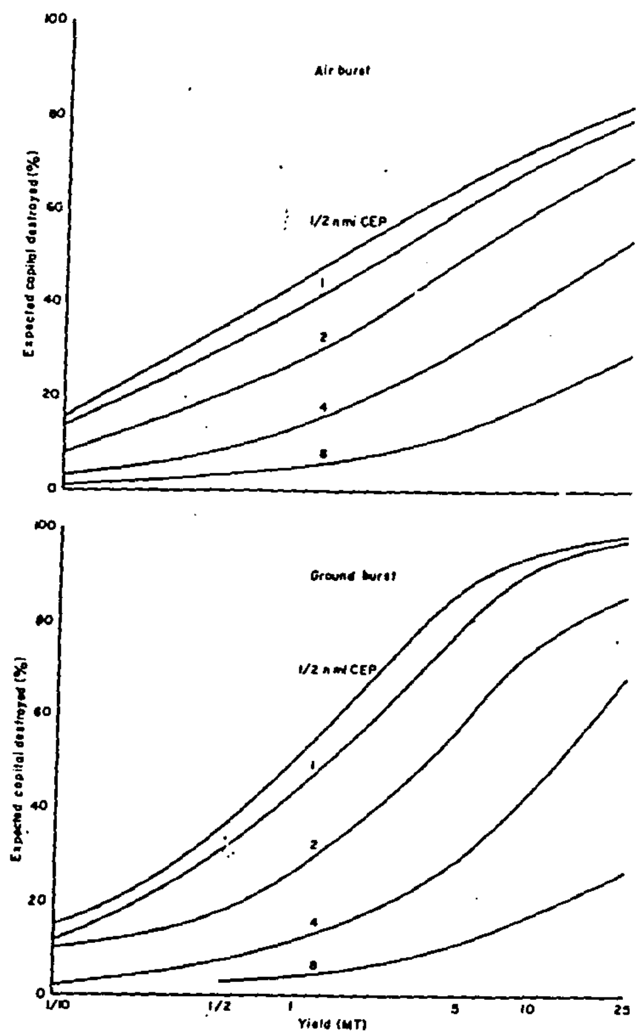
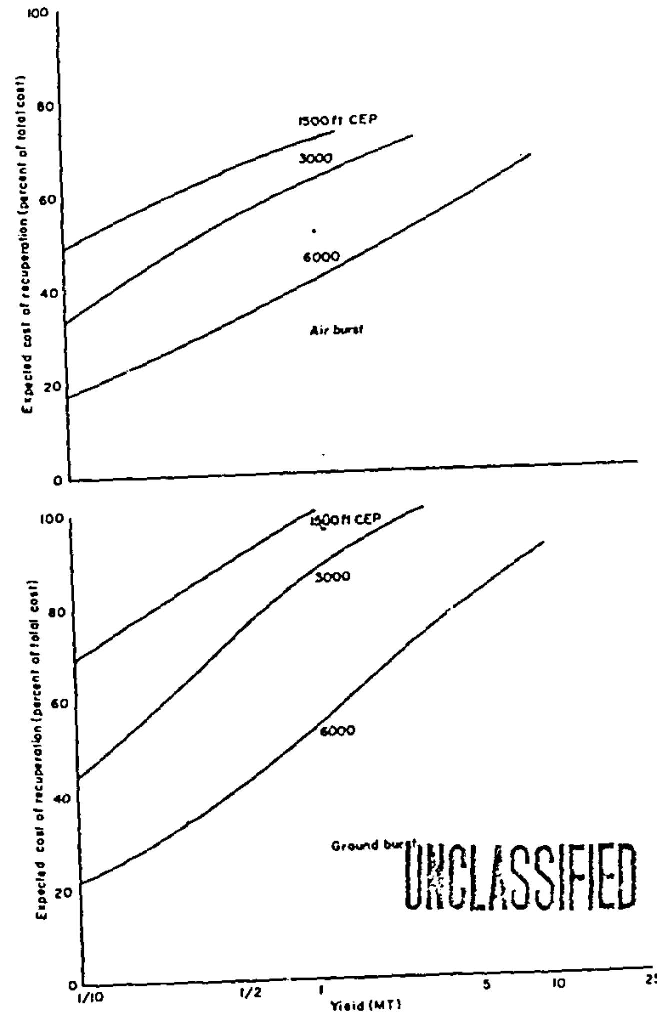


Fig. 30—Dayton: capital destroyed vs yield, by CEP: ground and



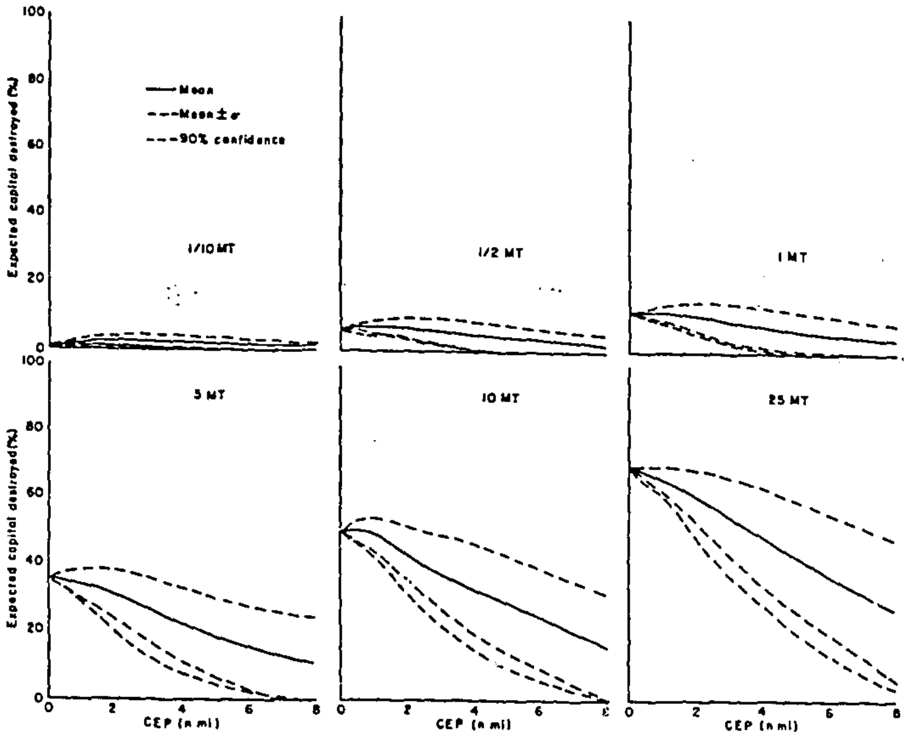


Fig. 32—Moscow: capital destroyed vs CEP, showing standard deviation and 90 per cent confidence; ground burst; DGZ—Kremlin

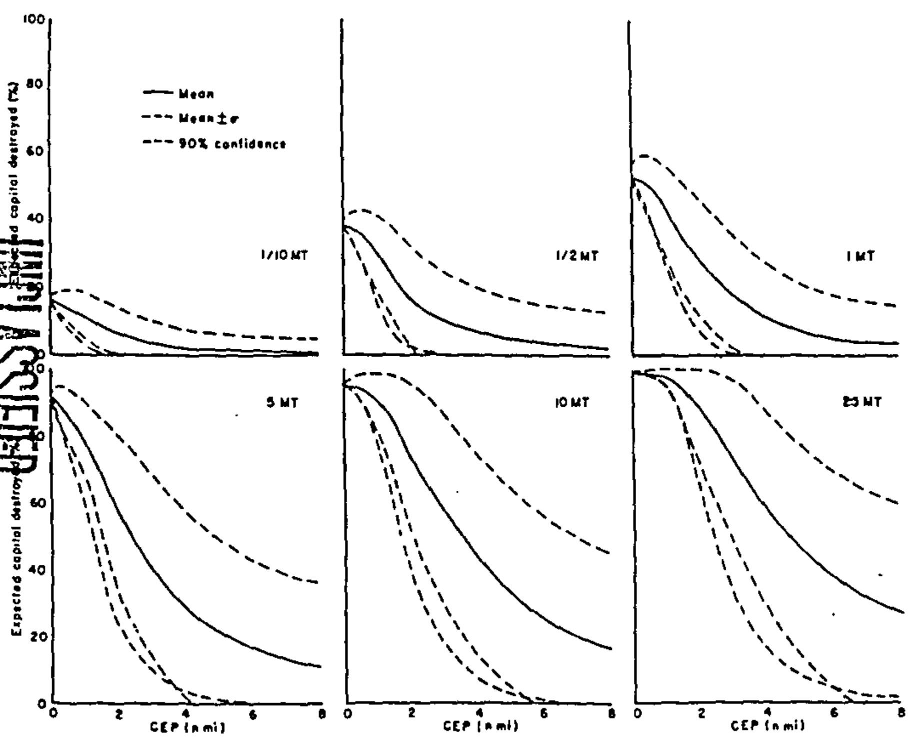


Fig. 33—Dayton: capital destroyed vs CEP, showing standard deviation and 90 per cent confidence; ground burst; DGZ—city center

SECRET

UNCLASSIFIED

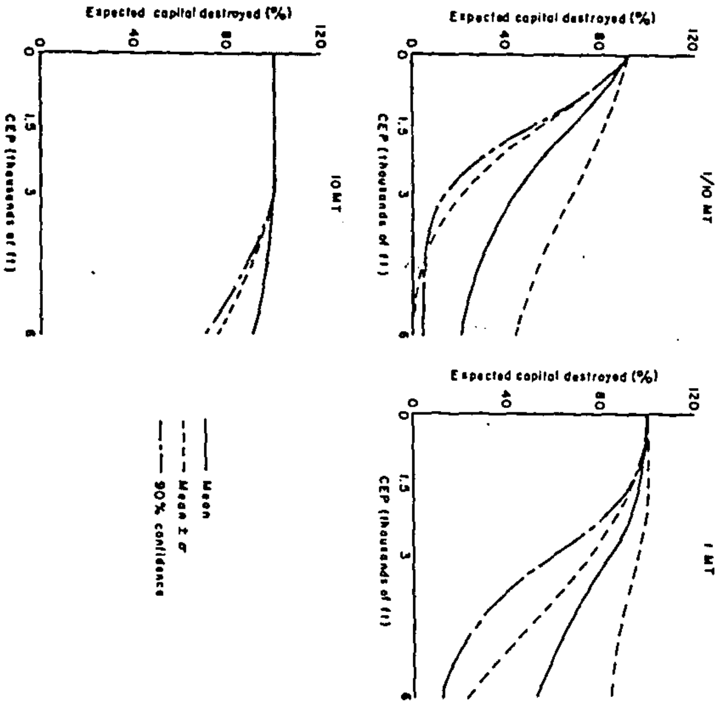


Fig. 34—Geneva Steel Plant: capital destroyed vs CEP; ground burst

SECRET

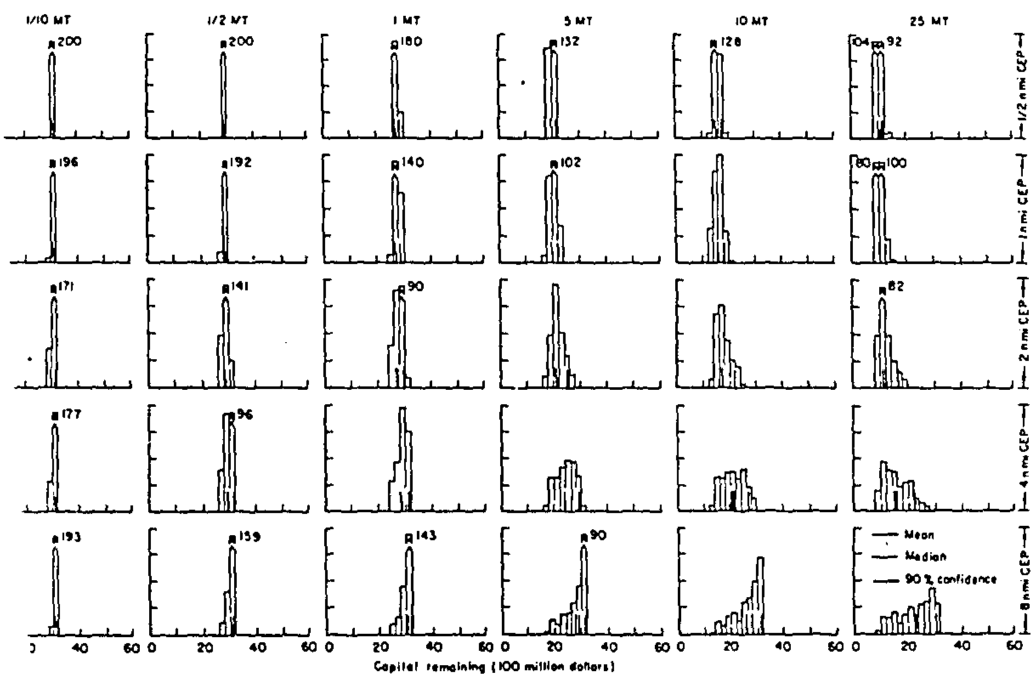


Fig. 35—Moscow: frequency distributions for 200 single bomb drops; capital remaining

UNCLASSIFIED

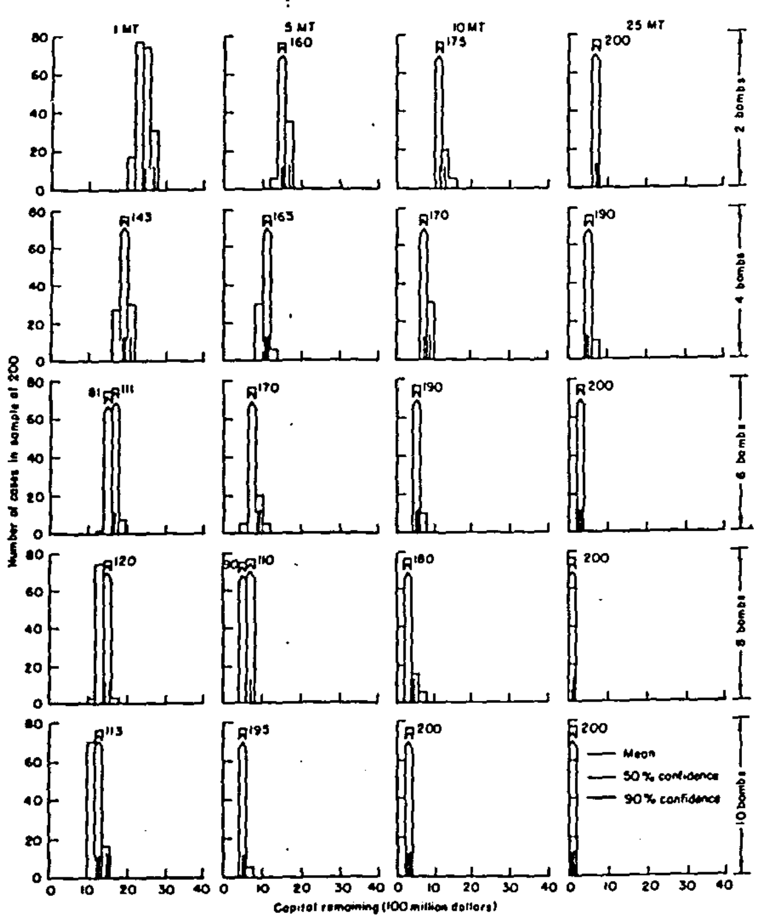


Fig. 36a—Moscow: frequency distributions for 200 multidrops, 1-n-mi CEP; capital remaining

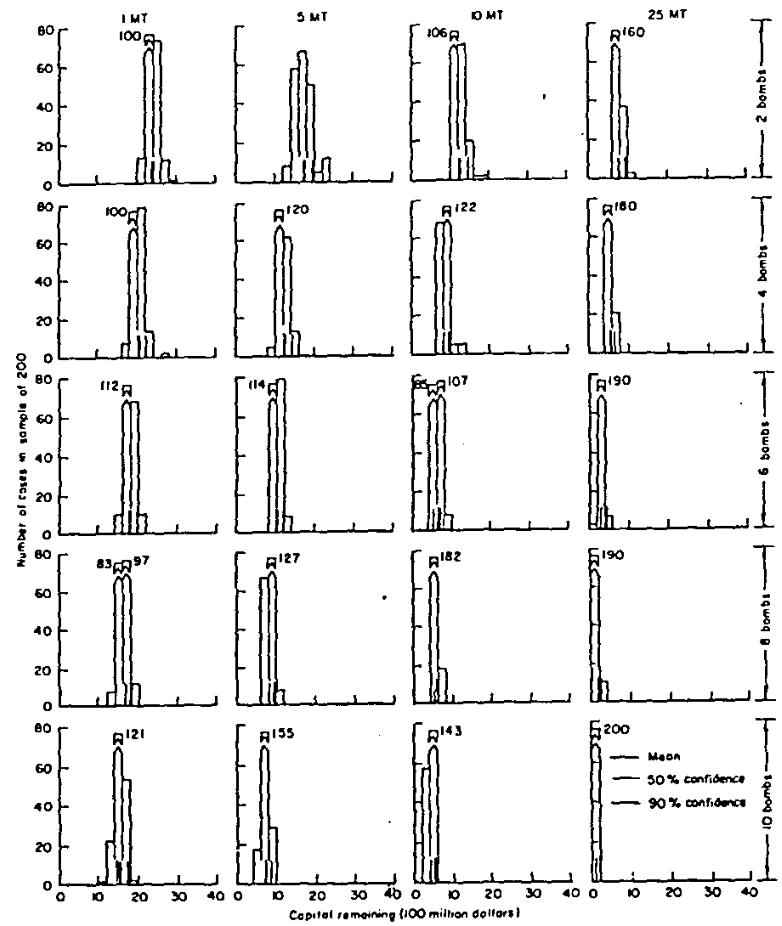


Fig. 36b—Moscow: frequency distributions for 200 multidrops, 2-n-mi CEP; capital remaining

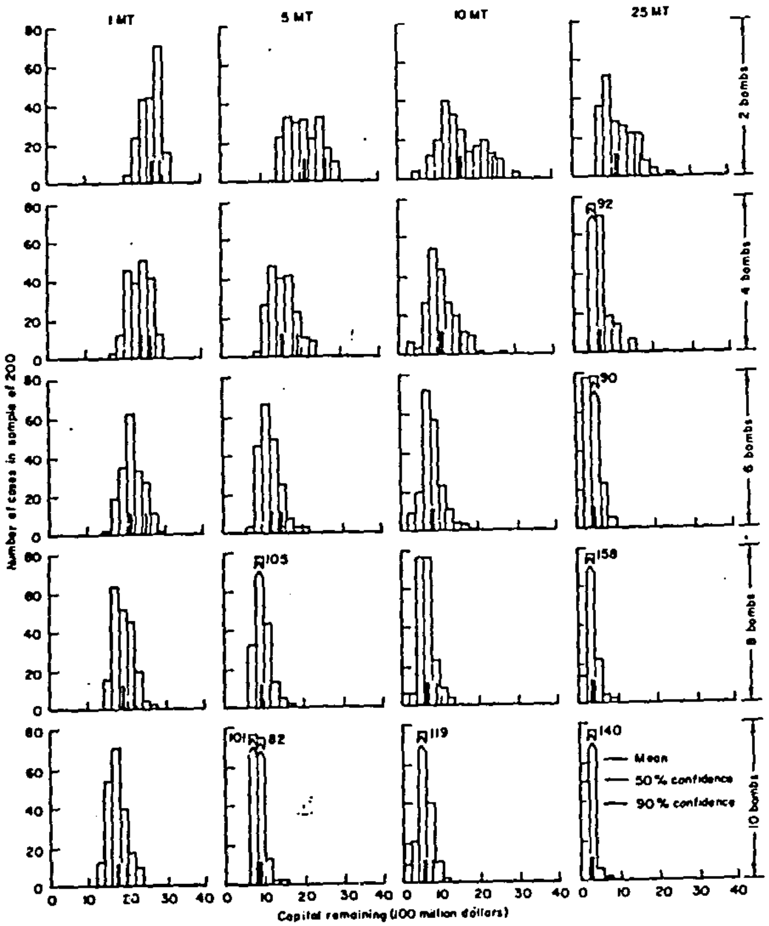


Fig. 36c—Moscow: frequency distributions for 200 multidrops, 5-n-mi CEP; capital remaining

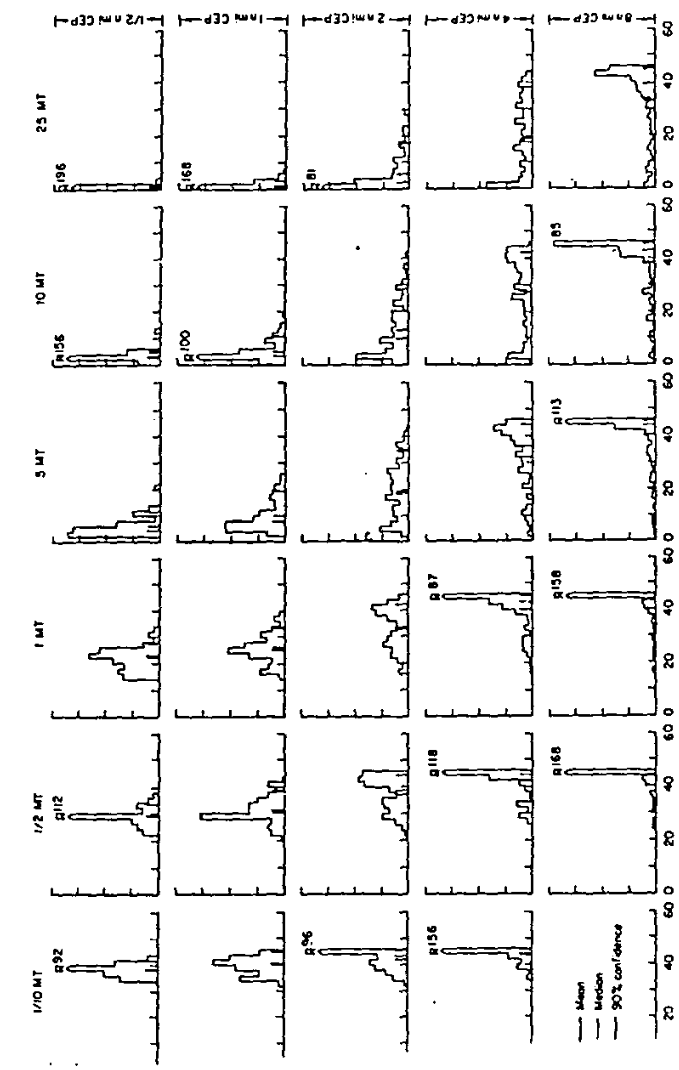


Fig. 37—Dayton: frequency distributions for 200 single bomb drops; capital remaining

UNCLASSIFIED

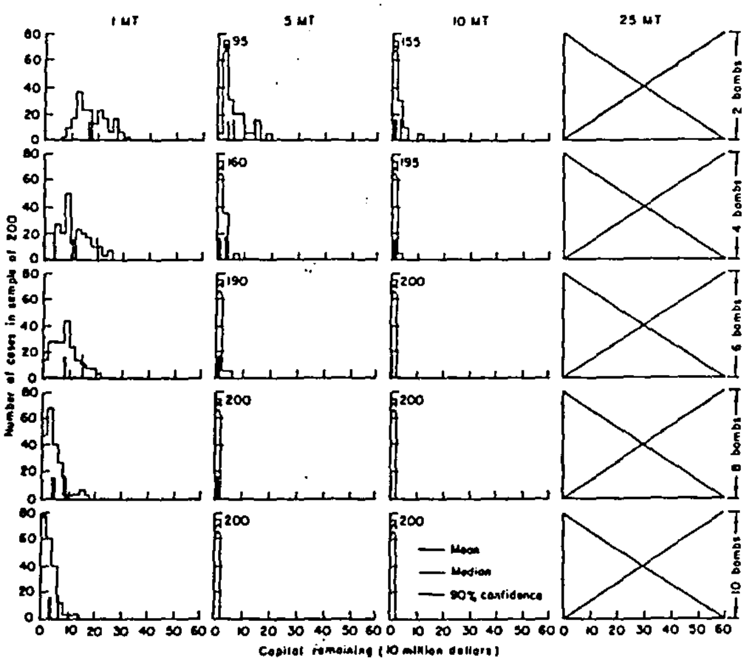


Fig. 38a—Dayton: frequency distributions for 200 multidrops, 1-n-mi CEP; capital remaining

SECRET
RESTRICTED DATA ATOMIC ENERGY ACT—1946

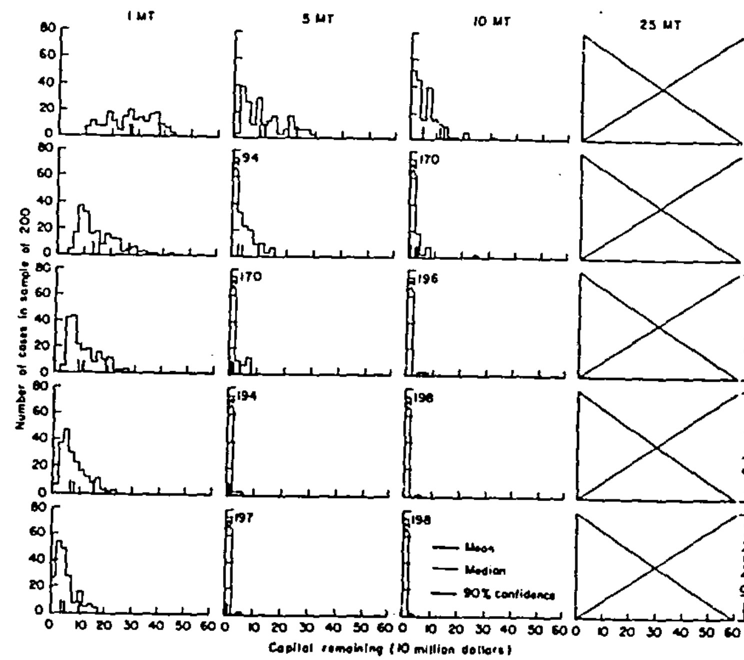


Fig. 38b—Dayton: frequency distributions for 200 multidrops, 2-n-mi CEP; capital remaining

UNCLASSIFIED

SECRET

UNCLASSIFIED

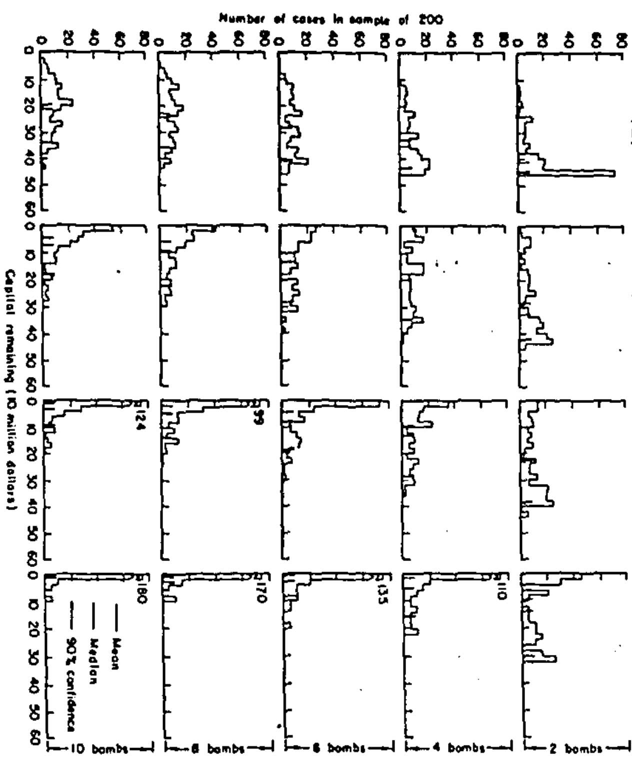


Fig. 38c—Dayton: frequency distributions for 200 multidrops, 5-n-mi CEP; capital remaining

UNCLASSIFIED

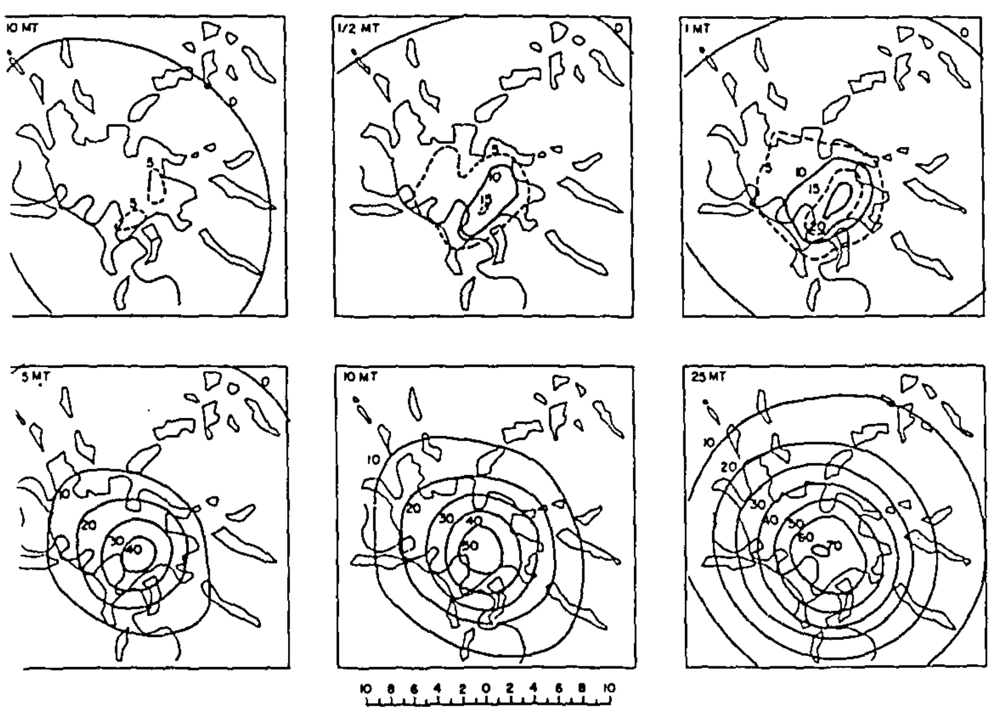


Fig. 39—Moscow: contours of GZ's producing equal capital destruction (per cent capital destroyed)

SECRET

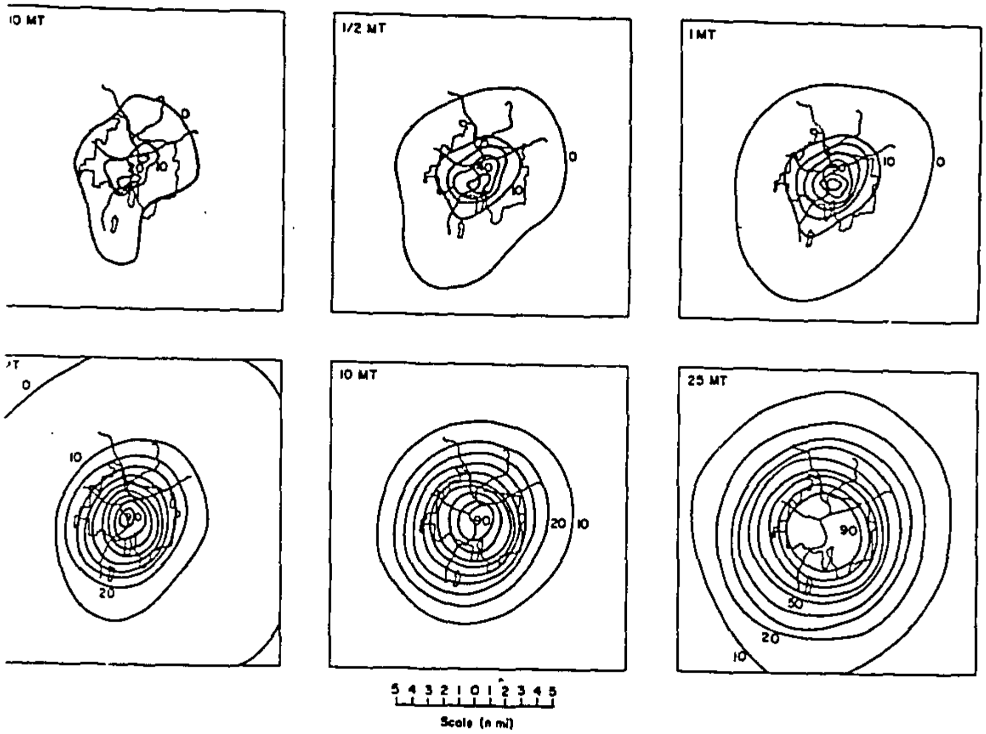
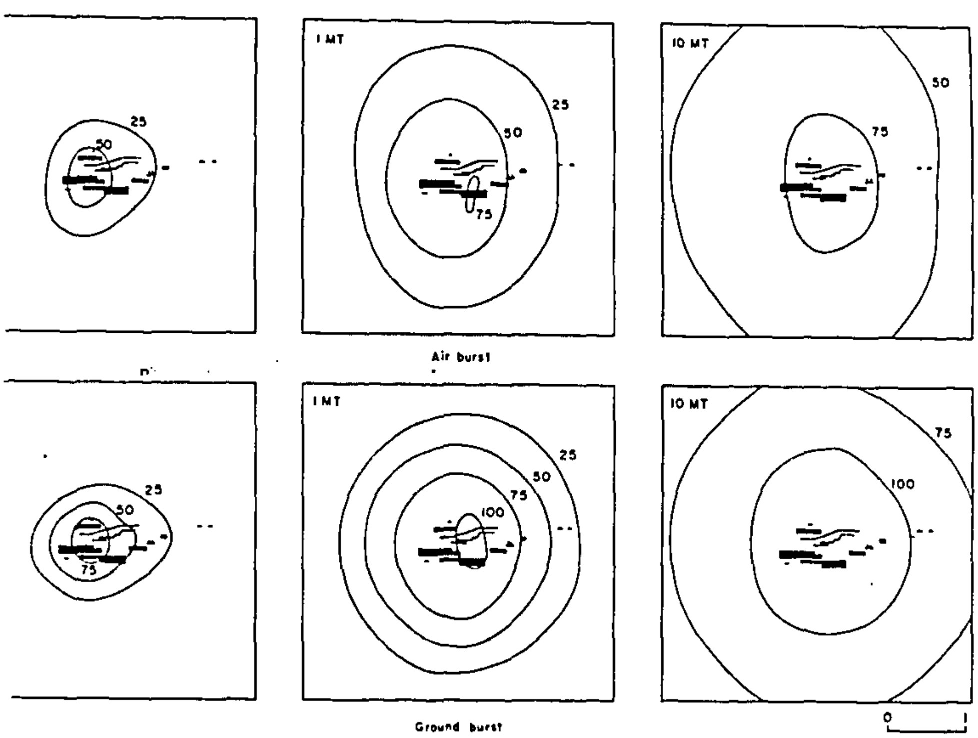


Fig. 40—Dayton: contours of GZ's producing equal capital destruction (percent capital destroyed)



). 41—Geneva Steel Plant: contours of GZ's producing equal capital destruction (percent capital destroyed)

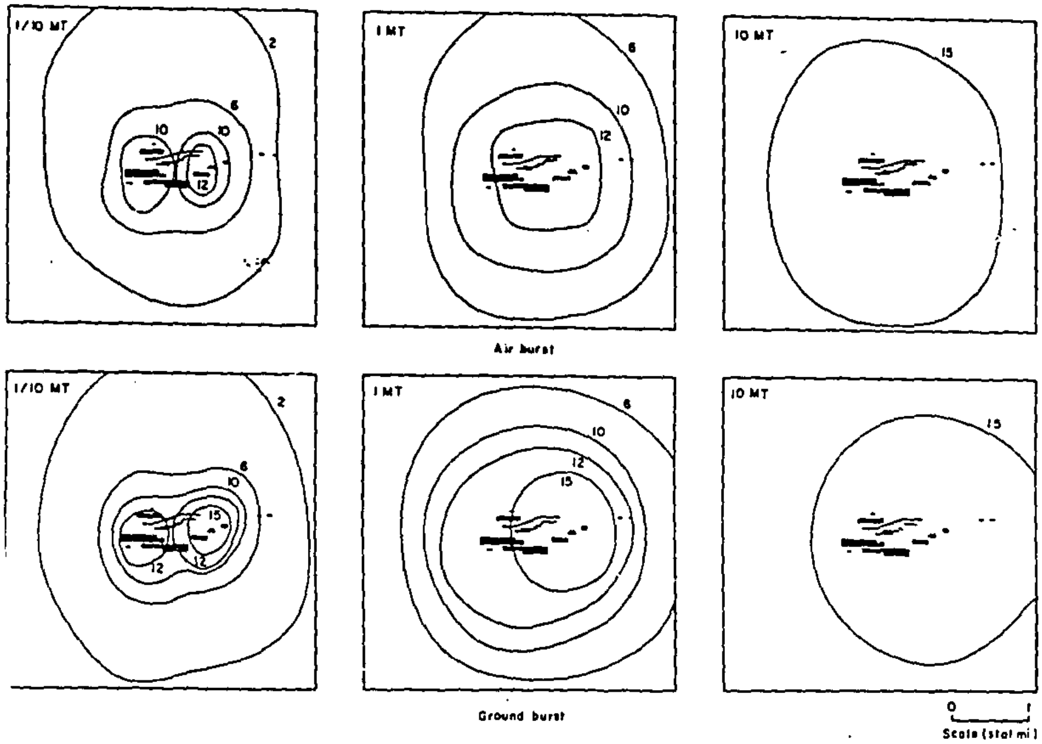


Fig. 42—Geneva Steel Plant: contours of GZ's producing equal minimum recuperation time (time out, in months)

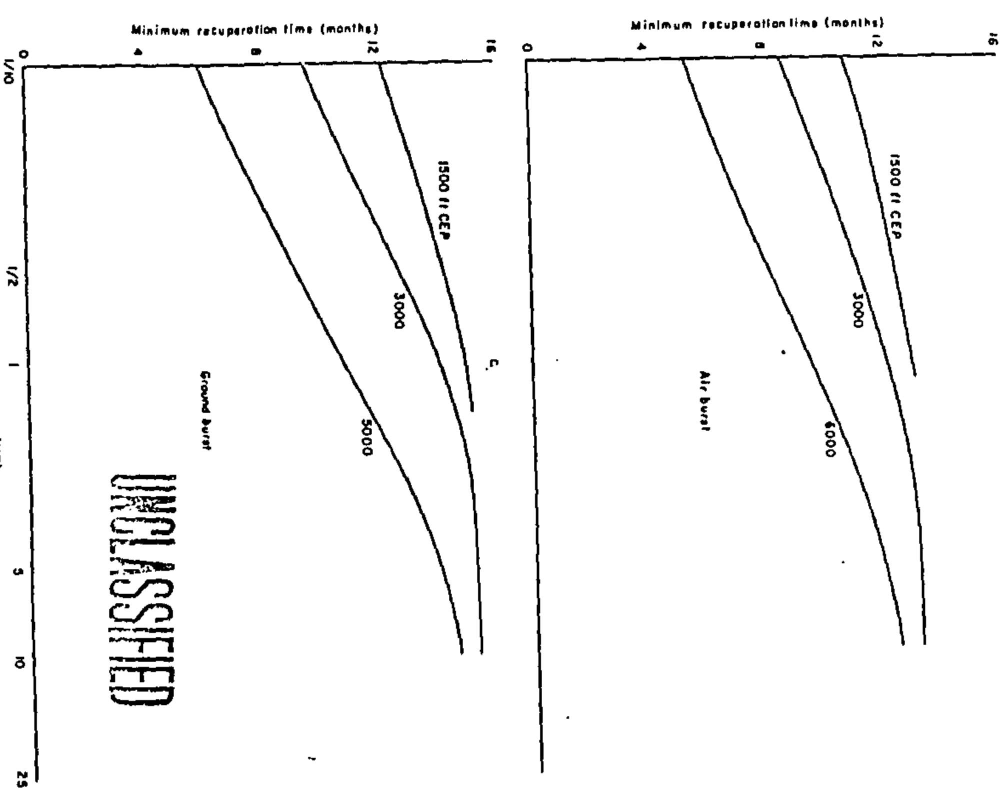


Fig. 43—Geneva Steel Plant ...

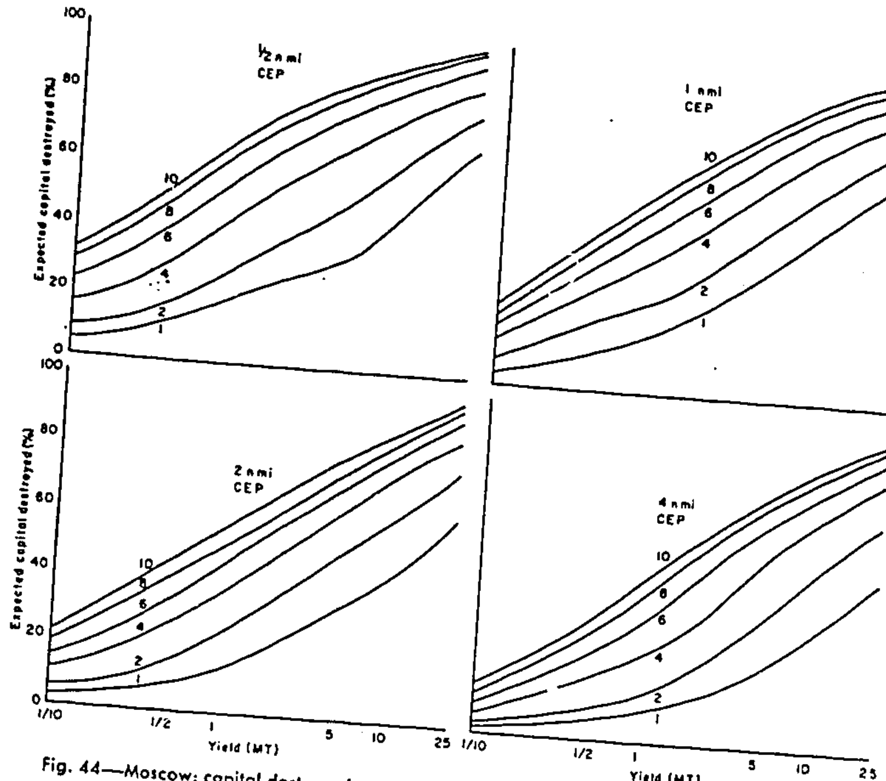


Fig. 44—Moscow: capital destroyed vs yield, by number of bombs; ground burst (numbers on curves show number of bombs dropped)

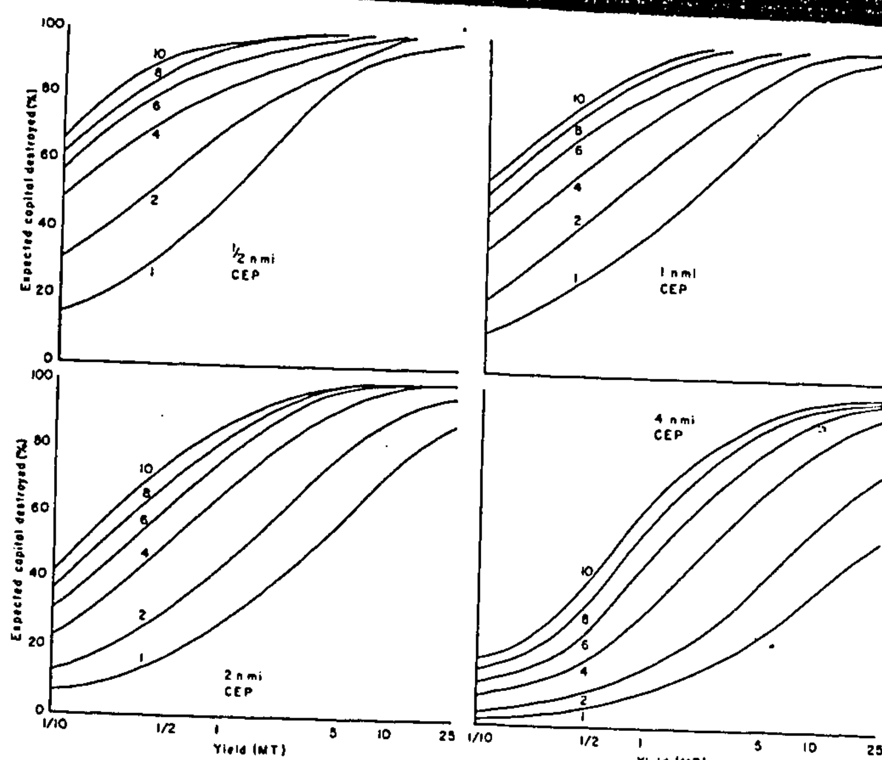


Fig. 45—Dayton: capital destroyed vs yield, by number of bombs; ground burst (numbers on curves show number of bombs dropped)

RESULTS ON DESTRUCTION OF DWELLINGS

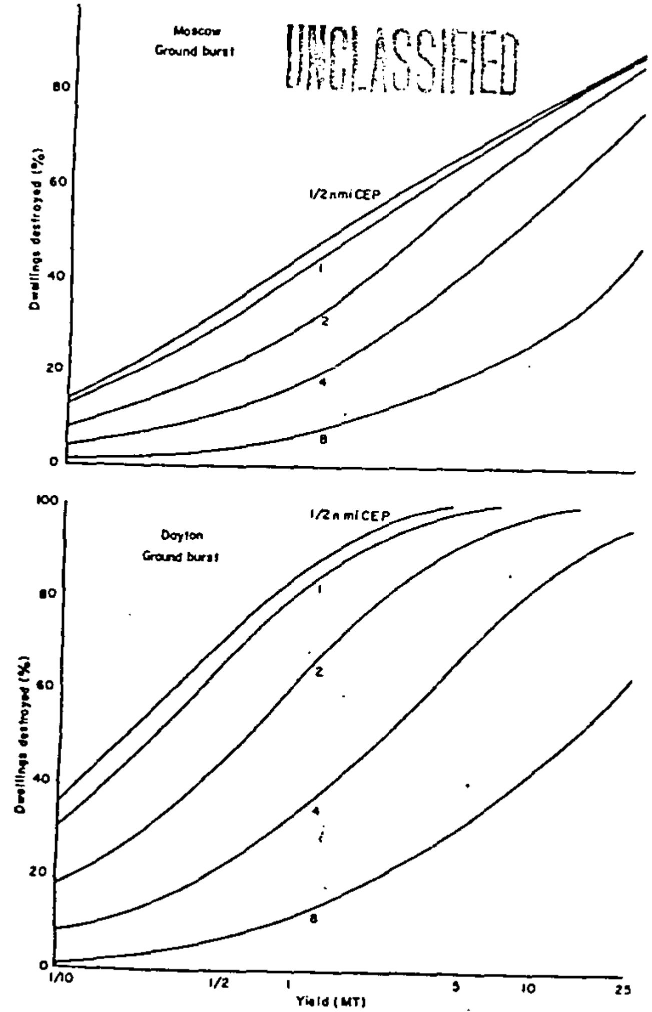


Fig. 46—Moscow and Dayton: dwellings destroyed vs yield, by CEP; ground burst

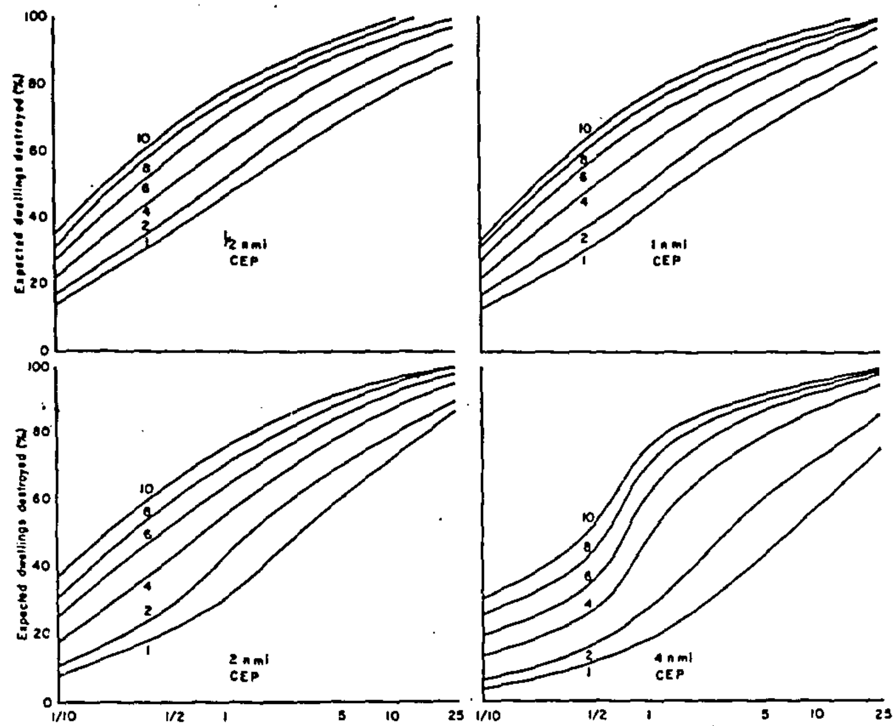


Fig. 47—Moscow: dwellings destroyed vs yield, by number of bombs (numbers on curves show number of bombs dropped)

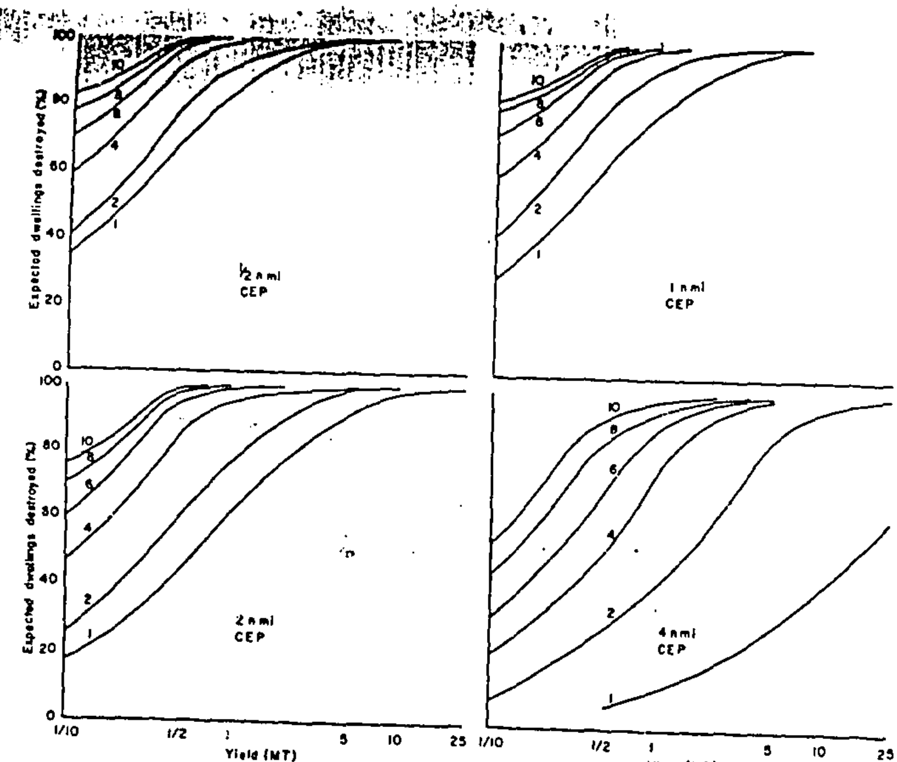


Fig. 48—Dayton: dwellings destroyed vs yield, by number of bombs (numbers on curves show number of bombs dropped)

SPECIAL COMPARISONS

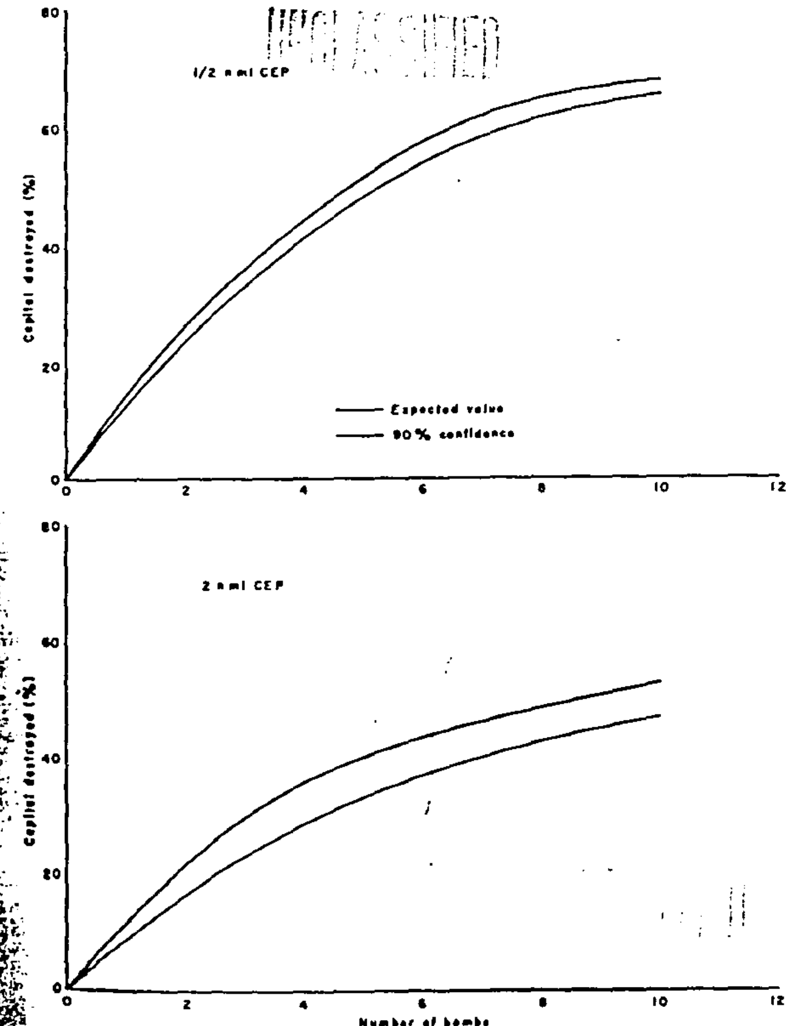


Fig. 49—Moscow: cost of confidence (in number of bombs); 1 MT; ½- and 2-n-mi CEP; ground burst

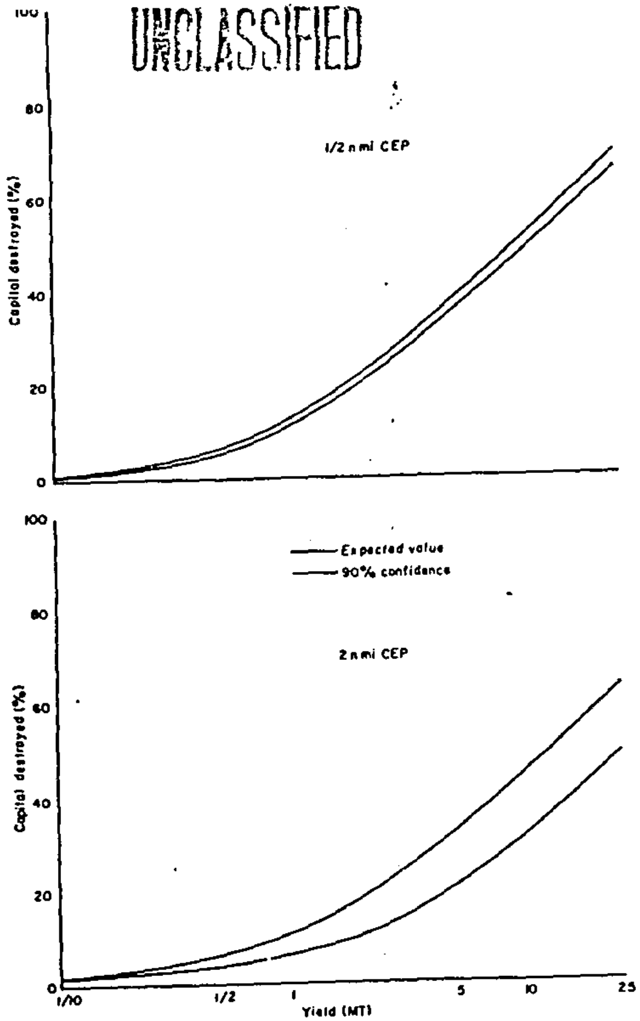


Fig. 50—Moscow: cost of confidence (in yield); ½- and 1-n-mi CEP; ground burst

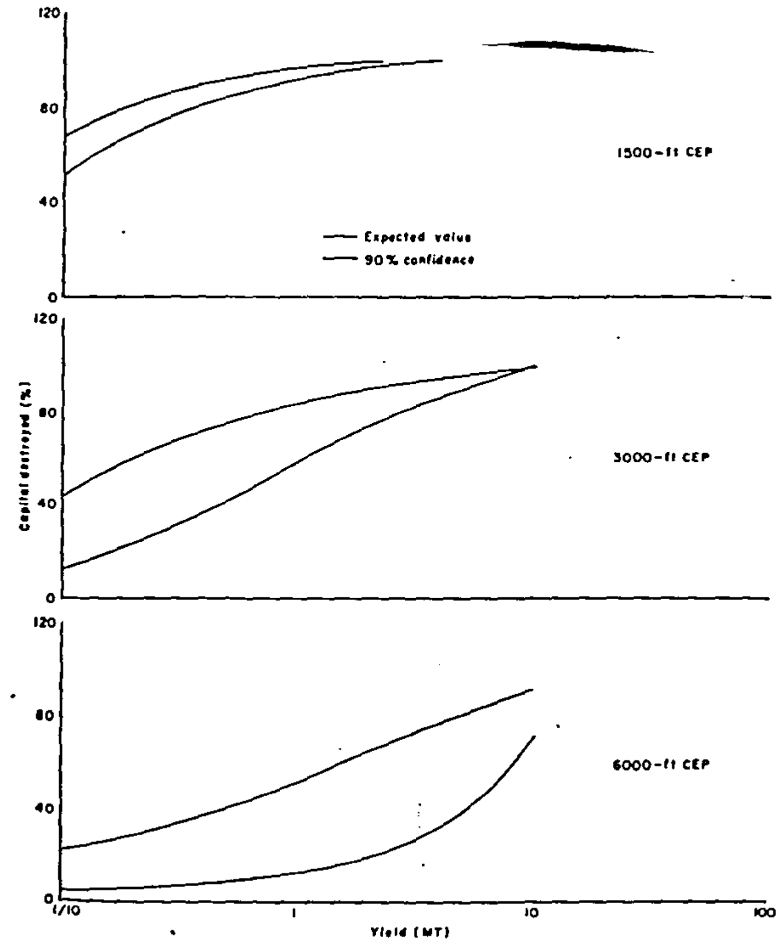


Fig. 51—Geneva Steel Plant: cost of confidence (in yield); ground burst

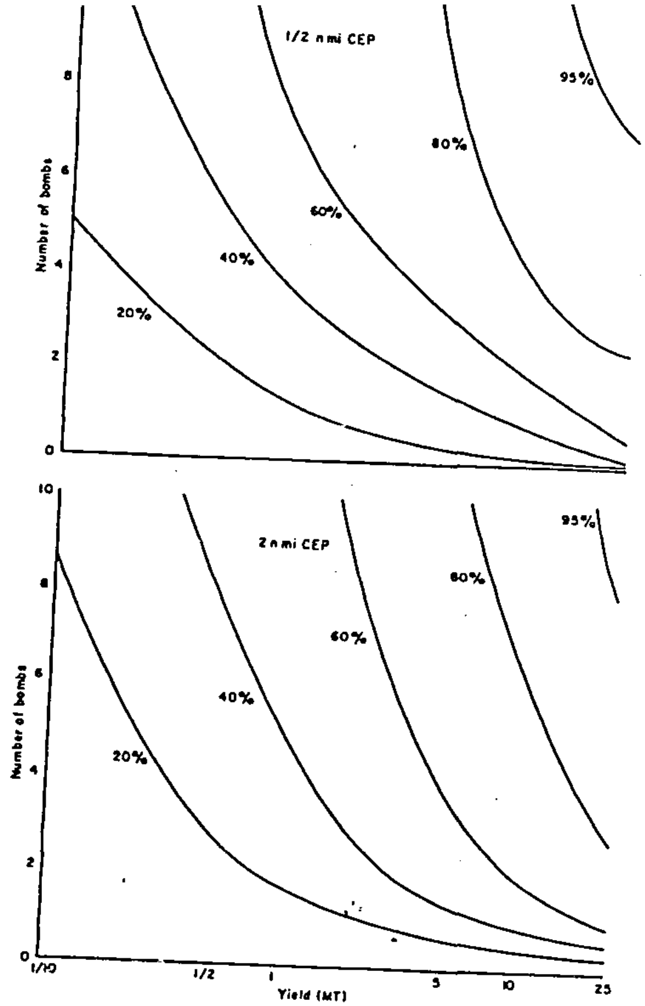


Fig. 52—Moscow: trade off—number of bombs vs yield, by capital destroyed

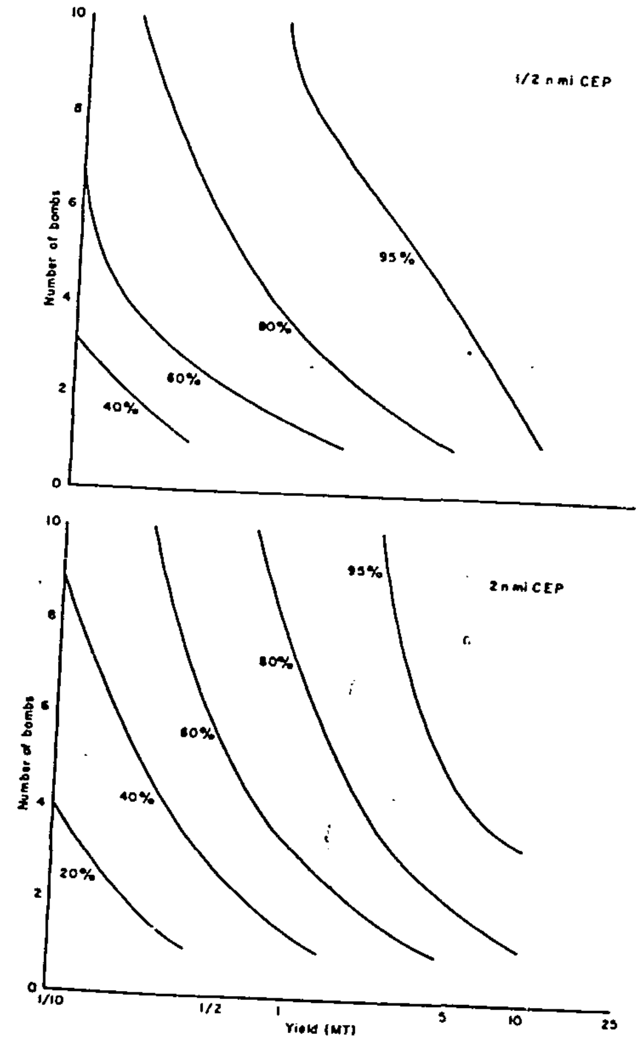


Fig. 53—Dayton: trade off—number of bombs vs yield, by capital destroyed

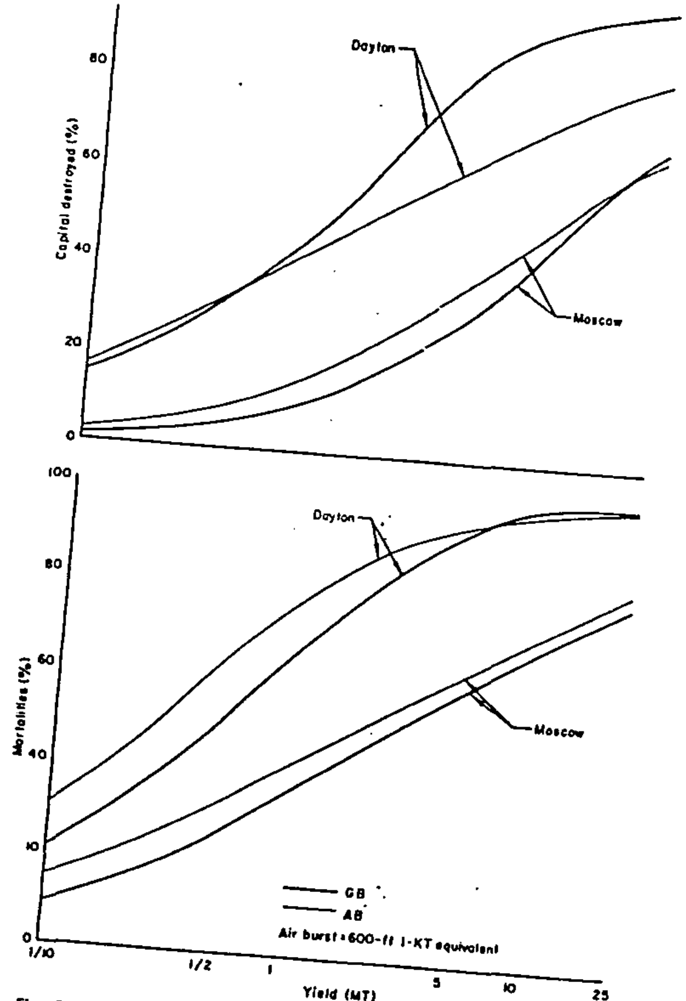


Fig. 54—Dayton and Moscow: comparison of air burst and ground burst, showing mortalities and capital destroyed

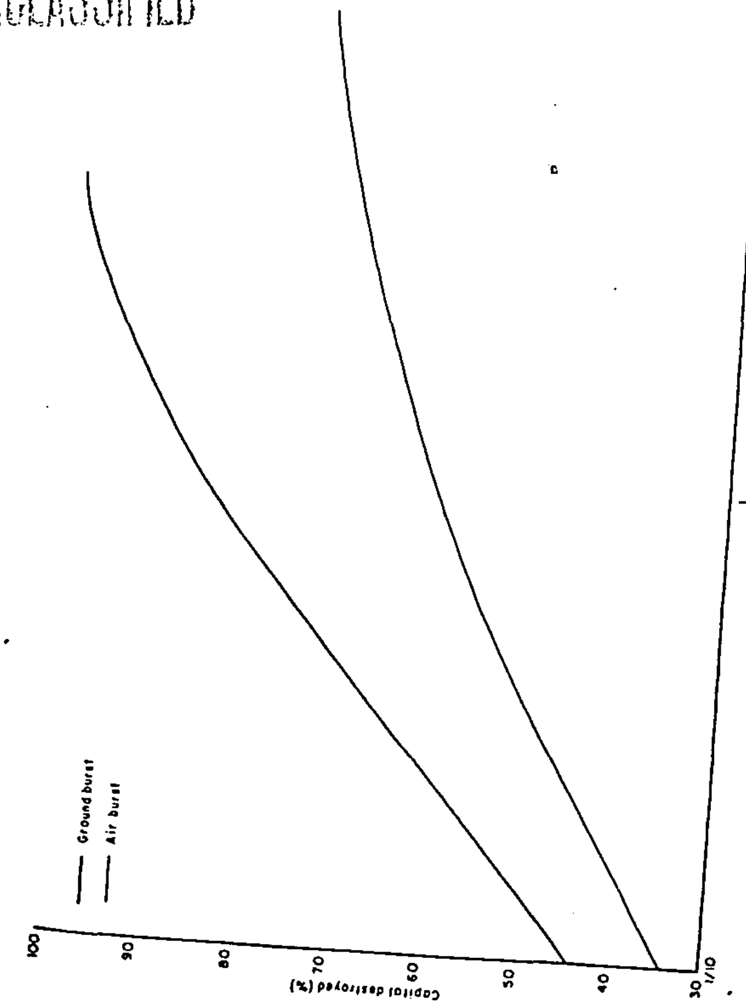


Fig. 55—Geneva Steel Plant: comparison of air burst and ground burst

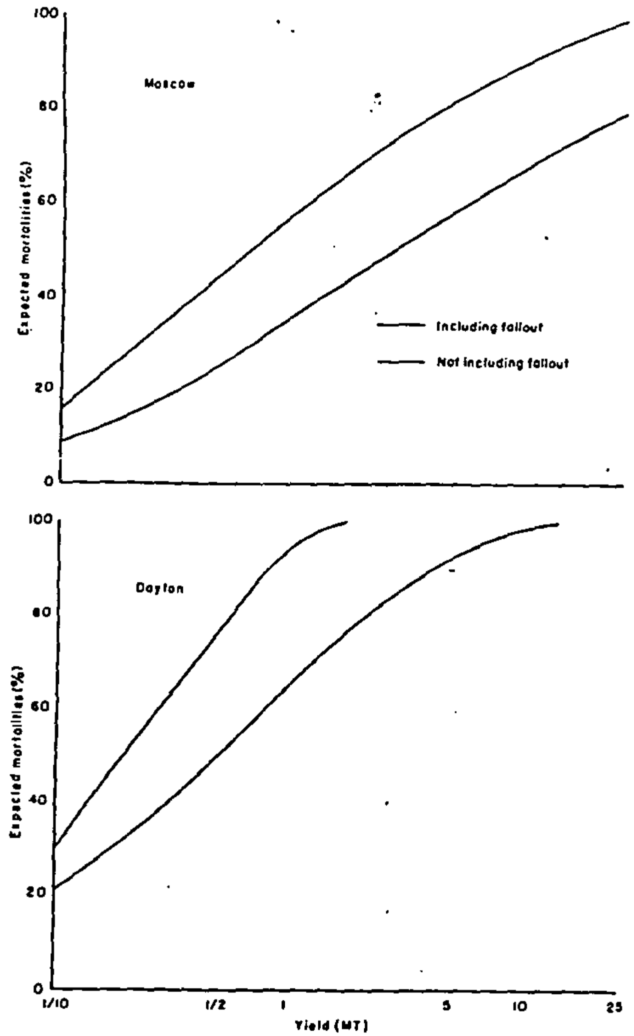


Fig. 56—Moscow and Dayton: effect of fallout, ½-n-mi CEP; ground burst; unwarned

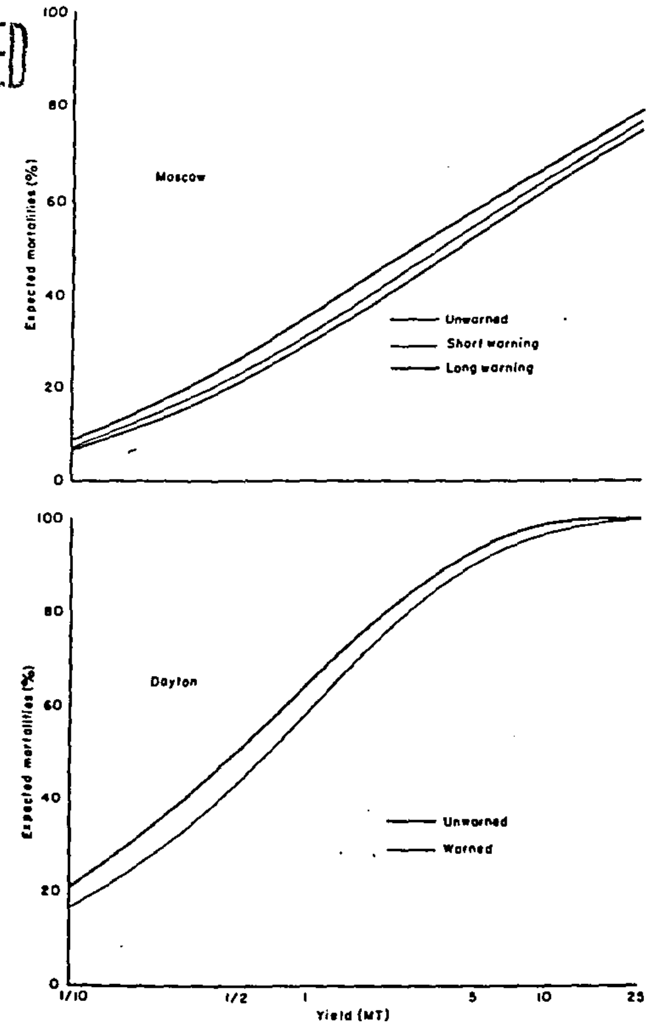


Fig. 57—Moscow and Dayton: effects of warning and shelter, ½-n-mi CEP; ground burst

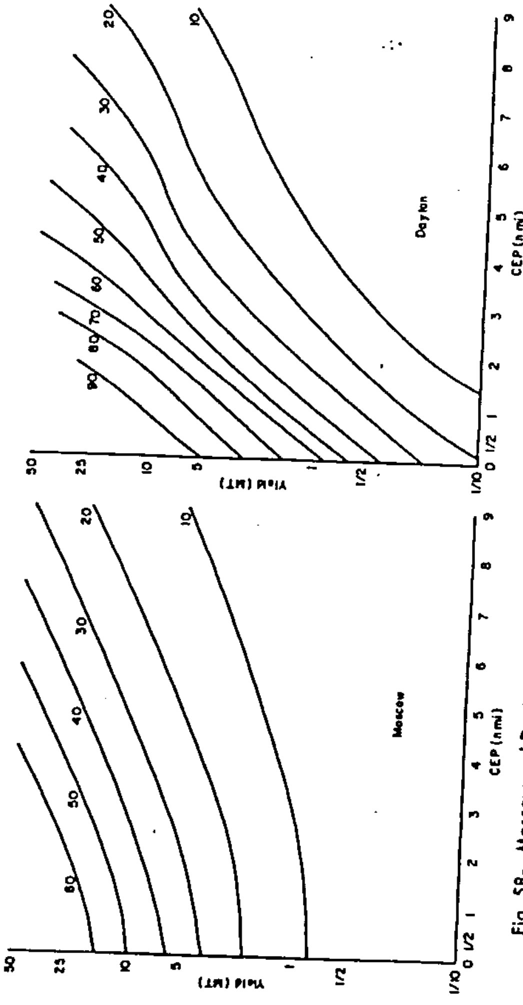


Fig. 58—Moscow and Dayton: trade off—yield vs CEP, by capital destroyed (numbers on curves show percent of expected capital destroyed)

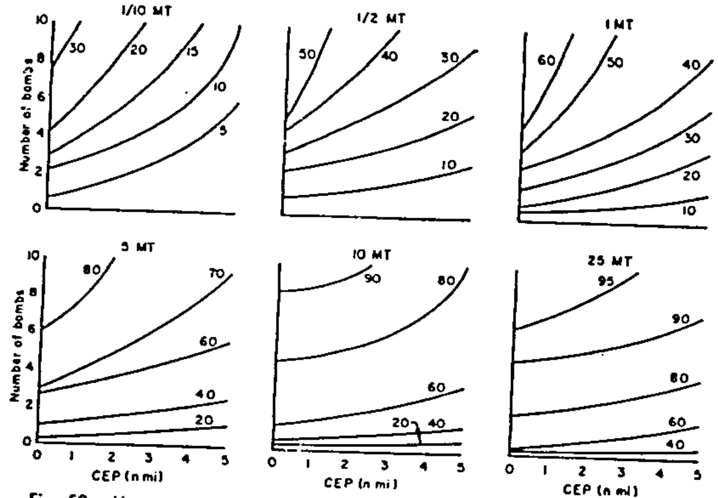


Fig. 59—Moscow: trade off—number of bombs vs CEP, by capital destroyed (numbers on curves show percent of expected capital destroyed)

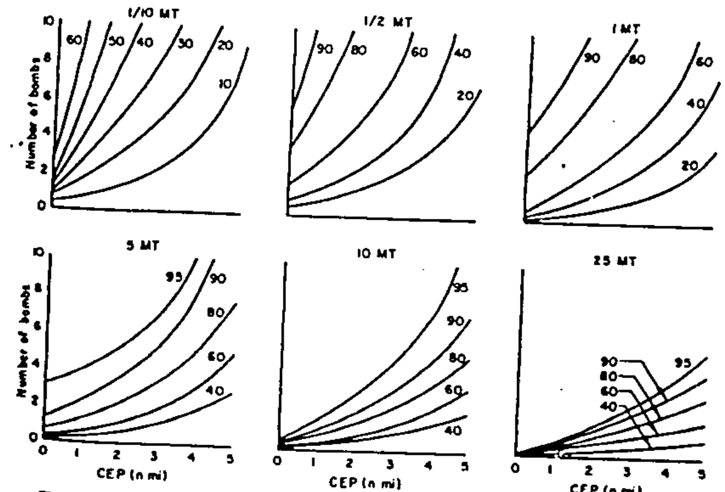


Fig. 60—Dayton: trade off—number of bombs vs CEP, by capital destroyed (numbers on curves show percent of expected capital destroyed)

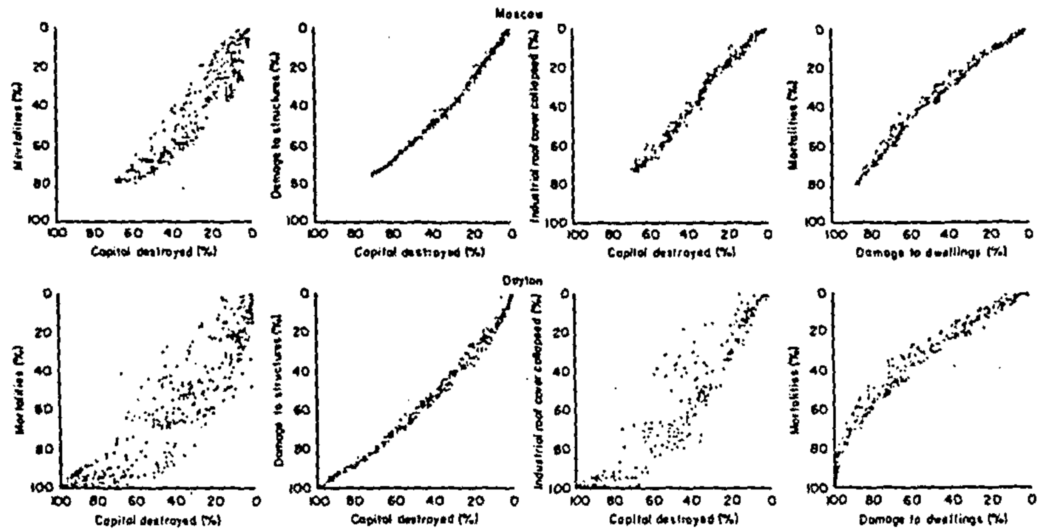


Fig. 61—Moscow and Dayton: scatter diagrams, showing correlation between types of damage (each dot represents one bomb)

UNCLASSIFIED

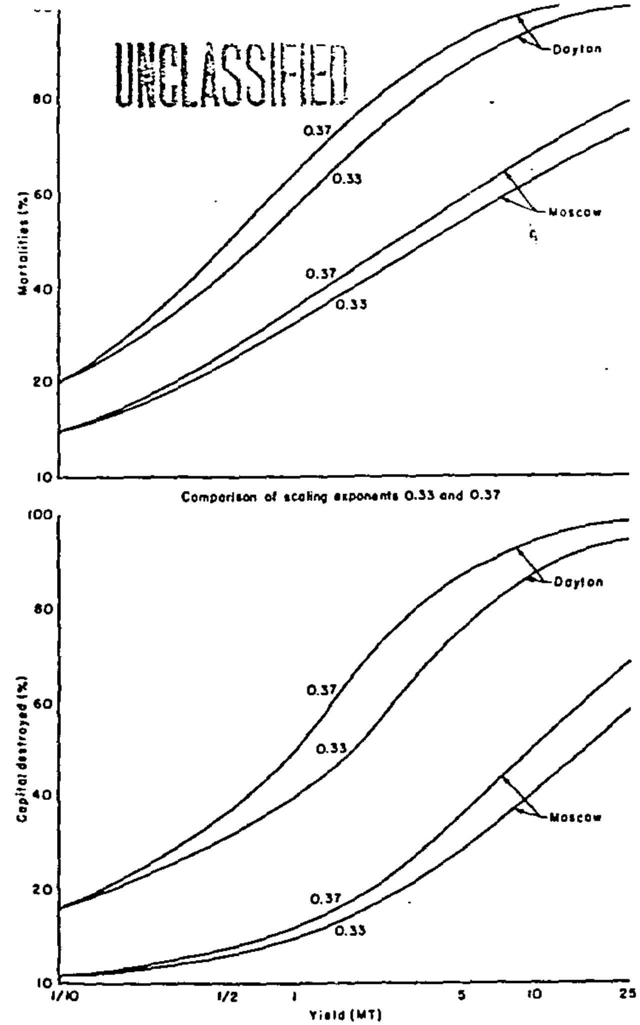


Fig. 62—Moscow and Dayton: sensitivity to cube-root scaling, showing mortalities and capital destroyed, ½-n-mi CEP; ground burst

UNCLASSIFIED

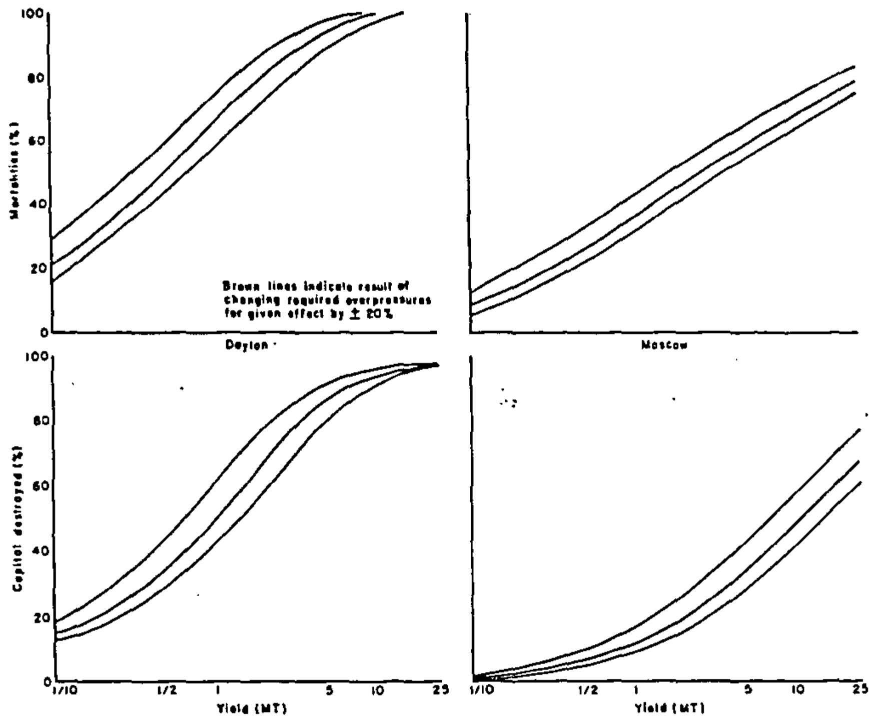


Fig. 63—Moscow and Dayton: sensitivity to changes in vulnerability assumptions, showing mortalities and capital destroyed

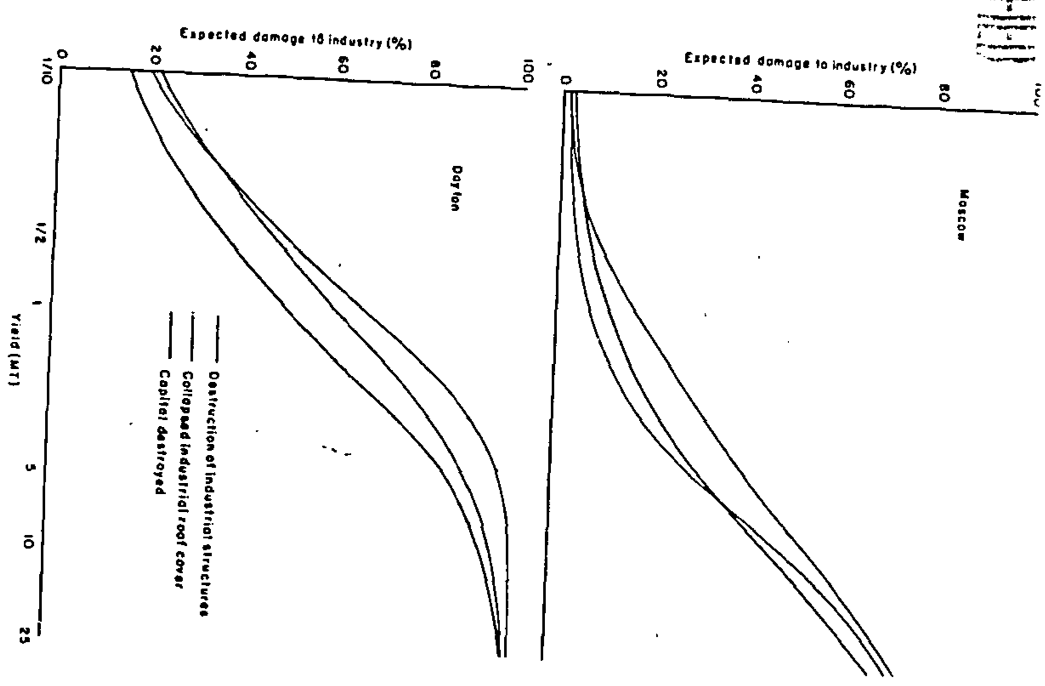


Fig. 64—Moscow and Dayton: comparison of industrial damage indices, ½-n-mi CEP; ground burst

UNCLASSIFIED

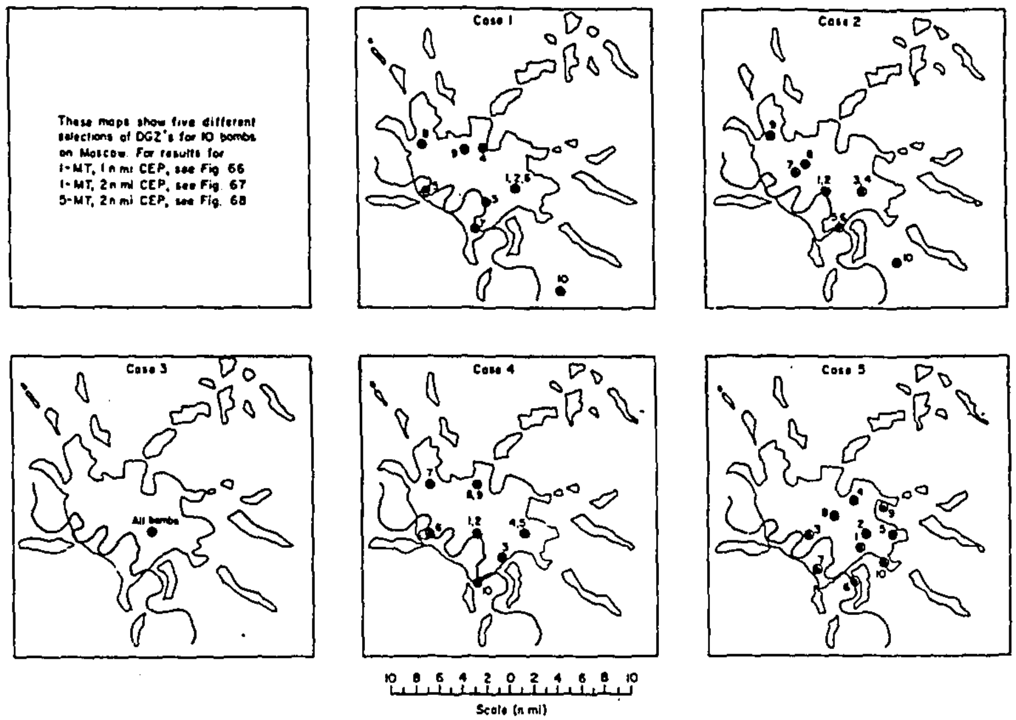


Fig. 65—Moscow: sensitivity to selection of DGZ's, showing five different selections of DGZ's for ten bombs on Moscow

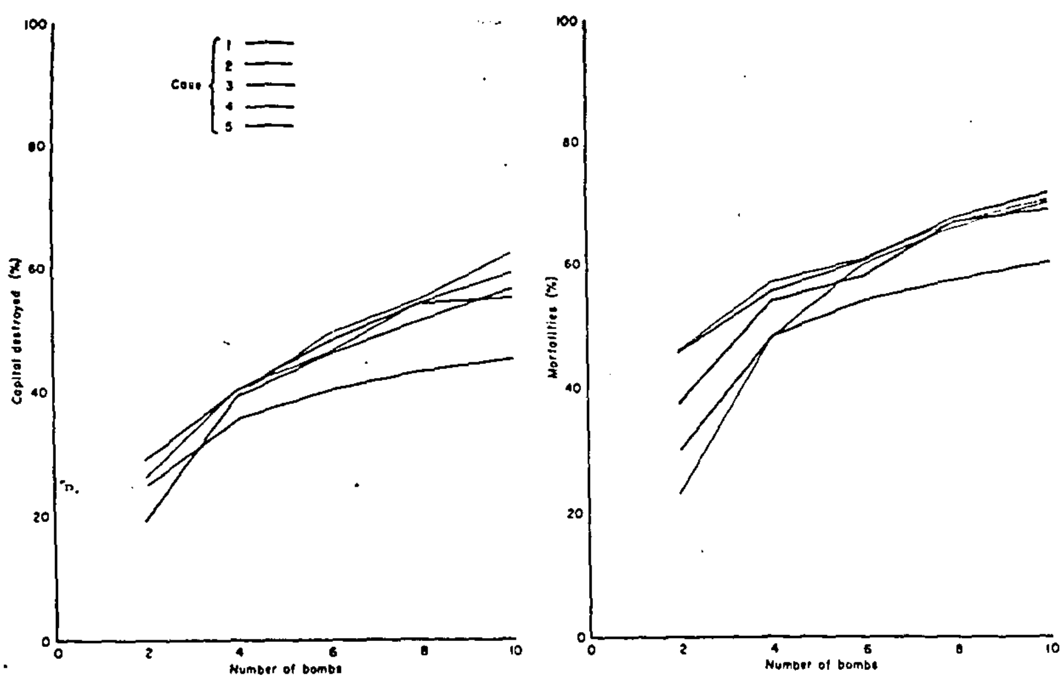


Fig. 66—Moscow: sensitivity to selection of DGZ's, 1 MT, 1-n-mi CEP

UNCLASSIFIED

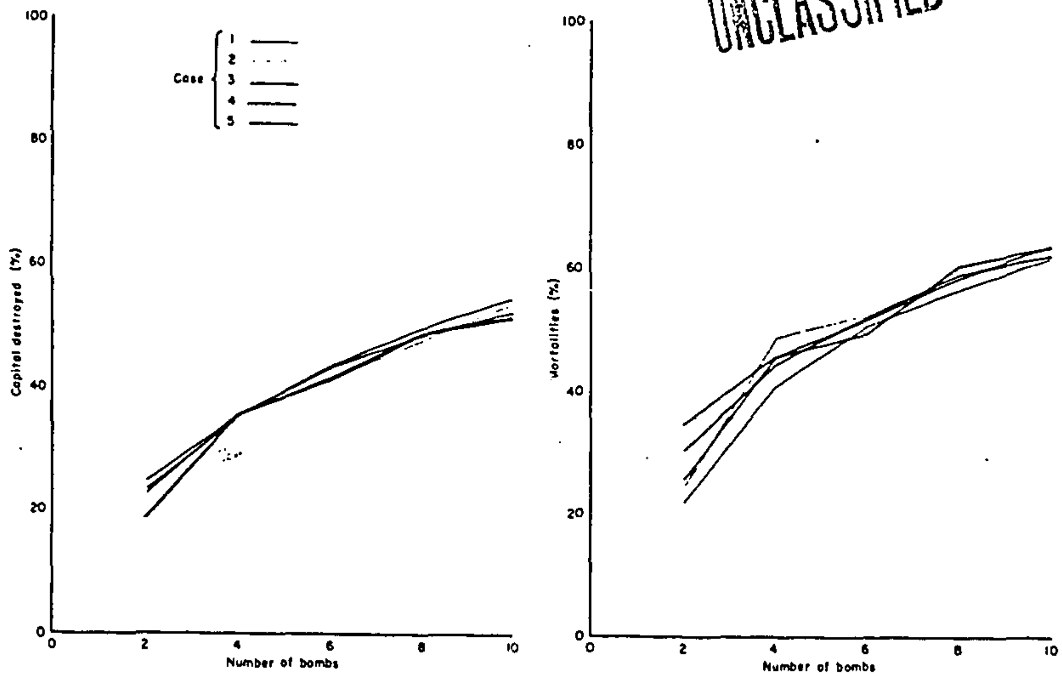


Fig. 67—Moscow: sensitivity to selection of DGZ's, 1 MT, 2-n-mi CEP

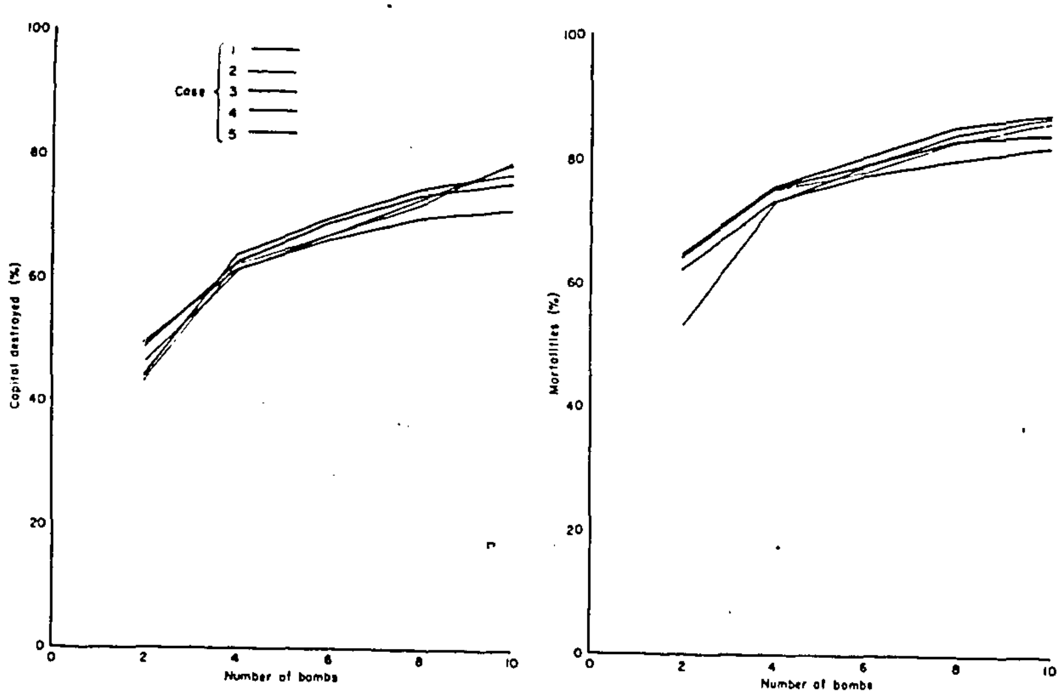


Fig. 68—Moscow: sensitivity to selection of DGZ's, 5 MT, 2-n-mi CEP

UNCLASSIFIED

SUPER BOMBS

UNCLASSIFIED

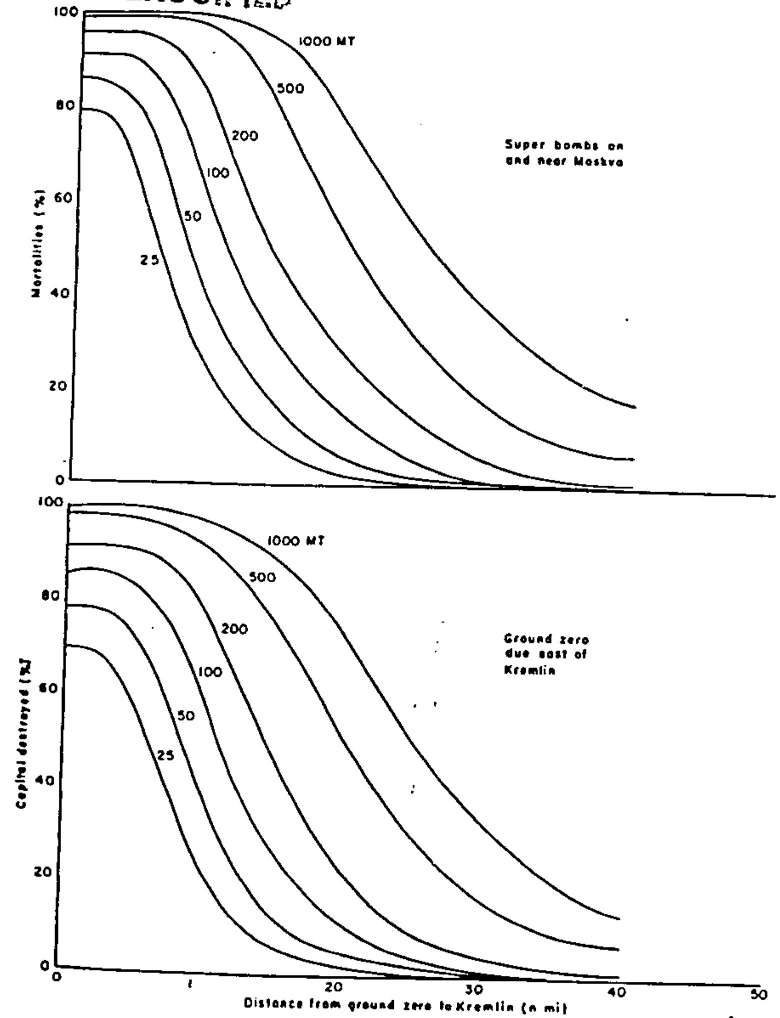


Fig. 69—Moscow: capital destroyed vs distance from GZ to Kremlin, by yield