DEPARTMENT OF DEFENSE
WASHINGTON HEADQUARTERS SERVICES
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WASHINGTON, DC 20301-1155

SEP 12 2013

[redacted]

Subject: OSD MDR Case 10-M-1080

[redacted]

We have reviewed the enclosed document in consultation with the Department of the Air Force (USAF), Department of Homeland Security (DHS), and Department of Energy (DOE). USAF, DHS, and DOE have no objection to declassification in full. However, OSD has declassified it in part. OSD excised information is exempt from declassification under Executive Order 13526, section 3.3(b)(4) and (8). Section 3.3(b)(4) protects information that would impair the application of state-of-the-art technology within a U.S. weapon system. Section 3.3(b)(8) protects information that would seriously impair current national security emergency preparedness plans or reveal current vulnerabilities of systems, installations, or infrastructures relating to the national security.

OSD stands as the appellate authority and will coordinate any appeals regarding this case. A written appeal must be filed within 60 days explaining the rationale for reversal of the decision. Reference should be made to OSD MDR Case 10-M-1080. Letters of appeal should be sent to the following address:

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Attention: Luz Ortiz
4800 Mark Center Drive
Suite 02F09-02
Alexandria, VA 22350-3100

If you have any questions, contact me by e-mail at Records.Declassification@whs.mil.

Sincerely,

Luz Ortiz
Chief, Records and Declassification Division

Enclosures:
1. MDR request
2. Document AD0385285

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Chief, RDD, ESD, WHS
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10-M-1080

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AD 385285

TM(L)-1960/092/00

Final Report for the Office of Civil Defense

Civil Defense Warning System Research Support

Volume III: Use of Damage Assessment

Information for Warning (U)

31 January 1966

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TM-L-1960/092/00

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Date: SEP 5 2013

TECHNICAL MEMORANDUM

(TM Series)

[redacted]

This document was produced by SDC in performance of contract OCD-PS-64-183
Work Unit Number 2212E

Final Report for the Office of Civil Defense

Civil Defense Warning System Research Support

Volume III: Use of Damage Assessment Information for Warning (U)

J. O. Neilson
of the
Special Research and Development Projects Staff

31 January 1966

SYSTEM DEVELOPMENT CORPORATION
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OCD REVIEW NOTICE

This report has been reviewed in the Office of Civil Defense and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Office of Civil Defense.

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FOREWORD

Volume III, this Volume, and two companion volumes contain the findings, conclusions and recommendations resulting from the study of warning system requirements under Contract OCD-PS-64-183. The three volumes are as follows:

TM-L-1960/090/00
Final Report for the Office of Civil Defense
Civil Defense Warning System Research Support
Volume I: Radio Warning System Studies
31 January 1966

TM-L-1960/091/00
Final Report for the Office of Civil Defense
Civil Defense Warning System Research Support
Volume II: Research Studies
31 January 1966

TM-L-1960/092/00
Final Report for the Office of Civil Defense
Civil Defense Warning System Research Support
Volume III: Use of Damage Assessment
Information for Warning (U)
31 January 1966

The volumes were authored by the Special Research and Development Projects Staff composed of:

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1.0 INTRODUCTION

In April 1964, System Development Corporation (SDC) was awarded a contract (OCD-PS-64-183) by the Office of Civil Defense to continue activities in the area of civil defense warning system research support. The basic contract was modified and amended several times. This volume and two others, TM-L-1960/090/00 and TM-L-1960/091/00, are, together, the final report recognized by the contract. These volumes of the final report represent the results of the research effort.

SDC performed the following tasks during the course of the contract:[1]

1. Assisted OCD in evaluating, selecting, and implementing a nationwide radio-based alert and warning system.

2. Selected optimum radio warning system configurations on the basis of operational and performance requirements and designated areas for detailed engineering study.

3. Determined, on the basis of operational and performance requirements, optimum signaling procedures to be used in the transmission and distribution elements of a radio-based alerting and warning system. Studied the need for and degree of security of signaling and other related factors leading to the engineering design of signaling devices.

4. Studied the civil defense decision to warn at all levels of government--federal, state, and local.

5. Evaluated the feasibility and effectiveness of providing strategic warning to industry. Determined tradeoffs between shutdown of industry following strategic warning and possible escalation of a crisis and no shutdown and probable damage to or destruction of plant and surrounding community. Where it appeared feasible to provide such strategic warning for shutdown purposes, evaluated the impact upon federal warning systems and procedures.

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1. Several other tasks were originally scheduled, but were not performed. These omitted tasks include a study of the optimum relationship between warning system development and shelter system development; an investigation of civil defense alerting conditions; and an analysis of improved processing of warning information at various civil defense operational levels. These tasks were omitted when tasks undertaken under the terms of the technical support clause of the contract (item 9 below) were assigned sufficiently high priority by OCD to necessitate reducing the overall scope of work undertaken.

6. Developed reliability criteria for evaluating both current and planned warning systems including expressions for describing the levels of reliability at which a warning system will operate, and a mathematical model for the performance required of the improvements of any warning system if that system is to achieve a predetermined level of reliability.

7. Determined the degree to which federal warning programs have been accepted by Congress. Collected and assembled material showing the legislative and fiscal history of these programs. Analyzed the development of the program in terms of the interaction of civil defense agency personnel with Congress. Traced changes in the nature of and the funding requested for program proposed, and the nature of and funding provided for programs accepted.

8. Determined the warning information that could be derived from a nuclear detection or damage assessment system. Reviewed and evaluated the warning potential of current, planned, and proposed nuclear detection and damage assessment systems.

9. Provided technical assistance and liaison on radio-based alerting and warning systems, and in other areas that were mutually agreed upon by OCD and System Development Corporation.

This volume (Volume III) of the final report discusses the relationship existing between warning and damage assessment (burst sensor) systems that are currently in existence or have been proposed to the Office of Civil Defense (Task 8).

The first two sections of this report presents the Introduction and the Summary and Conclusions of the study. Section Three examines the warning requirements and the resulting requirements for damage assessment systems. The sufficiency of automatic damage assessment systems is examined in Section Four, where 477L Phase I (NUDETS), Bomb Alarm System (BAS), Improved Bomb Alarm System, and Western Union's Survivable Damage Assessment System are examined in detail not only for their suitability for warning, but also their overall capabilities. Section Five examines the sufficiency of manual damage assessment methods in the same light. Section Six provides some insights into the accuracies and ranges of applicability of scaling laws for Blast, Initial Radiation, and Time to Second Thermal Maximum. Annexed are the corrected thermal scaling formulas, and a bibliography, and brief glossary.

Volume One, TM-L-1960/090/00 is composed of the findings of studies in the area of radio-warning and are described in Items 1 through 3 and 9, above.

Volume Two, TM-L-1960/091/00, contains the findings of all other unclassified warning research studies described in Items 4 through 7 and 9, above.

2.0 (U) SUMMARY AND CONCLUSIONS

(U) The main interest of the Office of Civil Defense (OCD) in damage assessment systems has been centered in the area of estimating damage to the civil population and resources.[1] In addition OCD is developing an active interest in researching the area of increased accuracy of nationwide fallout predictions.[2]

(U) The purpose of this study is to examine the feasibility of utilizing information obtained from damage assessment systems for warning purposes, and to examine existing, as well as some proposed, systems for their capabilities for providing the desired information. Specifically, 477L (NUDETS); the Bomb Alarm System; Improved Bomb Alarm (an unnamed system under study by Western Union); and the present OCD manual system are examined. This list is far from complete and other systems have been or are being proposed such as General Electric's PHYLIS; Sperry Rand's System; Royal Research's; etc., but information on those systems has not been made available to the System Development Corporation.

(U) A study of the efficacy and accuracy of scaling laws of detonation effects is also included to illustrate the difficulty of estimating weapon characteristics from weapon effects. No effort has been made to determine the accuracies with which the various effects can be measured, rather the emphasis has been placed on the variability of the effects, even for weapons of the same yield. This, of course, increases the difficulty of any method of damage assessment.

2.1 (U) SUMMARY

(U) In investigating the utilization of damage assessment information for warning purposes, it is evident that such information is not available until after an attack has been initiated. Since the information must be collected, evaluated, and disseminated to those affected, it appears that such damage assessment information could only be applied in two areas, i.e., tactical warning and fallout forecasting.

(U) Tactical warning is considered only because of the possibility of a previously undetected attack. Its inclusion does not signify that any probability of such an occurrence is implied, but that such an occurrence is not impossible.

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1. Office of Civil Defense, Excerpts, Congressional Testimony and Actions on Civil Defense, January-June 1965, MP-30-A, pp. 76, 106.

2. Ibid., p. 127.

(U) While tactical warning can be disseminated by an unselective nationwide warning system, the dissemination of fallout forecasts requires a selective warning system to provide the fallout information to those who will be directly affected. From a consideration of the accuracy of fallout predictions, it appears that the county level is the optimum level at which the warning should be disseminated. However, no effort is expended to determine the accuracies of the various techniques of fallout prediction or the accuracies necessary in the determination of location, yield and height of burst.

[redacted] For this study, the stated OCD requirements for yield and location accuracies for the 477L system were used although it is evident that the yield requirement is not adequate. [redacted]

OSD 3.3(b)(4)

(U) For fallout prediction purposes, the cloud dimensions, particularly the diameter, is of paramount importance. Since the cloud diameter is not a linear function of the yield, the permissible percentage error in yield actually decreases as the yield increases for a constant cloud diameter error.

(U) The data evaluation centers, because of the complexity and multiplicity of the computations involved in fallout calculations and the time constraints for warning, would have to be automated to some degree. Communications also would be complex in that, if the county was the warning level, over 3000 terminals would be involved. Again the need for rapid dissemination is evident.

(U) The requirements placed on the data gathering system for warning information are as follows:

> For all cases, the system must be an area coverage, not a point coverage system. In the case of tactical warning, only the fact that a detonation has taken place is of concern, no other information is required. For fallout predictions, the minimum requirements are the yield, location and time of burst. To prevent false alarms, height of burst is extremely desirable. Cloud dimensions are also helpful, but these can be estimated to a sufficient degree of accuracy if adequate meteorological information is available.

(U) In an effort to determine if there is an existing system that will provide the necessary information, several automatic damage assessment systems, as well as OCD's manual procedures were examined. The systems investigated were 477L (NUDETS), the Bomb Alarm System, Improved Bomb Alarm, and an as yet unnamed system under study by Western Union.

[redacted] The 477L system consists of four sensor sites on the Washington-Baltimore area. Each site is equipped with electromagnetic pulse (EMP) detectors for yield and location determination, optical sensors for yield determination, and a seismic sensor for height-of-burst determination. A computer is also associated with one site for processing the information gathered by all the sites. The reports generated by the system include time of detonation, yield (either by EMP or optical means), location, and height-of-burst (if available). Tests conducted on the system indicate that its capabilities are as follows:

OSD 3.3(b)(4)

[redacted]

False Alarm Rate	At best, about one per month. More during seasons of heavy sferic activity.

[redacted] While 477L is the most ambitious and sophisticated system yet attempted for damage assessment, it is not suitable for warning purposes. For tactical warning, it falls short in its rather high false-alarm rate (at best, about one per month). For fallout warning, the main problems seem to lie in the areas of yield and height-of-burst determination. The questionable optical yield determination, the untenable EMP yield determination, and the unavailability of height-of-burst information [redacted] makes fallout predictions guesswork at best.

OSD 3.3(b)(4),(8) OSD 3.3(b)(4)

[redacted] The Bomb Alarm System is designed to detect nuclear events [redacted] at selected locations. At the present time, 99 locations have been instrumented. It has a very high reliability and availability. During 1963, the system had an ultimate target area availability of 99.98 percent with no false alarms reported.

(U) For use in fallout prediction, BAS has no value whatsoever. The only information it supplies is the fact that a nuclear detonation has occurred somewhere near a sensor triad. No information as to yield, height-of-burst, or location is provided.

[redacted] The above noted reliability and availability of the system makes it ideal as a tactical warning "trigger." However, there are two degrading factors: (1) The poor coverage of the system, and (2) the questionable sensor performance during marginal weather. These two factors would indicate that the system, while probably the best we now have, is usable only in a limited way for tactical warning.

(U) Improved Bomb Alarm would be an extension of the present Bomb Alarm System. Additional sensors, two optical and one EMP, would be added to each existing sensor. The EMP sensor would supply the time of detonation and information on the localization of the event. Elevation information would be supplied by the use of a segmented optical sensor that would classify bursts as to ground or air. The other optical sensor would merely be a backup for the existing sensor. Yield would be determined by time-to-first-thermal minimum.

(U) This system provides some improved capability for fallout prediction over BAS. At least, some idea as to the size of the weapon and burst height is given; but the estimates provided, especially the burst height, are of questionable worth in any semisophisticated fallout prediction scheme. As for use as an alarm trigger, the same comments made for BAS apply.

(U) Western Union's Survivable Damage Assessment System would consist of approximately 1000 blast and radiation sensors contained in blast shelters rated at 100 psi overpressure, and supplied with auxiliary power sufficient for 48 hours. They would be distributed on the basis of one set of sensors per expected target and located one to five miles from the expected burst point depending on the type of target. Each set of sensors would be shielded as much as possible from EMP and gamma radiation. Nuclear data effects would be measured and stored at the time of the explosion, collected by aircraft at a later time via radio-teletype, then retransmitted to ground collection points (processing centers) and disseminated to users from there. It has been estimated that ten aircraft and three ground processing centers would be required for adequate coverage. With ten aircraft, it is estimated that every sensor set could be interrogated once an hour. Landline check and maintenance circuits would also be provided.

(U) As a damage assessment system, the above scheme seems to have little merit. Its most obvious deficiency is lack of a multiplicity of sensors in a given target area. A single blast sensor reading gives little indication of the actual situation existing in the target area.

(U) The data collection scheme, while novel and relatively more reliable than landline would be under similar circumstances, has the disadvantage of not being realtime. For the application of this system to either tactical warning or fallout warning, the delays are intolerable.

(U) The OCD manual procedures involve measurement of certain visually observed characteristics of a nuclear event such as the duration of flash, cloud dimensions, and time of travel of the sound of the explosion. The parameters devised from these measurements are the yield and the location of the detonation. The accuracies obtainable by the methods employed are as follows:

Function	Method	Accuracy
Location	"Flash-to-Bang"	Probably no better than ±5 miles at 100 miles
	Triangulation	No better than ±0.5 miles
Yield	Ten minute cloud diameter	Uncertain, probably within a factor of two
	Maximum cloud diameter	Not usable
	Cloud top height	-70% to +280% at five megatons
	Cloud bottom height	-92% to +1000% at five megatons
	Duration of flash	With no height of burst information, probably within an order of magnitude

From the above, it is evident that, except for location by triangulation and ten minute cloud diameter for yield, no one of these methods yield satisfactory information.

(U) Examination of the scaling laws reveals part of the problems in estimating the parameters of a nuclear detonation. Depending on the effect being measured, a given yield can produce effects that vary anywhere from 15 percent to 500 percent from their nominal values. This would appear to make damage assessment a very difficult task, even just for fallout purposes.

(U) It appears that data from damage assessment systems can be profitably used for warning. In particular, for tactical warning and fallout prediction warning _if_ accurate data is available.

(U) The minimum damage assessment data required for warning purposes is time of detonation, yield, height-of-burst, and cloud parameters, if available. It must also be an area system rather than a point system.

[redacted] At the present time, there does not exist a damage assessment system that can provide the necessary information with any degree of precision or reliability.

3.0 (U) WARNING REQUIREMENTS

3.1 (U) WARNING RATIONALE

(U) The utilization of damage assessment information for warning purposes presupposes that attack information exists that can be evaluated in terms of the threat to all, or a given segment of, the population within sufficient time for warning of the threat to be disseminated to the affected population and protection or evasive action can be taken. This idealized formulation requires a data gathering system to collect the attack information; a threat evaluation center(s) to determine the nature and extent of the threat; and a suitable warning system to provide threat information to those affected. It is obvious that an attack must take place before damage assessment information is available. However, this attack might be undetected until the damage information becomes available. Thus, there are really two aspects to the nature of the warning disseminated: (1) the existence of an attack, that is, tactical warning, and (2) the effects of such an attack on that portion of the population not directly affected by the attack, that is, weapon's effects warning. It must be noted that the inclusion of tactical warning in this study is only a recognition of the possibility of such an event and does not assign any probability to such an occurrence.

(U) The requirements placed on the data gathering system are discussed below, but one point should be made here. It appears that one of the most critical items is the reaction time of the system and its ability to disseminate the required information on a real time basis to the evaluation center. This implies that either a communication system exists for the sole use of the data gathering system, or if it is a communications system shared with others, it must have top priority for the dissemination of the damage information.

(U) Concerning the data evaluation center, it must, in some sense, operate in real time when evaluating and disseminating threat and warning information. This implies that human intervention and decision making at this level must be held to a minimum and that most operations must, to some degree, be automated. This is particularly true when considering such involved processes as fallout prediction.

(U) Another requirement placed on the data evaluation center is that it be capable of disseminating selective warnings. Obviously, tactical warning need not be selective, but the warning of weapon's effects to prevent confusion should only be distributed to those who will be affected by them. For the purposes of this study, it will be assumed that the warning system is capable of warning on an individual county basis, an area averaging about 100 square miles.

3.2 (U) TACTICAL WARNING

(U) It is recognized that the first indication of an attack (e.g., a sub-launched missile attack) could be the attack itself.[1] In such an attack, warning would be disseminated after the fact. Nevertheless, the knowledge that such an attack had occurred would have to be placed in the hands of the decision makers as rapidly as possible. Normal communications would probably not be rapid encugh to be effective. Thus, the parameter needed here is a positive indication of a nuclear explosion and the time of occurrence.

3.3 (U) WARNING OF WEAPON'S EFFECTS

(U) In order to discuss weapon's effects, it is necessary to distinguish between the nuclear explosion and the effects of the explosion.[2] The explosion itself consists of initial nuclear radiation, thermal radiation, the electromagnetic pulse (EMP), air blast, and the resulting seismic shock from the blast. The effects of the explosion, on the other hand, are the damages caused by these elements of the explosion and by the residual radiation that is generated by the explosion. Since we are discussing the utilization of damage assessment information for warning, the implication is that some information concerning the explosion has been obtained, evaluated in terms of threat to the population (or subset thereof) in a timely fashion, and the warning to the population has been disseminated in time for the public to take some protective or evasive action.

(U) To obtain damage assessment information, it is necessary to measure some of the attributes of the explosion itself. However, since the damaging effects caused by the initial radiation, thermal EMP, air blast, and seismic forces of the explosion (i.e., the direct weapons effects) occur simultaneously with the explosion itself, it is unlikely that timely warning of these dangers to those affected can be provided by information developed in a damage assessment system. Therefore, it would appear that the only threat against which a damage assessment system can provide timely warning is that associated with residual radiation.

(U) There are two types of residual radiation.[3] The first is a contaminated zone around ground zero and consists of very early stem fallout and neutron-induced radiation from the explosion. This zone is contained within the area affected by heavy blast and thermal damage and thus hardly presents a warning problem. The second type is fallout occurring away from the actual detonation

1. Ibid., p. 76.

2. Glasstone, Samuel, The Effects of Nuclear Weapons, United States Atomic Energy Commission, April 1962, p. 28ff.

3. Ibid., p. 414ff.

location. Assuming that the blast is self-alerting within the one psi ring, those areas extending beyond 13 miles for a one-megaton explosion and 37 miles for a 20-megaton explosion that are threatened by radiation, would require warning. Since these distances are far in excess of the stem diameter, one can expect 20 to 30 minutes before the first fallout reaches the ground. Only fallout occurring within the first 24 hours will be considered in this study. Such fallout will account for approximately 60 percent of the total, but deposit rates after this time period are very low and the total period for almost complete fallout could take years.

(U) The minimum parameters necessary to predict fallout are: (1) the burst point, (2) the yield, and (3) the time of the burst. The maximum set of parameters would add to the above list: (4) height-of-burst, and (5) the cloud dimensions. The cloud dimensions, along with the necessary meteorological information, will completely determine the area of fallout. Also, by knowing the yield and height of burst, it is possible to determine the cloud dimensions with a fair degree of accuracy knowing the structure of the atmosphere above the burst point.[1] Cloud dimensions have been included in the list of parameters desired, however, because they can, with some care, be measured visually and supply valuable information.

(U) After the cloud dimensions have been determined by any of the available means, fallout patterns and arrival times may be determined by any of several available methods.[2] The accuracies obtainable by these methods vary, but the method employed by Schuert gives the limits of fallout in three cases to within 20 nautical miles, and in another case, to within 50 nautical miles. These figures are probably representative of the accuracies that can be expected.

3.4 (U) COVERAGE

(U) The coverage of any system is of paramount importance. It is not sufficient to provide coverage in suspected target areas. The system, to be effective, must cover the entire United States and bordering areas, particularly for fallout prediction. No matter how reliable and accurate the incoming missiles may be, there are bound to be some strays. For damage assessment of

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1. Kellogg, W. W., Atomic Cloud Height as a Function of Yield and Meteorology, P-881-AEC, The RAND Corporation, 14 June 1956.

2. Glasstone, Samuel, op. cit., p. 497ff.; Anderson, A. D., A Theory of Close-in Fallout, USNRDL-TR-249 N5 083-001, U.S. Naval Radiological Defense Laboratory, 23 July 1958; Schuert, E. A., A Fallout Forecasting Technique with Results Obtained at the Eniwetok Proving Ground, USNRDL-TR-249 NS 081-001, U.S. Naval Radiological Defense Laboratory, 3 April 1957; etc.

resources, target area instrumentation is permissible, but when dealing with fallout, every source of fallout must be known and accounted for. This requires an area coverage rather than a point coverage system.

3.5 (U) ACCURACY REQUIREMENTS

[redacted] All comments on the sufficiency of a given procedure are based upon the stated OCD requirements that locations of nuclear explosions must be determined [redacted]

OSD 3.3(b)(4)

(U) One comment seems in order on these types of requirements. It is probably true that location estimates are normally distributed due to the fact that the observation of angles, etc., possess normally distributed errors. This makes it possible then to talk in terms of one sigma errors. However, the measurement of the accuracy of yield determination in terms of percentage errors does not lend itself to a similar treatment. Let M be the measured value and T the true value, then the percentage error E is given by

$$E = 100 \frac{M - T}{T}$$

$$= \frac{100\,M}{T} - 100.$$

Since both M and T must be non-negative, it is evident that E has the following limitations:

$$-100\% \leq E < \infty \cdot$$

Thus the curve is not normal but rather finite to the left and infinite to the right with (hopefully) a mean of zero percent. This dilemma will not be pursued further, but a redefinition of the accuracy of yield determination seems to be in order.

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1. Required Accuracy of NUDENTS (477L) Reports for Office of Civil Defense (U), Memorandum for the Director of Defense Research and Engineering, 21 August 1964 (Confidential).

(U) Even though the stated OCD values will be used, it should be pointed out that they were developed for an entirely different purpose than the one being investigated here. In predicting fallout, the cloud dimensions are of paramount importance. Let W be the weapon yield. If the yield is accurate to only $\pm W/2$, the cloud diameter, if calculated for NRDL data,[1] can vary by ± 5 miles for a one-megaton detonation; ± 12 miles for a ten-megaton; and ± 32 miles for a one-hundred megaton. However, if a limit is placed on the permissible error in the cloud diameter, then the permissible error in the yield is not a fixed percentage but rather becomes smaller as the yield increases. In fact, if the allowable error in cloud diameter is ± 5 miles, then an error of ± 54 percent is allowable for a one-megaton detonation, but only ± 20 percent for a ten-megaton detonation, and down to ± 8 percent for an one-hundred megaton detonation.

[redacted] ~~(RD)~~ The lower limit of ± 8 percent is approaching the variability that identical weapons have in actual yield.[2]

(U) Thus a dilemma exists. The higher the yield, the more accurate the yield determination must be, but the higher the yield, the more difficult it is to determine.

(U) The five mile limit on the error of the cloud diameter is for illustrative purposes only. Until the techniques to be employed in fallout forecasting are studied, no firm statements can be made as to the necessary accuracies in yield, location, and height of burst determinations. However, it does seem evident at this time that fallout forecasting and selective warning on the county level is possible.

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1. Moulton, Jr., J. F., op. cit., pp. 1-80ff.

2. Moulton, Jr., J. F., Nuclear Weapons Blast Phenomena (U), DASA 1200, Defense Atomic Support Agency, March 1960 (Secret-Restricted Data), p. 1-165.

4.0 (U) SUFFICIENCY OF AUTOMATIC DAMAGE ASSESSMENT SYSTEMS

(U) In this section, several automatic damage assessment systems will be evaluated in light of their ability to provide the desired information for warning as described in 3.0 above. No claim is made as to the exhaustiveness or representativeness of the systems under consideration, but rather they are systems for which sufficient information was available to study in detail their capabilities and effectiveness.

4.1 (U) 477L PHASE I (NUDETS)

4.1.1 (U) Description

OSD 3.3(b)(4)

[redacted] Phase I[1] of the 477L NUDET System is designed to report nuclear detonations occurring in the vicinity of the Washington-Baltimore area; the headquarters of the Commander-in-Chief; Atlantic Forces (CINCLANT); and certain key places. Although the sensors have a theoretical range of 250 miles in all directions, [redacted]

[redacted] At the sensor sites there are two EMP sensors, one for EMP detection and yield determination and the other for direction finding; an optical sensor for yield determination; and seismic sensors for use in height-of-burst determination and credence establishment. (The validity of some of these uses will be discussed below in Section 4.1.3.)

[redacted] The EMP sensor for detection and yield determination consists of two subsystems: the first determines that, in fact, the EMP exceeds a certain threshold and determines the time to first crossover[2] for yield determination. The second determines that the rise time of the pulse is consistent with that of nuclear events. The direction finding EMP antenna is a crossed-loop antenna that determines direction by comparing the polarity and voltage in each of the loops. EMP reports from at least three sensor sites must be presented to the

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1. Corf, J. R., Handbook for Phase I 477L NUDETS Nuclear Detonation and Reporting System (U), SR-127, The MITRE Corporation, March 1965 (Confidential).

2. The first crossover of the EMP occurs when the electromagnetic field reverses polarity for the first time.

RDPC before a user's report is generated. This is subject to seismic confirmation under certain conditions.

[redacted] The optical sensor system is equipped with two photoelectric cells whose main response is in the red portion of the spectrum. The system is triggered either by the receipt of the light pulse from the first thermal maximum or by the EMP. It then measures the time to the second thermal maximum, and computes the yield by use of Glasstone's formula.[1]

[redacted] The seismic sensor system consists of two seismometers positioned one above the other approximately one to two hundred feet deep. This configuration is used to enhance the reception of Pn (longitudinal) waves. (The Pn wave is a ducted seismic wave that travels just beneath the Moho with a speed of approximately 8.2 km/sec.) The Pn wave is assumed to be the first arriving at the sensor while the slower waves, e.g., the S (transversal) and the various surface waves, arrive later. By using the state configuration, the phase difference of the two seismometers is used to detect the Pn wave signals and suppress the others. Because the Pn wave is radiated upward from the Moho, it will be detected by the lower seismometer before it is detected by the upper one. The output of the two seismometers will therefore be out of phase. This phase difference is used to enhance the Pn wave. The other waves, conversely, hit both seismometers at the same time and can be suppressed because the outputs of the seismometers are in phase.

[redacted] The seismic sensor system serves two functions: (1) it provides a credence logic feature, and (2) it assists in determining the height-of-burst. The credence logic dictates that for the first report EMP messages must be received from at least three sites within ten milliseconds of each other and a seismic report must be received that is time correlated with the EMP messages. For subsequent reports, three EMP messages within ten milliseconds of each other is required, provided three seismic signals have been received in the last five minutes.

[redacted] Determining the height-of-burst requires both the EMP location function and the seismic sensors. The distance to the burst point from a given sensor site is known from the information generated by the EMP sensor. Since the speed of the Pn wave is known, the time for the Pn wave to arrive (assuming a surface burst) can easily be calculated. Any time delay in the arrival of Pn above the calculated time is attributed to the air travel time of the shock wave before it strikes the ground. Then, by the use of shock wave travel time formulas, the height-of-burst can be obtained.

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1. Glasstone, Samuel op. cit., pp. 74-77. This formula has been shown to be in error. See Section 5.2 below.

4.1.2 (U) Capabilities

(U) The capabilities herein reported are derived from the 477L Phase I simulation model[1] and the results of the Category I and II tests.[2] (Category I tests are carried out by the contractor to ensure the user of the system that the components and system work according to specifications. Category II tests are the formed acceptance tests of the first module or unit of the system.) The comments below are broken down into the following categories: (1) ground zero location determination, (2) yield determination, (3) height-of-burst determination, (4) false alarms, (5) false dismissals, (6) availability, and (7) detection rate.

[redacted] Ground Zero Location. Two sets of figures are available for the accuracy to which ground zero can be located. The simulation model was used to determine the figures presented in Table 1. Here, it is assumed that the EMP sensors have a one sigma azimuth error (one standard deviation).

Table 2 presents the data derived during the Category II tests. This data reflects the actual, but unknown, errors present in the system.

[redacted] Yield Determination. In yield determination, optical data has priority over EMP data. Thus, if only one site reports optical data it will be used. If no optical data are present, the averages of all the reported EMP times to first crossover will be used to determine yield. The formulas employed for yield determination are:

$$Y = 975\, t_2^2$$

for optical data, and

$$Y = \left(\frac{t_1}{9.1}\right)^7$$

for EMP data, where

Y = yield on kilotons

t_1 = EMP time to first crossover in microseconds, and

t_2 = time to second thermal maximum in seconds.

1. Croft, J. R., op. cit., p. 25ff.

2. Brown, D. E., et al., 477L Phase I (NUDETS) Category II Test Report and System Evaluation, TM-4105, The MITRE Corporation, January 1965. (Secret-Restricted Data.)

Table 1. Ground Zero Accuracy From Simulation Model Data (U)

[redacted]

OSD 3.3(b)(4),(8)

Table 2. Ground Zero Accuracy From Category II Tests (U)

[redacted]

[redacted] The accuracies to which yield is given by the optical yield formula is dependent on whether or not the Glasstone formula holds true. If Glasstone is correct, then the results can be expected to be within ±30 percent with a confidence level of 68 percent (one sigma), and within ±200 percent with a confidence level of 90 percent. However, if the SRI formulas[1] hold rather than Glasstone's, then the accuracies involved are not only a function of yield, but also of the proximity of the burst to the ground and the type of surface over which the bomb was detonated. For instance, if a t_2 of four seconds was observed, the Glasstone formula would give a yield of about 16 megations and with the SRI formula, about 44 megatons--an error of 157 percent. This point will be discussed further in Section 4.1.3 below.

[redacted] The yield determination by EMP time to first crossover is even less accurate. Category II tests demonstrated that there is only a 50 percent probability of determining the yield to within a factor of two.

[redacted] Height of Burst Determination. There are essentially two basic limitations in the determination of the height of burst. The first lies in the basic nature of the seismic waves. There is not a single sharp wave associated with an explosion but rather a series of waves traveling at various speeds. It has been estimated from Category II testing of 477L that it takes on the order of five minutes after a single explosion before the waves have passed and the seismic sensors have calmed down enough to take another unconfused reading.

[redacted] The second limitation imposed on this function is the relative lack of information, i.e., test data, on the shock travel time to the ground from air bursts and the comparative crudeness of the scaling laws. [redacted] OSD 3.3(b)(4),(8)

[redacted] False Alarms. During the period from 1 July 1964 to 15 October 1964, an average of 5.6 false alarms were generated per month. In considering this number, however, it must be realized that the test period covered the season of the year with the highest sferic activity. When this is considered, the apparent false alarm rate would be about 3.6 per month average over the year.

[redacted] Beside the high sferic activity, the seismic message rates during the test period averaged about 164 messages per day per sensor site with one site [redacted] averaging 384 per day. With certain engineering changes, however, it is felt that the average rate could be reduced anywhere from 5 to 41 false seismic reports per day per site.[2]

OSD 3.3(b)(4)

1. See Section 5.2 below.

2. Ibid., p. 401.

~~(U)~~ The actual number of three-site, correlated EMP reports during the test period was 350, or about 4 per day. Engineering studies of the false reports indicate that if reports whose first half-cycle times are less than 21 micro-seconds and greater than 55 microseconds are eliminated along with those sets of reports that contain more than the 20 percent variation in the indicated first half-cycle times, the number of false EMP reports per day could be cut to about 0.72 or about 5 per week.

~~(U)~~ All things considered, then, with the above changes, the false alarm rate could be cut to less than one per month, or about one-sixth the present rate.

~~(S) (RD)~~ False Dismissals. False dismissals occur when the EMP waveform does not have the proper characteristics. [redacted]

OSD 3.3(b)(4),(8)

1. Ibid., p. 331,

2. Ibid., p. 336ff.

(~~S~~) Availability. The system requirement for availability is that the system be available 90 percent of the time with a confidence level of 90 percent. The system became operational on 1 July 1964. For some unknown reason, the availability computations did not begin until 1 August 1964. For the period from 1 August to 31 October, the system was available 96 percent of the time. By using all the failure data for all subsystems from the beginning of operation (up to 18 months for some subsystems) to 31 October, the availability is 92.5 percent. Thus, it appears that the system has met the availability requirement.

(~~S~~) Detection Rate. There was no maximum detection rate test during the Category II tests. Tests made with the simulation model showed that the system could process 17 detonations (and 7 false reports due to sferics) in a 9-minute period. Sferics were being reported at the rate of 15 per minute per site. It has also been shown that when the sferic rate becomes 28 per site per minute, the input buffers will become saturated and no detonations can be reported at all.

4.1.3 (U) Evaluation

(~~S~~) EMP Subsystem. The use of EMP for the location of burst point and the time of the event is a perfectly legitimate use of this effect of nuclear detonations. The accuracies obtained are not as good at locations such as CINCLANT compared with close-in locations, but are probably within the state-of-the-art for such a technique operating with comparatively short signals. However, they are certainly adequate for fallout predictions.

(~~S~~) (~~RD~~) The somewhat mysterious attenuation of the VLF portion of the EMP pulse at [redacted]

OSD 3.3(b)(4)(8)

(~~S~~) (~~RD~~) The utilization of EMP, however, for determination of yield is another matter. While it can be, and has been, shown[2] that time-to-first-crossover has some functional relationship with yield, this relationship is

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1. Martell, D. L., et al., An Experimental Study in Nuclear Detection (U), TM-4152, The MITRE Corporation, 11 January 1965 (Secret-Restricted Data) p. 107ff.

2. Brown, D. E., et al., op. cit., p. 314.

OSD 3.3(b)(4),(8)

somewhat tenuous. [redacted] All in all, it appears that EMP time-to-first-crossover is not a sufficient measure of yield.

(U) Optical Subsystem. The determination of yield by optical measurement of the time-to-second-thermal maximum, with knowledge of the height of burst, is accurate and produces consistent results but the method as applied in 477L leaves something to be desired. First, there is ample evidence that time to second maximum is a function of height of burst, and, secondly, there is considerable doubt as to the validity of Glasstone's formula.

In 477L, Glasstone's formula[4] for air bursts is used exclusively for the optical determination of yield whether or not the burst is determined to be a surface burst or not. However, the very next sentence after the description of the formula for an air burst, Glasstone states: "For contact surface bursts, the respective times are greater by 30 percent or so."[5] Thus, for a one-megaton surface burst, the time to second maximum (t_2) is about 1.32 seconds, and the system would indicate a burst of 1.69 megatons, an error of 69 percent. This percentage error is constant.

(~~RD~~) As to the validity of the Glasstone formulas in general, there are two sources that indicate that they are not valid. During the proof testing of the sensors of 477L at the Pacific Proving Grounds, a statement was made by

1. Ibid., pp. 310-311.

2. Graham, W. R., "Computer Solutions to Maxwell's Equations" (U), Proceedings of the Symposium on EMP Effects on Military Systems, Vol. 1, (U), ESD-TR-64-602, Vol. 1, January 1965 (Secret-Restricted Data), p. 73.

3. Suydam, B., "Theory of Radio Flash-Numerical Method" (U), ibid., p. 51.

4. Glasstone, Samuel, op. cit., p. 76.

5. Ibid., p. 77.

one of the authors of the report that "the time-to-second-thermal-maximum... does not follow [Glasstone's formula] within ±20 percent at 400 miles."[1] The second source is the work by Hillendahl,[2] and later confirmed by SRI, which indicates that: "the square root scaling given in the Effects of Nuclear Weapons predicts times about 30 percent too short at 1 kT and about 30 percent too long at 3.8 MT. At higher yields, the error would be even more significant."[3] In view of the fact that Hillendahl's work was available in 1959 (three years before the system requirements were written for 477L[4] and the results of the proof tests in 1962), it is difficult to understand why Glasstone's formula is in use in 477L.

(U) Seismic Subsystem. The nature of seismic waves emanating from a seismic disturbance on the surface of the earth is surprisingly complicated when the waves are observed by seismological instruments near (within 650 miles or so) the source. Since the arrival of the first shock is the only event of interest here, only two waves need be considered, i.e., Pn (described in 4.1.1 above) and p, a direct wave from the source traveling at about 6.34 km/sec.[5] Depending on the distance, either p or Pn will be the first waves arriving at the sensor.

(U) To determine the arrival time of p, the formula is:

$$t_1 = \frac{D}{3.93}$$

where t_1 is in seconds and D in miles. However, the corresponding formula for Pn is not so simple. The Pn wave starts out as a direct wave from the disturbance, strikes the Moho at an angle so that it is refracted into a horizontal wave that travels along the Moho, then leaks out as it travels at the same incidence angle as it entered. Thus, we have a situation as depicted in Figure 1.

1. Attridge, Jr., W. S., 477L System Design (U), TM-3366, The MITRE Corporation, 15 August 1962 (Secret-Restricted Data), p. B-7.

2. Hillendahl, R. W., Characteristics of Thermal Radiation from Detonations (U), Vol. III, USNRDL-TR-383, AFSWP-902, 30 June 1959 (Secret-Restricted Data).

3. Rogers, J. C., and T. Miller, Survey of the Thermal Threat of Nuclear Weapons (U), SRI Project No. IMU-4021, Stanford Research Institute, July 1963 (Secret-Restricted Data), p. A-22.

4. System Performance Specifications for 477L Phase I (U), ESD-TDR-62-229, 8 October 1962 (Secret).

5. Richter, C. F., Elementary Seismology, W. H. Freeman and Company, San Francisco, 1958, p. 282ff.

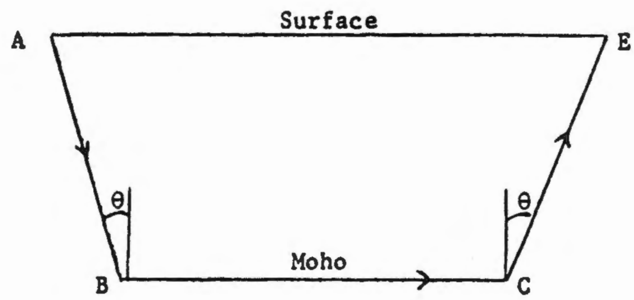

Figure 1. Direction of Travel of Pn.

To determine the total travel time of Pn, first assume that the depth d of the Moho is 30 km; the seismic velocity in the crust is 6.34 km/sec; and, below the Moho, 8.2 km/sec. Now the total distance traveled in the crust, $\overline{AB}$ plus $\overline{CE}$ is given by

$$\overline{AB} + \overline{CE} = 2d \sec \theta,$$

and along the Moho,

$$\overline{BC} = \overline{AE} - 2d \cot \theta$$

The angle θ necessary to make the ray become horizontal is determined by Snell's law and is

$$\sin \theta = \frac{6.34}{8.2} = 0.77317$$

substituting, dividing each distance by the velocity for that distance, and simplifying, we find that the travel time, t_2, for a given surface distance, D (= $\overline{AE}$), is

$$t_2 = \frac{D}{5.08} + 8.92$$

where t is in seconds and D in miles. To determine the crossover distance at which p arrives <u>after</u> Pn, we merely equate the two equations and find that the travel time equations for each zone is as follows:

$$t = \begin{cases} \dfrac{D}{3.93} & D < 155 \text{ miles} \\ \\ \dfrac{D}{5.08} + 8.92 & D \geq 155 \text{ miles} \end{cases}$$

[redacted] The fact that p was the first wave to arrive for close-in distances was determined empirically, but not conceptually, during the Category II tests.[1] However, it was not realized that Pn is the first wave beyond 155 miles, and thus only one formula for computing seismic travel time is included in 477L. The net effect of this is that, for detonations beyond 155 miles, the computed seismic travel time will be overestimated thus biasing the height-of-burst calculations to give a lower burst altitude. The seismic sensor configuration that enhances the Pn wave and attenuates the p wave is also brought into question by these facts.

(U) It should be noted that the above derivation is in reality only hypothetical. The depth of the Moho varies locally; the seismic velocities in the crust are still known with little precision;[2] and it is not entirely clear that the p wave at moderate distances would have sufficient amplitude to trigger the seismic sensor. All in all, these seismic problems appear to be solvable only in retrospect where careful study of the records after a detonation could determine just what seismic phenomena was observed by the sensors. In discussing these problems as applied to earthquakes, Richter observed:

> "If standard transit times for the principal recorded waves can be established in a given area, epicenters can often be located by routine methods with sufficient accuracy... Setting up such standards, bitter experience has shown, calls for a large group of stations with accurate timing, constituting a network with average spacing not much over 20 kilometers, continuously maintained and further supplemented by additional emergency installations to record aftershocks and large artificial explosions. Such an extended effort is only practicable in a region at least as active as California, where earthquakes are frequent enough to yield results in a limited number of years."[3]

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1. Brown, D. E., et al., op. cit., p. 49.

2. Richter, C. F., op. cit., p. 686.

3. Ibid., p. 290.

[redacted] Summary Evaluation. From the above discussions of the system capabilities and subsystem evaluation, it appears that 477L, while the most ambitious and sophisticated system yet attempted for damage assessment, is not suitable for warning purposes. For tactical warning, it falls short in its rather high false alarm rate (at best, about one per month). For fallout warning, the main problems seem to lie in the areas of yield and height of burst determination. The questionable optical yield determination, the untenable EMP yield determination, and the unavailability of height-of-burst information [redacted] makes fallout prediction guesswork at best.

OSD 3.3(b)(4),(8)

4.2 (U) BOMB ALARM SYSTEM (BAS)

4.2.1 (U) Description

(U) The BAS[1] was designed to provide positive identification of nuclear events occurring at selected targets within the contiguous United States. The method of sensing the event is the identification of the characteristic double thermal pulse of a nuclear explosion via the use of solar cells and certain discriminating logic circuits. Each of the targets is surrounded by three (or a multiple thereof) sensors arranged in the form of an equalateral triangle with approximately 19 miles separation. Each sensor is associated with a unique Signal Generating Station (SGS).

(U) The SGS is located within 20 miles of the sensor, but in no case is it within the target area. The function of the SGS is to provide power to the sensor and monitor its status. The status of a sensor may be green (operating normally, no malfunction), yellow (possible malfunction), or red (detection of nuclear event). The SGS's are connected by a loop circuit to a Master Control Center (MCC). There are no more than ten SGS's on each loop and only one from each target area; thus the sensors at each target area report to three different MCC's. About 50 SGS's (total) report to any given MCC.

(U) There are six MCC's in the United States which periodically poll the SGS's to determine the status of the sensors. However, if a red signal is generated by a sensor, it will take precedence on the loop and be sent to the MCC without delay. The six MCC's, in turn, are all connected to the various Display Centers (DC).

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1. Western Union Telegraph Company, United States Air Force Display System 210-A, Bomb Alarm; Description of the Nationwide System, March 26, 1962.

(U) The DCs are the termination points of the system. They contain two pertinent displays: The Map Display Panel and the Communicator's Display Panel. The Map Display Panel consists of an outline map of the United States on translucent plexiglass. Behind the map are a number of red lamps indicating the location of each of the targets. These lamps are not visible from the front until they are lighted. A lamp will not go on unless two of the three sensors at a target are in red condition, or, if two are yellow, and one is red. The Communicator's Display Panel shows the status of every sensor in the system. There are also appropriate signals and alarms for certain unusual conditions.

[redacted] The sensor[1] itself consists of three silicon wafers commonly called solar cells. These are mounted within the sensor housing so as to provide 360° coverage in the horizontal and 10° up from the horizon. The criteria for detection of a nuclear event are as follows:

1. The irradiance of the first pulse must have a rise time less than 30 microseconds, a time differential greater than a preset level (unspecified), and an irradiance of at least 14 milliwatts per square centimeter.

2. The irradiance of the second pulse must be 25 milliwatts per square centimeter one second after the first pulse and continue at or above this level for at least one second.

When the first criterion is satisfied, the status of the sensor goes from green to yellow; when the second is satisfied, from yellow to red. This sequence then triggers the SGS to send a red condition to the MCC.

4.2.2 (U) Capabilities

[redacted] At the present time, there are 99 target areas under continuous surveillance by BAS. Based on one sensor availability, the system, during 1963, had an ultimate target area availability better than 99.98 percent at the 90 percent confidence level.[2] During this time period there were also 13 single sensor red alarms, but not a single confirmed (or "Map Alarm") in the system.[3]

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1. Eldridge, R. G., Description and Capabilities of the Bomb Alarm System (U), W-6794, The MITRE Corporation, 1965, p. 3, (Secret).

2. Western Union Telegraph Company, Bomb Alarm System Study, Doc. No. 800, 1 May 1964, (Secret, Restricted Data) p. iv.

3. Ibid.

(U) The repeat capability[1] of the system is such that if a sensor, the communication lines, and the SGS survive the first explosion, the complex will be able to repeat its function with a maximum delay of 11.5 seconds depending on the load being handled by the MCC's and other SGS's on the associated loop.

[redacted] The count capability[2] is questionable. In the greater Washington, D.C., area, for instance, the sensor configuration has multiple triads and one large weapon would probably be counted as four detonations. Also, there are significant target areas, such as missile fields, that are not covered by the system. All this makes any count of weapons expended by an enemy through the use of BAS highly suspect.

[redacted] The yield detection range of the sensor is [redacted] There is some indication[3] that the lower limit cannot be met under high ambient light conditions such as bright sunshiny days. It is difficult, however, to determine the degree of degradation experienced under these conditions.

[redacted] Poor visibility is also a rather serious problem concerning the probability of detection of a nuclear event. A recent study[4] indicates that on the basis of water vapor content of the atmosphere, the probability of detection is reduced to 0.05 in some areas [redacted] and 0.67 [redacted] during certain seasons. This problem, if indeed true, would seriously degrade the system performance, probably beyond the point of minimum usability.

OSD 3.3(b)(4)(8)

4.2.3 (U) Evaluation

(U) For use in fallout prediction, BAS has no value whatsoever. The only information it supplies is that a nuclear detonation has occurred somewhere near a sensor triad. No information as to yield, height of burst, or location is provided.

[redacted] The above noted reliability and availability of the system makes it ideal as a tactical warning "trigger." However, there are two degrading factors: (1) The poor coverage of the system, and (2) the questionable sensor performance during marginal weather. These two factors would indicate that the system, while probably the best we now have, is usable only in a limited way for tactical warning.

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1. Ibid., p. 20ff.
2. Eldridge, R. G., op. cit., p. 9.
3. Millman, R. J., and E. S. Paul, BAS Sensor Evaluation Study (U), W-7637, The MITRE Corporation, 14 May 1965 (Confidential), p. 8.
4. Eldridge, R. G., and E. S. Paul, Probable Performance Characteristics of the Bomb Alarm System (U), W-7591, The MITRE Corporation, 26 April 1965 (Secret-Restricted Data).

4.3 (U) IMPROVED BOMB ALARM SYSTEM

4.3.1 (U) Description

(U) The Improved Bomb Alarm System[1] (IBAS) would be based on the BAS. Existing sensors would be utilized as now, but additional sensors would be placed at the SGS. This, in some cases, would require relocation of the SGS's because of terrain shielding these additional sensors. The added sensors would consist of a backup optical sensor similar to the present sensor; an EMP sensor of high threshold and weighted toward the higher frequencies; a yield determination sensor (optical); and a burst elevation sensor (optical). The EMP sensor would provide two items of information: (1) the zero time of the detonation, and (2) information as to the localization of the detonation. The yield determination would be based on the time to first thermal maximum (or minimum). The usual method of using time-to-second-thermal-maximum is not employed in order to enhance the repeat capability of the system.

(U) The burst elevation sensor is simply an optical device segment in the vertical so that bursts sensed below a certain elevation angle (unspecified) would be classified as ground bursts; and those above, air bursts. Distant air bursts sensed by the ground burst portion of the sensor would be discriminated by the (assumed) lack of an EMP signal. The MCC's and DC's would still retain their functions and would also be supplied with a printout indicating location, ground or air burst, yield and EMP presence indicator.

4.3.2 (U) Capabilities

OSD 3.3(b)(4),(8)

(U) The IBAS has essentially the same capabilities as BAS with the addition of crude burst height and yield determination. [redacted] It is also subject to the same limitations as BAS, only more so, because the new sensors are located at the SGS at an increased distance from the target area.

4.3.3 (U) Evaluation

(U) This system provides some improved capability for fallout prediction over BAS. At least, some idea as to the size of the weapon and burst height is given, however, the estimates provided, especially the burst height, are of questionable worth in any semisophisticated fallout prediction scheme. As for its use as an alarm trigger, the same comments as those made for BAS apply.

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1. Anon., Bomb Alarm System Study, pp. 35-40.

4.4 (U) WESTERN UNION'S SURVIVABLE DAMAGE ASSESSMENT SYSTEM[1]

4.4.1 (U) Description

(U) This system consists of approximately 1000 blast and radiation sensors contained in blast shelters rated at 100 psi overpressure, and supplied with auxiliary power sufficient for 48 hours. They would be distributed on the basis of one set of sensors per expected target and located one to five miles from the expected burst point depending on the type of target. Each set of sensors would be shielded as much as possible from EMP and gamma radiation. Nuclear data effects would be measured and stored at the time of the explosion and then collected by aircraft at a later time via radio-teletype and retransmitted to ground collection points (processing centers) and disseminated to users from there. It has been estimated that ten aircraft and three ground processing centers would be required for adequate coverage. With ten aircraft, it is estimated that every sensor set could be interrogated once an hour. Landline check and maintenance circuits would also be provided.

4.4.2 (U) Capabilities

(U) The blast sensor would have a dynamic range from 0.5 psi to 99 psi. The readout would be in increments spaced 2 db relative to 0.5 psi. The radiation sensor would have a dynamic range of from one milliroentgen per hour to 10,000. The readout would be in increments spaced 5 db relative to one milliroentgen per hour.

4.4.3 (U) Evaluation

(U) As a damage assessment system, the above scheme seems to have little merit. Its most obvious deficiency is an inadequate number of sensors in a given target area. A single blast sensor reading gives little indication of the actual situation existing in the target area. A high reading would indicate that the burst point of a weapon of unknown size was somewhere in the vicinity of the sensor, but a low reading, say 2 psi, gives little or no information except that somewhere, at a distance of 17 miles, a 10-megaton device was detonated; or, at 8 miles, a one-megaton device; or at 22 miles, a 20-megaton device, etc. Radiation readings at a point location are also of questionable value. If the readings are high, a nuclear device has been exploded in the area; if low, it is probably from fallout. In either case, these conditions could be predicted from other information.

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1. Private Communication from J. Pence, Western Union, June 1965.

(U) The data collection scheme, although novel and relatively more reliable than landline would be under similar circumstances, has the disadvantage of not being realtime. For the application of this system to either tactical warning or fallout warning, the delays are intolerable.

(U) In short then, none of the required parameters for tactical or fallout warning can be derived from the information provided by this system.

5.0 (U) SUFFICIENCY OF MANUAL DAMAGE ASSESSMENT METHODS

5.1 (U) COMMENTS ON PROCEDURES FOR THE LOCATION AND YIELD DETERMINATION OF NUCLEAR EXPLOSIONS

5.1.1 (U) Introduction

(U) This section represents a critique of two Office of Civil Defense publications.[1] These documents are procedural manuals for estimating weapon characteristics by visual means with minimum instrumentation such as stop watches, compasses, devices for measuring vertical angles, etc. The observers, usually three, are placed symmetrically around a potential target area at distances ranging from 50 to 100 miles and report the various phenomena they are able to observe. These include such things as cloud dimensions, azimuth of burst point from their post, duration of flash, approximate distance to the burst point, etc. The procedures used are discussed below.

5.1.2 (U) Estimating Distance From Sound

(U) Distances measured by the "Flash-to-Bang" method are subject to two major sources of error: the variation of the speed of sound due to temperature, and the "wind-effect." The former can be corrected in the following way:[2]

$$C = 49.04\,(T + 459.69)^{1/2}$$

where

C = the velocity of sound at temp. T, and

T = the average[3] temperature over the path in degrees Fahrenheit

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1. Office of Civil Defense, Nuclear Weapons, Phenomena and Characteristics, March 1961; and Appendix C; Methods and Procedures for Estimating Weapon Yield and Location of Ground Zero, undated.

2. Gray, E. D., (ed.) American Institute of Physics Handbook, McGraw-Hill Book Company, Inc., 1957, p. 3-62ff.

3. The average temperature in most cases can be sufficiently approximated by averaging the temperatures at the probable target and the observation post.

To illustrate the magnitude of this correction, consider the following table:

Table 3. Magnitude of Temperature Correction (U)

(Tabulation on this page is UNCLASSIFIED)

Flash-to-Bang Time Duration	Uncorrected Distance (32°F)	True Distance 59°F	True Distance 86°F
5 min.	61.8 mi.	63.5 mi.	65.1 mi.
10	123.6	126.9	130.2
15	185.4	190.4	195.3

(U) The significance of the temperature correction can easily be seen from this table, and it is recommended that it be employed in all determinations of distance using the "Flash-to-Bang" procedure.

(U) The "wind-effect" can best be explained by the fact that while sound travels through a given air mass at a given speed when the air mass is moving, its velocity components must be added to those of the sound-wave front to give the true velocity of the sound with respect to a fixed observer on the ground. To give some idea as to the magnitude of errors involved, consider a 20 mph (=29.33 ft./sec.) wind blowing against the oncoming sound. This would slow up the speed of sound for a fixed observer by a corresponding amount and produce an error in measuring distances of +0.33 miles per minute of travel. Thus, for a true distance of 50 miles (at 32°F), and the wind blowing as above, the apparent distance would be 51.35 miles. Conversely, for a 20 mph wind blowing with the sound, the apparent distance would be 48.65 miles.

(U) It is assumed that the wind force is constant over the entire path between the target and the observation post. This, of course, is hardly ever true. Therefore, there appears to be no feasible way, at the present time, to make suitable corrections to distances measured by sound travel.

(U) One note of caution should be sounded at this time. At reasonable distances from a nuclear explosion, the shock front becomes acoustic in nature and is refracted by the atmosphere so that, besides the arrival of the ground sound wave, several other sound rays could arrive at the observation site with varying intensities. This multiplicity of apparent arrival times could be confusing and distances should be calculated on the basis of the arrival of the first shock.[1]

1. Moulton, Jr., J. F., op. cit., p. 1-80ff.

5.1.3 (U) Accuracy of Angular Measurements for Locating Ground Zero

(U) When multiple observers are employed to locate ground zero, it will be sufficient for them to report their respective azimuths with an accuracy equal to $\pm$ (57/D)°, where D is the distance to the probable target. If only one observer is used (assuming that he also has "flash-bang" information), the accuracy should be $\pm$ (29/D)°. These accuracies in azimuth will produce measurements within $\pm$ 1 mile and $\pm$ 1/2 mile in location, respectively, perpendicular to the line of sight.

5.1.4 (U) Estimating Yield From Cloud Parameters

(U) Comparison of the NRDL data[1] and the parameters in the OCD references indicates some discrepancies exist between the two sets of data. Particular attention is drawn to Figure 1 of the NRDL document. Elementary calculations produce the following equations for determining cloud diameters at 10 minutes and at maximum:

$$D_{10} = 1.16\ W^{0.424} \qquad \text{(all yields)}$$

and

$$D_{max.} = 0.688\ W^{0.532} \qquad (W \geq 150\ \text{kT})$$

where

D_{10} = Cloud diameter at 10 mins.

$D_{max.}$ = Maximum cloud diameter

W = Yield in kilotons

From these, and the information in References 1 and 2, the following table has been constructed for comparison purposes.

1. Schuert, E. A., op. cit., pp. 17-19.

Table 4. Cloud Diameters (U)
(Tabulation on this page is UNCLASSIFIED)

Yield (MT)	Cloud Diameter (10 min.)		Cloud Diameter Max.	
	D_{10} (NRDL)	D_{10} (OCD)	$D_{max.}$ (NRDL)	$D_{max.}$ (OCD)
1	22	20	27.1	26.5
2	29	28	39.2	36.9
3	35	32	48.7	47.2
4	39	34	56.7	57.6
5	43	38	64.0	62.2
10	58	52	92.4	92.1
15	69	66	114.7	101.0
20	77	80	133.7	138.2

(U) These differences between the NRDL data and the OCD data will not be explored further; however, data sources should be reviewed to eliminate these discrepancies.

Concerning the use of cloud radii for yield estimation, it would be well to heed the warning of Quenneville and Nagler:[1]

> "Since the variability in cloud radius under various meteorological conditions is not well understood, particularly for yields in the megaton range, only an average cloud radius curve is shown. Nuclear clouds continue to grow laterally for a while after their maximum height has been attained. Also, because the winds often move different levels of the cloud in different directions, there will be an apparent continued widening of a nuclear cloud. Therefore, the cloud radius curve must be considered to give the radii only approximately and only at about ten minutes after the burst."

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1. Quenneville, L. R., and K. M. Nagler, A Note on Nuclear Cloud Dimensions, U. S. Department of Commerce, Weather Bureau, September 1959.

This indicates that maximum cloud diameters are most likely not suitable for estimating yields. However, if weapon yields of 1 megaton or greater are considered, even a ±20 percent variance in the 10-minute cloud diameter would probably give yields within ±50 percent. From the discussion in 3.5 above, this is not sufficient for our purposes.

(U) Because of line-of-sight problems and the general presence of obscurations to vision on the horizon, it is possible to develop formulas to check the validity of cloud radius information. Since most of the obscurations are confined to elevations less than five degrees above the horizon, we will consider valid only those radii whose elevation is greater than this. Two formulas are recommended because of the variability of cloud height. Let d_1 be the distance at which the lowest (-20 percent)[1] clouds are five degrees above the horizon; d_2, the distance for the highest (+20 percent) clouds. Assuming normal atmospheric refraction and the NRDL cloud data, then, we have:

$$d_1 = 72.76 + 0.732D - 0.00095D^2, \text{ and}$$

$$d_2 = 103.47 + 0.971D - 0.00215D^2$$

where D is the cloud diameter in miles at 10 minutes. The distances are applied as follows:

1. If the observed distance is less than d_1, the radius information is always valid.

2. If the distance is greater than d_1, but less than d_2, the information is probably valid.

3. If the distance is greater than d_2, the information is never valid.

Some representative values are given in the following table:

Table 5. Visibility Ranges (U)

(Tabulation on this page is UNCLASSIFIED)

(Cloud dia.)	d_1	d_2
10 mi.	80 mi.	113 mi.
20	87	122
30	94	131
40	100	139
50	107	147
60	113	154
70	119	161
80	125	167

1. Office of Civil Defense, Estimating Survivors and Resources Remaining After a Nuclear Detonation for Civil Defense Purposes (Draft), Undated, Appendix C.

Comparisons were also made between the NRDL data and the OCD data for the cloud top and base at 10 minutes, and again discrepancies appeared as follows:

Table 6. Vertical Cloud Dimensions (U)
(Tabulation on this page is UNCLASSIFIED)

Yield (MT)	Height of Cloud Top (10 mins.)		Height of Cloud Base (NRDL)
	NRDL	OCD	
1	70,000 ft.	70,000 ft.	46,000 ft.
2	78,000	76,000	49,000
3	82,000	82,000	51,000
4	86,000	90,000	52,000
5	90,000	93,000	53,000
10	101,000	103,000	55,000
15	110,000	110,000	56,000
20	118,000	113,000	57,000

(U) The OCD cloud base figures were not included. However, two sample calculations were made that indicated that the altitudes used to construct the nomogram were about 10 percent greater than the NRDL heights given above. The differences in the cloud top heights are generally not significant except for the 4, 5, and 20 megaton values.

(U) Since cloud height figures can vary ± 20 percent, their effect on yield determination can be significant. For instance, a five megaton weapon would produce a cloud whose top could range from 72,000 feet to 108,000 feet, and the base, from 42,000 feet to 64,000 feet,[1] These figures would provide yields, based upon cloud top, from 1.5 to 19 megatons; based upon cloud base, 400 kilotons to 55 megatons, using the extremes of height for each yield.

1. Ibid., p. C-5.

5.2 (U) DETERMINATION OF YIELD OF A NUCLEAR EXPLOSION FROM THE FLASH DURATION

5.2.1 (U) Introduction

(U) The present OCD procedures for yield determination of nuclear explosions by the duration of the flash[1] are based on the figures given by Glasstone.[2] Since that work was published, however, Stanford Research Institute has published new data[3] that is significantly different. Therefore, it is necessary to derive a new procedure for this method of yield determination.

5.2.2 (U) Derivation of Air Burst Flash Duration

(U) Present OCD procedures use the following formula for determining the yield, W, of a nuclear explosion from the duration of flash t, as follows:

$$W = 0.0022\ t^2 \qquad (1)$$

where t is in seconds and W in megatons. Converting W to kilotons and solving for t, we find:

$$t^2 = 0.45455\ W$$

$$t = 0.67420\ W^{1/2}$$

To convert t into terms of t_{max}, the time to second thermal maximum, we note that Glasstone gives

$$t_{max} = 0.032\ W^{1/2}$$

thus

$$t = 21.07\ t_{max}.$$

1. Nuclear Weapons, Phenomena and Characteristics, Department of Defense, Office of Civil Defense, March 1961, p. 76.

2. Glasstone, Samuel op. cit., pp. 74-77.

3. Rogers, J. C., and T. Miller, op. cit.

OSD 3.3(b)(4),(8)

5.2.3 (U) Evaluation of OCD Formula

~~(S) (RD)~~ In an attempt to verify equation (1) utilizing the new definitions of t_{max} and the power dissipation curves as defined by SRI,[1] some difficulty was encountered. Consider, for example, a [redacted] air burst. Assuming that the fireball acts as a "black body," at 1500° C it should be radiating power at the rate of 56.13 watts/cm^2. Using Glasstone's formula for determining the maximum size of the fireball, we find that it has a radius of about [redacted] and thus a surface area of [redacted] it should, therefore, be radiating power at the rate of 3.484×10^{11} watts (0.08295 kT./sec.).[2] However, when corresponding time (3.015 secs.) from Glasstone is used in the power dissipation equations, it is found that the power being radiated (after adjustment for the new t_{max}) is 1.433×10^{12} watts (0.25833 kT./sec.). This rate of power dissipation corresponds to a temperature of over 2500° C.

~~(S) (RD)~~ This difficulty disappears, however, if it is assumed that Glasstone's figures are for a ground surface burst, rather than an air burst. Using the new definitions of t_{max} and $P(t*)$[3] contained in the appendix, we find that the fireball should be radiating power at the rate of 3.085×10^{11} watts. Using Glasstone's figures for the size of a surface contact fireball, we find that it has a surface area of [redacted] and, thus, is radiating 3.027×10^{11} watts; a difference of only two percent. Thus equation (1) is in error.

5.2.4 (U) Methodology and Determination of Flash Duration Formulas

(U) Assuming that the 1500° C figure (and the corresponding 56.13 watts/cm^2) is valid, it is a simple matter to determine the correct formulas for the three situations. We can consider low altitude air blasts, surface contact ground blasts, and surface contact water blasts. It is only necessary to find a t^* which satisfies the equation

$$\frac{P_{max}\ P^*(t^*)\ (4.20 \times 10^{12})}{A_r} = 56.13 \qquad (2)$$

1. These formulas are summarized in the Annex to Section 6.

2. One kT./sec. = 4.20×10^{12} watts.

3. $P(t^*)$ is the time normalized power dissipation based on t_{max} as the unit of time.

where

$t^* = t/t_{max}$

P_{max} = the power dissipation rate at second thermal maximum

$P^*(t^*)$ = the scaled power equation, and

A_r = the area of the radiating surface as given by Glasstone[1]

~~(S) (RD)~~ Making the proper substitutions, we find, for an air burst,

$$\frac{28.1316\ t^{*-1.60}\ W^{0.58}\ X\ 10^{12}}{565.04724\ W^{0.8}\ X\ 10^{6}} = 56.13$$

$$t^* = 69.574\ W^{-0.1375}$$

and

$$t_a = 3.13083\ W^{0.2825} \qquad (3)$$

For a surface contact ground burst

$$\frac{4.70106\ t^{*-1.45}\ W^{0.51}\ X\ 10^{12}}{4.90914\ W^{0.8}\ X\ 10^{8}} = 56.13$$

$$t^* = 34.618\ W^{-0.20}$$

and

$$t_g = 1.2809\ W^{0.29} \qquad (4)$$

For a surface contact water burst

$$\frac{15.7466\ t^{*-1.45}\ W^{0.51}\ X\ 10^{12}}{4.90914\ W^{0.8}\ X\ 10^{8}} = 56.13$$

$$t^* = 79.684\ W^{-0.20}$$

$$t_w = 2.94830\ W^{0.29} \qquad (5)$$

1. Glasstone, op. cit., p. 77.

5.2.5 (U) Utilization of Duration of Flash Data

(U) Examination of equations 3 through 5 reveal that the flash duration for air and water surface burst are almost identical, differing by only about 2 seconds for a 100 megaton burst, but the ground burst flash duration is only about 43 percent of that for an air burst. This fact is further complicated in that as soon as the fireball touches the ground, the duration of the flash will be reduced. The closer the burst to the ground, the closer the time will be to t_g. Thus it appears unlikely that a distant observer will be able to gain any useful information as to yield from the duration of the flash when it is used by itself.

5.3 (U) CONCLUSIONS

(U) In light of the above discussions, it appears that the manual damage assessment methods are not without merit. The following, however, are the limitations on the methodology.

5.3.1 (U) Location of Burst

(U) Whenever possible, the triangulation method should be employed to locate the point of detonation. The flash-to-bang method, because of uncertainties of wind and temperature effects, will generally tend to produce erroneous results as noted in 5.1.2 above.

5.3.2 (U) Yield and Height of Burst Determinations

(U) No one method, with the possible exception of ten-minute cloud radius, will produce sufficiently accurate results. Top and bottom of cloud measurements should be discarded out of hand for this purpose. Duration of flash, because of the variations between surface and air bursts, does not in itself give accurate enough results; but when used with, say, ten-minute cloud radius, appears to have merit. When ten-minute cloud radius and flash duration are combined, a crude estimate of height of burst can be obtained. If the flash is shorter than expected for the cloud radius on the air burst curve, then the burst is close to the ground; if the flash matches the radius, then it is probably a pure air burst. The functional relationship, however, between flash duration and yield in transition zone (the zone between a pure air and a ground burst) defies analysis at this time. The point being that, according to Glasstone,[1] the maximum fireball size for a given yield is greater than the height at which early fallout ceases to be a problem. Thus the fireball can still touch the ground and be in the transition zone for determination of yield.

1. Glasstone, op. cit., p. 77.

5.3.3 (U) The Human Factor

(U) The use of humans for sensors brings up a severe limitation. This is simply that the human, operating under stress, observing a hitherto unobserved cataclysmic event, will not in general make accurate observations of that event. All of the above discussion of manual damage assessment techniques assumes a perfect (or near perfect) observer, and this, in all probability, is a most faulty assumption.

6.0 (U) SOME NOTES ON SCALING

(U) In any damage assessment system it is necessary to extrapolate from known test data to determine the effects of detonations of unknown or untested size. This is particularly true of very high yield weapons that might be employed in an attack but that have never been actually tested. This section will examine some of the scaling laws, and where known, indicate their accuracies and ranges of applicability.

6.1 (U) DEFINITIONS

OSD 3.3(b)(4),(8)

~~(S) (RD)~~ One of the most difficult concepts to define is that of a surface burst versus an air burst, for it really depends on the particular nuclear effect being examined. Moulton has pointed out[1] that there are essentially three definitions of an air burst when viewed from blast, thermal, and fallout effects. From a blast standpoint, the reflected wave must not overtake the incident wave above the fireball and coalesce with it; [redacted] From a thermal standpoint, the apparent thermal yield, when viewed from the ground, is not affected by surface phenomena, such as heat transfer to the surface, distortion of the fireball by the reflected shock wave during the second thermal pulse, thermal reflection from the surface, etc.; [redacted] Finally, from a fallout viewpoint, an air burst is any burst that does not produce significant early fallout; [redacted] for greater yields. Taking a serious look at blast effects, however, he concludes that a surface burst must be defined as a burst that occurs within -5 to +25 actual feet of the surface. This then leaves a gap from 25 feet to a scaled [redacted] (fallout considerations) as a transition zone in which the characteristics of the burst slowly change from that of a surface burst to that of a free air burst.[2]

(U) All references to scaled distances will be in terms of reducing the distances to correspond to a [redacted] Thus the conversion from actual distance to scaled distance involves nothing more [redacted]

6.2 (U) INITIAL RADIATION SCALING

~~(S) (RD)~~ The initial burst of radiation from a nuclear event consists of neutrons and gamma radiation. The integrated neutron flux values are given by the empirical relation[3]

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1. Moulton, Jr., J. F., op. cit., p. 4-184ff.

2. Ibid, p. 2-97.

3. Blizard, E. P., et al., Nuclear Radiation Criteria for Hardened ICBM Systems (U), STL/TR-59-0000-00735, Space Technology Laboratories, Inc., December 1959 (Secret-Restricted Data), p. 3.

$$N_T = \frac{1.8 \times 10^{22}\ W}{R^2} \exp\left(\frac{-R\rho}{0.78}\right)$$

where

N_T = integrated neutron flux in neutrons per square centimeter

R = actual distance in feet

W = total yield in megatons

ρ = ambient air density in grams per cubic centimeter

This relation is probably valid to within a factor of two. However, studies indicate that the flux could be greater by a factor of 50 percent to as much as 200 to 300 percent.[1] The neutron dose in rads is then given by[2]

$$D_n(\text{rad}) = 2.3 \times 10^{-9} N_T$$

[redacted] ~~(RD)~~ There are essentially two sources of gamma rays: those produced by inelastic scattering of neutrons produced by the fission process, and those produced directly by the fission process. When these two sources are summed, an approximate expression can be derived to give the maximum dose rate, and the total dose as follows:[3]

$$G_M = \frac{2.7 \times 10^{18}\ W}{R^2} \exp\left(\frac{-R\rho}{1.17}\right)$$

$$G_T = \frac{3 \times 10^{12}\ WA}{R^2} \exp\left(\frac{-R\rho}{B}\right)$$

1. Ibid, p. 5.
2. Ibid, p. 4.
3. Ibid, p. 14ff.

where

G_M	=	the maximum dose in rad/sec. (lasting about 0.2 microseconds)
G_T	=	the total dose in rads
W	=	yield in megatons
R	=	distance in feet
ρ	=	ambient air density in grams per cubic centimeter
A, B	=	parameters which are a function of the yield as follows:

W	A	B
0.1	7.2	1.26
0.4	8.73	1.32
1	9	1.38
4	10.4	1.44
10	11.7	1.95
20	27	3.09

OSD 3.3(b)(4),(8)

[redacted] ~~(RD)~~ The accuracy of these formulas is not too good however.[1] When considering distances farther than the 100 psi ring, G_M is accurate to within an order of magnitude and G_T to within a factor of five. Consider, for instance, [redacted] detonation at the 50 psi ring (about 2.2 miles). The total dose from neutrons could range from 0.52 to 2.12 rads, while the total gamma dose could range from about 1.2×10^3 to 3×10^4 rads. In both cases it can be seen that the range of values makes the correlation of yield from prompt radiation measurements an unprofitable pastime. It should also be noted that, since the EMP is the result of initial radiation, it is not difficult to understand the lack of dependence of its effects on yield because of the uncertainties involved in the scaling of initial radiation to yield.

1. Ibid., p. 19.

OSD 3.3(b)(4),(6)

6.3 (U) THERMAL PULSE SCALING

~~(S)~~ ~~(RD)~~ The effect of altitude on the time to second thermal maximum (t_{max}) is quite marked, shortening it until, [redacted] Up to this altitude, an empirical relationship has been derived as a function of the density of the atmosphere at the altitude of detonation.[2] This relationship is

$$t_{max} = 0.045\ W^{0.42}\left(\frac{\rho}{\rho_o}\right)^{0.39}$$

where

t_{max} = time to second thermal maximum

W = yield in kilotons, and

ρ, ρ_o = atmospheric density at ambient and sea level, respectively

It must be pointed out, however, that there is very little data available and this relationship is strictly empirical and not confirmed by theoretical considerations. It is certainly intuitively obvious that as the density of the atmosphere decreases, the shorter the time that the hydrodynamic wave effect has to act, and thus the time to thermal minimum is shorter.

6.4 (U) BLAST EFFECTS SCALING

6.4.1 (U) Conventional Sachs' Scaling Laws

(U) The Conventional Sachs' Scaling Laws as usually presented are as follows:[3]

(a) Pressures - peak static, peak dynamic, peak total pressures

$$P_2 = \left(\frac{P_{02}}{P_{01}}\right) P_1 \text{ at distance } \lambda 2 = \left(\frac{P_{02}}{P_{01}}\right)^{1/3} \lambda 1$$

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1. Ibid., p. 19.
2. Rogers J. C., and T. Miller, op. cit., p. A-30.
3. Classtone, Samuel op. cit., p. 128ff. Also Moulton, Jr., J. F., op. cit., p. 2-82ff.

(U)

where

P_i = blast pressures from ith explosion

P_{0i} = ambient atmospheric pressure associated with ith explosion

λ_i = scaled distance from ith explosion = $\frac{R_i}{(W_i)^{1/3}}$

R_i = actual distance from ith detonation

W_i = yield in kilotons of ith detonation

(b) Positive Impulse

$$I_2 = \left(\frac{W_2}{W_1}\right)^{1/3} \left(\frac{P_{02}}{P_{01}}\right)^{2/3} \left(\frac{C_{01}}{C_{02}}\right) I$$

$$\text{at distance } \lambda 2 = \left(\frac{P_{02}}{P_{01}}\right)^{1/3} \lambda 1$$

where

I = positive impulse associated with ith explosion

C_{0i} = speed of sound in ambient atmosphere associated with ith explosion

(c) Time - time of arrival of blast fron and positive phase duration

$$t_2 = \left(\frac{W_2}{W_1}\right)^{1/3} \left(\frac{P_{01}}{P_{02}}\right)^{1/3} \left(\frac{C_{01}}{C_{02}}\right) t_1$$

at distance

$$\lambda 2 = \left(\frac{P_{01}}{P_{02}}\right)^{1/3} \lambda 1$$

(U) These equations apply only in homogeneous atmospheres, e.g., the transfer of effects of a given explosion in a given homogeneour atmosphere to that of another different explosion in a possibly different homogeneous atmosphere. In reality, this statement implies that these scaling equations apply only to "constant" atmospheres of unvarying properties such as those on the surface of the earth where properties remain essentially unchanged with respect to distance.

6.4.2 (U) Modified Sachs' Scaling Laws

~~(S) (RD)~~ In Conventional Sachs' Scaling, the ambient conditions in the vicinity of the burst are used. In the real atmosphere, the conditions generally remain constant horizontally at any given altitude. However, it is obvious that in the vertical dimension, the ambient conditions could hardly be called constant. Although Sachs' Laws were meant to be applied only in the homogeneous or horizontal case, it is possible to get fairly accurate results in the vertical or, nonhomogeneous case by a simple device.[1] In the formulas given in Section 6.4.1, two simple substitutions are made. The first is that instead of horizontal distances being used, the slant range is used for points differing in altitude from the burst point. The second substitution is that the ambient conditions at the point of interest rather than those existing at the burst point are used in the computations. It is obvious that this procedure is no more than a device to circumvent the tedious process of ray tracing in a constantly varying atmosphere. But it must also be pointed out that they work with a fair degree of accuracy as will be shown in the next section.

6.4.3 (U) Accuracy of Sachs' Scaling Laws

(U) The following comments apply to both the conventional and modified Sachs' Scaling Laws.

~~(S) (RD)~~ Experimentally,[2] it has been shown that free-air pressures, distances and times can be scaled to ±15 percent over the following ranges:

Yield	[redacted]
Burst Altitude	
Distance (Scaled)	
Temperature	- -47.7 to 30.5° C.

OSD 3.3(b)(4),(8)

1. Ibid., p. 2-85.

2. Ibid., p. 2-95.

~~RESTRICTED DATA~~
~~ATOMIC ENERGY ACT 1954~~

[redacted] ~~(RD)~~ Blast parameters along the surface, with the exception of the positive duration parameter, have the same accuracies of estimation provided the scaled height of burst rule is observed. This, however, does not apply in the precursor region.[1] The positive duration parameter can only be estimated, at best, to ±25 percent, and in worst cases to ±50 percent. In the precursor region, estimation of any parameter is very risky and should, in general, not be attempted.

[redacted] ~~(RD)~~ The positive phase impulse does not scale to $W^{1/3}$ for surface bursts. For air bursts, it <u>appears</u> that the impulse scales to $W^{1/3}$ to ±15 percent for the radiated yield range.

[redacted] ~~(RD)~~ When considering surface bursts (defined as with 17 actual feet of the surface) as opposed to air bursts (burst height greater than 160 ft/kT$^{1/3}$), the scaled values can be brought into agreement by the following procedures.[2] "Taking the blast parameters obtained at various scaled, <u>horizontal</u> distances from free air burst of yield W as reference, the same peak overpressures will be observed at the same scaled slant ranges above a surface burst in free air as those which are observed from a free air burst of yield [about] 2W. ...the same peak overpressures along the surface at various scaled distances from a surface burst are observed at the same scaled distances from an air burst of yield 1.6 W." These relations hold generally to ±13 percent.

[redacted] ~~(RD)~~ The 1.6 W value was obtained empirically from data that indicated "reflection values" ranging from 1.28 to 1.96. In one detonation, the Koa shot of the HARDTACK series. a value of 341.1 was noted. Moulton also notes[3] that the 1.6 W relation holds down to about the 10 psi level where the curve then approaches that of the 2W free air burst. He concludes that a single reflection value probably does not exist. He also notes that in the 10 to 1 psi range, overpressures are more rapidly attenuated over land than over water, and the opposite is true below 1 psi.

6.5 (U) SUMMARY

(U) From the above discussion on scaling, it becomes obvious that scaling laws are generally of more use to the deliverer of a weapon than the recipient. It is much easier to determine the amount of damage a weapon can inflict than

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1. Glasstone, Samuel <u>op. cit</u>., p. 133. The precursor region is an auxiliary blast wave formed in front of the main blast wave producing gradually increasing pressures to a less than normal peak. This condition usually occurs with low blast heights over heat absorbing surfaces.

2. Moulton, Jr., J. F., <u>op. cit</u>., p. 2-96.

3. <u>Ibid</u>., p. 4-194.

it is to determine the yield, height of burst, etc., from the effects that the receiver of the weapon observes. For example, consider two identical weapons, one detonated over Los Angeles and one at Denver. Time to second thermal maximum for the Denver detonation will be 92 percent, as long as the one at Los Angeles. Overpressures observed at Denver will only be 85 percent of those observed at Los Angeles at the same scaled distance. The same effect would be true for the other phenomena, solely because of the decrease in air pressure. In short, the effects of one detonation cannot be transferred directly to another of equal yield. There are too many uncertainties involved to make weapons effects assessment, even just for fallout, a simple task.

ANNEX TO SECTION 6

[redacted] ~~(RD)~~ The following is a summary of thermal pulse parameters.[1] All times are in seconds (except where noted), and all yields are in kilotons.

1. Time to Second Thermal Maximum

$$t_{max} = \begin{cases} 0.045\ W^{0.42} & \text{for air bursts} \\ 0.037\ W^{0.49} & \text{for contact surface bursts} \end{cases}$$

2. Power Dissipation at Second Thermal Maximum (kT/sec.)

$$P_{max} = \begin{cases} 3.68\ W^{0.58} & \text{for air bursts} \\ 2.06\ W^{0.51} & \text{for water surface contact bursts} \\ 0.615\ W^{0.51} & \text{for land surface contact bursts} \end{cases}$$

3. Total Energy Radiated as Thermal Energy

$$E = \begin{cases} 0.55\ W & \text{for air bursts.} \\ 0.23\ W & \text{for water surface contact bursts} \\ 0.07\ W & \text{for land surface contact bursts} \end{cases}$$

4. Scaled Power Dissipation Formulas

$$P^*(t^*) = 1.82 t^{*-1.60}\ e^{-9e^{-2.73t^*}}\ e^{-9e^{-1200t^*}} \quad \text{(air bursts), and}$$

$$P^*(t^*) = 1.82 t^{*-1.45}\ e^{-9e^{-2.73t^*}}\ e^{-9e^{-1200t^*}} \quad \text{(contact surface bursts)}$$

1. Rogers, J. C., and T. Miller op. cit., Appendix F.

where

$$P^* = P/P_{max}, \quad \text{and}$$

$$t^* = t/t_{max}$$

Note for $t^* > 3$, the formulas are sufficiently approximated by

$$P^*(t^*) = \begin{cases} 1.82t^{*-1.60} & \text{(air bursts)} \\ 1.82t^{*-1.45} & \text{(contact surface bursts)} \end{cases}$$

APPENDIX A

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APPENDIX B

GLOSSARY

AUTOVON (AUTOmatic VOice Network). An automatic voice circuit switching network operated by the Defense Communications Agency (DCA).

Black Body. If for all values of the wavelength of the incident radiant energy, all the energy is absorbed. The body is called a black body. It also radiates energy according to Planck's Radiation formula.

Blast Wave. See Shock Wave.

Bomb Alarm System. A system designed to detect the detonation of nuclear weapons at a certain number of specific locations in the United States.

Burst - Air. The explosion of a nuclear weapon at such a height that the expanding fireball does not touch the earth's surface when the luminosity is a maximum (in the second pulse).

Burst - Ground. (Surface Burst) The explosion of a nuclear (or atomic) weapon at the surface of the land or water or at a height above the surface less than the radius of the fireball at maximum luminosity (in the second thermal pulse). An explosion in which the weapon is detonated actually on the surface (or within $5W^{0.3}$ feet, where W is the explosion yield in kilotons, above or below the surface) is called a contact surface burst or a true surface burst. See Air Burst.

Electromagnetic Pulse (EMP). A traveling wave motion resulting from oscillating magnetic and electric fields. Familiar electromagnetic radiations range from X-rays (and gamma rays) of short wavelength, through the ultraviolet, visible, and infrared regions, to radar and radio waves of relatively long wavelength.

Fallout. The process of phenomenon of the fallback to the earth's surface of particles contaminated with radioactive material from the radioactive cloud. The term is also applied in a collective sense to the contaminated particulate matter itself. The early (or local) fallout is defined, somewhat arbitrarily, as those particles which reach the earth within 24 hours after a nuclear explosion. The delayed (or world-wide) fallout consists of the smaller particles which ascend into the upper troposphere and into the stratosphere and are carried by winds to all parts of the earth. The delayed fallout is brought to earth, mainly by rain and snow, over extended periods ranging from months to years.

Fireball. The luminous sphere of hot gases which forms a few millionths of a second after a nuclear (or atomic) explosion as the result of the absorption by the surrounding medium of the thermal X-rays emitted by the extremely hot (several tens of millions degrees) weapons residues. The exterior of the fireball in air is initially sharply defined by the luminous shock front and later by the limits of the hot gases themselves (radiation front).

NUDETS (477L). A system, covering the Washington area, designed to provide the location, yield, and height of burst of a nuclear detonation.

Radiation - Residual Nuclear. Nuclear radiation, chiefly beta particles and gamma rays, which persists for some time following a nuclear (or atomic) explosion. The radiation is emitted mainly by the fission products and other bomb residues in the fallout, and to some extent by earth and water constituents, and other materials, in which radioactivity has been induced by the capture of neutrons.

Scaling Law. A mathematical relationship which permits the effects of a nuclear (or atomic) explosion of given energy yield to be determined as a function of distance from the explosion (or from ground zero), provided the corresponding effect is known as a function of distance for a reference explosion, e.g., of 1-kiloton energy yield.

Sferic. Natural surges of atmospheric electricity generally associated with lightening.

Shock Wave. A continuously propagated pressure pulse (or wave) in the surrounding medium which may be air, water, or earth, initiated by the expansion of the hot gases produced in an explosion. A shock wave in air is generally referred to as a blast wave, because it resembles and is accompanied by strong, but transient, winds. The duration of a shock (or blast) wave is distinguished by two phases. First there is the positive (or compression) phase during which the pressure rises very sharply to a value that is higher than ambient and then decreases rapidly to the ambient pressure. The positive phase for the dynamic pressure is somewhat longer than for overpressure, due to the momentum of the moving air behind the shock front. The duration of the positive phase increases and the maximum (peak) pressure decreases with increasing distance from an explosion of given energy yield. In the second phase, the negative (or suction) phase, the pressure falls below ambient and then returns to the ambient value. The duration of the negative phase is approximately constant throughout the blast wave history and may be several times the duration of the positive phase. Deviations from the ambient pressure during the negative phase are never large and they decrease with increasing distance from the explosion.

Tactical Warning. A notification of enemy initiated hostilities.

Thermal Radiation. Electromagnetic radiation emitted (in two pulses from an air burst) from the fireball as a consequence of its very high temperature; it consists essentially of ultraviolet, visible, and infrared radiations. In the early stages (first pulse of an air burst), when the temperature of the fireball is extremely high, the ultraviolet radiation predominates; in the second pulse, the temperatures are lower and most of the thermal radiation lies in the visible and infrared regions of the spectrum. From a high-altitude burst, the thermal radiation is emitted in a single short pulse.

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