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NWC TP 5039
Part 3

# Measured Temperatures of Solid Rocket Motors Dump Stored in the Tropics and Desert

## Part 3. Desert Storage

by
Howard C. Schafer
*Range Department*

MAY 1977



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## FOREWORD

This report (Part 3) describes the desert dump storage portion of a continuing effort to determine the thermal environment of dump-stored ordnance. Part 1 contains a summary of results for tropics and desert storage and Part 2 a sample of the raw data obtained by the Naval Weapons Center (NWC), China Lake, California. This is a continuing effort sponsored by the Naval Air Systems Command under AirTask A3303300/008B/6F31332300.

This report has been reviewed for technical accuracy by Dr. Richard Ulrich.

Released by
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Under authority of
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(U) *Measured Temperatures of Solid Rocket Motors Dump Stored in the Tropics and Desert. Part 3. Desert Storage*, by Howard C. Schafer. Naval Weapons Center, China Lake, Calif., NWC, May 1977. 86 pp. (NWC TP 5039, Part 3, publication UNCLASSIFIED.)

(U) Measurement sites were established in the Mojave Desert (China Lake) and Death Valley National Monument to obtain empirical data that could be used to more accurately predict the thermal environment of desert dump-stored ordnance. Data obtained from these measurement sites are presented and analyzed. These data are presented in terms of cumulative probability and maximum-minimum daily temperatures. The environmental criteria determination investigations at NWC are continuing and this report represents only a sample of the vast amount of information available at this Center.

## CONTENTS

Figures, contd.

## INTRODUCTION

There are many events in the stockpile-to-target life (see Appendix A) of a weapon system.[1-4] Of these, dump storage is possibly the most misunderstood. This lack of understanding has resulted in unrealistic design and qualification requirements that have added significantly to the manhours and costs incurred in the development of weapon systems. As part of the environmental criteria determination effort at NWC, work has been conducted, and is continuing, to obtain empirical data that can be used to more accurately predict the thermal environment of dump stored ordnance.

In 1959, NWC recognized the need for a concerted attack on the problem of developing thermal criteria for future weapon systems. After many false starts, in 1963 the decision was made to organize a task force to investigate the total environmental criteria determination problem. In 1964, the Quality Assurance Division at NWC assembled the nucleus of personnel who have continued to study these problems. A lack of qualified personnel and insufficient funding made it necessary to analyze the overall problem to determine the most critical of those areas requiring immediate attention. The key seemed to be in the thermal area of storage and transportation, since no meaningful analysis of humidity, precipitation, corrosion, vibration, or shock effects could be conducted without a thermal basis. It was also determined that, for the majority of Naval material, 75-90% of the life of an item is spent in transportation and storage. Based on these facts, it was decided to conduct a concentrated study of the thermal regimes in the areas of transportation and storage on a worldwide basis.

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[1] Naval Weapons Center. *Environmental Criteria Determination for Air-Launched Tactical Propulsion Systems. Part 1. Stockpile-to-Target Sequence*, by Howard C. Schafer. China Lake, Calif., NWC, July 1968. (NWC TP 4464, Part 1, publication UNCLASSIFIED.)

[2] -----. *Environmental Criteria Determination for Air-Launched Tactical Propulsion Systems. Part 2. Technical Support for Stockpile-to-Target Sequences*, by Howard C. Schafer. China Lake, Calif., NWC, July 1968. (NWC TP 4464, Part 2, publication UNCLASSIFIED.)

[3] -----. *Environmental Criteria Determination for Air-Launched Tactical Propulsion Systems. Part 3. Description of the Environment*, by Howard C. Schafer. China Lake, Calif., NWC, August 1968. (NWC TP 4464, Part 3, publication UNCLASSIFIED.)

[4] Department of Defense. *Environmental Criteria and Guidelines for Air-Launched Weapons.* Washington, DC, DoD, 30 July 1976. (MIL-STD-1670A, publication UNCLASSIFIED.)

Storage of Naval material can be grouped into three major categories: covered, igloo, and dump. Because of the well developed Naval system of worldwide storage complexes, igloo and covered storage of material is by far the most prevalent. A study was therefore conducted and a series of technical reports issued on "Storage Temperatures of Explosive Hazard Magazines."[5-10] In addition, a report was published summarizing all results obtained through 1971.[11]

Although covered and igloo storage of Naval material is most prevalent, dump storage generally results in the more extreme thermal exposure situations. (A detailed discussion of the dump storage situation is given in Appendix B.) Since no data were available on dump storage, instrumented storage dumps were established at representative locations worldwide so that statistical data could be derived on a variety of ordnance items. Sites were established to sample the temperate and sub-arctic cold as well as the tropics and desert exposure situations. This report, however, concerns itself solely with the results from two desert dumps storage sites; one located in the Mojave Desert at China Lake and the other at Death Valley National Monument.

One of the more misleading aspects of a statistically infinite worldwide dump storage measurement program such as described in this report is that the measured object must stay so exposed for years on end. Their surfaces tend to degrade normally; but this degradation is more than should be expected from a like item when stored under combat conditions. Remember that, in combat, the time of exposure before use can be measured in days or a few weeks. Readers are encouraged to contact the author for more details regarding information presented in this report.

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[5] Naval Ordnance Test Station. *Storage Temperature of Explosive Hazard Magazines. Part 1. American Desert*, by I. S. Kurotori and H. Schafer. China Lake, Calif., NOTS, November 1966. (NOTS TP 4143, Part 1, publication UNCLASSIFIED.)

[6] ------. *Storage Temperatures of Explosive Hazard Magazines. Part 2. Western Pacific*, by I. S. Kurotori and H. Schafer. China Lake, Calif., NOTS, June 1967. (NOTS TP 4143, Part 2, publication UNCLASSIFIED.)

[7] ------. *Storage Temperature of Explosive Hazard Magazines. Part 3. Okinawa and Japan*, by I. S. Kurotori and H. C. Schafer. China Lake, Calif., NOTS, June 1967. (NOTS TP 4143, Part 3, publication UNCLASSIFIED.)

[8] Naval Weapons Center. *Storage Temperatures of Explosive Hazard Magazines. Part 4. Cold Extremes*, by I. S. Kurotori and H. C. Schafer. China Lake, Calif., NWC, May 1968. (NWC TP 4143, Part 4, publication UNCLASSIFIED.)

[9] ------. *Storage Temperature of Explosive Hazard Magazines. Part 5. Carribbean and Mid-Atlantic*, by I. S. Kurotori and H. Schafer. China Lake, Calif., NWC, March 1969. (NWC TP 4143, Part 5, publication UNCLASSIFIED.)

[10] ------. *Storage Temperatures of Explosive Hazard Magazines. Part 6. Continental United States*, by I. S. Kurotori, R. Massaro, and H. Schafer. China Lake, Calif., NWC, November 1969. (NWC TP 4143, Part 6, publication UNCLASSIFIED.)

[11] ------. *Summary of Selected Worldwide Temperatures in Explosive Hazard Magazines*, by I. S. Kurotori and H. C. Schafer. China Lake, Calif., NWC, February 1972. (NWC TP 5174, publication UNCLASSIFIED.)

# PROCEDURE

The rocket motors and virtually all the other ordnance and material used in this extended measurement series were taken from Armv, Navy and Air Force surplus storage. Even though these items had served their intended in-fleet purposes, they were considered adequate for our needs and representative of present and future hardware, when viewed in the thermodynamic context. For example, a 1944 model van truck is thermodynamically similar to a 1976 model, as far as the van body's thermal shielding characteristics are concerned.

## INTERNAL MOTOR CONFIGURATIONS

When a particular inert rocket motor was available, it was used intact; but in the case of rocket motors, once-fired hardware was much more plentiful. However, to utilize the once-fired hardware, an inexpensive durable propellant simulant was needed. The Chemistry Staff of the NWC Propulsion Development Department found just such a simulant; it turned out to be thoroughly dried desert blow sand. (A comparison of the thermal properties of blow sand versus propellant and explosive inert thermal simulants is given in Appendix C.)

Initially, all rocket motors used in this measurement series were cartridge-loaded, inert production motors. However, indications are that the general rocket motor grain configuration of the future will be case-bonded rather than cartridge-loaded. Therefore, most of the inert rocket motors since added to the measurement sequence have been configured to simulate the case-bonded type motor. This was greatly facilitated by the use of the blow sand. Previously, it had cost from $10,000 to $25,000 to cast thermocouples into each inert case-bonded motor due to (1) the very viscous propellant causing "sweeping" of the thermocouples from the desired locations, and (2) the short pot-life of the propellant. While examining the results reported herein, keep in mind the following:

1. ASROC rocket motors at the China Lake site are the cartridge-loaded type.
2. Sparrow motors are all sand-filled, except the one containerized motor at the China Lake site which is a production inert simulant Mk 6 Sparrow.
3. Sidewinder rocket motors contain production inert grains.
4. The 2.75 FFAR motors contain plastic simulant and are cartridge-loaded.
5. Zuni (5-inch) motors are about 50% sand-filled and 50% cartridge-loaded.

It is interesting to note that the resulting thermal data for any items smaller than 8 inches in diameter do not allow one to readily differentiate between the case-bonded and cartridge-loaded units. Apparently the differences of the masses of the units are so small that this point loses overall significance.

## THERMOCOUPLING

It was concluded early in the program that the 12 o'clock position of an exposed missile (containerized or bare) reached the highest temperature. A set of copper-constantan thermocouples were, therefore, positioned through the 12 o'clock position of each test item. A point halfway between the ends of the container was chosen for the thermocouple placement pattern in order to negate the moderating influence of thermal "end effects" (the result of heat escaping in all three dimensions from the surface of the container rather than just penetrating downward). In hot climates, these end effects are always responsible for the measurement of a "cooler" temperature in parts other than the central portion of the missile at the point of measurement. The center position was chosen only after fully-instrumented Sparrow sand-filled motor measurements indicated that the effect was less pronounced than within 1.5-2 calibers of the ends of the motor. The central portion of the motor was the most thermally stable and extreme and, therefore, universally used for the measurement series.

### Thermocouple Construction

All thermocouples were copper-constantan (Type T). The hot junction for internal measurements was a welded or silver-soldered 1/16- to 1/18-inch-diameter ball. Two types of surface thermocouples were used for shipping container or motor skin. The most universal and easiest to install is the area averaging type which consists of a 0.005-inch-thick, 1/4-inch-square copper plate. The constantan wire is silver-soldered to one corner, the copper wire to another corner, and the assembly attached to the area of interest with epoxy. Early in the program these units were simply taped to the surface of interest. This attachment method was satisfactory for short times at locations where the installation was regularly inspected for thermocouple lift off. However, for long term, "abandoned" site measurement jobs, this attachment method did not prove satisfactory. Another, more time consuming method was to

1. Drill two small holes about 1/8- to 1/4-inch apart in the surface to be measured

2. From the underside, place the copper wire in one hole and the constantan wire in the other

3. Silver-solder the wires in place

4. Grind down the solder joints so the surface is again smooth

5. Repaint

Comparative data from both types of installation indicated no significant measurement difference for either application method.

# INSTRUMENTATION

## Recorders

The mainstay of this measurement series was the Honeywell Model 15 Universal 24-point stripchart recorder. The state-of-the-art of this instrumentation mode stretches through at least 25 years. The manufacturer's advertised accuracy for this model is 0.25% of the full scale measurement range (-100 to +250°F). For our measurement series, this represented an error margin of less than 1°F. None of the more than 30 instruments used in this measurement series exceeded this overall error band.

Some problems resulted because the Honeywell recorders are essentially laboratory instruments and not intended for field use. They were, for all intents and purposes, abandoned on-site for months at a time. Since these instruments were not serviced for periods of three months to one year, failures had to be kept to a minimum through preventive maintenance. Data were recorded for 60 or 90 days with the recorder unattended before personnel were required to change the stripchart roll.

In May 1970, a 200-channel data logger was installed at the China Lake site and is still in operation. This digital tape instrument is more accurate as well as vastly more complicated and sensitive than the Honeywell recorder, but its out-of-laboratory reliability has yet to be proven. The data logger can run up to five or six months on a single tape at an hourly sampling rate, and the tape can be input directly to the computer for quick data reduction. Reduction of the more reliable Honeywell charts, on the other hand, is a strictly manual operation.

After five winter months of data were lost one year due to a malfunction of the data logger's rewind mechanism, it was decided that paralleling important data channels with the cumbersome Honeywell recorder would be a worthwhile precaution. This did, indeed, prove worthwhile and allowed the data for November-December 1970 and January-March 1971 to be salvaged. In short, the more sophisticated instrumentation proved superior in a situation where a "babysitter" was constantly available, but for off-Center primitive conditions, sample speed, some accuracy, and ease of data reduction must be sacrificed in exchange for usable data.

Because of the relatively slow sample rates necessary, slow temperature changes encountered, and the low narrow band of temperature sampled in this type of sequence, the normal thermocouple and instrument errors either were not encountered, or were classified as "in the noise."

## Data Reduction

During the first few years, a complete program of data reduction was followed. But costs were prohibitive and the number of data channels being reduced had to be decreased; only daily maximum and minimum temperatures were considered. This method then indicated the "extreme" days so that complete data for any of those days could be obtained when desired. However, since this method left much to be desired for any type of statistical treatment, it was subsequently decided to revert to reduction of every data point on the Honeywell chart, but only for selected channels. The majority of the cumulative probability displays presented herein were derived in this way. Appendix D describes the procedure for statistical handling of data.

This program points up the obvious need for a balance between the quantity of data available and the funding available to reduce these data and thereby give them meaning. The data logger at the China Lake site seems to be one solution to this problem. It skips the costly hand reduction steps and feeds data directly into a computer in a compatible language. This method was used almost exclusively for reduction of the desert storage data.

## RESULTS

### DATA PRESENTATION METHODS

It was at first intended to show only a yearly profile of ordnance exposures with diurnal plots for the extreme days. The yearly profile would, of course, place the diurnal cycle in some type of context. Figures 1 through 3 are examples of yearly profiles for the ASROC missile in desert dump storage. A comparison of these figures will give some indication of year to year variances for the dump storage situation. Equal weight is given to all portions of the line depicting the daily temperature variance; in fact, each line represents the loose equivalent of half a sine wave. However, since the sun rises and sets, there are few hours of exposure at the top end of each daily "line." Since the thermal response of the missile to a given sun exposure is a dynamic situation, the amount and intensity of sun exposure will dictate the severity of the exposure. The data of Figures 1 through 3 are recognized as not being too usable for an in-depth analysis, but they are important to show the year to year variance and peak day of exposure for a given geographical location.

To illustrate the relationship between locations at various depths in a missile and their response to the thermal forcing functions, it is always more useful to show the ideal example, if available, rather than the more common situation. Although it is difficult to find an "ideal" extreme thermal heating day in the ordnance context, Figure 4 tries to present just such a situation. The attempt to provide a classic example, however, is not totally successful.

As we analyze Figure 4, notice first that the trace labeled "container skin" should not be notched as it is at 1300 hours. Also, there are dips in the tailoff after the peak. This, then, is more nearly the actual rather than ideal extreme heating case. As a rule of thumb, any time a 5 knot or greater wind blows, the maximum heating situation will not occur, no matter what the rate of insolation or ambient

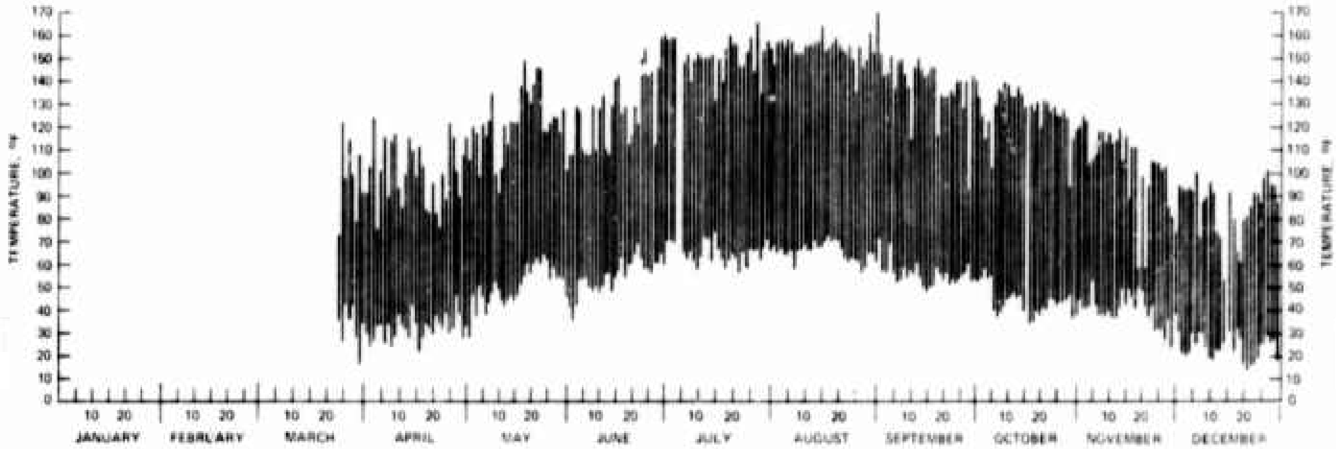


FIGURE 1. Temperature Profile of ASROC Shipping Container Skin, Dump Stored at NWC, 1967.

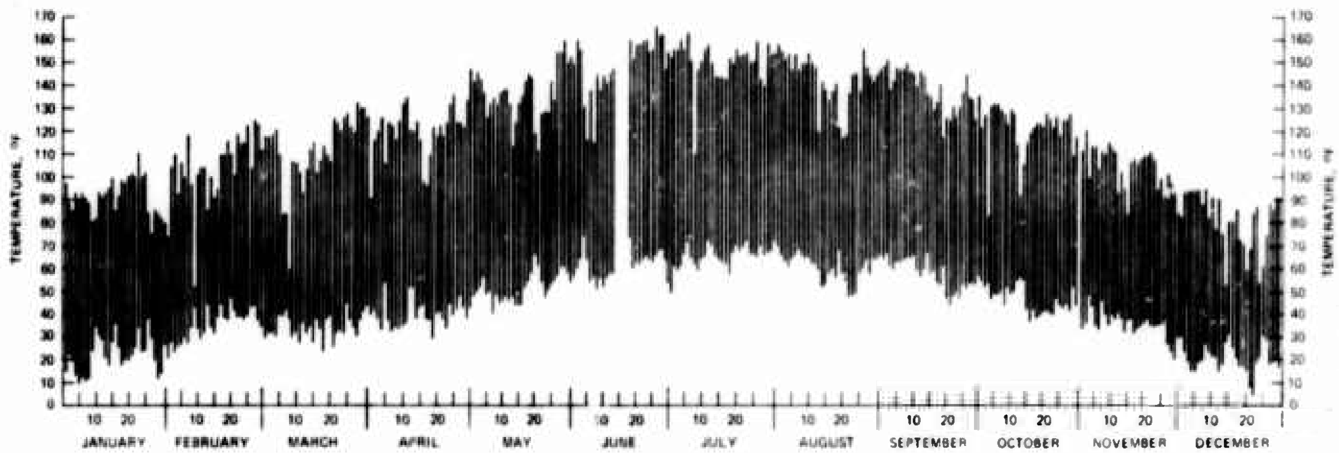


FIGURE 2. Temperature Profile of ASROC Shipping Container Skin, Dump Stored at NWC, 1968.

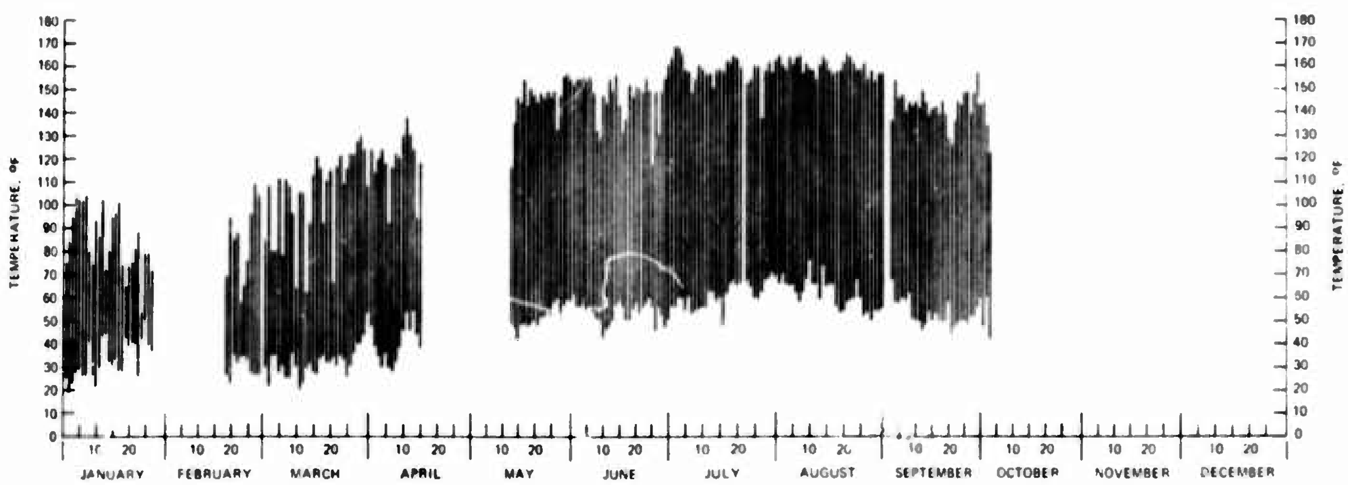


FIGURE 3. Temperature Profile of ASROC Shipping Container Skin, Dump Stored at NWC, 196[illegible].

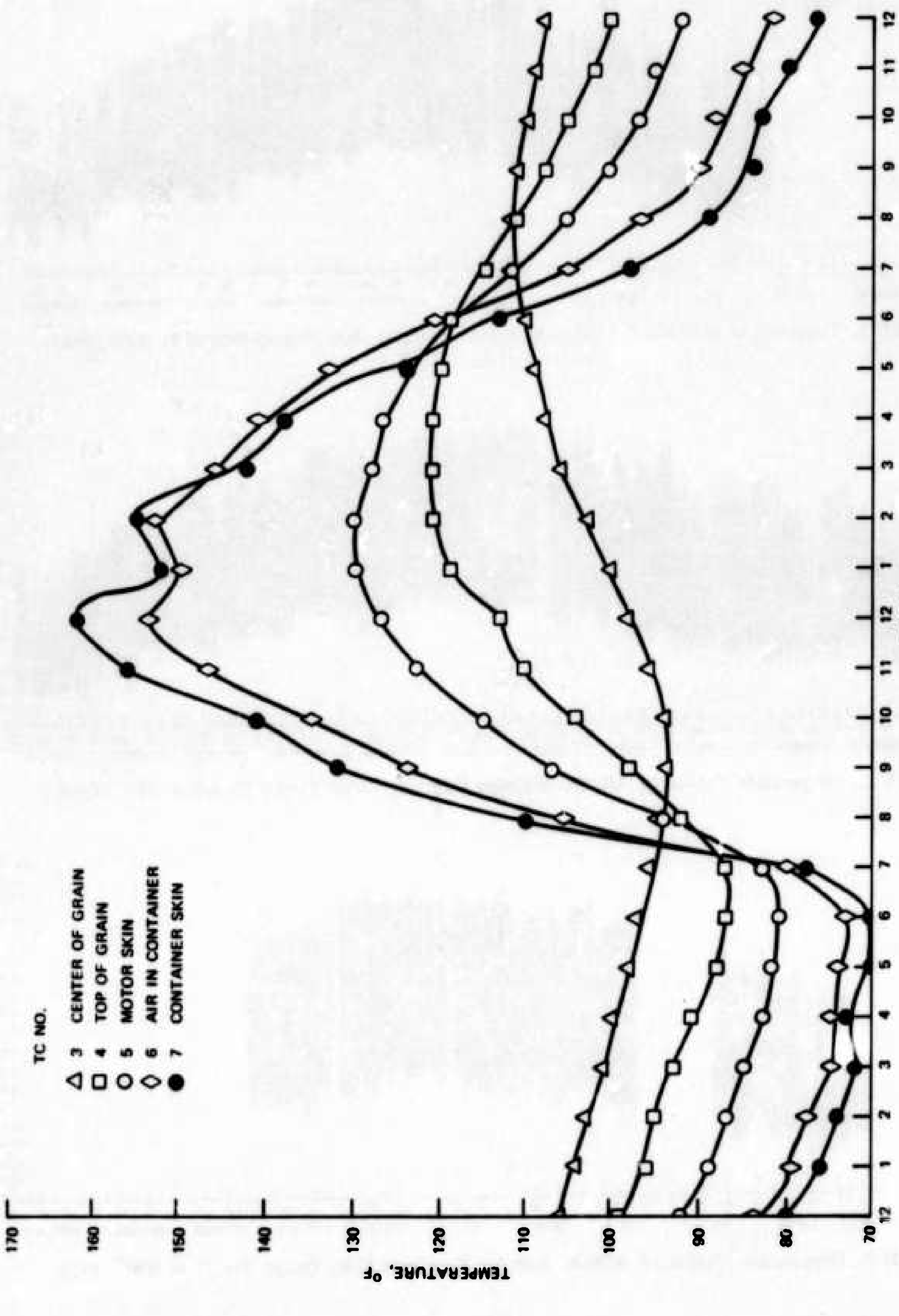


FIGURE 4. "Ideal" Ordnance Thermal Heating Day.

meteorological air temperature. Also, even a small cloud drifting across the sky and shading the ordnance can be expected to cause a temperature drop from the possible maximum. The inconsistencies seen in Figure 4 could have been caused by any of the above.

The "air in container" trace of Figure 4 shows that the air temperature in the shipping container rapidly followed that of the container skin as well as, though to a lesser extent, the thermal dips so evident in the "container skin" trace. The air temperature trace, however, is not indicative of the temperature all the air in the container will experience. For example, the air in the bottom of the shipping container will be cooler than shown by the trace in Figure 4. The intent, though, was to report the maximum thermal situation for any given enclosed item, therefore, all the data in this figure depict the most extreme point for the locus of points making up the area of interest.

Notice next that the "missile skin" trace shows a much lower thermal level than that for the "container skin" trace; the container skin temperature peaked at about 165°F. This indicates that, in this case, the missile need only have been designed to 130°F to survive the 165°F situation.

The interior grain (center and top) traces show that the magnitude of temperature is, again, much less than 165°F. Especially notable is the fact that not only is the maximum temperature less, but the minimum daily temperature is greater; the "center of grain" trace shows only a fraction of the daily temperature variance exhibited by the container surface.

The time phase shift of the various positions in respect to the maximum temperature is also relevant. From Figure 4, it can be seen that the container skin temperature peaked at about noon (usually between 1200 and 1300 hours). The skin of the encased missile did not peak until about 1400 hours, while the center of the motor peaked at 2000 hours (after sundown at this location). This time phase shift makes it simple to visualize why it is physically impossible for the enclosed missile to reach the elevated temperatures exhibited by the shipping container. If the missile has any mass, it takes time to heat (and cool) that mass. The primary forcing function (radiant heating) is applied at a constantly changing rate. By the time a large mass has started to thermally "move", the primary forcing function may have already peaked and started its downward trend to a progressively lesser set of heating circumstances. Due to these circumstances, if an analog situation is desired as the end result, present specifications requiring a thermal soak at an elevated temperature do not represent the actual environment.

The preceding discussion demonstrates how complex and difficult it is to develop thermal criteria for missile or component design. As stated previously, the bar graph maximum and minimum temperatures (Figures 1 through 3) only define the band of exposure response. The day plots (Figure 4) are also inadequate in that they are too detailed to be useful in determining what value, or profile of values, should be specified from the almost infinite choice available when designing missiles for worldwide use.

The logical next step was to employ the three-sigma value commonly used in missile design; the three-sigma value seems to be in evidence for all hardware development programs in DoD. Therefore, it was deemed reasonable to place the measured data into some format that would enable the designer to identify the three-sigma point and, at the same time, present a visual indication of how much time per year an item could be expected to be subjected to a specific (or band) temperature value. The cumulative probability curve thus seemed the best approach. Simply stated, the cumulative probability curve is constructed by plotting the summed observations from the minimum, ascending in magnitude, to the maximum temperature value. (A detailed description of how these curves are constructed can be found in the report reference 11.)

## COMPOSITE OF DATA

To save the casual reader much time and effort, the first cumulative probability curve, Figure 5, is presented as an overlay single figure compilation of the thermal response of any material when dump (field) stored in the desert. It seems safe to say that further measurements will verify that the hot half of Figure 5 is good for all but the cold regions of the earth's surface.

Figure 5 is, in reality, a combination of the three major ordnance-type exposure situations: (1) white painted, (2) olive drab or haze gray painted, and (3) thin shell or small mass in a shipping pack. The envelope line in common with all material is the left-hand boundary of the cross-hatched band. Anything with a white painted exterior exposed to the sun, wind and elements, no matter what the mass, will exhibit a thermal response enveloped between the common cold boundary and the double-dashed line. This, of course, is based on five continuous years of hourly measurement. The curve shape will vary as times shorter than one year are used since the hot end will not be as hot nor the cold end as cold, etc. All non-white exterior painted stores when so exposed will respond thermally as depicted by the cross-hatched area. If, however, the shipping container is a thin shell construction, the container itself will exhibit higher thermal energy levels. It is for this special case that the separate dashed line is included. Depending upon where on the circumference of the thin shell shipping container the measurement is taken, the thermal response will fall between the common cold line and the hot dashed line. Keep in mind that only the shipping container will experience the extreme dashed line energy levels. The ordnance or material inside will experience only the less extreme cross-hatched thermal situation. This is an extremely important fact - *the ordnance will not statistically experience the thermal levels of the thin skin shipping container.*

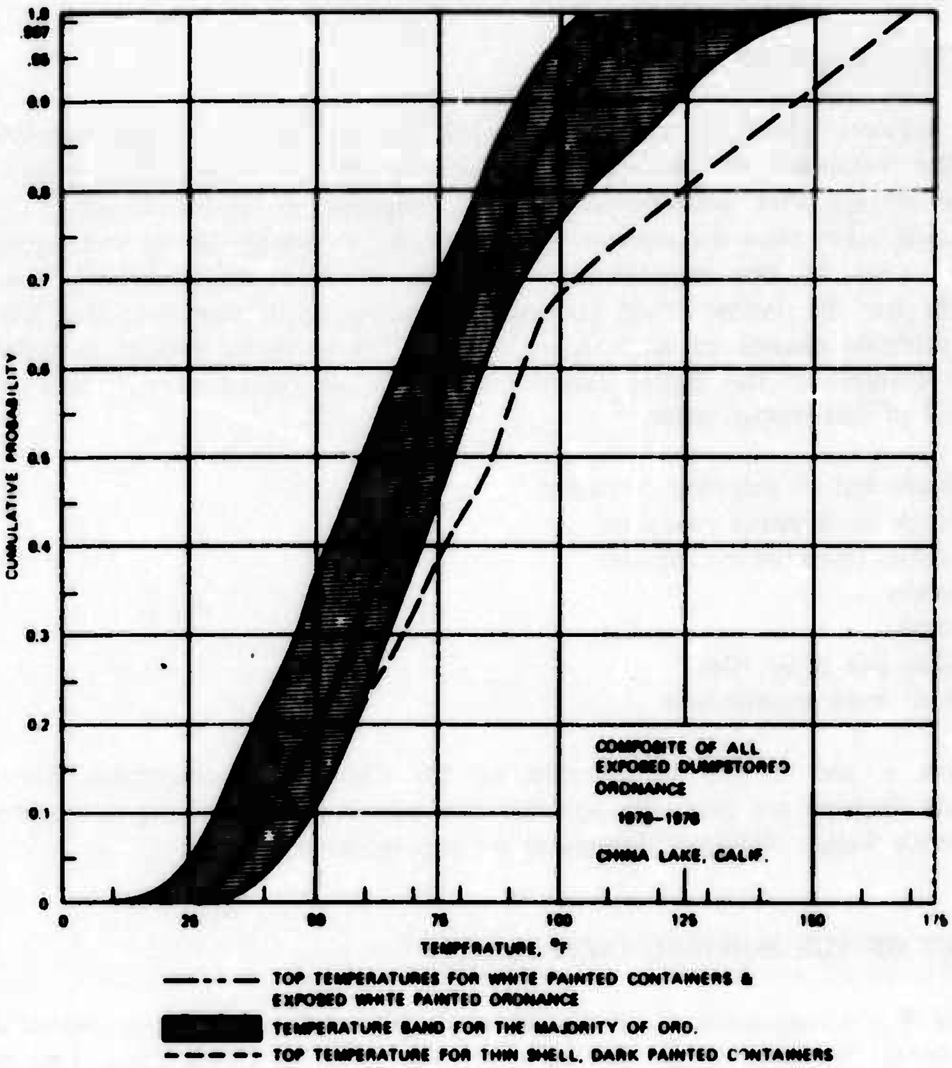


FIGURE 5. Composite of All Dump-Stored Ordnance, 1970-1976.

## Composite Data Background

Any engineer would, of course, be skeptical of the above sweeping statements. Therefore, the remainder of this report will present the 10 million data points for desert dump storage that contributed to this composite envelope. Figure 5 is, in essence, nothing more than a composite overlay of the following figures and represents a total enveloping of this representative sampling of field measurements. Thermal response data for the below listed ordnance categories, with pertinent examples of cumulative probable chance of occurrence, are provided in figure format in following sections. An example of the digital data from which these figures were derived can be seen in Part 2 of this report series.[12]

1. Missile out of shipping container
2. Missile in shipping container
3. Missiles mounted on aircraft
4. Bombs
5. Fuzes
6. Naval gun projectiles
7. Small arms ammunition

Figures 6 and 7 are photographs of the China Lake exposure site. The following data displays are primarily for this site; however, contributing desert storage data from Death Valley National Monument are also presented.

## MISSILE OUT OF THE SHIPPING CONTAINER

Figure 8 is a composite of all thermocouple reports for a five year period from an 8-inch-diameter Sparrow missile set on a build-up stand at China Lake. This figure is composed of four channels times 8,760 hourly data points per year times five years, or a total of 175,200 data points. When compared to the generally accepted mathematical concept of infinite data points, this value far exceeds the normally quoted 300-500 data points. Since subsequent China Lake data samples and 1975 and 1976 calendar years data did not show any information contradictory to the 1970-1974 figures, all the 1970-1974 composite figures can, in reality, be considered accurate for the seven year period 1970-1976 and, in essence, can be said to represent 61,320 data points per data channel.

In summary, since this type of exposure is usually rare and of extremely short duration, designers and reliability people should carefully consider the stockpile-to-target sequence before assigning extreme out-of-container temperature limits to a unit.

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[12] Naval Weapons Center. *Measured Temperatures of Solid Rocket Motors Dump Stored in the Tropics and Desert. Part 2. Data Sample*, by H. C. Schafer. China Lake, Calif., NWC, November 1972. (NWC TP 5039, Part 2, publication UNCLASSIFIED.)

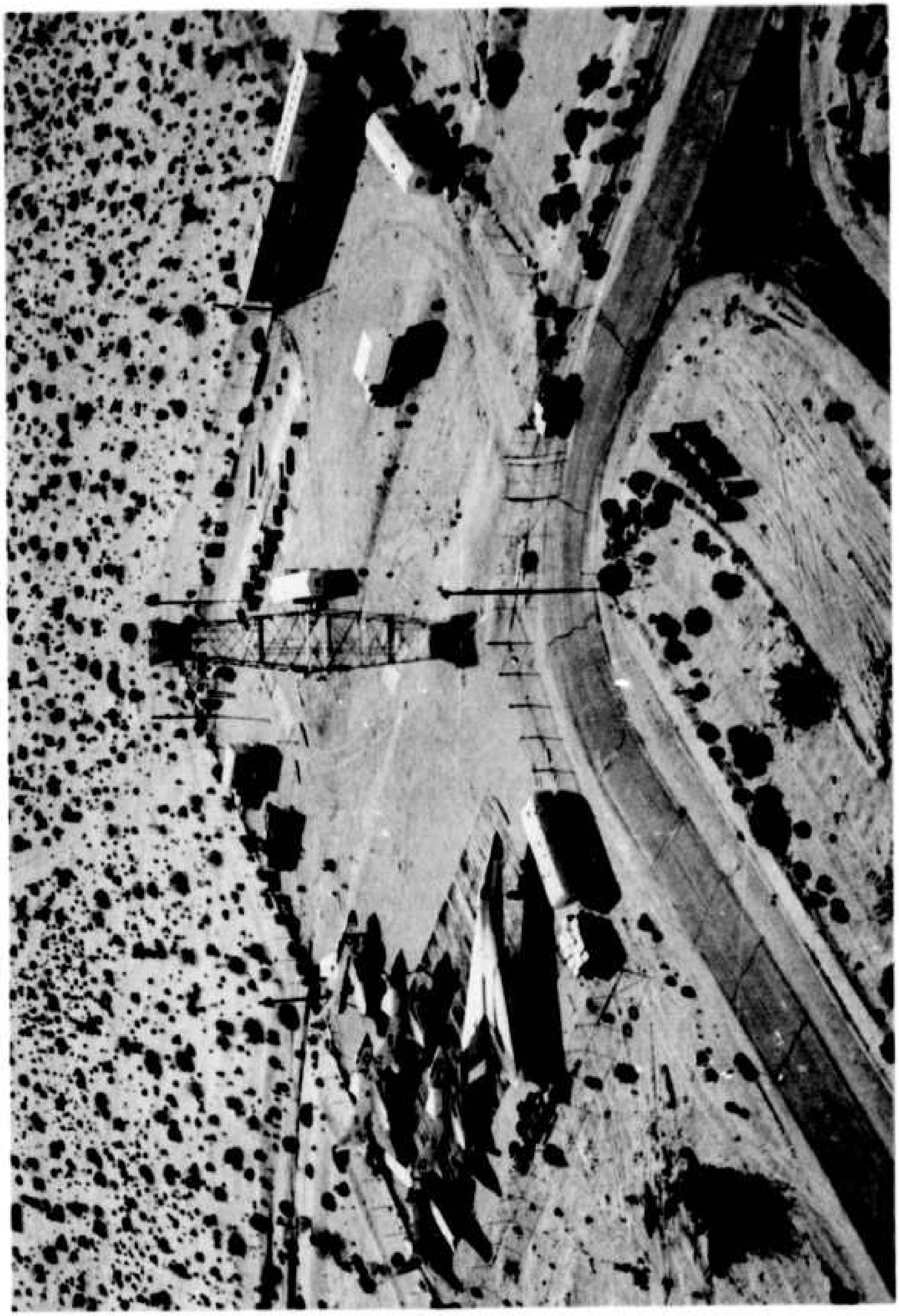

FIGURE 6. NWC Measurement Site (LHL 160883).

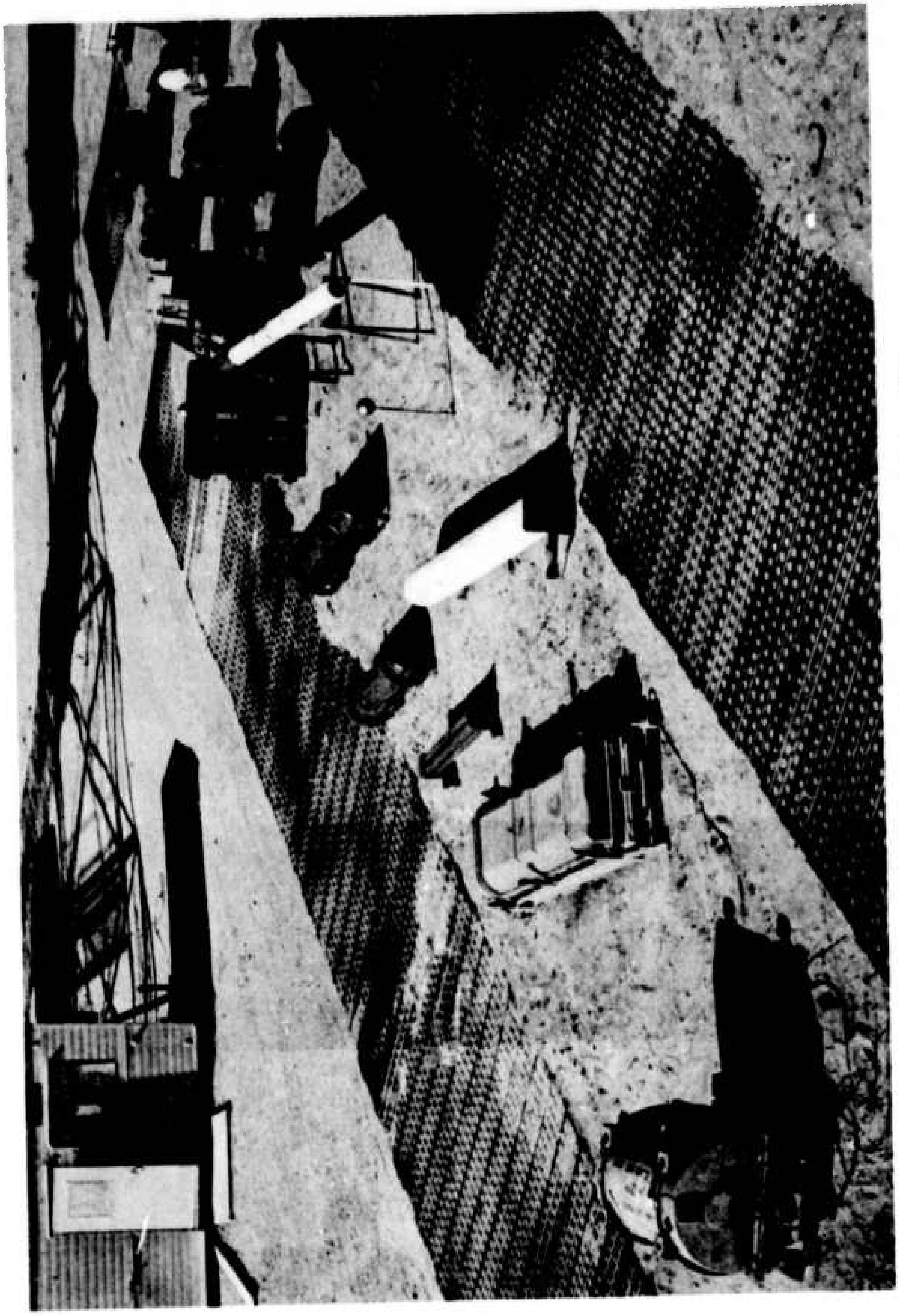

FIGURE 7. ASROC and Sparrow Missiles Dump Stored at NWC.

NWC TP 4464, Parts 1-3 (see References 1-3) can help in setting such limits and MIL-STD-1670A (see Reference 4) can provide guidelines on how to handle these limits.

## MISSILE IN SHIPPING CONTAINER

In the more normal dump or ready-use exposed storage situation, the missile is kept inside some type of shipping container or combination container and launcher. For the majority of cases observed by the author during two wars, the in-container dump stored missile was usually in a stack of like items, not separately segregated into one-unit lots. The data herein presented are for one-unit lots and, therefore, extreme in the real world overall use context.

Figure 9 is a composite of the thermal responses for a large missile in its shipping container and for the container itself. This figure can be thought of as the composite report of the seven year span from 1970 through 1976. Care has been taken to separate the differing responses of the shipping container and the missile proper in this figure; notice the cross-hatchings of the three measurement areas are different. This different cross-hatching was done to provide information needed by the container designer. Note that the top point of the missile thermal response band is only about 140°F, while that for the thin metal wall shipping container is about 170°F.

A composite of thermal responses for the containerized 8-inch-diameter Sparrow rocket motor is depicted in Figure 10. Surprisingly, the bands of exposure through the years in Figure 10 are narrower than for the commensurate band in Figure 9. It must be remembered, though, that the cylindrical containers housing these two pieces of ordnance (ASROC and Sparrow) had different diameters. The larger diameter offered a greater surface area normal to the direct rays of the sun. Since both cylinders were oriented to permit maximum normal exposure during the day, the larger container apparently took more advantage of this exposure. Also, steel is a surprisingly poor conductor of heat and although the area heated by the sun and reradiating downward onto the encased missile was proportionate, the large missile reached a higher temperature than the small one. This may be evidenced by the large spread of the "missile skin and inhibitor" display in Figure 9 above a cumulative probability of 0.8 compared to the commensurate display of Figure 10. Notice also that the band shapes of the two figures are otherwise similar.

The 5-inch-diameter missile is represented by two candidates, Zuni and Sidewinder. This is because missiles as small as 5 inches are usually grouped into combination launcher-shipping containers. The Zuni, for instance, is housed four at a time and launched from a white cylindrical aluminum launcher, and the mass of the 13-inch-diameter four-rocket agglomerate is, therefore, more than one would expect from a single 5-inch-diameter missile. Figure 11 is the composite display of all thermocouple data throughout a Zuni system exposed at China Lake for a five year

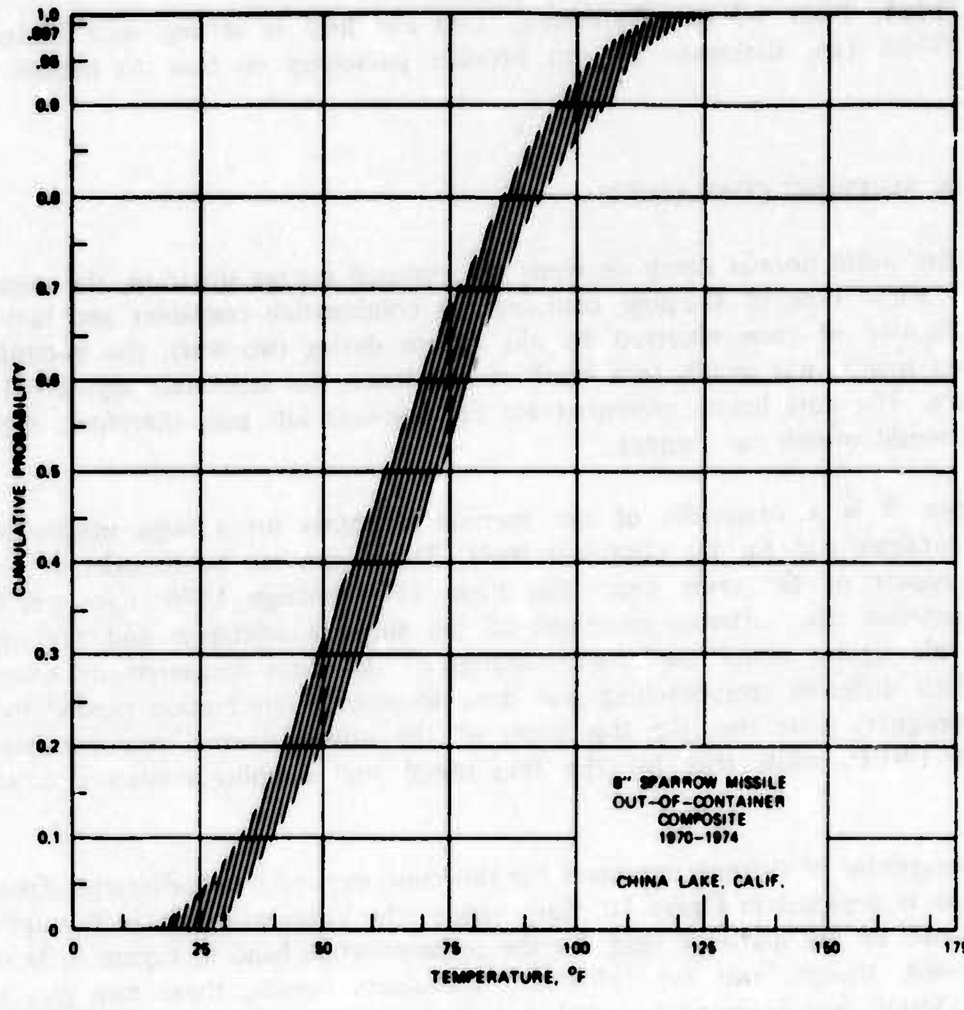


FIGURE 8. Composite of 8-Inch Sparrow Missile Out of Container, 1970-1974.

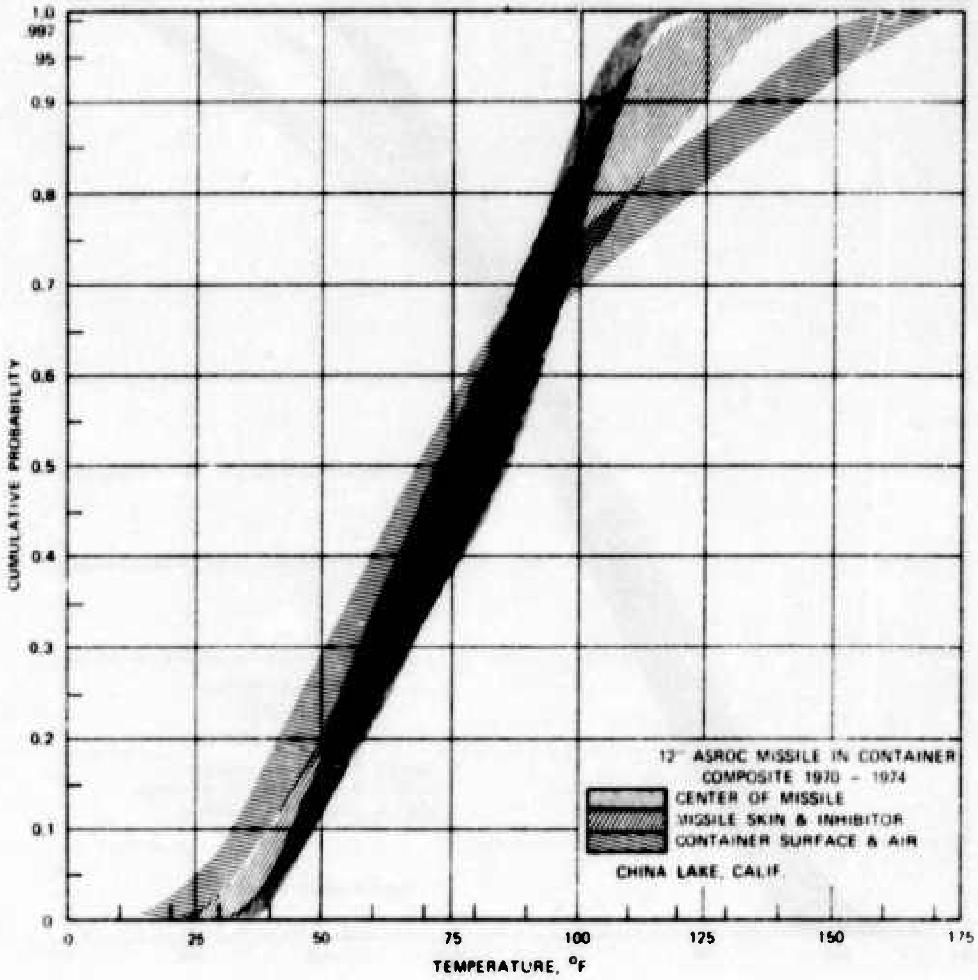


FIGURE 9. Composite of 12-Inch ASROC Missile in Container, 1970-1974.

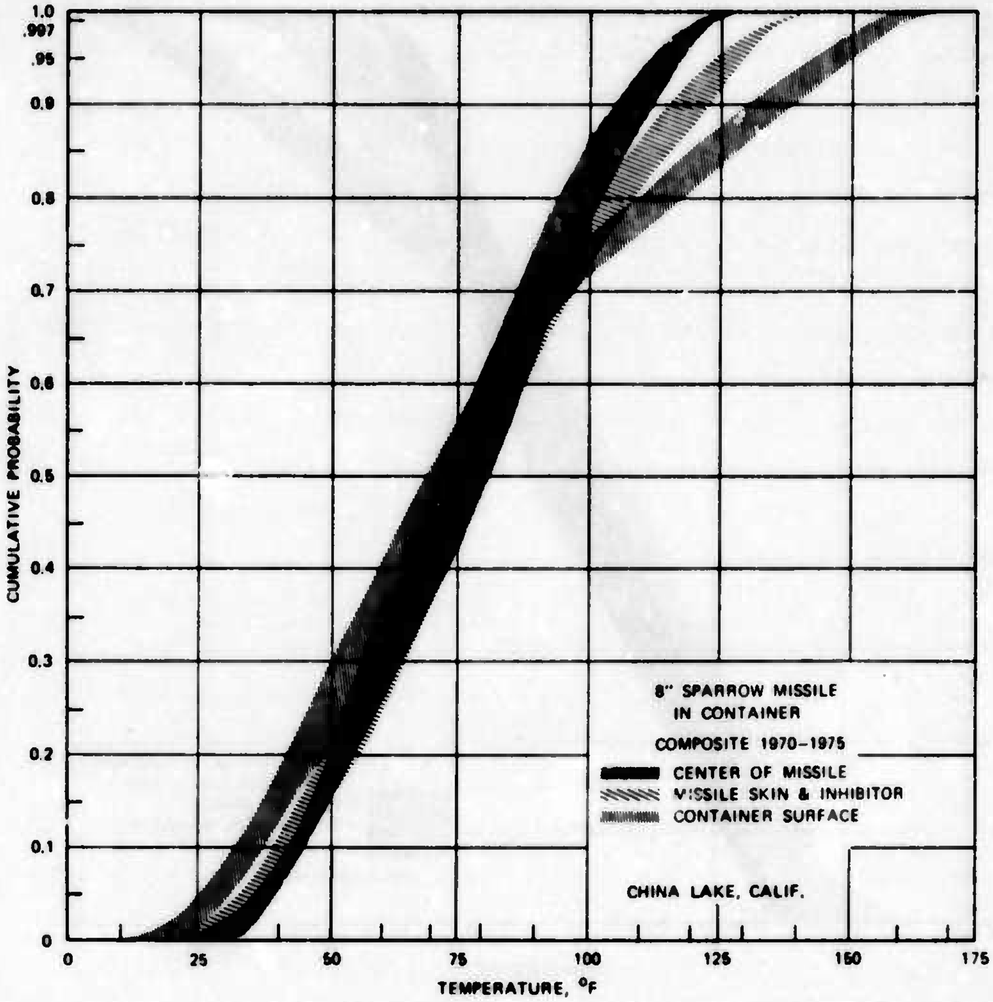


FIGURE 10. Composite of 80-Inch Sparrow Missile in Container, 1970-1975.

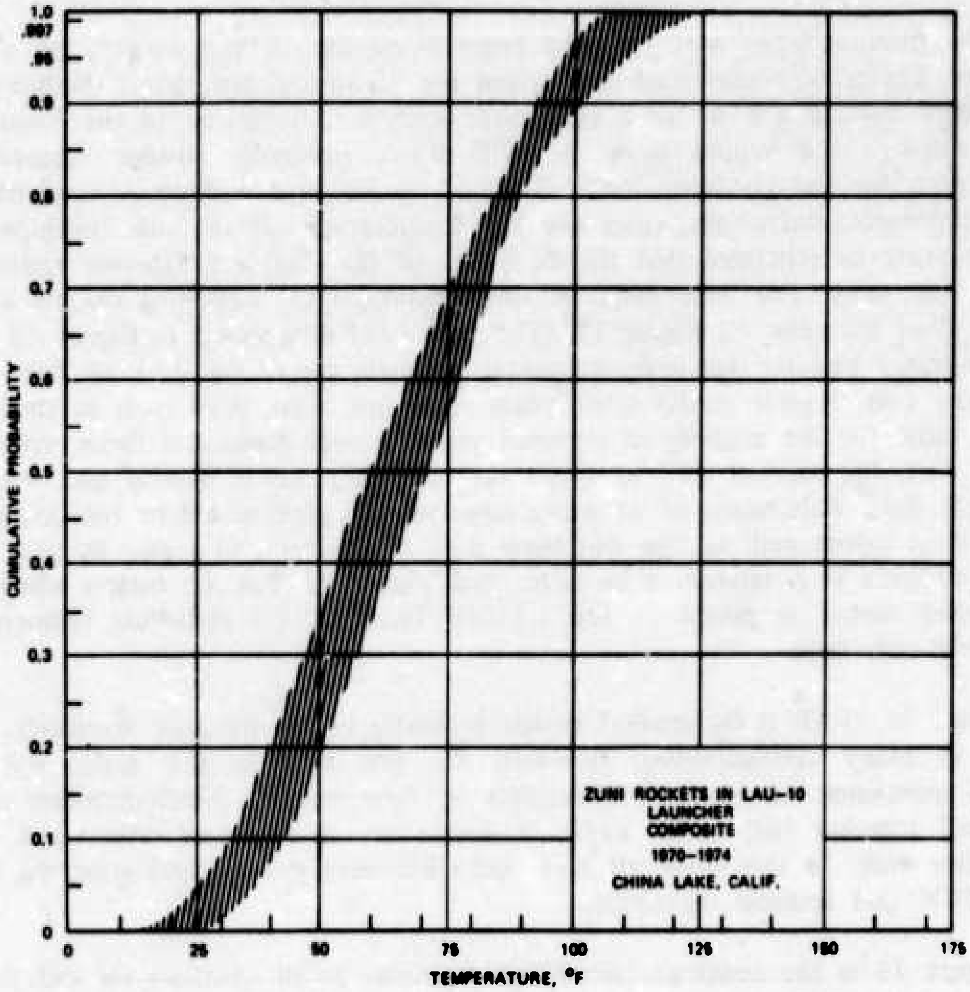


FIGURE 11. Composite of Zuni Rockets in LAU-10 Launcher, 1970-1974.

period. The thermocouples were typically mounted on top of the launcher, top of top west motor, center of bottom east motor, and top of bottom east motor. Notice what a white paint coating will do for a cylindrical container. Compared to the Figure 10 Sparrow display, the results show a 40°F lower maximum storage temperature exposure even for the container itself. This, of course, will lead to a more narrow band of exposures, statistically, since the low temperature side of both envelopes are similar. It must be reiterated that the diameters of the Zuni and Sparrow containers are about the same. For more detail as to exposure of the individual rounds in the four-holer Zuni launcher, see Figure 12. (The year 1973 data shown in Figure 12 were picked arbitrarily because that series happened to be on top of the stack of Zuni data. It is, in any case, typical of the other years of record. Also, plots such as shown in Figure 12 exist for the majority of reported years for each composite figure presented herein. In fact, the method used to derive the composite was to overlay and envelope all pertinent data. Publication of all these separate data plots would be too costly for a general data report such as this, but these data are available on a case by case basis from the author.) It is interesting to note from Figure 12 that, no matter where the 5-inch rocket motor is placed in the LAU-10 launcher, the statistical temperature spread is not very large.

The 2.75 FFAR is the smallest rocket presently in the ordnance inventory. It is packaged in many configurations; however, the one used in this series was the four-round container. In essence, it consists of four separate 3-inch-diameter metal tubes joined together only at the ends. In service use, it is painted either dark haze gray or olive drab. In this series, all 2.75 containers were painted haze gray, the same as the ASROC and Sparrow containers.

Figure 13 is the composite record of responses at all locations on and in the container for the 2.75 in desert dump storage. Figure 14 is a year's worth (year selected at random) of more definitive data. Notice that there is a temperature spread between rounds in the container. Also, the container walls are hotter than the rounds, even though there is less than 1/8-inch air gap between the container wall and rocket motor. Again, even though the container is painted haze gray, the maximum temperature portion of the curves is not as extreme as reported for the large missiles during the same exposure period.

Plastic Multipack Containers

Since the trend in container design may be toward multiunit loads in plastic containers, data were collected for Sidewinders in four-unit flat-topped white (Figure 15) and gray (Figure 16) plastic containers. These figures are for the only one-year span of data available. Notice in these figures that, statistically, the thermal differences between the top and bottom of these containers, and the temperatures of the enclosed loads, are not much different. The white container shows the least total differences and, overall, is the cooler of the two. This is easily explained by the reflectivity of the white surface versus the absorptivity of the gray. Since there is next to no air space

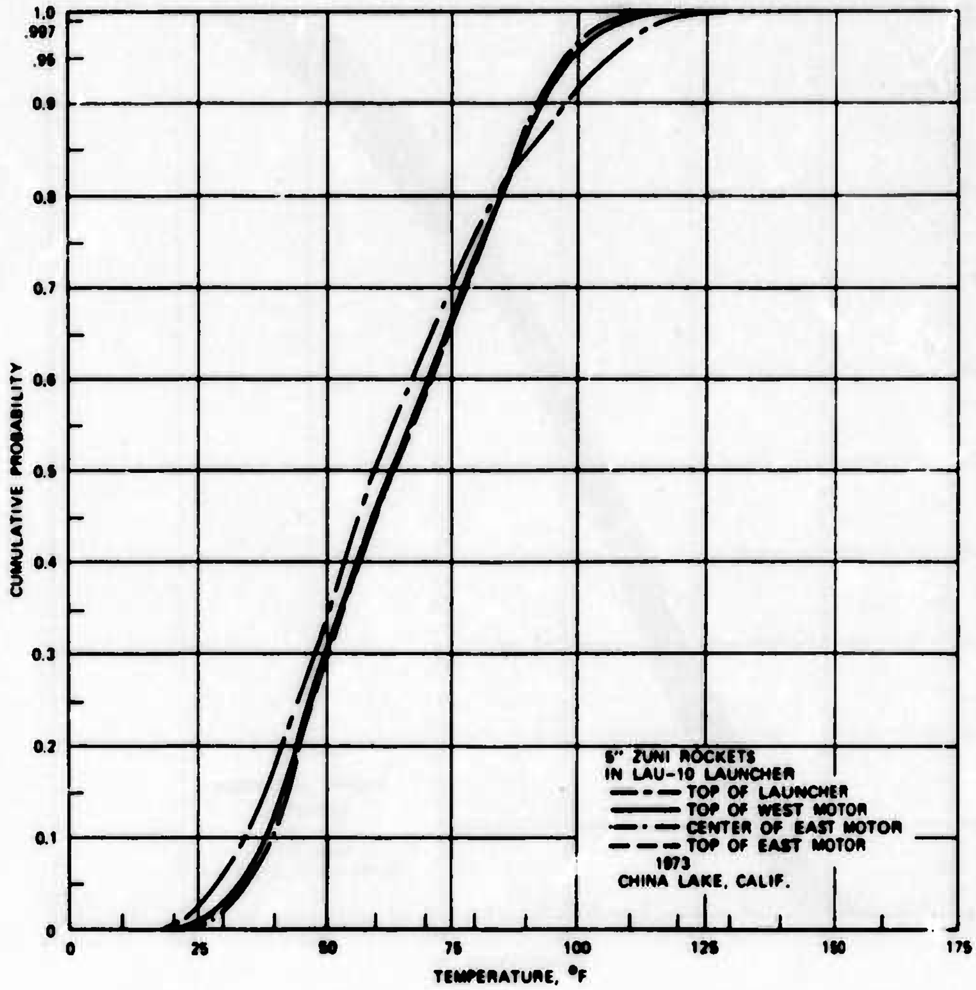


FIGURE 12. 5-Inch Zuni Rockets in LAU-10 Launcher, 1973.

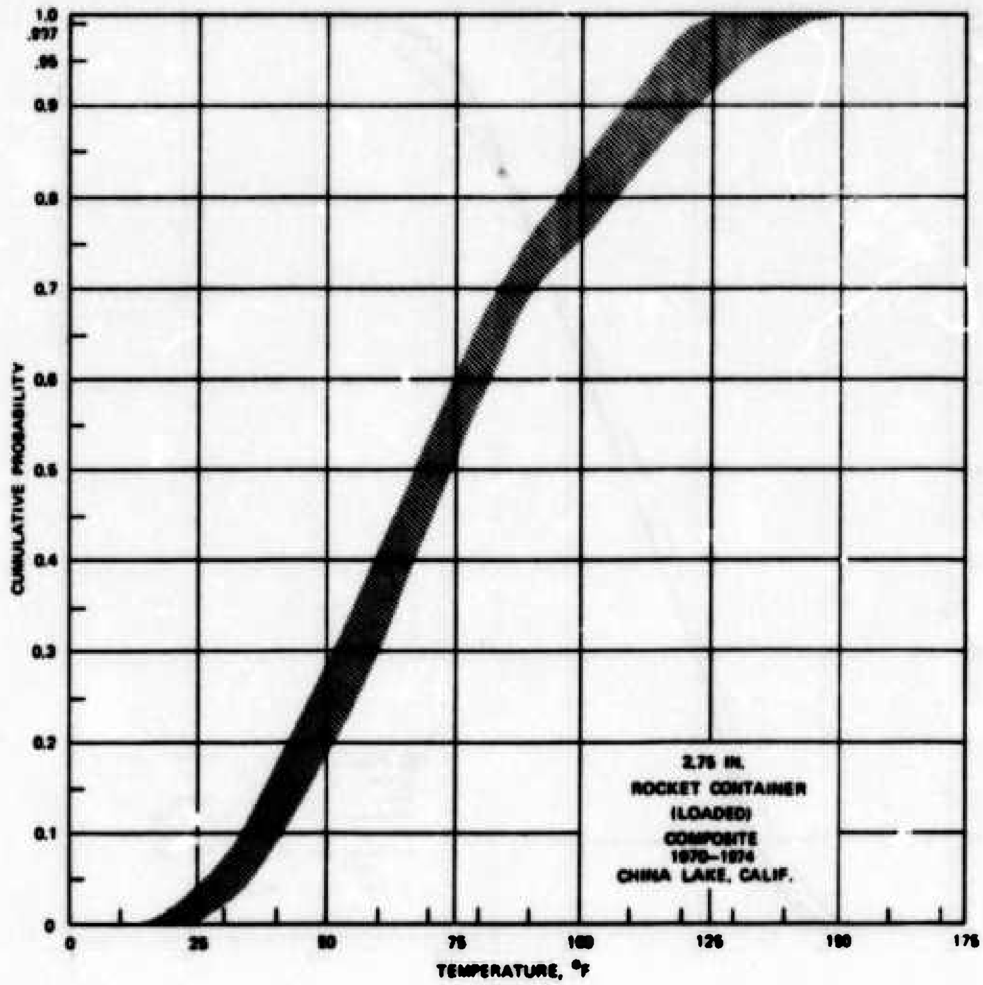


FIGURE 13. Composite of 2.75-Inch Rocket Container (Loaded), 1970-1974.

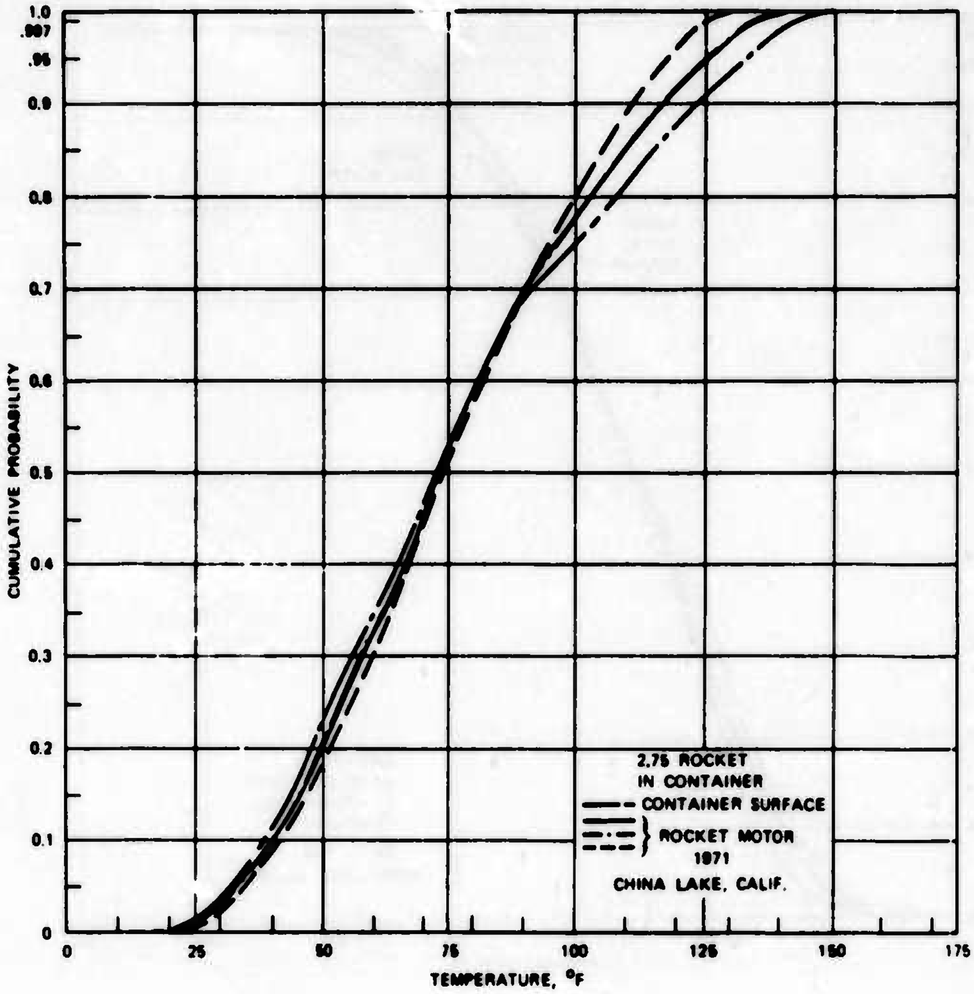


FIGURE 14. 2.75-Inch Rocket in Container, 1971.

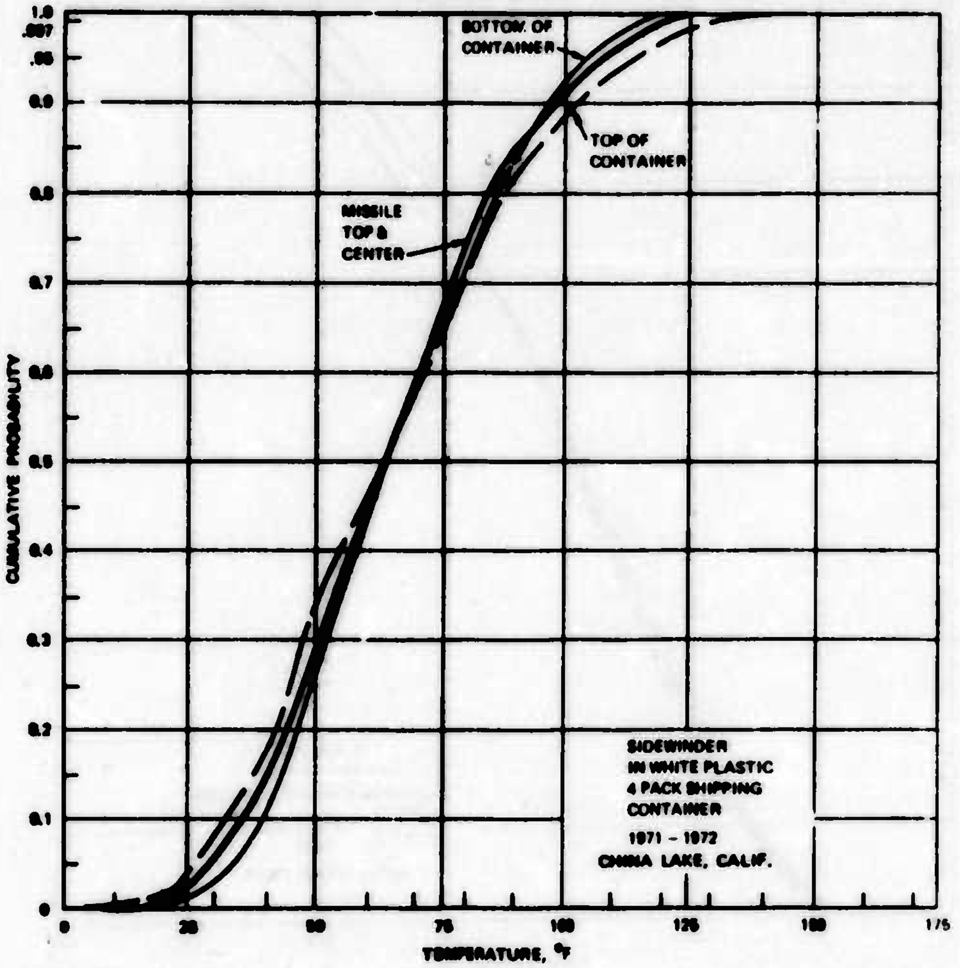


FIGURE 15. Sidewinder in White Plastic Four-Pack Shipping Container, 1971-1972.

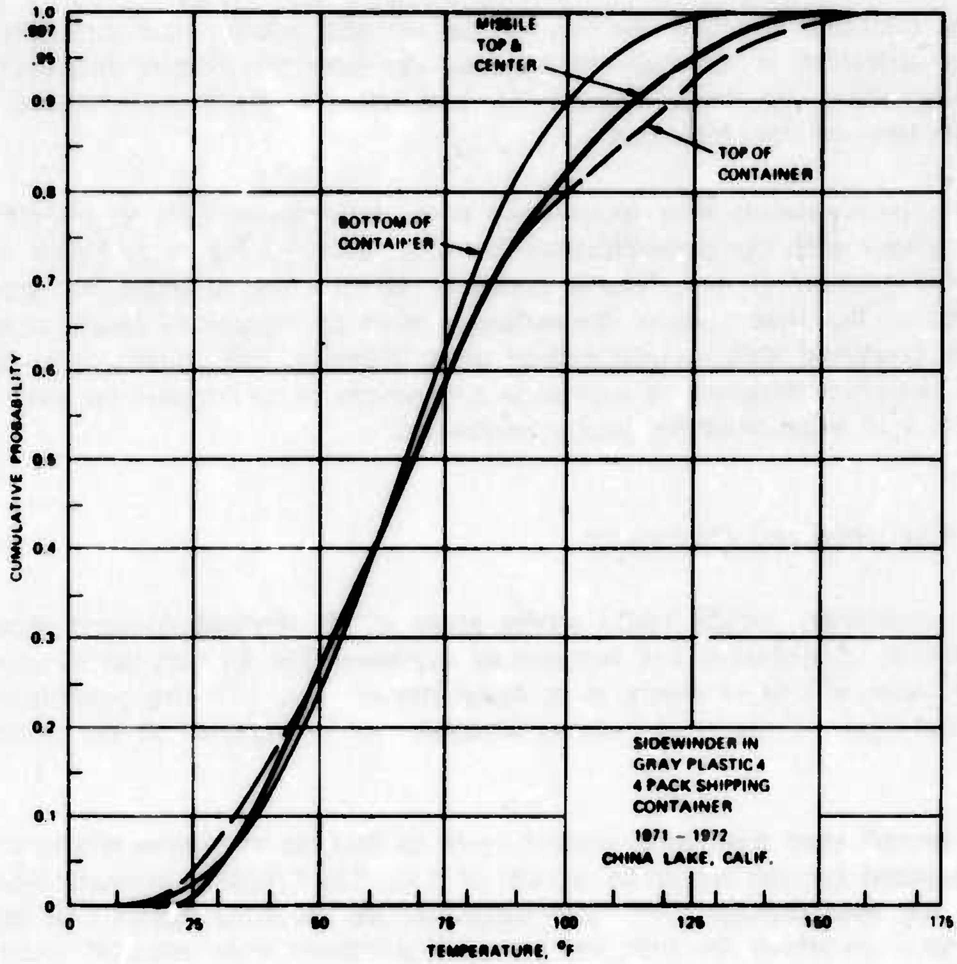


FIGURE 16. Sidewinder in Gray Plastic Four-Pack Shipping Container, 1971-1972.

between the container top and the top of the enclosed missile, it is surprising that there is any difference in the two temperatures. The same temperature differences are approximately shown in both Figures 15 and 16 for the top-of-container and top-of-missile thermocouple locations.

The top-of-container skin temperature curve from about 0.89 to 1.00 (Figure 15) is at variance with the generalizations for white units of Figure 5. Figure 5 will probably need revision as more plastic container data become available, but has not been changed at this time because the incidence of dump storage of plastic-contained units is low compared with metal-contained units. However, this could change in the future and, therefore, designers of such units are encouraged to consider the data from Figures 15 and 16 when designing plastic containers.

## MISSILES MOUNTED ON AIRCRAFT

The on-aircraft, airfield ready service phase of the stockpile-to-target sequence often is blamed for ordnance hot temperature exposure. The layman usually assumes that the exposure will be as severe as in dump storage. The following paragraphs will shed statistical light on the most extreme exposures to be expected in the on-aircraft situation.

All aircraft were positioned pointed south so that the maximum missile surface would be exposed for the maximum amount of time. The exposure sequence began in early 1971 and went through 1976. Each legend for the following figures indicates the type of aircraft on which the unit was mounted. All items were mounted under the aircraft's wing in the "hanging" mode; none were hung off the side or occupied a fuselage or centerline station. Figures 17 through 21 show the composite exposure data for the 2.75 rockets, 5-inch Zuni rocket, 5-inch Sidewinder, 8-inch Shrike and 18-inch Bullpup missiles, respectively. Since there is not much difference between these figures, they will not be discussed in detail. They are presented to provide the users of MIL-STD-1760A with some data on which to base the thermal criteria for this event in the life of a missile. Keep in mind that the normal duration of such an exposure situation is only a few hours or days at a time, and the aircraft are moved. Therefore, these data represent as extreme a situation as could result from any short time exposure.

## BOMBS

An ancillary effort to the program reported herein was to place old iron bombs on similar aircraft at the same measurement site as for missiles. This was done more to check instrumentation and technique than anything else. These data, however, may be useful in the large context since information on a recognized simple system may aid in putting data from the more complex guided missiles into perspective.

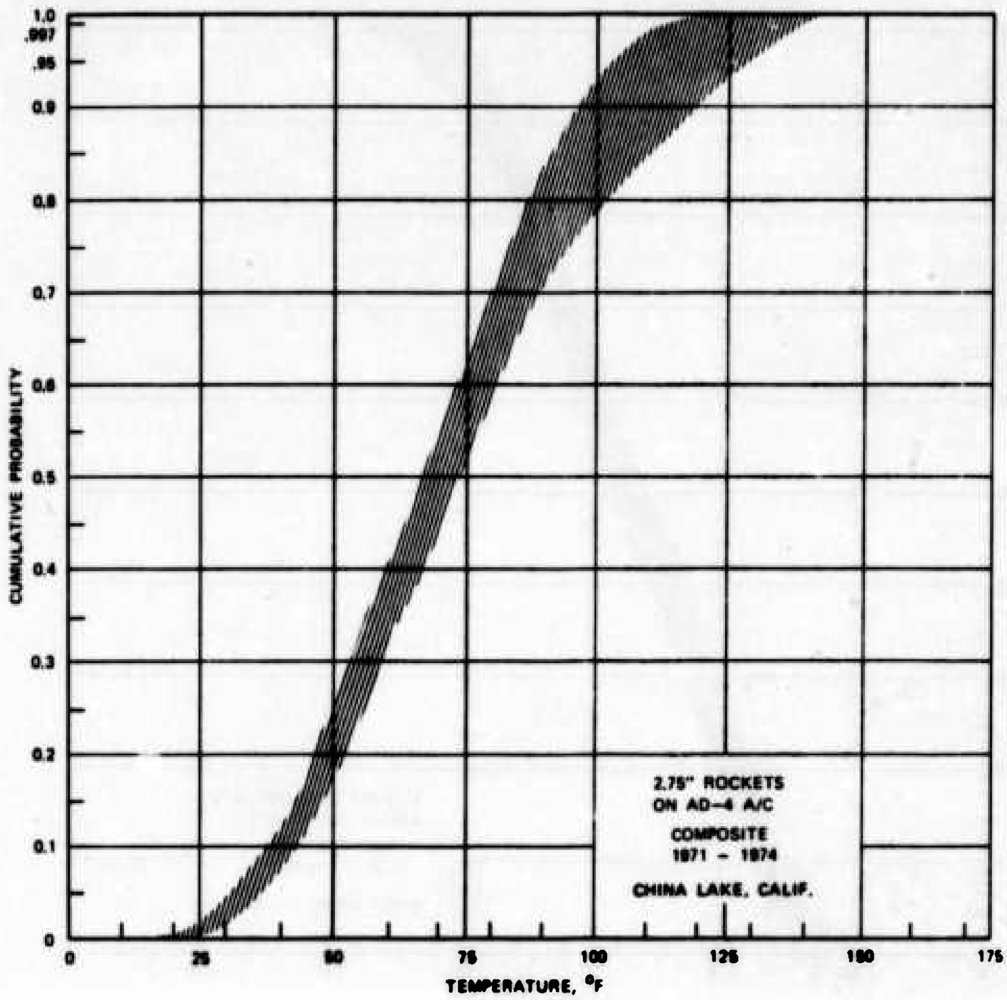


FIGURE 17. Composite of 2.75-Inch Rockets on AD-4 Aircraft, 1971-1974.

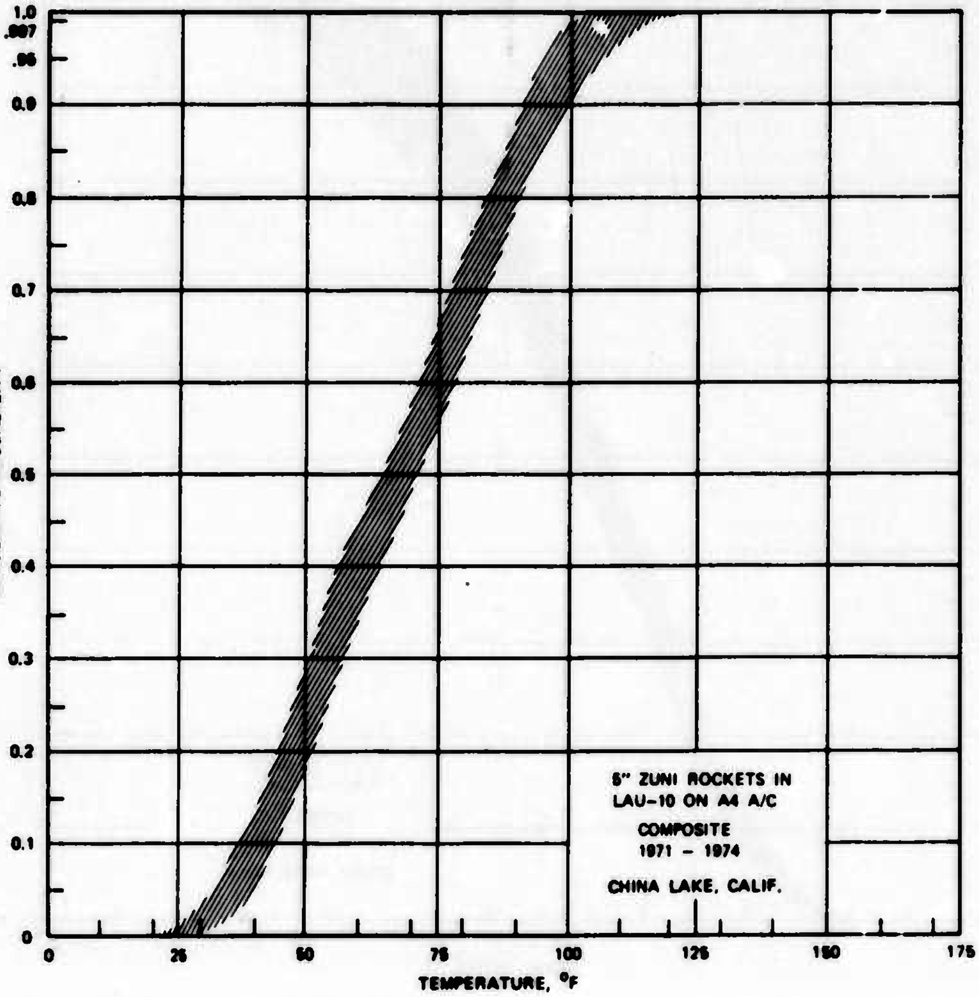


FIGURE 18. Composite of 5-Inch Zuni Rockets in LAU-10 on A4 Aircraft, 1971-1974.

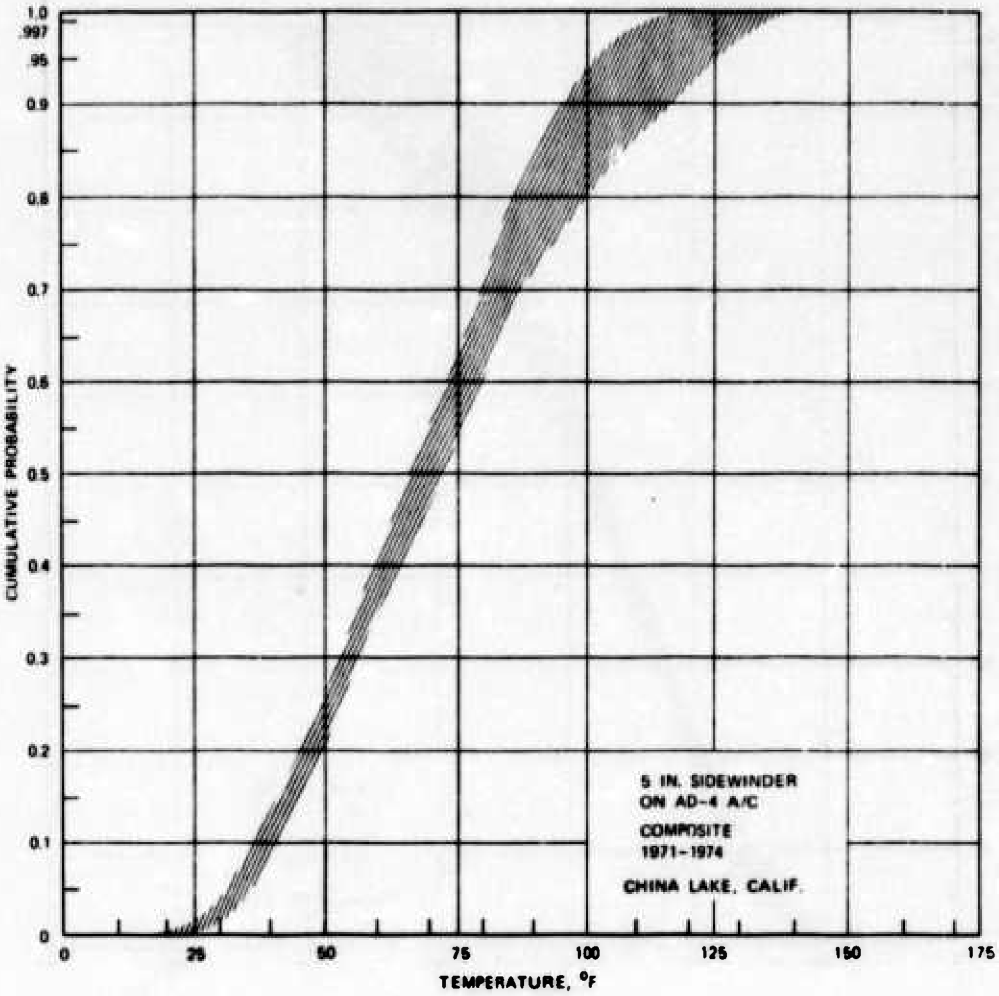


FIGURE 19. Composite of 5-Inch Sidewinder on AD-4 Aircraft, 1971-1974.

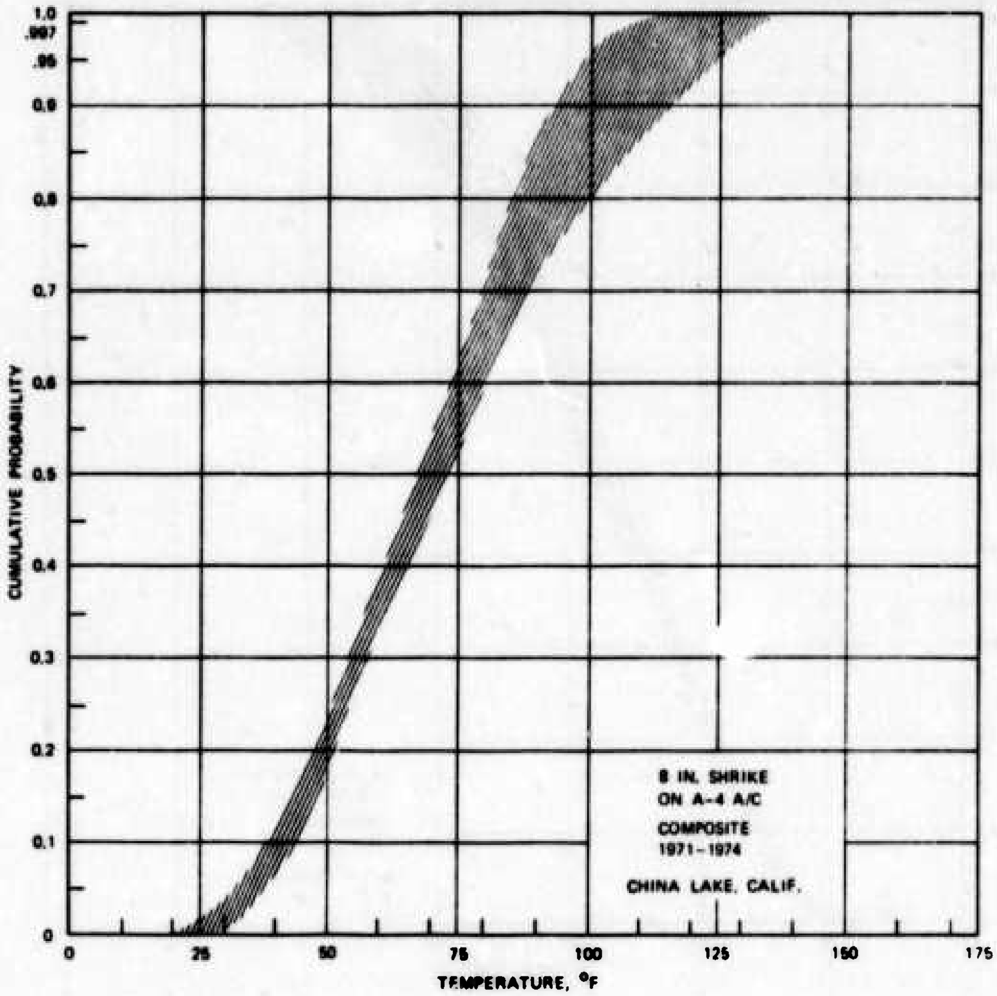


FIGURE 20. Composite of 8-Inch Shrike on A-4 Aircraft, 1971-1974.

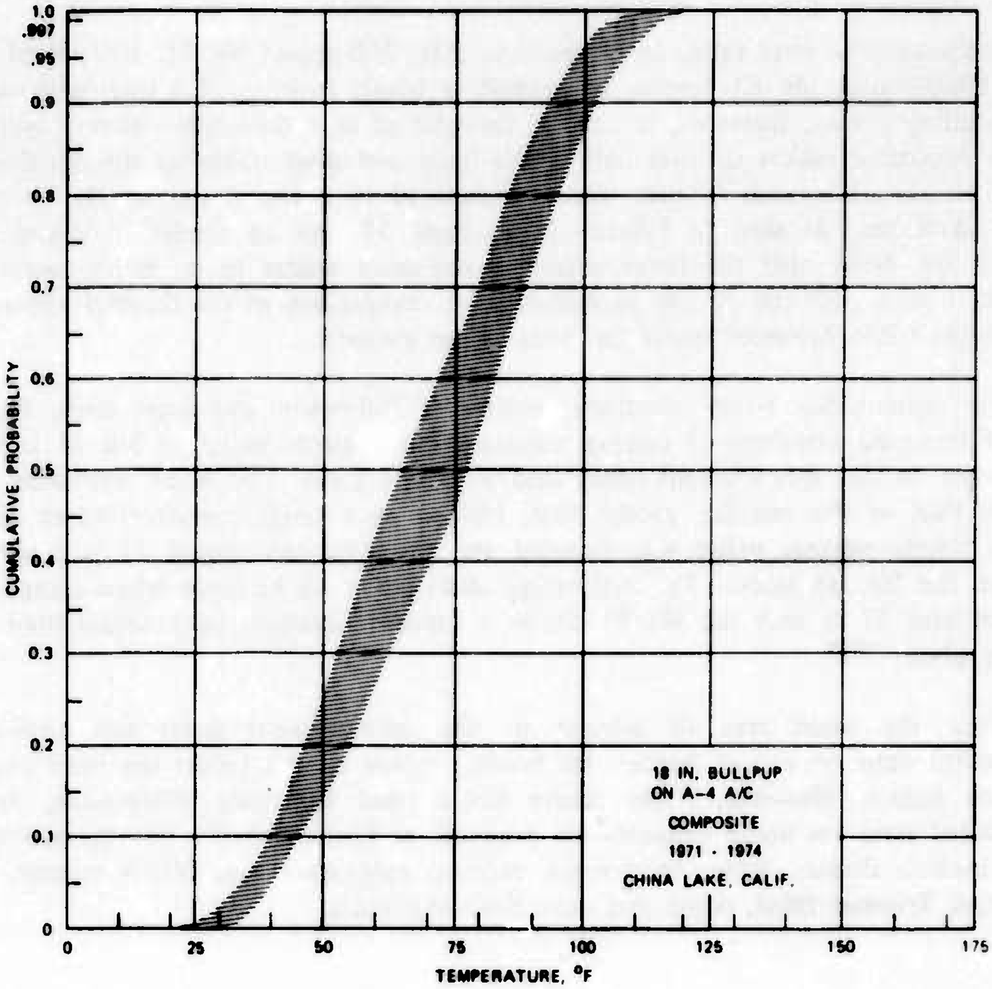


FIGURE 21. Composite of 18-Inch Bullpup on A-4 Aircraft, 1971-1974.

Measurements were taken for 100-pound AN, 250-pound Mk 81, 500-pound Mk 82, and 1000-pound Mk 83 bombs. In general, a bomb consists of a shell with some explosive filling inside; therefore, it can be thought of as a thermally uniform system. Since the explosive makes up over half of the mass and steel makes up the remainder, thermally the bomb system is quite simple compared to a rocket motor. The thermal response envelopes, as seen in Figures 22 through 25, are all similar in shape and absolute value. Note also the larger diameter ordnance seems to be more thermally responsive. Figures 22 and 25 are presented as a comparison of the thermal responses of the bombs while mounted under the wing of an aircraft.

The present day bomb inventory consists of 250-pound and larger units. Figure 26 is the recorded envelope of thermal response for a single pallet of Mk 81 bombs dump stored in the measurement compound at China Lake. The bomb exposure was much like that of the missiles, except that, instead of a single containerized or all-up missile, a whole normal pallet was exposed and instrumented. Figure 27 is a similar record for the Mk 83 bomb. The interesting observation to be made when comparing Figures 26 and 27 is that the Mk 81 shows a higher maximum temperature than the Mk 83 by about 5°F.

Since the main area of interest in this measurement series was obtaining environmental data on rocket motors, the bomb portion of this report has been passed over rather lightly. However, if the reader has a need for more information, much more detailed data on bomb exposure are available at China Lake.[13] The thermal data on hand include tropics, arctic, truckborne, railroad piggy-back van, DODX boxcar, live Minol 4 and Tritonal filled, white and olive drab exposures.

## FUZES

Problems with some in-fleet use fuzes (e.g., premature bursts, high dud rate, and environmental damage) prompted NWC to include fuzes in our measurement series. In all cases, the exposure was planned to reveal the time-temperature history of the most extreme circumstances of dump storage.

The M990 bomb fuze was included in this measurement sequence since it had for a time been a bad actor. The fuze system was exposed in its regular fuze box, painted haze gray. Figure 28 is a composite of all thermal repsonses from this containerized fuze system. Notice that the maximum temperature during the five years of exposure in a pure desert environment was about 130°F. This is because the shipping container was square, not a cylinder laid on its side as with the ASROC rocket motor.

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[13] Naval Weapons Center. *Measured Temperatures of Solid Rocket Motors Dump Stored in the Tropics and Desert. Part 1. Discussion and Results*, by H. C. Schafer. China Lake, Calif., NWC, November 1972. (NWC TP 5039, Part 1, publication UNCLASSIFIED.)

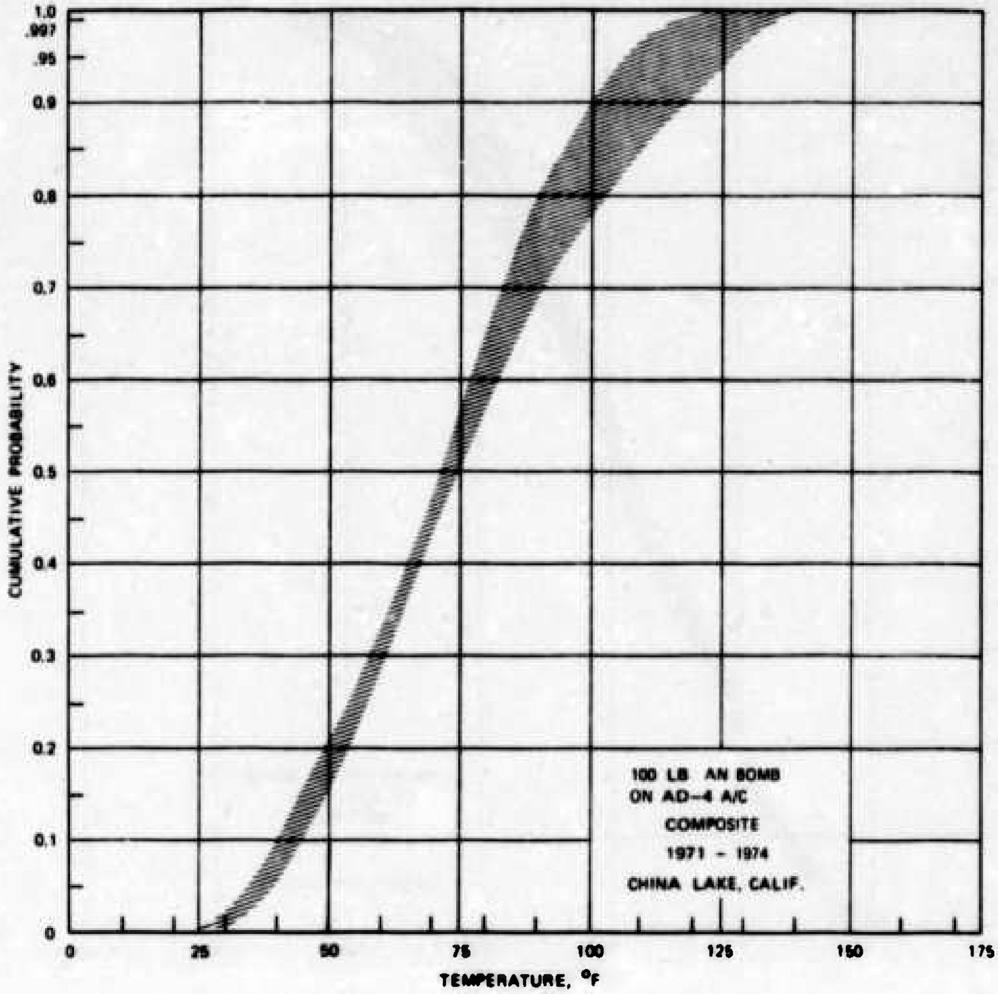


FIGURE 22. Composite of 100-Pound AN Bomb on AD-4 Aircraft, 1971-1974

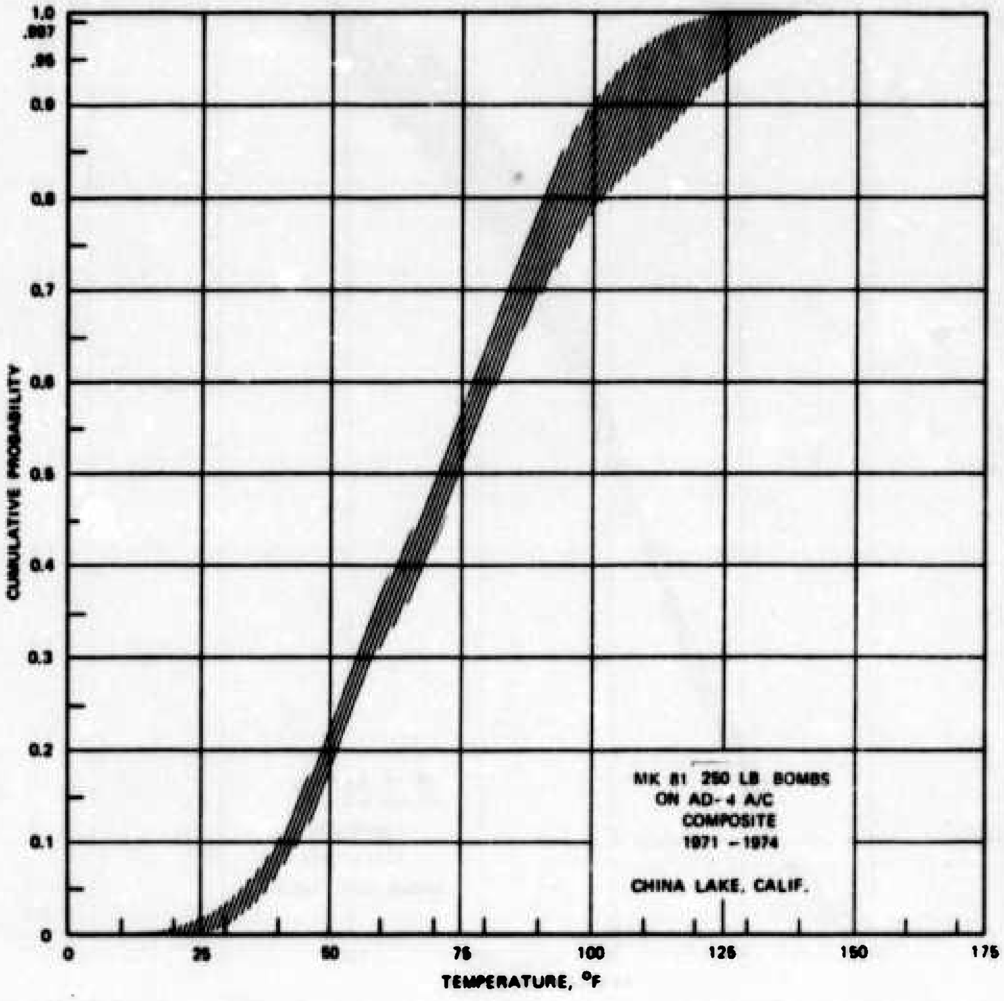


FIGURE 23. Composite of Mk 81 250-Pound Bombs on AD-4 Aircraft, 1971-1974.

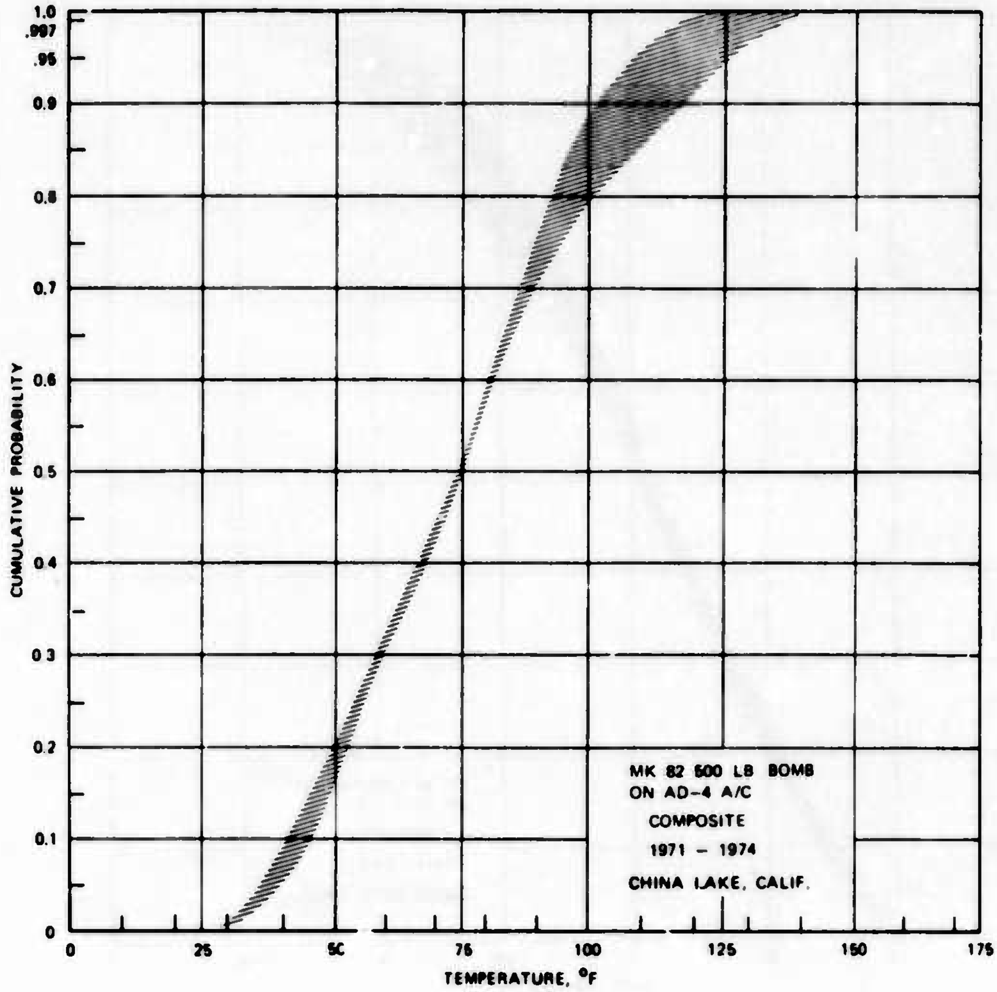


FIGURE 24. Composite of Mk 82 500-Pound Bomb on AD-4 Aircraft, 1971-1974.

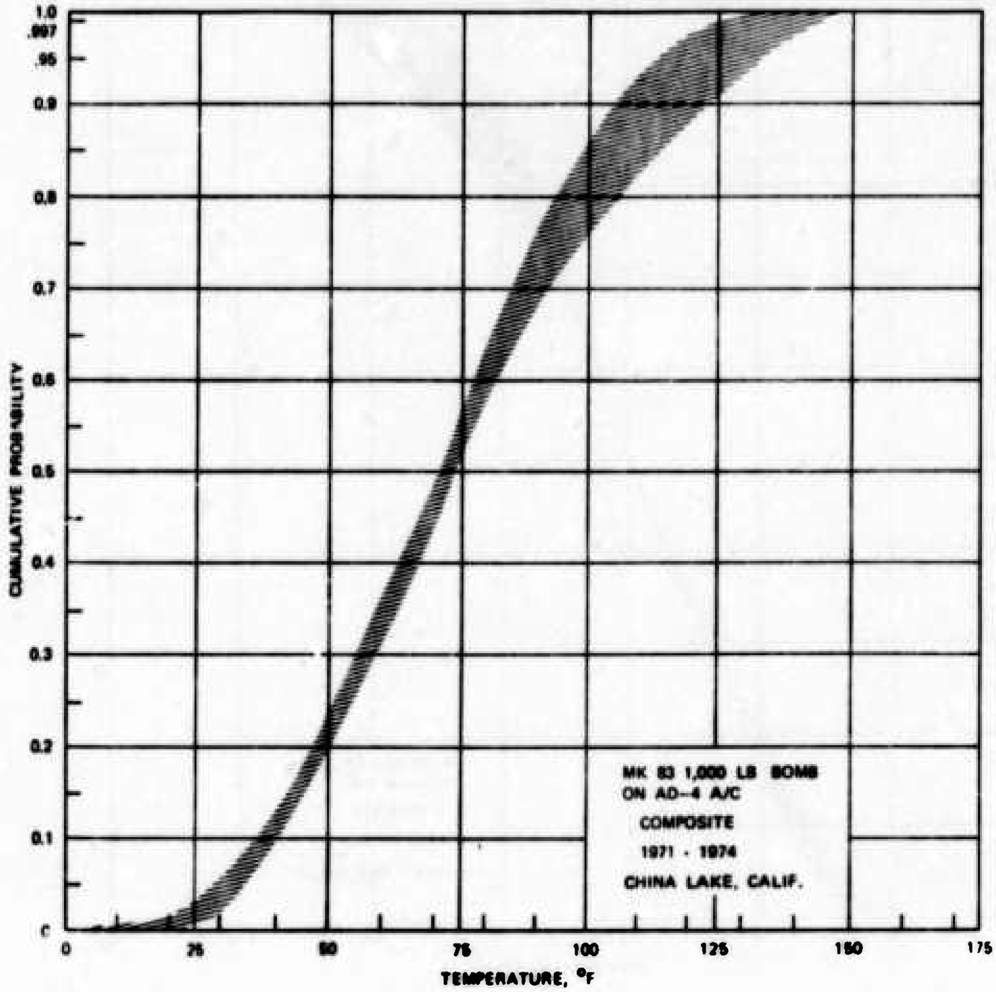


FIGURE 25. Composite of Mk 83 1,000-Pound Bomb on AD-4 Aircraft, 1971-1974.

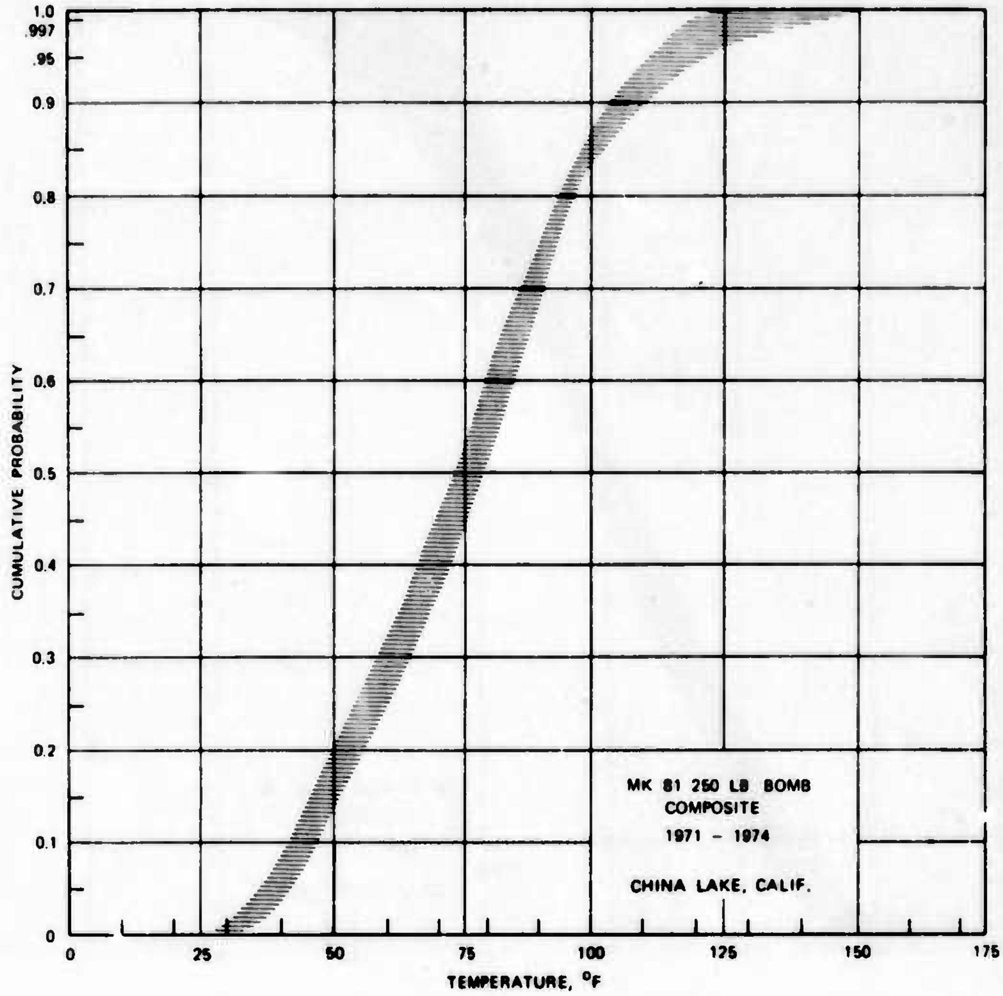


FIGURE 26. Composite of Mk 81 250-Pound Bomb, 1971-1974.

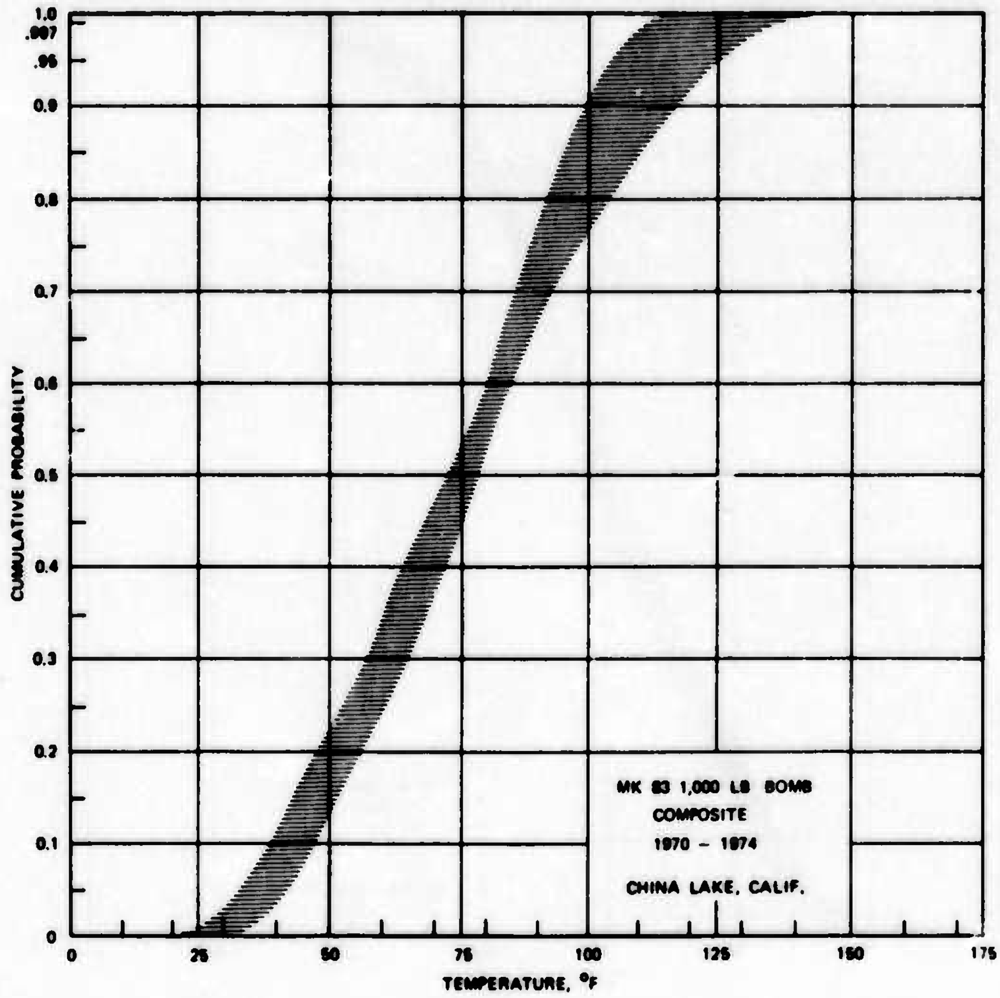


FIGURE 27. Composite of Mk 83 1,000-Pound Bomb, 1970-1974.

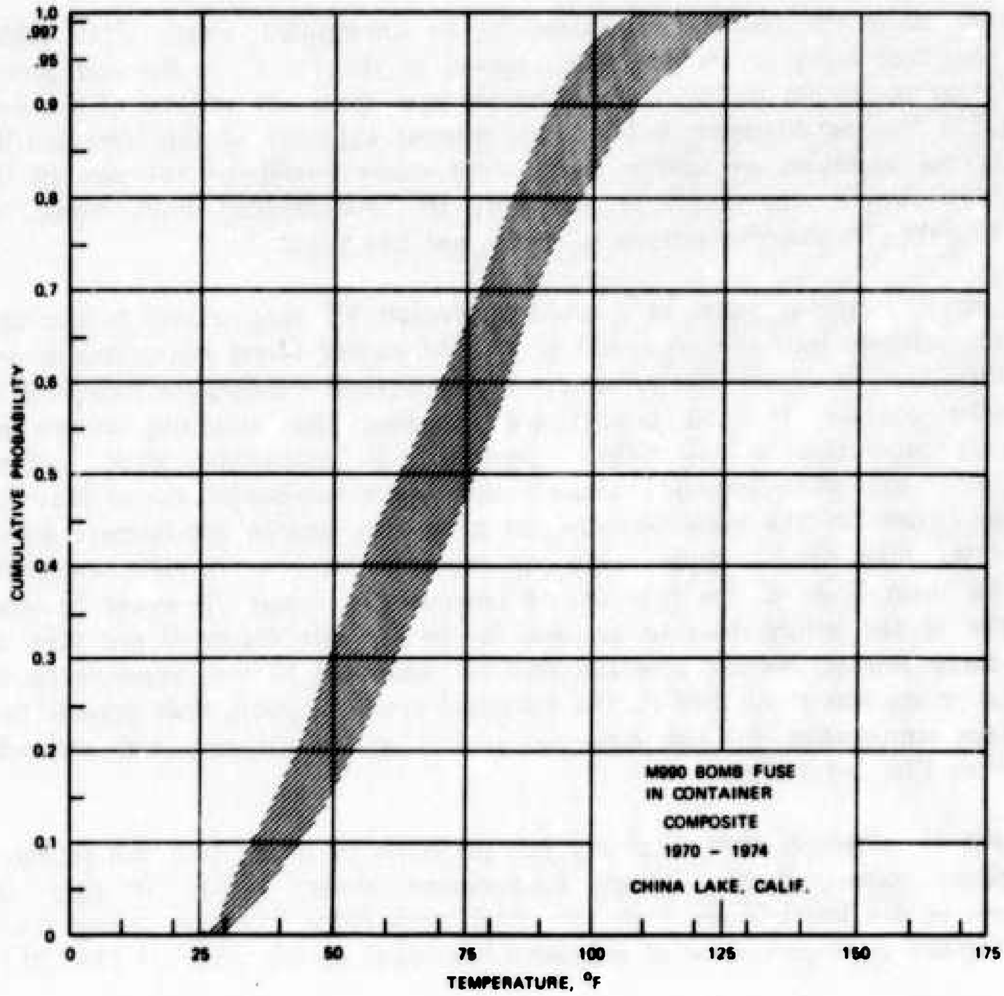


**FIGURE 28. Composite of M990 Bomb Fuze in Container, 1970-1974.**

Figure 29 is the response composite for an unmounted, single 5"/38 caliber projectile nose fuze lying on its side fully exposed to the sun for a five-year period. Notice that the maximum hourly temperature response from any portion of this item was about 135°F. One difference between the thermal exposure of this item and the possible thermal exposure of similar disassembled fuzes would be the size of the components. However, the exposure time for the disassembled units would, of necessity, be only one sunshine portion of a day, not five years.

Figure 30 is the response of a similarly exposed VT fuze, except in this case the fuze was screwed into the nose well of a 5"/54 caliber Naval gun projectile and covered with a brass fuze cap. The projectiles were palletized standing on their base on a wire pallet adapter. For all intents and purposes, this mounting affords no environmental protection at all. The temperature is statistically more uniform throughout the fuze when mounted normally than when fictitiously mounted as was the case for Figure 29. The brass fuze cap acts as an oven that in one instance shields the top of the fuze window from direct sun exposure, but, in the main, uniformly heats up the main body of the fuze and all components. Figure 30 would be more representative of the information to be used in the thermal design of gun fuzes to withstand dump storage. Notice, however, that the maximum hour of exposure during the five-year period was about 140°F. The individual yearly response lines indicate that the maximum temperature for one hour per year is quite constantly high and only varied between 135 and 139°F.

It can be assumed, then, that any gun projectile or bomb fuze will probably not experience desert dump storage temperatures above 140°F. If they are containerized, as are bomb fuzes, then the upper temperature exposure during desert dump storage can be expected to be somewhat less; more on the order of 125-130°F.

## PROJECTILES

Naval gun projectiles were subjected to exposure because of the effort to develop a rocket assisted projectile. Army 105 mm Howitzer projectiles were also exposed because it was found necessary, during the Viet Nam conflict, to remove the packaging from the rounds in order to be ready for a fire fight on a moment's notice. As with the fuzes, the exposure was planned to reveal the time-temperature history of the most extreme circumstances of dump storage.

In all cases, the projectiles were palletized on the standard Naval wire pallets and pallet adapters, with the projectile base down. The top pallet adapters were open wire for the 5"/54, 120 mm and 6-inch projectiles, and enclosed black sheet metal for the 5"/38 and 105 mm projectiles. Most exposures were single pallet loads, with only the 105 mm Howitzer at China Lake in a two-pallet stack.

Figures 31 is a composite of thermal responses for the 5"/54 projectiles at China Lake. It is interesting to note in comparing Figures 30 and 31 that, statistically,

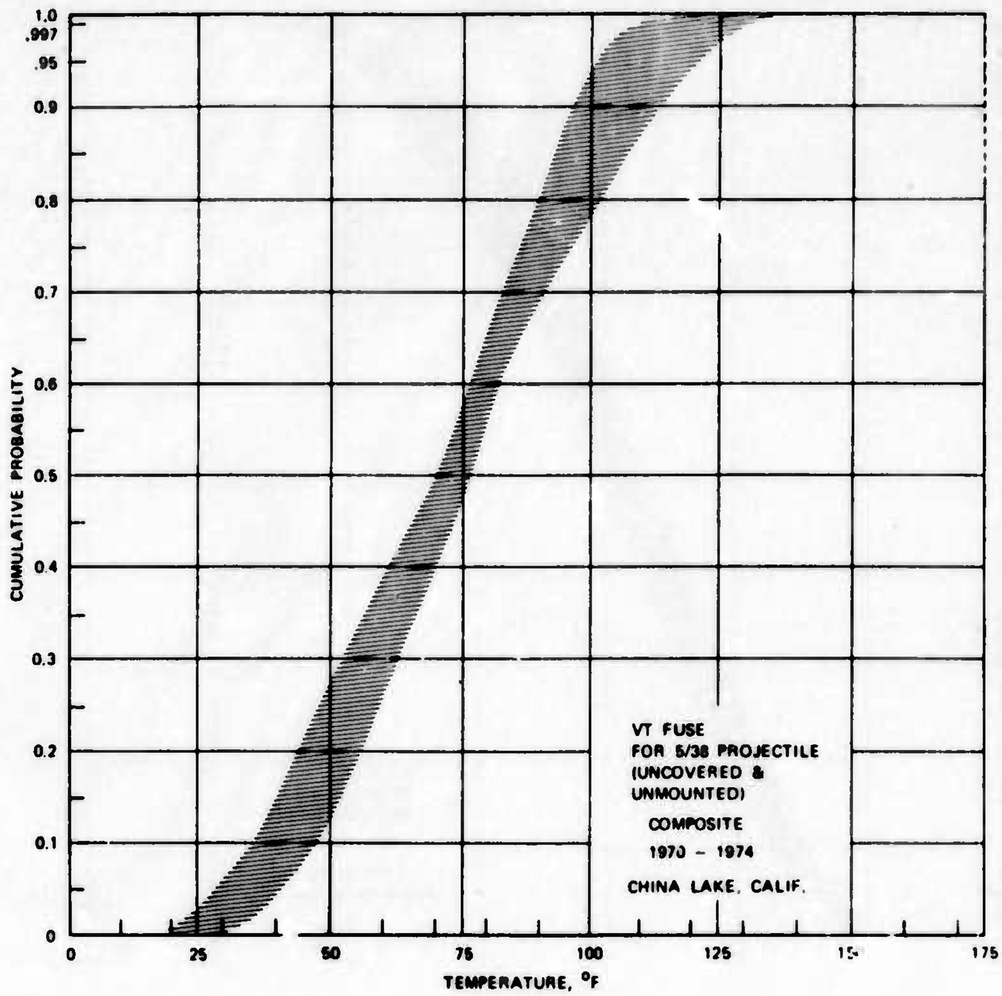


FIGURE 29. Composite of VT Fuze for 5"/38 Projectile (Uncovered and Unmounted), 1970-1974.

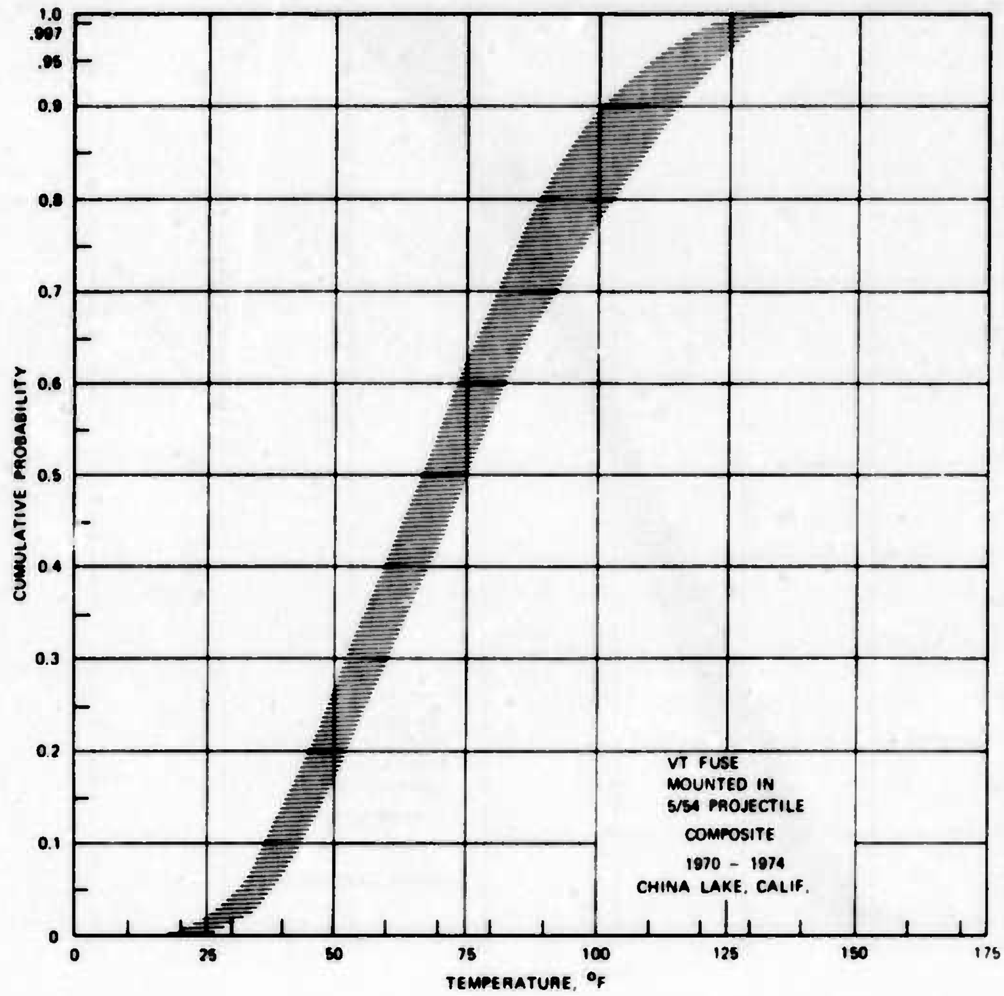


FIGURE 30. Composite of VT Fuze Mounted in 5"/54 Projectile, 1970-1974.

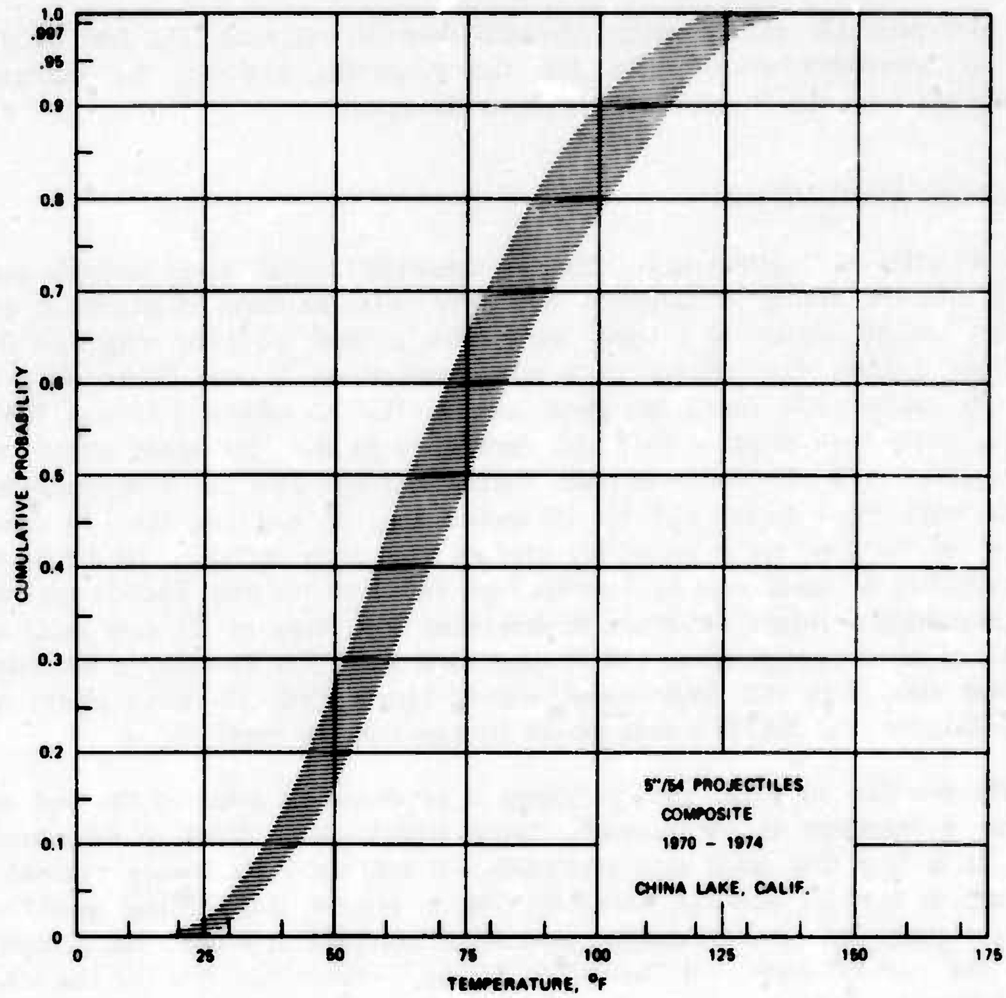


FIGURE 31. Composite of 5"/54 Projectiles, 1970-1974.

the fuse and projectile exhibit nearly identical thermal responses. The fuse band of exposure is somewhat cooler than for the projectile; however, the maximum temperature hour for the five-year span is about the same.

## SMALL ARMS AMMUNITION

Small arms ammunition is packaged in lightweight, small, easily portable metal containers that the average infantryman can carry with minimum effort. Small arms ammunition usually consist of a fixed round with a total individual weight of 0.05 pound. Most modern day infantry small arms ammunition is even lighter since the standard 30 caliber rifle round has given way to the 22 caliber, 5.56 mm NATO round. The basic bulk shipping pack still appears to be the "30 caliber ammo can" used extensively in World War II and the Korean conflict. This can is approximately 3.5 inches wide by 7 inches high by 10 inches long. In addition, the "50 caliber ammo can" of the same era is extensively used in small arms packaging. Its dimensions are approximately 6 inches wide by 7 inches high by 11 inches long. Readers can refer to the appropriate ordnance document to determine how many of any type small arm round, in any given configuration, will fit into each pack. For example, in bandoleers and 8-round clips, only 192 .30-06 rounds will fit into a small 30 caliber ammo can, whereas 300 loose 7.62 NATO rounds can be packaged in the same volume.

This overview of small arms packaging is presented to point up the fact that small arms ammunition is not generally dump stored, nor subject to single-round exposure. It is true that small arms ammunition is sometimes abnormally exposed in single round or machine gun belt situations; but, in general, this situation would not continue for years on end nor, usually, even for a full week at a time. The exception would be the case of abandoned "battlefield pickup" ammunition that has lain where it was dropped until recovered. The thermal degradation of battlefield pickup ammunition is of minor interest, however, when other factors such as physical condition, dirtiness, corrosion of each round, etc., are considered.

The thermal mass of most small arms ammunition is, in general, the same; although there is an order of magnitude difference between 38 caliber single round and a 50 caliber machine gun round. Based on this and the fact that single-round exposure is not a common situation, only ammunition in a container was addressed in this measurement series. The intention was to discover the most extreme representative thermal exposure that small arms ammunition might experience in desert exposure.

The dump stored small arms ammunition ranged from the 30 caliber carbine round of World War II fame through the 20 mm aircraft cannon round. Measurements were made for the 30 caliber carbine, .30-06, 7.62 NATO, 50 caliber machine gun, and 20 mm M51A1B1 aircraft cannon rounds. The general exposure was in single can lots in open, pure desert conditions with an unobstructed sun view. Single thermocouples were placed on the top-center-round and on the center of the can center round. In one instance, a stack of 125 96-round-packed cans (12,000 rounds) was similarly instrumented.

Figure 32 is a summary of exposure data for all small arms ammunition exposed at the Main Dump Storage Thermal Measurement Site at NWC. Notice that the band of values has a maximum temperature extreme value of just over 150°F with a maximum extreme temperature spread of 150 to 110°F, or 40°F. This means that desert dump stored small arms ammunition has next to no chance of attaining a temperature level in excess of 150°F for even one hour during the entire length of time that the box would be in dump storage. This is still true even if the storage time were five years, which is ridiculous since normal dump storage times are measured in terms of days or hours not years.

To break down the composite of Figure 32, we will start with the record of the smallest individual unit in the measurement series. Figure 33 is the plot of thermal responses for the 30 caliber carbine ammunition in a small ammo box for the period 1970-1974. (The data for 1975 and 1976 are no different than shown herein for all small arms ammunition, thus, for all intents and purposes, these figures are valid for seven rather than five years of exposure.) The line not in the group, but indicating more severe cumulative probable chance of occurrence of temperature, is for the spring, summer and fall (hottest desert months) of 1970. The group of lines each represent the full (8,760 hours) year. Notice that, for the overall cumulative data, the maximum response temperature is about the same. The yearly variance is indicated by the spread of the curves as they go from a cumulative probability of 1.00 down through a cumulative probability of 0.0. The surprising thing is that not one of the seven years of measurement had a cumulative probability of 1.00 that reached 150°F. A maximum of 146°F was reached for less than one hour per year, even though the ammunition can was painted olive drab.

Figure 34 is the record for the .30-06 ammunition exposed at China Lake. Most of the general remarks about Figure 33 also apply to this situation. The main differences are that the extreme two lines are for a single 50 caliber ammunition container and the rest of the lines are for a 12,000-round stack of containers. Notice that the maximum exposure response temperature is a solid 25°F less for mass ammunition storage than for single can storage. Even though the single can storage lines were for an incomplete year (1970), a comparison of Figures 33 and 34 will indicate the expected error in the temperature response shift of these two sets of thermal responses. (Most errors will be found in the "cold" portion of the single can set, and no errors in the 12,000-round set.) The lesson of Figure 34 is that the massed, single location storage method commonly used by combat forces is most likely to result in lesser maximum response temperatures. Therefore, the data reported herein can be thought of as extremely conservative when applied to the normal dump storage of small arms ammunition in the hot regions of the world.

Figures 35 and 36 are presented only for completeness and because they do exist. Figure 35 is for the standard 50 caliber machine gun ammunition in a single 50 caliber ammo can. Figure 36 is for a full can of Mk 2, M51A1B1, 20 mm aircraft cannon ammunition in a link belt. All the containers were painted olive drab, except for the Mk 2 Naval container which was painted haze gray.

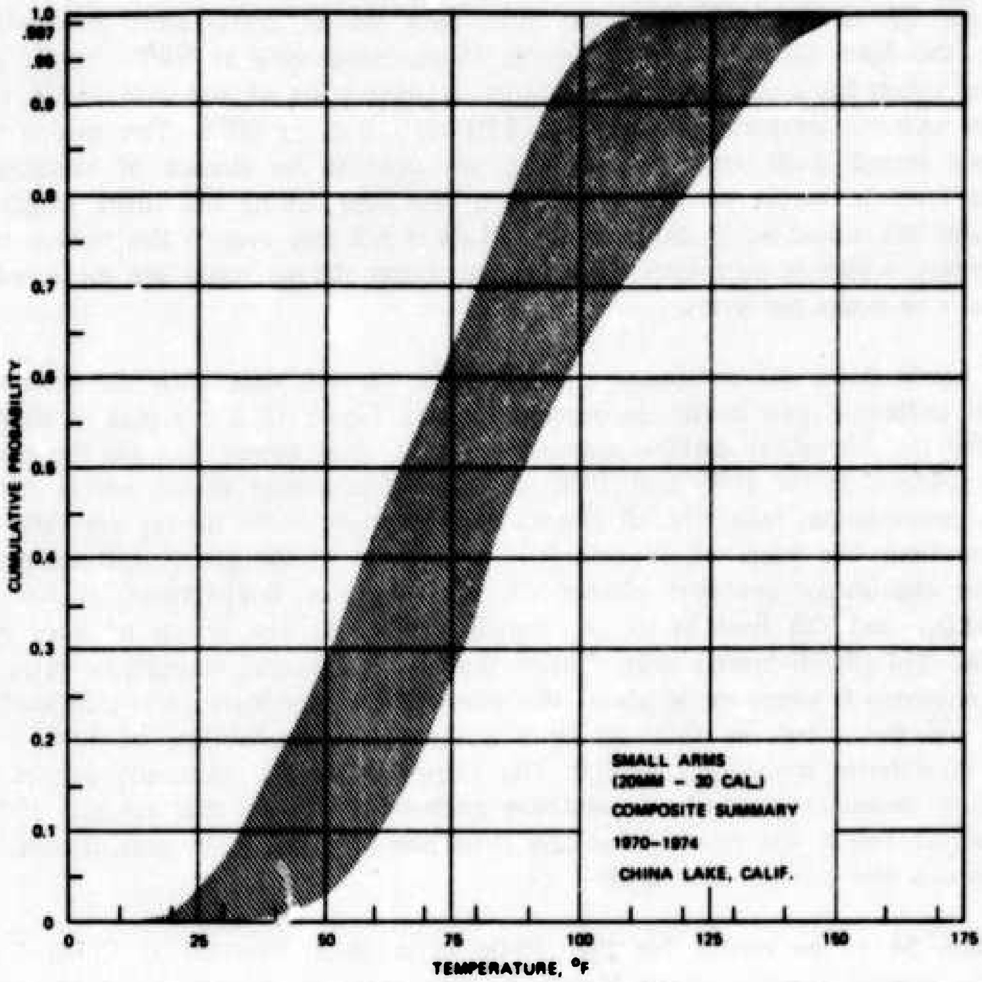


FIGURE 32. Composite of Small Arms Ammunition (20 mm, 30 Caliber), 1970-1974.

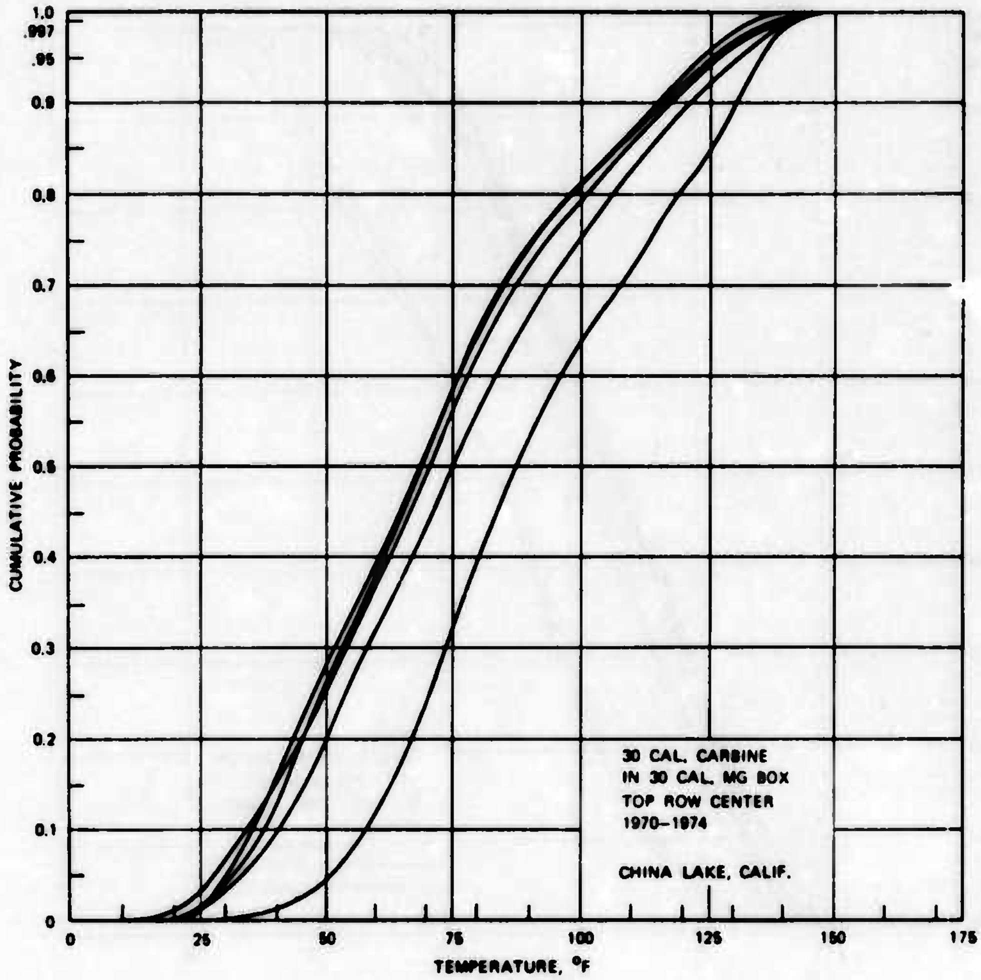


FIGURE 33. Composite of 30 Caliber Carbine Ammunition in Small Ammo Box, 1970-1974.

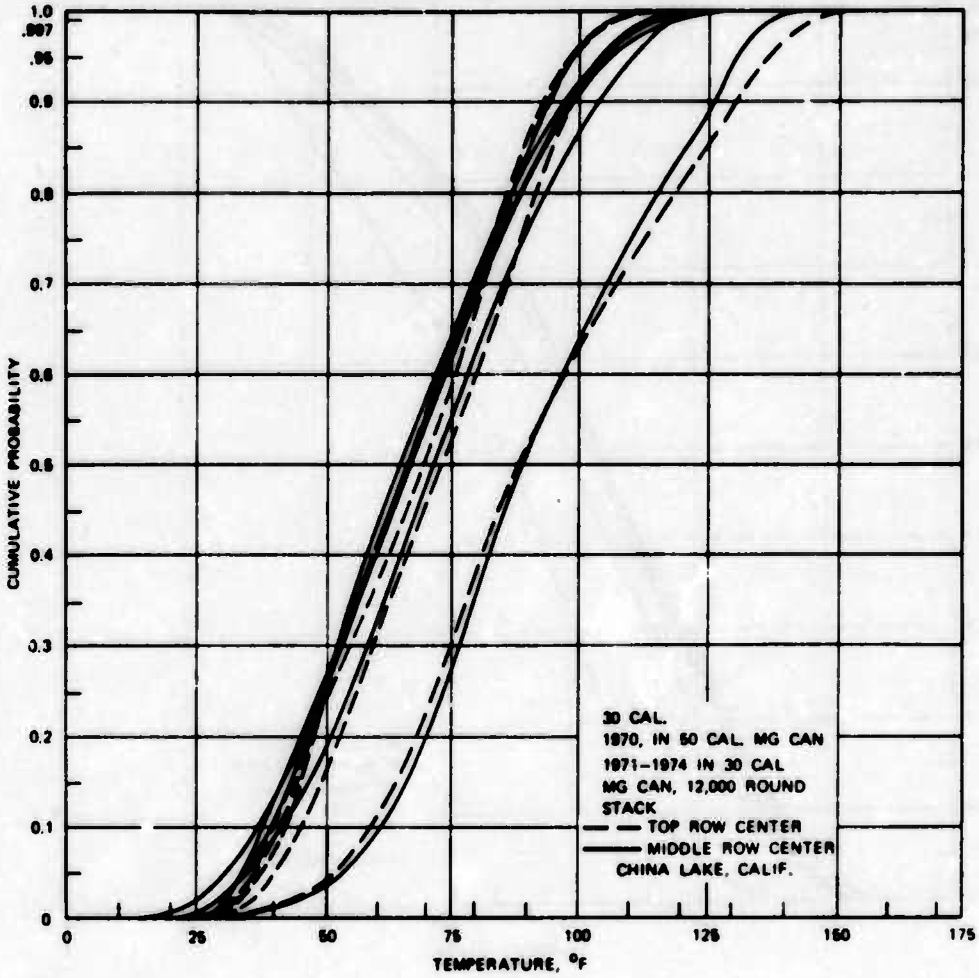


FIGURE 34. Composite of 30 Caliber Ammunition in Large Ammo Box and 12,000-Round Stack, 1970-1974.

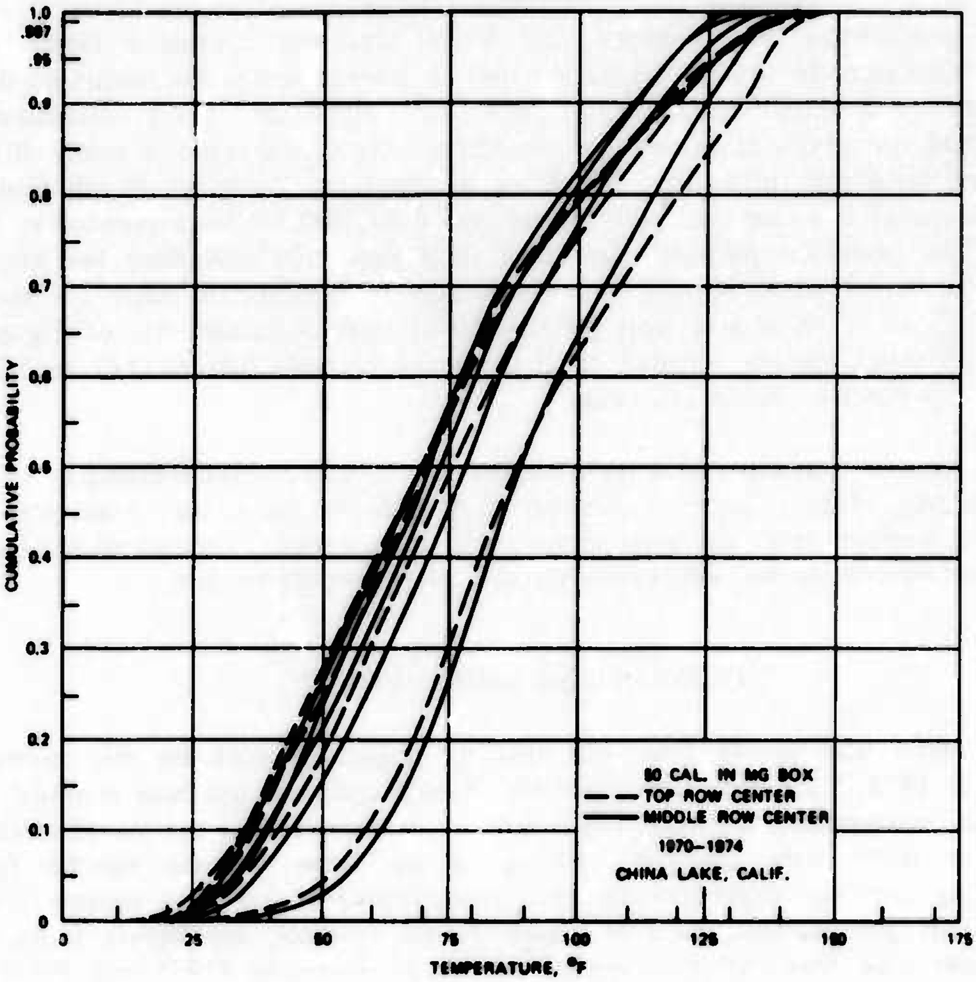


FIGURE 35. Composite of 50 Caliber Machine Gun Ammunition, 1970-1974.

A single small can of empty 7.62 NATO brass was exposed at Death Valley National Monument to address the notion that air temperature is the maximum driving force for dump stored ordnance. If this were true, the 110°F maximum air temperatures normal during the summers at China Lake should result in vastly differing thermal response data than the 125+°F air temperatures for which Death Valley is noted. Figure 37 is a one-year plot of the empty 7.62 NATO brass exposed at Death Valley. (This brass was purposely unloaded since Park rules prohibited live ordnance exposed in the National Monument.) The maximum temperature value for the top round in Figure 37 is greater than for the .30-06 single container data of Figure 34, but the difference can be equated to the amount of mass deleted (1/2 to 2/3) by removing the powder, primer and bullet.

It must be reiterated that these figures are, in main, extreme examples of what to expect from dump storage. Remember that, in some cases, only brass was used, single cans were exposed, and most importantly, these data are for exposures of up to seven years whereas, in real life, exposures of a month would be rare.

## CONCLUSIONS AND SUMMARY

I would first like to point out that the original artwork for this report was prepared in 1975. Since that time a wealth of additional data has been returned from the various measurement matrices. These data are as important to the overall statistical context as those data originally serving as the bases for the various figures (representing only the original 4-year data compilation). It has since become evident that the data presentations, such as Figure 17 for example, are representative of a much longer time span. After overlaying data from succeeding (1975 and 1976) and preceeding years (1965-1970) on the presented summation figures, there was no instance where the added data changed the presented exposure bands. It therefore seems safe to say that this report is, in general, presenting data for the decade 1966-1976. If this is so, then the statistical probability is that these data are representative of at least the next decade and, quite probably, the remaining years of the reader's natural life.

As shown by the thermal response data for air-launched weapons dump stored in the desert, the MIL-STD specified temperature value of 165°F can no longer be considered an all-inclusive run-of-the-mill target for designers. Data presented in this and other reports (see References 5 through 13) clearly indicate that the common design use of 165°F for air-launched missiles may be one of our most all-pervading errors. The data reported herein also indicate that an approach to upper temperature design and storage limits as prescribed in MIL-STD-1670A (see Reference 4) would result in more situation oriented design goals for air-launched weapons. Based on this, it is recommended that the casual use of 165°F, or any other arbitrary number, be purged from the DoD acquisition cycle. Figure 5, or a like worldwide dump storage display, may be a basis for generalized thermal design information; however, this generalization should be approached with much thought and much more data.

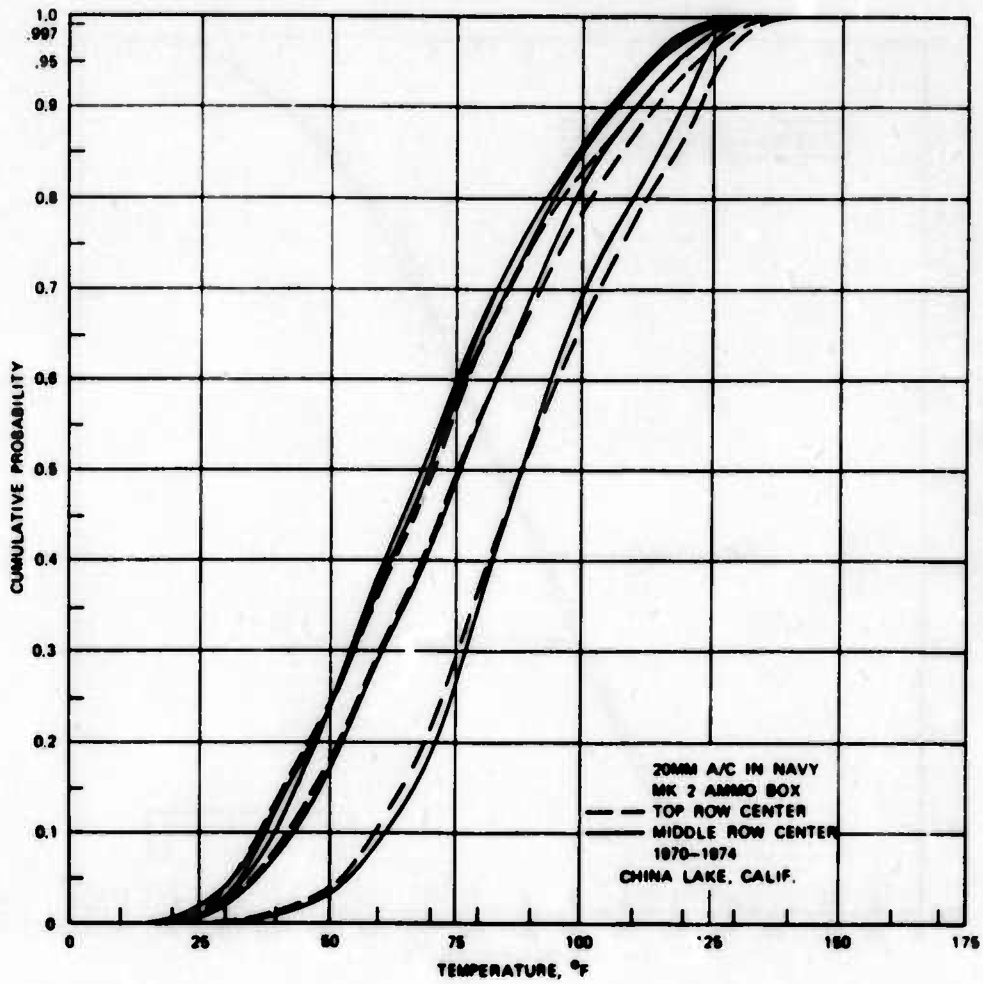


FIGURE 36. Composite of 20 mm Aircraft Cannon Ammunition in Navy Mk 2 Ammo Box, 1970-1974.

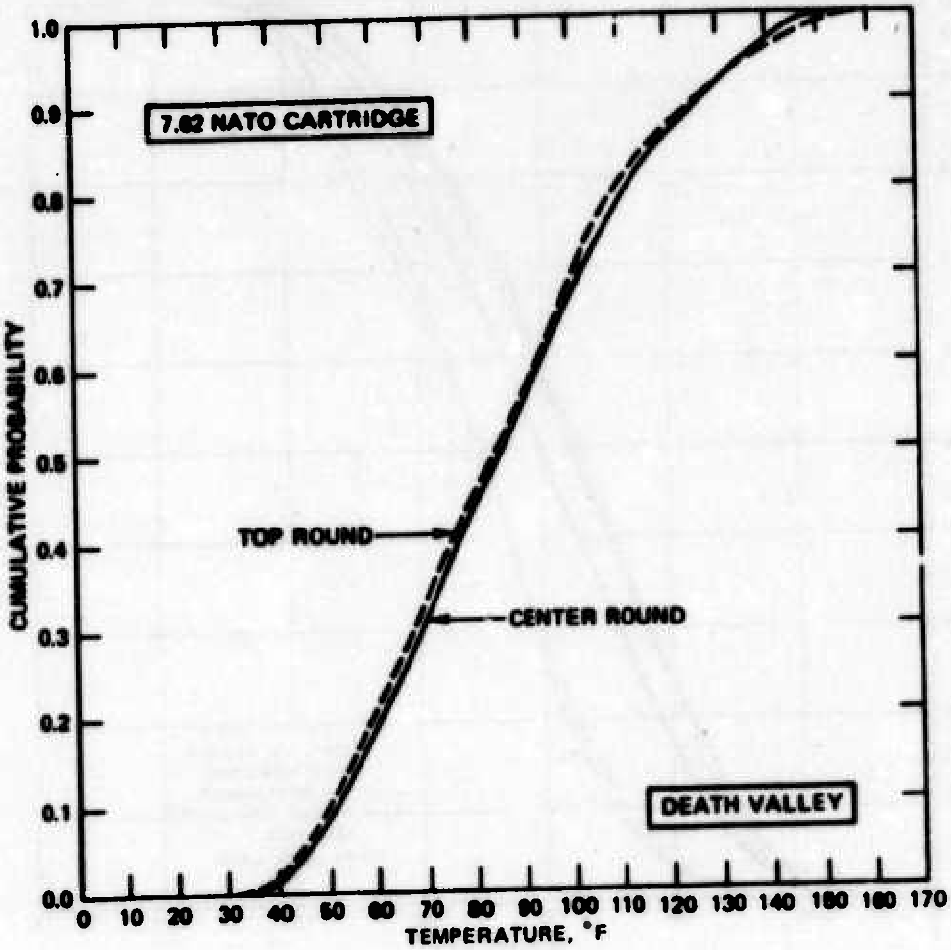


FIGURE 37. Thermal Response for Empty 7.62 NATO Cartridge Exposed in Death Valley, 1971.

## Appendix A
## STOCKPILE-TO-TARGET SEQUENCE

This appendix presents a method for determining the use life of an air-launched rocket motor and consists of graphically outlining the probable life of an air-launched unit. It can be seen in Figure A-1 that no matter what the air-launched ordnance item is, during its life span, it will follow the events as depicted in the diagram.

In general, the sequence starts at the component manufacturer level. It can be assumed that the components will be built in the manufacturing centers of industrialized nations of the world. Therefore, the components will be shipped from the manufacturer to assembly depot by only four different modes of transportation: truck, rail, ship, or air.

The assembly depot can be assumed to be located in a manufacturing complex, or if in a remote location, it will have the equivalent facilities of a modern manufacturing complex. All subcomponent storage will be in some type of covered area, either above ground storehouses or earth covered igloos. Therefore, the component will be protected from the adverse effects of exposure to the weather. On assembly, the units will be packaged and palletized for delivery to the fleet. If manufactured in the United States, the unit is then shipped via truck, rail, or air to one of the established Naval Ammunition Depots (NAD), situated within the

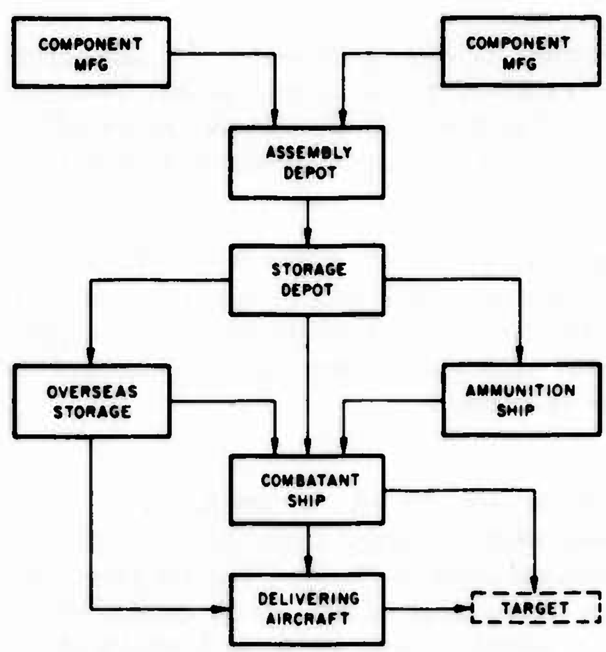


FIGURE A-1. Stockpile-to-Target Sequence.

continental boundaries. Once at the ammunition depot, the unit will be placed in a standard "explosive hazard magazine" as per instructions delineated in NavWeps OP-5, Volume I. Again, there will be no outside storage and a very small chance of storage in above ground storehouse facilities.

From the continental United States storage depot, the item will be sent to either (1) an aircraft carrier, (2) overseas for storage or use, or (3) stored on board an ammunition ship. In the vast preponderence of situations, the unit will be transported via ship to a forward area or loaded on board an aircraft carrier for a tour of duty. During wartime, the use of civilian merchant ships is a good probability. Therefore, the use of non-Navy ships and the inherent chance of cargo mishandling must be recognized. Once at a forward storage area, three storage modes are possible: (1) igloo storage, (2) above ground storehouse or primitive covered storage, and (3) primitive dump storage. It has been observed, even during the first hectic days of the Viet Nam emergency, that at the forward storage depots, the air-launched rocket motors and components received preferential treatment. Where there were storage igloos, the bombs, gun ammunition, ballistic rockets and some pyrotechnics were dump-stored to provide room for the more sophisticated air-launched guided missile components. This is only an indication, but a strong one, that the air-launched rocket will, whenever possible, receive preferential treatment. However, it was also observed that the Marine Air Wings were forced to dump-store even air-launched rocket components at forward airfields. Following investigations disclosed that even as Butler-type huts became available, the air-launched guided weapons were given preferential treatment. The forward storage situation is the most severe portion of the stockpile-to-target sequence that a weapon can be expected to experience.

Another flow sequence (Figure A-1) shows the unit being loaded onto an ammunition ship for at-sea-transfer to an aircraft carrier. This operation has become increasingly popular in the limited war situation where the aircraft carrier is used more as a Naval Air Station than a tactical weapon system as in World War II.

The land counterpart of the aircraft carrier is the Marine Corps forward airfield. In a wartime situation, a forward airstrip will be cut from the terrain and any natural hill and valley area used for dump storage of the explosive components. Usually, there will be few or no pieces of elaborate handling gear or specialized tools and equipment to transport or service the ordnance.

Since the unit is to be used in both circumstances, it should be designed so it will be usable and function when air-carried from either situation. Therefore, the more stringent environmental considerations of Marine Corps use should be given recognition. Instead of the "antiseptic" conditions of an aircraft carrier, the unit may sit in the sand, wind, and rain for a period of time before it is manhandled to the "hot line" and installed on the aircraft from which it is later launched.

A study of Figure A-1 will reveal that all variations of paths have not been discussed here. There are many possible combinations of the enumerated stations in the sequence; however, the other combinations would lead to no new environmental criteria that have not already been identified. Therefore, for brevity, they have been omitted.

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# Appendix B
# A DISCUSSION ON DUMP STORAGE

Use of dump storage is more easily predicted than is apparent at first observation. The majority of times that the Navy will resort to dump storage can be illustrated by the following two examples. The first circumstance is when a new airfield is put into operation and there are no magazine facilities available. This was the case at both Da Nang and Chu Lai during the Viet Nam emergency. However, even during this emergency, the air-launched tactical missiles were given preferred treatment. In most cases, this meant that they were placed in hastily prepared revetments or covered by a canvas tarpoline. The second situation is when the present forward staging area or Naval magazine is overloaded by the gross volume of the operation. This happened in both Korea and Viet Nam. In 1965 at Subic Bay, there were not enough available igloo magazine structures to accomodate the gross tonnage of ordnance that was being "funneled through" on its way into action. Although the personnel did an extremely good job of handling the situation, there were makeshift bamboo and canvas "shelters" (Figure B-1) and vast amounts of dump-stored ordnance for the first few years. Eventually, the required igloo-type structures were constructed and the problem became less severe. However, the fact remains that dump storage did exist for some type of ordnance for a time. Again, the more sophisticated items in the naval arsenal were given the best treatment, as common sense would dictate.

The unforeseen times when a dump storage-type situation can and does exist was graphically demonstrated when an aircraft carrier did not make a scheduled pickup of a load of assorted ordnance (Figure B-2). The load had been staged to the dock area and remained at least three weeks awaiting the ship. This particular load was staged in late April and, therefore, at 15 degrees north latitude, was exposed to the hottest portion of the tropical exposure. (The sun is directly overhead, and it is still the dry season.) It is not known how much longer this particular load remained there before it was either returned to the magazine or loaded onboard an ammunition ship or aircraft carrier.

The aircraft ordnance hot line also approximates the dump storage situation. In forward areas, the squadron ordnance personnel will draw the projected ordnance for a limited number of strikes. They will then remove it from the container where appropriate, assemble and/or arm it as necessary in readiness for the installation on the aircraft. Generally, this phase of operation is of short time duration.

## EXPOSURE PHENOMENA

In this measurement series, the dump storage situation has been reproduced with the intent of simulating the extreme situation. The candidate ordnance was exposed singly, in close approximation with, or directly situation on the ground. The ordnance when in containers, or exposed bare, was positioned with the longitudinal

FIGURE B-1. Typical Temporary Shelter.

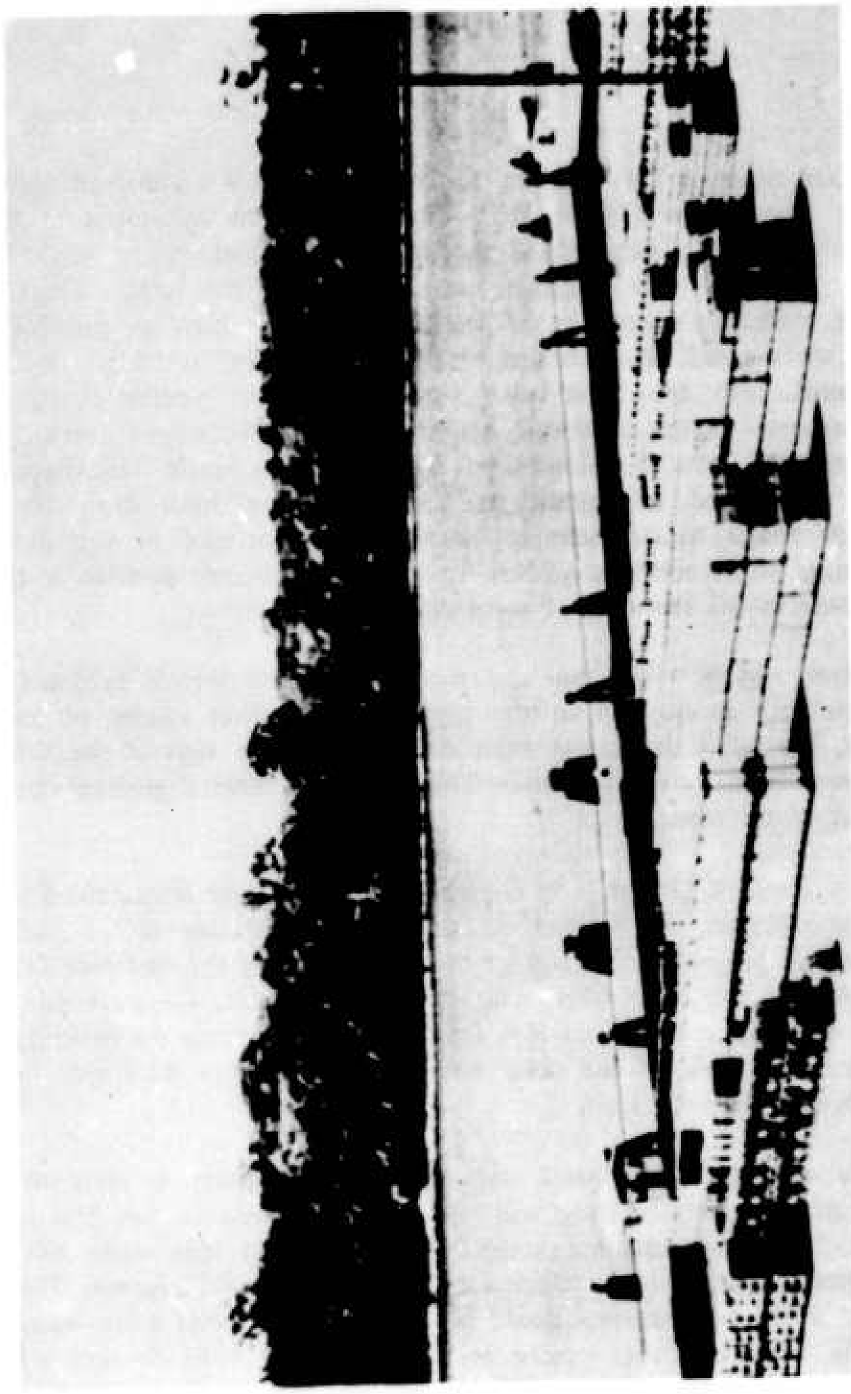

FIGURE B-2. Ordnance Stacked for Ship Loading.

axis pointing nominally true north and south. The geographic location of the exposure sites also was carefully selected for the maximum exposure potential. Since it is recognized that the extreme year does not occur each year, the ordnance has been left in these locations indefinitely.

## Single Exposure

The general situation for exposure of ordnance in the combat-oriented storage dump is in like item groups (Figure B-3). There is not enough room in the Naval magazines to spread out a shipload of tactical missiles, and in the airfield storage dump situation, the larger the magazine area the bigger the target. Therefore, the containerized or palletized ordnance is stacked about as high as possible with a forklift, or the surface will allow before the stack becomes unstable. This tends to compact the units into the most easily accessible, most volumetrically efficient grouping commensurate with revetment height, soil conditions, and terrain features. Therefore, the thermal mass is much more than that of a single unit. Because most containers are constructed of metal, the conduction of heat from the warmer containers to the cooler would seem to become of importance in not allowing the exposed edge units to respond as quickly to extreme exposure profiles as the single exposed unit would in the same set of meteorological circumstances.

The analysis can be taken one step more if the exposure is explored in more detail. The single unit is exposed to the sun from just after sunrise till just before sunset. However, the point of normal exposure to the direct rays of the sun changes almost 180 degrees from sunrise to sunset. Therefore, the thermal gradient through the item will tend to do likewise.

Now, if a stack of 100 units in contact with each other is examined instead of a single unit, the following is observed. At sunrise, the east side of the stack is fully exposed. As the day progresses, the top of the stack replaces the east side in exposure to the direct rays of the sun. After solar noon until sunset, the west side becomes more and more exposed to the direct rays from the sun, relieving the majority of even the top units of the stack of the solar load. However, these west side units were "cold" until shortly after solar noon.

It can be seen that the central units of the stack cannot be seriously exposed for any length of time at all. They will probably only assume the general thermal energy level of the free circulating ambient air. The east side units will only be expected to achieve slightly higher temperatures than the "cold" center. Therefore, it is the west side or the top row that could be expected to exhibit a maximum thermal profile. Since the west side units receive no direct sunlight until the day is half over, they will not exhibit maximum temperatures, so this leaves only the top row. Now, the units of the top row will be expected to progressively shade the unit to the east of it as the sun goes from the solar noon position to sunset. This shading and the thermal conductivity will tend to modify the exhibited thermal profile of even these

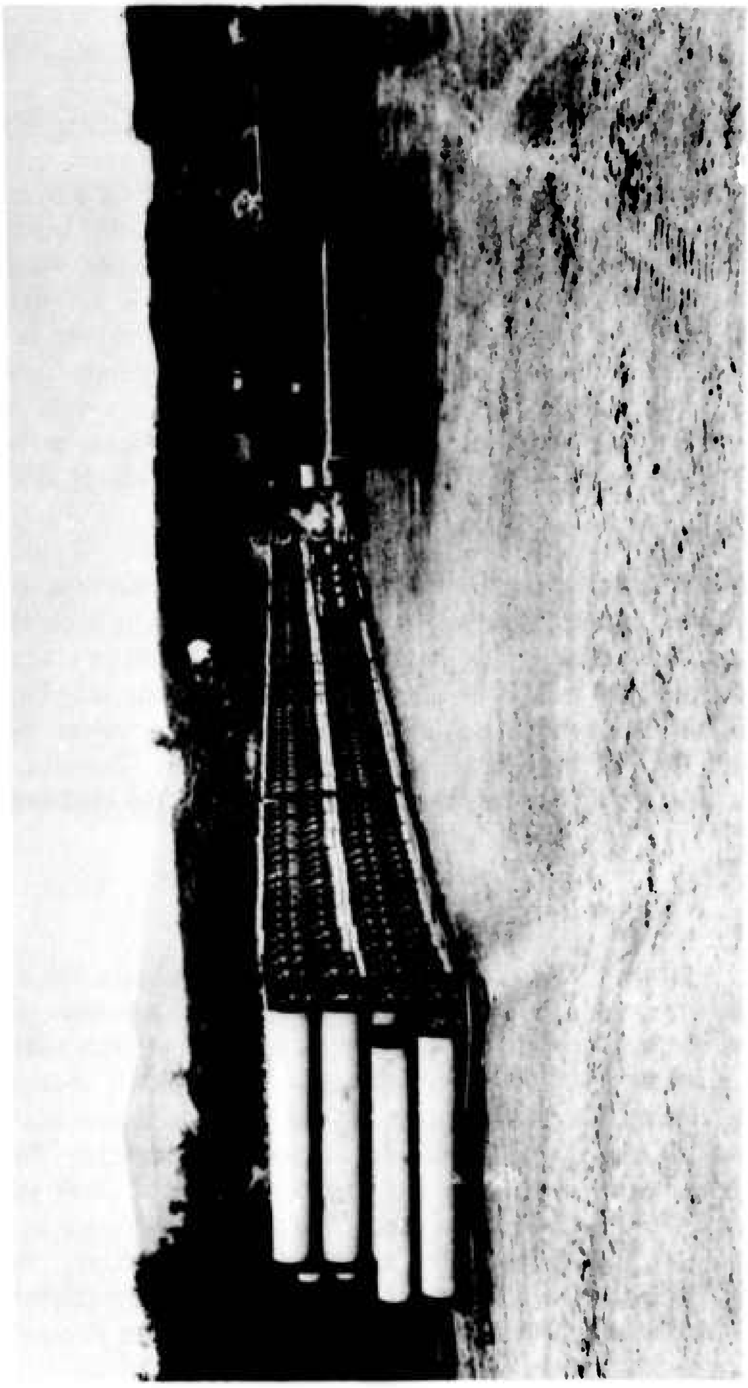

FIGURE B-3. Typical Forward Dump Storage Area.

fully exposed units, except for the top, west round. The high temperature of this unit can only be moderated by conduction. Since the maximum temperature of a single unit occurs at about 1600 hours daily, it can be assumed that if any unit in the stack approaches the single round exposure temperature profile, it will be the top, west corner unit.

## North-South Orientation

The above assumption is made on the premise that the stack is oriented with the longitudinal axis of the ordnance pointing directly north and south. If the stack was placed in an east-west orientation, the morning rays of the sun would hit the ends of the shipping containers, not the side. Since the surface area per unit would be so small, there would not be a large enough quantity of heat available to penetrate into the containers to start the temperature rise necesary for maximum possible exposure. The only time during the whole day when a normal exposure would occur would be at solar noon when the top row was subjected to the maximum possible heat flux. However, the normal exposure would be cut down progressively as the sun's position changed until sundown.

More should be said about the effect of container to container conduction. The usual configuration of a missile inside of its shipping container is such that it is almost completely surrounded by dead air. It is true that solar irradiation will cause thermal siphon to move the air, but even this effect is not as efficient at removing heat from the container wall as the conduction of heat through the metal of one shipping container to that of the one beneath or next to the hot unit. Therefore, the container metal would preferentially receive the excess heat instead of the enclosed missiles.

## Ground Contact

The missile will tend to reach more extreme temperatures for a given situation if it is in contact with the ground instead of being elevated from contact with it. Some of the more obvious reasons for this are as follows: (1) the reflection from the earth as a whole is about 50% of the sun's energy that strikes it. For desert sand, the reflectivity is even higher. (2) The velocity of the wind decreases nearer the surface. (3) The conductivity of dry dirt is about the same as an insulator. Soil temperatures as high as 160°F have been measured in the first 0.125 inch of earth surface; however, 2-6 inches below the surface, the soil is about the same temperature as the average air temperature. Only 12 feet below the surface at China Lake, the year round temperature is 70±5°F, with the maximum seasonal temperature shifted three months. In Japan, only 26 feet below the surface, no temperature change is measured.

Due to the above, the unit sitting on the ground receives reflected radiation from the ground, cannot give off heat by conduction quickly to the soil, and is not as apt to be cooled by the prevailing breeze.

## Geographic Location

It is not generally recognized that all field exposure is not equally conducive to the chance of occurrence of maximum, or extreme, thermal exposure. In most people's minds the desert, for example, is either the man-killing place they endured when driving from coast to coast during last summer's vacation, or the shifting hot sand dunes of the Sahara Desert of the "late-late show."

The facts are more apparent to the personnel of NWC since it is located in the Mojave Desert. The desert is generally less severe, during the summer season, as the altitude increases. In the great depressions in the desert surface, or valleys ringed with mountains (for example Death Valley), extreme temperatures are experienced; however, some desert mountain areas and high plateaus are very comfortable in the summer. (It is interesting to note that the high temperature of 134°F ascribed to Death Valley has only been reported one time.) Therefore, it may be shortsighted to design military, or even civilian equipment, to the worldwide extreme.

The other major error in understanding is caused by the reality of human comfort. A summer day in humid Washington D.C. can be much more severe than a higher temperature dry day at China Lake, in the context of human comfort. However, the ordnance does not transpire, nor generate internal heat. No matter what the amount of moisture in the air, the unit is concerned only with the air temperature, solar radiation excepted. The lack of understanding of this has led many World War II ex-GI's now in the military-industrial complex to earnestly state that the South Pacific is as hot as any place on earth. In the human context this may be true; in the context of ordnance it is not.

In summary, it must be stated that the values given in this report can be considered conservative in light of the customary military use of the air-launched tactical missile.

## Forcing Functions

A word should be said about the importance of the various factors that contribute to the overall heating, or cooling, of exposed ordnance. In the past, investigators have tried to predict the importance of the various meteorological and geological heat sources and, in most cases, have not been too successful.

The most important source of heat, and the only one that leads directly to the extreme hot temperatures, is direct radiation from the sun. Even so, for the maximum heating rates necessary to yield the higher ordnance temperatures, all the heat sources must be considered. The second most important source is reflected radiation. This is usually a reflection of direct sunlight off a towering cloud bank sitting on a line of hills or mountains surrounding the valley in which the ordnance is exposed. The other forcing functions have little influence in an active sense on the high ordnance temperature situation. The most commonly mentioned of the other heat sources is outside air temperature and the wind velocity. Ground reflected radiation, geologic heat and reflected radiation from other bodies have also been mentioned, but not much can or has been done with these inputs. Again, it must be stressed that only direct and reflected radiation can lead to an ordnance temperature greater than that of the outside air. Therefore, all other situations can only modify the radiation-induced situation. For example, if the maximum radiation possible for the latitude is exhibited with plenty of focused reradiation, and a brisk wind is blowing, then the ordnance skin will not show temperatures much above that of the moving air. As a rule of thumb, there will not be a maximum ordnance temperature situation demonstrated if the wind velocity is above 5 knots. (Also, there cannot be a spasmodic cloudy sky condition that at times blocks the sun from the ordnance.) For these reasons, the general meteorological-calculated approach to the daily profile of ordnance temperatures has not been successful.

## PROBABILITY OF DUMP STORAGE

Another facet that needs recognition is that the stockpile-to-target life of a weapon is such that it is not dump stored for extended periods of time. In the case of even conventional freefall weapons, the rate of expenditure in a use situation is such that they do not remain in the Naval magazine for any length of time. If they do, then the use rate is down and the volume of that type ordnance is such that they are placed in covered storage.

The chance of any given weapon, or the entire fleet purchase of units, being exposed to a maximum dump storage situation must also be investigated. If the supposition that the unit life is as much as 3% dump storage, then this 3% value must be interpreted in the cyclic context. Since the majority of wars have been fought in the temporate and tropic zones of the earth's surface, this situation in all probability will remain the case. The 365-day year is an occurring cyclic relationship. On the earth's surface, there is only a limited number of places where the ocean or other large body of water does not influence the climate. Of the remainder, not many are wind free.

### Example

Now an attempt will be made to loosely join all the factors together. Three percent of a 365-day year is roughly 11 days. If the logistical pressure was so great that the unit was indeed dump stored at all, it would be expended before the next yearly cycle came around. Therefore, only one 11-day exposure is recognized. Now the unit must be dump stored in a pure desert situation, in an area not under a marine influence. This eliminates all Naval usage, and all but helicopter borne Marine and Army usage. Now, for the land Army storage situation, the chances of a conflict taking place in the hot portion of the year, if indeed it is to be fought in the desert, can be related to the months of June, July, and August. Granted, portions of some May and September months are fairly warm, other portions of some June, July, and August months are cool. Therefore, only one-fourth of a yearly cycle is assumed to provide the situation in which values as herein stated could be experienced.

If a shipment of 100 weapons is used as the quantity that is dump stored, the two areas where this would take place are a front line sub-port airfield or a Naval magazine. The method used to stack weapons this size is shown in photographs taken at Da Nang in 1965. Notice in Figure B-3 that ordnance is stacked so that it can be retrieved from either end of the pile. Also notice that the height of stack is four high for the Zuni LAU-10 launcher. Discussions with magazine personnel indicate that for rough ground the limit is three-five units high if the shipping container is as stable as that for most tactical missiles. In the Naval magazine, the stack height is dependent on the reach of the forklift. The ground is usually covered with asphalt and is not irregular.

Given the "Da Nang" situation, the 100 rounds would be stacked four high in a single row. Therefore, only 25 of the 100 would be exposed to any appreciable solar radiation. The most extreme situation would seem to be that the pile was oriented with the weapons' longitudinal axis north-south. Then, only one out of the 100 units would have a chance of being subjected to the total heat load.

In summary, if there is only a 3% chance of any dump storage, one-fourth of a year cycle capable of full exposure, only one of 100 in a stack capable of receiving maximum solar radiation for enough of a diurnal cycle to reach maximums, then

$$0.03 \times 0.25 \times 0.01 = 0.000075$$

or

0.0075% chance of exposure of any one
weapon ***used in the pure inland desert.***

This would seem to indicate that the dump storage situation has been overemphasized.

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## Appendix C
## THE USE OF SILICA FOR INERT MOTOR GRAIN SIMULANT

Special casting of an inert case-bonded rocket motor presents many problems. The first is time; it takes weeks to schedule, fabricate, pour, cure, and deliver a single motor. The second is cost; to place thermocouples in an amorphous mass while casting a motor is difficult. Precision placement usually cannot be accomplished. To circumvent these problems, it was decided to try and find a propellant simulant. Thermal diffusivity was singled out as the single most important property in a simulant. If the thermal diffusivity of the simulant were equal to that of the propellant, then measured motor responses would be equivalent for both propellant and simulant.

Thermal diffusivity ($\alpha$) is equal to the thermal conductivity (k) divided by the product of the density ($\rho$) and the specific heat (c) or:

$$\alpha = \frac{k}{\rho c}$$

For example, the thermal diffusivity of the polybutadiene propellant family in general, and RDS-507 PBCT specifically, is as follows:

$$k = 0.20 \text{ Btu} \times \text{ft/hr} \times \text{ft}^2 \times {}^\circ\text{F}$$
$$\rho = 108.8 \text{ lb/ft}^3$$
$$c = 0.29 \text{ Btu/lb} \times {}^\circ\text{F}$$

Therefore, the thermal diffusivity ($\alpha$) is as follows:

$$\alpha = \frac{0.2}{108.8 \times 0.29}$$

$$= 2.53 \times 10^{-4} \frac{\text{in}^2}{\text{sec}} \text{ or } 1.63 \times 10^{-3} \text{ cm}^2/\text{s}$$

The above values for the physical constants were obtained from data contained in the CPIA M-2 Propellant Manual, and data measured by Jack Pakulak at NWC.

The most workable, easily obtained, and least expensive simulant turned out to be desert silica blow sand from the Propulsion Development Department's "back yard" here at NWC.

The physical constants of the silica sand are as follows:

$k = 0.19$ Btu × ft/hr × ft$^2$ × °F
$\rho = 103$ lb/ft$^3$
$c = 0.18$ Btu/lb × °F at 100°F

$$0.04 \frac{ft^2}{hr} = \frac{in^2}{sec}$$

Therefore, the thermal diffusivity ($\alpha$) is as follows:

$$\alpha = \frac{k}{\rho c} = \frac{0.19}{0.18 \times 103} \times 0.04$$

$$= 4.1 \times 10^{-4} \frac{in^2}{sec} \text{ or } 2.50 \times 10^{-3} \text{ cm}^2/\text{s}$$

The above values for the physical constants were obtained from data found on pages 451 and 461 of the McGraw-Hill textbook, *Heat Transfer*, by McAdams, 3rd Edition, and data measured by Billy D. Martin of NWC measuring the sand used in the simulation.

These data will also allow the use of thoroughly dried silica sand as a propellant simulant for other types of motors. The specific heat value for silica varies linearly along the following matrix:

$c = 0.1667$ at 32°F
$c = 0.2061$ at 212°F
$c = 0.2315$ at 392°F

The density of silica sand can be varied through paricle size manipulation. The $\rho$ value will vary from 87 lb/ft$^3$ to a normal value of 102 lb/ft$^3$ to a dense maximum of 156 lb/ft$^3$. The density can therefore be varied at will to fit the necessary $\rho$ value.

The following table was exerpted from *Langes Handbook of Chemistry*, 10th Edition, and the *Chemical Engineers Handbook* by J. H. Perry, 2nd Edition.

TABLE C-1. Density of Sand.

| Sand | Density, lb/ft$^3$ |
|---|---|
| Dry, coarse | 87-93.5 |
| Dry, fine | 87-103 |
| Moist, fine | 118-128 |
| Sandstone | 137-156 |

Table C-2 provides some typical values of propellant and explosive mixtures. As seen in Table C-2, an approximation of $3 \times 10^{-4}$ $in^2/s$ can generally be used for the thermal diffusivity of propellants and explosives. Silica sand at $4 \times 10^{-4}$ $in^2/s$, then, is a reasonable inert simulant for the thermal response of rocket motors and warheads.

TABLE C-2. Some Propellant Characteristics.

| Family | k, $\frac{Btu \times ft}{ft^2 \times hr \times {}^\circ F}$ | $\frac{lb}{ft^3}$ | c, $\frac{Btu}{lb \times {}^\circ F}$ | $\frac{in^2}{sec}$ |
|---|---|---|---|---|
| HBX-1 explosives | | | | $3.56 \times 10^{-4}$ |
| Inhibitor | | | | $2.0 \times 10^{-4}$ |
| Double base propellants | 0.12 | 104 | | $1.4 \times 10^{-4}$ |
| C55A PBCT | 0.19 | 111 | 0.3 | $2.28 \times 10^{-4}$ |
| Polyurethanes | 0.25 | 111 | 0.29 | |
| Polysulfides | 0.15-0.3 | 105-111 | 0.26 | |

This method of thermal analysis was suggested by Warren K. Smith of NWC (retired).

The dry blow sand has been imperically shown to be equivalent in thermal response in field trials over the last decade at NWC. A set of graphical comparisons of case-bonded rocket motor response is available in NWC TP 5365, *Measurement of Missile Thermal Response During Captive Flight at High Altitudes*, Part 1, *Program Summary and Results* (AD 909245) and Part 2, *Detailed Description of Equipment and Results* (AD 909394).

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## Appendix D
## STATISTICAL SAMPLE

The sheer volume of data available made the data reduction task enormous. Initially, every data point obtained was to be used to develop specific trends and geographic identifiers for at least a single year cycle. However, after each geographic location of interest had been characterized, the search continued for an alternate method, using a data sampling technique, that would reduce the volume of the reduction job, hopefully, with negligible induced errors. It must be remembered that each cumulative probability, or chance of occurrence, plot for each thermocouple location is an integration of between 4,380 and 8,760 data points (depending on the recorder speed or return cycle). For example, from only one 24-channel potentiometer stripchart recorder at one location, between 150,000 and 210,000 data points would be accrued. During the majority of the dump storage and thermal environment measurement program, there were between 23 and 31 of these machines running continuously.

The key to reducing the data reduction workload was the fact that only a single data point per channel was taken every so often (i.e., at 1 hour, 1.1 hours, or 2 hours depending on the location). It was reasoned that even "continuous" time-temperature recording is, in actuality, only the codified chance sampling of a possibly non-continuous time-temperature history. The non-continuous, or non-predictability, of the next temperature is especially evident in the response to the sun, wind, rain, and air of a thin wall shipping container exposed in the tropics. There are many times when common sense would dictate that the container wall must be hotter than the air inside, since the air inside continues to gain energy. However, at the time the recorder was ready to sample the container wall temperature, a small "buttermilk" cloud could have shielded the container from the sun and a zepher might have cooled the skin temperature below that of the enclosed air. This is exactly the type of phenomena that makes an hour to hour, or day to day thermal response prediction of ordnance or material from meteorological data next to impossible. (This is one of the factors that leads the author to prefer the statistical rather than specific treatment of the data.)

If, in fact, our continuous measurements are only samples, then it is quite probable that a lesser number of data points would yield the same shape and magnitude of cumulative probability curve for a given thermocouple, location, and time cycle. It was found that the statistician had long ago solved this problem for us. The theory of random numbers has demonstrated that a certain confidence can be had in the correctness of your approximation of "truth" if you incorporate a given number of data points from the total group (or cycle of interest). If you only have one measurement, you can definitely say that it is possible to experience that measured value. But, it now becomes a problem to indicate how often that value will be valid and how often it will be in error. Of course, the more measured values you have, the more confident you become as to the correctness of the "truth". The pitfall here is, what if all the measured values of temperature were taken in December on the desert? If the weapon works only during December on the desert, the "truth" should be known to a good certainty. However, if the weapon must function all year in the desert, then the "truth" is not so well known after all. Thus, the cardinal responsibility of each investigator, or user of any data is to be certain that he at least understands (1) the use context of the data and, (2) hopefully, a bit about the yearly cycle of interest for any weapon, material, or even consumer goods. The yearly cycle is usually in no way tied to a particular geographical area; in most cases, the "extreme" exposures do not impinge on any given item for even a single cycle.

It was seen from the work done with statistics by the reliability discipline, that good results could be obtained, in our context, with very small samples of data ***if they were, in fact, selected at ramdom*** from the cycle of interest. Therefore, since the reliability types consider 300 data points to be sufficient, it was decided that about 1200 would also be adequate or, in statistical terms, "statistically infinite".

The number of data points is, it must be stated, somewhat arbitrary. The author felt that 60 days should be picked from any given year at random. These 60 days would then be used for an accumulation of their integral 24-hour cycle of sampled data points. This arbitrary decision was made fully realizing that each daily cycle of temperature responses of ordnance in the tropic is not identical and, in fact, may be only somewhat similar in an overall sense when compared with the nearly sinusoidal precise responses of like units in the pure desert domain. It was also seen, however, that the reduction of 60 days worth of data in 24-hour groups would reduce the work by at least a factor of 6.

Being a novice in the art of statistics, the author then decided that perhaps he should not lay all the bet on the above approach. It was reasoned that the above would give the general shape of the cumulative probability curve, but what were the chances of having the extreme end points for the total data sample included? Therefore, the data were again scanned for the cycle's maximum and minimum data points. Since there are usually no more than 5-10 of these in the extreme of interest, it didn't consume too much time and gave more assurance that the cumulative probability curves not only had the correct shape but, hopefully, the correct end points for the cycle of interest.

The year was split into its random parts by reference to a "Table of Random Numbers". It was necessary to modify this table for only 366 numbers. The first 60 of the 366 numbers were recognized and referenced to the Julian calendar with its numbered dates. The result is shown below.

| Serial | Number | Date | Serial | Number | Date |
|---|---|---|---|---|---|
| 1 | 13 | 13 Jan | 36 | 311 | 7 Nov |
| 2 | 85 | 26 Mar | 37 | 293 | 20 Oct |
| 3 | 365 | 30 Dec | 38 | 166 | 15 Jun |
| 4 | 34 | 3 Feb | 39 | 360 | 26 Dec |
| 5 | 205 | 24 Jul | 40 | 247 | 4 Sep |
| 6 | 116 | 26 Apr | 41 | 354 | 20 Dec |
| 7 | 157 | 6 Jun | 42 | 102 | 12 Apr |
| 8 | 359 | 25 Dec | 43 | 232 | 20 Aug |
| 9 | 30 | 30 Jan | 44 | 276 | 3 Oct |
| 10 | 226 | 14 Aug | 45 | 295 | ~~22 Oct~~ |
| 11 | 335 | 1 Dec | 46 | 195 | 14 Jul |
| 12 | 221 | 9 Aug | 47 | 269 | 26 Sep |
| 13 | 117 | 27 Apr | 48 | 107 | 17 Apr |
| 14 | 184 | 3 Jul | 49 | 98 | 8 Apr |
| 15 | 109 | 19 Apr | 50 | 178 | ~~27 Jun~~ |
| 16 | 220 | 8 Aug | 51 | 88 | 29 Mar |
| 17 | 152 | 1 Jun | 52 | 10 | 10 Jan |
| 18 | 178 | 27 Jun | 53 | 60 | 1 Mar |
| 19 | 20 | 20 Jan | 54 | 76 | 15 Mar |
| 20 | 303 | 30 Oct | 55 | 204 | 23 Jul |
| 21 | 49 | 18 Feb | 56 | 342 | 8 Dec |
| 22 | 52 | 21 Feb | 57 | 263 | 20 Sep |
| 23 | 226 | ~~14 Aug~~ | 58 | 159 | 8 Jun |
| 24 | 186 | 5 Jul | 59 | 125 | 5 May |
| 25 | 198 | 17 Jul | 60 | 40 | 9 Feb |
| 26 | 80 | 21 Mar | 61 | 279 | 6 Oct |
| 27 | 114 | 24 Apr | 62 | 41 | 10 Feb |
| 28 | 281 | 8 Oct | 63 | 19 | 19 Jan |
| 29 | 110 | 20 Apr | 64 | 209 | 28 Jul |
| 30 | 199 | 18 Jul | | | |
| 31 | 241 | 29 Aug | | | |
| 32 | 95 | 5 Apr | | | |
| 33 | 121 | 1 May | | | |
| 34 | 295 | 22 Oct | | | |
| 35 | 13 | ~~13 Jan~~ | | | |

Notice that there were four reoccurring dates in the above 60 random selections (serials 23, 35, 45 and 50). These were arbitrarily discarded and the next random dates substituted. This is indicated by the strike-throughs in the table and the addition of serial 61, 62, 63, and 64 to the bottom of the table. When simplified into month-day order, the above becomes the following.

| Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 3 | 1 | 5 | 1 | 1 | 3 | 8 | 4 | 3 | 7 | 1 |
| 13 | 9 | 15 | 8 | 5 | 6 | 5 | 9 | 20 | 6 | | 8 |
| 9 | 10 | 21 | 12 | | 8 | 14 | 14 | 26 | 8 | | 20 |
| 20 | 16 | 26 | 17 | | 15 | 17 | 20 | | 20 | | 25 |
| 30 | 21 | 29 | 19 | | 27 | 18 | 29 | | 22 | | 26 |
| | | | 20 | | | 23 | | | 30 | | 30 |
| | | | 24 | | | 24 | | | | | |
| | | | 26 | | | 28 | | | | | |
| | | | 27 | | | | | | | | |

At first glance, the above table looks a little lopsided. However, if you re-group the numbers into seasons, then the grouping looks like it just might, in fact, be quite representative of the yearly cycle of exposure. It must be remembered that the summer is extreme only in desert and maybe temporate climate areas: it is of next to academic interest for material used in the arctic, for example. Winter is of importance in cold climates, and spring and fall seem to yield the thermal extremes in the tropics. (This is because the rainy season cancels out "summer".)

The re-grouping of number of days per three-month season of the sample reveals the following:

| Spring | Summer | Fall | Winter |
|---|---|---|---|
| 16 | 18 | 10 | 16 |

Notice that if there is any appreciable bias, it is toward summer, with the spring-fall time span very well represented. Therefore, for the author's uses (i.e., tropics and desert exposure predominantly), the sample was a pleasant surprise.

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| MAI (1) | MMJ (1) | Technical Library (1) |
| MAK (1) | MMN (1) | |

12 Oklahoma City Air Materiel Area, Tinker Air Force Base

| | |
|---|---|
| DSY (1) | MMC (1) |
| DSYS (1) | MME (1) |
| MAG (1) | MMEC (1) |
| MAI (1) | MMN (1) |
| MAK (1) | MMS (1) |
| MM (1) | OC-ALC (1) |

11 Sacramento Air Materiel Area, McClellan Air Force Base

| | |
|---|---|
| MM (1) | MMH (1) |
| MMA (1) | MMJ (1) |
| MMB (1) | MMN (1) |
| MMC (1) | MMS (1) |
| MME (1) | Technical Library (1) |
| MMEM, J. Phillips (1) | |

12 Warner Robins Air Materiel Area, Robins Air Force Base

| | |
|---|---|
| DSD (1) | MMB (1) |
| MA (1) | MME (1) |
| MAB (1) | MMH (1) |
| MAI (1) | MMN (1) |
| MM (1) | MMS (1) |
| MMA (1) | Technical Library (1) |

7 Strategic Air Command, Offutt Air Force Base

DO (1)
DR (1)
LG (1)
LGM (1)
LGS (1)
LGW (1)
Technical Library (1)

1 Air Force Avionics Laboratory, Wright-Patterson Air Force Base

4 Air Force Cambridge Research Laboratories, Laurence G. Hanscom Field
- Code LKI
  - I. I. Gringorten (1)
  - P. Tattleman (2)
- Technical Library (1)

16 Air Force Civil Engineering Center, Tyndall Air Force Base

| | | | |
|---|---|---|---|
| CA (1) | DO (1) | EAO (1) | EV (1) |
| DE (1) | DOE (1) | EM (1) | EVC (1) |
| DEE (1) | DOL (1) | EMR (1) | EVP (1) |
| DES (1) | EA (1) | EMS (1) | Technical Library (1) |

3 Air Force Environmental Technical Applications Center
- Technical Director (1)
- O. E. Richards (1)
- Technical Library (1)

1 Air Force Office of Scientific Research (Dr. J. F. Masi)
1 Air Force Rocket Propulsion Laboratory, Edwards Air Force Base (Technical Director)
1 Air Force Rocket Propulsion Laboratory, Edwards Air Force Base (Plans and Programs Office)
1 Air Force Rocket Propulsion Laboratory, Edwards Air Force Base (W. H. Ebelke)
1 Air Force Rocket Propulsion Laboratory, Edwards Air Force Base (D. Ross)
1 Air Force Rocket Propulsion Laboratory, Edwards Air Force Base (C. W. Schnare)
1 Air Force Rocket Propulsion Laboratory, Edwards Air Force Base (Dr. Trout)
1 Air Force Rocket Propulsion Laboratory, Edwards Air Force Base (RKMA, L. Meyer)
1 Air Force Rocket Propulsion Laboratory, Edwards Air Force Base (Technical Library)

26 Armament Development and Test Center, Eglin Air Force Base

| | | |
|---|---|---|
| AFATL (1) | DLQ (1) | SDM (1) |
| DL (1) | DLW (1) | SDMT |
| DL1 (1) | SD (1) | Carley (1) |
| DLD (1) | SD102 (1) | Holcomb (1) |
| DLEF (1) | SD15 (1) | Volz (1) |
| DLG (1) | SD2 (1) | TGWC (1) |
| DLGZ (1) | SD23 (1) | TS (1) |
| DLJ (1) | SD3 (1) | TSG (1) |
| DLJF (1) | SD7 (1) | TSW (1) |
| DLM (1) | SD9 (1) | Technical Library (1) |

1 Nellis Air Force Base (Technical Library)

2 Rome Air Development Center, Griffiss Air Force Base
- Code RCRM (1)
- Technical Library (1)

38 Wright-Patterson Air Force Base
- Director of Flight Dynamics Laboratory (1)
- Head, Research and Technology Division (1)

| | | | |
|---|---|---|---|
| AE (1) | ENF (1) | SD5 (1) | YHT (1) |
| AEA (1) | ENS (1) | SD65 (1) | YM (1) |
| AER (1) | FEE (3) | YA (1) | YP (1) |
| ASD (1) | PP (1) | YF (1) | YPL (1) |
| ASZTI (1) | RTSAW (1) | YFL (1) | YPT (1) |
| ASZTM, Pember (1) | SD (1) | YFT (1) | YX (1) |
| EN (1) | SD25 (1) | YH (1) | YXL (1) |
| ENA (1) | SD26 (1) | YHL (1) | YXT (1) |
| ENE (1) | SD27 (1) | | |

7 Assistant Secretary of Defense
DIECO (1)
F. W. Myers (1)
J. A. Mittino (1)
Explosives Safety Board (3)
E. F. von Marbod (1)
12 Director of Defense Research and Engineering
AD(ET) G. R. Makepeace (1)
OAD(ET) R. Thorkildsen (1)
OAD(T) Col. B. Swett (2)
DD(T&E) Lt. Gen. Lotz (1)
AMRAD Committee (2)
Col. Poole (1)
AD(CS) Greinke (1)
Col. H. Strickland USA (1)
Capt. J. Bres USN (1)
Col. M. Weber USAF (1)
5 Defense Advanced Research Project Agency, Arlington
Technical Director (1)
Strategic Tech (1)
Tactical Tech (1)
Tech Assessments (1)
Technical Library (1)
2 Defense Documentation Center
10 Joint Chiefs of Staff
Chairmans Staff Group (1)
Director J-3 (1)
WWMCCS ADP (1)
Standards Branch (3)
Europe/Middle East/African Div (2)
Director J-4 (1)
Director J-5 (1)
3 Library of Congress
1 National Security Agency, Fort George G. Meade (Sgt. M. H. Schafer)
1 Aerojet-General Corporation, Azusa, CA (Technical Library)
3 Aerojet Liquid Rocket Co., Sacramento, CA (via AFPRO)
Bert Loehr (1)
Technical Library (2)
1 Allegany Ballistics Laboratory, Cumberland, MD (Technical Library)
2 Applied Physics Laboratory, Johns Hopkins University, Silver Spring, MD
Dr. D. W. Avery (1)
Technical Library (1)
1 ARINC Research Corporation, Santa Ana, CA
2 Bell Aerospace Textron, Buffalo, NY
Technical Library (1)
D. L. Kidd (1)
1 Booze Allen, Bethesda, MD
2 Chemical Propulsion Information Agency, Applied Physics Laboratory, Silver Spring, MD
Sid Solomon (1)
Technical Library (1)
1 Cushing Neveil Incorporated of California, Los Angeles, CA

2 Dayton T. Brown, Inc., Bohemia LI, NY
- Technical Library (1)
- F. Gerber (1)

2 General Dynamics, Pomona Division, Pomona, CA
- 6-42, H. B. Godwin (1)
- Technical Library (1)

1 Governors State University, Park Forest, IL (Dr. T. Andrews)

1 Hercules, Inc., Bacchus Works, Magna, UT

2 Hughes Aircraft Company, Canoga Park, CA
- C. Clapp (1)
- Technical Library (1)

2 Institute for Defense Analyses, Arlington, VA
- Dr. R. C. Oliver (1)
- Technical Library (1)

2 Institute of Environmental Sciences, Mt. Prospect, IL

1 Lockheed-California Company, Burbank, CA

2 Lockheed-Georgia Company, Marietta, GA
- Technical Library (1)
- E. H. Parker (1)

1 McDonnell Douglas Astronautics, Huntington Beach, CA

2 McDonnell Douglas Corporation, Long Beach, CA
- Pabst (1)
- Technical Library (1)

1 McDonnell Douglas Corporation, Santa Monica, CA

12 McDonnell Douglas Corporation, St. Louis, MO
- Aircraft Division, Technical Library (1)
- Harpoon Project Office (1)
- Missile Division Technical Library (1)
- J. Gubser (2)
- F-18 Program Engineering (1)
- A. S. Torgerson (1)
- B. Dighton (1)
- W. J. Stampley (1)
- J. P. Capellupo (1)
- L. W. Guenther (1)
- GIDEP Rep. (1)

1 Marquardt Corporation, Van Nuys, CA

2 Martin Company, Denver, CO
- Reliability (1)
- Technical Library (1)

4 Martin-Marietta Corporation, Orlando, FL
- Engineering Library MP-30 (2)
- Code 143, J. A. Roy (1)
- Technical Library (1)

2 North American Rockwell Corporation, Columbus, OH
- Engineering Development Laboratories (1)
- Technical Library (1)

2 Philco-Ford Corporation, Newport Beach, CA
- R. Elston (1)
- Technical Library (1)

2 Raytheon Company, Waltham, MA
- Missile Systems (1)
- Technical Library (1)

2 Rocketdyne, Canoga Park, CA
- A. Kohl (1)
- Technical Library (1)

1 Rocketdyne, McGregor, TX (Technical Library)
1 Rockwell International Corporation, Los Angeles, CA (Technical Library)
1 Rohm and Haas Company, Huntsville, AL
3 Sandia Corporation, Albuquerque, NM
    Section 1541, Jerry T. Foley (2)
    Section 1543, Mark B. Gens (1)
3 Sandia Corporation, Livermore, CA
    C. A. Scott (2)
    Technical Library (1)
4 Texas Instruments, Inc., Dallas, TX
    B. Hatfield (1)
    J. Leslie (1)
    P. Watts, MS 296 (1)
    Technical Library (1)
5 The Boeing Company, Seattle, WA
    S. Barber, MS 8609 (1)
    J. P. Stebbins (1)
    F. P. Stevens, Standards Control (1)
    J. Stuart, MS 47-06 (1)
    Technical Library (1)
1 Thiokol Chemical Corporation, Bristol, PA
1 Thiokol Chemical Corporation, Wasatch Division, Brigham City, UT
1 United Technologies, Chemical Systems Division, Sunnyvale, CA
2 Value Engineering Company, Alexandria, VA
    J. Toomey (1)
    Oxnard Plant (1)
4 Vought, Incorporated, Systems Division, Dallas, TX
    R. N. Hancock, Unit 2-53483 (2)
    C. T. Morrow, P. O. Box 6144 (1)
    Technical Library (1)