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NWC TP 5039
Part I

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

Part 1. Discussion and Results

by
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CHINA LAKE, CALIFORNIA ■ NOVEMBER 1972

ABSTRACT

Measurement sites were established at worldwide locations to obtain empirical data that could be used to more accurately predict the thermal environment of dump-stored ordnance. Data obtained from measurement sites in the desert and tropics on solid rocket motors are presented along with an analysis of the data. The data are presented in terms of cumulative probability, maximum-minimum daily temperatures, and in a few cases as diurnal cycles. Part 1 of the report contains a summary of the results and a discussion of the general philosophy regarding the work. Part 2 is a compilation of some of the NWC data runs, exact evidence from which Part 1 is drawn, and will be of interest to only the serious investigator. This effort is not the final word on the NWC investigation, only a sample of the vast information available from this source.

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H. G. Wilson . . . . Technical Director

FOREWORD

This report covers part of a continuing effort to determine the thermal environment of dump stored ordnance. Part 1 contains a summary of the results and Part 2 a sample of the raw data obtained by the Naval Weapons Center (NWC), China Lake, California. This work is sponsored by the Naval Air Systems Command under AirTask F 00-311-008.

Warren W. Oshel of NWC has reviewed this report for technical accuracy.

Released by
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Quality Assurance Division
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Under authority of
G. W. LEONARD, *Head*
Propulsion Development Department

ACKNOWLEDGEMENT

A major portion of the credit for the success of this report is due to the efforts of Mr. Billy D. Martin who developed instrumentation repair and failure prediction methods that kept recorder breakdown at a minimum during the long periods of unattended operation. Also appreciated is the effort of Mr. Rolland J. Morey for his assistance in editing and presenting the material in this report.

The effort of many organizations has been, and is paramount in an undertaking of this type. The efforts of the Mine and Torpedo Division of the Naval Magazine, Subic Bay; the U.S. Army Tropic Test Center of TECOM; and the Instrumentation Branch at NWC are only the major contributors of the technician talent necessary to assure that the data continues to be provided.

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INTRODUCTION

Dump storage is possibly the most misunderstood event in the stockpile-to-target sequence of any weapon system. This has resulted in unrealistic design and qualification requirements that have added significant expenditures of manhours and money to the development of weapon systems. (References 1, 2, and 3 give a description of each event in the stockpile-to-target sequence.) As part of the environmental criteria determination effort at the Naval Weapons Center (NWC), China Lake, Calif., work is being conducted to obtain empirical data that can be used to more accurately predict the thermal environment of dump-stored ordnance.

The work reported herein covers data obtained from measurement sites in the desert and tropics on solid rocket motors.

BACKGROUND

In 1959, NWC recognized the need for a concerted attack on the problem of developing thermal criteria for future weapon systems. However, like many technical problems in the early stages of development, this one was prone to many false starts. In 1963 the decision was made to organize a task force to investigate the complete environmental criteria determination problem. In 1964 the Quality Assurance Division at NWC assembled the nucleus of personnel who have continued to study these problems. Due to a lack of sufficient qualified personnel and funds with which to attack the overall problem, it was necessary to analyze the problem to determine the most critical areas and those 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 to 90% of the life of an item will be spent in transportation and storage. Based upon these facts, it was decided to concentrate the effort on a study of the thermal regimes in the areas of transportation and storage on a worldwide basis.

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 are by far most prevalent. In realization of this fact, a study has been conducted which presently has resulted in publication of a series of technical reports on "Storage Temperatures of Explosive Hazard Magazines" (Ref. 4 through 9). In addition a report containing a summary of all results obtained thus far has been published (Ref. 10).

Although covered and igloo storage of Naval material are most prevalent, dump storage generally results in the more extreme thermal exposure situations. (A discussion of the dump storage situation is given in the Appendix A.) Since no data were available on dump storage, instrumented storage dumps had to be established at representative locations on a worldwide basis so that statistical data could be derived on a variety of ordnance items. Again within the constraints of manpower and money, a system of measurement sites was developed. The first site to be developed was in the Mojave Desert at China Lake. The first measurements were started on Naval 5-inch projectiles and shore bombardment rockets in May of 1964. This first site only returned 16 channels of information. It has been expanded and refined to the complex shown in Fig. 1 with a present day return of about 250 channels of information on a continuous time-temperature basis.

The second measurement site was established to sample the cold exposure situation. The location selected was in the Sierra Nevada mountains at the Marine Corps Mountain Warfare Training Center. This measurement site is located 25 miles from Bridgeport, California at an altitude of 8,000 feet. Measurements were started in November 1965. Figure 2 shows the modest scale that this site has assumed. The Marine Corps closed down the base in 1968, but the caretaker is cooperative and measurements are still being returned for this program. Although the temperatures measured here are not indicative of what can be expected in the Arctic, they are representative of temperate zone cold exposure where the majority of cold weather warfare situations are experienced.

The third site was developed to obtain information on tropical exposure. It was requested by weapon project personnel that this measurement site be established at the Naval Base, Subic Bay, Republic of the Philippines. This was done in September 1966. This was as close to Viet Nam as was deemed advisable where measurements could be taken without interfering with the US Combat effort. Even so, it soon became very apparent that the size and scope of this facility must remain limited. Although the Naval Magazine personnel were extremely positive in the support of this effort, their work load required that they work a 12-hour day, 6 1/2 day work week in addition to supporting this task. Figure 3 shows this measurement site. It is returning 53 channels of information.

It became clear when the three major climatological situations were covered that the low temperature extreme situation should be considered. Therefore, cold weather measurement sites were established at Fort Greely and Fort Richardson, Alaska in September 1967. Fort Greely is in the general area of Fairbanks, Alaska and is the site of the U.S. Army Test and Evaluation Command, Arctic Test Board. It seems to be as typical of Arctic exposure as is available in the DOD system. Fort Richardson, on the other hand, is located at Anchorage, Alaska. This is more indicative of the sub-Arctic exposure to which sophisticated Navy weapons may be subjected if dump-stored at points of deep water, year round, open ports.

FIG. 1. NWC Measurement Site.

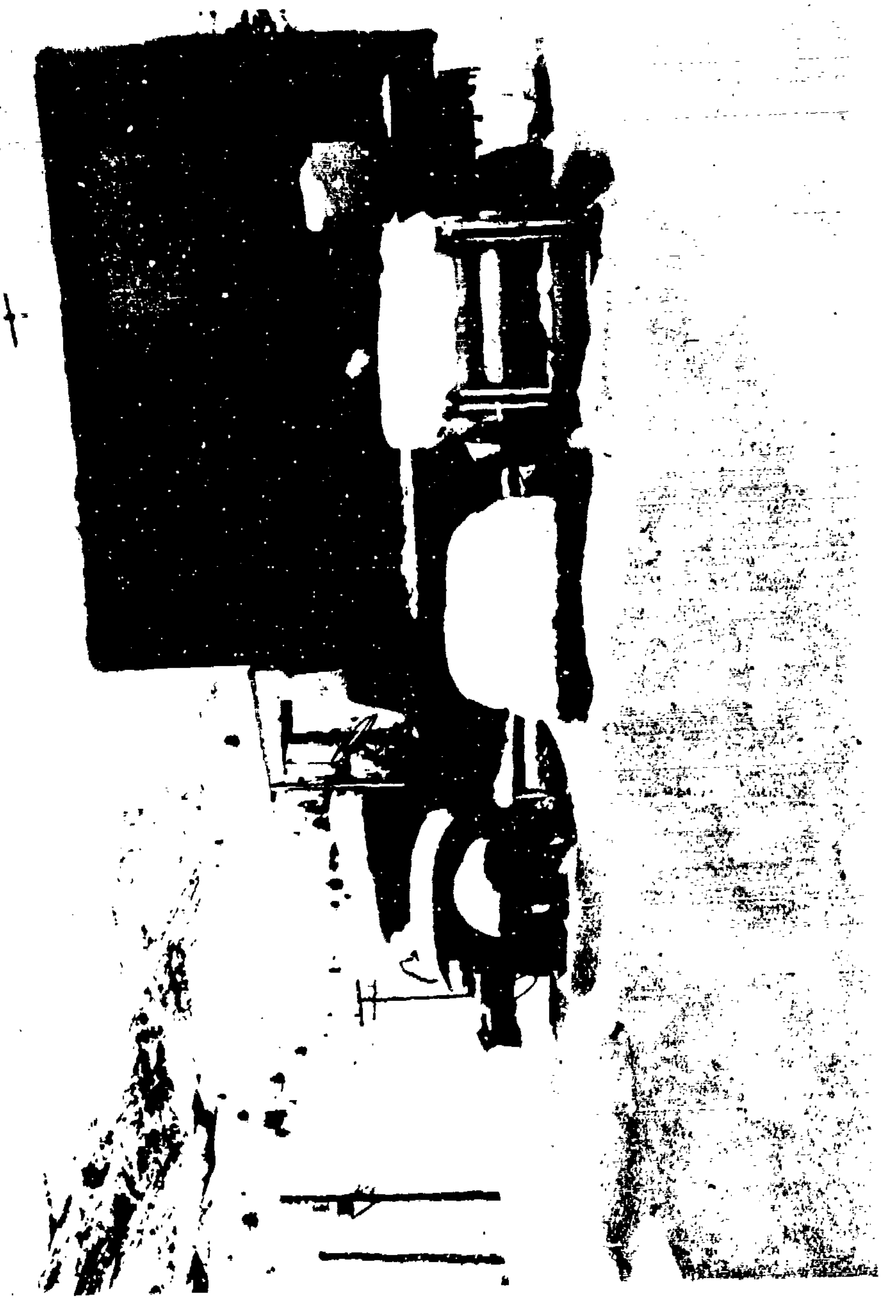


FIG. 2. Bridgeport Measurement Site.

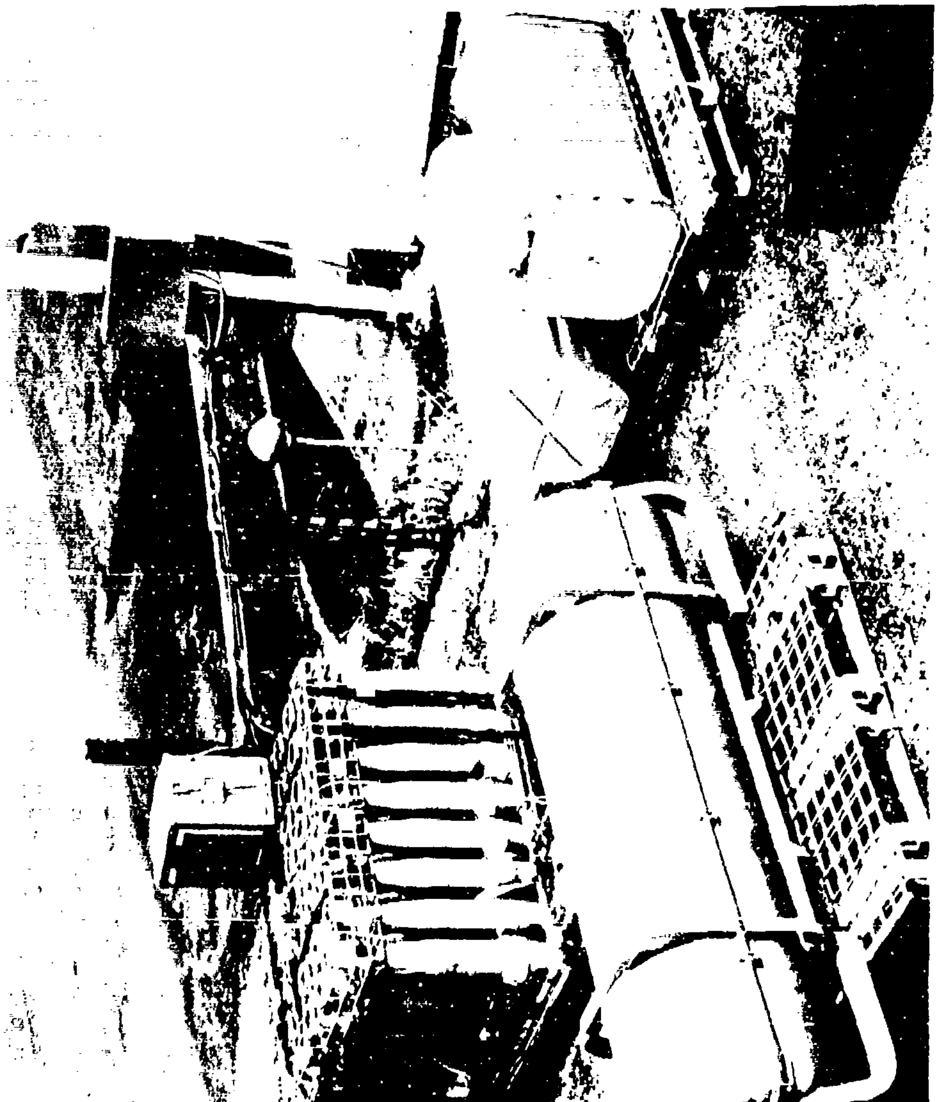


FIG. 3. Subic Bay Measurement Site.

Figure 4 shows the site at Fort Greely while Fig. 5 shows the site at Fort Richardson. (Fort Richardson is for all intents and purposes an extension of the U.S. Air Force Elmendorf Air Force Base.) The Fort Greely site is returning 36 channels of information while the Fort Richardson site returns 60 channels. The Fort Richardson site will be expanded to about 100 channels of information in the near future. The plan for retaining the three cold weather sites was to have information on the low-snow-cover Arctic, high-snow-cover sub-Arctic, and the high-snow-cover more moderately cold Sierra. Many, if not most, tactical weapons will have to function when fired in all three situations, but will never be stored in other than the latter two situations.

The sixth site established was another tropical site that could be expanded. Figure 6 shows the site at Fort Clayton in the Panama Canal Zone. The Fort Clayton site is ideal in that the time zone is the same as Washington, D.C. and the U.S. Army Tropic Test Center is located there. Fort Clayton is at about 9° North latitude while the Naval Magazine, Subic Bay site is at about 14° North latitude. Therefore, Fort Clayton is closer to the equator than Subic Bay. A comparison of the data from both sites indicates that there is very little difference in ordnance temperatures recorded. The Fort Clayton site was established in January 1968 and is returning on the order of 70 to 72 channels of data. As the need for more tropical measurements arise, the units will be exposed at Fort Clayton, not at Subic Bay. It is the intention to keep the Subic Bay measurement site small, and use it only for items that for some reason or another should not be placed at Fort Clayton.

The opportunity was given to NWC to participate in the establishment of a tropical environmental site in central Thailand. When the governments of the United States and Thailand agreed on the working relationships, the U.S. Army Natick Laboratories, Earth Science Division were given responsibility for project TREND (TRopical ENvironmental Determination). As per the long standing working relationship between NWC and Natick Laboratories, the Environmental Criteria Determination Section was invited to install an NWC thermal standard at the Sukirat measurement site, 35 kilometers south of the Thai Air Force Base at Korat. This site, on the escarpment of the Korat Plateau, is representative of the typical three tier canopy deciduous rain forest. The site could not have any military hardware located therein because of the Thai-American agreements. This was one of the motivating forces behind the development of the NWC Thermal Standard. (A description of the NWC Thermal Standard, its development and use is presented in Ref. 11 and 12.) Figure 7 shows the NWC Thermal Standard and recorder next to the U.S. Army Natick Laboratories meteorological measurement site in Thailand. The measurements at this site were started in February 1968.

Since NWC must depend on military and foreign personnel to be alerted to recorder malfunction between spasmodic visits to each site, some data have been lost. On the whole, however, the concept of "do

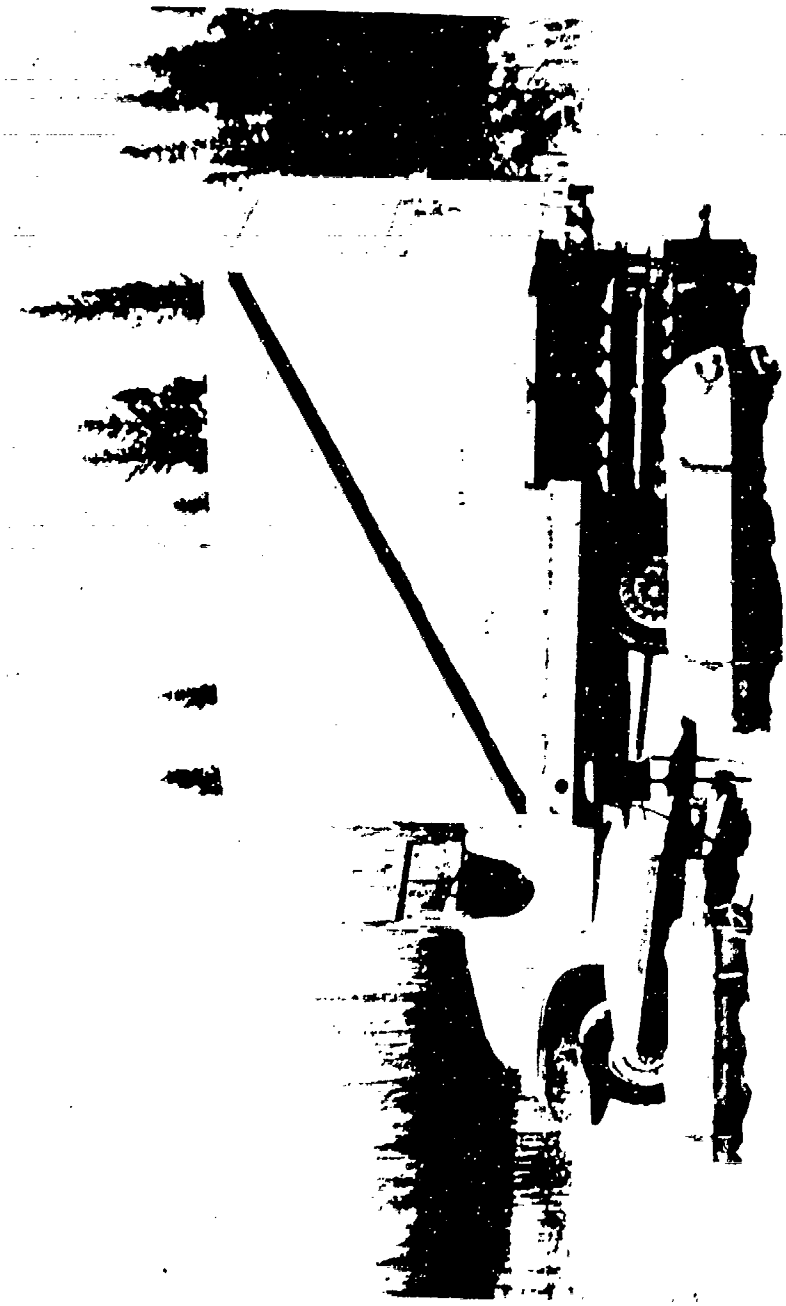


FIG. 4. Fort Greely Measurement Site.

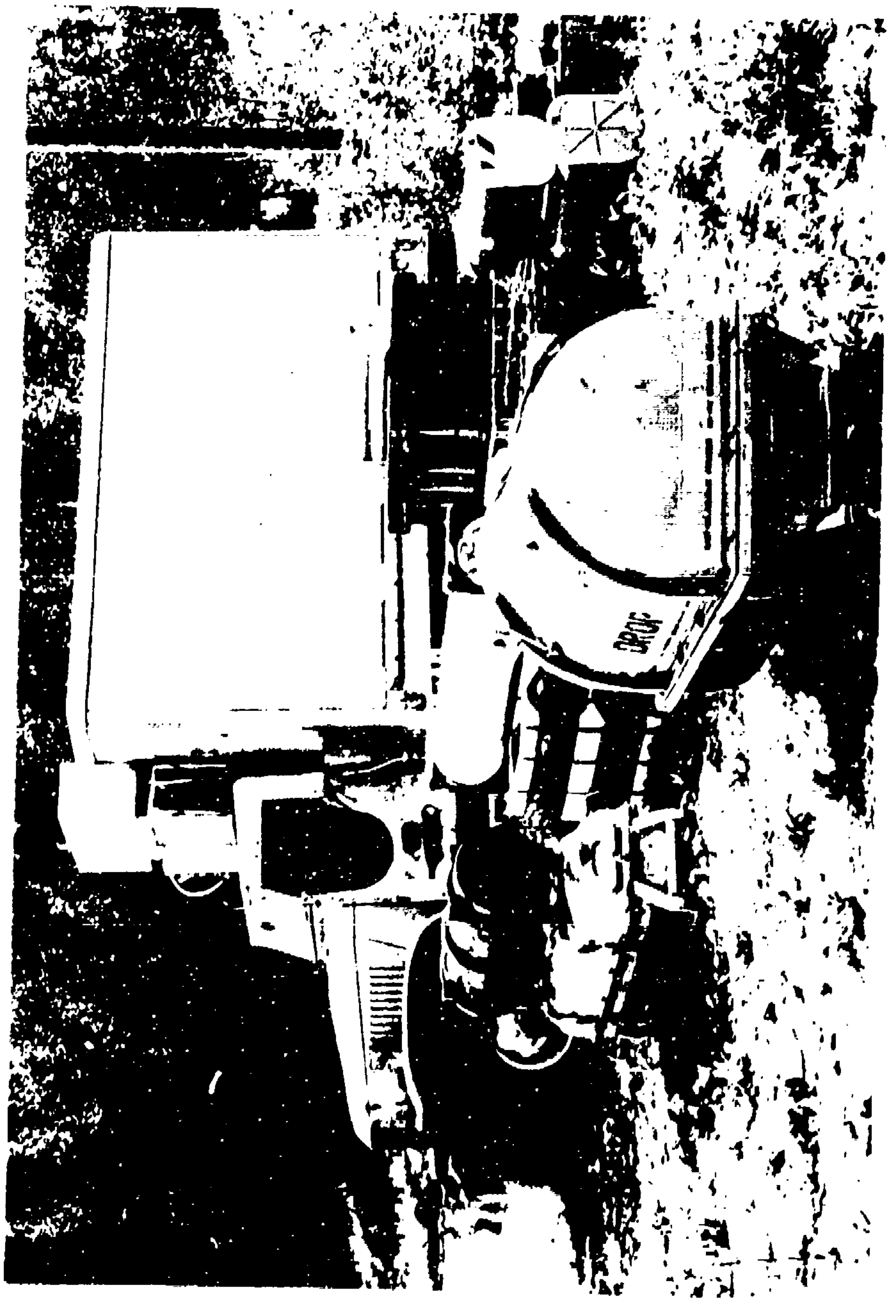


FIG. 5. Fort Richardson Measurement Site.

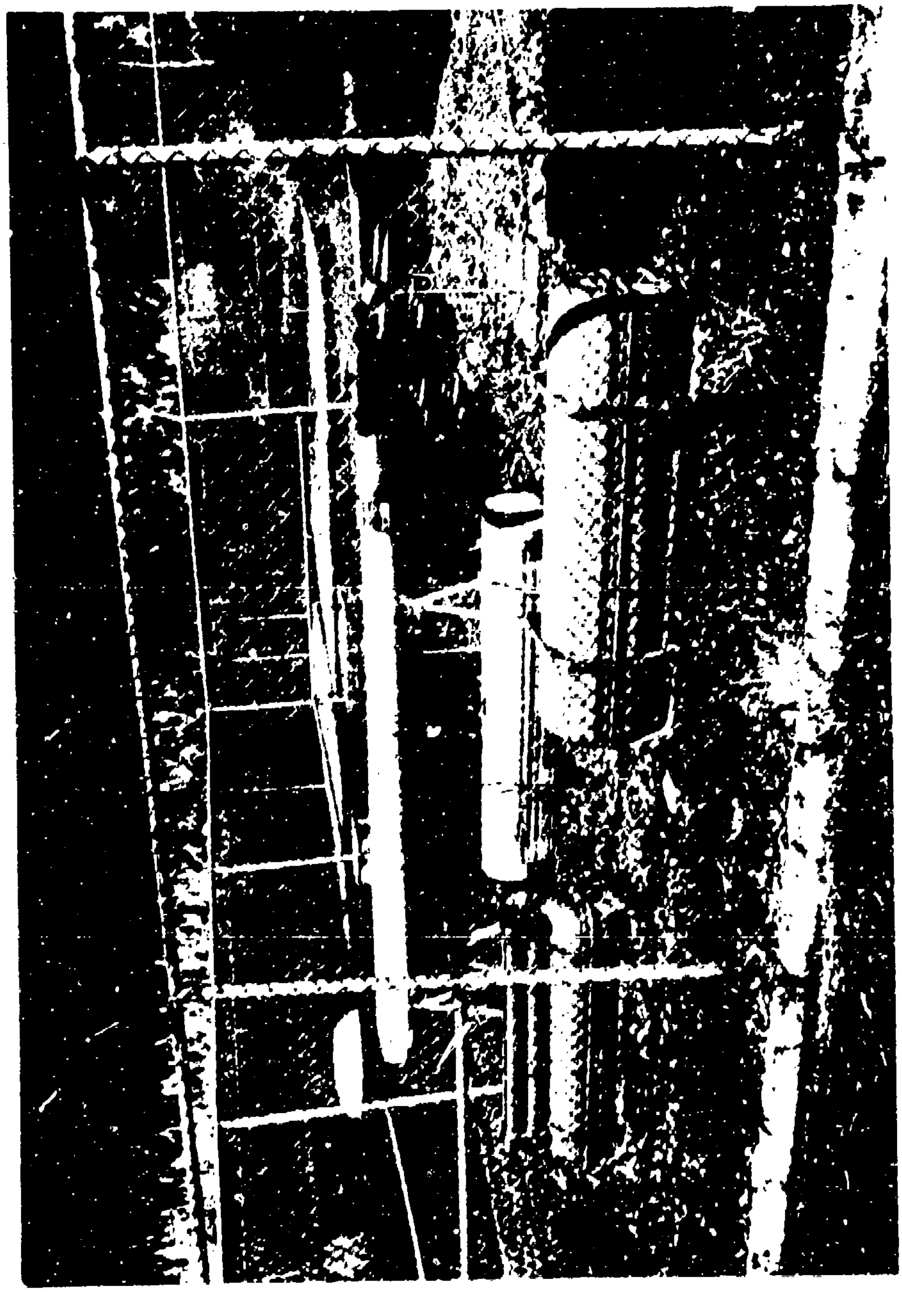


FIG. 6. Fort Clayton Measurement Site.

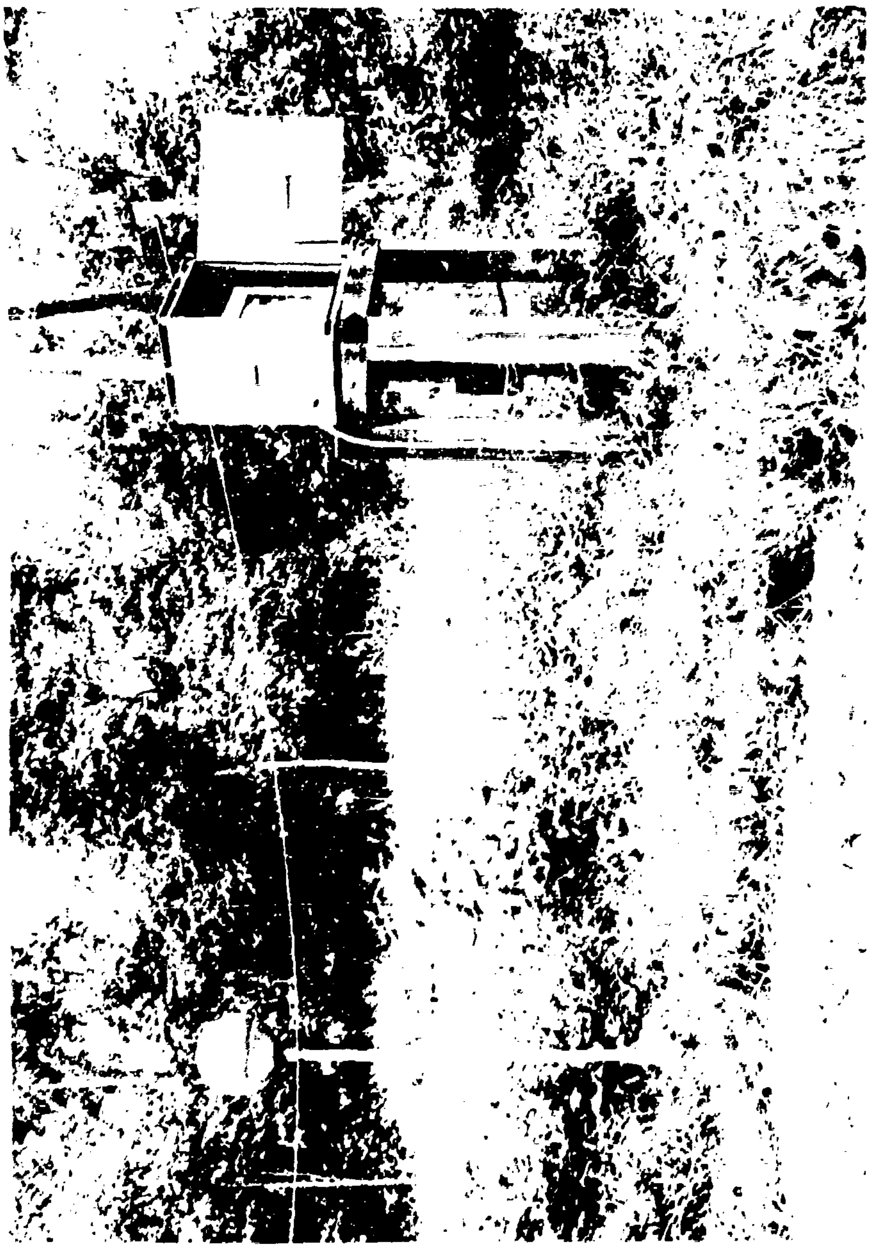


FIG. 7. Thailand Measurement Site.

not make the same mistake twice" has upgraded the equipment and techniques at the far flung sites. For example, we no longer suffer from frozen recorders in the Arctic nor "bug and plant" damage in the tropics. We also have not had an extension cable eaten by a small beast for many years.

Through the sponsorship of The Technical Cooperation Panel (TTCP) Rocket Propulsion Working Panel (D-5) Environmental Working Group, a tropical measuring site was set up at the Joint Tropical Research Unit, Innisfail, Queensland, Australia (Fig. 8). The Joint Tropical Research Unit (JTRU) is a cooperative effort between Australia and the United Kingdom, both of which are members of TTCP along with Canada and the United States. The Environmental Working Group installed 72 channels of instrumentation in conjunction with the already existing meteorological instrumentation at JTRU.

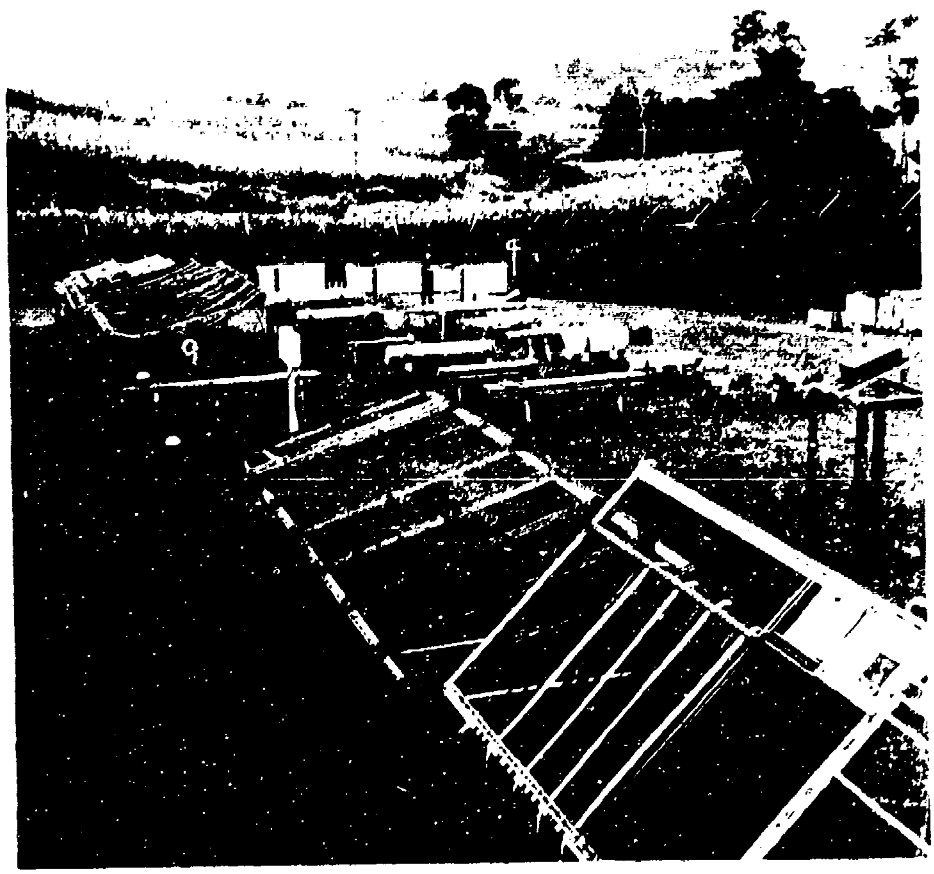


FIG. 8. Australian Measurement Site.

The installation was completed and in operation in October 1970. The arrangement was that the United States (in this case, NWC, China Lake) would provide all instrumentation and connecting thermocouple extension wire. The U.K. provided 5 instrumented rocket motors and the U.S. provided 13 instrumented rocket motors. Australia is taking care of the recorder maintenance and repair along with data reduction. All three Nations will equally share in the results of this endeavor.

Two areas of the earth's surface have had maximum meteorological air temperature ascribed to them. The highest, with a recorded temperature of 136°F is in Libya, the next highest with 134°F is Death Valley, California. Death Valley is only a short distance from the Naval Weapons Center so it was decided to add measurements from this location. In June 1970, a thermal standard was installed in the meteorological compound at the Visitors Center at Furnace Creek Ranch. Since this is the administrative hub of a major National Park, no ordnance could be located at this site. However, since there is also a thermal standard at China Lake a correlation should be possible.

In late 1970 it was determined that the data return from the Thailand site did not justify its expense, since it took at least an extra week to go from the Philippines to Thailand and return, the site could be reached only by an automobile, and the technician had to stay on site in the jungle until transportation could be arranged to return him to Bangkok from where he could leave the country. Therefore, in October 1970, this site was retired and the Navy equipment was returned to NWC.

An attempt has been made to gather, or measure other natural environmental functions at all of the sites. Stevenson shelter air temperature, humidity, solar radiation, and wind direction and velocity are generally available from Fleet Weather Center or Naval Air Facility, Air Force, ESSA, or Army Meteorological Teams' records of on-site measurement. However, obtaining vast amounts of meteorological data has lost some of its significance as more extensive statistical data have been received from exposed ordnance. At one time it was seen as imperative that meteorology be judicially collected and published in this type of report. It is now realized, however, that a weapon is not designed on a site-by-site basis. Its design is predicated on a single series of "qualification tests." Therefore, it behooves the environmentalist to classify the "world", not a single site. As will be seen later from the results of some of this work, statistically there is little difference between the thermal exposure of weapons in the tropics and the desert. It is now possible to construct a very tentative worldwide "high temperature cumulative distribution curve" for weapon design. In this sense, the engineer no longer cares what the meteorology of the many different "hot" areas may be. It is the response of his weapon in general that he is worried about.

PROCEDURE

The rocket motors, and virtually all the other ordnance and material, used in this extended measurement series were taken from surplus inventory of the Army, Navy, and Air Force. However, even though this material had served its intended in-Fleet purposes, it still was, for this use, representative of present and future hardware, when viewed in the thermodynamic context. For example, a 1944 model van truck is thermodynamically similar to a 1972 model, as far as the van bodies thermal shielding characteristics are concerned.

INTERNAL MOTOR CONFIGURATIONS

When a particular inert rocket motor was available, it was used intact. However, in the case of rocket motors, once-fired hardware was much more plentiful. Therefore, it was necessary to use the once-fired hardware and find an inexpensive durable propellant simulant. Through the efforts of the Chemistry Staff of the Propulsion Development Department at NWC, such a simulant was found. It turned out to be thoroughly dried desert blow sand. (A comparison of the thermal properties of the blow sand, and propellant and explosive inert thermal simulants is given in Appendix D of Ref. 13.)

Initially, all rocket motors used in this measurement series were cartridge-loaded, inert production motors. However, other work has indicated 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 that have been added are configured to simulate the case bonded situation. This was greatly facilitated by the use of the sand. Previously, it had cost from $10,000 to $25,000 to cast thermocouples into each inert, case bonded motor due to (1) the propellant being very viscous, causing "sweeping" of the thermocouples from the desired locations and (2) the short pot life of the propellant.

The ASROC rocket motors at the China Lake and Subic Bay measurement sites are of the cartridge-loaded type, while the ASROCs at the Panama, Queensland, Fort Richardson, Fort Greeley, and Sierra Nevada measurement sites are all sand filled. This should be kept in mind while examining the results reported herein.

The Sparrow motors are all sand filled except for the containerized motor exposed at China Lake. It is a production inert simulant Mk 6 Sparrow of the standoff grain type. The smaller rocket motors are about evenly divided between sand filled and inert production grains. In general, all Sidewinders rocket motors contain production inert grains; 2.75 FFAR motors also contain plastic simulant and are cartridge loaded, but the 5-inch Zuni motors are about 50% sand filled and 50% cartridge loaded. The NOTS 5-inch Spinner rockets are all sand filled. On anything smaller than an 8-inch-diameter, it is extremely difficult to tell which is "case bonded" and which is cartridge loaded from the resulting thermal data. The mass of the unit is apparently so small that this relationship loses overall significance.

THERMOCOUPLING

Early in the program it was decided that the 12 O'clock position of an exposed missile (containerized or bare) reached the highest temperatures. Therefore, the general thermocouple pattern was to place a set of copper-constantan thermocouples thru the 12 O'clock position. The point halfway between the ends of the container was chosen for the thermocouple pattern placement in order to negate the moderating influence of thermal "end effects". These "end effects" (which are the result of heat being able to escape in all three dimensions from the surface of the container, instead of just escaping by penetrating downward) are always responsible for the measurement of a "cooler" situation in hot climates than the central portions of the missile will experience. The "center" position was chosen only after measurements from the exposure of a fully instrumented Sparrow sand-filled motor indicated that within 1 1/2 to 2 calibers of the ends of the motor the effect was pronounced. The central portion of the motor was the most thermally stable and therefore used for the measurement series universally.

Thermocouple Construction

All thermocouples are of the copper-constantan type (Type T). The hot junction for internal measurements is a welded or silver-soldered 1/16- to 1/8-inch-diameter ball. The surface thermocouples for shipping container or motor skin are of two types. 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 and the copper wire to another corner and the assembly is attached to the area of interest with epoxy. Early in the program these units were only taped to the surface of interest. This attachment method is satisfactory for short times at locations where the set up will be regularly inspected for thermocouple lift off. However, for long term, "abandoned" measurement jobs, this attachment method can lead to trouble. The other, more time consuming method was to drill two small holes about 1/8- to 1/4-inch apart in the surface to be measured, place the copper wire in one and the constantan wire in the other, silver solder the wires in place, and then grind down the solder joints so that the surface is again smooth and repaint. A comparison of the data from these two types of installation indicated that there is no significant difference for this application.

INSTRUMENTATION

Recorders

The mainstay of this measurement series was the Honeywell Model 15 Universal 24 point stripchart recorder. The state-of-the-art on which this instrumentation mode is based is at least 25 years old. The manufacturer advertises an accuracy of measurement of 1/4 of 1% of the full full scale of the measurement range (-100 to +250°F) for this model. For this measurement series this represented less than 1°F error. None of the 30 odd instruments used in this measurement sequence exceeded this overall error band, when in operating shape.

The only trouble resulted because these are laboratory instruments and are not designed for field use. They were for all intents and purposes abandoned on-site for months at a time. Since the instruments were not serviced for periods of 3 months to 1 year, failures had to be anticipated and kept at a minimum with preventive maintenance. The recorders could record data for 60 or 90 days unattended before personnel were required to change the stripchart roll.

At the China Lake site only, a 200-channel data logger was put into operation in May 1970. This digital tape instrument is still in the "trial" period of operation. Compared to the Honeywell recorders it is more accurate and vastly more complicated and sensitive. Its out-of-laboratory use ability has yet to be proven. However, it can run up to 5 or 6 months on a single tape at an hourly sample rate, and the tape can be input directly to the computer for quick reduction. (On the other hand, reduction of the more reliable Honeywell charts is strictly a manual operation.)

After the loss of the five winter months of data during a malfuntion of the rewind mechanism, it was decided that the precaution of paralleling important data channels with the cumbersome Honeywell recorder was worthwhile. In this manner, the data herein reported for November and December 1970, and January, February, and March 1971 was salvaged. In short, the more sophisticated instrumentation is superior in a situation where a "babysitter" is constantly available. For off-station primitive conditions, it is wise to sacrifice sample speed, some accuracy, and ease of data reduction 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 were either not encountered, or were classified as "in the noise".

Data Reduction

During the first few years, a complete program of data reduction was followed. However, due to prohibitive costs, the number of data channels to be reduced was lowered, and only the daily maximum and minimum temperatures were considered. This method indicates the "extreme" days so that the complete data for only these days can be obtained when desired. However, this method left much to be desired for any type of statistical treatment. For the statistical treatment, it was decided to revert back to the reduction of every data point of the Honeywell chart, but only for selected channels. It is in this way that the majority of the cumulative probability displays herein presented were derived. The balance of what data can you get by with, and the dollars available with which to reduce it is a major dilemma for this type of mundane project.

The data logger at the China Lake site seems to be one solution to this problem. Since it skips the costly hand reduction steps and feeds data directly into a computer in a compatible language, these data were used almost exclusively for the desert portion of this report.

Thermocouple Placement

Since there were many motors used in this continuing measurement series, and only a few motor grain configurations, the following listing is given for the various types of measurement matrix. Whenever a cartridge-loaded configuration is being discussed, the thermocouples were placed through the matrix as follows:

1. On outside skin of shipping container
2. In air halfway between shipping container top wall and motor skin
3. On motor skin
4. On the top surface of the annular portion of the grain
5. On the inside surface of the annular portion of the grain
6. One-inch into the top spire of the cross shaped portion of the grain

An example of data from each of these positions is given in digital form in Part 2 of this report. A cross reference for the China Lake exposed ASROC with the recorder channel is as follows:

1. Channel 29
2. Channel 28
3. Channel 27
4. Channel 26
5. None
6. Channel 25

In the results portion of the report, channels 25, 27, and 29 have been extensively used.

When a motor is sand filled the thermocoupling pattern is much simpler. In this case the thermocouples are located as follows:

1. On outside skin of shipping container
2. In air halfway between shipping container top wall and motor skin
3. On motor skin
4. In the center of the sand

The decision to abbreviate the number of thermocouples was based on the cost of reducing volumes of data and the limited number of recorder channels available.

The thermocouple patterns for the two Sparrow motors exposed at China Lake are given in Ref. 13. These motors were originally thermocoupled for aerodynamic heating investigations and were added to the dump storage measurements after completion of these investigations. In general the thermocouple pattern of the Sparrow motor in a container is much like that of the ASROC. The major difference being that the Sparrow motor grain consists of two concentric cylinders instead of a shell and cruciform. A detailed example of digital data from Sparrow motors at China Lake is presented in Part 2 of this report.

The other Sparrow motors in use in this effort throughout the world are sand filled and, therefore, are thermocoupled in the same pattern as the other sand filled motors.

A description of instrument errors encountered during this measurement series is given in Appendix B.

RESULTS

At first it was 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. However, the daily maximum-minimum display does not depict what is actually taking place at any given time in the ordnance unit. Therefore, cumulative probability, or chance of occurrence displays were adopted to give a more accurate display. However, work is continuing to develop a more concise method of presenting massive amounts of data so that they are directly usable by the designer.

A good example of the possible, though not probable, dump storage situation to which a missile could be exposed is shown in the examples of ASROC and Sparrow missiles. It can be seen in Fig. 9 that these units were completely exposed to the "elements". The missiles have been positioned with their long axis pointed north and south at all of the participating Dump Storage Temperature Measuring Sites. These missiles have been arranged so that there should be no thermal interaction between separate units. (Re-radiation between missiles is possible, but shadow cover or overlap is not.)

ASROC DATA

The long term situation as it pertains to the heating and cooling of an ASROC missile container is shown in Fig. 10, 11, and 12. A comparison of these figures will given some indication of year to year variences for the dump storage situation. These figures indicate that equal weight is given to all portions of the line depicting the daily temperature varience. In fact each line represents the loose equivalent of a half sine wave. However, since the sun raises in the morning and sets in the evening, 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. Even though the data are recognized as being not too usable in an in-depth analysis, they are very important to show the year to year variance, and the peak day of exposure for the given geographical location. The shipping container skin temperature is shown because it is the thermal integrator to which the encased missile is exposed. Figures 10, 11, and 12 are for the desert situation, and are presented first because the desert is conducive to a wider annual ordnance temperature variance than the tropical or temporate situation.

The thermal situation for the tropics is presented from ASROC data measured at the Naval Magazine, Subic Bay in the Republic of the Philippines (Fig. 13 and 14). (Equivalent data for Fort Clayton in the Panama Canal Zone is available at NWC if desired.) Notice that the minimum tropical container temperature is quite constant year in and year out. This is directly attributable to the moderating effects of the ocean. Figure 15 shows the temperature profile of the rocket motor outside skin while dump stored in the shipping container Notice that the diurnal varience is less than shown in Fig. 13 and 14. The temperature profile at the center of the inert motor propellant grain is displayed in Fig. 16. Again notice that the diurnal varience is further damped. This damping would be expected with increased mass. Also, the time of maximum and minimum temperature during the 24 hour day is phase shifted, the deeper into the missile the measurement is taken. However, notice that the minimum temperature excursion shown in Fig. 13 through 16 is about the same.

To illustrate the relationship between locations at various depths in a missile and their response to the thermal forcing functions, it is always most useful to show the ideal example, if available, than the

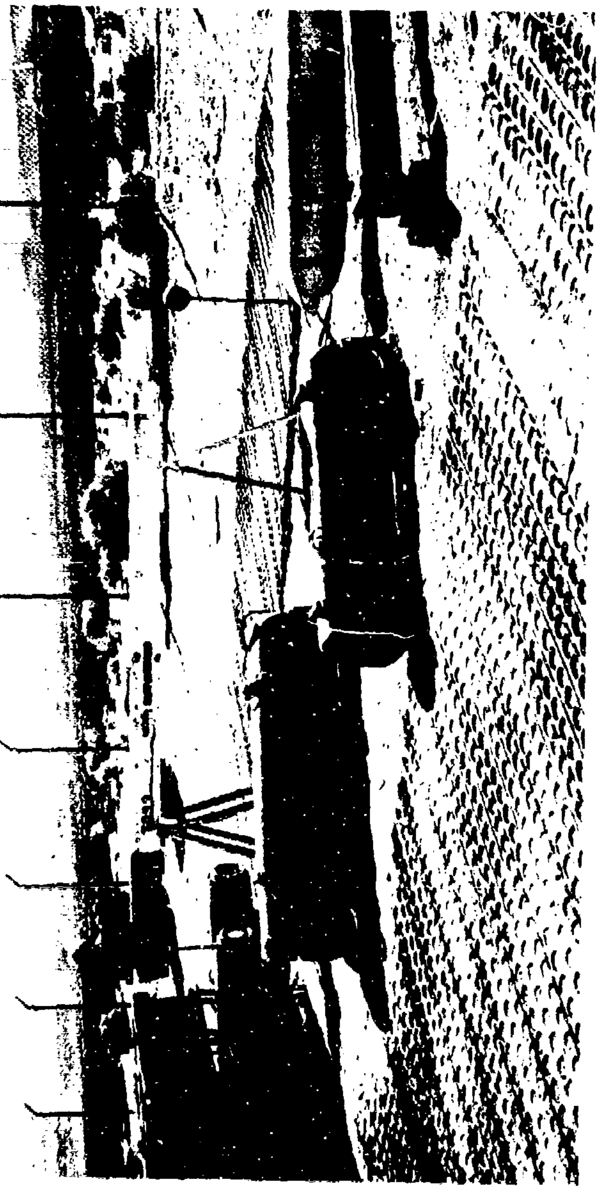


FIG. 9. ASROC and Sparrow Missiles Dump Stored at NWC.

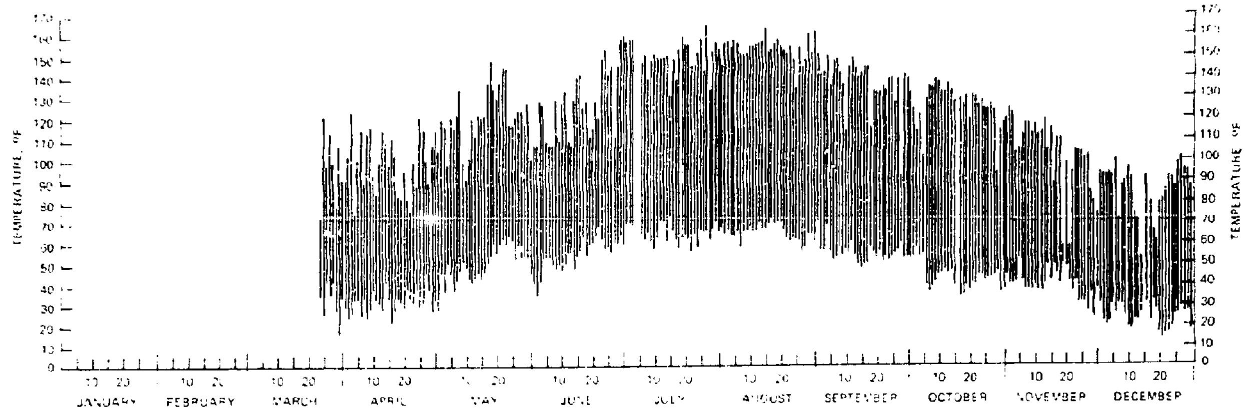


FIG. 10. Temperature Profile of ASROC Shipping Container Skin, Dump Stored at NWC - 1967.

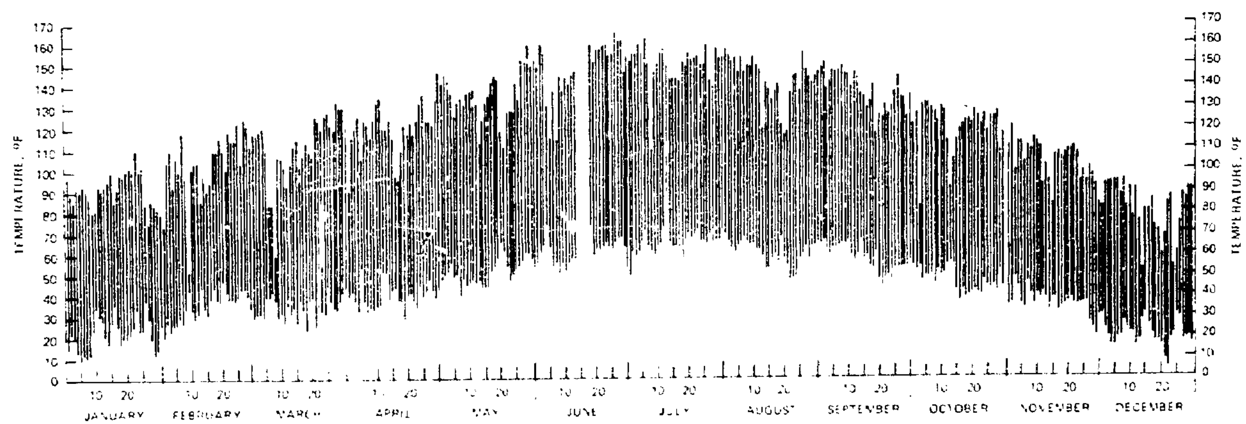
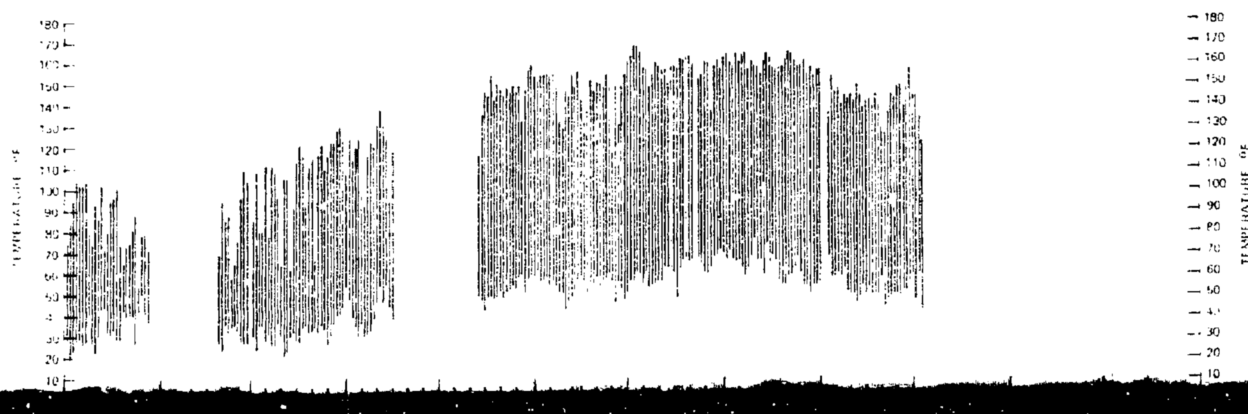


FIG. 11. Temperature Profile of ASROC Shipping Container Skin, Dump Stored at NWC - 1968.



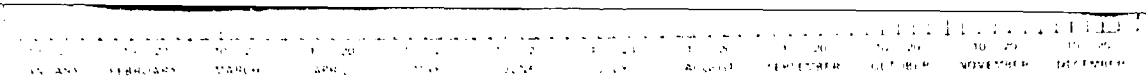


FIG. 10. Temperature Profile of ASROC Shipping Container Skin, Dump Stored at NWC - 1967.

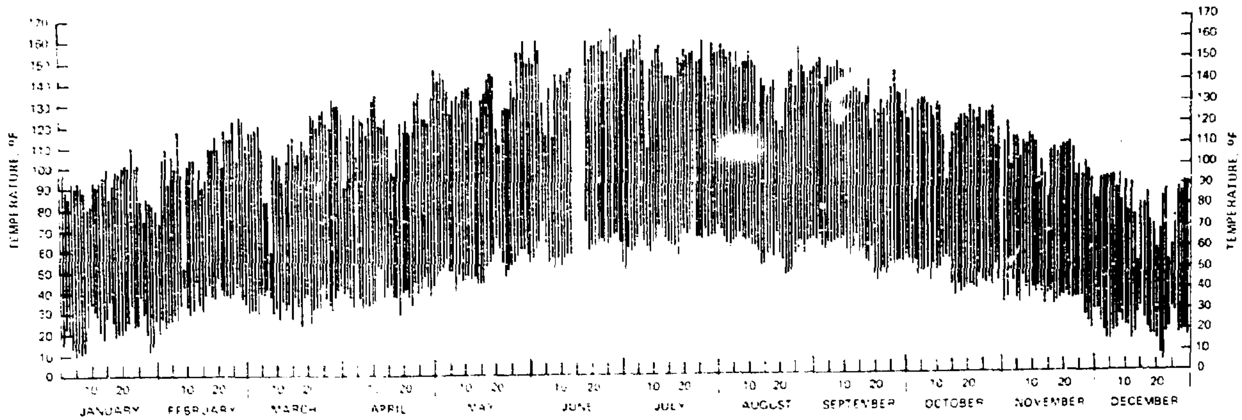


FIG. 11. Temperature Profile of ASROC Shipping Container Skin, Dump Stored at NWC - 1968.

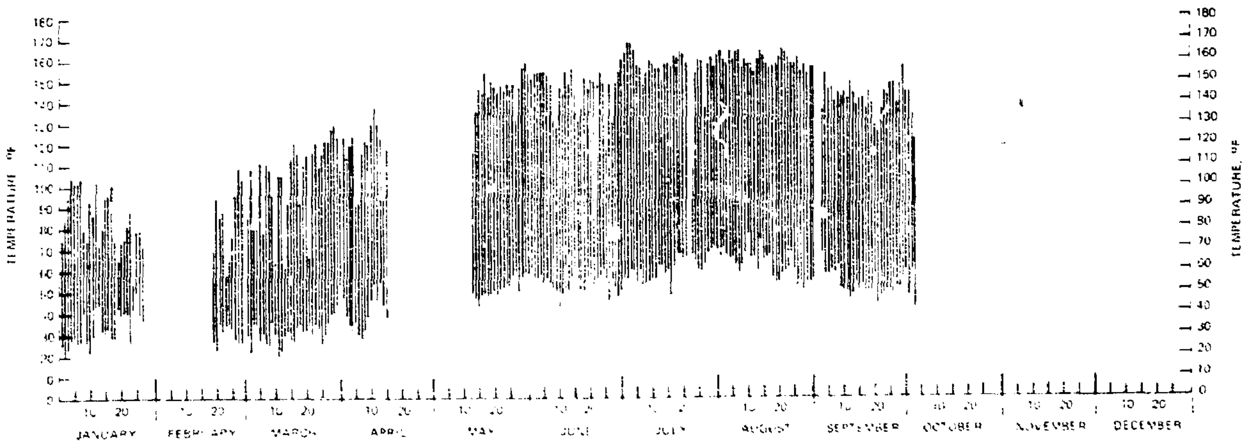


FIG. 12. Temperature Profile of ASROC Shipping Container Skin, Dump Stored at NWC - 1969.

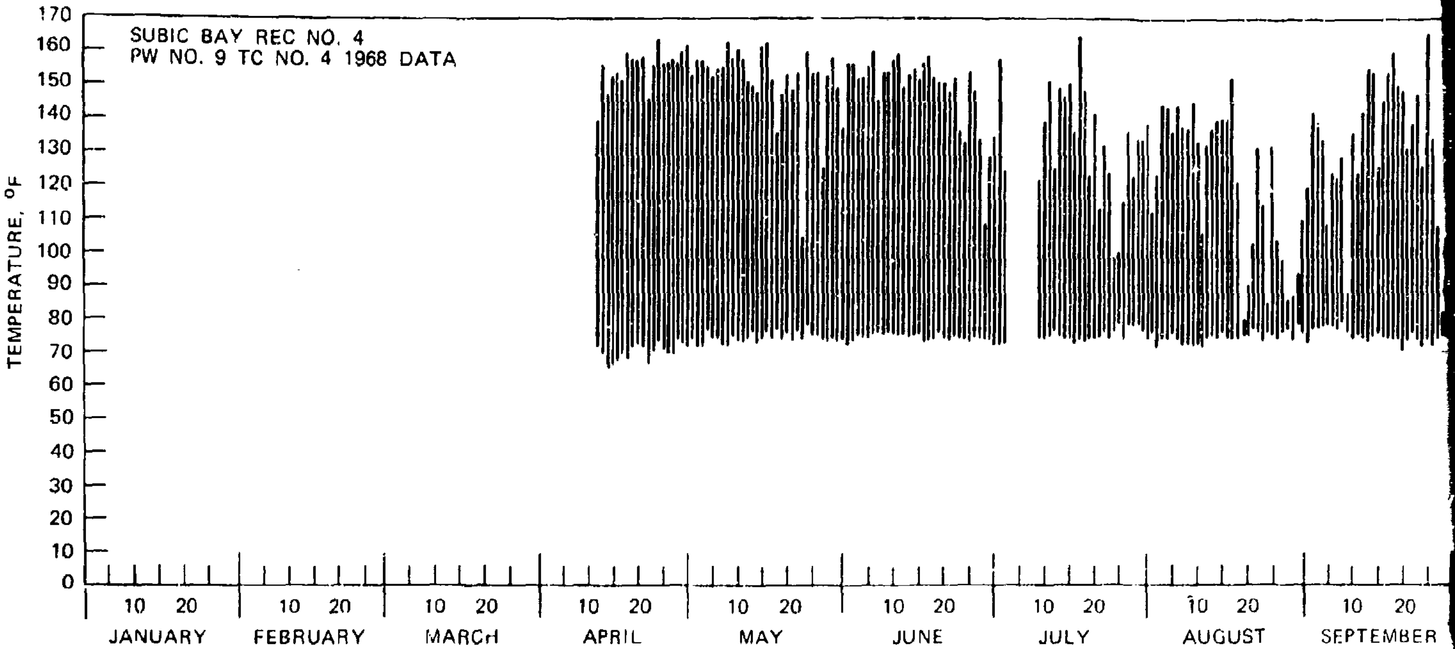


FIG. 13. Temperature Profile of ASROC Shipping Container Skin, Dump Stored at

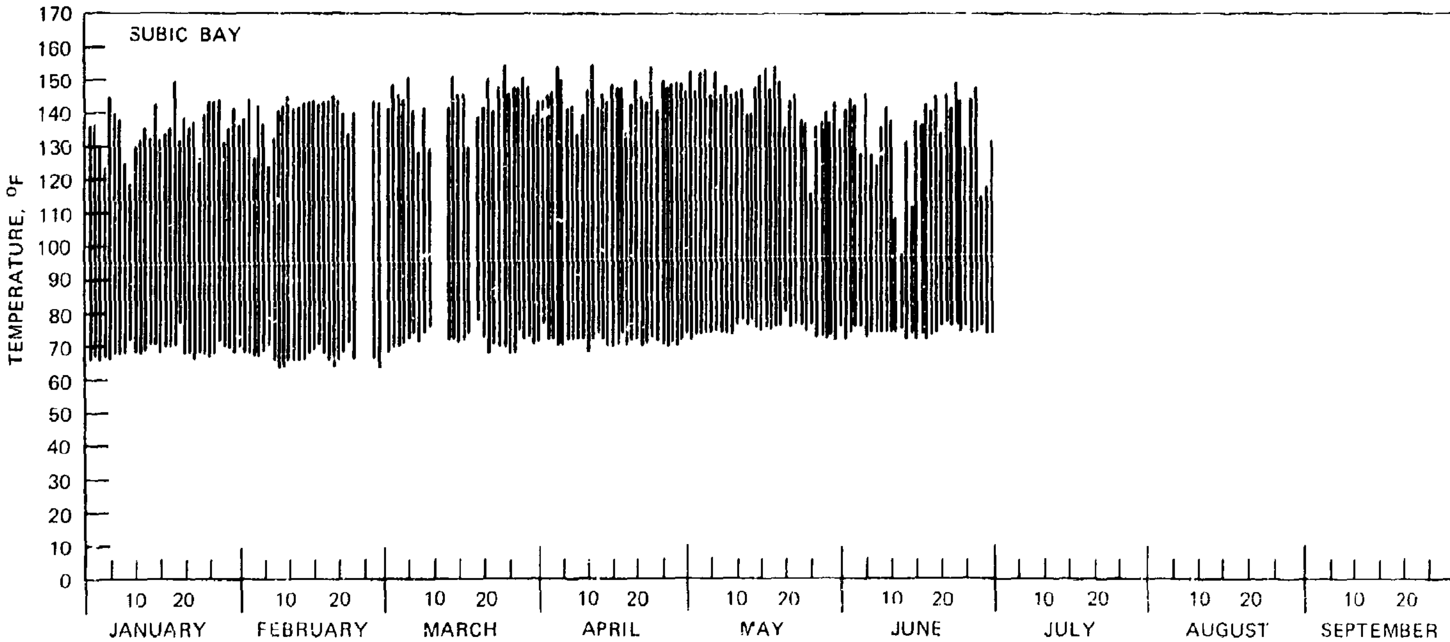
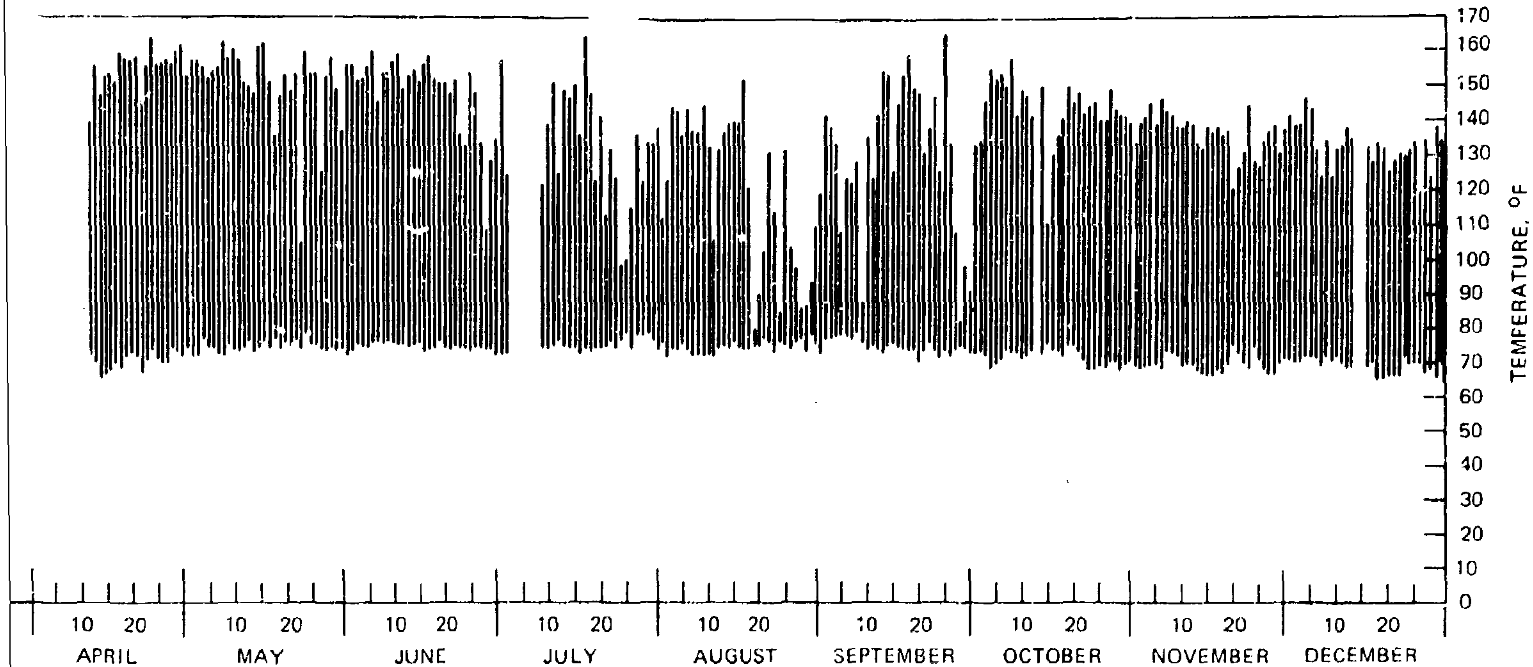
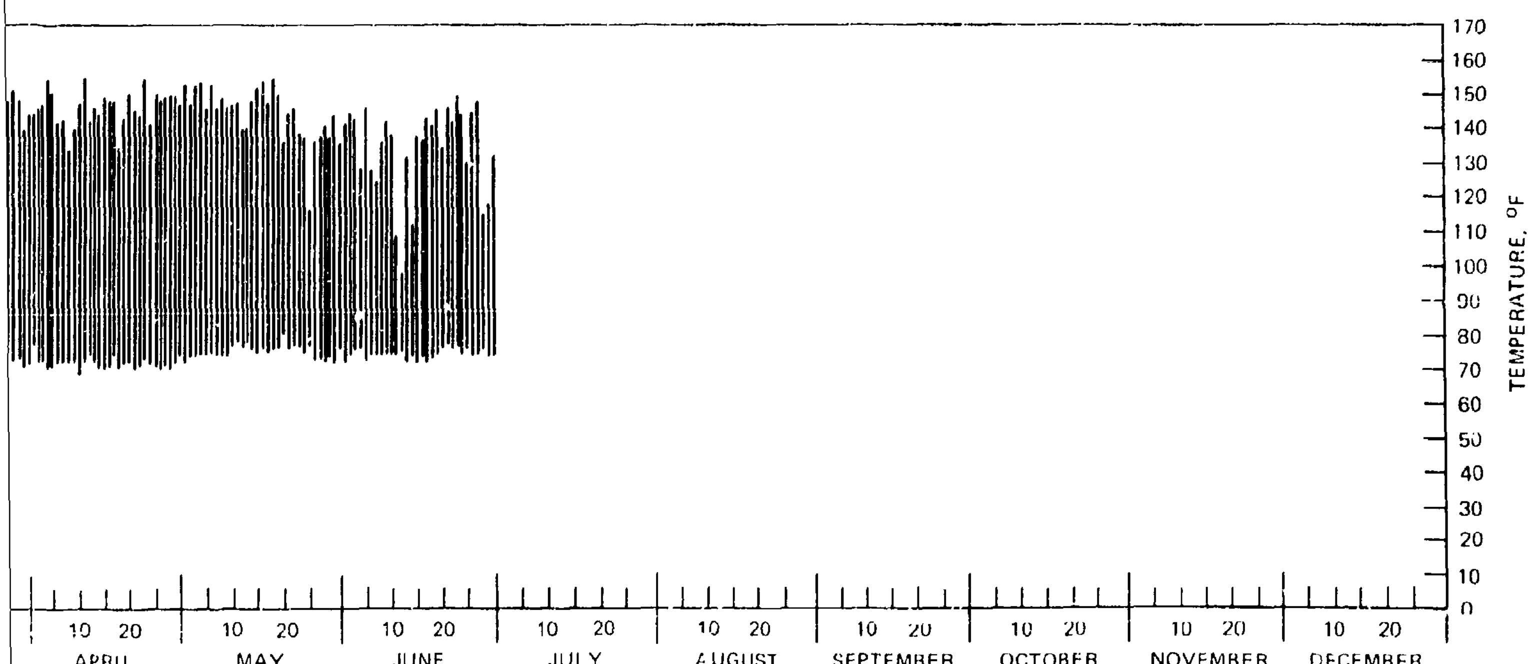


FIG. 14. Temperature Profile of ASROC Shipping Container Skin, Dump Stored at



-ature Profile of ASROC Shipping Container Skin, Dump Stored at Subic Bay - 1968.



-ature Profile of ASROC Shipping Container Skin, Dump Stored at Subic Bay - 1969.

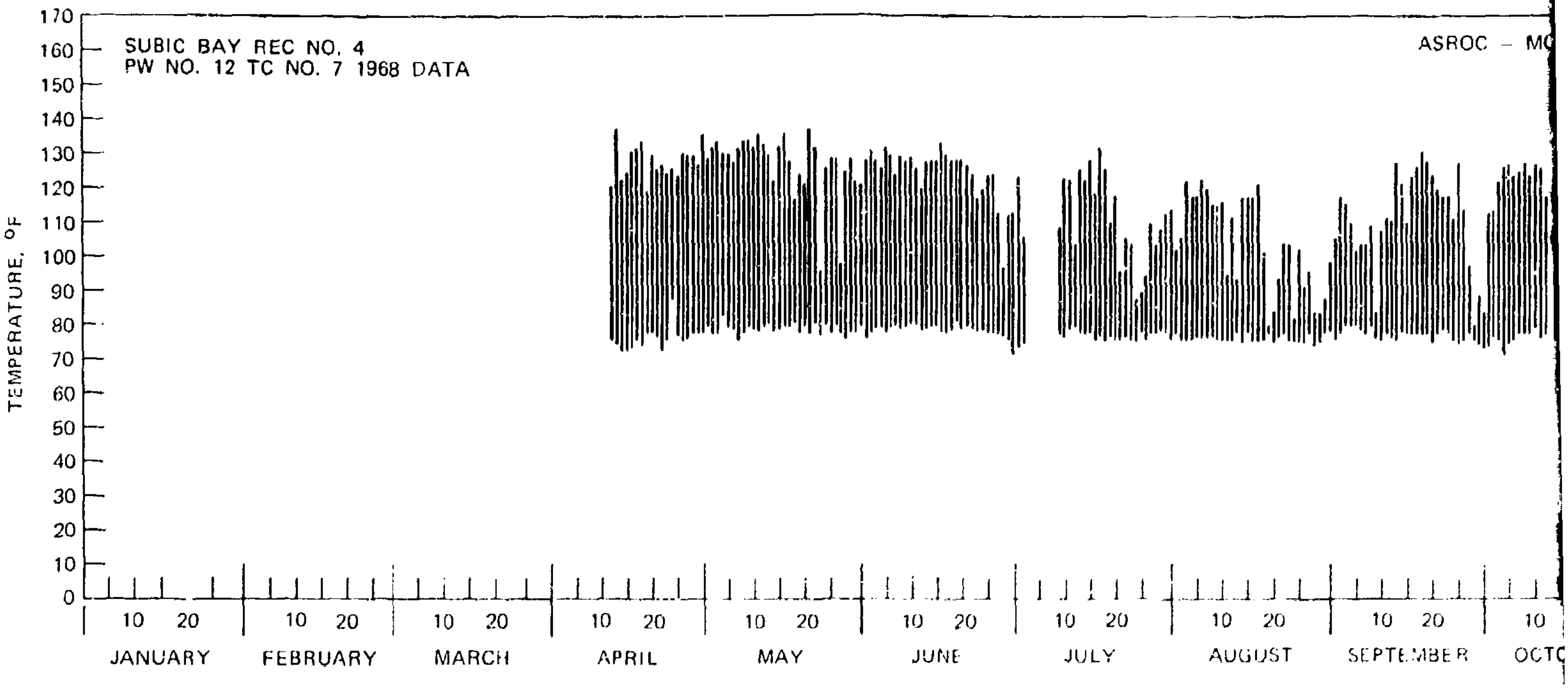


FIG. 15. Temperature Profile of Rocket Motor Skin While Dump Stored in Shipping

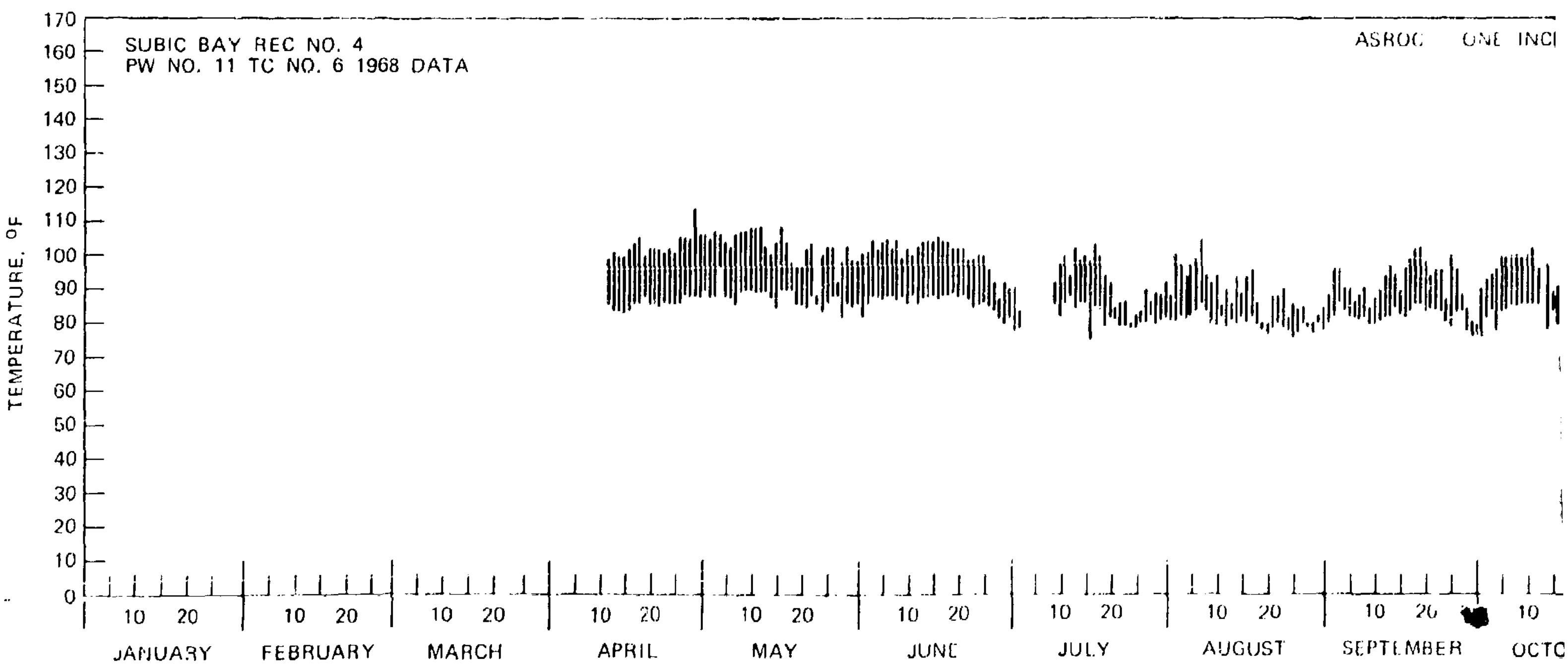
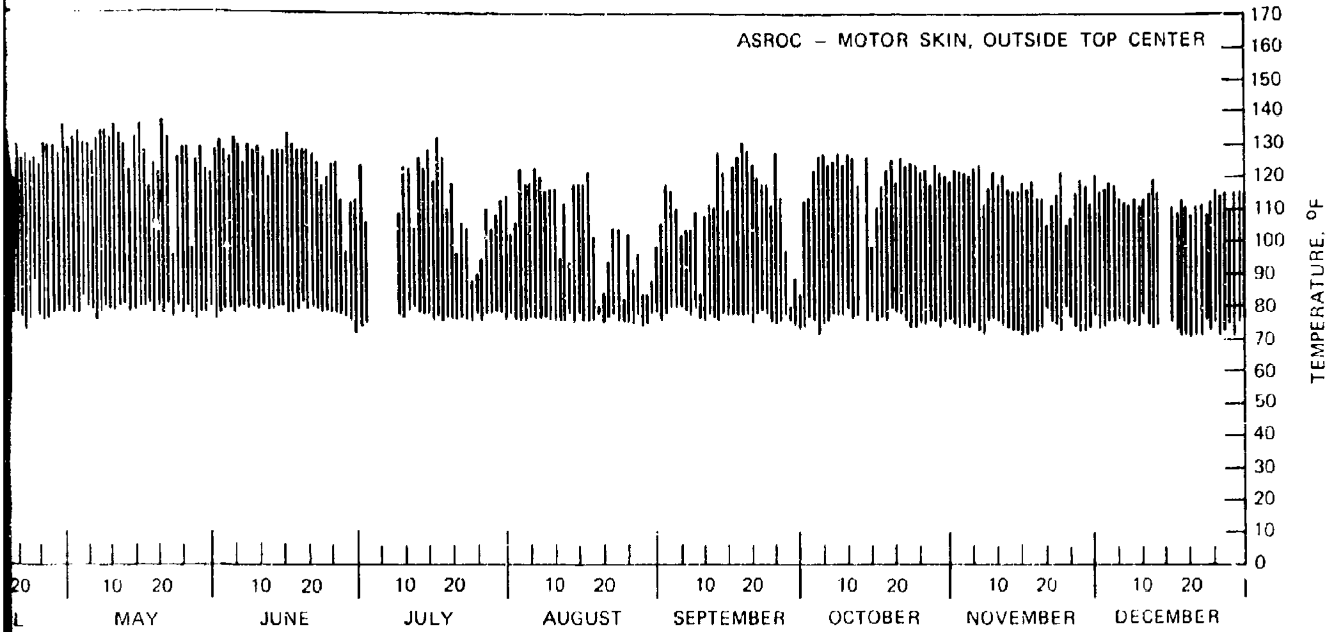
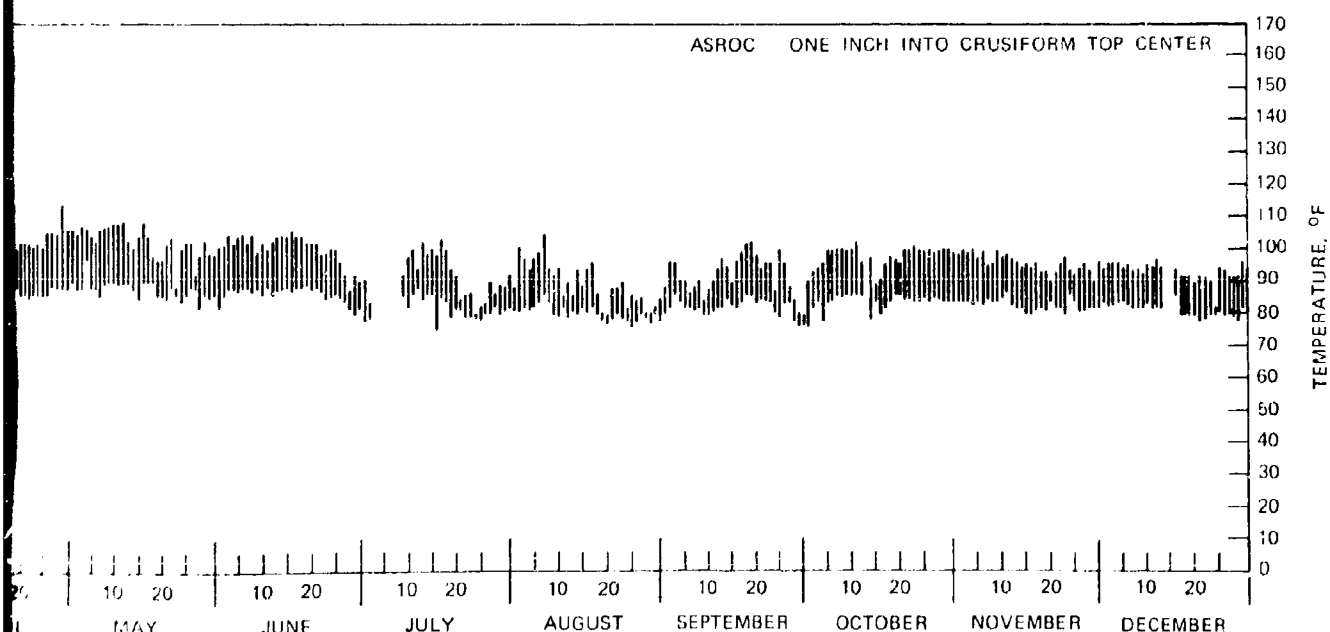


FIG. 16. Temperature Profile of Rocket Motor Propellant Grain.



e Profile of Rocket Motor Skin While Dump Stored in Shipping Container.



Temperature Profile of Rocket Motor Propellant Grain.

more common situation. However, it is difficult to find an extreme thermal heating day, in the ordnance context, that is ideal. Figure 17 is an attempt to provide such a situation. Notice that the attempt to provide a classic example is not totally successful. 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. However, this is more nearly the actual extreme heating case than the ideal situation. 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 meteorological air temperature. Also, if even a small cloud drifts across the sky shading the ordnance, the temperature can be expected to drop from the possible maximum. The inconsistencies shown in Fig. 17 could have been caused by any of the above reasons.

Notice in Fig. 17 that the air temperature in the shipping container rapidly followed that of the shipping container skin. The figure also shows, though to a lesser extent, the thermal dips so evident in the trace of the shipping container skin. The trace of air temperature is not indicative of what the temperature of all the air in the container will experience. However, since it was intended to report the maximum thermal situation for any given enclosed item, all the data in this report are the most extreme point for the locus of points making up the area of interest. For example, the air in the bottom of the shipping container will be cooler than the trace shown in Fig. 17.

Even though the container skin temperature is shown to peak at about 165°F, the motor wall (missile skin) responded at a much lower thermal level. This indicates that the missile need only be designed to 130°F, in this case, to survive the 165°F situation.

The other two traces in Fig. 17 are for interior motor grain locations. It can be seen that the magnitude of temperature is again much less than the 165°F. Notice 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.

Something should be said about the time phase shift of the various positions in respect to the maximum temperature. It would seem, from Fig. 17 that the container skin temperature peaked at about noon. (Usually this peak occurs 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; which is after sundown at this location. It is this time phase shift that 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, then 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 that the large mass has started to thermally "move",

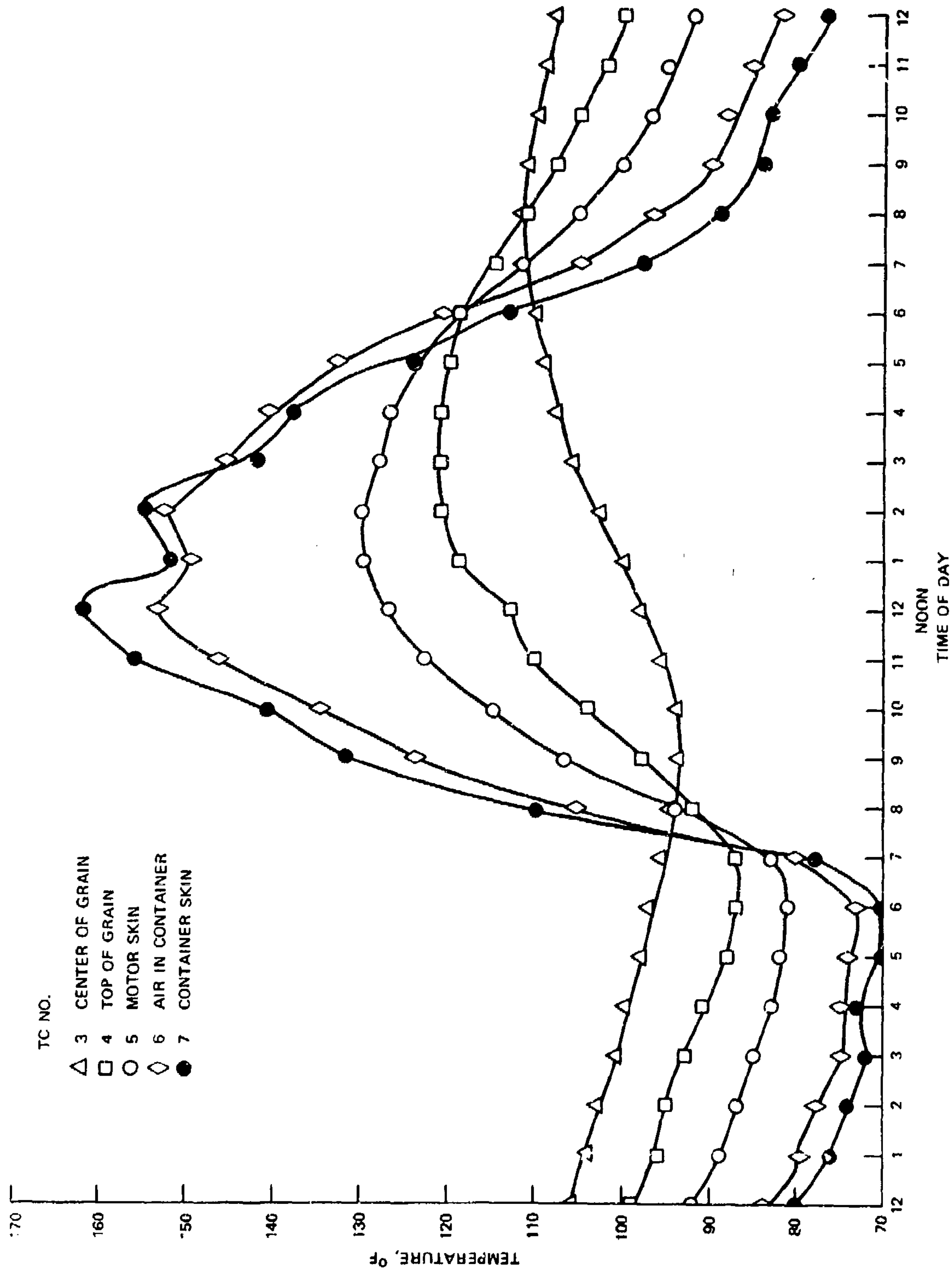


FIG. 17. Temperature Profiles of ASROC Motor in Shipping Container at NWC for 31 July 1969.

the primary forcing function may have peaked and started its downward trend to a progressively lesser set of heating circumstances. Due to these circumstances, the present specifications requiring a thermal soak at an elevated temperature do not represent the actual environment, if an analog situation is the wanted end result.

The more common situation, even though it was chosen originally to exhibit the maximum tropical heating situation of Subic Bay, is shown in Fig. 18 and is indicative of one of the better, smoother days in the tropics. A large, black cloud notched the trace at about 0900 to 1000 hours. Notice that the repercussions of this thermal notch are in evidence clear into the center of the motor grain. Also, it can be seen that the maximum temperature of about 165°F is reached for about an hour, but the onset and tailoff values are not near this value. If, as more times than not, more clouds had crossed over the unit, the high temperature trace would resemble a spike instead of a half sine wave.

The temperature of 14 May 1970 allowed the measurement of a quasi-textbook example of what a maximum heating day for ordnance should look like in the tropics. Figure 19 is the plot of ASROC response to that day at Subic Bay. Even so, notice that there is still a notch at noon that should not be there. Also, notice that even in May, which is in the dry season, with the sun directly overhead at 15°N, the temperature at the center of the motor grain was below 110°F. The shipping container skin in this case was just above 150°F maximum temperature.

Although the tropics possess the potential for extreme heating of ordnance, on the basis of continuous measurements over a period of years, the judgement is made that this potential is seldom realized. It has been observed that when the conditions are just right for a maximum ordnance heating situation, either wind, rain, or clouds obscure or completely negate the maximum heating situation.

Cumulative Distribution for Tropics

From the proceeding discussion it can be seen that it is extremely difficult to develop the criteria for missile or component design. As has been previously stated, the bar graph maximum and minimum temperatures only define the band of exposure response. The day plots are 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 for "worldwide" use.

It has been customary to use the three sigma values in missile design. On any program of hardware development in DOD the three sigma value seems to be in evidence. Therefore, it was deemed logical to place the measured data into some context that would enable the designer to be able to identify the three sigma point, and at the same time present a visual indication of how much of the time per year an item could

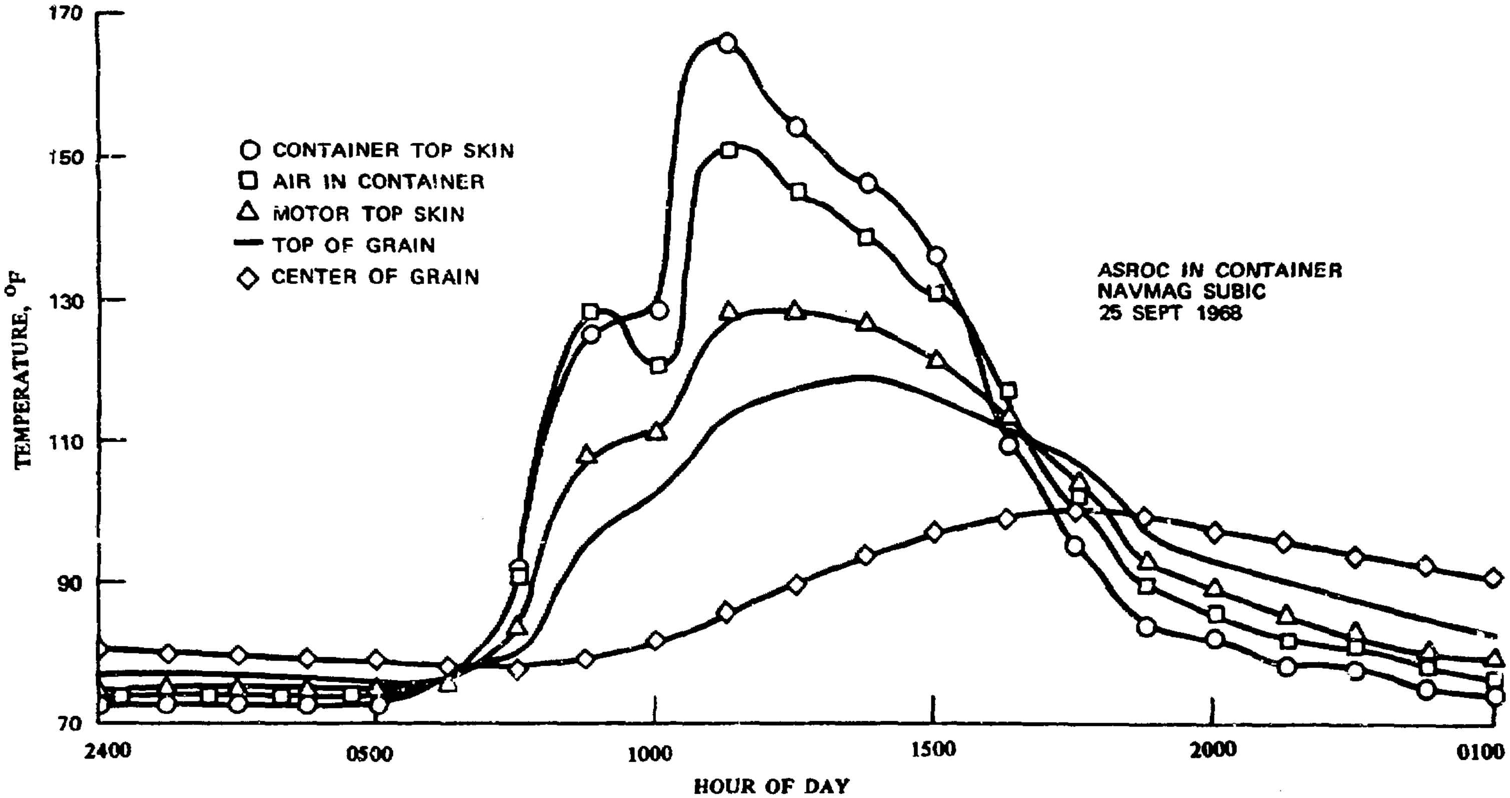


FIG. 18. Temperature Profiles of ASROC Motor in Shipping Container at Subic Bay for 25 September 1968.

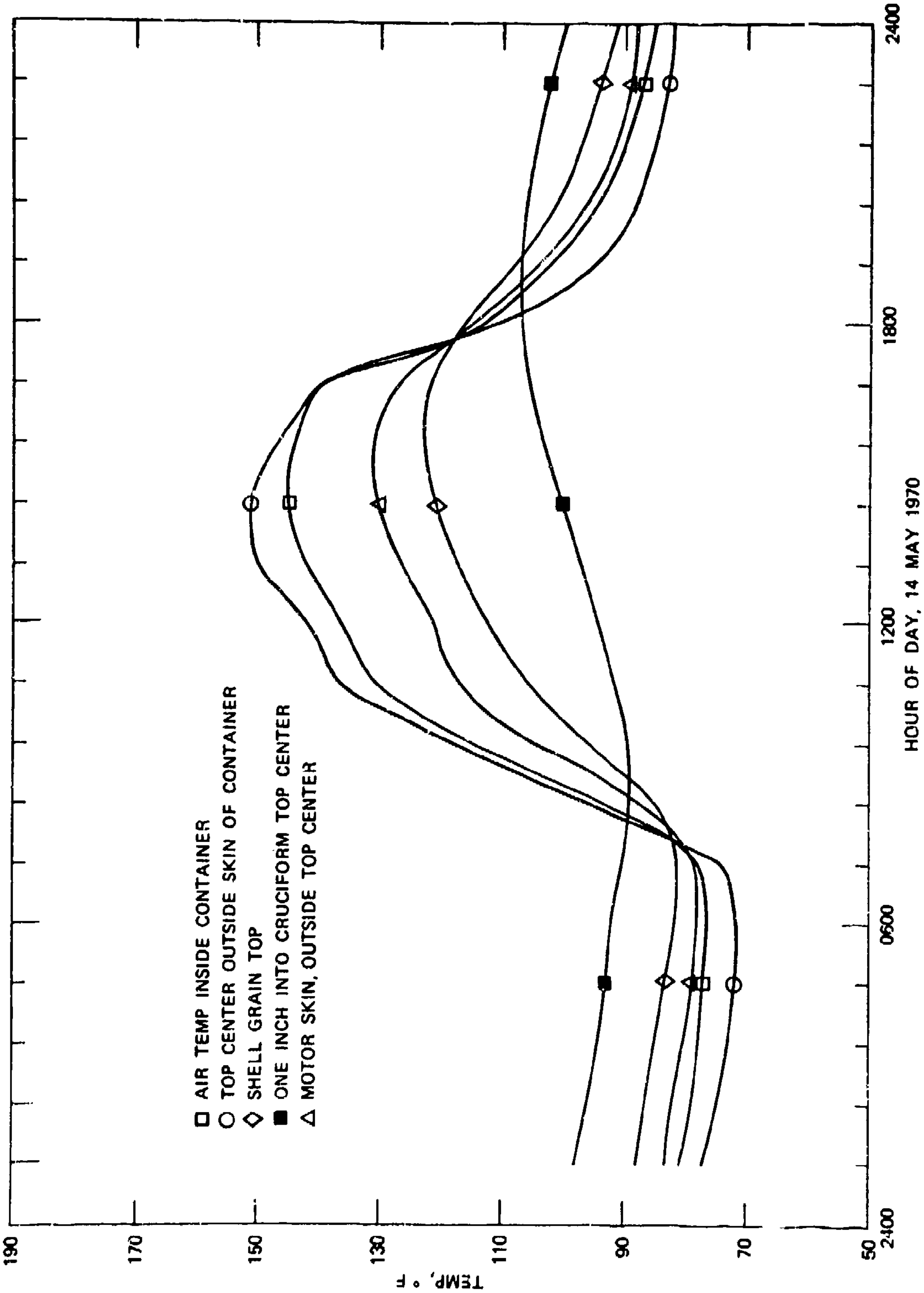


FIG. 19. Temperature Profiles of ASROC Motor Dump Stored in Shipping Container.

be expected to be subjected to a specific temperature value, or band of values. Therefore the cumulative probability concept seemed to be the best approach. The development of this concept is discussed in detail in Ref. 10.

The same type of information that was presented in bar graph format in Fig. 10 through 14 is shown in cumulative probability for each month of the year 1970 at Subic Bay in Fig. 20. Notice that the shape of all 12 curves in Fig. 20 are generally the same; however, the severity of the exposure for each month varies, as would be expected. The months of March, April, and May stand out as the "hot months" while the month of August would seem to be the "cold" month. This reinforces the observation that the spring season is dry and the sun is directly overhead at 15°N, while in August the sun is still about overhead, but so are the rain clouds. If these four months are deleted from Fig. 20, then the other months generally seem to track through most of the temperature band.

It is always of interest to see if the results of a measurement series are unique to that specific location or more representative of a larger geographical area. A comparison of Fig. 21 and 22 gives an insight into how comparable the measurements in the tropics are. Figure 21 is the monthly cumulative probability plot for the outside surface of the missile motor while encased in the shipping container exposed at Subic Bay. Figure 22 is the equivalent situation at Fort Clayton, Panama Canal Zone. It is of interest to see in the comparison that again the plots for the four months discussed above assume the same patterns in Fig. 21 as they did in Fig. 20. However, the spread between the monthly curves in Fig. 22 is not as great as that in Fig. 21. Also, in Fig. 22, the rank order of the monthly plots is different than that in Fig. 21. Notice in Fig. 22 that January thru April are the maximum heating months, while July thru December are grouped into a progressively colder order. It would seem that the month of August is not as "cold" in comparison in Panama as it is at Subic Bay. As would be expected, the low temperatures at both locations run between 65 and 78°F, as is shown much better by the bargraph presentation. The maximum temperatures are comparable in that the Fig. 21 band is between 120 and 133°F while the Fig. 22 band is between 116 and 130°F. This small difference in high temperature band values could have been caused by the difference in the configuration of the motor grain between the two measurement matrices. Even with the difference in motor configurations and the slight difference in solar radiation between 9°N and 15°N, this is a good engineering approximation of the "same".

As a source of interest, and in the interest of completeness Fig. 23 is included to show the month by month cumulative probability distribution for the center of the rocket motor at Subic Bay. It is of interest to note the small varience shown in temperature value between the highest and the lowest temperatures. It stands to reason that the center of

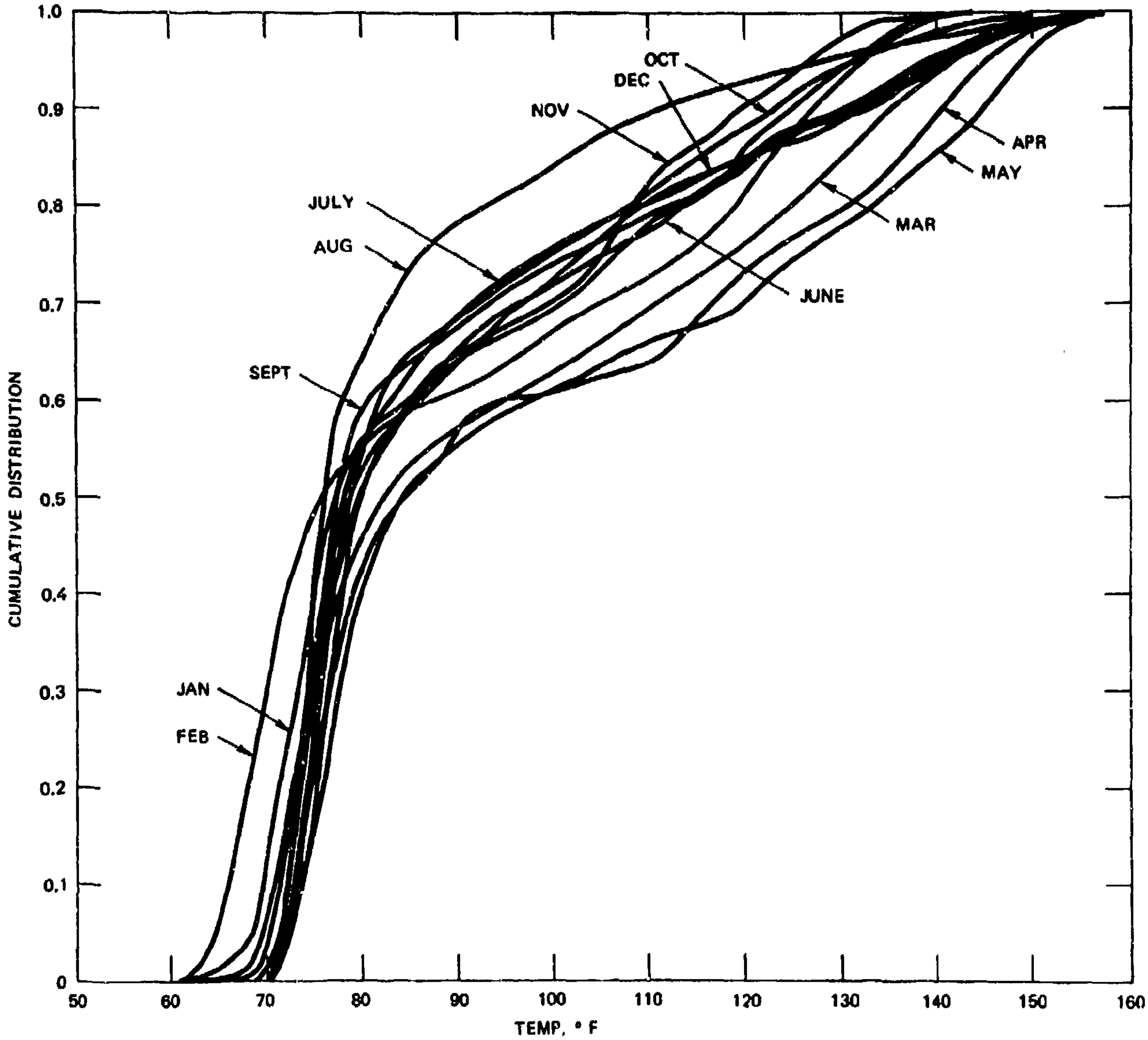


FIG. 20. Cumulative Distribution of ASROC Container Skin Temperatures at Subic Bay for 1970.

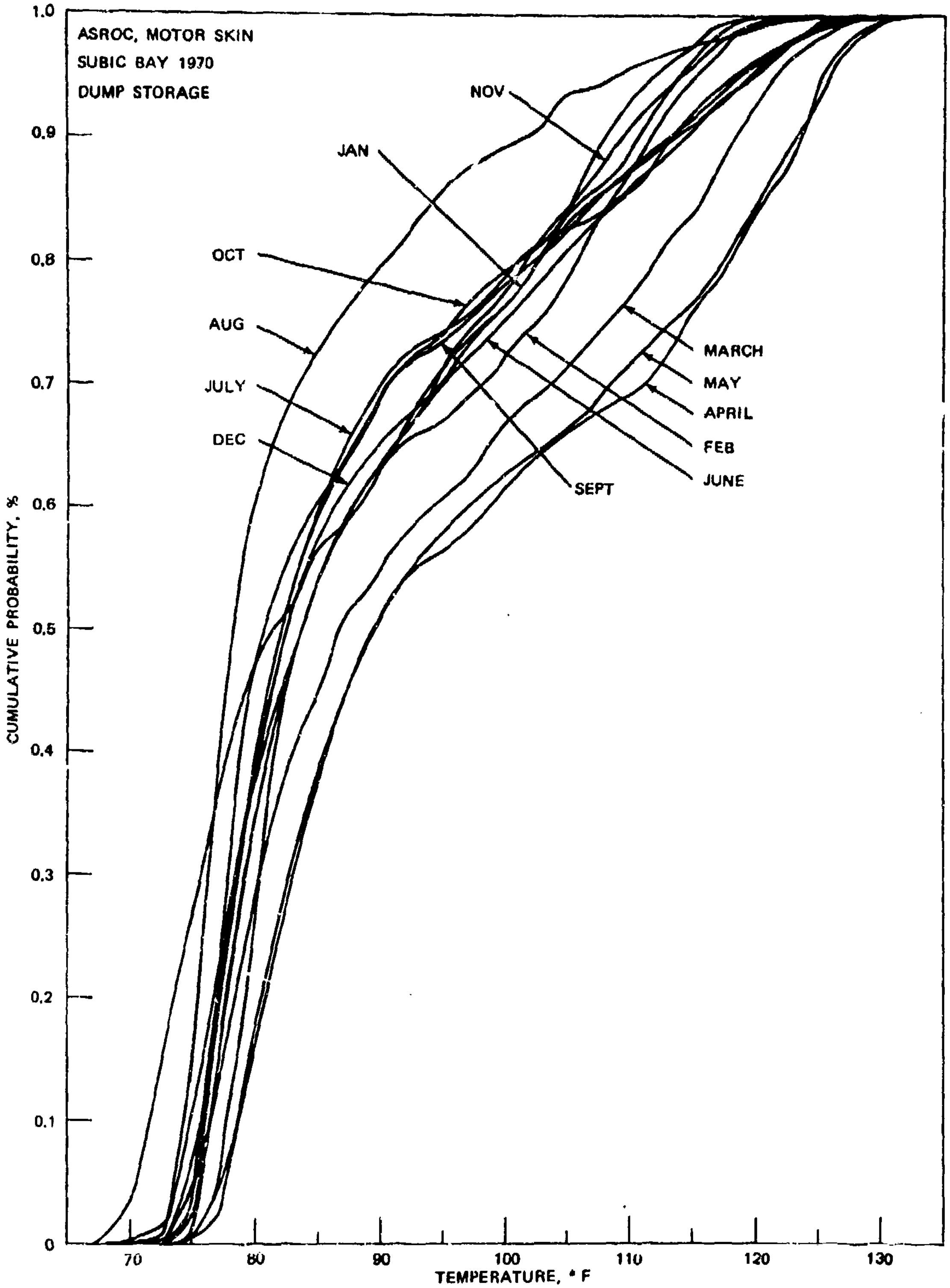


FIG. 21. Cumulative Distribution of ASROC Motor Skin Temperatures at Subic Bay for 1970.

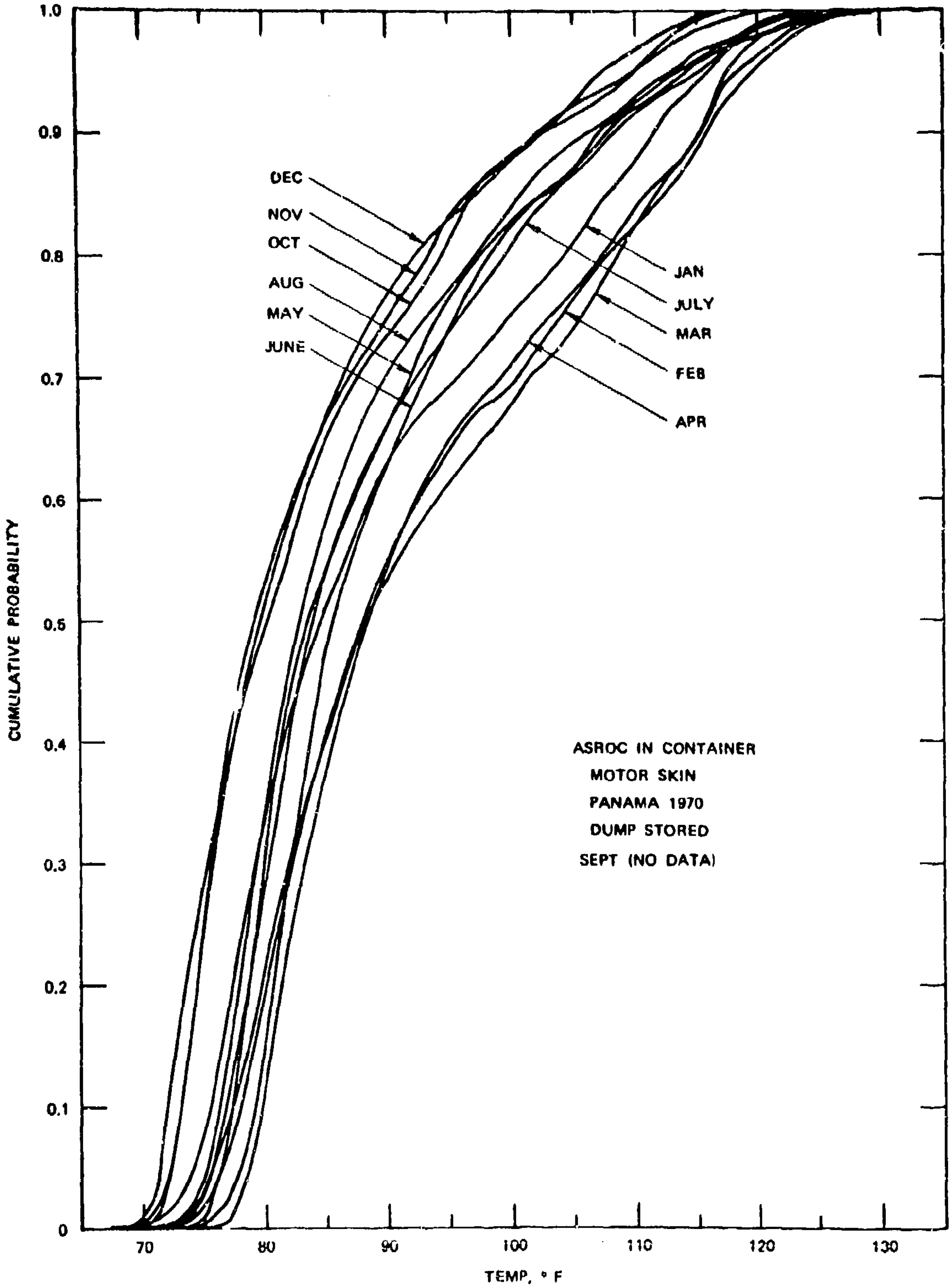


FIG. 22. Cumulative Distribution of ASROC Motor Skin Temperatures at Fort Clayton for 1970.

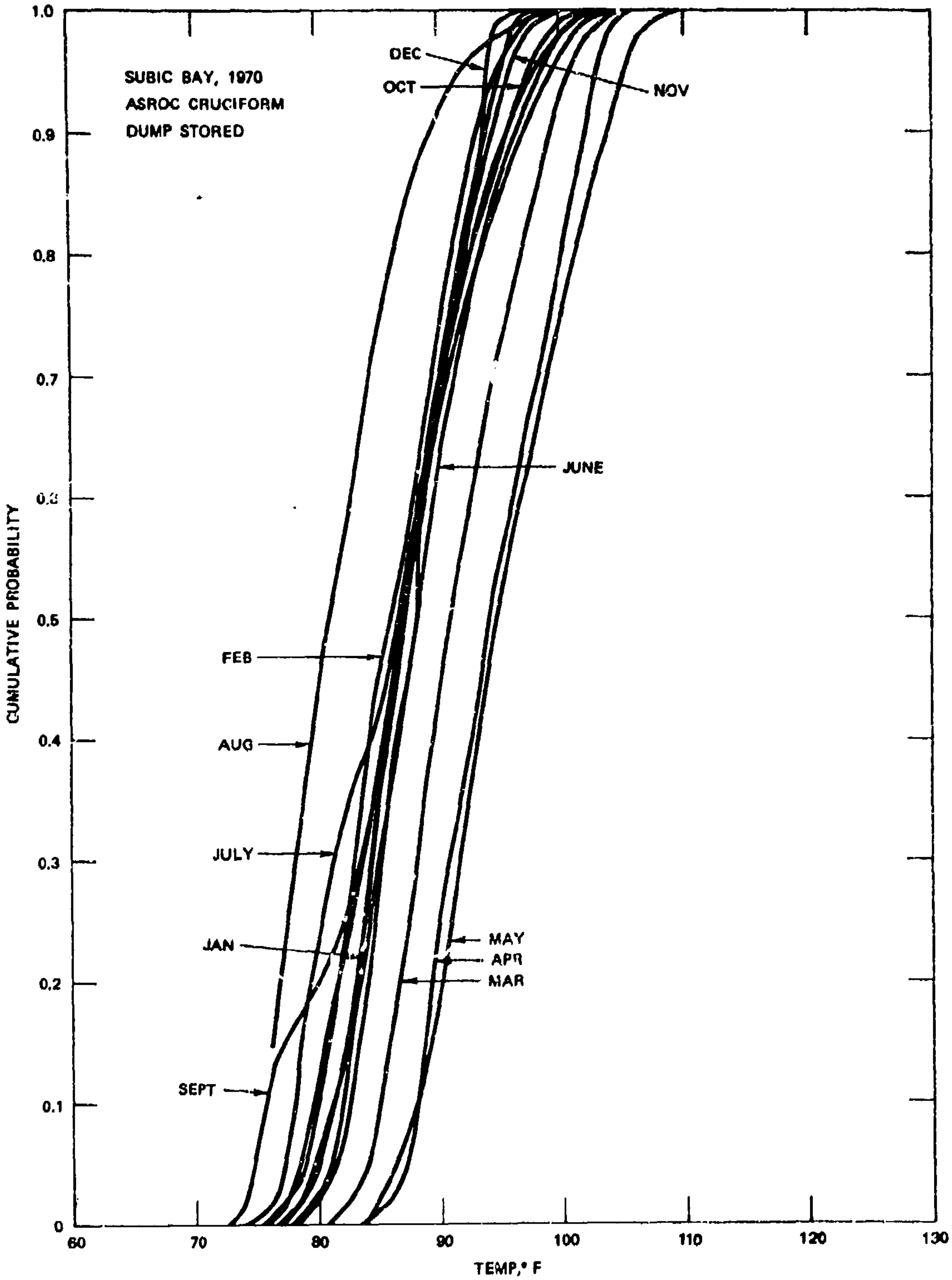


FIG. 23. Cumulative Distribution of Center of the ASROC Rocket Motor Grain Temperatures at Subic Bay for 1970.

even a 100-pound rocket motor will not exhibit much temperature change in a variable primary forcing function situation. Again it must be remembered that Fig. 18 and 19 showed that this thermocouple reported maximum temperature at about sundown, not at solar noon as was the case with the shipping container.

The above is of extreme importance when the design of internal missile parts or components is undertaken. A knowledge of the location of the particular component could well determine a lower temperature design limit, and hence result in a cost savings that would otherwise not be attainable.

Figure 24 is presented to compare the difference in year to year responses to dump storage exposure. As can be seen the response of the motor skin during 1969 was nearly identical to that during 1970. The difference between the two curves throughout their entire length is only a few degrees at the most. Again, in engineering terms, this difference is negligible.

ASROC Tropical Data Summary

Due to the large amount of data presented on the 12-inch diameter portion of the experiments, this section summary is present to recap the most usable data so that the casual reader can have an easy point of ready reference. The most usable information is the yearly accumulation of temperatures by hours for the shipping container, and the missile skin and center of the missile while in the container, at Subic Bay. This set of circumstances is shown together in Fig. 25, which is a summary of the information in Fig. 20, 21, and 23. Figure 26 is the summary of similar information for Panama. Only the missile skin and missile center profiles are presented because of a lack of confidence in the reported measurements for the shipping container surface.

The Fig. 26 information should be used by the designer when in need of 12-inch diameter high density thermal information.

Something should be said about the indicated "three sigma" points as revealed in Fig. 25 and 26. For the tropics, the temperature value that corresponds to 99.85% of all temperature measurements on an hourly basis during the year is found on the curves displayed in Fig. 25 and 26 at 0.9985 cumulative probability. The three sigma values for shipping container top surface from Fig. 25 would be about 155°F; the encased missile surface about 130°F, and the center of the missile about 110°F. In Fig. 26, the values are about 125°F for missile skin and 107°F for the center of a containerized, dump-stored missile. It is quite evident that the 0.9985 point is only one arbitrary point on a continuous curve. It may be that some other point on the curve is of more value to the designer. The 0.9985 point is equivalent to 0.9985 x 8760 or about 13 noncontinuous hours of possible exposure per year at or above the

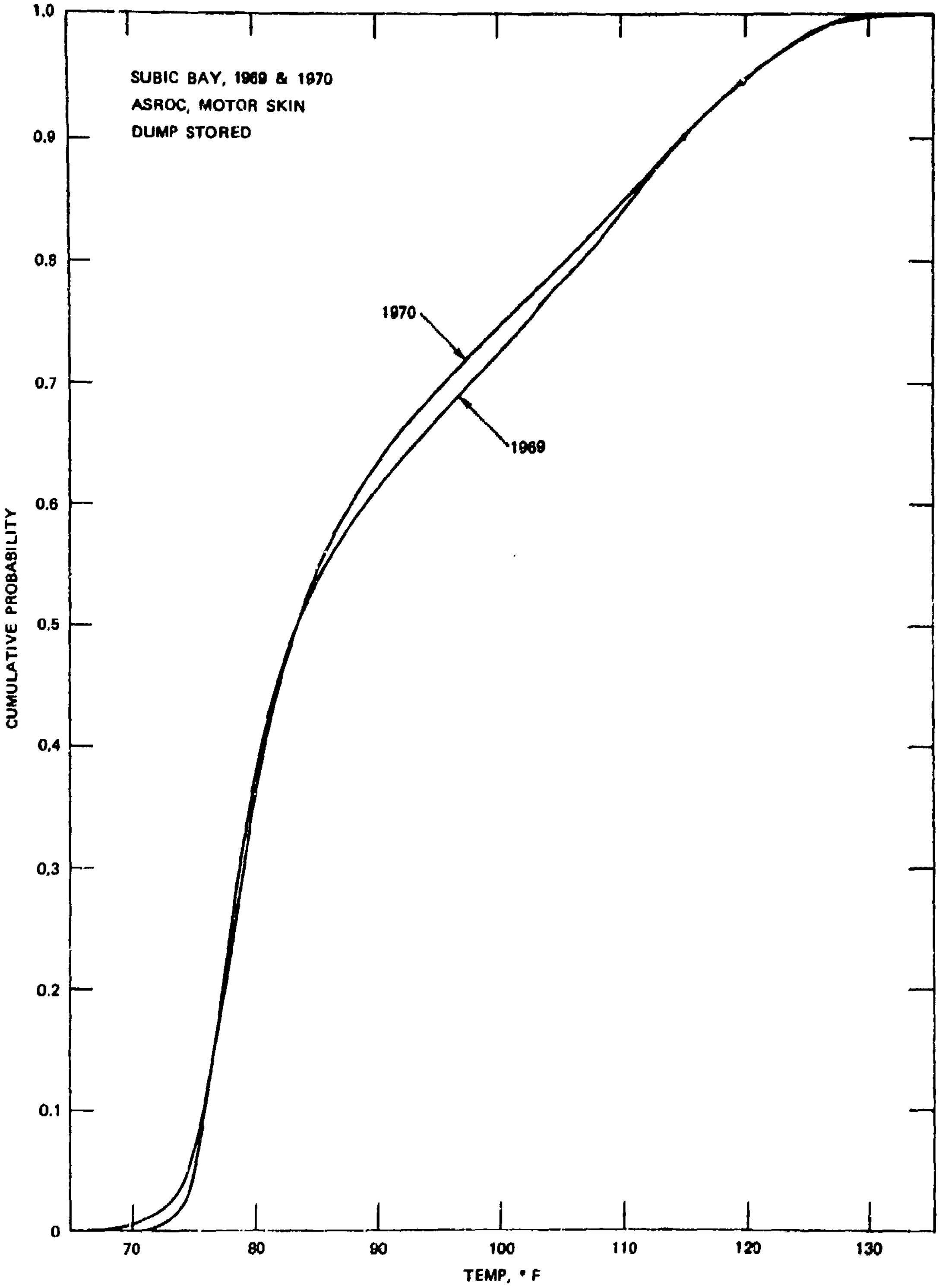


FIG. 24. Comparison of 1969 and 1970 ASROC Rocket Motor Skin Temperatures at Subic Bay.

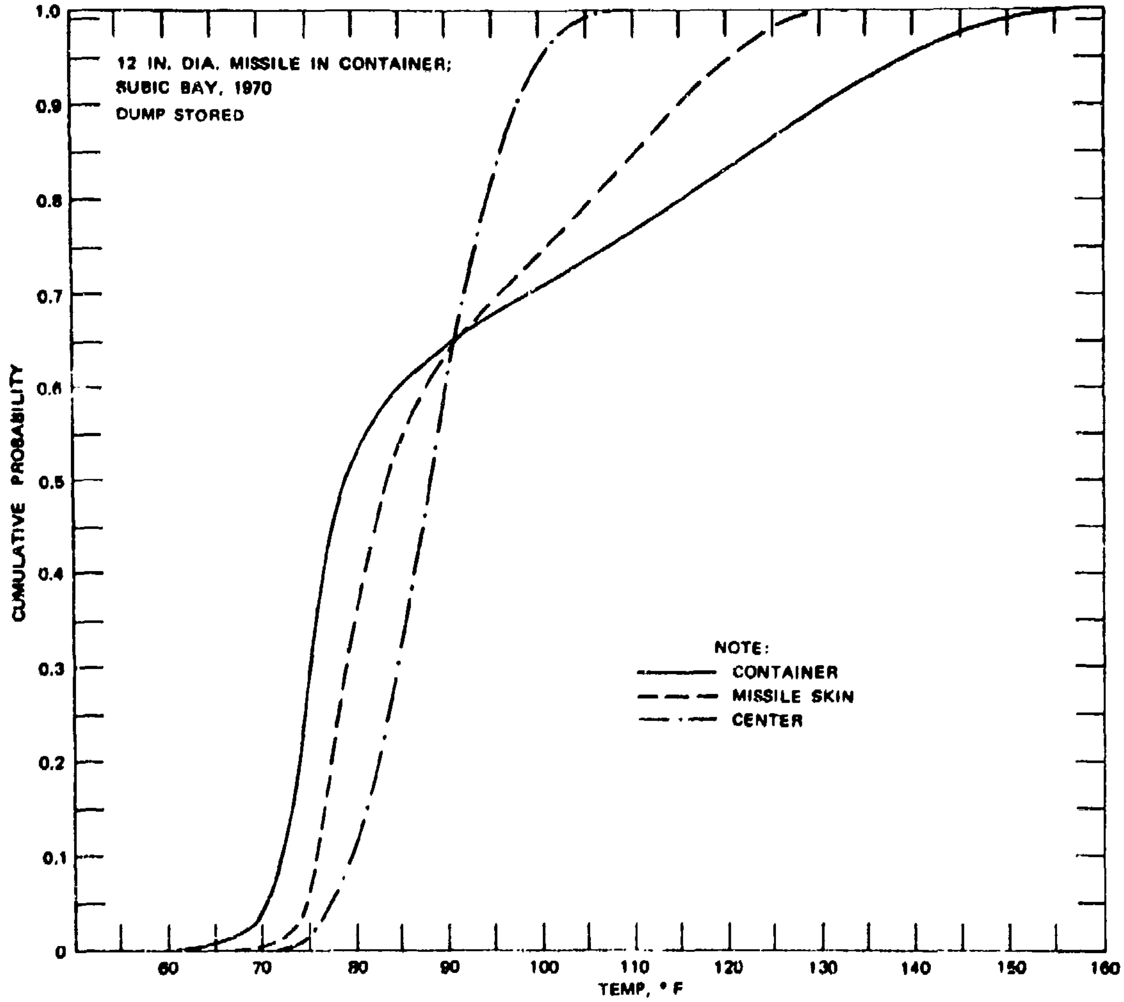


FIG. 25. Cumulative Distribution Summary of Dump Stored ASROC Temperatures at Subic Bay for 1970.

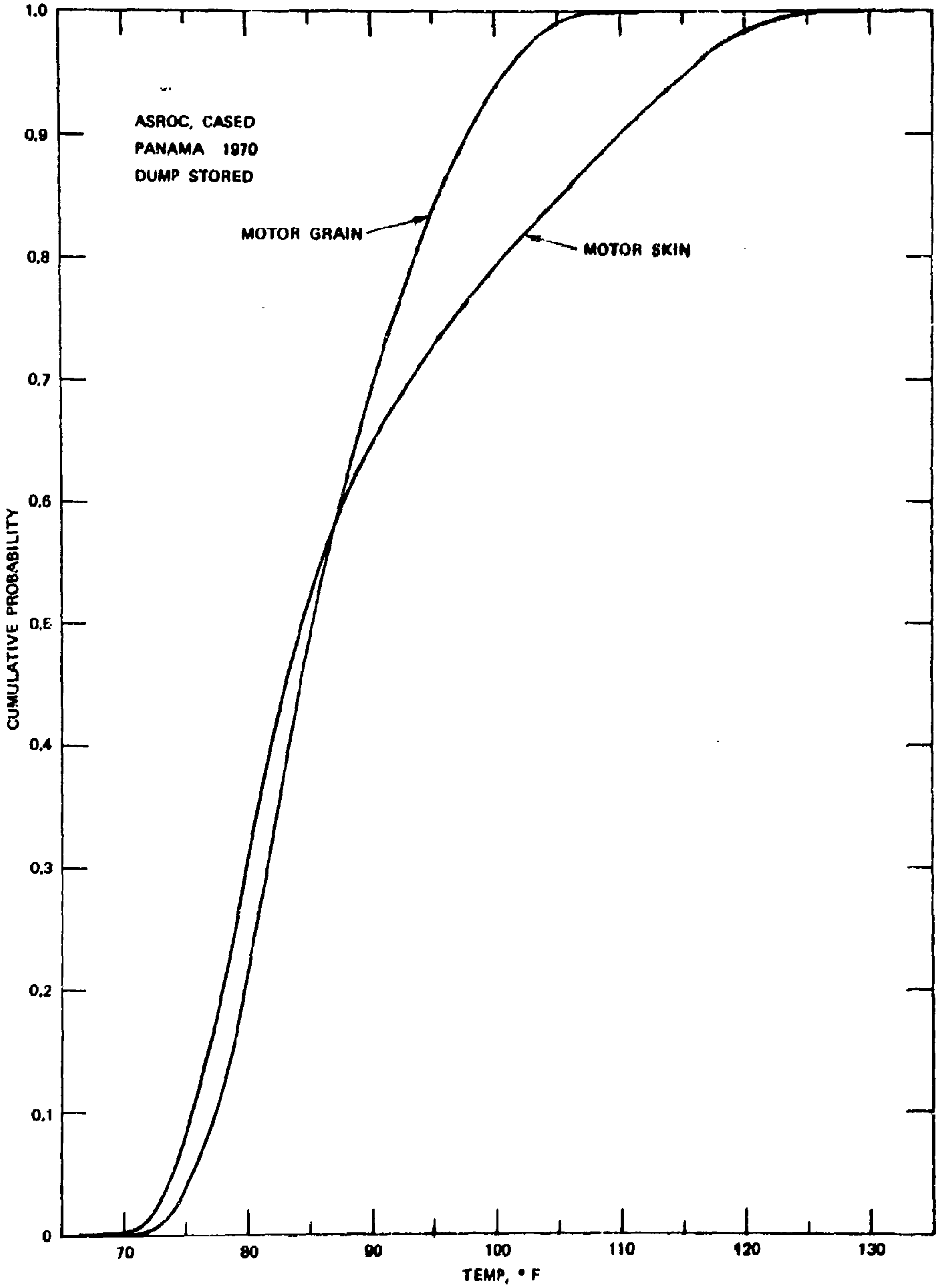


FIG. 26. Cumulative Distribution Summary of Dump Stored ASROC Temperatures at Fort Clayton for 1970.

temperature values given above. In general, this type of curve is useful if it is kept in mind that where the curve is vertical, or almost so, there are many data points; where the curve is flattening out, there are few data points. Therefore, as long as a temperature value is chosen from the flatter portion of the curve the designer should be relatively safe.

Desert Cumulative Distribution

The cumulative probability plots derived from desert continuous ordnance exposure indicate that the monthly spread of ordnance temperatures is somewhat different than in the tropics. Also, the maximum ordnance temperatures are slightly higher on a yearly basis. Figure 27 is the desert counterpart to Fig. 21 and 22 for the tropics. Notice that the monthly temperature spread in the desert is much larger, particularly at the low end of the scale. This is primarily due to the yearly variances in desert night-time temperatures. The monthly heat progression evident in Fig. 27 indicates that extended cycles of maximum ordnance exposure will probably occur only in July and August. These are the only two months where the minimum ordnance temperatures are above 75°F.

Plots for the center of the missile are shown in Fig. 28. This figure is the desert equivalent of the Fig. 23 tropical situation. As would be expected, temperatures plotted for the desert situation are slightly higher. Notice that the thermal lag has to some extent dampened out the diurnal effects such that the general curves shapes of Fig. 23 and 28 are more similar than the "motor skin" situations. However, the yearly spread of monthly ordnance temperature values shows a difference between months.

For completeness the desert counterpart of Fig. 20 for the tropics is given in Fig. 29. Again, the temperature spread is much greater in the desert and the maximum temperatures are higher. It is evident from Fig. 29 that the month of June has great heating potential in the desert.

The summation of Fig. 27, 28, and 29 in the yearly cycle context is shown in Fig. 30. This figure is the desert counterpart to the Fig. 25 display for the tropics. It is interesting to compare these two figures. Notice that Fig. 30 shows a cumulative probability at 1.0 about 10°F higher than that for Fig. 25 for all three situations presented. The difference in the minimum values in Fig. 30 is pronounced when compared with Fig. 25. It is the spread of ordnance temperatures over the year long interval in Fig. 30 that gives the three curves their gentle slope in comparison with the more abrupt situation of Fig. 25.

The "three sigma" points for the desert stored missile are also higher than for the tropical situation. As can be seen in Fig. 30, they are approximately 166°F for the top wall of the shipping container, 137°F for the motor skin, and 115°F for the center of the missile.

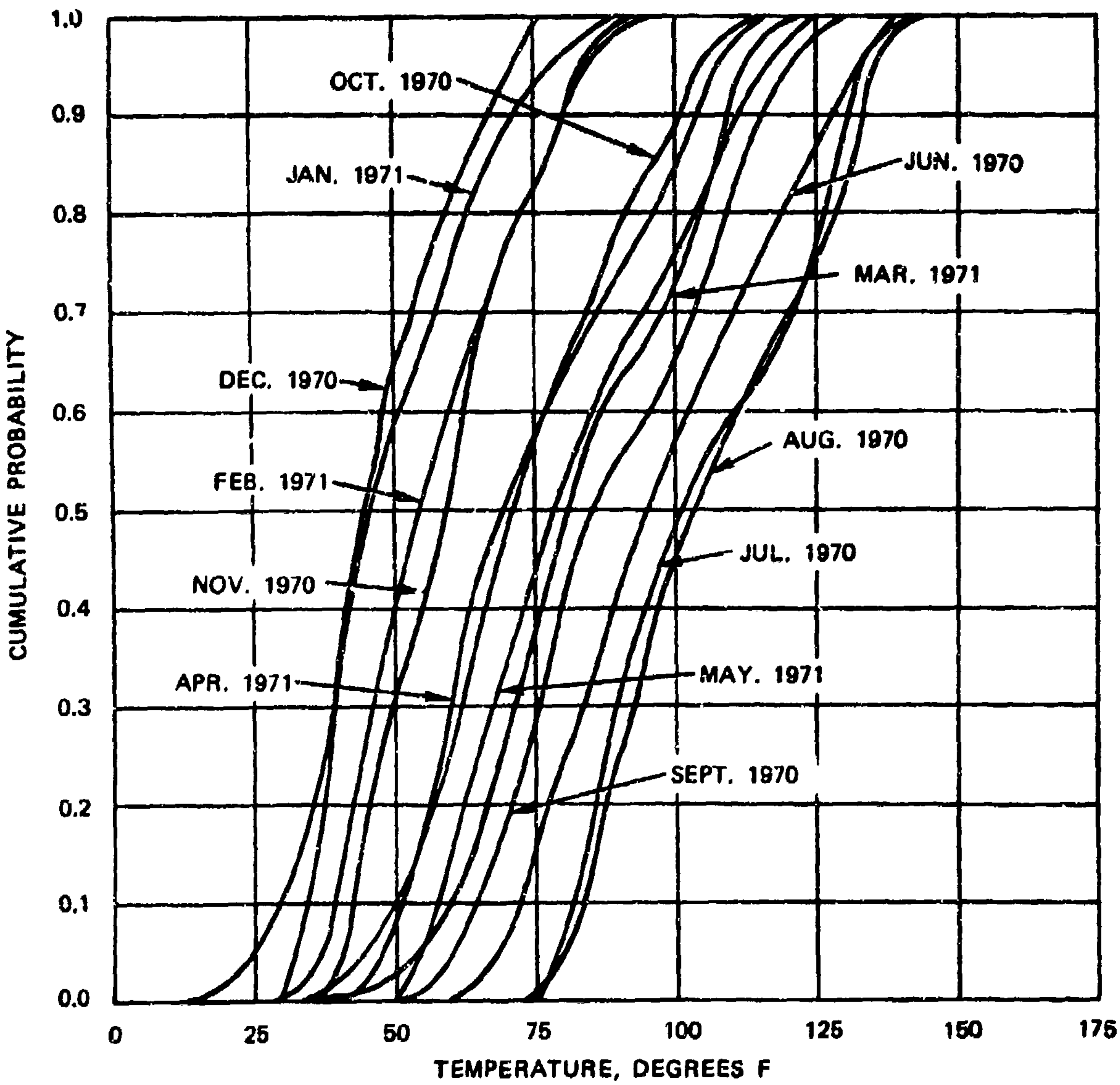


FIG. 27. Cumulative Distribution of ASROC Motor Skin Temperatures at NWC - June 1970 Through May 1971.

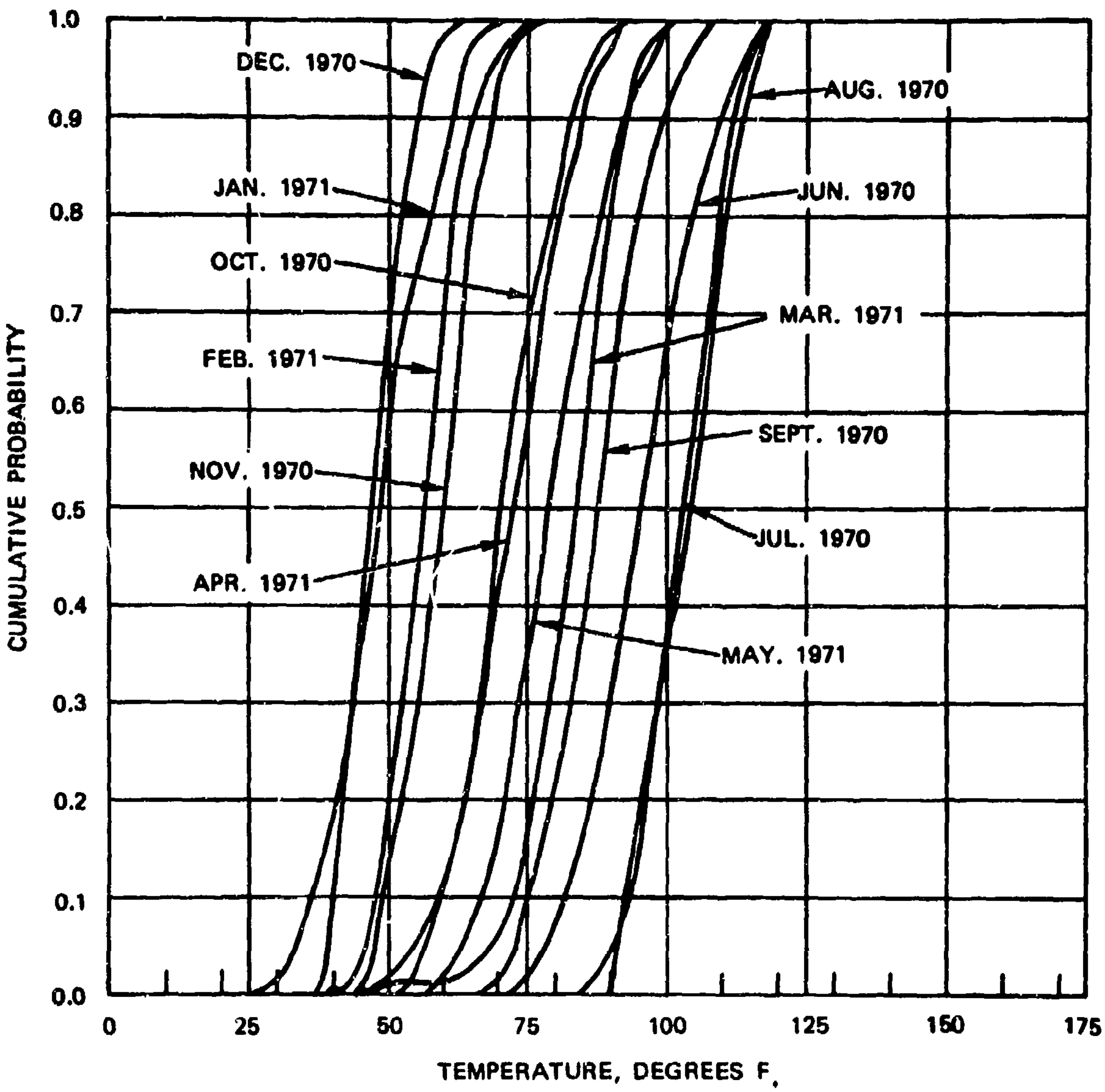


FIG. 28. Cumulative Distribution of ASROC Center of the Grain Temperatures at NWC - June 1970 Through May 1971.

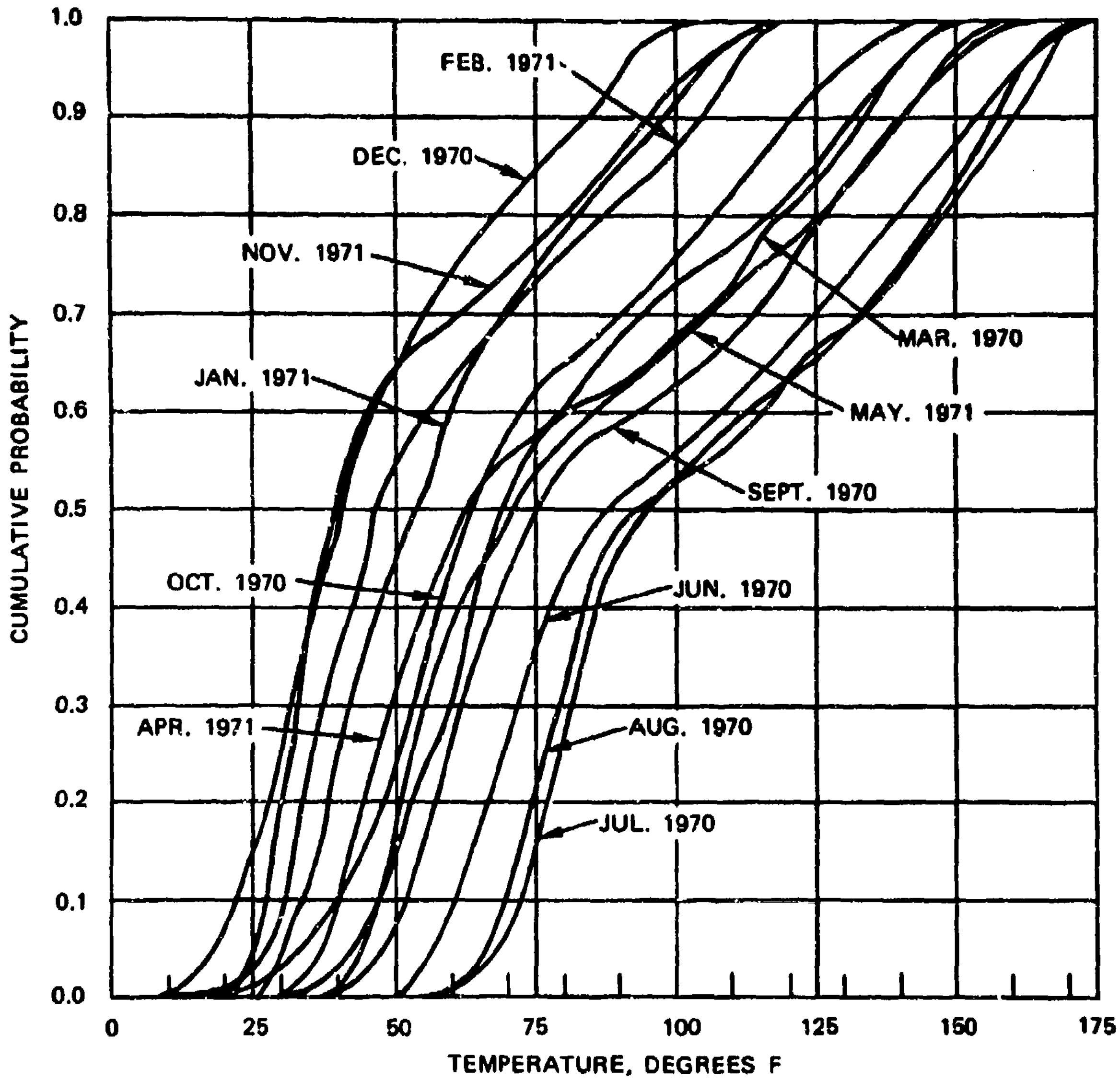


FIG. 29. Cumulative Distribution of ASROC Container Skin Temperatures at NWC - June 1970 Through May 1971.

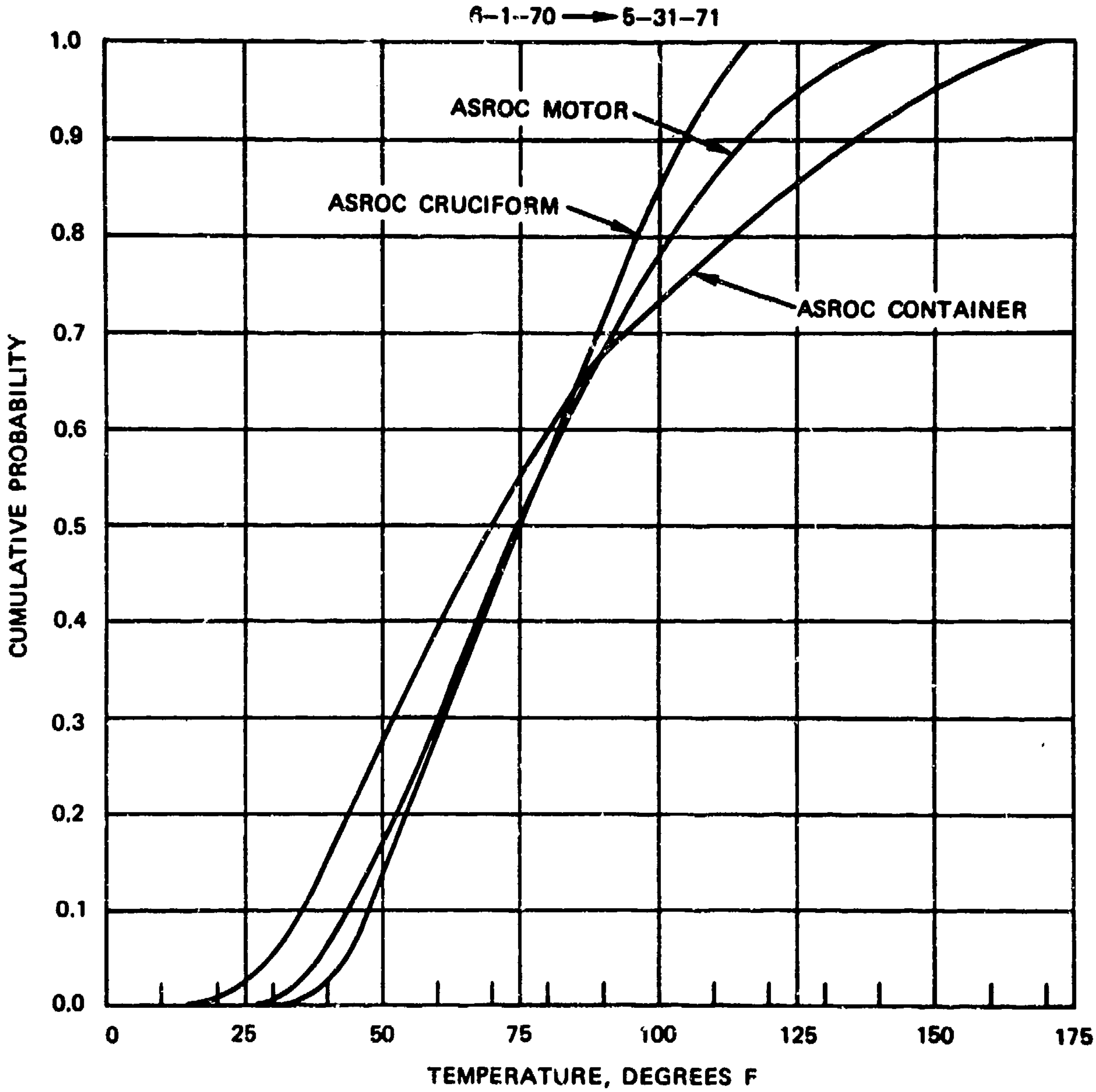


FIG. 30. Cumulative Distribution of Dump Stored ASROC Temperatures at NWC - June 1970 Through May 1971.

A comparison is needed to bring the maximum type day into context with the cumulative probability concept. When discussing the diurnal cycle to be expected for ordnance in containers, Fig. 17 which was derived from the ASROC exposed at China Lake, was given. By taking the 162°F maximum shipping container skin temperature, 130°F maximum motor skin temperature, and 111°F maximum motor center temperature and cross-checking these values on Fig. 30, an indication of the severity of this day plot can be obtained. As can be seen by observing the container temperature curve, in a 1 year period of 8760 hours, only 1.6% or about 140 hours in that year will have a temperature value in excess of 162°F. The Fig. 30 equivalent for 130°F on the top of the motor is 0.970 cumulative probability, or at or below 130°F 97% of the time in this 1 year. The center of grain value is 0.958 cumulative probability.

The interesting part of the example is that for this "textbook" day, the maximum temperature values at the three measured points represent three different cumulative probabilities. "Common sense" would dictate that a day should give the same cumulative probability for all measured points. However, the fact that the shipping container cumulative probability value of 0.984 is higher than the motor wall (0.970) and the center of the grain probabilities (0.958) indicates that the low temperature base for this time period was not high enough to allow the containerized motor to experience a "maximum" potential exposure. However, this is more representative of actual conditions. It is rare to have a 3 sigma day comprized of the same 3 sigma values at all stations of measurement on a missile. In contrast, the values shown in Fig. 18 and 19 for the tropics compare very well. The maximum temperature from Fig. 19 gives a shipping container cumulative probability of 0.999, motor skin value of 0.999, and a motor center value of 0.99. The equivalent values for Fig. 18 are about 1.0, 0.98, and 0.90, respectively. These values were derived from Fig. 25 which is only valid for tropical exposure.

SPARROW DATA

The Sparrow Mk 6 Mod 0 rocket motor was used as the source for 8-inch-diameter missile data. The Mk 6 was initially chosen because of the ready availability of hardware, and its required use in Sparrow aerodynamic heating work. As the measurement series was extended, use of the Mk 6 motor hardware continued, but the inert propellant grain was replaced with sand. The typical mode of Sparrow exposure can be seen in Fig. 9. The containerized Sparrow is the dark one in the right center of the photograph. Notice that it has a shipping container of the same design as the larger ASROC. This shipping container, though not standard throughout the logistic system, was chosen for use in these measurements because of its similarity to the ASROC container.

The response of the Sparrow under the same situations as previously reported for ASROC in Fig. 10, 11, and 12 is shown in the series of bar graphs presented as Fig. 31, 32, 33, and 34. The ASROC and Sparrow data can be directly compared to provide an indication of the differences in response of the two units (both equipped with a stand-off grain configuration) exposed to the desert environment.

Figure 33 gives a good example of problems that are encountered during a measurement series. It is quite obvious that in early February an aircraft was moved into the measuring site too close to the containerized Sparrow motor. During the day the unit was exposed to the sun until just before noon when it was covered by the shadow of the aircraft's wing. As can be seen, this drastically reduced the maximum exposure of the measured unit. This problem does, however, give a good indication of the value of even a simple open shelter to negate high ordnance temperatures. The missing data in Fig. 33 was necessitated by the use of this motor for other measurements.

For the sake of comparison of 8-inch and 12-inch diameter missiles, it was planned to use the day plot of the Sparrow rocket motor for 31 July 1969 (Fig. 35). This day was chosen so that a direct comparison could be made with the ASROC data shown in Fig. 17. However, the motor wall thermocouple on the Sparrow pulled loose during this time period and the data from this point were not representative. Therefore the comparison shown in Fig. 36 is presented. It is quite evident, on a statistical basis that the thermal exposures of the 8- and 12-inch-diameter missiles are for all intents and purposes identical.

The equivalent tropical situation is shown for ASROC, Sparrow, and a 5-inch-diameter Zuni rocket in Fig. 37. In this case, data from the motor skin thermocouples are presented. All the rocket motors were filled with oven-dried desert sand, and were therefore more representative of the case-bonded motor configuration than the stand-off grain configurations. It would seem logical that the smaller motor should get hotter than the larger one; however, in any case, the statistical displays of all three motors fall within a 10°F band. Also, none of the displays give values anywhere near the 165°F "specification" situation.

A cumulative probability plot for the 5-inch Zuni motor grain and motor skin is presented in Fig. 38, which is indicative of the tropical situation. Due to the smaller mass of the 5-inch motors and containers, the motor wall and center of motor cumulative probabilities are extremely similar. This may be indicative of a situation where the thermal gradient through the missile is of no consequence. It may be that motors smaller than 5 or 6 inches in diameter, when stored singly, do not have a high enough mass and consequently a thermal time constant to respond in the same manner as the 8- and 12-inch diameter missile. In any case, it seems evident that the majority of missiles must be designed to withstand

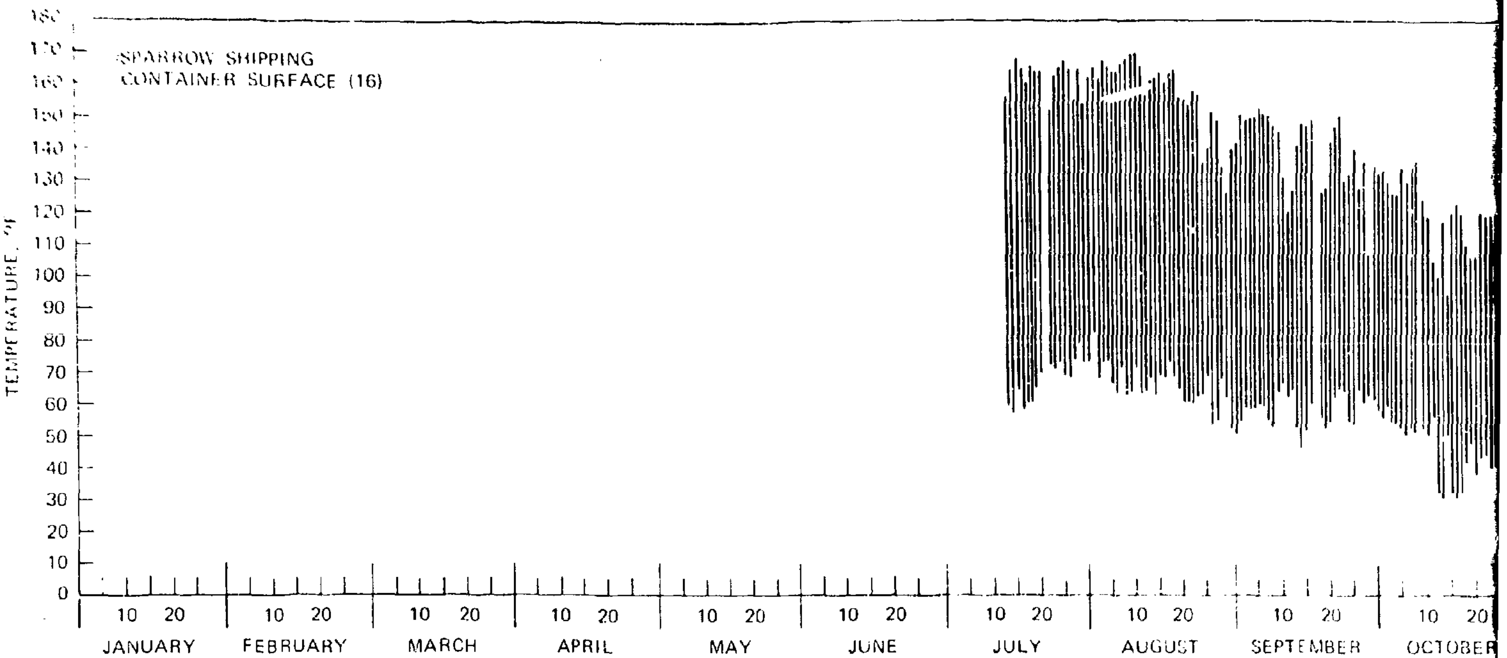


FIG. 31. Temperature Profile of Sparrow Shipping Container Skin Dump Stored at NWC

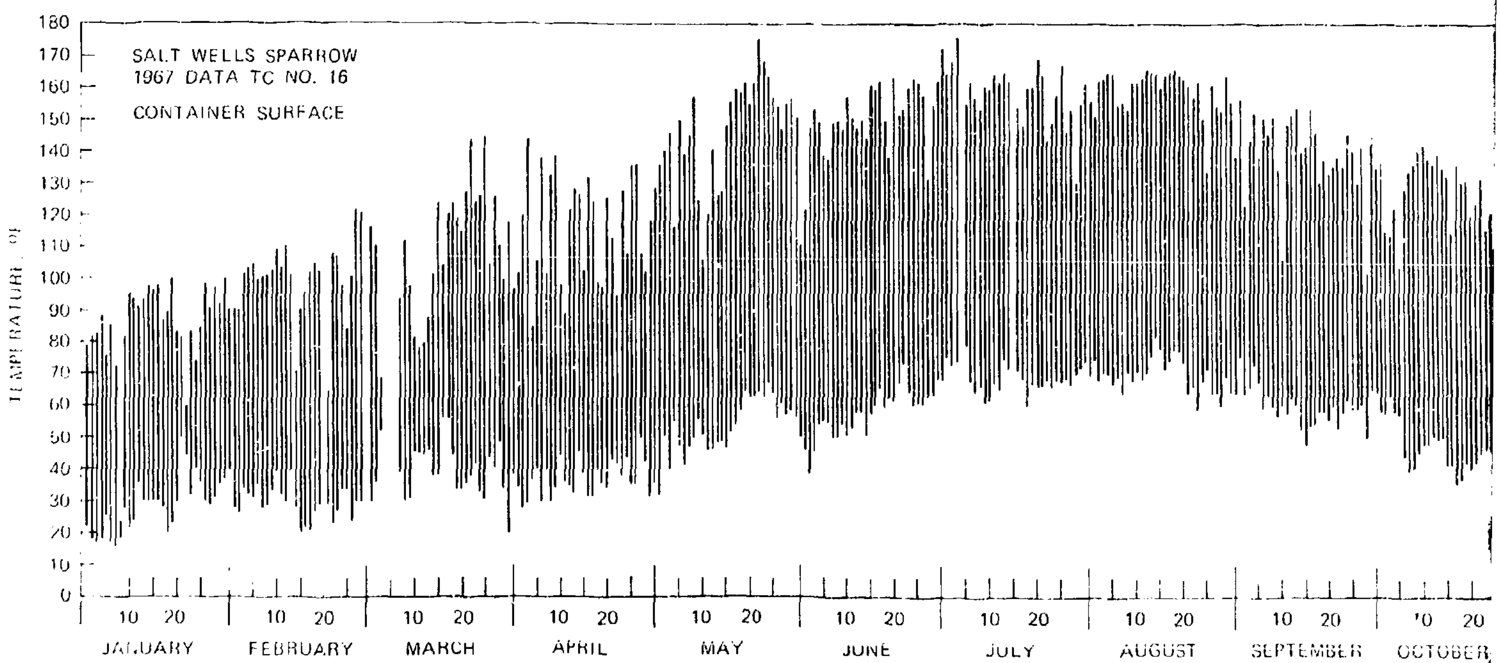
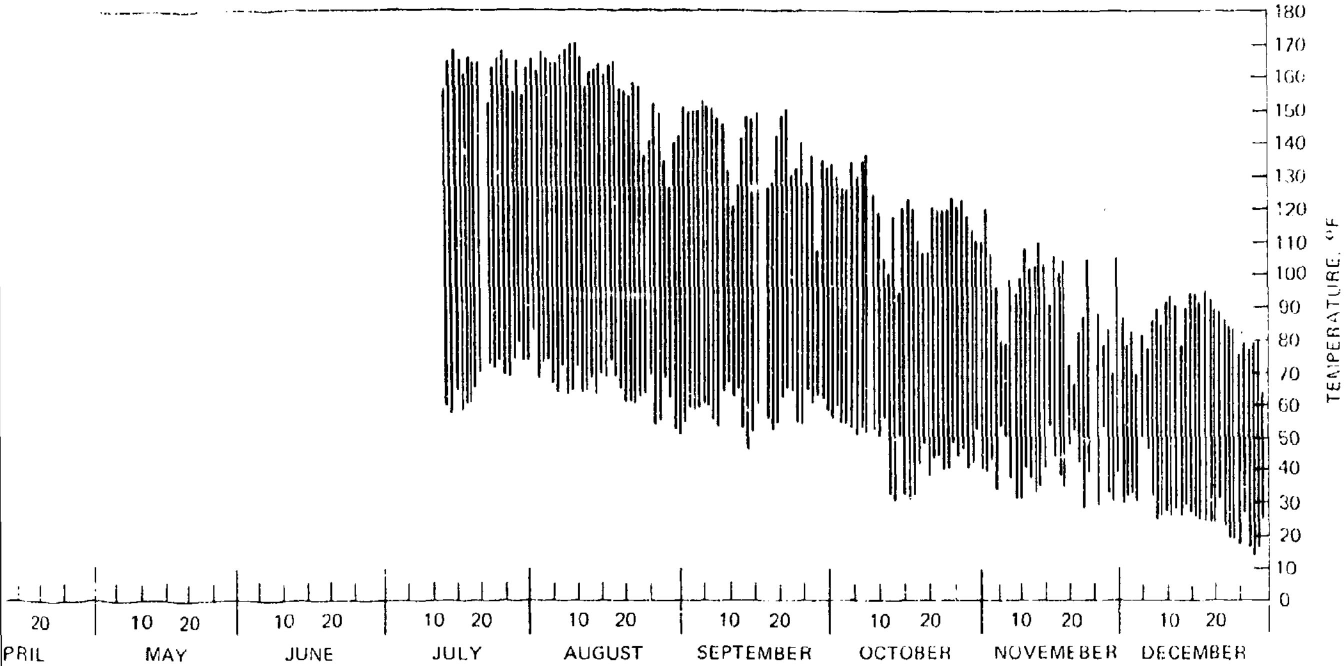
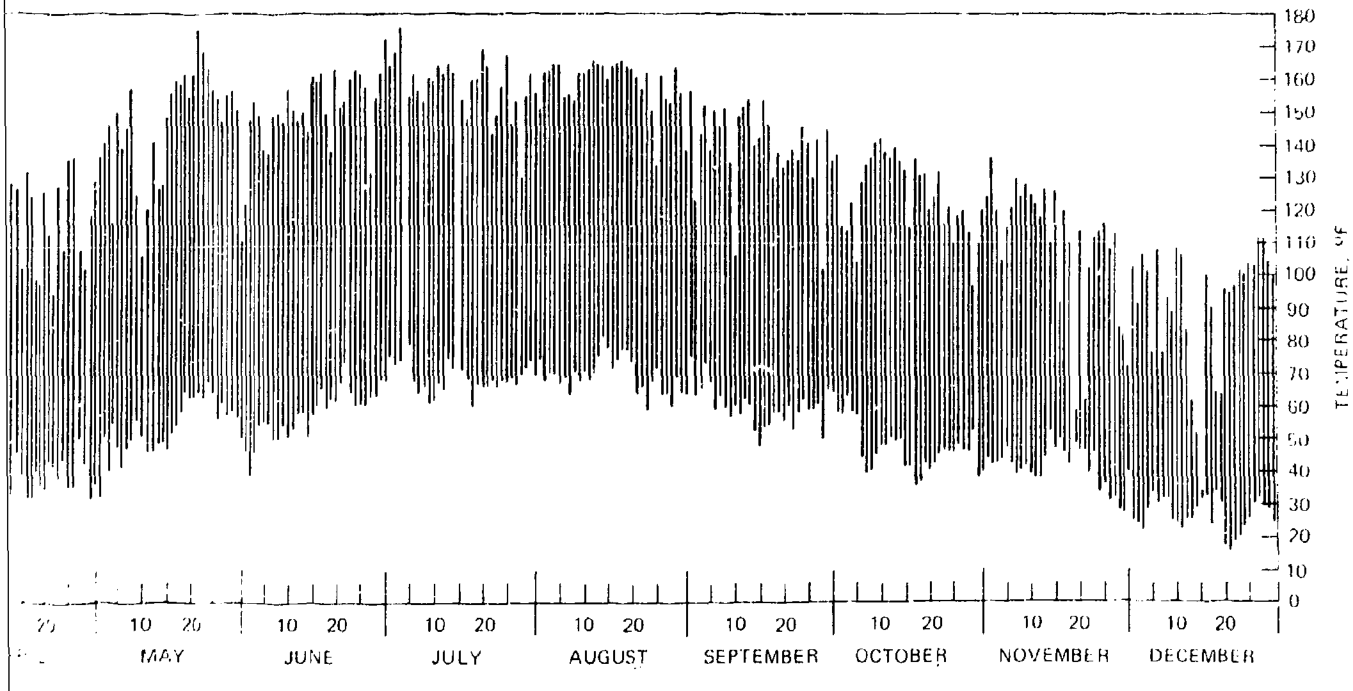


FIG. 32. Temperature Profile of Sparrow Shipping Container Skin Dump Stored at NWC



Profile of Sparrow Shipping Container Skin Dump Stored at NWC - 1966.



Profile of Sparrow Shipping Container Skin Dump Stored at NWC - 1967.

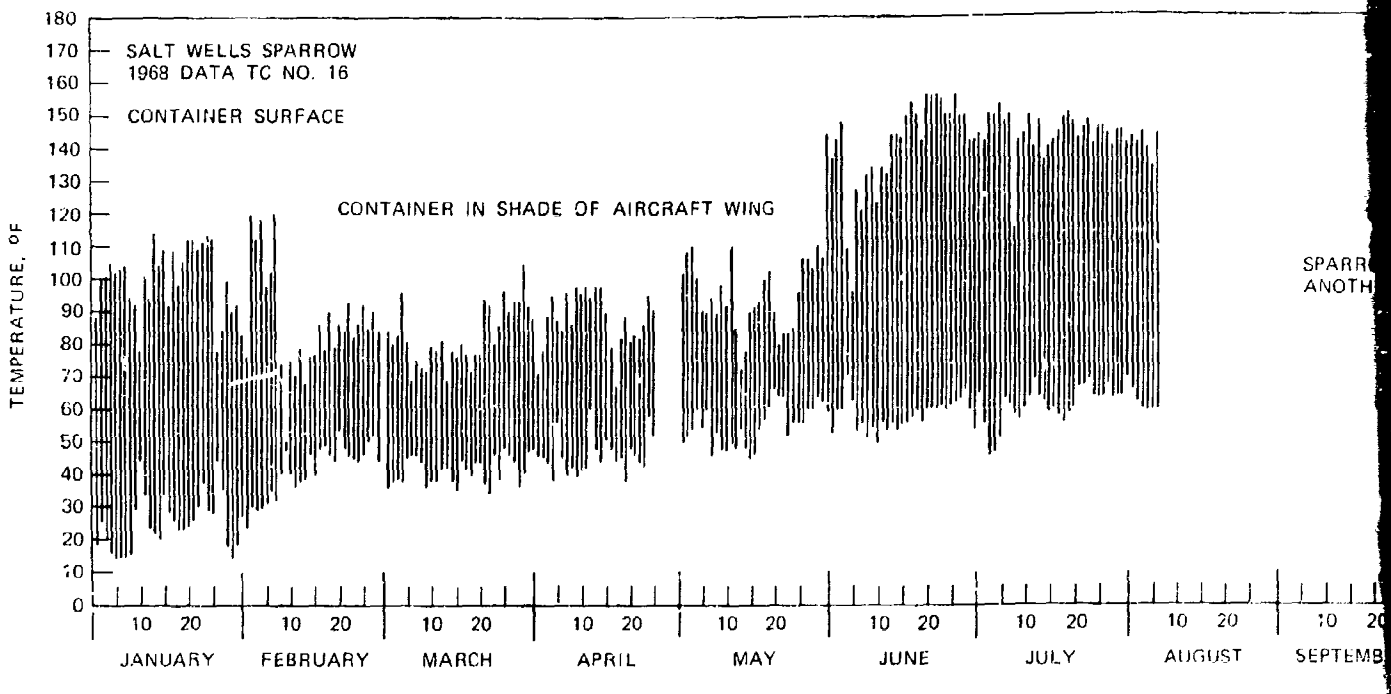


FIG. 33. Temperature Profile of Sparrow Shipping Container Skin Dump S

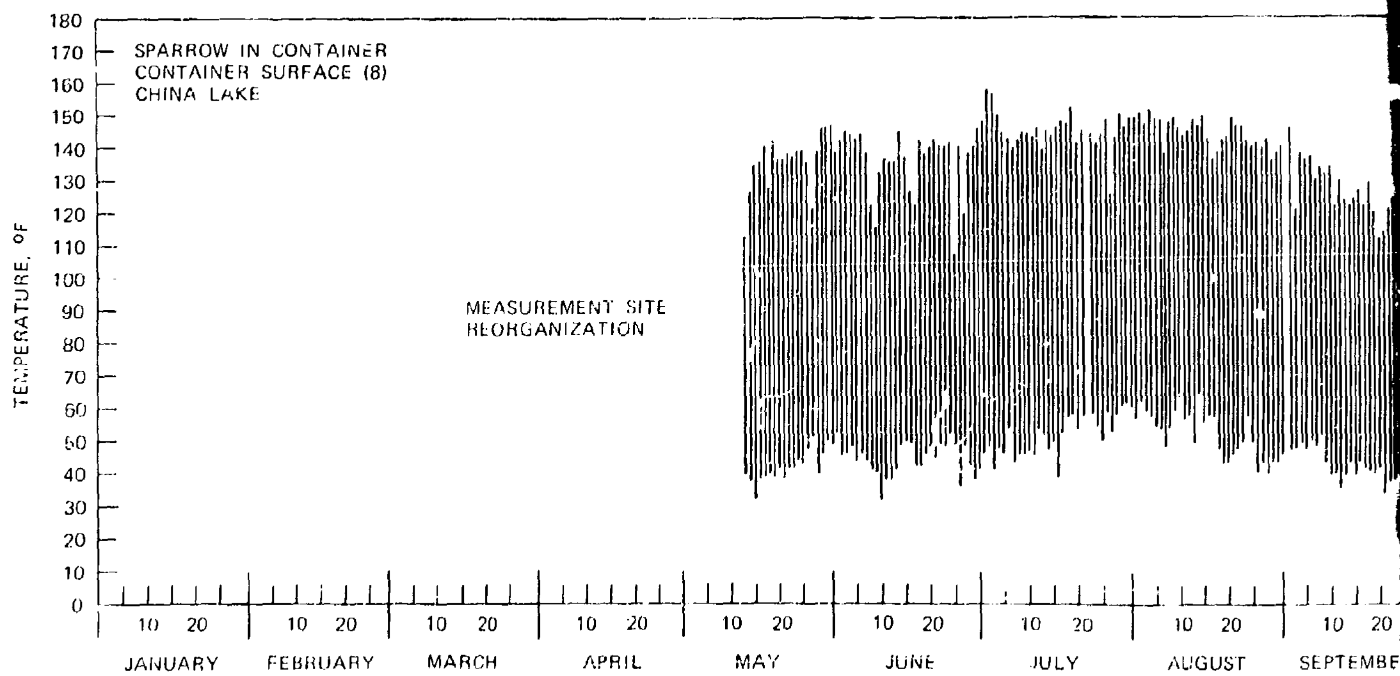
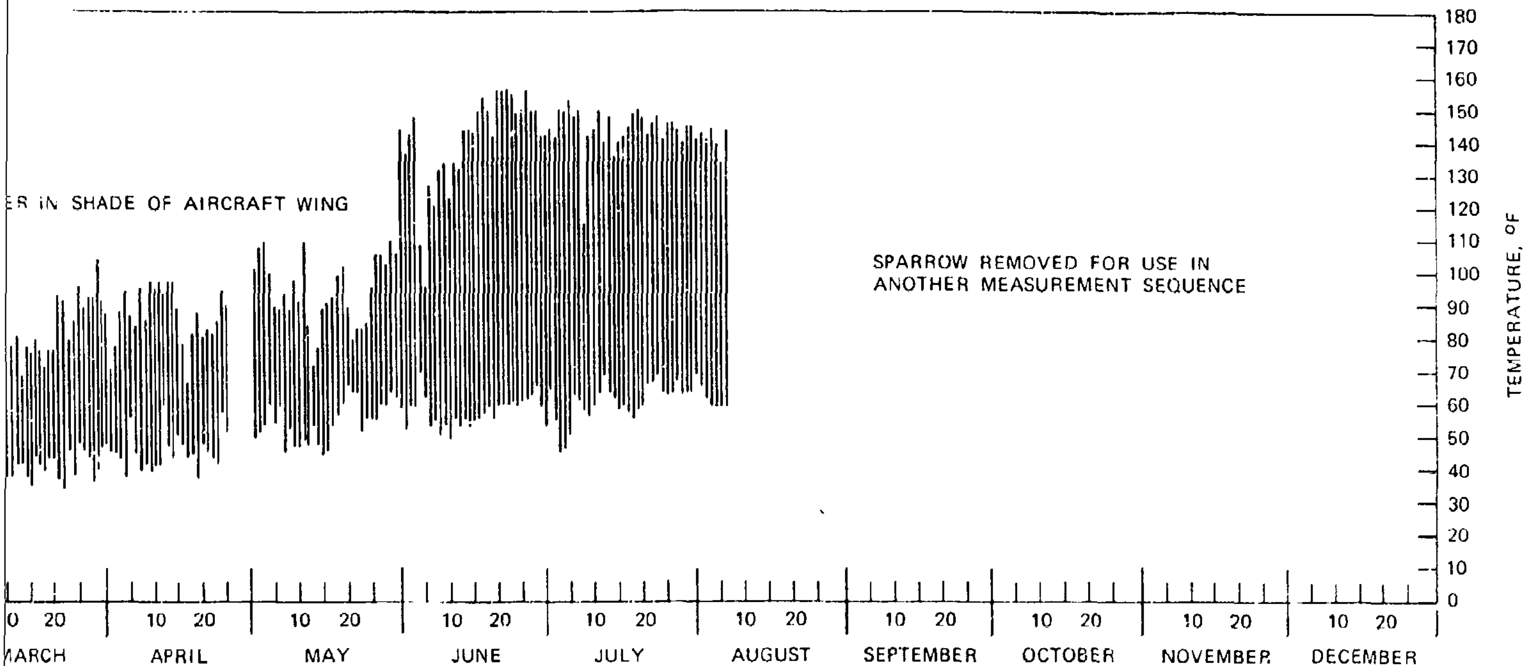
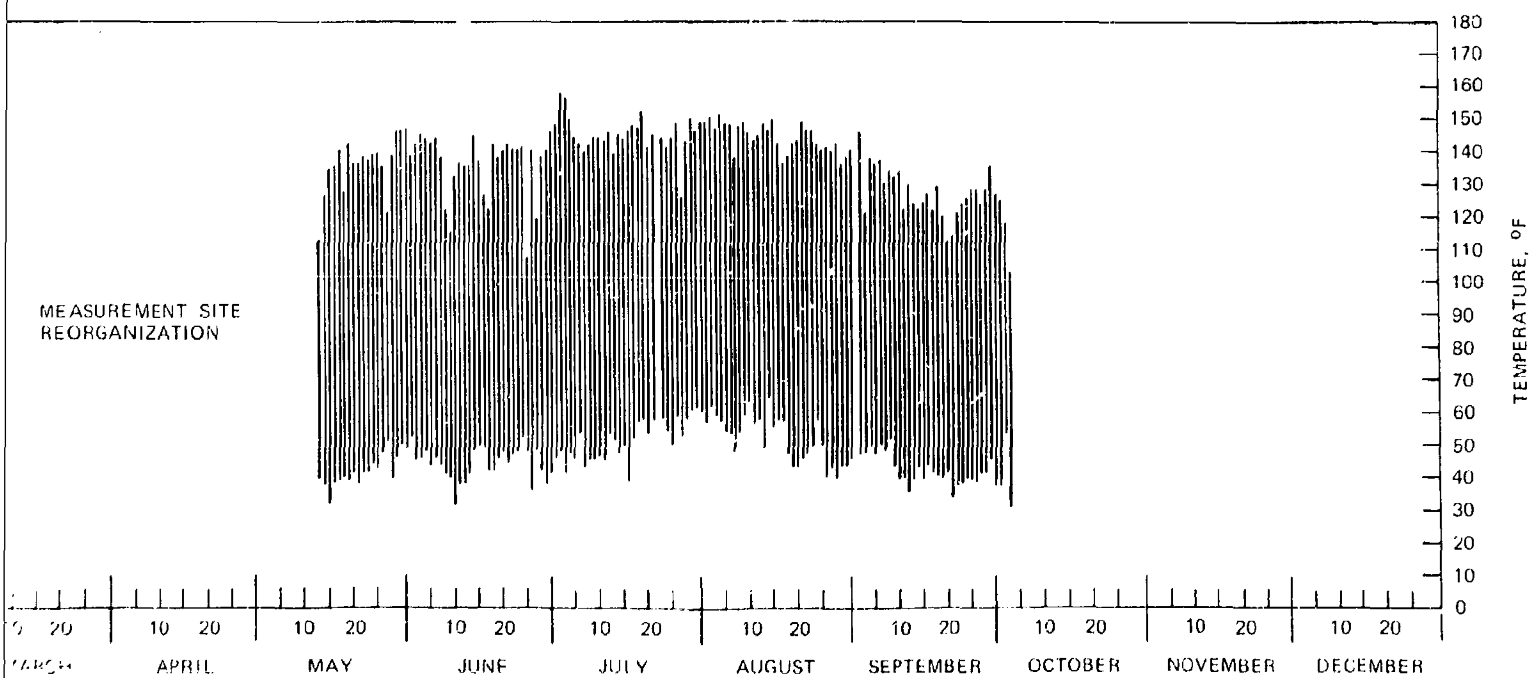


FIG. 34. Temperature Profile of Sparrow Shipping Container Skin Dump Sto



Temperature Profile of Sparrow Shipping Container Skin Dump Stored at NWC - 1968.



Temperature Profile of Sparrow Shipping Container Skin Dump Stored at NWC - 1969.

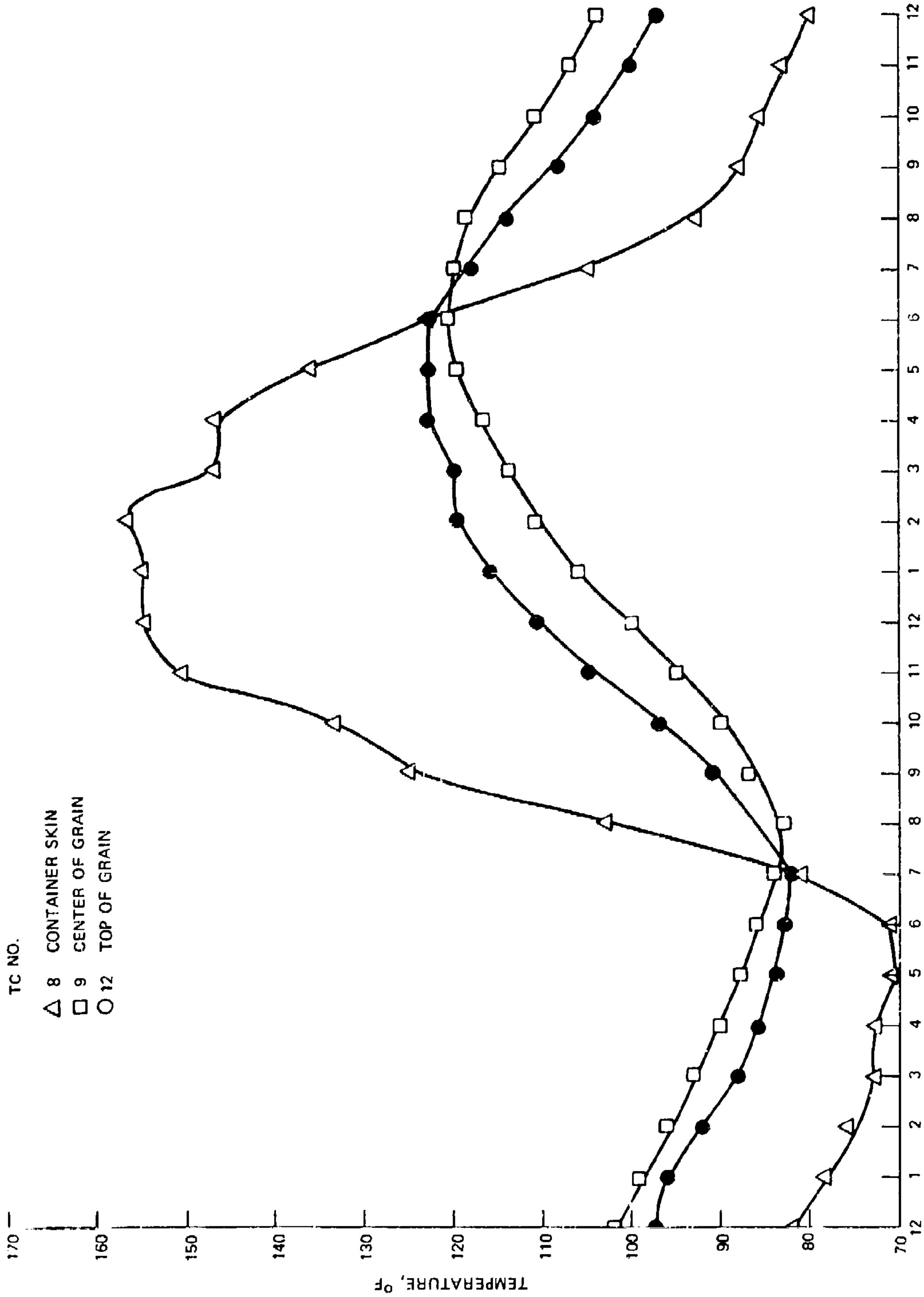


FIG. 35. Temperature Profile of Sparrow Motor and Container Dump Stored at NWC - 31 July 1969.

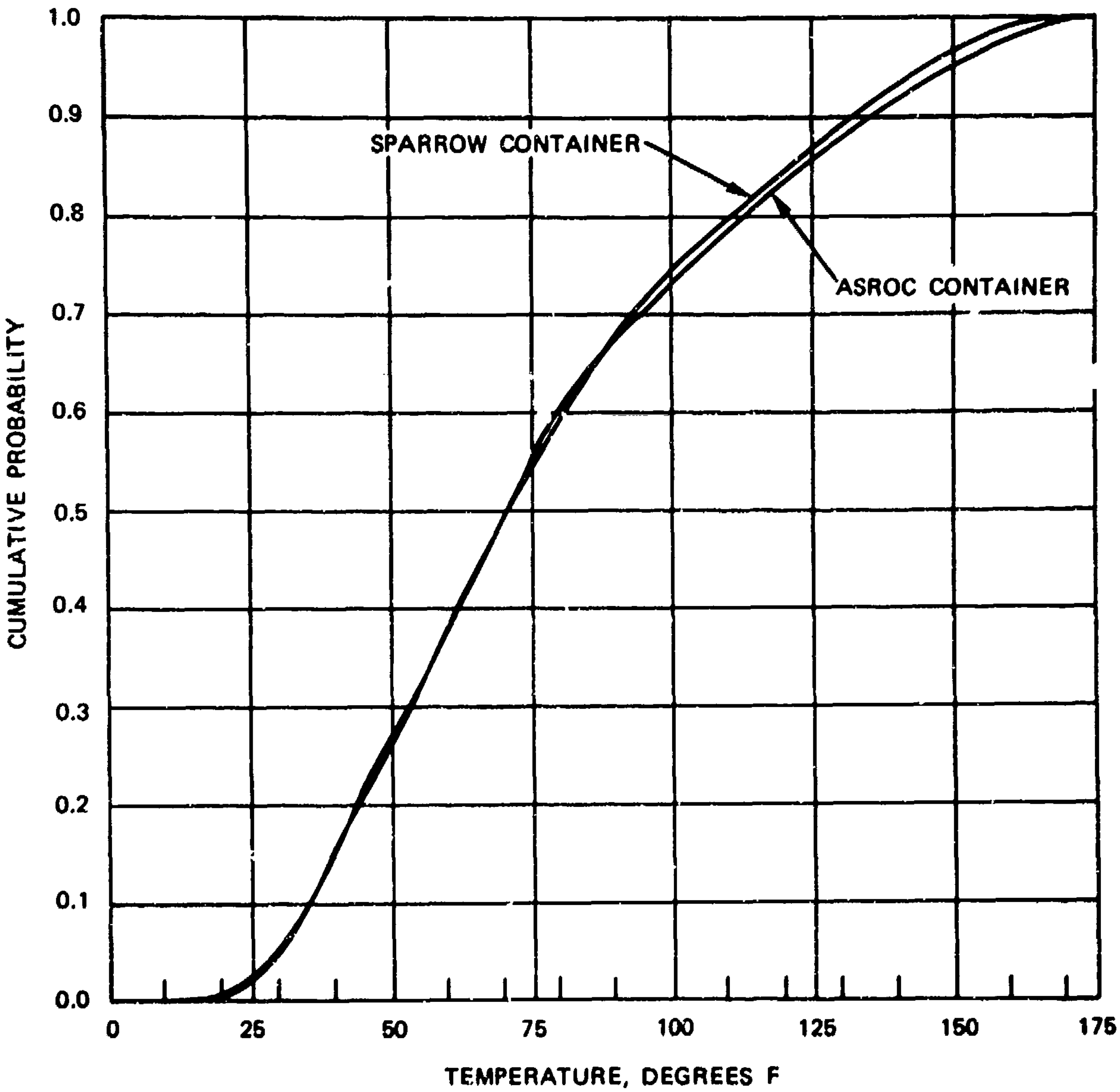


FIG. 36. Comparison of Cumulative Distribution of Temperatures for Sparrow and ASROC Container Skin Temperatures Dump Stored at NWC - June 1970 Through May 1971.

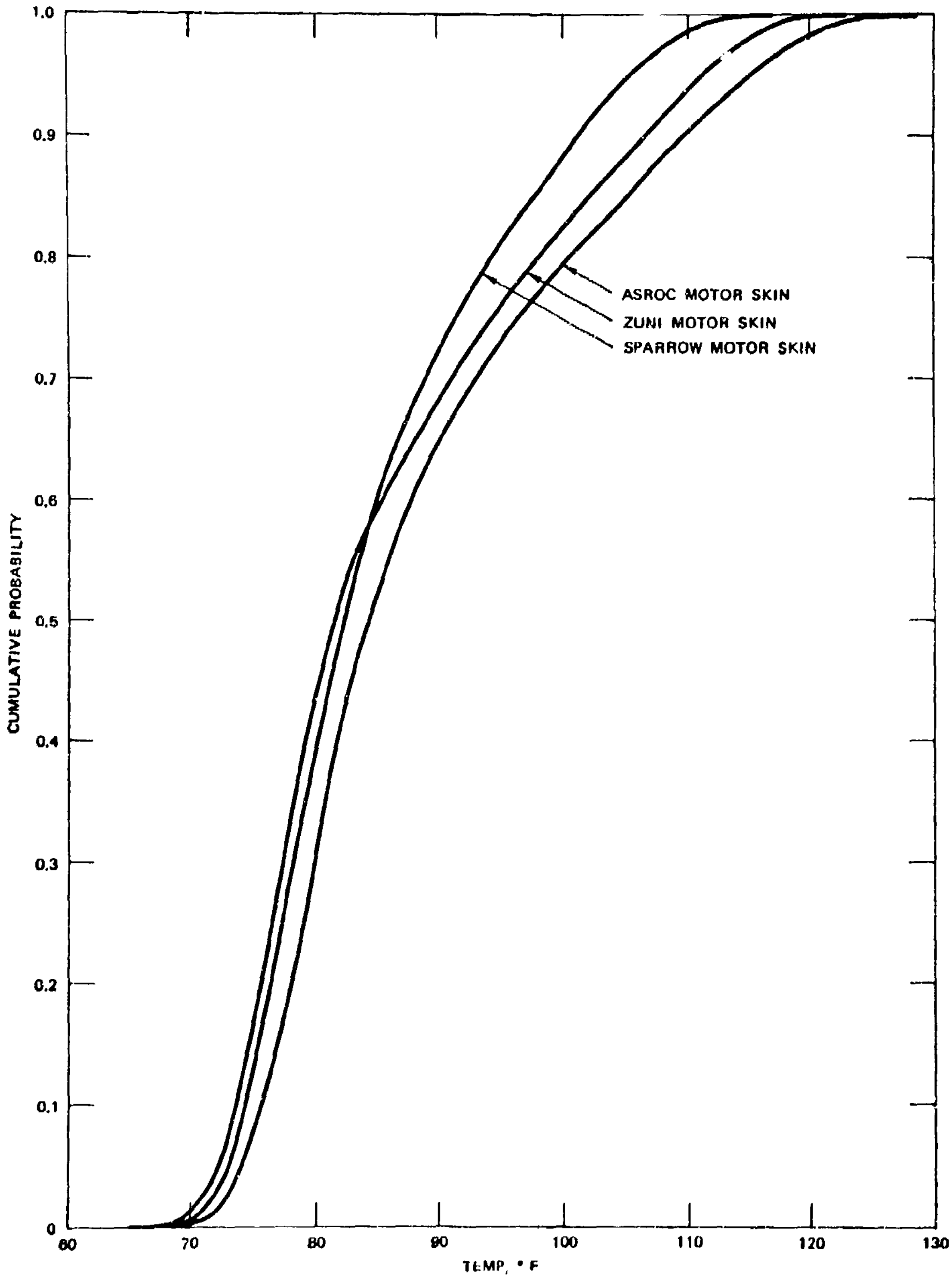


FIG. 37. Comparison of Cumulative Distribution of Rocket Motor Skin Temperatures for ASROC, Sparrow, and Zuni Motors Dump Stored in Containers at Fort Clayton - 1970.

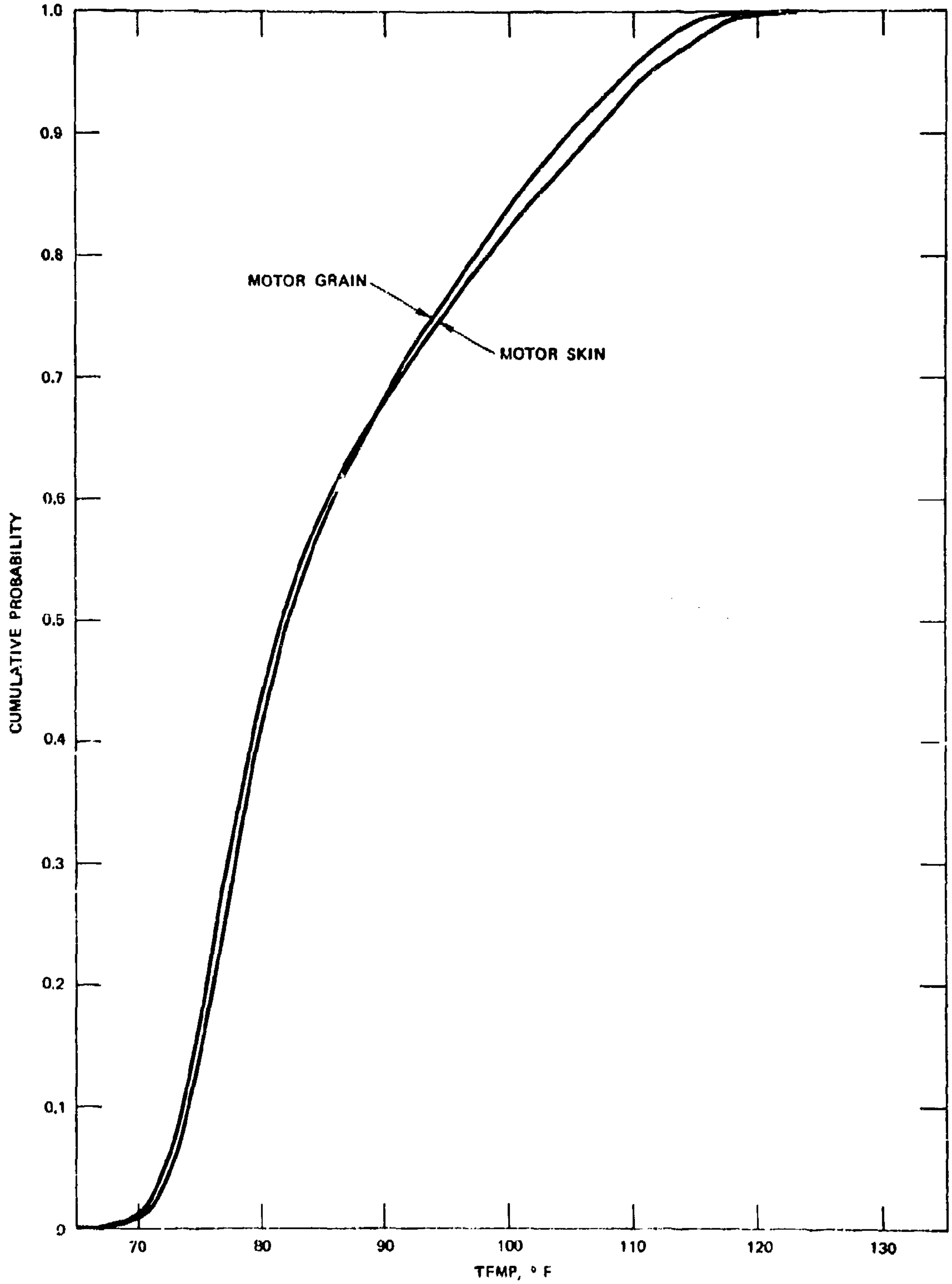


FIG. 38. Cumulative Distribution of Zuni Motor Temperatures, Dump Stored in Containers at Fort Clayton - 1970.

the thermal gradient situation that will occur during their normal life cycle.

All-Up Sparrow

All results reported thus far were for missiles in shipping containers. Before proceeding to exposure of all-up missiles out of containers, some basic facts which have a significant bearing on thermal exposure should be addressed.

1. Most Navy and Air Force missile are painted gloss white rather than gray or olive drab as are their containers.

2. It is less than desirable to put a bare missile on the ground, since dirt penetration can ruin the function of the control section. Also, a 500-pound missile is hard to handle if laid on the ground. Therefore, the missile is placed on a build-up stand, or at least on sawhorses in the more primitive "forward" airfields.

With these facts in mind, it is evident that free air will circulate over and under the missile and the paint will reflect radiant heat. Also, the time of "exposure" will be as short as possible. Units are only built up for use, and then loaded on the aircraft as soon as possible. (While on the aircraft, they are shielded by wings or fuselage.) All the above help to negate the "maximum" situation being exhibited by the bare missile. During all the air-carried work done at China Lake and elsewhere, the author has not measured any bare missile temperatures during preparation (i.e., missile build-up, stageing, etc.) that exceed the maximum air temperature for the day. No more than curiosity spot checks were conducted; however, these were done during the summer when an "extreme" would seem likely. Therefore, it can be viewed as a weighted indication of the in-Fleet situation. In the future it is intended to report more fully on the "on aircraft" exposure of various aircraft stores.

The data reported herein was from a Sparrow 8-inch diameter unit that was sand filled. It was built up for aerodynamic heating work reported in Ref. 13 and had thermocouples at skin quadrant points and in the center of the grain cylindrical "Star".

Yearly plots of temperatures at the top of the motor skin are shown in Fig. 39, 40, and 41. It can be seen that this continuous time plot is comparable to those for the ASROC and Sparrow missiles in containers. Notice that there is a good comparison between the data in Fig. 39 and 40, and the containerized ASROC and Sparrow data. However, Fig. 41 shows an indication of the effect of paint oxidation. The plot looks normal until the April-May break for rehabilitation of the complete measurement site. Then the rest of the reported year was at values lower than would be expected if a comparison with Fig. 40 and 41 were made. The lower

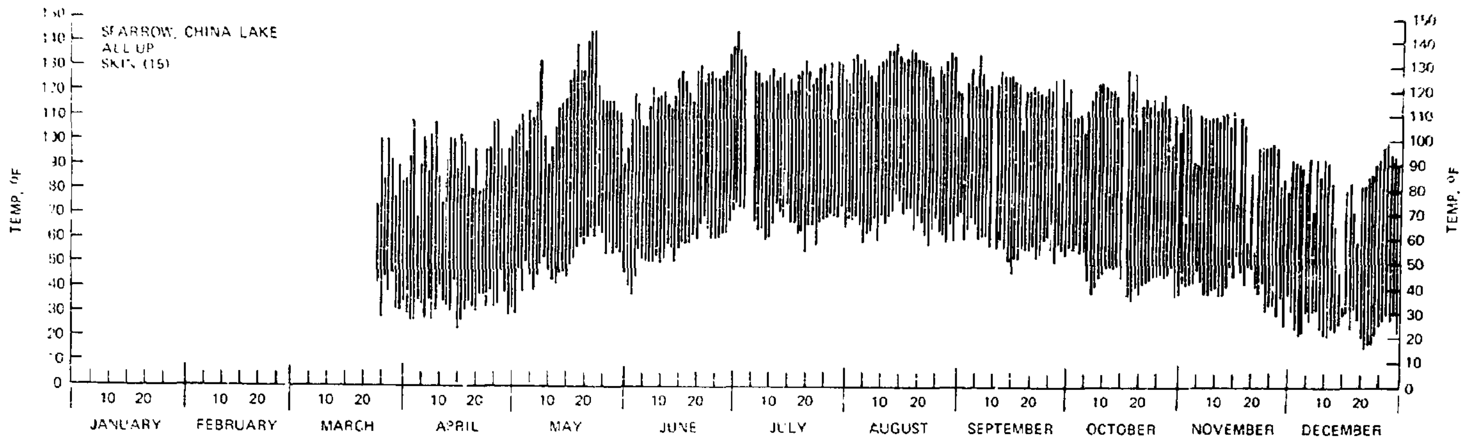


FIG. 39. Temperature Profile of Sparrow Rocket Motor Skin, Dump Stored at NWC as an All-Up Round - 1967.

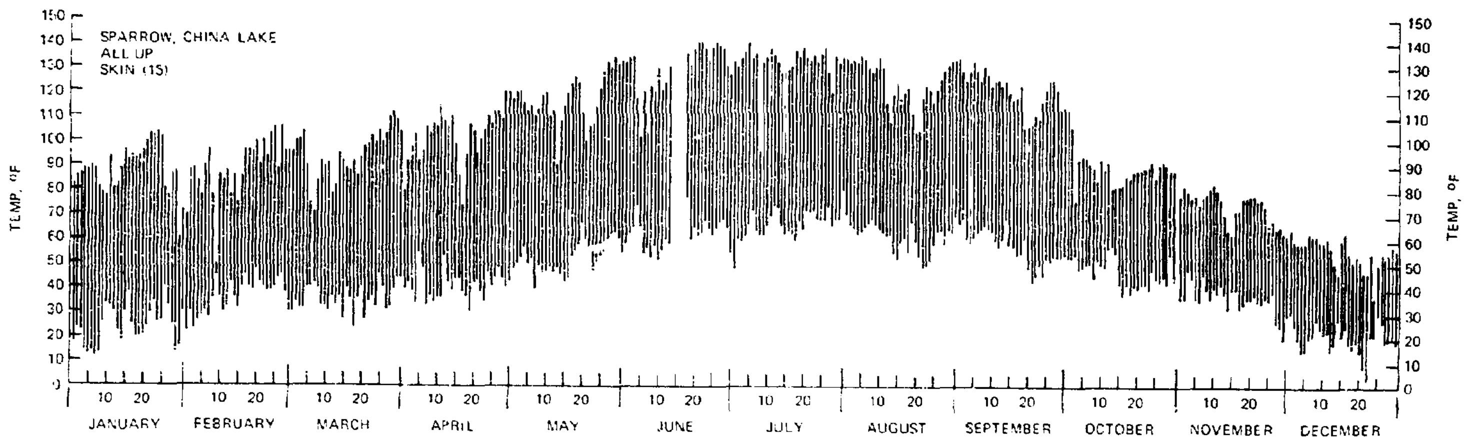
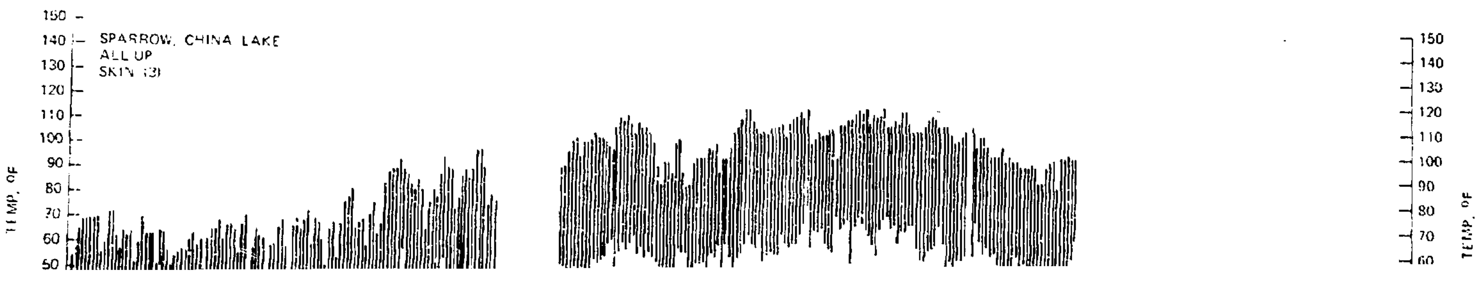


FIG. 40. Temperature Profile of Sparrow Rocket Motor Skin, Dump Stored at NWC as an All-Up Round - 1968.



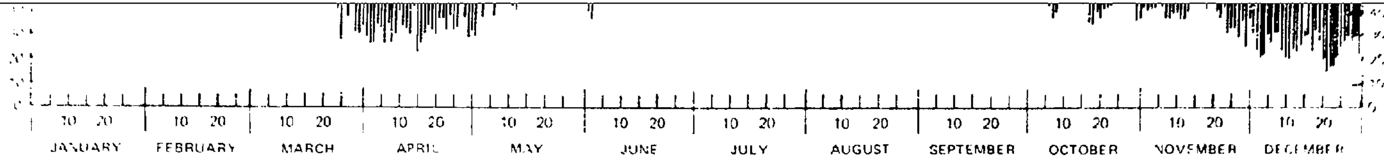


FIG. 39. Temperature Profile of Sparrow Rocket Motor Skin, Dump Stored at NWC as an All-Up Round - 1967.

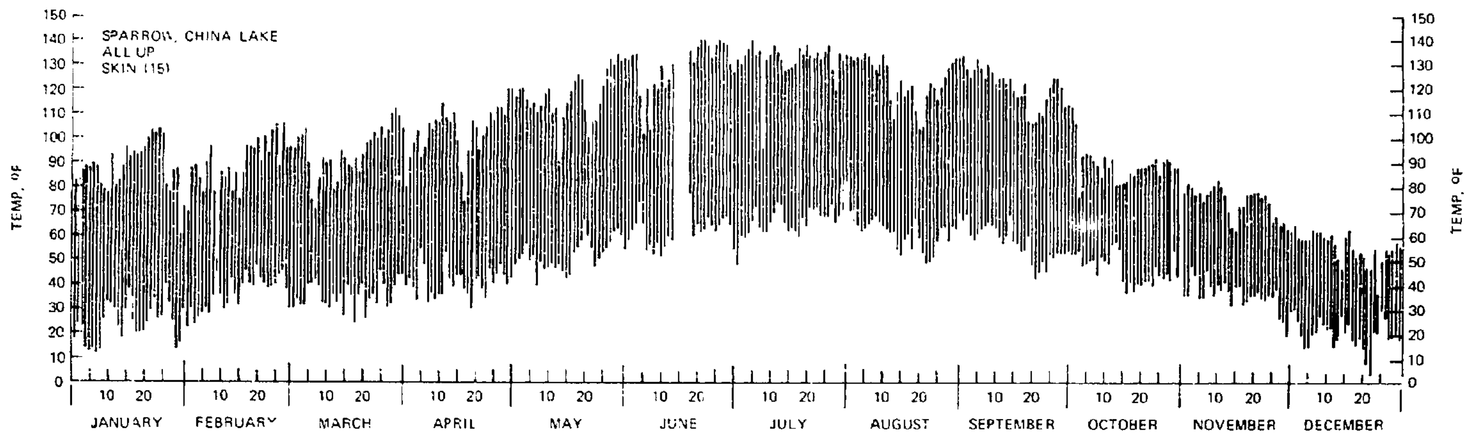


FIG. 40. Temperature Profile of Sparrow Rocket Motor Skin, Dump Stored at NWC as an All-Up Round - 1968.

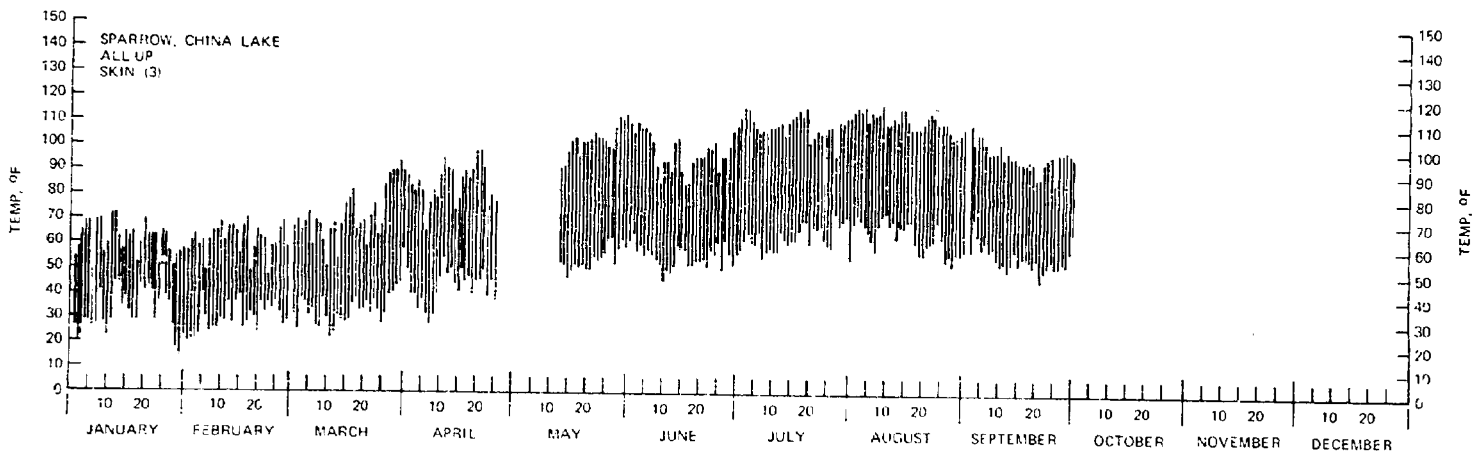


FIG. 41. Temperature Profile of Sparrow Rocket Motor Skin, Dump Stored at NWC as an All-Up Round - 1969.

temperatures were due to the fresh coat of white paint applied during rehabilitation. A comparison between these three figures indicates that a new missile will be more reflective than the "exposed" one and therefore the results reported herein are conservative.

A typical summer day plot for the 0 and 90 degree position on the motor skin, and center of the motor is given in Fig. 42. Notice that there is apparently little difference in the typical day between temperatures measured at the three positions. The primary difference is in the time phase shift. As was seen previously, the maximum temperature is on the west side of the motor in the late afternoon. Notice that there is a plateau evident in the two motor skin traces at about noon until 1500 hours. It is probable that a low velocity east to west wind was blowing during that period. Notice how effectively this limited the peak temperatures for the day. The motor semi-shielded its own west side allowing a gradual thermal build-up as the afternoon progressed. Notice that the center of the motor temperature peaked at about 1700 or 1800 hours, and that the minimum temperature is higher than that for the skin. The point in introducing the "bare" missile situation herein is to show that this exposure will not lead to missile temperatures greatly in excess of those measured in containers.

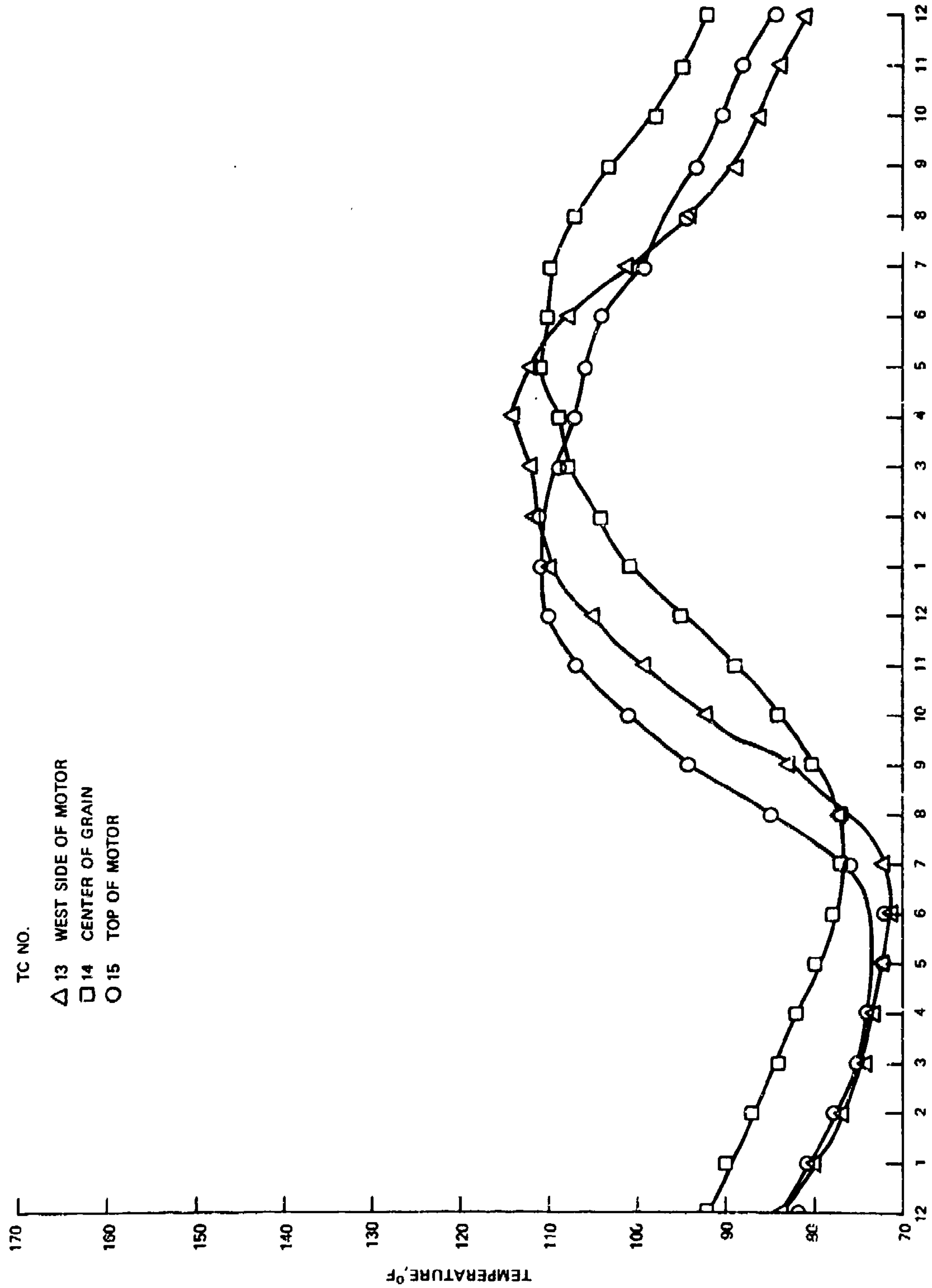


FIG. 42. Typical Daily Temperature Profile of a Dump Stored All-Up Sparrow Motor.

CONCLUSIONS

Storage of air-launched tactical missiles in open storage dumps does not occur except in extreme emergencies.

The 160 or 165°F temperatures are only found on thin-skinned shipping containers, and not all day, every day at that. There was no situation herein measured where even a missile motor skin ever experienced a temperature approximating 160°F.

Although storage container skin temperatures approaching 165°F were measured, the highest missile skin temperature measured, while in a container, was less than 140°F. A statistical analysis of all measured data indicates that, on a worldwide basis, the maximum motor skin temperature of 12-inch-diameter rocket motor would be less than 130°F 97% of the time, and that even a 5-inch-diameter Zuni rocket motor would not vary from these values by over 10°F. (This assumes a full calendar year of desert dump storage, which is inconceivable.)

There is no evidence supporting a gradientless thermal soak test procedure during design and/or qualification, if a "real life" high temperature simulation is the goal.

Data obtained from 2 1/2 years measurement on an all-up Sparrow missile exposed out of its container revealed no skin temperatures in excess of 140°F whe the paint was in good serviceable condition.

RESTRICTIONS ON OTHER USES OF THE DATA

It has come to the author's attention over the years that when little or no specific information exists to place an engineering decision into context that any related information that is available will be used. For example, the information for air-launched tactical propulsion systems (NWC TP 4464) was considered by the developer of small arms for the design environment. The author is not questioning this use of the data; however, it does indicate that use of this type of information for other than its intended purpose does exist.

This being the case, this section is intended to guide engineers in what the acceptable uses of the information in this report are.

Since the measurement matrices herein reported are solid rocket motors, and a solid rocket motor is primarily a cylindrical tube filled with rubber or plastic, then any item that is of an equivalent configuration will react in a similar manner as to what is herein presented.

For example, an Army 200 mm projectile or a missile warhead would be similar. Of less direct comparative ability, the electronics in a similar sized missile should react in a like manner, if not energized, if the density of packaging is close to that for the reported rocket motors. (As previously indicated, there is not much statistical difference in the response of an 8-inch and a 12-inch diameter motor. Therefore, the density of an electronics package only has to be in the general "density ballpark" of that reported herein.)

If a number of small pyrotechnic items or the like are packaged together (as is the general case) for possible dump storage, and the package density approximates that of the rocket motors reported herein, then these data could apply. In this situation it must be remembered that the outside "row" of small items may respond somewhat between the response given for the "container skin" and the motor skin. However, the majority of the items may only be subjected to the "motor center" environment.

Less acceptable use of these data would be as a baseline for operational temperatures for "in use" electronic equipment in aircraft and vehicles. It would be much better if measured data more cogent to the aircraft or vehicle system was used, but if finances or project schedules preclude this then, if used carefully, the information contained herein could be helpful.

These data should not be used in any way for a situation where the "greenhouse" effect is in evidence, nor where the item is shielded from direct radiation by something that allows free air circulation. An example of the first would be an aircraft bubble canopy cockpit. The data are too conservative for the former and too severe for the latter. The Sparrow exposure data shown in Fig. 33 are proof of why the data cannot be used for the latter situation.

Appendix

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 air field 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 over loaded by the gross volume of the operation. This happened both in 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" (Fig. 43) 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 (Fig. 44). 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 a 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.

FIG. 43. Typical Temporary Shelter.

FIG. 44. Ordnance Stacked for Ship Loading.

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 situated on the ground. The ordnance when in containers, or exposed bare, was positioned with the longitudinal 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 (Fig. 45). 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 fork-lift, 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 singly 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.

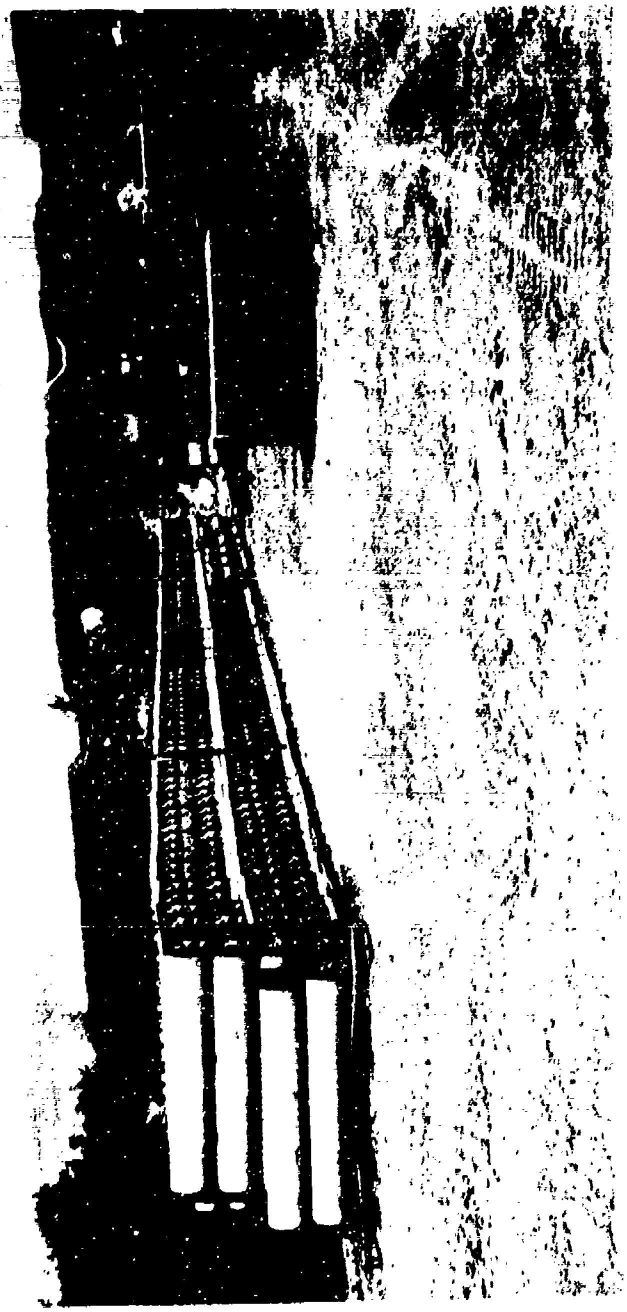


FIG. 45. Typical Forward Dump Storage Area.

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 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, then 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 raise necessary 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 is 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 no where 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 inches of earth surface; however, 2 to 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 3 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 surfaces, 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 ascribed to Death Valley of 134°F has only been reported one time.) Therefore, it may be short sighted 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 only is concerned with the air temperature, solar radiation excepted. The lack of understanding of this has led many WW 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 the 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 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 free fall 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, of 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 1/4 of a yearly cycle is assumed as providing 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 support 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 Fig. 45 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 3 to 5 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; 1/4 of a year cycle capable of full exposure; only 1 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 over emphasized.

Appendix B

INSTRUMENT ERRORS

As in all emperical work, the data presented herein are subject to error. Since these data are intended for use as a basis for designers, it was felt important to point out the sources for error. It was agreed in the inception of this project that an error base of plus or minus 2°F was an acceptable error tolerance. Other sources of error that might lead to a greater tolerance are discussed in the following paragraphs.

Thermocouple Lift-Off

The most troublesome source of error is that of not knowing the condition of thermocouple junction at any given time. During the extended multi-year measurement program a few surface thermocouples have been observed to have come loose and pulled away from the surface of interest. At first, it was deemed permissable to tape a container skin or missile surface measuring thermocouple to the surface of interest. However, it was discovered on quarterly or annual visits to the far flung measurement stations that the sun, wind, rain, and the wire's resilience had combined to force the tape to deform and the thermocouple to lift off the surface. This error is insidious in that the data will still look good and it is impossible to determine by looking at the data when the error started. The results of the sun striking the small mass thermocouple tab will always bias the data toward the extreme since the thermal time constant of the tab is in seconds and the thermal time constant of the missile skin is measured in minutes or hours. The only method of separating the erroneous data from valid data is to laboriously cross check between other missile skin temperatures and daily profiles. As was done herein, the simplest method is to not use suspect data at all. The final solution to this problem was to bond the thermocouple to the surface of interest. This introduced a layer of insulation between the thermocouple and surface of interest, but again, the error would be biased toward the extreme.

Thermocouple Placement

The location of the string of thermocouples was chosen to be halfway between the two ends of the item, and from the top surface to the center. Because of economics, it was decided in the early days of this measurement sequence that the use of thermocouples must be restricted to as few as possible to get the job done. If the measurement string for a rocket motor was placed halfway between the two ends of the unit, then end effects would be minimized. Also, if the string measured from the top motor surface down to the center bore, then the maximum solar noon gradient pattern would be exposed. Again, the quest for the extreme of the situation has led to errors in context. The thermodynamist must use container or motor wall temperatures to predict the profile of exposures of a new missile. Since only the "upper" half of the gradient was measured, and the sun's direction of maximum exposure has shifted greatly, though the thermocouple pattern has not, during the day, then only the maximum situation has been measured. If these data are assumed to apply around the total circumference of the new missile, then even a two dimensional calculation will offer extreme results. In actuality, if the missile is in close approximation to the ground, as all the candidate missile components were in this series, then the shifting thermal gradient envelope will be from missile wall to missile wall; not missile wall to center of missile. Also, the gradient will be from sun induced wall through to ground moderated wall. This being the case, then these data are misleading toward the extreme.

Sand Settling

A minor error was incurred in the use of loose sand as the propellant simulant, and the measurement of the 12 o'clock position for the motor wall thermocouple. Even though the sand was tamped into the motor on build-up, after the unit was physically shipped to the measurement site, some settling of the sand had occurred. When the motor is laid on its side, the void is most likely to be at the "top". In this case the top is the 12 o'clock position of the motor. Therefore, the motor wall thermocouple could be measuring a free metal surface, instead of one that could transmit heat directly into the sand. This would lead to a higher motor wall temperature. In fairness, this void would be measured in small fractions of an inch in depth.

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Measurement sites were established at worldwide locations to obtain empirical data that could be used to more accurately predict the thermal environment of dump-stored ordnance. Data obtained from measurement sites in the desert and tropics on solid rocket motors are presented along with an analysis of the data. The data are presented in terms of cumulative probability, maximum-minimum daily temperatures, and in a few cases as diurnal cycles. Part 1 of the report contains a summary of the results and a discussion of the general philosophy regarding the work. Part 2 is a compilation of some of the NWC data runs, exact evidence from which Part 1 is drawn, and will be of interest to only the serious investigator. This effort is not the final word on the NWC investigation, only a sample of the vast information available from this source.

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