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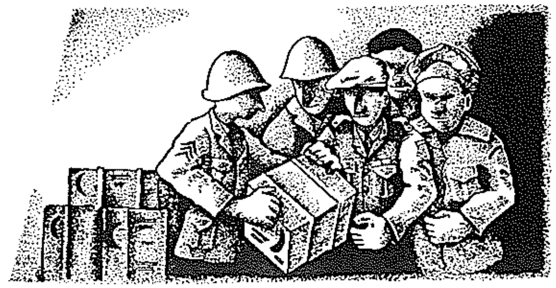
Recent and Current Work on High Temperatures in Storage and Transportation



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The work of the Environmental Protection Division on high temperatures in storage and transportation has taken three forms: (a) studies of short-duration, high-temperature extremes, (b) studies of slow, cumulative stress due to the entire high-temperature history, and (c) correlation of storage and transit space temperatures with climatic variables.

The present project was initiated as part of Research Project 7-83-02-009 in June 1952, at the request of representatives of the QM Food and Container Institute for the Armed Forces. In essence, the stated problem was to conduct surveys of temperature trends within shipholds, railroad boxcars, and warehouses for use in analyzing effects of temperature on packaged food items during shipment and storage with special reference to the frequency and duration of temperatures above 100°, 110°, 120°, and 130° F. An additional part of the problem was to determine world-wide frequency and probability of certain ambient air temperatures above the limits stated in order to develop a method of correlating storage and transit conditions with ambient conditions.

History of the Problem

Theoretical considerations. The problem as stated was of necessity defined in general terms. Scientists of the Division, after reviewing the literature and history of previous work, were convinced that the answers could not be simply stated since they involved fundamental philosophies of testing. Definition of the terms "temperature trends," "effects," etc., used in the problem, depends upon a definite statement of what action is to be determined by the results of research and what type of results will be significant in terms of that action. Such a definite statement requires answers to four questions: (1) What laboratory testing method is used to simulate field conditions? (2) What is the particular temperature mechanism of food degradation in relation to which storage environments should be analyzed? (3) Is design or acceptance predicated upon a calculated small loss or upon the assumption that products must be given absolute protection in storage at any observed extreme, providing that the extreme is observed at a position and under conditions in storage analogous to those which confront the tested product in the laboratory? (4) Is it desirable to design and test products for different geographic areas, or for different modes of storage and transport?

Although these questions may seem obvious, it was found they have separately or together often been neglected in the demand for a simple, general, all-embracing statement of climatic extremes. For example, a host of additional questions is implied by the fundamental four. In the case of packaged subsistence, is it reasonable to assume that individual, unpackaged cans of beans should be subjected to temperature regimes in testing ovens like those which prevail in the hottest air at the top of any conceivable storage space? Beans in storage or transit will almost always be packaged in fiber containers with dead-air spaces and moderate radiation shielding which act as effective heat-transfer barriers. A survival ration, on the other hand, which may be placed in dark metal containers within three inches of an airplane wing surface, might very well be tested under such conditions. Thus, the point of temperature measurement with relation to the subsistence in field conditions is critical.

The particular mechanism of food degradation must condition all analysis of temperature in food storage environments. Brief periods of excess of temperature over certain critical values may produce discrete, irreversible changes like the melting of fats. Migration of such materials into other components of a multicomponent packaged food item can then occur. In this case short-duration temperature extremes are sought in the analysis.

For other food items, however, there is a cumulative degradation which is a summation function of all temperatures at moderately high levels. For these items mean values resulting from the integration of the entire temperature history are the aim of analysis.

In connection with short-term temperature extremes, is a so-called calculated risk a more compelling standard for determining test cycles than the possible marked deterioration of even the smallest fraction of subsistence shipped? It is argued that any such deterioration might, through spoilage, lowered nutritive value, or unacceptability, prejudice the effective operation of troops in the field. However, design for less than observed extremes based on calculated risk allows much greater diversity of items, lower cost, and heightened initial acceptability.

In attempting to estimate probability of deterioration of a given item under either sudden or slow, cumulative stress, a considerable number of logistic situations must be considered, even with the assumption of a static logistic picture. Alterations of this picture in the future make calculation of probability of deterioration extremely complex.

Lastly, the determination of correlation with ambient conditions will have value under either of two suppositions: (a) that predictive formulas may be derived which will enable extrapolation beyond the range of the data available, in order to determine near-absolute extremes in remote areas of maximum heat stress, or (b) that the geographic area and the method of shipment and storage may be determined for certain items, facilitating differential testing.

In actual laboratory practice, oven testing of individual products in cans, or ration packages (rather than in shipping cartons) is the rule. Temperatures within air spaces in cartons have therefore been those sought in the field as the closest analogy to simulated oven conditions. It also appears that it is not now possible to determine in advance the route, destination or method of storage and transport for any important Quartermaster subsistence items. Therefore, correlation with ambient conditions has been pursued only to obtain estimates of storage conditions in world-wide areas of extreme heat stress which are remote and inaccessible for research or during periods of more extreme stress than those prevailing during research.

Short-duration extremes of storage temperature. The question of calculated risk versus near-absolute protection from temperature extremes has not been answered for situations where storage temperatures briefly exceed critical values. Aware of the logistic intricacies involved in estimating calculated risk, Environmental Protection Division research originally sought for occurrences of short-duration extreme high temperatures, where measured in situations analogous to test-oven conditions. It was felt that if such extremes could be shown to be within present ranges, or if relatively simple techniques of storage could bring them within these ranges, there was little need to assess the calculated risk. The search for short-term extremes is like finding the weakest link in the chain of subsistence handling from acceptance to consumption. Situations originally sought for intensive study were therefore those storage or transit conditions expected to produce either sustained or sudden maximum heat stress within storage spaces. Situations of slow, cumulative stress were given less attention.

Cumulative stress. More study has recently been devoted to long-term, cumulative heat stress and the use of effective mean temperatures for simulation of its effects. Evidence is mounting that all forms of subsistence are semiperishable, no matter how preserved. Degradation is a function of the entire temperature history for many classes of foods.

Because many degradation reactions in foodstuffs (other than pronounced bacterial spoilage) follow an exponential relation with temperature, the arithmetic mean of widely cycling temperatures is only a rough approximation to temperature experience of food in cartons, if it be desired to estimate storage life under cycling, from constant temperature trials. For many foodstuffs, however, a uniform effective mean temperature can be computed, exposure to which will produce roughly the same amount of degradation as the fluctuating temperatures of actual storage in the same length of time. This will of necessity be higher than the arithmetic mean. However, the excess of this temperature over arithmetic mean is relatively constant for a specified rate of change of reaction rate with temperature and for a specified range of cycling. Hicks has computed the theoretical excess of effective mean temperature over arithmetic mean temperature for various reaction rates and cycle ranges *(1)*.

Present results indicate that for packaged subsistence the daily or monthly arithmetic mean carton air temperature is normally less than one degree above the food temperature mean. In addition, even over the rather extreme type of diurnal cycle in food temperature experienced in boxcars at Yuma, computation following Hicks' method indicates that the arithmetic mean of food temperature is less than one degree lower than the effective daily and monthly food temperature (for Q_{10} rating of 2). Therefore, we have considered arithmetic mean temperature (derived from maximum and minimum) in carton air of the carton experiencing greatest extended or peak heat stress as the critical parameter for investigation, since effective mean food temperature may be derived from it. When the mechanism of food degradation is known, food storage experience can thus be reduced to a series of monthly effective temperatures or to a single effective temperature where one static mode of storage is concerned.

Correlation of interior with ambient conditions. It now appears that, in the case of boxcar studies at Yuma, the effective mean storage temperature, which can be derived from a simple means of carton air maxima and minima, is reliably correlated with free air monthly mean temperature.

Further study is necessary to determine whether similar correlations with monthly means exist in areas of less static air mass conditions than Yuma in the summer. Prediction may also be possible for analogous storage like tarpaulin-covered dumps or tents. Domestic and foreign warehouses and ships, where conditions are complicated by ventilation, movement of stored items, varying construction and orientation, present more difficult problems of correlation. In any case, however, simple effective temperature history may be constructed for storage trial duplication.

Current research using data gathered in Army warehouses indicates that correlations of the order of significance found in the Yuma boxcar study exist between specific warehouse and free-air temperatures. For example, the correlation coefficient of mean monthly temperatures over a period of one year in a typical warehouse at the Atlanta General Depot, and mean monthly outside temperatures as reported at a nearby United States Weather Bureau Station is 0.99; the line of regression is $y = 0.3 + 1.10x$ (standard error of estimate of 1.6° F.), where y is the warehouse and x the weather bureau mean monthly temperatures.

The current study of temperature regimes in Army warehouses had corroborated empirical findings of the National Canners' Association to the effect that: (1) in most domestic warehouses mean annual temperatures do not reach 80° F., and (2) the average warehouse temperatures are from 3° to 10° F. higher than the average outside temperature.

The National Canners' Association also reports that vitamin loss in foodstuffs stored for one year at a constant temperature is similar to that of foodstuffs stored under fluctuating warehouse temperatures if the constant temperature be equal to the yearly mean of warehouse temperatures *(2)*. Calculations based on Hicks' work with effective food temperatures would suggest that for many warehouses where yearly range of monthly mean warehouse temperatures is less than 25° F., such a yearly arithmetic mean is a good approximation to effective mean temperature.

Figure 1 is a map showing for the Quartermaster warehouse research during 1949: the location of the warehouses, the annual average warehouse temperature, the effective average, and the average annual free-air temperature.

Figure 2 shows similar averages for the hottest month, 1949. It should be remembered that temperature will vary with location within the warehouse. The relationships discussed above are based on measurements taken at a high storage level; that is, at a level as high as stores can be stacked.

The effective yearly mean temperatures shown in the figures may be used as a constant oven-testing temperature to duplicate the fluctuating warehouse temperatures of any specific warehouse in the 1949 study for foodstuffs with Q_{10} rating of 2.

History of problem prior to assignment as a phase of Project 83-02-009. High temperature occurrence in storage and transit with emphasis on short-term extremes has been intermittently the concern of Quartermaster research and development since the beginning of extensive operations in the Pacific in 1942. Table 1 gives the specific data. During summer 1943, two temperature-measurement tests in open and covered dump storage were conducted, one at Blue Hill, Massachusetts, and a more ambitious and carefully instrumented test at Blythe, California, under desert conditions. The region from Yuma to Death Valley was se-

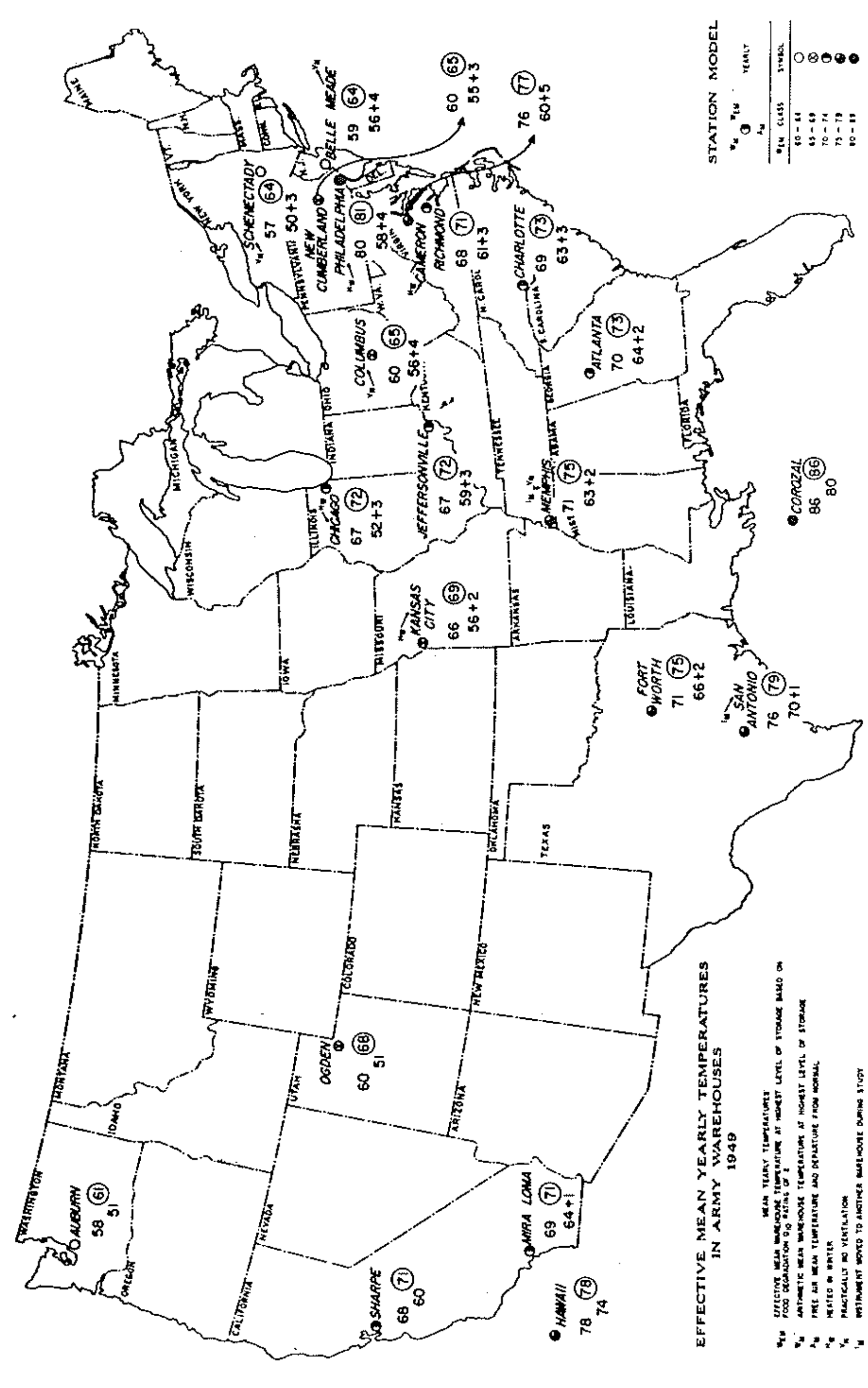

Figure 1. Effective mean yearly temperatures in Army warehouses—1949.

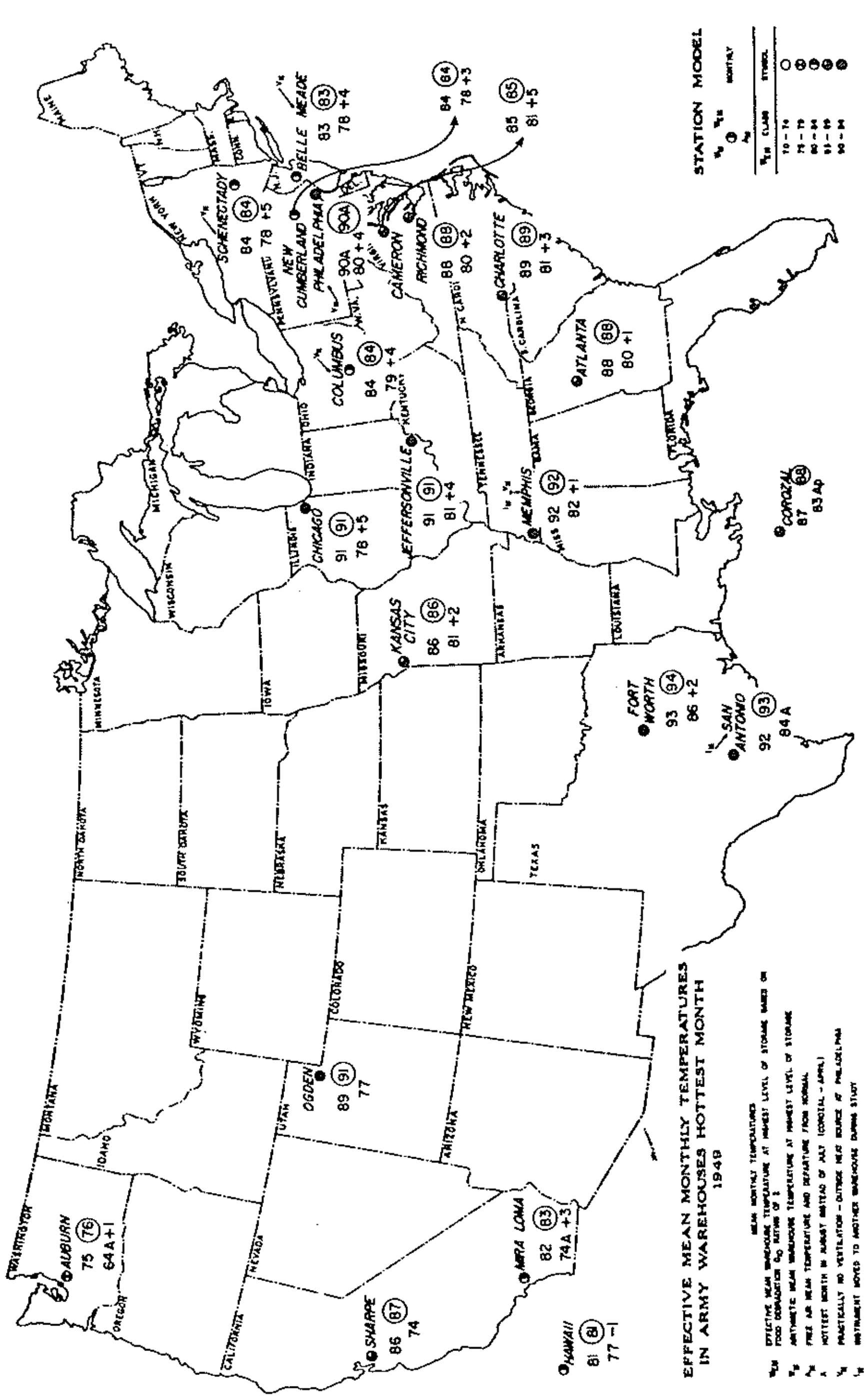

Figure 2. Effective mean montly temperatures in Army warehouses, hottest month—1949.

lected as the nearest American analogy to hot-dry conditions found in the Sahara and in Iran. In the Blythe test, there was recorded a maximum temperature of 126° F. within the air in the top center carton of a tight-tarpaulin-covered dump (a five-foot cube of cases of canned peas). Ambient temperature at the time was 113° F. Temperatures in the air under the tarp cover reached nearly 150° F. Temperatures over 120° F. were sustained in the carton for four hours. Food temperatures were not measured in this carton. In a larger stack, however, a food temperature of 115° F. was attained in canned luncheon meat, in a carton whose temperature was 117° F.

In the majority of the cartons tested, however, the maximum and mean temperatures were near 100° F. and it was recommended that storage of foods at 100° F. (surrounding tested item not in case) be accepted as a suitable laboratory approximation to storage in hot climates.

A field study of fungus in moist-tropical storage was conducted during the following summer at Indian Bay and Gainesville, Florida, in which Dr. David H. Miller of the Environmental Protection Division handled the climatological and heat measurements. Exhaustive readings were taken of temperature and humidity in storage dumps, of accompanying solar radiation, and numerous climatic variables within exposed and covered stacks. It is interesting that in this study, the inside surface in the top carton of a tightly-tarpaulin-covered dump, reached a maximum of 125° F., similar to the Blythe maximum. On 15% of days between 15 September and 9 October, maximum temperatures greater than 120° F. were reached at this position. It is also noteworthy that temperatures of the covering tarpaulin, presumably little higher than the air below it, were between 150° and 160° F.

Confirmation of these results was obtained from replies to a questionnaire distributed to actual Quartermaster storage dumps in locations of extreme heat accumulation all over the world, in the summer of 1945. Both hot-dry and hot-wet situations were embraced in 19 replies from the India-Burma-Iran area, from the Caribbean, the Canal Zone, and the Southwest Pacific. At Saipan, air in the top carton of a tarp-covered dump reached 125° F., when free-air temperature was 89° F. Food temperature was 110° F. Credence is lent to these values by very similar results from a station in the Palau Islands. Only one desert station, Khorramshahr, Iran, replied. Case-air temperature reported was 102° F.

The findings of these studies, scattered reports from the literature of temperatures as high as 160° F. at the top of small enclosed storage spaces in tents and airplanes, and a cursory study, from correspondence, of shiphold temperatures, were incorporated in EPS Memorandum Report No. 10, "High Temperatures and Accompanying Humidities in Transit and Short-Term Storage," 1947. Conditions for simulation of extremes of observed operational and storage temperatures were set up therein, without detailed specification as to the conditions of packing and placement with respect to the heat source. The figure 160° F. was recommended for hot-dry storage, 125° F. for hot-wet, and 90° F. for shipholds. The figure of 160° F. was adopted in regulations, but in some interpretations of these regulations, the position of the item with respect to that temperature was largely ignored, as often were the regulations.

Mr. Virgil O. Wodicka, QMFCI, at a conference in November 1945 on Deterioration of Fats and Oils, stated that because of the unrealistic

TABLE 1. Extreme Temperatures in Storage or Transit Observed or Reported in Literature. Degrees Fahrenheit

Source	Type Storage or Transit Space	Location	Max. Temp. in Air at Top of Space	Max. Temp. of Air in Most Critical Carton	Max. or Hourly Food Temp. (not necessarily concurrent with carton air temp. conditions as indicated)	Inter-hourly Maximum Temp. of Outside Air
Field Tests	Dump covered with tight tarp	Blythe, Calif., and Indian Bay, Fla.	150°-160°	126° (4 hours over 120°)	115° Maximum in food at top of stack	113°
Questionnaires	Dump covered with tight tarp	Marianas Islands, S. W. Pacific	Missing	125° (5 hours over 120°)	110° Food at top of stack (temp. at 1345 hours)	89°
Questionnaires	Warehouse—cement and asbes. roof	Agra, India	Missing	107°	98° (1500 hours) food at top of stack	110°
	Warehouse—corrugated iron roof	Pelilieu, Caroline Islands, S. W. Pacific	Missing	107°	100° (1100 hours) food at center of stacks	87°
Field Tests	Domestic Army warehouse wood frame and walls—asphalt roof	Fort Worth, Texas	111° (11 ft. from floor and 5 ft. from roof)	Missing	Missing	104°
Field Tests	Tents, closed tent	Fort Lee, Va.	156° (9 ft. from ground and 1½ ft. from canvas roof)	Missing	Missing	94°
Field Tests	Moving boxcars—loaded to 5 ft. with cartons of dried fruit	Near Needles, Calif.	134°	102°	Missing	About 111° F.
	Stationary boxcars—loaded to 5 ft. with cartons containing 6 No. 10 cans, beans, string	Yuma, Ariz.	132°	119°	113° Maximum	111° F.
Literature	Shipholds	Southwest Pacific, Marcus Island	110° Upper 'Tween Decks	Missing	Missing	102° (at time of hold temp. max.)

nature of the higher limits that had been suggested and the consequent curtailment of available subsistence, the QMFCI Laboratory was using six months at 100° F. as a measure of suitability of subsistence items for overseas shipment. Although some heat damage has been found in returned shipments from overseas, it is understood that this testing regime has continued to the present.

An ambitious study of temperatures at high and low locations conducted by the QM R&D Field Evaluation Agency, Ft. Lee, Virginia, in QM domestic warehouses between 1949 and 1950 yielded no new extremes. Temperatures in the Fort Worth Quartermaster Depot at 11 feet from the floor and about four feet from the roof reached a maximum of 111° F., free air being 104° F. This was the highest observed.

A series of observations was made in an empty boxcar at Alexandria, Virginia, and in another at Yuma, Arizona, in summer 1952. Temperature in cars loaded with dried fruit moving from the Pacific Coast to the Gulf Coast was measured through cooperation with the Department of Agriculture. Report on this research was made in EPD Special Report No. 60, 16 June 1953, in which maximum air-space temperature at top of car was given as 130° F. at Cameron, 138° F. at Yuma, and 134° F. in the moving car. Temperatures in cartons were obtained only in the transit test. A maximum of 102° F. was obtained in the air in a carton on the day of maximum air-space temperature. Although instrumentation was not elaborate, the results suggested that future tests should be confined to a stationary car, since air motion above ten m.p.h. markedly reduces the maximum temperature produced by a given combination of radiation load and ambient temperature.

Interviews with steamship companies in New York and extensive perusal of their logs in critical heat-accumulation areas like Suez, Panama, and the Southwest Pacific showed no hold temperature in a moving ship greater than 110° F. It was therefore concluded that, except for ships at dockside (on which little or no data is available), moving ships and boxcars, like domestic and overseas warehouses, may be disregarded in the search for extreme heat stress.

The conditions of both short-term and cumulative extreme stress appear to be the tightly covered dump or tent and the standing boxcar. Inasmuch as the heat accumulation of the stationary ship is analogous to the standing boxcar (steel roof over hatch, steel sides), the smaller air mass and less circulation of the boxcar offers a situation favoring higher temperatures than the ship. In ships there is conduction and convection from side plates cooled by warm or cool sea water rather than hot desert air. In boxcars the cargo is very near the hot roof.

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