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AUTHORITY
DSTL, AVIA 6/20574, 18 Nov 2008; DSTL, AVIA 6/20574, 18 Nov 2008

[redacted]

(14)

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FWE-231

This document consists of 22 pages

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THE EFFECTS OF NON-UNIFORM ABSORBTIVITY OF THERMAL RADIATION FROM NUCLEAR EXPLOSIONS ON THE TEMPERATURE RISE IN AN AIRCRAFT SKIN

TIS Issuance Date: September 21, 1959

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RAE-Technical Note Mech. Eng. 268

THE EFFECTS OF NON-UNIFORM ABSORBTIVITY OF THERMAL RADIATION FROM NUCLEAR EXPLOSIONS ON THE TEMPERATURE RISE IN AN AIRCRAFT SKIN

B. J. Brinkworth, M.Sc.

July 1958

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THE EFFECTS OF NON-UNIFORM ABSORBTIVITY OF THERMAL RADIATION FROM NUCLEAR EXPLOSIONS ON THE TEMPERATURE RISE IN AN AIRCRAFT SKIN

SUMMARY

An analysis is made of the maximum temperature rise in a thin sheet exposed over a long narrow area to thermal radiation from a nuclear explosion. The study is extended to cases in which heat is absorbed outside this area to a lesser degree than inside it.

The results are applied to the temperature rise in aircraft skins subject to aerodynamic cooling and irradiated through rectangular apertures, and also to the effects of the non-uniform absorbtivity where there are insignia.

It is shown that the effects of conduction to lesser-irradiated areas are substantial, and that the temperature rise in areas under insignia is less than would be expected from their greater absorbtivity.

1 INTRODUCTION

The effects on aircraft in flight of thermal radiation from nuclear explosions pose some unique problems in transient thermal conduction. In a previous study[1], the influence of convective cooling by the airstream on the temperature rise in thin skins was determined for situations in which the skin was uniformly irradiated. It was assumed that the region being studied was not affected by conduction of heat to other parts of the structure, though this could clearly have an important effect in many situations, and requires further study.

Perhaps the most elementary instance of conduction to another part of the structure occurs when the skin is only partly, or non-uniformly, irradiated, and heat is transferred to another part of the skin itself. Practical situations of this kind arise when, for example, thermal radiation passes through an aperture and falls on a small area of an internal surface. Sometimes the irradiated area is exposed to the airstream, so that heat is lost both to the surrounding material and to the air.

Another, and commoner instance concerns the temperature rise in the part of a skin beneath insignia having a higher absorbtivity than the

surrounding reflective finish. Again, heat is lost both to the adjacent parts of the skin and to the airstream. These two situations are very similar, and differ only in that the surrounding material is also irradiated in the case of areas under insignia.

These particular situations are studied in the present Note, using a generalised analysis so that the results can be expressed in non-dimensional form, covering a range of the variables relating to the majority of practical cases. To avoid unnecessary repetition, it is assumed that the characteristics of the thermal input pulse from a nuclear explosion and certain aspects of the numerical analysis used are familiar to the reader. Reference may be made, if necessary, to the earlier study[1].

2 THIN SKIN IRRADIATED THROUGH A LONG PARALLEL SLOT

2.1 Assumptions

The situation studied concerns a thin skin irradiated through a long parallel slot and cooled on one side by an airstream. In a general analysis, the following assumptions are necessary, though they may nearly all be discarded if a particular situation having special characteristics is being studied.

(a) The heat transfer coefficient between skin and boundary layer is constant.

(b) The thermal properties of the skin are constant.

(c) The reflectivity of the surface is constant.

(d) The skin and boundary layer temperatures are initially equal.

(e) There are no temperature gradients through the skin.

(f) There is no heat loss by re-radiation.

A simple numerical analysis will be used, in which the skin will be divided into discrete elements of width Δx, and time into intervals Δt. Fig.1 illustrates the nomenclature used. It will be further assumed that

(g) The rate of heat input is uniform over the irradiated area and is zero beyond it (i.e., the aperture is very close to the skin or the radiation is collimated).

(h) The heat transfer process is one-dimensional (i.e., the aperture is long enough for the temperatures to be uniform in the lengthwise direction).

(i) The temperature of an element is defined by the temperature at its centre.

(j) Heat is transferred internally only between adjacent elements.

(k) The total heat input during a time interval is absorbed instantaneously at the beginning of the interval, raising the temperature accordingly.

(l) The temperature distribution relaxes during an interval by heat transfer to the airstream and the adjacent material at a rate determined by the temperatures at the beginning of the interval.

2.2 Numerical analysis

Consider the rise in temperature in the nth element, (Fig.1) assumed to be of unit length perpendicular to the paper, and at a temperature T_n above that of the boundary layer at the beginning of a typical time interval.

The nett heat input during a time interval Δt is

$$P(t)\,\Delta x\,\Delta t - h\,T_n\,\Delta x\,\Delta t + (T_{n-1} - T_n)\,\frac{k\ell\Delta t}{\Delta x} + (T_{n+1} - T_n)\,\frac{k\ell\Delta t}{\Delta x} \qquad (1)$$

(if $n > r$, $P(t) = 0$).

At the end of the interval, the temperature rise will have increased to T_n', so that the total heat retained will be

$$zc\ell\,\Delta x\,(T_n' - T_n) \qquad (2)$$

and (1) and (2) are equal.

Multiplying (1) and (2) by $\frac{\Delta x}{k\ell\Delta t}$ and equating, we have

$$\frac{P(t)\,(\Delta x)^2}{k\ell} - \frac{h\,(\Delta x)^2}{k\ell}\cdot T_n + (T_{n-1} - T_n) + (T_{n+1} - T_n) = \frac{zc\,(\Delta x)^2}{k\Delta t}\,(T_n' - T_n) \qquad (3)$$

Now if

$$\frac{zc(\Delta x)^2}{k\Delta t} = M \qquad (4)$$

equation (3) may be re-arranged thus:-

$$\frac{P(t)(\Delta t)}{zc\ell} - \frac{h\,\Delta t}{zc\ell}\cdot T_n + \frac{T_{n-1} + (M-2)\,T_n + T_{n+1}}{M} = T_n' \qquad (5)$$

Let $P(t)\,\Delta t = \Delta Q(t)$, the total heat input per unit area during the interval, and make the substitutions

$$\Delta Q(t) = \frac{\Delta Q(t)}{Q}\cdot Q \qquad (6)$$

$$\frac{Q}{zc\ell} = T_i \qquad (7)$$

$$\Delta t = \frac{\Delta t}{t_{max}}\cdot t_{max} \qquad (8)$$

and

$$\frac{ht_{max}}{zc\ell} = b \text{ (see ref 1)} \qquad (9)$$

Then equation (5) becomes

$$\frac{\Delta Q(t)}{Q} \cdot T_i - b \cdot \frac{\Delta t}{t_{max}} \cdot T_n + \frac{T_{n-1} + (M-2)\, T_n + T_{n+1}}{M} = T_n' \qquad (10)$$

Now T_i is the "ideal" temperature rise which would result if the entire heat input were absorbed. Dividing each term by T_i, we may introduce a non-dimensional temperature rise scale in which

$$\frac{T}{T_i} = \Gamma \qquad (11)$$

Then equation (10) becomes

$$\frac{\Delta Q(t)}{Q} - b \cdot \frac{\Delta t}{t_{max}} \cdot \Gamma_n + \frac{\Gamma_{n-1} + (M-2)\, \Gamma_n + \Gamma_{n+1}}{M} = \Gamma_n' \qquad (12)$$

Thus, the temperature rise in a given element at the end of a time interval may be determined numerically from the temperature rise in that element and its immediate neighbours at the beginning of the interval. The computational effort involved depends on the value of M, which may be chosen arbitrarily so long as it is greater than 2. If M equalled 2, the temperature of an element would not depend on its previous history, and if M were less than 2, the previous history would have a negative effect on the temperature rise, which is unreal physically. It is very convenient, in practice, to make M = 3, since then the numerical work merely involves averaging the initial temperatures. Equation (12) then becomes

$$\frac{\Delta Q(t)}{Q} - b \cdot \frac{\Delta t}{t_{max}} \cdot \Gamma_n + \frac{\Gamma_{n-1} + \Gamma_n + \Gamma_{n+1}}{3} = \Gamma_n' \qquad (13)$$

which can be evaluated so long as $\frac{\Delta Q(t)}{Q}$ is known as a function of $\frac{t}{t_{max}}$.

In making M = 3, certain other factors are also determined, since

$$M = \frac{zc(\Delta x)^2}{k\Delta t}$$

$$= \frac{zc\, L^2}{k\, t_{max}} \cdot \left(\frac{\Delta x}{L}\right)^2 \cdot \frac{t_{max}}{\Delta t}$$

The function $\frac{zcL^2}{k\, t_{max}}$ is a characteristic parameter, so let

$$B = \frac{zcL^2}{k\, t_{max}} \qquad (14)$$

Then $$M = B \cdot \left(\frac{\Delta x}{L}\right)^2 \cdot \frac{t_{max}}{\Delta t} \qquad (15)$$

The non-dimensional temperature distribution has been computed for $2 < B < 200$ and $b = 0$, 0.04 and 0.08, which embraces the majority of practical situations. In the analysis used, M was always 3, and the number of material elements and time intervals were chosen to satisfy equation (15). The smallest number of elements used was $\frac{L}{\Delta x} = 5$; odd numbers were used so that an element coincided with the centreline, which is a centre of symmetry.

Fig.2 illustrates a typical variation of temperature rise with time, showing how the heat spreads out into the adjacent non-irradiated skin. In this example, the distribution after the maximum is not shown, to avoid confusion of the diagram.

The maximum temperature rise occurs at the centre of the irradiated area, and this is plotted in Fig.3 in non-dimensional form.

2.3 Accuracy

In using a finite difference analysis, the accuracy achieved depends on the number of elements of space and time employed, and it is often difficult to assess the accuracy without repeating the computations with more elements and comparing the solutions. In this particular situation, however, an analytical solution exists for the special case of a constant rate of heat input and no air cooling[2] ($b = 0$). This solution, using the present notation, is

$$\Gamma_m = \frac{2}{\sqrt{\pi}} X e^{-X^2} + \mathrm{erf}(X) - 2X^2 \,\mathrm{erfc}(X) \qquad (16)$$

where $$X^2 = \frac{zcL^2}{16 k t_h} \qquad (17)$$

and t_h is the total heating time.

The present method was used with $\frac{L}{\Delta x} = 5$ and $M = 3$ for $X = 0.485$ and 0.685 and the comparative solutions obtained for Γ_m were:-

Numerical	0.694	0.824
Analytical	0.708	0.838

The error in both cases was less than 2%, from which it is concluded that the results of the previous analysis should not be less accurate. The errors involved in applying the results to real situations are clearly likely to be much greater than the computational errors.

2.4 Example

In the previous study[1], an example was considered in which a bomber aircraft was exposed to thermal radiation from a 2Mt explosion when flying straight and level at a Mach number of 0.8 at 45,000 ft. The convective heat transfer coefficient at a point 12 ft downstream from the wing leading edge was found to be

$$h = 1.61 \times 10^{-3} \text{ cals cm}^{-2} \text{ sec}^{-1} {}^{\circ}\text{C}^{-1}$$

and for a 26 gauge skin in DTD 546 material this gave

$$b = 0.088$$

Now suppose that this part of the skin was in the upper surface of the wing and had been irradiated through an aperture over a rectangular area L = 2 cm wide, and the total thermal dose was Q = 10 cals cm^{-2} after correction for obliquity of the surface and its reflectivity.

For DTD 546, $k = 0.27$ cals cm^{-1} sec^{-1} $^{o}C^{-1}$

$z = 2.79$ gr cm^{-3}

and $c = 0.21$ cals gr^{-1} $^{o}C^{-1}$

so that $\frac{k}{zc} = 0.46$ cm^{2} sec^{-1}

and if $L = 2$ cm

and $t_{max} = 1.43$ secs,

$B = 6.1$,

from equation (14)

Then from Fig.3

$$\Gamma_m = 0.35$$

(It is evident that, in this case, convective cooling to the airstream is very small compared with the heat transfer to the surrounding material).

From equation (6),

$$T_i = 381^{o}C$$

and thus $T_m = 132^{o}C$

Then if the assumptions of section 2.1 are valid, the maximum temperature rise is $132^{o}C$.

3 TEMPERATURE RISE UNDER INSIGNIA

3.1 Adaptation of previous analysis

The identification letters and other insignia on a bomber aircraft cover considerable areas of the skin and have a higher absorbtivity than the surrounding finish. It is possible to use the previous analysis to determine the rise in temperature in the skin behind such insignia, if certain further assumptions are made. The validity of the analysis will be considered later.

For parts of insignia covering rectangular areas, the situation is only slightly different from the irradiation of a skin through a rectangular aperture. In the latter instance, there is no heat input beyond the edge of the irradiated area (i.e. if n > r). If the input to the surrounding skin is P(t), the effective input to the areas under insignia will be

$$P(t)_{in} = P(t) \frac{a_{in}}{a} \qquad (18)$$

and correspondingly

$$\frac{\Delta Q(t)_{in}}{Q} = \frac{\Delta Q(t)}{Q} \cdot \frac{a_{in}}{a} \qquad (19)$$

In this case, Q is the total thermal dose corrected for the obliquity and reflectivity of the plain skin. Then the maximum temperature rise is expressed in terms of the "ideal" temperature rise in the skin outside the insignia, which will be the T_i upon which the non-dimensional temperature Γ is based (vide equation (10)).

The variation of Γ_m with B and $\frac{a_{in}}{a}$ is shown in Figs.4 and 5 for b = 0 and b = 0.08 respectively. It is indicated that the temperature rise under highly absorbing areas is substantially less than would be estimated from their absorbtivity only. This will be illustrated in the following example.

3.2 Example

The maximum temperature rise is required in the 16 gauge light-alloy skin beneath a black identification number (say number one, for convenience) 2 in. wide (5.1 cm) for which $a_{in} = 1.0$.

A total thermal dose of 50 cals cm^{-2} is incident normal to the surface, which is finished with a white reflective paint for which a = 0.2. The average heat transfer coefficient for the region gives b = 0.08, and the weapon yield (4Mt., say) gives $t_{max} = 2.0$ secs.

Now $Q = 10$ cals cm^{-2}

and hence $T_i = 104^{\circ}C$

for a 16 gauge skin in DTD 546.

As before, $\frac{k}{zc} = 0.46$ cm^2 sec^{-1}, so that, from equation (14)

$B = 28$

Also $\frac{a_{in}}{a} = 5$

Hence, from Fig.5,

$$\Gamma_m = 2.25$$

and thus $T_m = 234^{\circ}C$

Therefore, the maximum temperature rise (in the centre of the number) would be 234°C. It might have been assumed, in making a first estimate of the maximum temperature rise, that there was no conduction to adjacent areas. The estimate would then be obtained by multiplying the temperature rise in the surrounding areas by $\frac{a_{in}}{a}$. From a previous analysis[1], the maximum temperature rise in the white region would be 0.57 T_i, so that the estimated maximum temperature rise in the black region would be 2.85 T_i = 297°C., an overestimate of about 30%.

The error in this simple approach becomes less for large values of B, but greater for small values of b. In the example given above, the value of b is too high for a typical situation, and had it been zero, for example, the error in the simple estimate would have been nearly 80%.

4 LIMITS OF VALIDITY OF THE GENERAL ANALYSIS

4.1 Effect of paints

On very thin skins, the heat capacity of any reflective finishes applied to the surface may be of the same order as that of the skin itself. This can be allowed for approximately, if the thickness and nature of the paint is constant and its thermal properties known. Then the heat capacity per unit area, zcl, would be that of the combined skin and paint, though the thermal diffusivity $\frac{k}{zc}$ would probably not be affected since most paints are poor conductors of heat.

When insignia are applied on top of the existing finish, the thickness and thermal properties of the paint within the area of the insignia are likely to be different from those of the surrounding finish. Such a case would have to be analysed individually, since the general analysis assumes constant properties throughout. This is not thought to be very important in view of the fact that most insignia are found on fairly thick skins, to whose heat capacity they would make a negligible contribution.

The presence of a paint film of low conductivity on the exposed surface may prevent the realisation of the assumed zero temperature gradient in the thickness direction. The significance of this cannot be assessed without greater knowledge of the thermal properties of typical finishes, but deserves further study.

4.2 Effect of shape

One of the assumptions upon which the analysis rests is that there is no heat loss in the lengthwise direction, i.e. that the irradiated area is very long. It is valuable to determine how long it should be in practice for the error in using the results to be acceptable. The analysis itself can be used to indicate the order of the length required.

Suppose the length of the area is Y. Then from Fig.3, applied to heat flow in the lengthwise direction, the approach to zero heat flow ($\Gamma_m = 1.0$) would depend upon the parameter

$$B^* = \frac{zc\ Y^2}{k\ t_{max}} \qquad (20)$$

Fig.3 does not extend beyond $\Gamma_m = 0.76$ since this would require input data after $t = 10\ t_{max}$, which are not available. However, it is estimated that Γ_m would reach 0.9 (10% error) for $B^* = 800$ and 0.95 (5% error) for $B^* = 1700$.

For most light alloys, the thermal diffusivity $\frac{k}{zc}$ is of the order of $0.5\ cm^2\ sec^{-1}$, and for megaton weapons, t_{max} = 1 to 2 secs. Then it is indicated that under these circumstances, an irradiated area may be considered long if Y = 30 cm (10% error) or 40 cm (5% error) approximately.

These lengths are smaller than those of the straight portions of most standard identification numbers[3] and it is considered to be legitimate to use the analysis for curved portions also. Furthermore, it is indicated that heat flow for one absorbing area would not be seriously affected by another one further away than Y/2, i.e. 20 cm, say, even for megaton explosions.

The temperature rise beneath roundels and other national emblems cannot be treated rigorously with the present method, although estimates should be possible which are not enormously in error. In this connection, and for the case of irradiation through a circular aperture, it is worth noting that the temperature rise at the centre of a circular area of diameter D must always be less than that in the centre of a long strip of width D. Then the value of Γ_m corresponding to $B = \frac{zcD^2}{kt_{max}}$ would always be a safe estimate.

5 CONCLUSION

A simple numerical analysis has been devised for computing the maximum temperature rise in a thin skin irradiated over a long narrow area, and extended to cases in which heat is absorbed outside this area to a lesser degree than inside it.

The results have been applied to the temperature rise in aircraft skins subject to aerodynamic cooling and irradiated through long apertures, and also to the effects of non-uniform absorbtivity where there are identification numbers and other insignia.

It is shown that the effects of conduction to non-irradiated or lesser-irradiated areas are substantial, and that the temperature rise in areas under insignia is less than would be expected from a consideration of their greater absorbtivity.

ACKNOWLEDGEMENT

Nearly all the extensive numerical computation employed in this Note was carried out by Mr. D. J. Nosworthy of this Department.

NOTATION

The symbols used are defined as follows:-

a	absorbtivity of surface
b	parameter $\frac{h\, t_{max}}{zc\ell}$
B	parameter $\frac{zcL^2}{k\, t_{max}}$
B^*	parameter $\frac{zcY^2}{k\, t_{max}}$
c	specific heat of skin material
D	diameter of irradiated area
h	heat transfer coefficient between boundary layer and skin
k	thermal conductivity of skin material
ℓ	thickness of skin
L	width of irradiated area
M	function $\frac{zc\ (\Delta x)^2}{k\Delta t}$
$P(t)$	thermal input per unit area per unit time
Q	total thermal dose per unit area × absorbtivity
$\Delta Q(t)$	thermal dose per unit area incident during interval Δt
t	time
Δt	interval of time
t_{max}	time at which $P(t)$ has maximum value
t_h	total heating time for square pulse
T	temperature rise above initial value
T'	temperature rise at end of time interval
T_i	"ideal" temperature rise $\frac{Q}{zc\ell}$
T_m	maximum temperature rise
Γ	non-dimensional temperature rise $\frac{T}{T_i}$
Γ_m	maximum value of $\Gamma = \frac{T_m}{T_i}$
Δx	width of space element

NOTATION (Contd)

X	parameter $\left(\frac{zcL^2}{16\,k\,t_h}\right)^{\frac{1}{2}}$
Y	length of irradiated area
z	density of skin material

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n	denotes typical space element
r	denotes last element before discontinuity boundary
in	denotes within discontinuity boundary

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erf(u) error function $\frac{2}{\sqrt{\pi}} \int_0^u e^{-u^2}\,du$

erfc(u) complementary error function $\frac{2}{\sqrt{\pi}} \int_u^\infty e^{-u^2}\,du$

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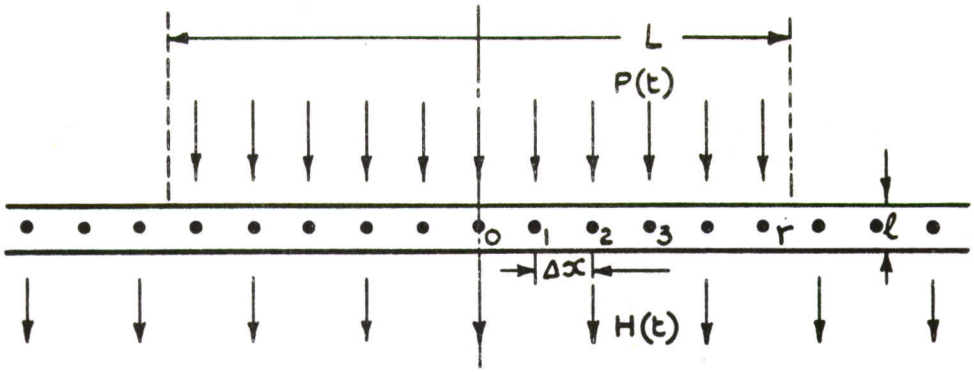

Fig. 1--Nomenclature.

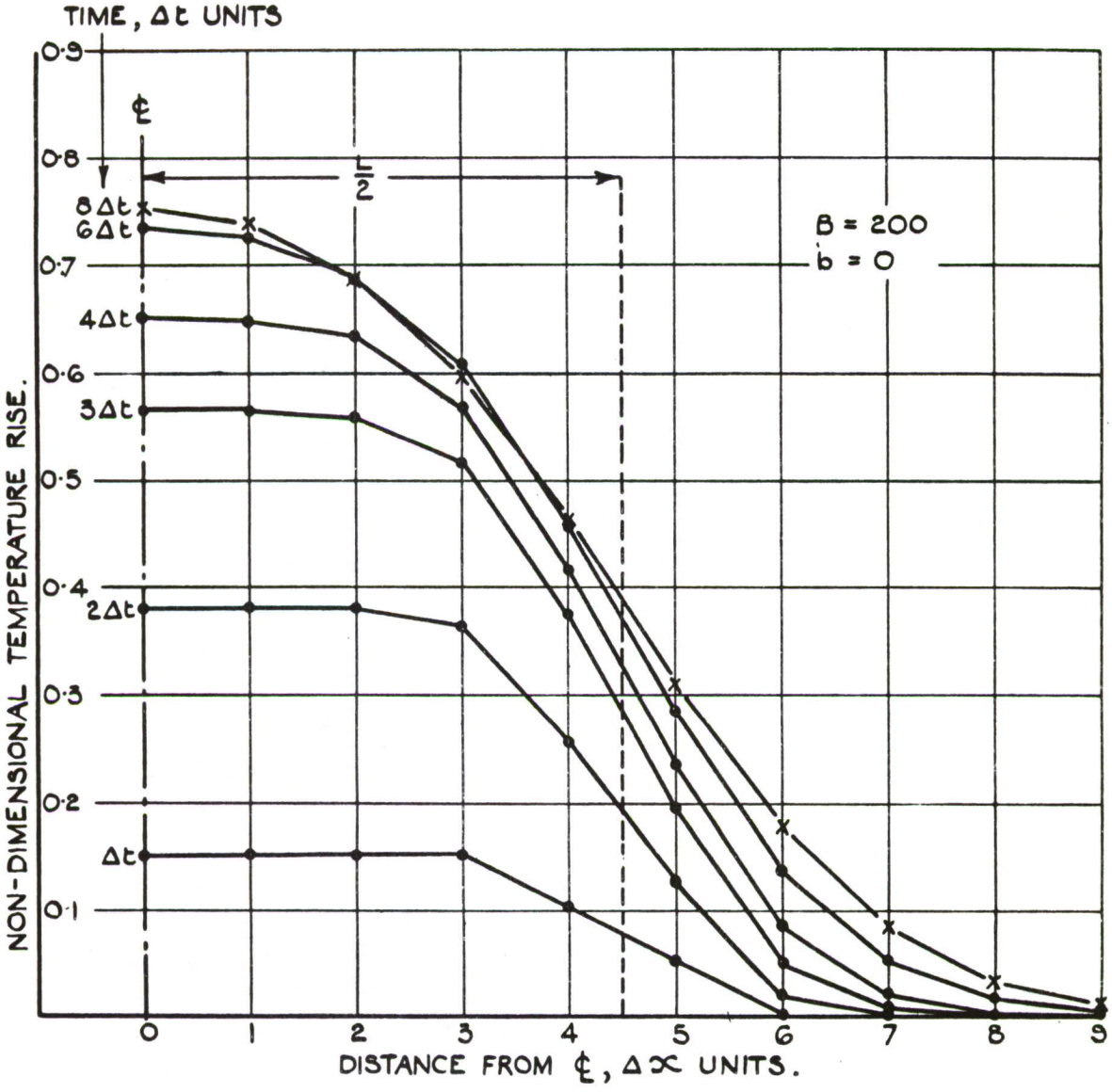

Fig. 2--Typical temperature distribution.

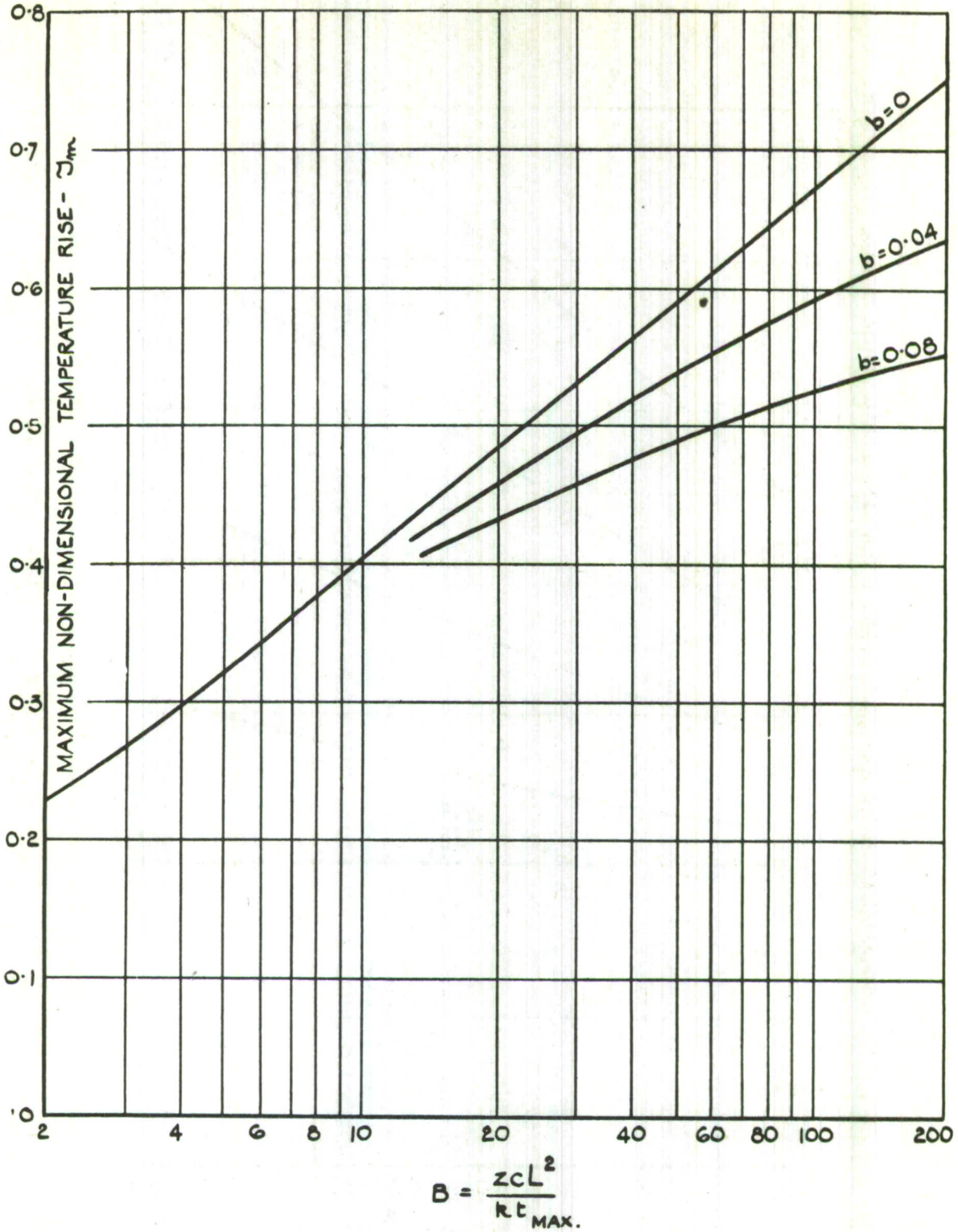

Fig. 3--Maximum temperature rise.

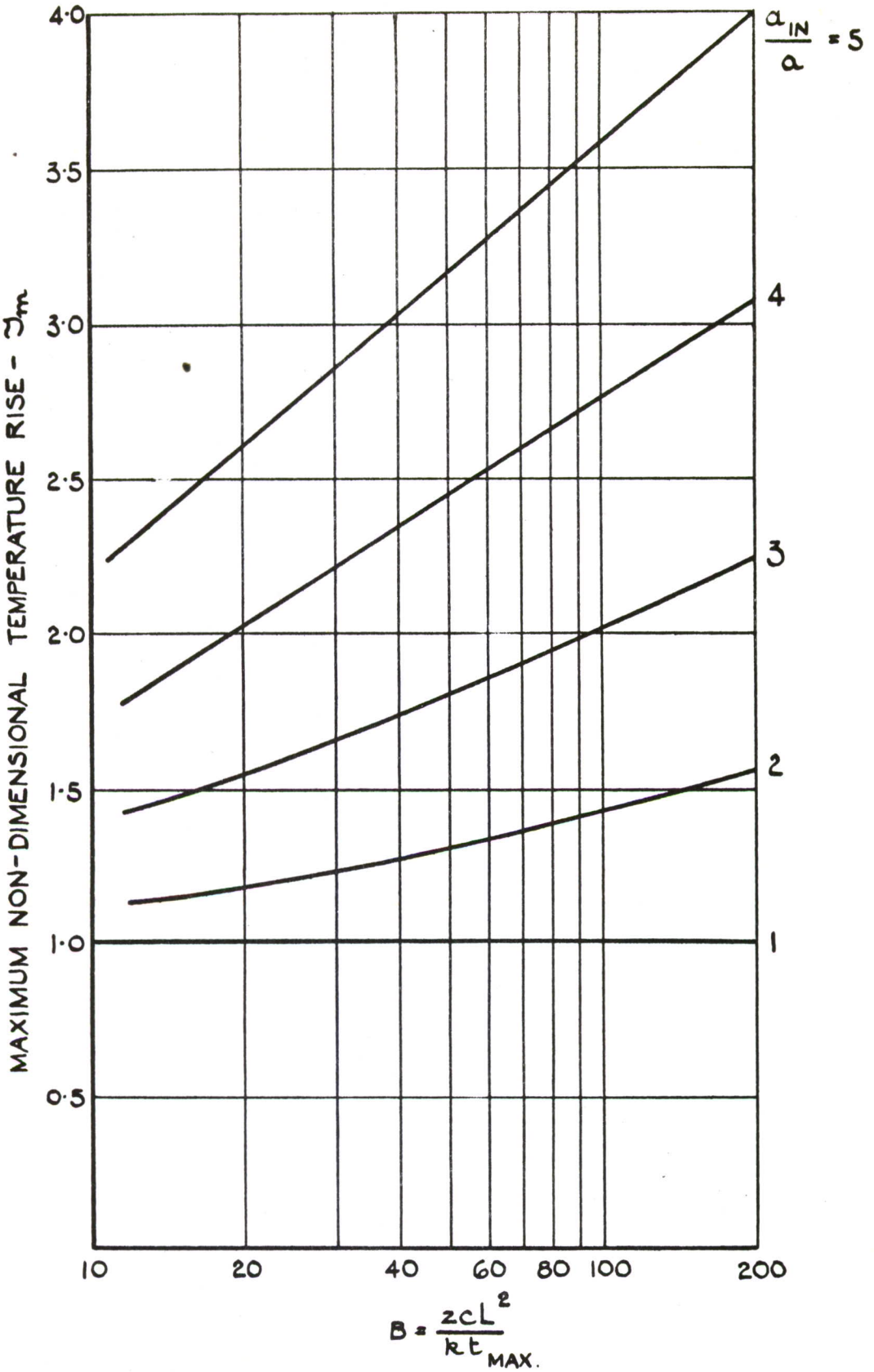

Fig. 4--Maximum temperature rise under insignia b = 0.

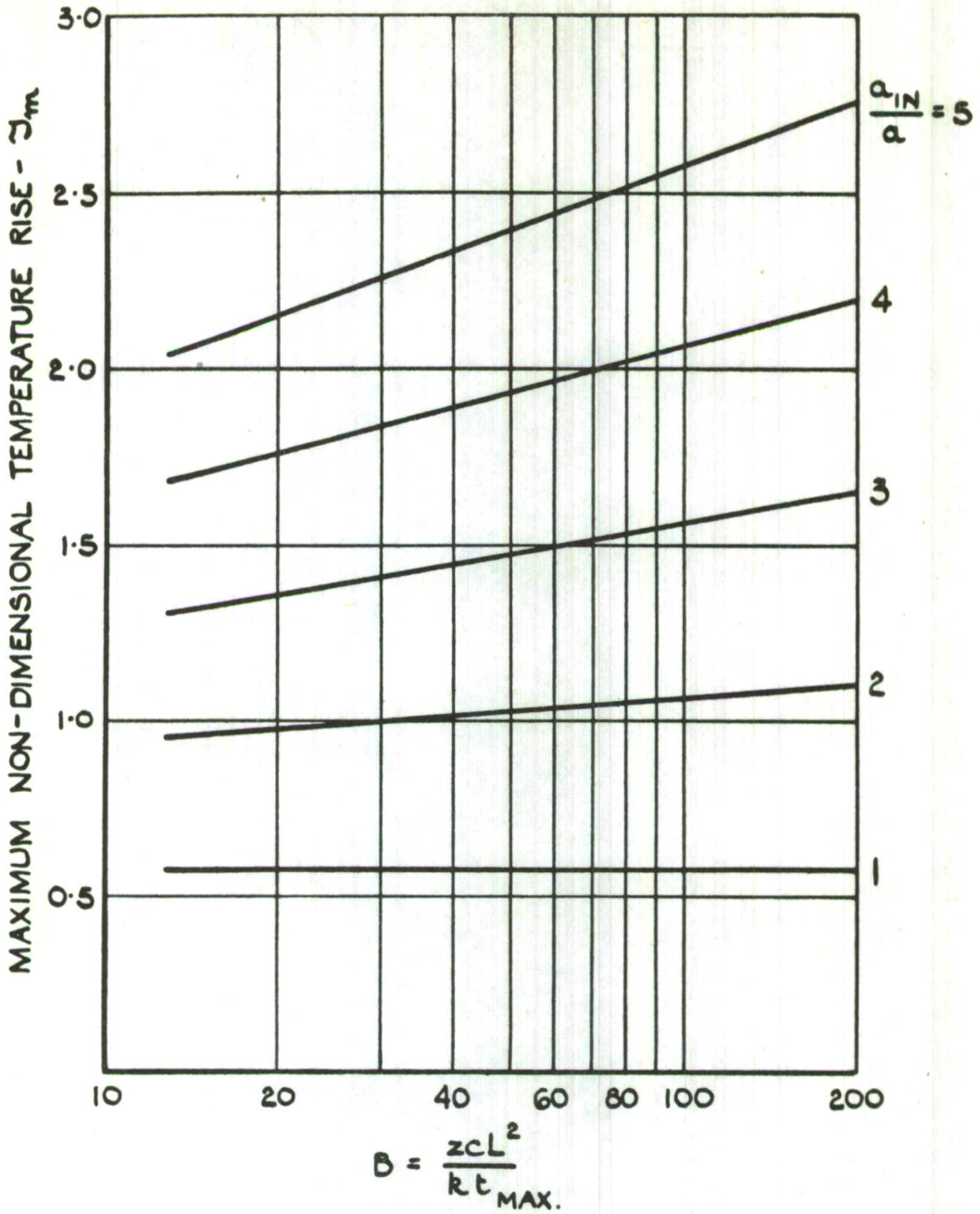

Fig. 5--Maximum temperature rise under insignia b = 0.08.

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62 Commanding Officer, U.S. Naval Schools Command, U.S. Naval Station, Treasure Island, San Francisco, Calif.
63 Superintendent, U.S. Naval Postgraduate School, Monterey, Calif.
64 Commanding Officer, Nuclear Weapons Training Center, Atlantic, U.S. Naval Base, Norfolk 11, Va. ATTN: Nuclear Warfare Dept.
65 Commanding Officer, Nuclear Weapons Training Center, Pacific, Naval Station, San Diego, Calif.
66 Commanding Officer, U.S. Naval Damage Control Tng. Center, Naval Base, Philadelphia 12, Pa. ATTN: ABC Defense Course
67 Commanding Officer, Air Development Squadron 5, VX-5, China Lake, Calif.
68 Director, Naval Air Experiment Station, Air Material Center, U.S. Naval Base, Philadelphia, Pa.
69 Commander, Officer U.S. Naval Air Development Center, Johnsville, Pa. ATTN: NAS, Librarian
70 Commanding Officer, Naval Air Sp. Wpns. Facility, Kirtland AFB, Albuquerque, N. Mex.
71 Commander, U.S. Naval Ordnance Test Station, China Lake, Calif.
72- 75 Commandant, U.S. Marine Corps, Washington 25, D.C. ATTN: Code AO3H
76 Commanding Officer, U.S. Naval CIC School, U.S. Naval Air Station, Glynco, Brunswick, Ga.

AIR FORCE ACTIVITIES

77 Assistant for Atomic Energy, HQ, USAF, Washington 25, D.C. ATTN: DCS/O
78 Deputy Chief of Staff, Operations HQ. USAF, Washington 25, D.C. ATTN: Operations Analysis
79- 80 Assistant Chief of Staff, Intelligence, HQ. USAF, Washington 25, D.C. ATTN: AFCIN-3B
81 Director of Research and Development, DCS/D, HQ. USAF, Washington 25, D.C. ATTN: Guidance and Weapons Div.
82 The Surgeon General, HQ. USAF, Washington 25, D.C. ATTN: Bio.-Def. Pre. Med. Division
83 Commander-in-Chief, Strategic Air Command, Offutt AFB, Neb. ATTN: OAWS

84 Commander, Tactical Air Command, Langley AFB, Va. ATTN: Doc. Security Branch
85 Commander, Air Defense Command, Ent AFB, Colorado. ATTN: Atomic Energy Div., ADLAN-A
86 Commander, Air Force Ballistic Missile Div. HQ. ARDC, Air Force Unit Post Office, Los Angeles 45, Calif. ATTN; WDSOT
87 Commander, Hq. Air Research and Development Command, Andrews AFB, Washington 25, D.C. ATTN: RDRWA
88- 89 Commander, AF Cambridge Research Center, L. G. Hanscom Field, Bedford, Mass. ATTN: CRQST-2
90- 94 Commander, Air Force Special Weapons Center, Kirtland AFB, Albuquerque, N. Mex. ATTN: Tech. Info. & Intel. Div.
95- 96 Director, Air University Library, Maxwell AFB, Ala.
97 Commander, Lowry AFB, Denver, Colorado. ATTN: Dept. of Sp. Wpns. Tng.
98 Commandant, School of Aviation Medicine, USAF, Randolph AFB, Tex. ATTN: Research Secretariat
99 Commander, 1009th Sp. Wpns. Squadron, HQ. USAF, Washington 25, D.C.
100-102 Commander, Wright Air Development Center, Wright-Patterson AFB, Dayton, Ohio. ATTN: WCOSI
103-104 Director, USAF Project RAND, VIA: USAF Liaison Office, The RAND Corp., 1700 Main St., Santa Monica, Calif.
105 Commander, Air Defense Systems Integration Div., L. G. Hanscom Field, Bedford, Mass. ATTN: SIDE-S
106 Chief, Ballistic Missile Early Warning Project Office, 220 Church St., New York 13, N.Y. ATTN: Col. Leo V. Skinner, USAF
107 Commander, Air Technical Intelligence Center, USAF, Wright-Patterson AFB, Ohio. ATTN: AFCIN-4Bla, Library
108 Assistant Chief of Staff, Intelligence, HQ. USAFE, APO 633, New York, N.Y. ATTN: Directorate of Air Targets
109 Commander-in-Chief, Pacific Air Forces, APO 953, San Francisco, Calif. ATTN: PFCIE-MB, Base Recovery

OTHER DEPARTMENT OF DEFENSE ACTIVITIES

110 Director of Defense Research and Engineering, Washington 25, D.C. ATTN: Tech. Library
111 Director, Weapons Systems Evaluation Group, Room 1E880, The Pentagon, Washington 25, D.C.
112-119 Chief, Defense Atomic Support Agency, Washington 25, D.C.
120 Commander, Field Command, DASA, Sandia Base, Albuquerque, N. Mex.
121 Commander, Field Command, DASA, Sandia Base, Albuquerque, N. Mex. ATTN: FCTG
122-123 Commander, Field Command, DASA, Sandia Base, Albuquerque, N. Mex. ATTN: FCWT
124 Administrator, National Aeronautics and Space Administration, 1520 "H" St., N.W., Washington 25, D.C. ATTN: Mr. R. V. Rhode
125 U.S. Documents Officer, Office of the United States National Military Representative - SHAPE, APO 55, New York, N.Y.

ATOMIC ENERGY COMMISSION ACTIVITIES

126-128 U.S. Atomic Energy Commission, Technical Library, Washington 25, D.C. ATTN: For DMA
129-130 Los Alamos Scientific Laboratory, Report Library, P.O. Box 1663, Los Alamos, N. Mex. ATTN: Helen Redman
131-135 Sandia Corporation, Classified Document Division, Sandia Base, Albuquerque, N. Mex. ATTN: H. J. Smyth, Jr.
136-138 University of California Lawrence Radiation Laboratory, P.O. Box 808, Livermore, Calif. ATTN: Clovis G. Craig
139 Argonne National Laboratory, P.O. Box 299, Lemont, Ill. ATTN: Dr. Hoylande D. Young
140-141 Bettis Plant, U.S. Atomic Energy Commission, Bettis Field, P.O. Box 1468, Pittsburgh 30, Penn. ATTN: V. Sternberg
142-143 E. I. du Pont de Nemours and Co., Savannah River Laboratory, Document Transfer Station 703-A, Aiken, S.C.
144-145 General Electric Co., Aircraft Nuclear Propulsion Department, P.O. Box 132, Cincinnati 15, Ohio. ATTN: J. W. Stephenson
146-148 General Electric Co., P.O. Box 100, Richland, Wash. ATTN: M. G. Freidank
149 U.S. Atomic Energy Commission, Hanford Operations Office, P.O. Box 550, Richland, Wash. ATTN: Technical Information Library
150 Holmes and Narver, Inc., 828 S. Figueroa St., Los Angeles 17, Calif. ATTN: Sherwood B. Smith, Chief Project Engineer
151 Knolls Atomic Power Laboratory, P.O. Box 1072, Schenectady, N.Y. ATTN: Document Librarian
152 Lovelace Foundation, 4800 Gibson Boulevard, Albuquerque, N. Mex. ATTN: Dr. Clayton S. White, Director of Research
153 National Lead Company of Ohio, P.O. Box 158, Mt. Healthy Station, Cincinnati 31, Ohio. ATTN: Reports Library
154 U.S. Atomic Energy Commission, New York Operations Office, 376 Hudson St., New York 14, N.Y. ATTN: Reports Librarian
155-156 Phillips Petroleum Co., NRTS Technical Library, P.O. Box 1259, Idaho Falls, Idaho
157 Chief, Radiological Health Branch, Office of Chief of Engineering Services, U.S. Public Health Service, Department of Health, Education and Welfare, Rm. 3072, North Building, 4th and C Streets, S.W., Washington 25, D.C. ATTN: James G. Terrill, Jr.
158 U.S. Atomic Energy Commission, San Francisco Operations Office, 518 17th St., Oakland 12, Calif. ATTN: Technical Operations Div.
159-160 Union Carbide Nuclear Co., ORGDP Records Department, P.O. Box P, Oak Ridge, Tenn.
161-163 Union Carbide Nuclear Co., X-10 Laboratory Records Department, P.O. Box X, Oak Ridge, Tenn.
164 University of California at Los Angeles, Atomic Energy Project, P.O. Box 24164, West Los Angeles 24, Calif. ATTN: Thomas G. Hennessy, M.D.
165-166 University of California Lawrence Radiation Laboratory, Technical Information Div., Berkeley 4, Calif. ATTN: Dr. R. K. Wakerling
167 University of Rochester, Atomic Energy Project, P.O. Box 287, Station 3, Rochester 20, N.Y. ATTN: Technical Report Control Unit
168 Reynolds Electrical & Engineering Co., Inc., P.O. Box 352, Las Vegas, Nev. ATTN: Mrs. Elizabeth E. Heyer and Mrs. Gertrude M. Schroer
169 Weapon Data Section, Technical Information Service Extension, Oak Ridge, Tenn.
170-200 Technical Information Service Extension, Oak Ridge, Tenn. (surplus)