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MEASUREMENTS OF THERMAL RADIATION
FROM DELETIONS IN DGGS

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OPERATION SNAPPER

Project 4.6

**THE TIME-COURSE OF
THERMAL RADIATION AS MEASURED
BY BURNS IN PIGS**

REPORT TO THE TEST DIRECTOR

by

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March 1953

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ABSTRACT

The biological effects of the high intensity thermal radiation from atomic bomb explosions were first studied under controlled conditions in the field at Operation GREENHOUSE. Supplemental data were required to further define the time in which a skin burn was produced. Anesthetized young Chester White pigs were placed in protective containers and exposed to the thermal radiation from two atomic bomb explosions. Exposures were limited by aperture plates, each of which contained ten circular ports. Exposure times through these ports were varied by electrically operated shutters. Other containers were used to compare large (3 x 4.5 in.) and small (0.75 in.) area burns. Resultant burns were analyzed grossly and microscopically for degree of severity. The burn severity was related to the amount of energy producing the same degree in the laboratory and then compared to measured thermal energy from field data. The most severe burning occurred in the second 0.1 sec period. There was little increase in the severity of a burn after 0.5 sec. No significant burns were produced on normal skin after 0.6 sec, despite the presence of a relatively large amount of measured incident energy. Small burns through limiting apertures were of the same severity as large burns produced behind large apertures on the same animal. Further information is needed from the laboratory on the effect of thermal pulse shape and on the effect of a variable spectrum of radiant energy in burn production.

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CHAPTER 1

OBJECTIVE

1.1 GENERAL

1.1.1 Time of Burning

Since Operation GREENHOUSE it became increasingly apparent that the exact time of clinically significant cutaneous burning by the major thermal pulse must be known. This was important not only to carry out realistic laboratory experiments, but also to settle the question of the efficacy of evasive action.

1.1.2 Correlation of Measured Energy and Burns

The instrumental methods used for measuring the thermal pulse in the field and the laboratory standards for evaluating the energy causing different grades of severity of burns had improved. Since it was possible to correlate measured thermal energy and burn severity, further field testing was indicated.

1.1.3 Comparison of Small and Large Area Burns

There was a need to settle the question of accuracy of using a small area burn for test purposes. To eliminate any doubt, the severity of small and large area burns had to be compared in the same animal.

1.2 BACKGROUND

1.2.1 Previous Investigations

A study of the Japanese casualties from the atomic bombing showed that the morbidity and mortality from thermal burns was high. Little was known about burns caused from a brief pulse of high intensity radiant energy. In 1947 a laboratory study was begun, supported by the Atomic Energy Commission, using combustibles and the carbon arc as sources for the heat to produce burns on experimental animals. The question of valid simulation of bomb radiation arose. There was no data available to answer this.

There were no immediate skin biopsies of burns from the humans in Japan nor from the animals at Operation CROSSROADS that could be compared with the microscopic appearance of the lesions produced in the laboratory.

There was a wide divergence of opinion on the time required to cause burns from the bomb. The opinions ranged from 20 msec or less to 3 sec or more. The time of applying thermal energy influences the severity of the burn.^{1/}

Ultraviolet light has a photo-chemical as well as a thermal effect in causing erythema, but whether this was a factor in bomb burns was not known. Nor was it evident how important the visible or infrared portions of the spectrum were in burn production.

These and other questions such as influence of skin color, correlation of thermal measurements and burns, and the protective effects of fabrics led to the experiments at Operation GREENHOUSE.

1.2.2 Results from Operation GREENHOUSE^{2/}

A timing shutter was used which exposed the skin through an open port during the initial flash. At about 20 msec a diaphragm covered this and opened another port to expose skin during the thermal pulse from the fireball. There were no burns sustained from the initial flash by any animal at any station on two shots. Burns from the bomb occurred after the initial 20 msec.

Pigs were placed behind a sliding shutter which exposed the skin progressively after bomb zero. It appeared that all burning had ceased after 0.5 sec. The accuracy of this result was questioned because of the slow traverse of the shutter and the possible interference by dust.


The surface appearance, depth and healing time of burns of various sizes were the same. Some have been skeptical of this result and maintain that the small area burn is not a valid test of severity.

The measurements of thermal energy did not agree in all cases with the severity of the burns as gaged by laboratory standards.

The burns in white and dark pigs were equally severe at the nearest station but at the more distant ones the depth of burn

^{1/} J. B. Perkins, H. E. Pearse, and H. D. Kingsley, A Study of Radiant Energy Burns: The Effect of Exposure Time and Intensity, UR-217 (University of Rochester Atomic Energy Project Report), 1952.

^{2/} Pearse, H. E., et al, Thermal Radiation Injury, Operation GREENHOUSE, Annex 2.7, Final Report.



and its healing time were greater in the dark animals. This observation needed further study.

There were no burns on skin protected by army uniform fabrics. The degree of their protection was not known. They were tested at energy levels which were too low to estimate their effect. Further laboratory evaluation was needed before a range could be determined for accurate placement in the field.

Perhaps the most important result was the demonstration that the surface appearance, microscopic changes and healing of burns from the atomic bomb were comparable to those from laboratory sources. This gave confidence in the results of laboratory testing.

CHAPTER 2

METHODS

2.1 LOCATION OF STATIONS

Plans were made in the pre-test period to obtain information at three levels of thermal energy at each of two air bursts. The location of stations was planned using the best predictions obtainable on expected thermal yield of the bombs to be used. The desired energies were 30, 20 and 10 cal/cm². The stations were set up on the Bio-Med Line on Yucca Flat. The distances of the stations are shown in Table 2.1.

TABLE 2.1

Distances of Bio-Medical Thermal Stations

<u>Shot</u>	<u>Actual Range to G.Z. in feet</u>	<u>Actual Slant Range in feet</u>
3	3560	4955
	5150	6199
	7880	8601
4	3490	3642
	4200	4327
	5090	5195
	* 7780	* 7849

* This station was used on Shot 4 to obtain information on small and large area burns.

2.2 STATIONS

2.2.1 Shutter Plates

In perfecting the design of the pair of shutter plates shown diagrammatically in Fig. 2.1 it was intended that information would be obtained on the following:

- a) the severity of the burns produced in the first 5 consecutive 100 msec periods,

b) the severity of the burns caused by six cumulative increments of 100 msec each from 0 to 0-600 msec,

c) the severity of six burns created by decreasing the exposure progressively, cutting off from the beginning of the pulse successive increments, each 100 msec longer than the previous one; the last and shortest exposure thus ran from 600 msec to the end of the pulse, and,

d) the severity of the total, unmodified burn to serve as a control at each distance.

Each shutter plate had two rows of five 1.5 in. circular apertures in an overall area of 4 x 10 in. These were covered with fused quartz to prevent sand-blasting of the animal's skin during the shock wave.

The operation of the solenoid activated shutter plates was initiated by the flash of the bomb on photo-electric relays.

Four pigs were placed in individual aluminum cylinders at each of three stations. Each of two cylinders had one type of shutter plate in its wall giving two pairs of shutters at each location.

The fabrication and calibration of the shutters, the design, fabrication and placement of the cylinders were done by the members of Project 4.2. A detailed description of this equipment is given in their report. Although the reports are separated, it should be pointed out that this was a collaborative effort in which the group at the Naval Medical Research Institute provided and placed the physical equipment and the group at the Atomic Energy Project of the University of Rochester provided the animals and conducted the biological experiments herein reported.

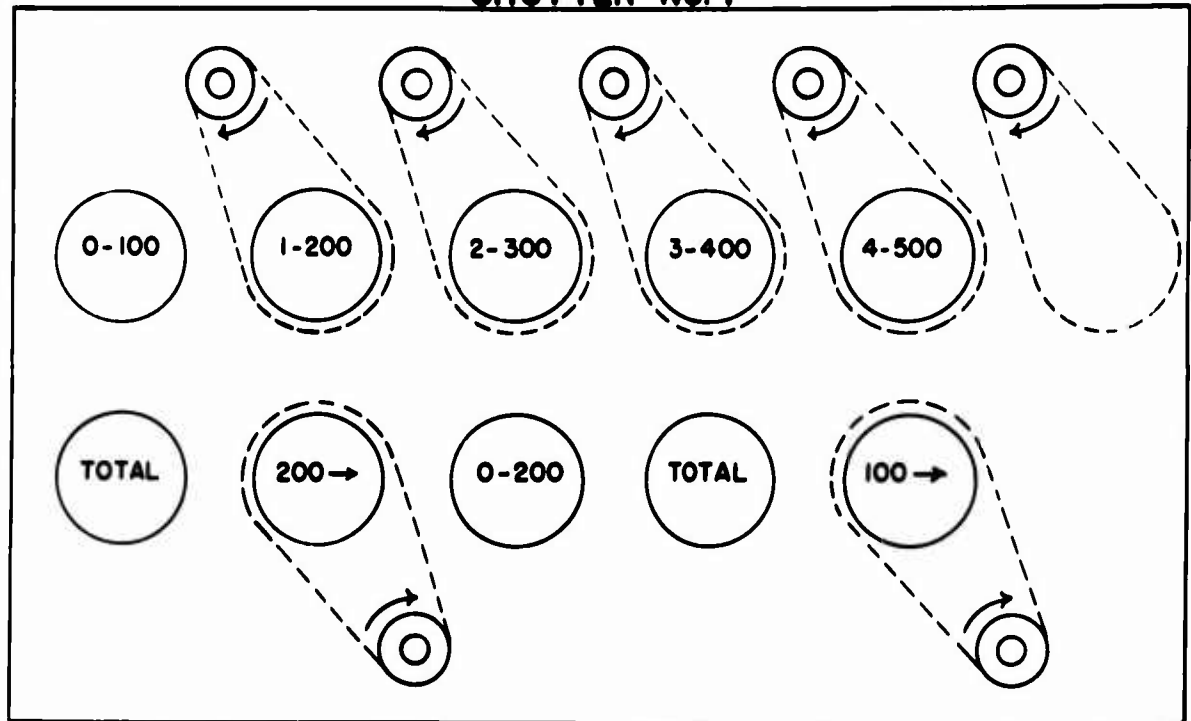
2.2.2 Large and Small Area Containers

To compare small and large area burns, four animals were placed in individual plywood containers suspended from A-frames at the 8601 ft station for Shot 3 and the 7849 ft station for Shot 4. Each container was faced with 1/4 in. transite sheet (compressed asbestos and Portland cement) having a central rectangular aperture 3 x 4.5 in. and four 0.75 in. (1.9 cm) diameter circular openings. Each of the latter was 1 in. away from the four corners of the rectangular opening. These ports were not covered by quartz. India ink was applied to limited areas of the skin on some of the animals in these containers at Shot 4.



SHUTTER NO. 1

FA21 48731 - 12



SHUTTER NO. 2

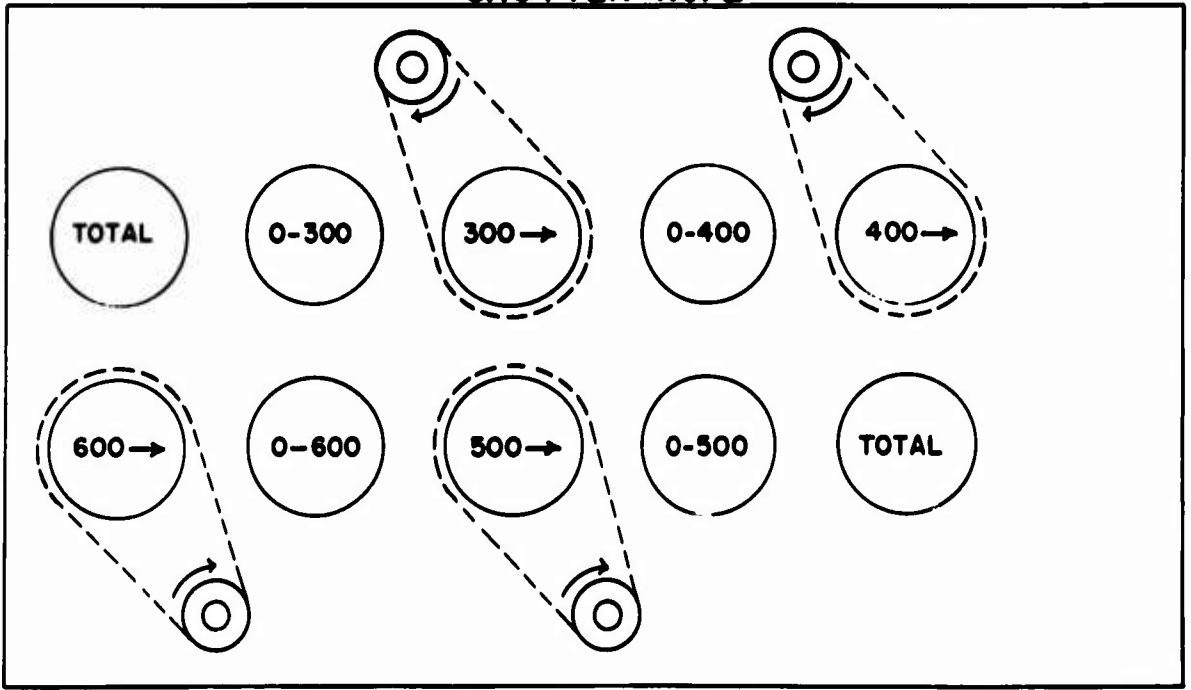


Fig. 2.1 Schematic Diagram of the Two Types of Shutter Plates Used at Thermal Stations





2.2.3 Animal Protection

The animals placed in aluminum cylinders were protected against cold by thermostatically controlled strip heaters in the walls of the containers. Ventilation was provided by electrically driven fans in the end bells of the cylinders which were fitted with shutters to prevent excess dust during the blast wave.

2.2.4 Orientation of Animals

All shutter plates and containers were oriented with the anticipated height of the burst to present a plane surface perpendicular to the incident radiation. All apertures were at least 24 in. above the ground surface.

2.3 ANIMALS

Thirty-two Chester White pigs were procured from the laboratory supply source and were maintained under laboratory cage conditions for 10 days or more prior to shipment to Nevada Proving Grounds. This period of time was required to insure that the animals were free from systemic disease and dermatitis. They were shipped via railway express with an attendant who supervised feeding and care en route. At Nevada Proving Grounds the animals were placed in prepared animal runs in groups of eight. Feeding and care were similar to conditions maintained in the University of Rochester laboratory. On the day prior to testing the weights ranged from 11.1 to 19.1 kg with 23 weighing from 14.5 to 17.0 kg. The age ranged from 10 to 14 weeks. All animals were identified with numbered ear tags.

2.4 ANESTHESIA

Pigs were anesthetized with Dial in Urea-urethane injected intraperitoneally. The dose used for Shot 3 was 70 mg per kg based on the fasting weight on the day prior to the test. For Shot 4 the dose was increased to 72.5 mg per kg in order to reduce the reflex movement in a few animals as indicated by the burns from Shot 3.

2.5 EVALUATION OF BURNS

2.5.1 Gross Appearance

Burns were observed and photographed in color as soon as possible upon the return of the animals to the laboratory. After each shot each of several observers determined the severity of burn and assigned a value for the type of injury. A template was used to orient the observer for location of burns on the side of the animal. The assessment was made objectively without the observer's knowledge

[REDACTED]

of the type of exposure causing the lesions. On D + 1 the evaluation of the burn was repeated after the animals were anesthetized with intravenous sodium pentobarbital. Biopsies of each burn were obtained at this time and the animals sacrificed.

2.5.2 Microscopic Evaluation

At 24 hours after burning surgical biopsies were taken from all lesions in such a way as to obtain representative burned tissue and adjacent normal skin. After fixation and staining with hematoxylin and eosin, the microscopic sections were studied and evaluated with regard to both depth and types of thermal effects. Objective interpretation was assured by examination of each section without knowledge of the gross appearance or classification.

Depth was measured in millimeters from the skin surface to the average level of thermal damage of the epidermis or of the hair follicle epithelium with a microscope optical micrometer.

Qualitative evaluation of the thermal effects was categorized according to a descriptive terminology from laboratory studies. These gradations in order of increasing severity were:

- a) acidophilic coagulation with vacuolization of epidermal cells
- b) epidermal-dermal separation
- c) shrinking and spindling of epidermal cells
- d) bleb formation
- e) basophilic dermal coagulation
- f) carbonization

Combinations of these gradations were often observed. Final interpretation and classification of each section were based upon the most severe microscopic damage.

2.5.3 Energy Values Assigned to Burns

Each burn was classified according to the descriptions given in Table 2.2. After the burn was classified, the number of calories which would produce such a burn in the laboratory was determined from the time-intensity threshold values (Figure 2.2) 2/. Each curve on this graph represented the 50 per cent probability of the lesion being produced with the amount of energy and the time

TABLE 2.2

Gross Appearance and Classification of Burns on Pigs

Surface Appearance	Descriptive Term	Laboratory Grade
Erythema Mild Moderate Severe	Red Burn	1+
Patchy Coagulation Mild Moderate Severe	Spotted White Burn	2+
Uniform Coagulation Mild Moderate Severe	White Burn	3+
Steam Bleb Mild Moderate Severe	Blistered White Burn	4+
Carbonization Mild Moderate Severe	Charred Burn	5+

specified. The assigned caloric values for burns behind ports at identical conditions of distance and time of exposure were then averaged.

2.5.4 Thermal Energy Measurements

Thermal measurements made by Project 8.3 ^{3/} were used for comparison with clinical burn data. Values of total unobscured thermal energy at each station were obtained from the curves of Total Thermal Energy vs Slant Range for the appropriate shot (Figures 5.3 and 5.4, pp. 69 and 70) ^{3/}.

^{3/} A. Broido, et al, Thermal Radiation from a Nuclear Detonation, USNRDL Project 8.3, Operation TUMBLER-SNAPPER. September 1, 1952.

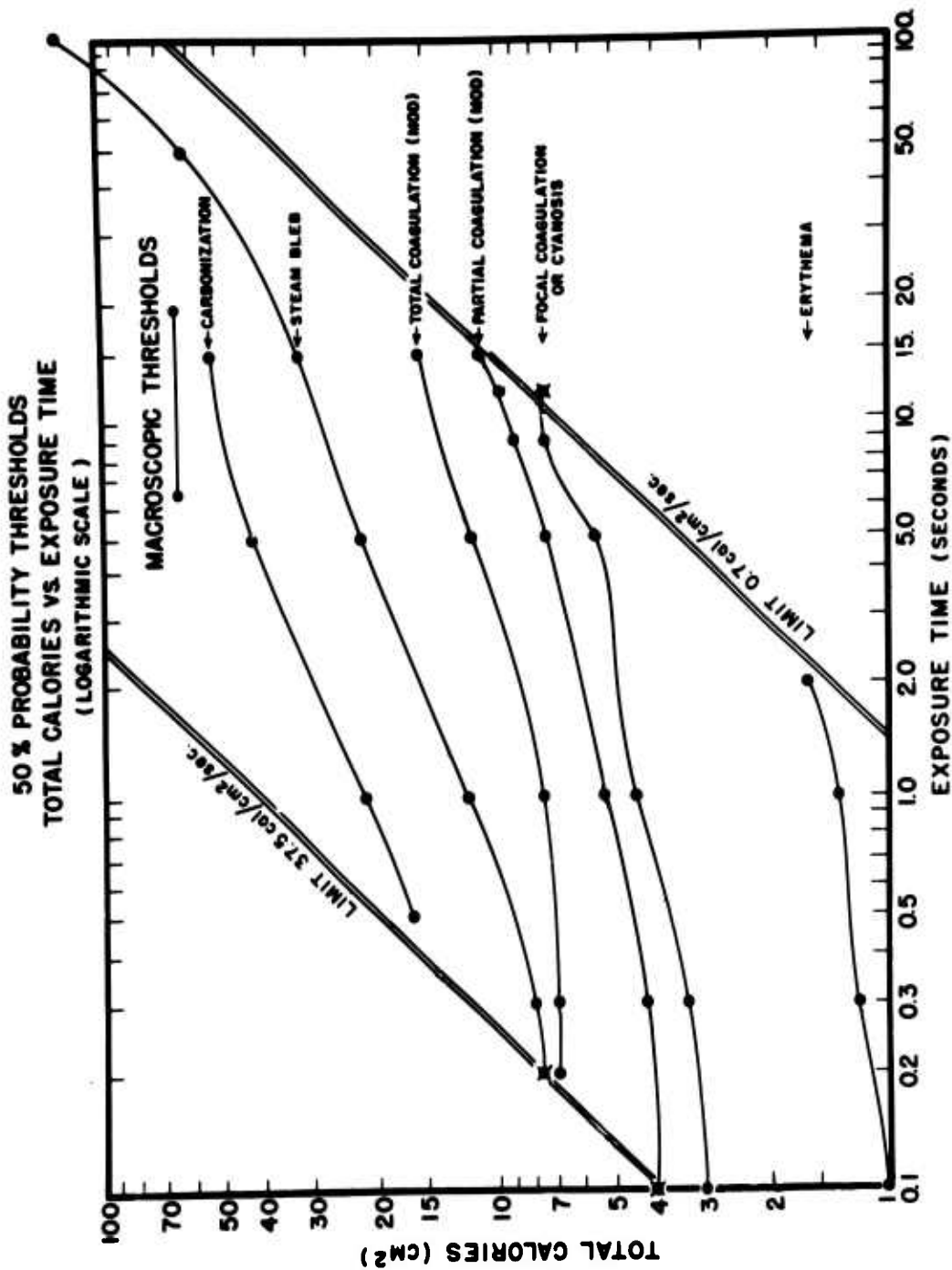


Fig. 2.2 Curves Reproduced from Work of Perkins et al Showing Threshold Energies for Various Degrees of Injury as Assessed by Surface Appearance

██████████

To account for local obscuration at the various stations it was assumed that:

1) there was no obscuration until the arrival of the shock wave at the station in question, after which no further thermal energy reached the station,

2) the percentage obscuration at the two-foot high apertures could be found by linear interpolation between that at 0 ft elevation and 10 ft elevation. Thus, on Fig. 5.19 (p. 88) 3/, Attenuation Due to Local Obscuration for Air Bursts, a curve was drawn $1/5$ of the distance from the 0 ft curve to the 10 ft curve, which was taken to represent the percentage attenuation at the 2 ft elevation.

Calculations of the thermal energy in the various time periods were found by planimetry of the Normalized Intensity vs Time curves of Fig 5.9 (p. 75) 3/. (The stations were close enough to ground zero so that the slight correction in shape of the intensity-time curves due to selective atmospheric absorption could be ignored). The method was as follows:

1) The area of the rectangle of height 100 per cent of Total Energy/sec and length 1.0 sec was measured. This area represented the total thermal energy received.

2) Areas under the appropriate curve were measured in the time periods 0 to 0.1 sec, 0 to 0.2 sec, 0 to 0.3 sec, etc.

3) The areas found in (2) were expressed as percentages of the area from (1).

4) The percentage of total thermal energy received in the other time periods (0.1 sec to 0.2 sec, 0.2 sec to 0.3 sec, 0.1 sec on, 0.2 sec on, etc.) were found by differences of the values found in (3).

5) The products of the percentages from (3) and (4) times the total unobscured thermal energies from Figs. 5.3 and 5.4 (pp. 69 and 70) 3/ gave the thermal energy in the various time periods.

Inasmuch as the shock wave reached no station before 0.6 sec, no corrections for obscuration were made for time periods up to 0.6 sec. For the periods of 0.1 sec on, 0.2 sec on, etc., the amount of thermal energy lost by obscuration was found by multiplying the appropriate percentage attenuation by the total unobscured thermal energy and subtracting this amount from that calculated in (5) above. Table 2.3 presents the results of these calculations.


TABLE 2.3

Calculated Thermal Energy from Project 8.3 Measurements

Time Periods (Sec)	Shot Number 3				Shot Number 4			
	Per Cent Thermal Energy	Energy Delivered in Given Time Periods (cal/cm ²)			Per Cent Thermal Energy	Energy Delivered in Given Time Periods (cal/cm ²)		
		4955'	6199'	8601'		3642'	4327'	5195'
0-∞	100	37	23	12	100	40	28	19
0-S**		33 *	21 *	12 *		35 *	25 *	18 *
0-0.1	5.8	2.1	1.3	0.7	9.3	3.7	2.6	1.8
0.1-0.2	19.8	7.3	4.6	2.4	24.8	9.9	6.9	4.7
0.2-0.3	15.7	5.8	3.6	1.9	13.2	5.3	3.7	2.5
0.3-0.4	9.6	3.6	2.2	1.2	8.2	3.3	2.3	1.6
0.4-0.5	7.1	2.6	1.6	0.8	5.3	2.1	1.5	1.0
0-0.2	25.6	9.5	5.9	3.1	34.1	17	9.5	6.5
0-0.3	41.3	15	9.5	5.0	47.3	19	13	9.0
0-0.4	50.9	19	12	6.1	55.5	22	16	10
0-0.5	58.0	22	13	7.0	60.8	24	17	12
0-0.6	63.0	23	14	7.6	65.1	26	18	12
0.1-∞	94.2	31	20	11	90.7	31	22	16
0.2-∞	74.4	24	15	8.9	65.9	21	16	12
0.3-∞	58.7	18	12	7.0	52.7	16	12	9.0
0.4-∞	49.1	14	9.7	5.9	44.5	13	9.5	7.5
0.5-∞	42.0	11	8.1	5.0	39.2	11	8.5	6.4
0.6-∞	37.0	9.3	6.9	4.4	34.9	8.8	7.3	5.6

* Obscuration at 2 ft elevation considered after arrival of shock wave.

** Shock wave arrival.



2.6 OPERATIONS

On D-1 the fasted pigs were weighed and clipped with electric clippers having an extra fine head. The skin was washed with water and inspected for dermatitis or injury.

From H-6 to H-3 the animals were transported to the station sites where they were given the calculated amount of anesthesia intraperitoneally. After sleep was induced they were placed in the exposure containers. Great care was taken to ensure even contact of the sides of the animals against the inner surfaces of the aperture plates.

Approximately 2 hours after the bomb detonation, the animals were recovered from the stations. Careful observations were made as to the condition of ports and shutters to verify that proper operation had occurred. The animals were then returned to the laboratory for evaluation of the burns.


CHAPTER 3RESULTS3.1 SURVIVAL OF ANIMALS

There was one death from anesthesia, occurring at Shot 3 in an animal exposed in an open container suspended from the A-frame. All other pigs were recovered in good condition.

3.2 BURNS - SURFACE APPEARANCE

Satisfactory burns for analysis were produced on all surviving animals exposed except one. In this case (Shot 3, 4955 ft) there was mechanical failure of the release of an aperture plate dust cover at the -5 sec signal. There was evidence, based on inconsistency of the appearance of burns, that one port shutter at Shot 3 and two port shutters at Shot 4 did not operate properly. These are designated in Tables 3.1 and 3.2 by "No Data". After Shot 3, the burns on three animals showed evidence of blurring of the longer duration exposures and at the extreme ends of the aperture plates. This appeared to be due to athetoid movements of the animals which were present with light anesthesia. Slightly increasing the anesthesia dosage for animals exposed at Shot 4 prevented motion without affecting mortality.

Abrasions existing prior to exposure caused a greater severity of burn in the involved area. This was presumably due to reduced reflectance. Such lesions were always linear or small in diameter, and could be easily detected. Despite great care in positioning an animal behind an aperture plate, there was occasionally slight angulation of the skin surface behind a port. This resulted in a slightly uneven burn, which was graded by the most severely injured portion. The majority of burns were uniform in surface appearance with sharply delineated margins. There was a variable amount of palpable and visible edema which usually disappeared by the 24 hour examination. All burns, regardless of their severity, were surrounded by a 1-3 mm contiguous zone of erythema. Tables 3.1 and 3.2 show the summary of burn data for Shot 3 and Shot 4 respectively. The average of assigned energy in cal/cm² for each exposure condition is also shown in the table.

3.3 EFFECTS OF TOTAL THERMAL PULSE

Figure 3.1 shows the severity of burns produced by exposure to the total thermal pulse of the two bombs at the distances indicated.

TABLE 3.1

Tabular Summary of Burn Severity and Assigned Thermal Energy*

Shot 3

Exposure Period (Sec)	Pig No. 4955'	Avg. cal/cm2*	Pig No. 6199'	Avg. cal/cm2*	Pig No. 8601'	Avg. cal/cm2*
Total	400 5+ Mod 380 5+ Mod 394 5+ Sev 393 5+ Mod 393 No Data	33 (20)	396 4+ Sev 364 4+ Sev 4+ 4+ Mod 387 5+ Mod 392 5+ Mi 392 5+ Mi	27 (16)	384 3+ Sev 391 3+ Mod 358 3+ Mi 360 3+ Mi 360 1+ Sev	8.3 (6.5)
0-0.1	400 1+ Mi 380 2+ Mod	2.7	396 1+ Mi 364 1+ Mi	1.0	384 0 391 0	1 1
0.1-0.2	400 2+ Sev 380 2+ Mod	6.2	396 2+ Sev 364 2+ Mi	4.6	384 0 391 0	1
0.2-0.3	400 1+ Mi 380 2+ Mi	2.5	396 1+ Mi 364 1+ Mi	1.0	384 0 391 0	1
0.3-0.4	400 0 380 1+ Mi	1.0	396 0 364 0	1	384 0 391 0	1
0.4-0.5	400 1+ Sev 380 0	1.7	396 0 364 0	1	384 0 391 0	1
0-0.2	400 3+ Mod 380 2+ Sev	7.3	396 3+ Mi 364 2+ Sev	5.9	384 1+ Mod 391 1+ Mod	1.9
0-0.3	394 5+ Mod 393 No Data	14.8	387 3+ Mod 392 5+ Mi	10.3	358 2+ Mi 360 2+ Mi	4.0
0-0.4	394 5+ Mod 393 No Data	16.4	387 3+ Sev 392 5+ Mi	11.2	358 2+ Mod 360 2+ Mi	4.4
0-0.5	394 4+ Sev 393 No Data	14.5	387 4+ Mod 392 4+ Mi	10.3	358 2+ Sev 360 2+ Mi	5.2
0-0.6	394 No Data 393 No Data		387 5+ Mi 392 4+ Mi	14	358 3+ Mi 360 2+ Mi	6.1

TABLE 3.1 (Continued)

Tabular Summary of Burn Severity and Assigned Thermal Energy*

Shot 3

Exposure Period (Sec)	Pig No.	4955'		Pig No.	6199'		Pig No.	8601'	
			Avg. cal/cm ² *			Avg. cal/cm ² *			Avg. cal/cm ² *
0.1-Total	400	5+ Mi	30.5	396	4+ Mod	14	384	2+ Sev	6.8
	380	5+ Mod	(17.5)	364	3+ Sev	(9.3)	391	2+ Mod	(5.5)
0.2-Total	400	3+ Sev	11.0	396	3+ Sev	9.5	384	1+ Mi	2.4
	380	3+ Sev	(7.4)	364	3+ Mi	(6.9)	391	1+ Mod	(1.9)
0.3-Total	394	2+ Sev	7.2	387	2+ Mi	4.2	358	0	1
	393	No Data	(5.8)	392	1+ Mod	(3.0)	360	0	
0.4-Total	394	2+ Mod	5.9	387	0	3.3	358	0	1.5
	393	No Data	(4.2)	392	2+ Mi	(2.5)	360	1+ Mi	(1.2)
0.5-Total	394	0	1	387	0	1	358	1+ Mi	1.0
	393	No Data		392	0		360	0	
0.6-Total	394	No Data	1	387	0	1	358	0	1
	393	No Data		392	0		360	0	

* Calculated from laboratory data of Perkins. "Total" based on 2.0 sec exposure in laboratory. Values in parentheses based on total of 0.6 sec exposure (See Figure 2.2).

Abbreviations - Mi - Mild
 Mod - Moderate
 Sev - Severe

TABLE 3.2

Tabular Summary of Burn Severity and Assigned Thermal Energy*

Shot 4

Exposure Period (Sec)	Pig No. 3642'	Avg. cal/cm2*	Pig No. 4327'	Avg. cal/cm2*	Pig No. 5195'	Avg. cal/cm2*
Total	389 5+ Sev 5+ Sev	37 (23)	361 5+ Mod 5+ Mod	31.6 (19)	366 5+ Mi 5+ Mi	30 (18)
	397 5+ Sev 5+ Sev		386 5+ Mod 5+ Mod		387 5+ Mi 5+ Mi	
	362 5+ Sev 5+ Sev		359 4+ Sev 5+ Mi		357 5+ Mi 5+ Mi	
	377 5+ Sev 5+ Sev		379 5+ Sev 5+ Mi		365 5+ Mod 5+ Mi	
0-0.1	389 3+ Mi 397 3+ Mi	6.2	361 1+ Mi 386 2+ Mod	2.6	366 1+ Mod 378 2+ Sev	3.5
0.1-0.2	389 4+ Mi 397 3+ Sev	7.4	361 2+ Sev 386 3+ Mi	5.8	366 2+ Mi 378 3+ Mi	5.0
0.2-0.3	389 3+ Mi 397 1+ Mi	3.7	361 0 386 2+ Mi	2.4	366 0 378 1+ Mi	1.0
0.3-0.4	389 1+ Mod 397 0	1.0	361 0 386 0	1	366 0 378 0	1
0.4-0.5	389 1+ Mi 397 0	1.0	361 0 386 0	1	366 0 378 0	1
0-0.2	389 5+ Mod 397 5+ Mod	13.5	361 4+ Mod 386 3+ Mi	7.3	366 3+ Sev 378 3+ Sev	7.3
0-0.3	362 5+ Mi 377 5+ Mi	13.5	359 No Data 379 5+ Mi	13.5	357 5+ Mi 365 3+ Mi	9.9
0-0.4	362 5+ Sev 377 No Data	18.5	359 4+ Mod 379 5+ Mod	13.0	357 3+ Sev 365 4+ Sev	10.5
0-0.5	362 4+ Sev 377 3+ Sev	11.3	359 4+ Sev 379 4+ Sev	14.5	357 4+ Mod 365 4+ Mod	10.5
0-0.6	362 4+ Sev 377 5+ Mod	17.8	359 4+ Sev 379 5+ Mi	16.2	357 4+ Mod 365 4+ Mod	10.5

TABLE 3.2 (Continued)

Tabular Summary of Burn Severity and Assigned Thermal Energy*

Shot 4

Exposure Period (Sec)	Pig No.	3642'	Avg. cal/cm ² *	Pig No.	4327'	Avg. cal/cm ² *	Pig No.	5195'	Avg. cal/cm ² *
0.1-Total	389	5+ Mod	32	361	4+ Mi	15.5	366	3+ Sev	11.2
	397	5+ Mod	(18)	386	4+ Mi	(9.4)	378	3+ Sev	(8.0)
0.2-Total	389	4+ Sev	19.4	361	3+ Sev	11.0	366	2+ Sev	8.0
	397	4+ Sev	(11.6)	386	3+ Sev	(7.4)	378	3+ Mod	(6.5)
0.3-Total	362	3+ Sev	9.6	359	No Data	8.6	357	1+ Mi	2.3
	377	3+ Sev	(7.2)	379	3+ Mod	(7.0)	365	1+ Mod	(1.8)
0.4-Total	362	3+ Mi	7.7	359	1+ Mi	4.5	357	0	1
	377	No Data	6.2	379	2+ Sev	(3.5)	365	0	
0.5-Total	362	2+ Mi	5.5	359	0	1	357	0	1
	377	2+ Mi	(3.7)	379	0		365	0	
0.6-Total	362	1+ Mi	2.6	359	0	1	357	0	1
	377	1+ Sev	(-)	379	0		365	0	

* Calculated from laboratory data of Perkins. "Total" based on 2.0 sec exposure in laboratory. Values in parentheses based on total of 0.6 sec exposure (See Figure 2.2).

Abbreviations - Mi - Mild
 Mod - Moderate
 Sev - Severe

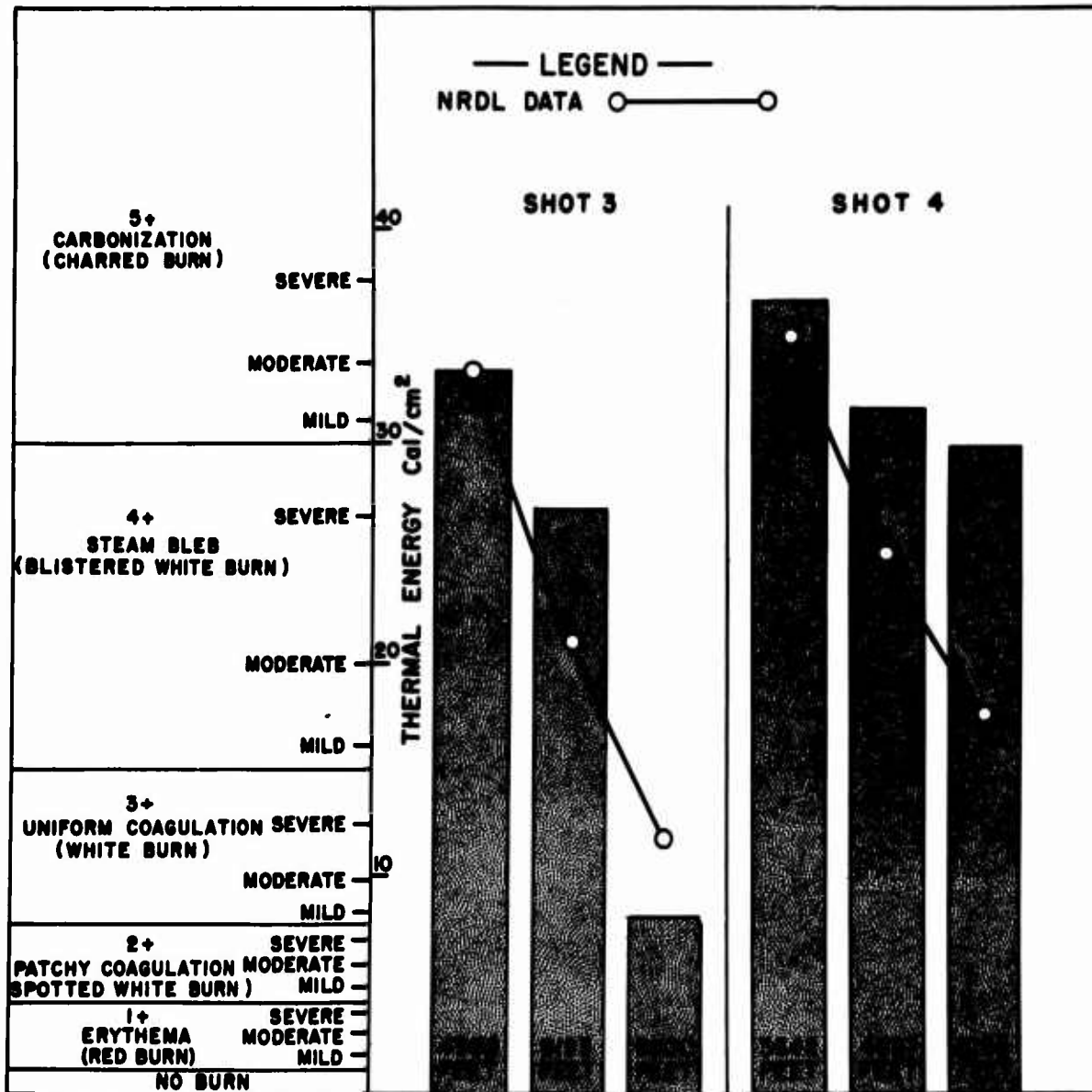


Fig. 3.1 Comparison of Burn Severity, Assigned Energy Causing Burns and Energy Calculated from NRDL Data for Total Exposure Time at Thermal Stations for Shots 3 and 4

Note: Energy assigned to burns is based on 2.0 sec laboratory exposures.

[REDACTED]

At the left of the graph, the descriptive grading is shown and is compared to caloric values in the numerical column. The latter values are based on 2 sec exposures in the laboratory $\frac{1}{2}$. This time was chosen since at 2 sec 90 per cent of thermal energy had been delivered. The points connected by the solid line represent extrapolated data from the calorimetric measurements made by Project 8.3. It is evident that there is a fair correlation between the severity of burn and the measured energy. The first station (3642 ft) at Shot 4 demonstrates a difficulty attendant upon burn assessment by gross appearance. Burns showed the maximum severity distinguishable, namely severe carbonization or charring. Once this state is reached, the effects of added energy cannot be determined grossly. No explanation is apparent for the more severe appearance of the effects at the 6199 ft station at Shot 3 and all stations at Shot 4. Two possibilities are offered to account for this finding. First, the field thermal pulse is characteristically different from the trapezoidal pulse used in the laboratory. In the bomb thermal pulse there is a sharply ascending ramp which reaches a maximum in about 0.15 sec and is followed by a more slowly descending ramp and long tail. Second, there is a changing spectrum of radiant thermal energy occurring with time. Further laboratory experimentation is necessary to assess the role of these two factors in burn production.

3.4 BURNS FROM 0.1 SECOND PERIODS OF THE THERMAL PULSE

The comparison of the thermal energy in cal/cm² calculated from the calorimetric measurements (Par 2.5.4) at the first station and the energy value in cal/cm² based on the appearance of burns at each station is shown in Fig. 3.2 with separate plots for each shot. Each point represents the energy determined during the successive 0.1 sec periods after inception of the flash. In this group, burns were assigned caloric values based on laboratory exposures of 0.1 sec. The most severe clinical burns were always produced in the second 0.1 sec period at each shot at all stations. From comparison of caloric values in Tables 2.3 and 3.1 it is apparent that burn energy was higher than calculated energy for the first 0.1 sec period at the near stations at each shot, the same at the intermediate stations at each shot and higher at the distant station at Shot 4. In contrast to this there was higher calculated energy for every 0.1 sec period thereafter except the 0.1-0.2 sec interval at the 6199 ft station, Shot 3, and the 5195 ft station, Shot 4, where they were the same.

In Shot 3 the calculated energy in the period 0-0.1 sec and that in 0.4-0.5 sec for the first two stations was approximately equal but the burns showed much greater severity in the former period. Similarly in Shot 4 where the calculated energies in the periods 0-0.1 sec were approximately equal to those in the periods 0.3-0.4 sec the burns in the first period were far more severe. For example, in the

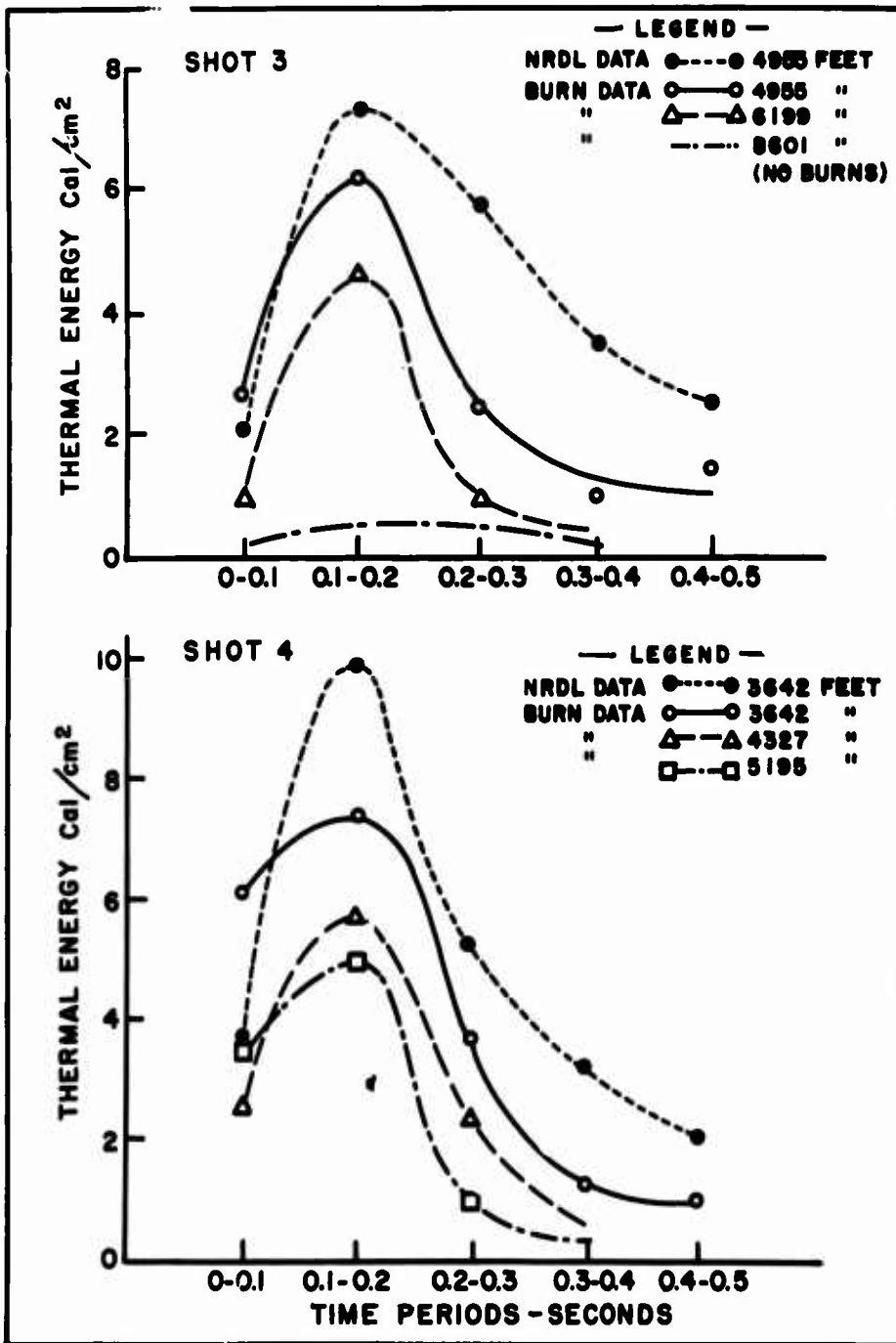


Fig. 3.2 Thermal Energy in 0.1 Sec Periods Determined from Burns at All Stations and from Physical Measurements at Inner Stations, Shots 3 and 4

[REDACTED]

3642 ft station, Shot 4 where the calculated energy in 0-0.1 sec was 3.7 cal/cm², two 3+ burns were produced. In contrast, calculated energy in 0.3-0.4 sec of 3.3 cal/cm² produced a 1+ burn and no burn.

Movies taken at 64 frames per second of the fronts of the stations during the period to 0.5 sec revealed no evidence of mechanical failure of shutters or interference by dust.

From the above evidence it was concluded that the measured thermal energy was far more effective in producing thermal burns in the early phases of the thermal pulse than in the later periods. It was also apparent, that, for the weapons involved, the second 0.1 sec period was the most effective in producing burns.

3.5 BURNS FROM EXPOSURE TO INCREASING INCREMENTS OF THE THERMAL PULSE

Plots of the data from the increasing periods of exposure are shown in Fig. 3.3 for each shot. The calorie values assigned to the burns were based on exposures of the same time intervals in the laboratory, using Perkins' data ^{1/}. The curve of calculated data was taken from Table 2.3 using the values for the inner station only at each shot. There was no data for the 0-0.6 sec exposure at the 4955 ft station, Shot 3, because of dust cover and shutter failures. The erratic data obtained at the 0-0.5 sec exposure was explained somewhat by the location of this port on the side of the animal. By reference to Fig. 2.1 the order of shutter ports can be seen. On several of the pigs (Nos. 394, 392, Shot 3; Nos. 362, 377, 379, 357, 365, Shot 4) the 0-0.5 sec port was in front of the depression formed at the junction of the hind leg and flank. Hence, the failure to maintain normal exposure in these areas probably explains the low values for burns. No other contour effects were observed that seriously affected the results.

There was only a mild increase in burn severity observed in this series of burns beyond the exposure period of 0-0.4 sec in both Shots. In 3 animals at Shot 3, there was evidence of very slight increase in severity of the burns after 0-0.5 sec exposures.

When the burns from increasing increment exposures were compared with the total exposure burns on the same animal, it was evident that severity equal to at least one of the two total burns was attained in all 5 of the animals in Shot 3 before or during the 0-0.6 sec exposure. In 2 animals, No. 394 at 4955 ft and No. 392 at 6199 ft, this occurred in 0-0.3 sec. The others were similar by 0-0.6 sec.

At Shot 4, four of the six animals had burns of severity equal to a total exposure burn in the intervals 0-0.3 sec to 0-0.4 sec. In Pig No. 377 at 3642 ft and No. 365 at 5195 ft, burns did not

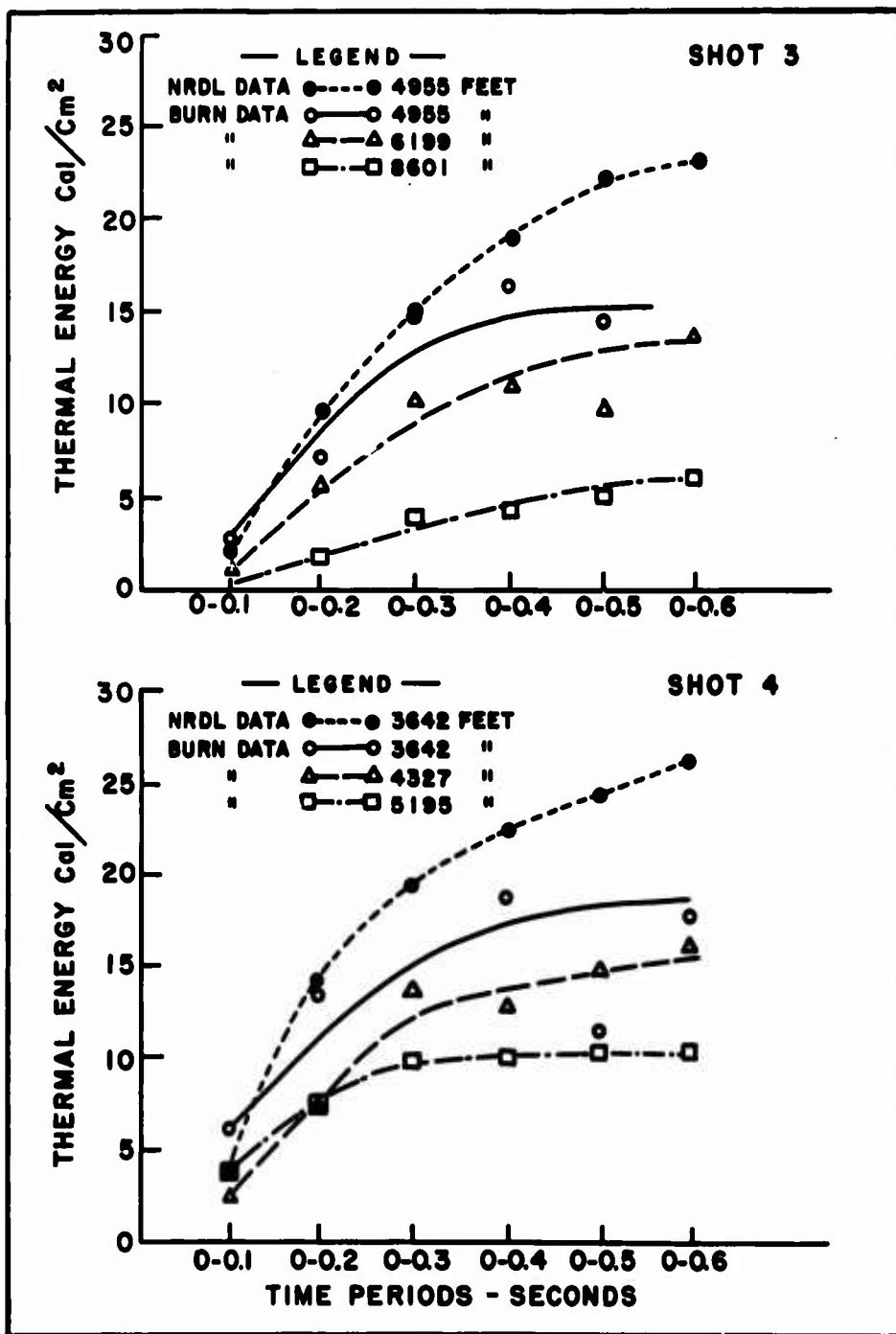


Fig. 3.3 Thermal Energy in Increasing Increments of Exposure Time Determined from Burns at All Stations and from Physical Measurements at Inner Stations, Shots 3 and 4

[REDACTED]

attain the severity of the total burn by 0-0.6 sec. In the case of No. 377, the shutter for the port 0-0.4 sec and 0.4 sec-total failed. This would indicate that the 0-0.5 sec and the 0-0.6 sec exposure may also have been involved, but there was no conclusive evidence for this. In the other animal, the lack of good apposition of the skin behind the ports was indicated by the less severe burns of the lower row, 0-0.5 sec and 0-0.6 sec, compared to the more severe 0-0.4 sec burn on the upper row.

From this series of exposures it was concluded that nearly all the effective thermal energy for the production of cutaneous burns had been delivered within the first 0.5 sec. Table 2.3 shows that in this time for Shot 3, 58 per cent and for Shot 4, 60.8 per cent of the thermal energy had been delivered. The remaining amount had little effect in causing increased severity of burns. In the case of both Shots 3 and 4 at the inner stations this would amount to approximately 11 cal/cm². If this amount of energy from the carbon arc were applied to skin surface over a 2.0 sec period, it would cause a severe 3+ burn on normal skin.

3.6 EFFECTS OF INCREASING INITIAL CUT-OFF OF THE THERMAL PULSE

In Fig. 3.4 comparisons are shown between the calculated thermal energy (NRDL data) at the innermost station delivered after the time cut-off by the shutters and the assigned energy from burns under the same conditions at all stations. Data from Shots 3 and 4 are plotted separately. To the left of each graph a column showing total thermal energies is presented to complete the range of exposures. It is evident that the burn severity decreased more rapidly than the calculated energy. Burns produced after 0.3 sec at each Shot were mild. There were no significant burns produced when the thermal energy in the first 0.6 sec had been blocked by the shutters. Only two animals, Nos. 362 and 377 at the 3642 ft station, Shot 4, revealed burns beyond this time. In Par. 3.5, question was raised concerning the operation of the shutter for No. 377. Any failure would have been reflected in this series of burns. The per cent of energy delivered after 0.6 sec was 37 per cent for Shot 3 and 35 per cent for Shot 4. At the inner stations this amounted to 9.3 cal/cm² and 8.8 cal/cm² respectively. In the laboratory these amounts delivered to an animal even over a 2.0 sec period would produce moderate coagulated (white) burns. Since it was demonstrated that there was no significant burning after 0.6 sec both by the increasing increment exposures and by the increasing initial cut-off exposures, the burns were re-assigned energy values on the basis of an 0.6 sec laboratory burn with the carbon arc source. These data are presented in Tables 3.1 and 3.2 in parentheses beneath the figure for 2.0 exposure data. The average percentage of measured energy producing the total exposure burns for all stations at Shot 3 was 64 per cent, while at Shot 4 it was 81 per cent. The latter figure was elevated by the unexplained severe

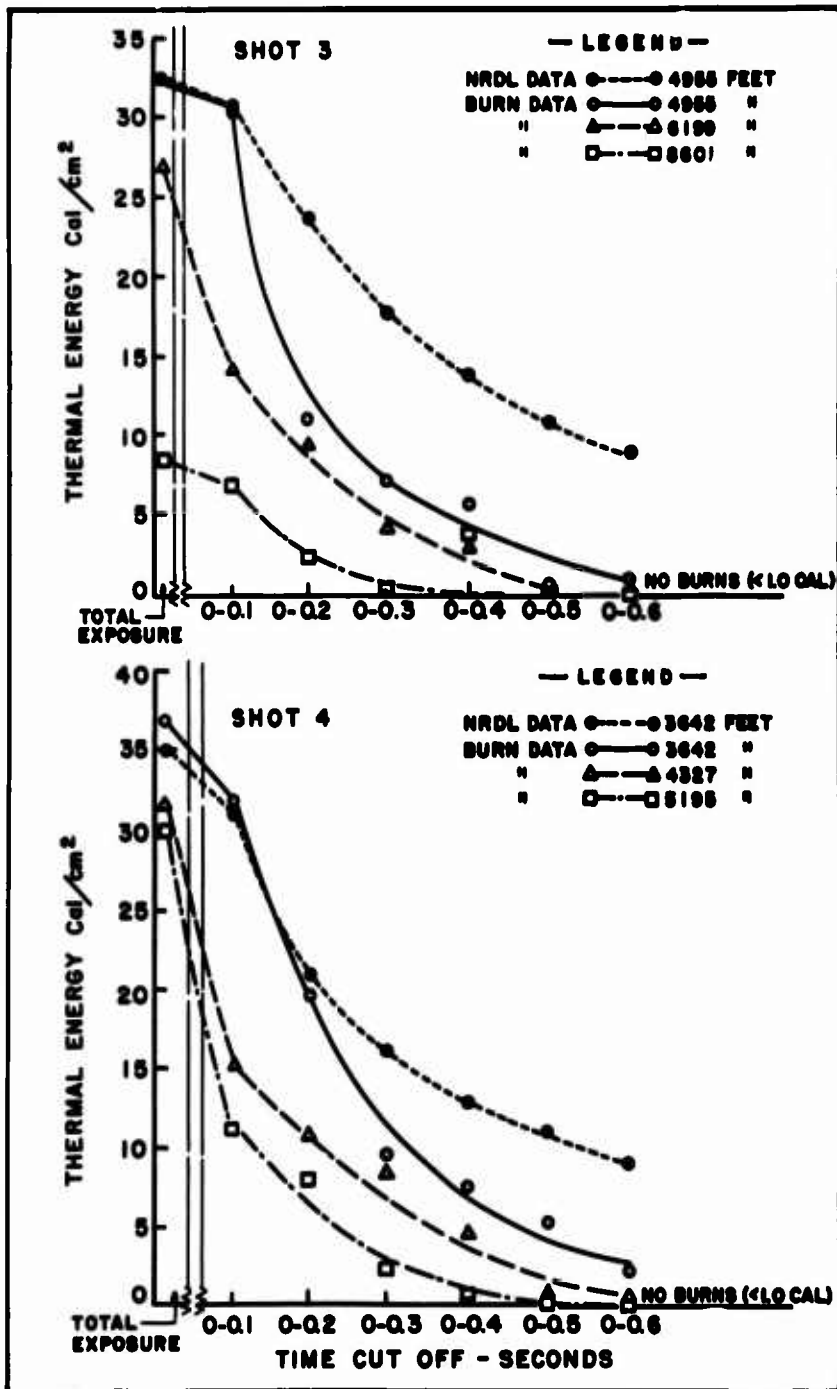


Fig. 3.4 Thermal Energy After Increasing Time Cut Off by Shutters as Determined from Burns at All Stations and from Physical Measurements at Inner Stations, Shots 3 and 4
 Note: Energy Assigned to burns is based on the open period of the shutter with total defined as 2.0 sec.

[REDACTED]

total exposure burns at the 5195 ft station. The lower figure compared well with the calculations of per cent of measured energy delivered in the first 0.6 sec-63 per cent, Shot 3 and 65 per cent, Shot 4 (Table 2.3). It was concluded from this that approximately 70 per cent of the measured total thermal energy delivered in the first 0.6 sec was responsible for the cutaneous burns produced by exposure to the weapons involved.

A further comparison of the effectiveness of various portions of the thermal pulse was made by inspecting Tables 3.2 and 3.3. For Shot 3 the burns produced in the period of 0-0.2 sec at all stations were approximately equal in severity to those produced by the portion of the pulse from 0.2 sec to total. For Shot 4, the burns in the first 0.2 sec were slightly more severe than those caused in the later period. In calculations of the measured energy (Table 2.3) there was 25.6 per cent at Shot 3 and 34.1 per cent at Shot 4 in the 0-0.2 sec interval. In the period from 0.2-0.6 sec, 37.4 per cent for Shot 3 and 31 per cent for Shot 4 were delivered. This supported the evidence that the 0.2 sec period accounted for 1/2 of the effective burning which ended by 0.6 sec.


3.7 RESULTS OF COMPARISON OF SMALL AND LARGE AREA BURNS

The three animals recovered from the 8601 ft station, Shot 3, and the four animals recovered from the 7849 ft station, Shot 4, were evaluated for a comparison of the burns behind the small (0.17 in. diameter) aperture and the large rectangular (3 x 4.5 in.) aperture. Two of the three animals from Shot 3 showed burns diagnosed as 2+ severe and the third was rated 3+ severe in the large areas. There were no significant differences noted grossly or microscopically between the large and small areas where the animal presented a plane surface to the ports. Of the four animals recovered from the 7849 ft station, Shot 4, 2+ mild to 2+ moderate burns were observed in both large and small ports on normal skin areas. In areas where India ink had been applied prior to the Shot, there was severe superficial blistering and carbonization, but microscopically, no differences in burn depth could be detected.

3.8 MICROSCOPIC EVALUATION OF BURNS

3.8.1 General

The lesions observed in the skin of the animals were those usually seen in "flash" burns and are outlined in 2.5.2. In reporting the results, reliance has been placed principally on the depth of the burn, instead of other criteria, since depth is the most reliable biological estimate of the intensity of the hyperthermia. This estimate of depth is based on changes in the corium and the epithelial cells of the epidermis and hair follicles. Frequently the depth as



measured by hair follicle epithelial changes was slightly greater than that observed in the corium. However, this difference was too small to have effect on the final results as reported. Difficulties in the estimation of depth were encountered in the burns because of the following factors:

- (1) slight differences in the morphology of injured and uninjured corium
- (2) variations of thickness of corium
- (3) contraction of coagulated or carbonized skin
- (4) absence of vascular or inflammatory reaction.

If biopsies had been taken later than 24 hours, the development of an inflammatory barrier might have helped in outlining the depth of irreparable injury. The results were extremely variable and unsatisfactory in regard to the total exposure burns as can be seen in Tables 3.1 and 3.2. The depth evaluation did not compare with gross evaluation. An improved method is needed for the microscopic determination for the depth of damage in skin.

The lesions produced in this experiment resembled closely those resulting from laboratory arc burns. The sharp demarcation between injured and normal tissue, and the absence of edema, congestion and inflammatory reaction at 24 hours were similar. The main difference between the arc burn and the burn produced in the field was that the contour of the former was that of a half moon, while the contour of the latter was that of a truncated cone.

3.8.2 Burn Depth - Shot 3

Total exposures at all three stations resulted in burns averaging 0.5 mm at the first, 0.8 mm at the second and 0.3 mm at the third station. Carbonization, basophilic dermal coagulation and bleb formation were observed in inverse proportion to the distance from ground zero. The lower figure for the first station as compared with the second may be due to the contraction of the burned skin.

With the 0.1 sec time period burns, the greatest effect occurred from 0.1-0.2 sec with an average depth of burn of 0.5 mm at the first station, 0.06 mm at the second station, and none at the third station. Depth of burn with this exposure was also correlated with qualitative evidence of more severe burn damage than was observed at the other time periods. Progressively decreasing and minimal evidence of burn damage resulted from 0.1 sec time interval exposures after 0.3 sec. These observations were generally substantiated by the results obtained with the other time exposures studied. At Shot 3 the microscopic comparison of 0-0.2 sec burns as compared to

0.2 sec-total burns did not support the similar gross appearance of the two.

From the microscopic data obtained from Shot 3 (Table 3.3) it may be concluded that the peak of greatest thermal damage to skin occurred from 0.1-0.2 sec and that only slight damage occurred after 0.4 sec at the stations used.

3.8.3 Burn Depth - Shot 4

Total exposures at all three stations resulted in burns averaging 0.7 mm in skin depth. No significant average difference in depth of burning at any of the three stations was observed. There was carbonization, basophilic dermal coagulation and occasional bleb formation in nearly all of these exposure effects.

With the 0.1 sec time period burns the greatest effect occurred from 0.1-0.2 sec with an average depth of burn of 0.3 mm at the first station, 0.1 mm at the second station and 0.08 mm at the third station. Depth of burn with this exposure was also correlated with qualitative evidence of more severe burn damage than was observed at the other 0.1 sec time periods. Progressively decreasing and minimal evidence of burn damage resulted from 0.1 sec time period exposures after 0.3 sec. These observations were generally substantiated by the results obtained with the other time exposures studied. As in Shot 3, the comparison of 0-0.2 sec burns and 0.2-total burns did not support the similar gross appearance.

From the microscopic data obtained from Shot 4 (Table 3.4) it may be concluded that the peak of greatest thermal damage occurred from 0.1-0.2 sec and that only slight damage occurred after 0.4 sec at the stations used.

TABLE 3.3

Microscopic Data - Shot 3

Average Depth of Burn in Millimeters

Period of Exposure (Sec)	Slant Range 4955 (ft)	Slant Range 6199 (ft)	Slant Range 8601 (ft)
Total	0.5	0.8	0.3
0-0.1	0.06	0.02	0
0.1-0.2	0.5	0.06	0
0.2-0.3	0.08	0.1	0
0.3-0.4	0.02	0	0
0.4-0.5	0.02	0	0
* 0-0.1	0.06	0.02	0
0-0.2	0.2	0.3	0.04
0-0.3	0.4	0.4	0.16
0-0.4	No Data	0.5	0.06
0-0.5	0.4	0.4	0.18
0-0.6	No Data	0.4	0.3
0.1-Total	0.5	0.4	0.2
0.2-Total	0.9	0.4	0.04
0.3-Total	0.3	0.06	0
0.4-Total	0.3	0.04	0
0.5-Total	0	0	0.02
0.6-Total	No Data	0	0

* Repeated to facilitate comparison

TABLE 3.4

Microscopic Data - Shot 4

Average Depth of Burn in Millimeters

Period of Exposure (Sec)	Slant Range 3642 (ft)	Slant Range 4327 (ft)	Slant Range 5195 (ft)
Total	0.7	0.7	0.8
0-0.1	0.2	0.1	0.1
0.1-0.2	0.3	0.1	0.1
0.2-0.3	0.1	0.03	0
0.3-0.4	0.06	0	0
0.4-0.5	0.02	0	0
* 0-0.1	0.2	0.1	0.1
0-0.2	0.3	0.6	0.3
0-0.3	0.6	0.5	0.4
0-0.4	0.6	0.4	0.4
0-0.5	0.8	0.4	0.6
0-0.6	0.8	0.5	0.8
0.1-Total	0.5	0.5	0.6
0.2-Total	0.6	0.1	0.4
0.3-Total	0.6	0.2	0.1
0.4-Total	0.4	0.1	0
0.5-Total	0.1	0	0
0.6-Total	0.1	0	0

* Repeated to facilitate comparison



CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS FROM RESULTS OF THE WEAPONS TESTED

The skin burns produced in the period between 0.1 and 0.2 sec after bomb detonation are the most severe of any created by an 0.1 sec interval of the thermal pulse.

By increasing increments of exposure, the major severity of thermal burns is attained within the first 0.3 sec and the maximum severity within the first 0.5-0.6 sec after bomb detonation.

When pig skin is shielded from the first 0.6 sec of the thermal pulse, no significant burns are produced. Yet the calculated per cent of measured thermal energy delivered after this time was 37 per cent for Shot 3 and 35 per cent for Shot 4.

Burns produced in the first 0.2 sec of the thermal pulse are approximately equal in severity to those produced in the period of 0.2 sec to the end of the pulse. Calculations from measured energy reveal approximately 30 per cent of the total in the first 0.2 sec and an equal amount in the 0.2-0.6 sec period.


There is better correlation between the measured thermal energy and that determined by evaluating the skin burns from laboratory standards during the first 0.3 sec than during later periods of the thermal pulse where the measured values are always significantly higher.

There are no apparent differences between the severity of small diameter (0.75 in.) and large (3 x 4.5 in) burns when sustained in the same animal.

Existing methods for microscopic evaluation are inadequate for the study of the depth of burns when dermis is involved.

4.2 RECOMMENDATIONS

Since there is not good correlation between measured thermal energy and the severity of burns after 0.3 sec, re-examination of instrumentation for measurements of effective thermal energy is required. A study of the spectrum of the thermal pulse and its effect upon cutaneous burns is also indicated.



Further work should be done first in the laboratory and later in the field on the influence of skin color on burn severity.

As soon as laboratory results warrant, further field tests should be made on the protective effects of fabrics against burns.

Improved methods should be developed for the assessment of burn depth.



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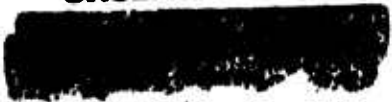
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