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EFFECTS FROM THE TAIL OF SIMULATED NUCLEAR WEAPON THERMAL PULSES

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Abstract

Will evasive action after detonation of a nuclear weapon result in less severe burns? Some field and laboratory studies have indicated that the tail of the thermal pulse adds nothing to burn injury and that late evasive action is probably useless. Because of the nature of the thermal pulse of nuclear weapons, the final forty per cent of the total exposure occupies well over two-thirds of the exposure time. Since large weapons have a long thermal pulse, escape from the final 40 per cent of the exposure from such weapons might often be possible. The following experiment compares the severity of burns resulting from the first 83 per cent and the first 60 per cent of the full field pulse.

Pulses simulating those of 25, 101, 228, 405, 912, and 1,622 kiloton weapons were used. Burns were produced on young Chester White pigs by radiant exposures of 10 calories/cm^2 (delivered in the form of the first 83 per cent of 12 calorie/cm^2 nuclear weapon exposures) and 7.3 calories/cm^2 (delivered in the form of the first 60 per cent of 12 calorie/cm^2 nuclear weapon exposures). Twenty-four hours after burning, the lesions were biopsied and the depth of damage was assessed histologically.

Since the 7.3 calorie/cm^2 burns are less severe than the 10 calorie/cm^2 burns, some portion of the pulse tail does add to the thermal damage to bare skin. One might well be able to avoid even more of the pulse tail following the detonation of weapons greater than 200 kilotons in size, and such action should be protective. Smaller weapons, however, deliver so much of their energy so rapidly that evasive action after their detonation is probably useless.

EFFECTS FROM THE TAIL OF SIMULATED NUCLEAR WEAPON THERMAL PULSES

Does evasive action after detonation of a nuclear weapon afford protection against burns? For small weapons the answer is obviously "no," since a high percentage of their energy is released in a fraction of a second. However, the larger the weapon the longer the thermal pulse, and escape from the final thirty, forty or fifty per cent of the exposure from large weapons becomes a possibility. Will avoiding the energy in the tail of the pulse result in a less severe burn? Some field and laboratory studies have suggested that it may not.

During a field experiment (1) attempts were made to determine how much damage occurred in each 0.1 second after detonation of an atomic weapon. The results of this study indicated that the initial 70% of the energy released was just as injurious to bare skin as was the whole thermal pulse, i.e., the final 30% of the energy in the pulse tail added nothing to the burn. This experiment, of necessity, suffered two severe limitations: a wide variety of weapon pulses could not be investigated, and severity of the burns was judged chiefly by their surface appearances, a technique which may be misleading when other than very mild lesions are compared (2). Nevertheless, a subsequent laboratory study seemed to corroborate the field results (3). As originally reported, the laboratory study was thought to have compared the effects of the initial 50%, 70% and 90% of pulses simulating those of weapons of 10, 100, 1000 and 10,000 kiloton size. Data from later field experiments, however, revealed that 46%, 65% and 83% were closer to the percentages of the pulses employed. With this more nearly accurate estimate, the conclusions of that study were that the initial 65% of the pulse is as damaging as the initial 83%, but is more injurious than the first 46% of the energy delivered. This was true for all four pulses. Since only mild burns were produced, surface appearance as the criterion for severity should have been sufficiently accurate to detect differences due to the amputation of the tail of the pulse. But the limitation of the laboratory experiment was its consideration of only mild burns. Although this was clearly pointed out in the report, the notion that the results are applicable to all degrees of burn is prevalent.

To provide data on the effects of pulse tail amputation on the production of severe burns and, more particularly, to learn something of the possible benefits of evasive action after weapon detonation, the following experiment was undertaken.

METHODS

Young Chester White pigs, anesthetized with intraperitoneal Dial urethane (Ciba) in doses of 65 mgm/Kg. were the experimental animals. The hair was clipped from the sides, and the skin was washed.

The heat source was a modified 24 inch Army carbon arc searchlight (4). The ambient temperature in the burning room was controlled to avoid wide variations in skin temperature.

The thermal pulse of a nuclear weapon was simulated by placing a rotating, slotted wheel between the source and the exposure port (5). The wheel is so constructed that the following relationships are accurate and reproducible.

1) $\frac{t_r}{t_{max}} = 12.415$

2) $\frac{t_{exp}}{t_{max}} = 10.5$

t_r = total rotation time of the wheel

t_{max} = time at which maximum irradiance is delivered

t_{exp} = time during which exposure to the heat source occurs

Although the rotation time of the wheel is 12.415 x t_{max}, because the last two segments of the wheel are blocked out, 10.5 x t_{max} represents the actual time of delivery of the radiant exposure. The constantly changing irradiance which occurs at the exposure port when this wheel is used simulated nearly exactly the first 83% of the thermal pulse of nuclear weapons (6). (The first peak is, of course, not considered.)

The size of the weapon simulated depends only on the rotation time of the wheel. The times used in this experiment and the approximate size of the weapons whose pulses were thereby simulated were:

2 seconds	25 kilotons
4 "	101 "
6 "	228 "
8 "	405 "
12 "	912 "
16 "	1,622 "

With each of the above rotation times, burns were produced by the delivery of 10 calories/cm^2. These exposures simulated the first 83% of the energy in 12 calorie/cm^2 nuclear weapon exposures. For comparison, 7.3 calories/cm^2 were delivered by blocking out the terminal segments of the wheel. These exposures corresponded to the initial 60% of a 12 calorie/cm^2 nuclear weapon exposure. Because of the nature of the nuclear weapon thermal pulse, delivery of the 7.3 calorie/cm^2 exposure required less than one-third the time for delivery of the corresponding 10 calorie/cm^2 exposure.

At each of the six exposure times burns were produced by exposures of both 7.3 calories/cm^2 and 10 calories/cm^2. These twelve treatments were randomly assigned sites on the sides of the animals and the treatment block was replicated twelve times to give a total of 144 burns, 36 on each of four pigs.

Twenty-four hours after burning, the exposed areas were biopsied. The specimens, which included normal tissue on each side of the burned area, were placed in 10% formalin and sections were stained by Hinshaw's modification of Verhoeff's elastic tissue stain (7).

Severity of the burns was assessed histologically by measuring the depth of dermal damage with the aid of a ruled ocular in the microscope. In addition, the percentage of the total dermal thickness destroyed by the burn was estimated. Because normal dermal thickness varies from one anatomical site to another and because the dermis is not of uniform depth even in a single microscopic section, exact estimates are not, however, possible. The percentage of the depth of hair follicle destruction was also estimated. Whenever the follicle was damaged at the junction of the subcutaneous fat and the deeper dermal extension it was termed full thickness damage even though many of the pig's hair follicles extended well into the fat.

RESULTS

The results are summarized in Tables I, II and III and are given in detail in Appendices I, II and III.

With thermal pulses simulating those of nuclear weapons from 25 kilotons to 1,622 kilotons, more dermal damage occurs from exposure to the initial 83% of the pulse (10 calories/cm^2) than from exposure to only the first 60% of the energy (7.3 calories/cm^2) (Tables I and II, Appendices I and II). With one possible exception (405 kiloton pulse) hair follicle damage is also greater for the 10 calories/cm^2 exposures (Table III, Appendix III). Hair follicle epithelium is always destroyed at least to the depth of dermal collagen damage and is almost invariably destroyed to a greater depth.

At least at the level of radiant exposure used in this experiment, some portion of the tail of the thermal pulse between 60% and 83% of the full pulse contributes significantly to burn severity. There is a tendency for the depth of damage of 10 calorie/cm^2 burns to decrease as exposure time increases, but within each exposure time a wide variety of burn severity is seen. With the three shorter exposures there is less variation in the severity of the 7.3 calorie/cm^2 burns. Because a few burns may be placed in areas where the skin is much thinner than average, occasional exposures will result in full thickness destruction of the dermis where they would ordinarily not be expected to do so (cf. Tables I and II, 912 kiloton -- 7.3 calorie/cm^2 burns).

DISCUSSION

The use of the modified carbon arc searchlight heat source and the rotating, slotted wheel permits nearly exact duplication of the thermal pulse of atomic weapons. However, the color temperature of the carbon arc is constant, that of an atomic weapon constantly changing. How this difference might influence the effectiveness of the tail of the pulse is not yet subject to laboratory investigation.

Within the limitation cited above, this experiment indicates that some portion of the pulse tail, between the time that 60% and 83% of the energy is delivered, does add to burn severity. For any weapon greater than 200 kilotons in size, evasive action might well lead to avoiding this portion of the exposure which occurs so slowly.

Whether a burn will be second or third degree depends on many factors other than the radiant exposure, the exposure time and the nature of the thermal pulse. The influence of initial skin temperature and of pigmentation are well known, but the great importance of dermal thickness and depth of hair follicles is often forgotten. If avoiding the tail of the pulse

Table I

Depth of Injured Dermis (in millimeters)

Total Wheel Rotation Time	Weapon Simulated	7.3 calories/cm^2 (60% of full pulse)	10 calories/cm^2 (83% of full pulse)
2 seconds	25 kilotons	Range: 0.23-0.54 Median: 0.30	Range: 0.30-1.38 Median: 0.77
4 seconds	101 kilotons	Range: 0.23-0.46 Median: 0.30	Range: 0.38-1.22 Median: 0.62
6 seconds	228 kilotons	Range: 0.15-0.46 Median: 0.23	Range: 0.30-1.38 Median: 0.54
8 seconds	405 kilotons	Range: 0.15-0.92 Median: 0.23	Range: 0.23-1.07 Median: 0.38
12 seconds	912 kilotons	Range: 0.07-0.54 Median: 0.23	Range: 0.23-0.62 Median: 0.46
16 seconds	1,622 kilotons	Range: 0.07-0.92 Median: 0.23	Range: 0.23-1.23 Median: 0.38

Table II

Fraction of Dermal Thickness Destroyed

Total Wheel Rotation Time	Weapon Simulated	7.3 calories/cm^2 (60% of full pulse)	10 calories/cm^2 (83% of full pulse)
2 seconds	25 kilotons	Range: 1/8 - 1/2 Median: 1/4	Range: 1/4 - FT* Median: 3/8
4 seconds	101 kilotons	Range: 1/8 - 1/2 Median: 1/4	Range: 1/4 - FT Median: 3/8
6 seconds	228 kilotons	Range: 1/8 - 3/8 Median: 1/8	Range: 1/8 - FT Median: 1/2
8 seconds	405 kilotons	Range: 1/8 - FT Median: 1/8	Range: 1/4 - 5/8 Median: 3/8
12 seconds	912 kilotons	Range: < 1/8 - FT Median: 1/8	Range: 1/4 - 5/8 Median: 3/8
16 seconds	1,622 kilotons	Range: < 1/8 - 3/4 Median: 1/8	Range: 1/4 - FT Median: 3/8

*FT - Full thickness of dermis destroyed

Table III

Fraction of Hair Follicle Damaged

Total Wheel Rotation Time	Weapon Simulated	7.3 calories/cm^2 (60% of full pulse)	10 calories/cm^2 (83% of full pulse)
2 seconds	25 kilotons	Range: 1/2 - 3/4 Median: 1/2	Range: 1/2 - FT* Median: 3/4
4 seconds	101 kilotons	Range: 1/4 - 5/8 Median: 1/2	Range: 1/2 - FT Median: 3/4
6 seconds	228 kilotons	Range: 1/8 - 3/4 Median: 1/2	Range: 1/2 - FT Median: 3/4
8 seconds	405 kilotons	Range: 1/8 - FT Median: 5/8	Range: 1/2 - FT Median: 5/8
12 seconds	912 kilotons	Range: 1/8 - FT Median: 1/2	Range: 1/2 - FT Median: 3/4
16 seconds	1,622 kilotons	Range: 1/8 - FT Median: 1/2	Range: 3/8 - FT Median: 5/8

*FT - Hair follicle destroyed to the junction of dermis and subcutaneous tissue affords some protection to the deeper portions of the hair follicles, as it apparently does (Appendix III), the area and number of third degree burns might well be reduced by evasive action.

At least at the three shorter exposure times, the 7.3 calorie/cm^2 burns are of more nearly uniform severity than are the 10 calorie/cm^2 burns. If this is more than coincidence in this small series of burns, the greater range of severity of burns produced by exposure to more of the pulse tail is likely due to variation in the local dissipation of energy delivered slowly at a low irradiance. With a low irradiance exposure, the amount of blood flowing through the skin might well play a decisive role in determining burn severity; a greater flow would afford protection by stabilizing tissue temperature. With the longer exposure times of large weapon pulses, even the first 60 per cent of the pulse is delivered with fairly low irradiances. If variations in blood flow are partly responsible for variations in severity, amputation of the tail of the pulse of larger weapons could not be expected to result in particularly uniform burns. The role of blood flow in determining depth of damage will be investigated at a later date.

SUMMARY AND CONCLUSIONS

1. To determine whether or not evasive action after the detonation of a nuclear weapon could decrease thermal burn severity, the effects from the initial 83 per cent of the pulse were compared with the effects from the first 60 per cent of the pulse.
2. Thermal pulses simulating those of 25, 101, 228, 405, 912 and 1,622 kiloton weapons were used. Burns were produced on young Chester White pigs by radiant exposures of 10 calories/cm^2 (delivered in the form of the first 83 per cent of 12 calorie/cm^2 nuclear weapon exposures) and 7.3 calories/cm^2 (delivered in the form of the first 60 per cent of

12 calorie/cm^2 nuclear weapon exposures).

3. Burns from the first 83 per cent of the pulse are more severe than are those resulting from exposure to only the first 60 per cent of the pulse.
4. Delivery of the first 60 per cent of the radiant exposure occupies less than one-third of the total exposure time. Escape from the final 40 per cent of the energy might often be possible through evasive action taken after detonation of weapons greater than 200 kilotons in size. Such evasive action should reduce burn severity.
5. A great range in the severity of burns produced by exposure to the initial 83 per cent of a weapon pulse is noted. The possible relationship between local blood flow and burn severity is discussed.

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Appendix I

Depth of Injured Dermis (in millimeters)

Total Wheel Rotation Time	Weapon Simulated	7.3 calories/cm^2 (60% of full pulse)	10 calories/cm^2 (83% of full pulse)
2 seconds	25 kilotons	0.23,0.23,0.23,0.30,0.30,0.30,0.30,0.35,0.38,0.38,0.46,0.54	0.30,0.38,0.38,0.46,0.53,0.77,0.77,0.77,1.07,1.38,1.38
4 seconds	101 kilotons	0.23,0.23,0.30,0.30,0.30,0.30,0.38,0.38,0.38,0.38,0.46	0.38,0.46,0.46,0.46,0.54,0.62,0.62,0.62,0.69,0.92,1.07,1.22
6 seconds	228 kilotons	0.15,0.15,0.15,0.15,0.23,0.23,0.23,0.30,0.38,0.38,0.38,0.46	0.30,0.38,0.38,0.38,0.46,0.54,0.54,0.62,0.62,0.69,1.23,1.38
8 seconds	405 kilotons	0.15,0.15,0.23,0.23,0.23,0.23,0.23,0.30,0.30,0.30,0.38,0.92	0.23,0.30,0.30,0.30,0.30,0.38,0.38,0.46,0.54,0.62,0.77,1.07
12 seconds	912 kilotons	0.07,0.15,0.15,0.15,0.23,0.23,0.23,0.30,0.30,0.30,0.54,0.54	0.23,0.23,0.30,0.38,0.38,0.46,0.46,0.46,0.46,0.46,0.62,0.62
16 seconds	1,622 kilotons	0.07,0.07,0.07,0.15,0.15,0.23,0.23,0.23,0.23,0.38,0.38,0.92	0.23,0.23,0.23,0.30,0.38,0.38,0.46,0.46,0.46,0.54,0.92,1.23

Appendix II

Fraction of Dermal Thickness Destroyed
(estimated to nearest one-eighth)

Total Wheel Rotation Time	Weapon Simulated	7.3 calories/cm^2 (60% of full pulse)	10 calories/cm^2 (83% of full pulse)
2 seconds	25 kilotons	1/8,1/8,1/4,1/4,1/4,1/4,1/4,3/8,3/8,3/8,3/8,1/2	1/4,1/4,1/4,3/8,3/8,3/8,1/2,1/2,1/2,FT*,FT,FT
4 seconds	101 kilotons	1/8,1/8,1/4,1/4,1/4,1/4,1/4,1/4,3/8,3/8,1/2	1/4,1/4,3/8,3/8,3/8,3/8,3/8,1/2,1/2,3/4,FT,FT
6 seconds	228 kilotons	1/8,1/8,1/8,1/8,1/8,1/8,1/8,1/8,1/4,1/4,3/8,3/8	1/8,1/4,1/4,3/8,3/8,1/2,1/2,1/2,1/2,3/4,FT,FT
8 seconds	405 kilotons	1/8,1/8,1/8,1/8,1/8,1/8,1/4,1/4,1/4,1/4,1/4,FT	1/4,1/4,1/4,1/4,3/8,3/8,3/8,1/2,1/2,1/2,1/2,5/8
12 seconds	912 kilotons	<1/8,1/8,1/8,1/8,1/8,1/8,1/8,1/8,1/4,1/4,1/2,FT	1/4,1/4,1/4,1/4,3/8,3/8,3/8,1/2,1/2,1/2,1/2,5/8
16 seconds	1,622 kilotons	<1/8,<1/8,<1/8,1/8,1/8,1/8,1/8,1/4,1/4,1/4,1/2,3/4	1/4,1/4,1/4,1/4,1/4,3/8,3/8,1/2,1/2,1/2,FT,FT

*FT - Full thickness of skin destroyed

Appendix III

Fraction of Hair Follicle Damaged
(estimated to nearest one-eighth)

Total Wheel Rotation Time	Weapon Simulated	7.3 calories/cm^2 (60% of full pulse)	10 calories/cm^2 (83% of full pulse)
2 seconds	25 kilotons	1/2,1/2,1/2,1/2,1/2,1/8,1/2,5/8,5/8,5/8,3/4,3/4	1/2,1/2,1/2,1/2,5/8,3/4,3/4,3/4,FT*,FT,FT,FT
4 seconds	101 kilotons	1/4,3/8,1/2,1/2,1/2,1/2,1/2,1/2,5/8,5/8,5/8	1/2,1/2,5/8,3/4,3/4,3/4,3/4,3/4,FT,FT,FT,FT
6 seconds	228 kilotons	1/8,3/8,3/8,1/2,1/2,1/2,1/2,1/2,1/2,5/8,3/4,3/4	1/2,1/2,5/8,5/8,3/4,3/4,3/4,7/8,FT,FT,FT,FT
8 seconds	405 kilotons	1/8,1/4,1/2,1/2,1/2,5/8,5/8,5/8,5/8,3/4,3/4,FT	1/2,1/2,1/2,1/2,1/2,5/8,5/8,3/4,3/4,3/4,FT,FT
12 seconds	912 kilotons	1/8,1/8,1/4,1/4,3/8,1/2,1/2,1/2,5/8,5/8,3/4,FT	1/2,5/8,5/8,3/4,3/4,3/4,3/4,3/4,3/4,3/4,3/4,FT
16 seconds	1,622 kilotons	1/8,1/4,1/4,1/2,1/2,1/2,1/2,5/8,3/4,3/4,3/4,FT	3/8,3/8,1/2,1/2,1/2,1/2,5/8,3/4,3/4,7/8,FT,FT

*FT - Hair follicle destroyed to the junction of dermis and subcutaneous tissue