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THERMAL BURNS FROM THE ATOMIC BOMB

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ABSTRACT

Primary thermal burns from the explosion of an atomic bomb are caused by brief exposure to intense radiant energy. Gross and microscopic evaluation of burn lesions produced by intense radiant energy from a carbon arc light and burning magnesium have been carried out in the laboratory. Since the time of application, the intensity and the spectrum of applied energy influence the character of the resultant lesion, it was necessary to compare the burns from an atomic bomb explosion to those produced in the laboratory. Experiments using anesthetized pigs and dogs were carried out at atomic bomb explosions and a range of thermal energies from 1.1 cal/cm² to 43 cal/cm² studied in respect to the skin effects. The time of burn production from various portions of the thermal pulse was determined by the use of various electrically operated shutters. The spectral effects of the bomb light were evaluated by the use of limiting filters over the exposed skin and also in front of calorimeters for measuring the energy causing the burns. Preliminary but inconclusive tests were made of the protective effects of certain fabrics. Some observations were obtained regarding the effects of combining ionizing radiation and burns. Sufficient data are obtained from the field to confirm and advance laboratory investigations of this type of burn.

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INTRODUCTION*

The primary burn from an atomic bomb explosion is caused by a brief exposure to high-intensity radiant energy, whereas the usual burn seen in civil life is from contact with lower temperatures. How this difference affects the local lesion, its systemic effect, clinical course, and mortality is not known.

Tsuzuki (12) stated that 90 per cent of the Japanese who sought aid in the first week after the atomic bombing did so because of thermal burns. In Hiroshima alone, there were approximately 70,000 cases of burns of which about 40,000 were serious. This created an enormous problem (Fig. 1) of clinical management which could not be satisfactorily handled. There is not yet a practical plan for the immediate mass treatment of so many burn casualties (3, 8). The first requisite of rational therapy is to understand the lesion to be treated. Hence, the first step toward the solution of the problem of the mass management of flash burns from the atomic bomb was knowledge of the characteristics of this injury.

In spite of the thousands of flash burns at Hiroshima and Nagasaki, there was not a single immediate biopsy available to illustrate the histological changes produced in skin. This was understandable in view of the confusion and difficulties created, but it did not permit a clear picture of the lesion in man. Many histological sections from Japanese casualties were reviewed

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Population at risk from A-Bomb

Figure 1. A schematic representation which assesses a uniform density of population exposed to a "nominal" 20 K.T. atomic bomb. The zone having a 1 kilometer radius, shown in black, where total destruction occurs contains 8% of the population. The crosshatched zone between 1 and 1.5 kilometers contains 10%, many of whom will have sublethal ionizing irradiation sickness combined with burns or wounds. The area between 1.5 and 3.5 kilometers has 82% of the population at risk who will be exposed to thermal burns or wounds, but not to serious ionizing irradiation. Here definitive surgical care will give high rewards.

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but all were obtained late after infection or repair had set in. Likewise, at the Bikini tests, when emphasis was focused on the effect of ionizing irradiation on the animals exposed, no immediate skin biopsies of thermal burns could be found. Thus, the investigator who attempted to reproduce the flash burn from the atomic bomb in the laboratory had no material for comparison.

In the laboratory, skin biopsies of the flash burns in experimental animals showed a direct relationship between the depth of injury and amount of energy applied (4, 6). In order to define the burn as a function of energy in the field it was necessary to evaluate the relationship of the intensity of the thermal energy from an atomic bomb to the severity and depth of the burn. This would define the burn as a function of energy.

Time dependence of burn production from the atomic bomb explosion was a matter of dispute which was argued on theoretical grounds. There were no data from observation of burning as a function of time after the explosion. In the manual, "The Effects of Atomic Weapons" (11), Fig. 6.6 showed an initial high intensity which dropped to a minimum of approximately 2,000°K in about 15 msec. A short null was followed by a rise to a second maximum of about 7,000°K in 0.3 sec after which the temperature fell. Nearly all of the thermal radiation was emitted in 3 sec and it ceased by 10 sec.

The initial flash attained a very high temperature but lasted only 15 msec. Because of this short duration, only 1 per cent of the total thermal energy was delivered in this period. Yet it was thought by some that, due to the high temperature and high ultraviolet content, flash burns occurred in this stage. One fact which argued against this was the lack of corneal burns in the Japanese. Since the blink reflex requires between 10-15 msec, it was

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presumed that the eye was open in this initial period but covered by the eyelid thereafter preventing a burn of the cornea. This was not reliable evidence, so the question of serious burning in the initial period required experimental study. A shutter was devised which closed one port and opened another during the null following the initial flash. When an animal was placed behind this shutter, one area of skin was exposed during the initial flash and a second area during the subsequent ball of fire.

As previously noted, the second maximum occurred in about 0.3 sec and the majority of the radiation from the ball of fire was delivered in 3 sec. It was necessary to determine when flash burns occurred in this period at different distances from the explosion. This information might show whether or not evasive action by exposed personnel could modify the burns.

The influence of thermal energy of various regions of the spectrum in the production of flash burns from the atomic bomb was not known. The depth of penetration varied directly with wave length, ultraviolet being the least and infrared the most penetrating. In addition to pure thermal injury, ultraviolet had a photochemical effect which reached a maximum at 2,970A. Wave lengths below 1,900A were absorbed by ozone. Since atmospheric attenuation was greatest for the shorter wave lengths, it was probable that they could be disregarded at the distant perimeters. By the use of appropriate filters over the exposure ports, the importance of energy from various regions of the spectrum could be evaluated.

The thermal energy released by the bomb explosion might be modified by nitrogen dioxide, ozone, atmospheric opacity to short wave

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lengths, scattering, absorption, and other attenuating factors. This might make extrapolation difficult, so it was desirable to measure at each station the total integrated energy and that passing through the exposure ports. This was done in such a way that the calorimetric instruments were exposed in exactly the same manner as the exposed areas of the animal's skin. Thus, the energy responsible for the burn could be determined.

It was well known from observations made upon the Japanese that the color, thickness, and composition of clothing influenced the burns received. Suitable garments protected the skin from injury when the thermal radiation was of sufficient intensity to cause a burn of the exposed skin. A few experiments have been done in which fabrics were tested in the field for their protective effect against burns from the thermal radiation from the bomb.

METHODS

Animals

Most of the work done in this laboratory has been done on young Chester White pigs because the skin of this animal was so similar to that of man. Ninety-one Chester White pigs have been exposed during experiments at 4 bomb tests. At one test 8 Danish Landrace pigs of mixed brown and black color and 15 adult fox hounds were used alongside the white pigs to observe the effect of color and species differences. Animals were either born and reared at the test site or were acclimated there for a sufficient time to assure good health. They were always under the care of a competent veterinarian, were well fed and were kept in clean,

comfortable open runs having a lean-to shelter at one end.

Prior to a test the area of skin to be exposed was closely clipped using power shears having a #40 head. Shaving or depilatories were not used for they had been found to cause skin irritation. The animals were then placed in well-ventilated containers (Fig 2), transported to the exposure stations, anesthetized and positioned behind individual exposure plates in structures constructed to withstand blast.

Anesthesia

Operational requirements made it necessary to place the animals in the stations some hours or even a day before they were exposed. Hence, a long-acting anesthetic without explosive hazards was necessary to assure anesthesia at the time of burning. To obtain this a series of 181 experiments were done on 12 anesthetic agents. It was found that Dial in Urea-urethane (Ciba) injected intraperitoneally was satisfactory in doses of 70-75 mg Dial per kg body weight for pigs and 60 mg per kg for dogs (5). The best results were obtained after fasting the animals for 24 hours prior to induction of anesthesia. The fasting weight was used for calculation of dosage.

Location of Stations

The thermal energy from an atomic bomb explosion is attenuated by passage through the atmosphere. Thus, burn severity will be a function of the distance from the bomb. In order to examine the effect of different levels of thermal energy on animal skin stations have been located to give exposures in cal/cm² of 1.1, 2.2, 3.8, 5.3, 9, 10, 12, 15, 20, 24, 28, 34, 36 and 43. This gave a range of all grades of burn severity from no

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Figure 2. For transportation animals were placed in aluminum cylinders having perforated ends which gave ventilation and protection from over heating. Mechanical power was needed to handle the weight of the animals during transport. Here a chain hoist which slides on a track is being used to load 10 pigs onto a truck (2 pigs in each cylinder).

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burn to a char which allowed comparison with burns created in the laboratory by the carbon arc searchlight.

The laboratory observations (6, 10) of over 1800 burns done under variable conditions of time and intensity of applied thermal energy had established five criteria of severity of surface damage which permitted grading the lesions. This laboratory grading system using the average values of Perkins et al (10) was as follows:

- 1) A 1+ burn had only erythema present 24 hours after exposure. It was caused by 2.3 cal/cm^2 in 0.3 sec.
- 2) A 2+ burn showed patchy or central coagulation with underlying erythema. It was caused by 4.5 cal/cm^2 in 0.3 sec.
- 3) A 3+ burn had complete coagulation of the surface without charring. It was caused by 7.5 cal/cm^2 in 0.3 sec.
- 4) A 4+ burn had a steam bleb formed immediately on its coagulated surface which persisted as a delicate air-filled blister. It was caused by 10 cal/cm^2 in 0.3 sec.
- 5) A 5+ burn was one showing charring or carbonization on its surface. It was caused by 19 cal/cm^2 or more in 0.3 sec. Changing the time of exposure slightly altered the energy required to produce any given grade.

By means of these laboratory standards it was possible to evaluate the burns created by the atomic bomb in terms of the thermal energy required for production of equivalent lesions by the carbon arc. This level of energy could be then compared to that actually measured in the field.

Shelters

Stations were designed to give adequate protection against calculated

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over pressure from the blast and to minimize the effects of ionizing irradiation on the contained animals. In the side of the station facing the bomb burst were ports behind which were bolted heavy aluminum plates with apertures through which thermal radiation passed. In some stations two animal containers, one above the other, were bolted to the back of the port in such a fashion that the flanks of the exposed animals were in contact with the apertures. The stations were ventilated with battery-operated blower and duct systems. Temperature and ventilation was regulated according to the needs of the animals as determined by environmental studies made in the area prior to building the shelters.

Aperture Plates

The exposure aperture plates were of three types, each constructed of 3/4-inch aluminum alloy, 6 x 12 inches in size. All openings in the plates were covered by fused quartz windows to eliminate sand blasting of the skin subjected to the explosion. Each of the three plates had at least one aperture which was not modified by a shutter, filter or fabric, so that each animal received the total integrated energy on this area of skin as a control for those modified by filters, fabrics or shutters.

The smallest hole in any aperture plate was 1.9 cm (0.75 in.) in diameter. This gave an adequate opening for good burns but it was felt to be close to the minimum consistent with biological validity because of edge effects. The openings ranged from this size up to 3 x 4 1/2 in. Burns through small and large apertures were compared side by side to observe differences in severity of burns between small and large area exposures.

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All of the timing shutters were activated by photoelectric relays which were initiated by the flash of the bomb. Equipment was wired through a central control panel. Power was supplied either from storage batteries or from power lines depending upon the location of the stations.

The types of aperture plates were as follows:

I Shutters for Time Resolution

(a) Fast Shutter

This plate had three round apertures. One was 2.2 inches in diameter which provided the unmodified exposure. The two remaining apertures were 1.125 inches in diameter. At the time of the flash from the explosion, one of these ports was open and the other was covered by a spring-loaded aluminum shutter. The shutter was timed to cover the open port and open the closed one at 20 or 25 msec, during the null between the two maxima. It was planned to give an evaluation of the burn produced by the initial flash in comparison to that from the ball of fire. This timing shutter was used at bomb tests.

(b) Slow Strip Shutter

This plate contained one rectangular aperture, 2 x 8 inches in size, placed horizontally. A quartz window covered the entire area. Behind the window (Fig. 3) was a thin sliding shutter which had an opening 2 x 5 in. Travel of the slide was initiated by a photocell signal. Transport time for the shutter was 2 sec. By this method, 3 in. at one end of the rectangular opening in the plate was closing and 3 in. at the other end was opening during the 2 sec following the initiation of the explosion. The central 2 in. was open throughout the exposure. Provision was thus made for

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Figure 3. The interior of a concrete station before placement of animals for testing. At #1 is a fast shutter plate having a large opening for total exposure, a smaller port open for the initial flash and a closed port which will be opened at 20-25 msec to gain exposure during the fire ball. A slow strip shutter is shown at #2 with the opening at the left and the sliding diaphragm operated by a small motor at the right. The plates at #3 and #4 have a large opening for total exposure on the left and three smaller ones for insertion of filters (#3) or fabrics (#4). The bracket which supports two animals in their containers one above the other is shown at #5. Pipes for ventilation (#6) supply air to each animal from a duct above. The panel for control of the equipment is shown at #7.

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assessment of the severity of the burn as a function of time after explosion. It was used on two tests.

(c) Multiple Time Shutter

From experience gained with the two shutters described above, it was evident that a more accurate time resolution was necessary so a third type was designed (Fig. 4 and 5) and used at subsequent bomb explosions. It was planned to obtain information on the time in which the thermal burns were sustained after detonation of a bomb as follows:

- 1) The severity of burns produced in the first five consecutive 0.1 sec periods.
- 2) The amount of burning which was produced at six periods having 0.1 sec increments from 0 to 0.1 through 0 to 0.6 sec.
- 3) The severity of six burns created by decreasing the exposure progressively, cutting off successive increments of 0.1 sec from the beginning of the pulse. This gave exposures covering the periods of 0.1 sec to the end of the pulse through 0.6 sec to the end of the pulse.
- 4) 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. Each aperture was 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.

Figure 4. A diagram of the pair of shutters used for multiple time resolution of the burn after detonation of an atomic bomb. In Shutter No. 1, top row, the first port is open at bomb zero. As the diaphragm swings to close it, at 0.1 sec, it opens the next port for the interval 0.1 to 0.2 sec and so on for the others. The second row has two open ports giving total burns, also one giving a burn after 0.1 sec and ports exposing for the first 0.2 sec and after 0.2 sec. The ports in Shutter No. 2 follow this sequence by permitting exposure before and after periods of 0.3, 0.4, 0.5 and 0.6 sec.

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Figure 5. A photograph of multiple time Shutter No. 1 which was used at two bomb tests. The solenoids which move the occluding diaphragms are at the top and bottom so as to be out of the way. They control the aluminum diaphragm which opens or closes each of two ports. The fused quartz used to prevent sand-blasting of the skin has been removed from the openings.

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II Filter Plate

This plate had four round apertures. One of these was 2.25 in. in diameter and had only a clear-quartz window covering it. The other three openings were 1.375 in. in diameter and were covered by optical filters. The filters used for infrared transmission were Corning No. 2404, Sharp Cut-off Red Glass which cut in at $6500\text{\AA}$. For the visible region, Pittsburgh Heat-absorbing Glass was found to be the most satisfactory because it had a high transmission, between 4000 to $8000\text{\AA}$, but it passed some infrared beyond this main spectral region. For the ultraviolet filter, it was found necessary to use a combination of 60 per cent aqueous solution of nickel sulphate and the Corning No. 9863 glass for two reasons: first, the No. 9863 glass tended to crack with moderate temperature changes, and second, both the No. 9863 glass and the nickel sulphate solution had minor transmission bands in the visible which the combination eliminated. The solution performed the added function of providing a filter with a large heat capacity which absorbed most of the energy. It had 60% transmission at $3000\text{\AA}$ with a range of 2500 to $3300\text{\AA}$.

III Fabric Plate

This plate was the same as that described for the use of filters with the exception that fabrics to be tested replaced the optical filters used. Quartz glass covered the openings in the plate behind which were placed herringbone twill cotton, serge and sateen, with or without under-shirt material. The skin of the animal's flank was placed in contact with the fabrics. In this way an attempt was made to assess the protective effect of these fabrics in preventing skin burns.

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Instrumentation

Two types of measurement of the thermal energy causing the burns have been used. At ^{the} tests a radiation calorimeter which measured total integrated energy was placed in each station so that the instrument measured the energy passing through the unmodified ports and through each of the optical filters at every location. This calorimeter had the disadvantage of giving total integrated energy without time resolution. At subsequent tests time-intensity measurements were made by others at points adjacent to the exposed animals so that a time resolution was obtained to compare the severity of the burn and the incident energy causing it.

Evaluation of Burns

As soon as possible after exposure, animals were retrieved from the stations and returned to the field laboratory. Additional anesthesia was administered if necessary. Careful gross evaluation of the lesions was made, identification checked, and the burns photographed in color. Biopsies of skin lesions were then performed. Biopsy material was identified, fixed, and embedded in paraffin blocks using Auto-Technicon equipment. The tissues were then returned to the laboratory in Rochester, New York for sectioning, mounting, and microscopic study. Following biopsy, the animals were returned to the runs, allowed to recover from anesthesia, and observed daily for healing of the local wounds. Repeated biopsies and photographs were performed as indicated during the healing of the lesions. A clinical record of daily observations was made of each animal.

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RESULTSCharacter Pathology and Course of Burns

The lesions produced in the white pigs in the field were similar to those seen in the laboratory from application of high intensity radiant energy from the carbon arc or burning magnesium. The dry, coagulated surface without much edema, cyanosis or weeping of serum was the same. In the severe burns the character of the central carbonization and peripheral white ring surrounded by hyperemia was exactly like that produced by the carbon arc (Fig. 6). In all grades of severity from a mild hyperemia to a char the burns produced by the bomb explosion duplicated those seen in the laboratory. The clinical course and healing by sequestration of the eschar were similar. They were unlike low temperature, contact burns which were variable in depth and edematous in their early stages.

Histologically these burns also resembled those produced in the laboratory by radiant energy for they had the same striking demarcation laterally (Fig. 7) and in depth that has been described as characteristic of the flash burn (5). The injury penetrated uniformly to a horizontal line where there was abrupt demarcation between living and dead tissue. The healing of pig burns of all grades of severity was like that of similar burns created from laboratory sources. In both, the coagulated surface formed a tough eschar which appeared to seal the damaged area. The epithelium grew from the intact hair follicles and proliferated under the eschar to cover the injured surface just as it did in the experiments

Figure 6a. The appearance of a severe 5+ carbonized burn in Chester White pig No. 265 13 hr after exposure to 34 cal/cm^2 .

Figure 6b. The same lesion 122 hr after burning. Note the zone of white coagulation surrounded by a ring of erythema outside the carbonized burn. A biopsy wound is in the lower margin.

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Figure 7. The trans-epidermal injury in Chester White pig No. 224 15 hr after exposure to 6.9 cal/cm^2 . In the center is seen the sharp demarcation between injured and uninjured epidermis at the edge of the exposed area.

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reported on burns from magnesium. The eschar then sequestered leaving an epithelialized surface (Fig. 8).

Fig. 9 shows the microscopic appearance of a 5+ burn in a Chester White pig 13 hr after exposure to 34 cal/cm^2 . The epidermis was coagulated on either side and completely destroyed in the center. Nuclear pyknosis and change in staining were seen in the upper layer of the dermis, but the exact depth of the burn was not apparent at this time. In all sections taken soon after burning the level of demarcation in depth was not obvious. Demarcation is well seen in Fig. 10 which is a section of pig skin 74 hr after exposure. The injured dermis then had a basophilic staining reaction, the blue color of which contrasted sharply with the red eosinophilic staining of the viable tissue. There was an inflammatory zone of leukocytic infiltration at the base of the dead tissue which separated it from the living dermis. Healing by proliferation of epithelium from the uninjured hair follicles was beginning.

The method of repair is seen in Fig. 11 which shows a section of pig skin taken 122 hr (5 days) after exposure. In this illustration, the epithelium is shown growing from the uppermost viable epidermis of the hair follicle and proliferating in a sheet beneath the eschar formed by the devitalized tissue. This proliferative response of the epithelium proceeded from all viable hair follicles with eventual meeting and blending of the individual sheets to form a new epidermis. Seen in section, this process began as a heaping up of epidermis at either side of the hair follicle followed by peripheral extension of a thin projection

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Figure 8. A 5+ burn from 34 cal/cm^2 in Danish Landrace pig No. 268 at 360 hr (15 days) after injury, showing shedding eschar with underlying healed depigmented epithelium.

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Figure 9. Section (X65) of Chester White pig No. 270 13 hr after exposure to 34 cal/cm^2 . There is coagulation and destruction of the epidermis but no obvious demarcation of the depth of the burn in the dermis at this time.

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Figure 10. Section (X65) of Danish Landrace pig No. 269 taken 74 hr after exposure to 34 cal/cm^2 . The line of demarcation in depth is indicated both by the basophilic staining of the burned dermis and the inflammatory reaction between living and dead tissue.

Figure 11. Section (X65) of Chester White pig No. 270 122 hr after exposure to 34 cal/cm^2 . A wedge-shaped layer of epithelium has grown out of the hair follicle in the lower left corner and is proliferating under the thick eschar.

of epithelium often only one or two cells thick. As this process proceeded away from the parent follicle, proximally it became thicker and took on the appearance of epidermis with new papillae while the leading edge remained thin. Fig. 12 shows the healing obtained in a pig at 228 hrs (9 1/2 days) after exposure to 34 cal/cm^2 . It is seen that the burned tissue was separated off the surface of the epidermis and covered it only as an eschar. Careful inspection along the space between epidermis and eschar showed attachment by hairs and occasional small areas of delayed healing. At this state, the leathery eschar which formerly covered the whole burn began to loosen and curl up at the edges. Beneath the curled edges was a delicate epithelium which covered the surface. The eschar could be easily removed (Fig. 8) when the surface beneath was completely healed.

Species Differences in Response to Thermal Energy

Grossly, dogs sustained more severe burns than did the white pigs exposed at the same stations. In 4+ and 3+ burns the skin of the dogs showed greater contracture and depression of the surface in the early stages. In 48 to 72 hr there was surrounding edema and the central burned area cracked and began to ooze serum and pus. Sloughing of the area occurred early leaving a dirty granulating surface which healed by contracture and marginal epithelialization. The less severe burns in the dogs were not striking in the early phases although some edema was present. In 24-48 hr there was increased swelling and serum began to weep from the wound. Some of these lesions sloughed. The dark colored pigs received more severe burns with deeper penetration (Fig. 13) of

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Figure 12. Section (X65) of Danish Landrace pig No. 269, 228 hr after exposure to 34 cal/cm^2 . The new epidermis has completely regenerated beneath the eschar which has separated in this location, but is loosely attached elsewhere. At this stage, the eschar may be easily pulled off exposing a healed surface beneath.

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Figure 13. A comparison of depth of injury as indicated by the thickness of the eschar at 124 hr in (a) white pig No. 202 and (b) in black pig No. 207 both with the same exposure to 10 cal/cm^2 , (X65). Restoration to normal epidermis is also more advanced in the white pig.

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injury than did white pigs exposed at the same stations. The healing time was longer in the dogs and black pigs than in the white pigs. With exposure to 6.9 cal/cm^2 the average healing time of the burns on white pigs was 8 days; of those on black pigs, 16 days; of those on dogs, 19 days.

Burns Produced Behind Filters

Twenty-four animals were exposed behind filter aperture plates which transmitted the unmodified radiant energy and that in the ultraviolet, visible, and near infrared portions of the spectrum respectively.

Through the port which admitted only the ultraviolet light, there were no burns produced in any of the animals at any station. These animals were observed carefully to determine if any delayed reaction occurred from the photochemical effects of ultraviolet light, but none was seen.

The burns produced behind the filter passing visible light were of the same degree of severity as those produced behind the infrared filters in 7 animals. In 4 animals slightly more severe burns were sustained behind the visible than behind the infrared filters.

The burns through the unmodified openings in the filter plates were always more severe than those through limiting filters at the same station. The clinical behavior and healing of the lesions produced behind visible and infrared filters was identical to that of unmodified burns of similar severity.

Burns Produced as a Function of Time

There were 19 pigs and 5 dogs exposed behind the fast shutter

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which separated the burn caused by initial flash and the fire ball. These fast shutters were set to shift at 20 or 25 msec, and in every instance no burn was sustained behind the aperture which was open during this period. Burns sustained through the ports which were open after 20-25 msec were equal in severity to those through the unmodified ports.

There were 19 pigs and 5 dogs placed behind the slow strip shutter. Each shutter was arranged so that the 5-inch opening shifted 3 inches in 2 sec in a cephalad direction. The burns produced appeared uniform over the caudad 5 inch length of burn which was that part exposed initially. Some of the burns showed an additional $3/8$ inch to $1/2$ inch of less severe damage at the cephalad end of the burned strip. Since burning occurred behind the opening portion of the shutter for a maximum distance of $1/2$ inch and since the shutter travelled 3 inches in 2 sec, the burn was produced in the first $1/3$ sec after the explosion.

There were 24 white pigs exposed behind the multiple time shutters. It was found that:

1. The skin burns produced in the period between 0.1 and 0.2 sec after bomb detonation were the most severe of any created by a 0.1 sec interval of the thermal pulse (Fig. 14).

2. By increasing increments of exposure, the major severity of thermal burns was attained within the first 0.3 sec and the maximum severity within the first 0.5 sec after bomb zero (Fig. 15).

3. No burns were produced if the skin was shielded from the first 0.6 sec of the thermal pulse. Yet the calculated amount of thermal energy after this period was 30 per cent of the measured incident energy. (Fig 16).

Figure 14. The severity of the field burn has been related to the amount of the applied energy which produced the same degree of burn in the laboratory. The burns in terms of cal/cm², shown in solid line, were most severe in the period between 0.1 and 0.2 sec after bomb detonation. The measured thermal energy, shown in the dotted line, correlates well for the first two 0.1 sec intervals but was consistently higher after this time.

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Figure 15. The severity of the field burn has been related to the amount of the applied energy which produced the same degree of burn in the laboratory. The burn severity in terms of cal/cm² is shown at three stations placed at different distances from a bomb explosion. The exposure was increased by increments of 0.1 sec. It is seen that in all cases the major severity was attained within the first 0.3 sec and the maximum severity by 0.5 sec after bomb zero.

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EFFECTIVE THERMAL ENERGY
AFTER TIME CUT OFF BY SHUTTERS

Figure 16. The severity of the field burn has been related to the amount of the applied energy which produced the same degree of burn in the laboratory. When the skin was shielded for periods increasing by 0.1 sec intervals after bomb zero it is seen that the severity of burns in terms of cal/cm², shown in the solid line, diminishes rapidly with each 0.1 sec prolongation of the time of shielding. No burns occurred after 0.6 sec. Yet the thermal energy, shown in the dotted line, was measured at 15 cal/cm² at 0.6 sec. It is evident that all of the measured thermal energy was not effective in causing cutaneous burns.

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4. There was fair relationship between the measured thermal energy and that determined by evaluating the skin burns from laboratory standards during the first 0.3 sec. After this time the measured values were always significantly higher.

Severity of Small and Large Area Burns

No difference was seen in the severity of burns produced by two bombs through apertures ranging from 1.125 in. in diameter to a rectangle 2 x 5 in. in size. To make sure of this, ⁸ pigs were exposed [redacted] behind a transite sheet having a central aperture 3 x 4.5 in. and four 0.75 in. circular openings 1 in. from each corner of the rectangular opening. No significant difference in severity could be detected by gross or microscopic examination between the small and large area burns in these 8 animals.

Protective Effects of Fabrics

In the experiment designed to test the protective effects of herringbone twill, sateen, and serge, with and without underwear, 30 exposures were made using 10 white pigs. With but one exception no burns occurred behind any fabrics at any station. This was due to placing the animals at stations where the level of thermal energy was too low to cause burns through the fabrics. To do such a field experiment successfully, extensive laboratory data should be obtained on the range of protection provided in order to place the animals accurately.

Effects of Ionizing Radiation on Thermal Burns

There were 10 animals which received sufficient ionizing radiation to cause death. It was noted that 7 animals had no sign of interference

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with the healing of their wounds in spite of fatal radiation sickness. After healing was completed, sections demonstrated that the epidermis was atrophic in appearance. Death occurred in two pigs on the 12th day from light Nembutal anesthesia given to obtain photographs and biopsies at a time when they were seriously ill. In one of them, a large hematoma developed in a venipuncture site.

In two dogs, the burns were covered with healthy granulations within 2 days of death. At this time, the wounds became gangrenous. In one pig, this terminal gangrene occurred in the biopsy wound which was open and unhealed at the time of death 10 days post operative. The terminal breakdown of the two unhealed burns and the biopsy wound in these animals contrasted strikingly with the uninterrupted healing seen in the others.

The uninterrupted healing of severe burns in pigs dying of irradiation sickness was a striking phenomena. If the burn progressed to the point of partial epithelialization, then healing proceeded in spite of mortal irradiation sickness. But granulating biopsy wounds or burns became gangrenous and sloughed when signs of irradiation sickness appeared. This may indicate that all efforts should be made to promote healing of burns and that all definitive surgery should be done early in those who have received significant amounts of ionizing irradiation. More observations will be required to confirm this.

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SUMMARY AND CONCLUSIONS

1. Thermal burn experiments were done at the detonation of ~~■~~ atomic bombs in which animals were exposed behind clear quartz, timing shutters, filters and fabrics in stations located at 14 different distances to cover the range from 1.1 to 43 cal/cm². This gave results from no burn to a char.
2. Radiation calorimeters were designed and placed in each station at ~~■~~ tests to measure the total integrated energy and that passing through limiting filters. At ~~■~~ tests measurements were made by others of the time resolution of the thermal energy incident on the exposed animals. These measurements provided for comparison of energy and burn severity.
3. Ninety-one white pigs, 8 black pigs, and 15 dogs were used as test animals. The white pigs proved the most satisfactory since fine gradations of color or coagulation of the skin were more readily detected than on the other animals.
4. Operational requirements made it necessary to place the animals in the stations several hours or even a day before they were exposed. Hence, a long-acting anesthetic without explosive hazards was necessary to assure anesthesia at the time of burning. Dial in urea-urethane (Ciba) injected intraperitoneally was satisfactory for this purpose.
5. These animal lesions have demonstrated, for the first time, the characteristic gross and microscopic pathology of burns from the atomic bomb. The lesions closely resembled those from laboratory radiant energy sources.

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6. In the laboratory, the time and intensity values of energy from the carbon arc have been obtained for 1800 burns of different degrees of severity in the white pig. Using these values as a standard, the burns from the bomb radiation could be assessed in terms of applied thermal energy.

7. No burns were produced in any animal through the filter transmitting only ultraviolet light.

8. The burns received behind filters transmitting visible and infrared rays were about equal in severity. Dark colored animals generally had a deeper burn than white ones.

9. No burns were produced by the initial flash during the first 20-25 msec. Burns created by the second maximum or fire ball were equal in severity to those caused by the exposure to the total thermal pulse.

██████████ by means of a sliding shutter the burn was found to be caused in the first $1/3$ sec after detonation of the bomb.

At ██████ subsequent tests using a more refined timing shutter it was found that:

a) That the skin burns produced in the period between 0.1 and 0.2 sec were the most severe.

b) That the major severity of thermal burns was attained within the first 0.3 sec and the maximum severity within the first 0.5 sec after bomb zero.

c) No burns were produced after 0.6 sec if the skin was shielded prior to that time.

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d) There was good relationship between the measured thermal energy and that determined by evaluating the skin burns from laboratory standards during the first 0.3 sec. After this time the measured values were always significantly higher.

10. The severity of burns has been compared when they were sustained through circular ports as small as 0.75 in. in diameter and through rectangular ports 3 x 4.5 in. No difference could be detected between the severity of the small and large area burns when sustained in the same animal or in different animals at the same station.

11. No information was obtained from a study of the protective effect of fabrics in these field tests. This type of experimentation should be preceded by extensive studies in the laboratory before attempting to confirm the results in the field.

12. Burns or wounds that had reached the stage of epithelialization healed in spite of fatal irradiation sickness but in a few cases those that were open and granulating became gangrenous. Further observations are needed on this to determine if definitive surgery should only be done early after exposure.

13. A most important attainment of these thermal burn experiments in the field was the acquisition of data to confirm and advance laboratory investigations.

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BIBLIOGRAPHY

1. Blakney, R. M., Davis, T. P., Krolak, L. J. and Pearse, H. E., Development of a Copper Sphere Radiometer, Univ. of Rochester Atomic Energy Report, UR-152: 76, 1951.
2. Butterfield, J. W. and Dixey, J. R. B., Burns from Atomic Bombs, J. Roy. Nav. Med. Service, 37: 9, 1951.
3. Evans, E. I., The Burn Problem in Atomic Warfare, J. Amer. Med. Assn., 143: 1143, 1950.
4. Hogg, L., Payne, J. T. and Pearse, H. E., Experimental Flash Burns: The Pathological Aspects, Arch. of Path., 49: 267, 1950.
5. Kingsley, H. D., Hogg, L., Payne, J. T. and Morton, J. H., Studies in Prolonged Anesthesia in Swine and Dogs, Univ. of Rochester Atomic Energy Report, UR-152: 65, 1951.
6. Morton, J. H., Kingsley, H. D. and Pearse, H. E., Studies on Flash Burns: Threshold Burns, Surg., Gyn. and Obs., 94: 317, 1952.
7. Morton, J. H., Kingsley, H. D. and Pearse, H. E., Studies on Flash Burns: The Protective Effect of Certain Fabrics, Surg., Gyn. and Obs. 94: 497, 1952.
8. Pearse, H. E. and Payne, J. T., Mechanical and Thermal Injury from the Atomic Bomb, New England Jour. of Med. 241: 647, 1949.
9. Pearse, H. E., Payne, J. T. and Hogg, L., The Experimental Study of Flash Burns, Annals of Surg., 130: 774, 1949.
10. Perkins, J. B., Pearse, H. E. and Kingsley, H. D., Studies on Flash Burns: The Relation of the Time and Intensity of Applied Thermal Energy to the Severity of Burns, Univ. of Rochester Atomic Energy

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BIBLIOGRAPHY (Cont)

Report, UR-217, 1952.

11. The Effects of Atomic Weapons, U. S. Government Printing Office, Washington, D. C., 1950.
12. Tsuzuki, M., Report on the Medical Studies of the Effects of the Atomic Bomb, General Report of the Atomic Bomb Casualty Commission, Appendix 9, National Research Council, 1947.

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