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THE EFFECTS OF FALLOUT RADIATION ON THE SKIN

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Fallout may be classified as the "worldwide" or the "close-in" type

Worldwide fallout results from the dissemination of minute particles of radioactive material from nuclear detonations which slowly settle out from the stratosphere and troposphere over the world. Due to the great dilution of this type of fallout and to the loss of activity with time evolved it does not impose a hazard to the skin but may result in a long-term hazard from internal deposition and possible genetic effects from low level irradiation.

Close-in fallout is most likely to result from large atomic detonations in which the fireball comes in contact with the ground, causing large amounts of material to be drawn up into the cloud where the radioactive products adhere to the ground particles. Due to the relatively large size of these particles they may then be deposited within several hundred miles of the detonation. With this type of fallout there is a real hazard not only to the skin, but also from whole body penetrating radiation and from internal absorption of radioactive materials. The nearer the site of detonation that fallout occurs the greater is the hazard. The nearer fallout takes place earlier and is therefore more active due to having undergone less radioactive decay and it is more concentrated since larger amounts (particularly larger particles) tend to fall out first.

The accidental exposure of some 240 Marshallese, 28 Americans and 23 Japanese fishermen during Operation Castle, March 1954, affords our most extensive experience with fallout effects on the human skin and in this talk frequent references will be made to data obtained on these people [1, 2]. Several other cases of human exposure to fission products or beta emitting material either accidentally or experimentally have been reported [3–8]. Skin lesions in cattle and horses have also occurred from fallout following experimental detonations at Alamogordo and in Nevada [9, 10]. Rather numerous experiments on the effects of beta radiation on the skin of animals have been reported and these data will be referred to, also [11–15].

First, some of the physical and biological factors related to skin damage from fallout will be discussed. The chemical and physical makeup of fallout will vary according to the type of terrain or soil over which the detonation occurs. All fallout is particulate in nature, but the size of the particles will depend to some extent on the physical and chemical characteristics of the soil. The fallout associated with the Castle detonation, March 1, 1954, was a white, powdery material largely composed of incinerated coral. Aside from the radioactive component the calcium oxide of the material was in itself irritating to the skin due to its caustic nature. Moreover it was probably partly dissolved in the perspiration on the skin thus increasing its irritating action. (Incidentally, this may have enhanced the radiation to the skin by bringing the radioactive materials in closer contact with the skin.) Fallout produced from other types of soil, other than predominantly coral, might vary considerably in chemical and physical makeup and irritation to the skin. Color and particle size would also vary. For instance siliceous type soils would probably form much less irritating fallout.

It goes without saying that for fallout to result in gross skin damage it would have to be sufficiently concentrated. It seems likely that the occurrence of fallout would have to be visible to result in such damage. For example, in the Marshall Island experience, the extent and severity of the skin lesions were directly related to the amount of visible fallout and on Utirik, the least contaminated island of the inhabited group no fallout was visible and no beta lesions of the skin developed.

The particulate nature of the material produces spotty distribution on the body. The Marshallese claimed that the material adhered closely to the skin and was difficult to brush off. This was borne out by the difficulties of complete decontamination. Areas of the body where perspiration is greater such as the neck folds, axillae, antecubital fossae etc. caused the material to stick and lesions were more predominant in these areas. The hair tended to collect the material also, particularly in view of the cocoanut oil hair dressing used by these people, which made decontamination extremely difficult. Clothing, even a single layer of cotton material, afforded almost complete protection as evidenced by the fact that almost all of the skin lesions developed on exposed parts of the body. The loose clothing worn would not have accounted for more than about a 25 percent attenuation of the radiation so that the protection must have been due in part to the fact that the loosely fitted clothing tended to hold the radioactive material away from the skin. It is also possible that the material did not stick to the clothing as well as to the skin.

There are certain *biological factors* known to influence the sensitivity of the skin to radiation. In addition to species differences, it is known that the skin of certain parts of the body is more sensitive than that of others. In general the thinner-skinned flexor surfaces of the body are more sensitive than the thicker-skinned extensor surfaces [16]. This was found to be true in the Marshallese since lesions were more prevalent on the front and sides of the neck, axilla and antecubital fossae. Another factor is associated with pigmentation of the skin. Darker-skinned people, brunettes, are known to be less sensitive to radiation than blonds or people with ruddy complexions [17]. A factor which was pointed out earlier is that areas of the body where perspiration is more profuse cause the fallout to collect resulting in greater skin effects.

Sources of radiation to the skin.—Damage to the skin results largely from the beta component of the fallout in view of the fact that the beta-gamma ratio is quite high. All of the energy of the beta particles entering the skin is absorbed in the skin. Soft gamma rays accounts for some of the radiation dose to the skin, and the harder gamma rays contribute least since they are more penetrating. The skin dose results from two sources of beta radiation, the fallout material in direct contact with the skin and the material on the ground.

1. *Contact source.*—The spotty distribution and particulate nature of the fallout in contact with skin results in multiple point sources on the skin. By far the greatest part of the skin dose comes from this source. Radiation is largely from the skin surface. However, the possibility must be considered that a certain amount of percutaneous absorption may take place and some penetration into the dermal region via the hair shafts, sebaceous and sweat glands may occur. The Castle fallout contained about *10 percent water soluble fission* products, some of which might conceivably have been absorbed percutaneously. Whitten *et al.* [18] have shown that thorium-x applied to the skin results in some percutaneous absorption and entry into the hair shafts and glands. We intend to investigate this problem with fission products on the skin by means of autoradiography.

2. *Ground source.*—A certain amount of the skin dose may result from beta radiation from the fallout material on the ground. This contribution is likely to be far less than that from the contact source. The lower parts of the body will receive the greater part of this radiation since the beta particles are completely stopped in 2 meters of air.

Estimation of beta doses to the skin from fallout is an exceedingly complicated problem and I will leave the main discussion of the subject to other speakers. The degree of skin reaction and damage is more dependent on the depth dose than on the surface dose of beta radiation and the depth dose is dependent on the energies of the beta particles of the component isotopes. Thus soft radiation confined largely to the dead horny layer and upper epidermis would be relatively ineffective in producing a reaction in the skin; more energetic radiation, penetrating through the epidermis, could result in transepidermal necrosis; and deeper penetration into the dermis could result in more severe ulcerating lesions. Each radioisotope has its own characteristic spectrum of energies with a maximum energy, but since relatively few particles are of this energy, the average energy, which is roughly one-third of the maximum energy and the 50 percent attenuation in tissue are more meaningful in estimating skin effects.

Figure 1 shows roughly the 50 percent attenuation in skin of several isotopes. With the same surface dose the more energetic beta emmiting isotopes will naturally result in greater damage to the skin.

Table 1 is made up of data from animal studies from several investigators and shows the energy dependence of betas from various isotopes in producing recognizable skin reactions. Note that the surface doses for thresh-

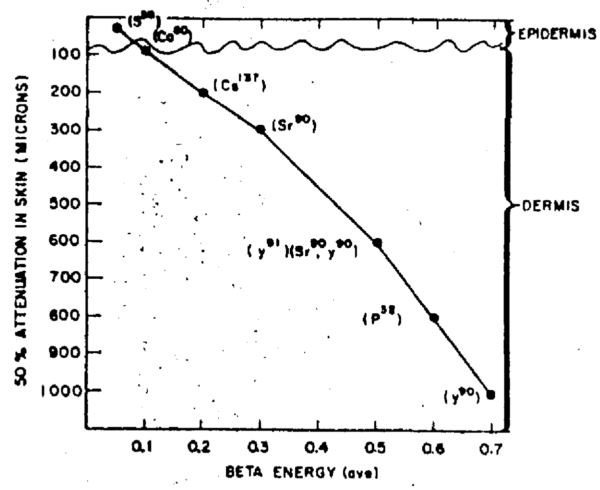

FIGURE 1.—*50 percent attenuation in skin (microns).*

old reaction (erythema, epidermal atrophy) are fairly dependent on the energy of the beta particles of the various isotopes. Thus it takes 20,000–30,000 rep from S^{35} (average energy 0.1 Mev.) to produce a reaction while it only takes 1500–2000 rep of Sr^{90}–Y^{90} or Y^{91} (average energy 0.5–0.6 Mev.) to produce the same reaction. It is of interest that Moritz and Henriques found that the dose at 0.09 mm. depth of the pigskin (estimated to be the epidermal thickness) was constant within several hundred rep to produce transepidermal injury [15]. Wilhelmy has also noted that it takes roughly the same dose of electrons and soft X-rays at the level of the subpapillary layer to produce erythema [19]. On this basis

TABLE 1.—SURFACE DOSE REQUIRED TO PRODUCE RECOGNIZABLE EPIDERMAL INJURY

Investigator	Animal	Isotope	Average energy (Mev.)	Surface dose (rep)
Henshaw, et al	Rats	P^{32}	0.5	1,500–4,000
Snider and Raper	Mice	P^{32}	.5	2,500
Raper and Barnes	Rabbits	P^{32}	.5	5,000
Lushbaugh	Sheep	S^{90}	.3	2,500–5,000
Moritz and Henriques	Pigs	S^{35}	.05	20,000–30,000
Do	do	Co^{60}	.1	4,000–5,000
Do	do	Cs^{137}	.2	2,000–3,000
Do	do	Sr^{90}	.3	1,500–2,000
Do	do	Y^{91}	.5	1,500–2,000
Do	do	Y^{90}	.7	1,500–2,000

Parker has advocated the use of beta detecting instruments with chamber walls corresponding in milligrams per square centimeter to the thickness of the relatively inert epidermal layer [20]. Thus in expressing skin dosage it is probably more informative to use the depth dose at the depth of the epidermal layer of the skin.

The above table also indicates the species difference in skin sensitivity to beta radiation. Rabbits and sheep required larger doses than mice to produce the same effect with roughly the same energy beta. Porcine skin, which is reputedly more like human skin than other animals, apparently is more sensitive than the rabbit or sheep skin. Some of these differences, aside from species differences, may be due to variation in thickness of the skin of different species and differences in techniques used.

Table 2 shows beta dosage data from some human experiments and accidents found to produce various effects on the skin. These data must be interpreted with great caution due to differences in experimental techniques and dosimetry. The severity of the skin reactions is represented by degrees. A first degree reaction implies erythema and/or dry desquamation; a second degree, transepidermal necrosis with ulceration; and third degree, further breakdown of the skin with the development of chronic radiation dermatitis. It can be seen that there is a considerable variation in dose reported to produce the various reactions.

In the Marshallese the skin dose could not be estimated with any degree of accuracy due to the complicated smear of beta spectra varying with time and the uneven distribution of the material on the skin.

The beta component of the fallout was found to have two major peaks of energy, one at 100 kev which accounted for 50–80 percent of the activity and one at 600 kev which accounted for 20–50 percent of the activity [1]. Fifty percent attenuation of the 100 kev component occurs at about 80 microns, about the depth of the epidermis. Fifty percent attenuation of the 600 kev component occurs at about 800 microns, fairly deep in the dermis; deep enough to irradiate many of the hair follicles. The relatively soft nature of the radiation was borne out by the superficial nature of most of the lesions that developed.

A very rough biological estimate of the dose to the scalp of the Rongelap people might be made by using the index of epilation. It is known that with 200 kvp X-ray a dose of about 400 r is necessary to produce epilation, and doses above about 700 r produce permanent epilation. Since regrowth of hair took place in the epilated Marshallese the dose to the hair follicles must have been in the above range. This dose must have been largely from the 600 kev component. Therefore the surface dose from this component must have been 4 to 5 times higher or in the range of 1,600–3,500 rep. The surface dose from the more abundant 100 kev component must have been much higher, by

TABLE 2.—HUMAN EXPOSURE TO BETA RADIATION

Investigator	Radiation	Est. dose (rep)	Reaction
Wirth and Raper	P^{32}	635	1st degree (threshold).
Do	P^{32}	1,180	2nd degree (threshold).
Low-Beer	P^{32}	*143	1st degree (threshold).
Do	P^{32}	7,000–17,000	2nd degree.
Robbins *et al.*	Cathode rays (1,200 kv)	1,000–2,000	3rd degree.
Knowlton *et al*	Fission products	3,000–4,000	2nd degree.
Do	(1 Mev. ave. energy)	5,000–10,000	3rd degree.
Do	do	5,000–10,000	3rd degree.
Do	do	8,000–16,000	3rd degree.

*Estimated dose in 1st mm. layer.

a factor of 5, 10 or more, but with very little penetration.

Estimations of the dose of skin irradiation from ground source beta has been made by Sondhaus [1].

If no shielding occurred and exposure is considered continuous the dose at the level of the dorsum of the feet was calculated to be about 2,000 rep, at hip level 600 rep and at head level 300 rep. This source of radiation was apparently insufficient, alone, to produce any lesions, though it probably contributed significantly to the severity of the foot lesions observed. With larger amounts of fallout, radiation from the ground source could be sufficient in itself to produce skin lesions.

Acute effects of beta radiation on the skin.—In general beta radiation effects on the skin are similar to effects produced by more penetrating radiation such as gamma or X-radiation. However, the less penetrating beta radiation produces more superficial lesions with less damage to the dermis. Consequently they are usually less painful and heal more rapidly.

The time sequence of development of beta lesions from fallout varies considerably with the dose to the skin. A primary erythema may or may not be observed beginning a few hours after exposure. This was not seen in the Marshallese, perhaps due to the dark color of their skin. During the first day or so itching, burning, or tingling of the affected skin may be experienced. As was pointed out these symptoms might in part be due to the chemical nature of the fallout. These early signs and symptoms are usually followed by an asymptomatic latent period before full-blown lesions develop. The length of the latent period may vary from a few days to several weeks which is usually related to the dose to the skin; the higher the dose the shorter the latent period. In the Marshallese the more heavily exposed group developed skin lesions about a week before less heavily exposed groups. Due to the particulate nature and uneven distribution of the fallout on the skin the developing lesions are likely to be spotty. A secondary wave of erythema may be seen along with gross changes in the skin. These changes may be in the form of simple tanning, pigmentation, and mild desquamation with low doses. This reaction might be classed as a *first degree reaction*. With higher doses vesiculation, complete epidermolysis and ulceration may occur. This severity of reaction might be classed as a *second degree reaction*. Spotty epilation may occur along with lesions of the scalp. Regrowth of hair is likely with a second degree lesion. Healing is usually accomplished within a week or two with repigmentation of the skin in milder lesions. Deeper lesions may heal with some scarring and lack of repigmentation.

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Chronic radiation effects.—With larger doses of radiation chronic radiation dermatitis may develop. These lesions do not heal well and on healing may break down and ulcerate again. Badly scarred skin with telangiectatic vessels may result. These severe reactions might be classed as *third degree reactions*. Repeated repair and breakdown may occur due to instability and poor vascularity of the dermis. It is in skin of type that malignant change may later take place.

Malignant changes in the skin has been observed in animals as a late effect of beta irradiation of the skin and presumably could also occur in the human skin. Though malignancy usually develops at the site of chronic radiation dermatitis, as a result of repeated exposure to radiation it has been reported to occur in animals following a single exposure to beta radiation with little or no chronic change in the skin.

Treatment of acute beta lesions is mainly symptomatic. With mild lesions, daily cleansing, application of bland antipruitic ointments and lotions may be all that is necessary. For more severe ulcerating lesions, cleaning with daily dressings, splinting and use of antibiotic ointments or antibiotics parenterally in case of secondary infections may be indicated. The use of Aloe Vera plant applications is claimed by some to enhance healing of radiation burns [21]. Lesions of chronic radiation dermatitis may be quite painful and the only effective therapy in such cases is early skin grafting [22].

Figures 2, 3, 4, and 5 illustrate typical lesions in the Marshallese people.

In conclusion I would like to summarize a few things we have learned about the effects of fallout on the skin, largely as a result of our Marshallese experience:

1. The best prophylactic measure, of course, is avoiding getting the fallout on the skin by taking shelter or covering as much of the body as possible with clothing. Prompt decontamination of the skin by thorough scrubbing with soap or detergent and water is of extreme importance. If the hair is seriously contaminated and difficulty is encountered in decontamination, shaving of the head is indicated.

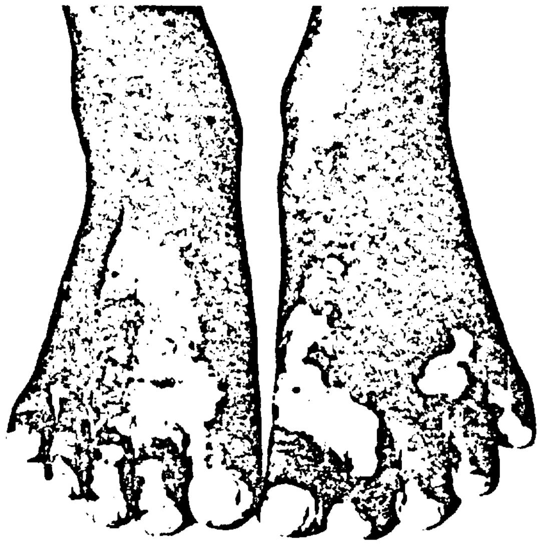

FIGURE 2.—*Beta radiation lesions of the feet at 4 weeks after exposure.*

FIGURE 3.—*Same case in Figure 2 at 6 months after exposure.*

FIGURE 4.—*Epilation in 7-year old girl at 28 days. Case No. 72.*

In the Marshallese certain factors afforded protection against the development of lesions: (1) Shelter, (2) Bathing, swimming, wading, (3) Clothing. Certain factors also favored the development of lesions: (1) As pointed out areas where perspiration is more profuse, (2) Delay in decontamination, and (3) Difficulties in decontamination.

2. Moderately severe beta lesions of the skin and epilation may result from fallout situations in which the whole body penetrating dose of radiation is sublethal. With such doses the skin lesions do not appear to complicate the radiation syndrome.

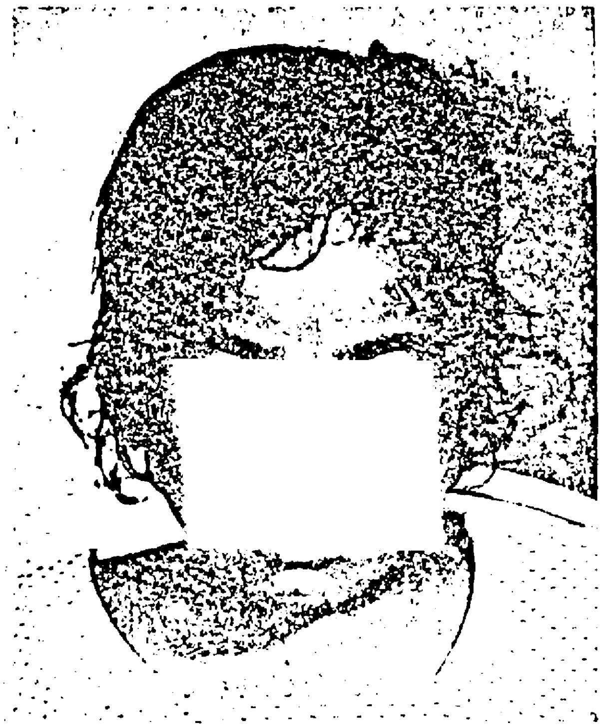

FIGURE 5.—*Same case as in Figure 4 six months after exposure showing complete regrowth of normal hair.*

3. However, in situations where skin lesions are associated with larger whole body doses of radiation i. e. in the lethal range or above, with greater hematopoetic depression, the lesions would become more easily infected, possibly affording portals of entry, leading to bacteremia or septicemia.

4. Severe skin irradiation with minimal whole body irradiation might result in situations where promp evacuation from the contaminated area occurred, but skin decontamination was delayed.

5. Early skin and eye symptoms might be mildly disabling during the first day or two after exposure to fallout and later symptoms associated with full blown lesions might be quite disabling. Late effects on the skin in the form of chronic radiation dermatitis and malignancy are possible complications.

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