RECORD #188

TITLE: Calculating Dose From a Hot Particle On the Skin

FICHE:

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

January 22, 1987

MEMORANDUM FOR: Those on Attached List

FROM: LeMoine J. Cunningham, Chief
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Division of Inspection Programs
Office of Inspection and Enforcement

SUBJECT: CALCULATING DOSE FROM A HOT PARTICLE ON THE SKIN

As a result of three incidents of excessive skin exposures from hot particles, IE issued Information Notice No. 86-23. That Information Notice included the information that "for purposes of showing compliance with 10 CFR 20.101(a), calculating skin dose averaged over 1.0 cm^2 at a depth of 7 mg/cm^2 is appropriate." The basis for this statement, as explained in the Information Notice, is the NCRP dose limit recommendations in NBS Handbook 59, which provide the basis for current regulations. We continue to believe that this position has a sound regulatory basis. Frank Congel and Bob Alexander also agree with this position.

For comparison with the dose limit, the continued use, as an interim measure, of the 1-cm^2 area and 7-mg/cm^2 depth for calculating skin-dose from hot particles also is supported by recent publications that consider the current state of knowledge of radiation damage to the skin, the inadequacies of current ICRP guidance in this area, and methods for calculating skin dose. Relevant information from these publications is provided in the enclosed document, which was prepared by John Buchanan. The enclosure also includes a relevant excerpt from the IE comments on the proposed major revision of 10 CFR Part 20. This enclosure is provided for your information.

LeMoine J. Cunningham, Chief
Operating Reactor Programs Branch, Section 2
Division of Inpsection Programs
Office of Inspection and Enforcement

Enclosure:
"Information on Calculating Dose from
a Hot Particle on the Skin - Use of
One-Square-Centimeter Area in Calculations"
(December 1986)

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INFORMATION ON CALCULATING DOSE FROM A HOT PARTICLE ON THE SKIN - USE OF ONE-SQUARE-CENTIMETER AREA IN THE CALCULATIONS

Summary

The continued use of a 1-cm^2 area for calculating skin dose from a hot particle is supported by recent scientific publications.

IE Staff Position On Compliance with Regulations

IE Information Notice No. 86-23: "Excessive Skin Exposures Due to Contamination with Hot Particles," (April 9, 1986) includes the following staff position.

> "A hot particle on the skin produces a very steep dose gradient with the dose dropping off rapidly as distance from the particle increases. The NCRP dose limit recommendations in NBS Handbook 59 (which provide the basis for the current NRC regulations) assumes that the critical area of the skin is 1.0 cm^2 and that the radiosensitive basal layer of cells is at a depth of 7 mg/cm^2 below the surface. For purposes of showing compliance with 10 CFR 20.101(a), calculating a skin dose averaged over 1.0 cm^2 at a depth of 7 mg/cm^2 is appropriate."

For comparison with the dose limit, the continued use, as interim measure, of the 1-cm^2 area and the 7-mg/cm^2 depth for calculating skin dose from hot particles also is supported by recent scientific publications. The use of these values is considered to be a conservative procedure which may overestimate the health detriment. These recent publications, which include discussions of the inadequacies of ICRP-26 recommendations on this topic, are summarized in the following sections of this document.

ICRP 26

ICRP Publication No. 26 (Paragraphs 182 and 183) recognizes two practical situations for monitoring of skin: (1) measurement of external radiation with dosimeters in which case the dosimeter measurements are treated as being representative of the skin and no problem of averaging arises, and (2) irradiation of the skin by contamination on the skin and the question of averaging does arise. For this second situation, the ICRP recommends using an areas of 100 cm^2 for averaging for "routine purposes" and an areas of 1 cm^2 in regions of highest dose equivalent for "accidents and suspected accidents." For extremely non-uniform dose distributions such as those from small particles in contract with the skin, the ICRP recommends assessing the "local distribution of absorbed dose," but states that it is inappropriate to relate such localized doses to the dose-equivalent limit.

Comments on ICRP 26 Recommendations, and Other Relevant Publications

In a 1980 publication, Charles and Wells summarized some of the limitations of the ICRP 26 recommendations as follows:

"For very small area exposures, perhaps less than 1 cm^2, such as those from small sources or radioactive particulates, the likelihood of chronic exposure of the same body site is reduced and the acute response to high local doses becomes of significant partical importance. The ICRP offer little guidance for this situation [in ICRP Publication 26, Paragraph 183].

An evaluation of the mean dose to an area of 1 cm^2, which was previously recommended by the ICRP [in ICRP Publication No. 9 in 1966], is no longer considered appropriate for comparison with the dose limit. In the absence of suitable guidance the averaging procedures will, however, probably continue to be used and is likely to represent a conservative approach for most situations. A sounder basis for operational procedures and a knowledge of the magnitude of pessimism embodied in averaging procedures is clearly necessary.

There is at present so little clinical or experimental data for non-uniform exposures that the ICRP [in ICRP 26] advice to predict local skin reactions on the basis of the absorbed dose distribution cannot be complied with . . . "

In work done for the NRC, PNL staff members (Traub et al., 1985), also recommended use of the 1 cm^2 area of averaging for dose calculations for sources smaller than 1 cm^2. In other work done for the NRC (Reece et al., 1985), PNL workers stated, with respect to the guidance in ICRP Publication 26, that it is unclear whether, for highly localized exposures, the ICRP 9 concept of averaging the dose over the square centimeter with the highest dose is still considered adequate by the ICRP. These workers also stated that, in 1983, a Nuclear Energy Agency (NEA) expert group on the assessment and recording of worker doses advised determination of the skin dose equivalent over an areas of up to 1 cm^2. In cases of nonuniform contamination, NEA recommended assessing the maximum skin dose equivalent over any 1 cm^2.

In a 1986 publication Rohloff and Heinzelman presented the results of their Monte Carlo calculations of dose rates for skin contamination by beta radiation. They make the following statements with respect to "point contamination":

"ICRP [in ICRP Publication 26] recommends for actual or presumed accidents that the dose equivalent should be averaged in 1 cm^2 in the region of the maximum dose equivalent and that this value should then be compared with the dose equivalent limits. For an extremely uneven activity distribution in the case of a point contamination, the average dose rate was calculated for different tissue depths for a circular area of 1 cm^2 at the location of the maximum dose rate. These average values for point contamination of 1 Bq activity only differ very slightly from the values for large-area contamination with activities of 1 Bq cm^{-2} per unit area. These differences increase with rising maximum energy of the beta radiation. The dose rate in tissue for ^{106}Rh, the nuclide with the highest maximum energy in our calculations, is shown in Figure 2 for an area and a point contamination. At a tissue depth of 0.07 mm, the dose rate of the plane source is only 3% higher than that of

the point source. This difference increases with growing tissue depth and amounts to about 16% at 2 mm depth. The differences are less significant for beta emitters with lower maximum energy. It can therefore be generally stated that, in the extreme case of a point contamination, the average dose rate on a area of 1 cm^2 at the location of maximum dose rate practically equals the dose rate for a large-area contamination with uniformly distributed activity, if the activity of the point contamination is the same as the activity per unit area for the large-area contamination."

In a 1986 article, Strather provided a report on a 1985 workshop on radiation damage to skin. With respect to current understanding of radiation damage, Strather makes the following statement.

"The skin, and its underlying structures, are frequently the limiting tissues in the radiation exposure of occupationally-exposed persons, or patients treated with radiotherapy. Overexposures can cause serious damage and long-term suffering and disability. Despite the fact that the skin is one of the most radiation-sensitive tissues in the body, and was one of the first tissues in which radiation damage was recognized, the mechanisms of radiation damage, the location of the sensitive cells, the interaction of the different cell systems involved, the effects of dose rate, and the different sensitivity of superficial and underlying tissues are only just starting to be understood."

With respect to results of animal studies and their impliations for radiation protection standards, Strather reports:

"A series of papers presented by Hopewell, Morris and Hamlet (UK) reviewed progress in a comprehensive study designed to examine the effects of localised beta irradiation on the pig skin, an animal with a skin structure very similar to that of man. It has been demonstrated using a range of beta-emitting radionuclides and sources of different diameters (0.1-40 mm) that the extent of acute damage becomes more pronounced at higher beta particle energies, and with increasing areas of irradiated skin. A major factor in the repair of the skin is the ability of undamaged basal cells of the epidermis to migrate into the affected area if this is small enough. An important observation has been that late dermal atrophy (a reduction in the thickness of the skin) has occurred at doses that produce only a minimal erythema.

Wells (UK) considered these data, from the point of view of the occupational health physicist applying ICRP recommendations related to irradiation of the skin. Ideally, when localised skin exposures from radioactive particles have occurred the dose distribution in the irradiated areas should be ascertained. In practice, and as ICRP make no specific recommendations for small areas, this may not always be possible, and often estimates of average skin dose over 1 cm^2 or 100 cm^2 are made instead of a few mm^2. The work on local skin irradiation by small (~1 mm) sources has demonstrated that if doses to the basal cells are averaged over 100 cm^2 then doses could fall well within acceptable limits, despite the fact that local doses could

be many times this average value, and could cause either acute effects or late dermal atrophy. Limitation of dose to an area of 1 cm^2 would, however, prevent any macroscopically visible non-stochastic effects, other than possibly a transient 'point' erythema. An added complication is that the basal cells are normally considered to lie at a depth of 70μm. In some parts of the body, such as the face, their depth can be considerable less (20-40μm), and thus estimating the dose at 70μm could appreciably underestimate the dose to these cells. These considerations indicate that a reassessment of current radiation protection guidelines for local skin irradiation may be needed."

In another 1986 article, Francis reported on a 1985 workshop on dosimetry of beta particles and low-energy x-rays. His report includes the following statements.

"The present state of knowledge of the relevant radiobiology and the implications for dosimetry were examined in the opening session. When the body is exposed to low penetrating radiation, the skin, eyes, and sometimes the testes, are the organs receiving the highest dose. In the case of the testes and eyes, the relative importance of the various detrimental effects and the location of critical cells are well established. However, biological data now becoming available from the exposure of animal skin suggested that the radiobiological bases of the current ICRP recommendations for human skin - particularly when the exposure is highly non-uniform both in depth and area - may not be well founded. There appears to be a need for an international review of both human and animal data to establish a consensus on the most relevant detrimental effect for protection and the location of the cells that are most at risk. This will pave the way for the development of more rational techniques in personal dosimetry."

In another 1986 article, Charles reviewed the current state of knowledge concerning radiation exposure of the skin, eye, and testis, drawing on information from the two 1985 workshops mentioned above. Relevant quotations from this paper includes the following:

"Uncertainties in radiobiology

...

The current annual ICRP dose limits for skin and eye are 0.5 Sv and 0.15 Sv. These are based on the avoidance of detrimental non-stochastic effects (cosmetic effects in the skin and cataract of the eye lens). In the case of the gonads the dose limits is based on stochastic effects (genetic detriment in offspring following exposure of germ cells). A weighting factor of 0.25 has been assigned to gonads by the ICRP and on this basis the acceptable single orgin exposure is 0.2 Sv. The ICRP in publication 41 ... have recently reviewed non-stochastic effects... The report [ICRP Publication 41] concludes that presently recommended dose equivalent limits provide a substantial margin of safety for all tissues, with the possible exception of the bone marrow, gonads and lens of the eye. This statement appears

to be re-assuring for skin exposure but the ICRP did not review information relating to small area skin exposure (<1 cm^2) and the identity of cells at risk was not discussed. It is also somewhat controversial as to whether skin cancer induction is in fact a more important end-point that may lead to a downward revision of the skin dose limit in the future. The particular organs which are therefore of concern in superficial radiation exposures are those for which dose limits offer the smallest margin of safety or for which radiobiological understanding is poor.

...

Stochastic Effects

ICRP publication 26 presents a logical approach to radiological protection by equating the risk associated with a whole body exposure to the sum of the risks of the comprising organs. In the case of skin cancer mortality the risk is considered to be much less than for other organs and a value of 10^{-4} Sv^{-1} has subsequently been given for a whole body exposure. The relegation of skin to an unimportant place in the stochastic risk table may however require further consideration because of the much higher risk of cancer incidence in this organ. The case for skin cancer incidence risk figures in excess of 10^{-2} Sv^{-1} for whole body exposure has been made by Charles and Lindop ... and more recent clinical and epidemiological studies have indicated risks which are even higher .... A life-time skin dose limit of 20 Gy (recommended in ICRP 26 to limit non-stochastic effects) could produce a high incidence of skin cancer. Although the latent period is likely to be in excess of 20 years the treatment of such tumours often leaves non-stochastic damage and their importance in the content of radiological protection should be reevaluated.

Non-Stochastic Effects

Non-stochastic effects are currently considered by the ICRP to be more important than stochastic effects and they recommend an annual skin dose limit of 0.5 Sv based on the proposition that cosmetically unacceptable changes may occur in skin at doses of 20 Gy or more delivered over weeks or months to a limited portion of skin. Few relevant data are in fact available to support this dose limit other than the work of Sulzberger et al. ... Recent follow-up studies of occupationally exposed groups indicate that the limit may be too high. Sub-clinical changes in dermal blood vessels after occupational exposures of 10-30 Gy of low LET radiation over a period of 8-25 years have been found using a capillary microscope ... and similar changes have been found in Japanese bomb survivors ...

Cells at Risk

In view of the biological importance of the basal cell layer and because of its proximity to the body surface it has been considered by the ICRP and others as the skin tissue most at risk. Early ICRP

publications referred to a minimal depth of 7 mg/cm^2 but considerable subsequent work has shown that the basal layer depth may be as little as 2 mg/cm^2 for some body sites. The work of Whitton ... in particular showed that early measurements of skin thickness had not accounted for the shrinkage of biopsy samples and had overestimated thickness by up to a factor of two. In an extensive study she measured epidermal thickness in man and her collated data are included in ICRPs Reference Man and presented in somewhat more detail in Fig 7. Recent data for Japanese subjects ... is in accord with the work of Whitton. The potential skin hazard from alpha radiation is apparent for the thinnest body sites (2 mg/cm^2) and has been underlined by epidemiology studies showing an excess of basal cell cancer in some uranium miners .... ICRP 26 specifies a range of 5-10 mg/cm^2 for the basal layer depth on exposed body sites and recommends the use of a mean value of 7 mg/cm^2.

The relative importance of stochastic and non-stochastic effects in fact depends on many biological and physical factors, particularly the area and volume of tissue irradiated. The irradiation of large areas to sub threshold doses for non-stochastic effects may entail a negligible cancer risk but a high risk of moist desquamation of ulceration. The epidermis and superficial dermis play a major role in stochastic and early non-stochastic effects but late non-stochastic effects such as ulceration or tissue atrophy depend amongst other things on vascular damage in the mid/deep dermis. The ICRP view that non-stochastic effects are limiting for radiological protection applications, and that the relevant dose is that to the epidermis, is undoubtedly too simplistic.

Non-Uniform Skin Exposures

For very small areas of exposure, perhaps less than 1 cm^2, such as those from small sources or radioactive particulates, the acute response to high local doses becomes of significant practical importance. In such cases ICRP 26 offers the following advice:

> 'The local distribution of absorbed dose should be assessed and used to predict possible local skin reactions. It is inappropriate however to relate such localised absorbed doses to the absorbed dose corresponding to the dose equivalent limit'. Para. 183.'

The ICRPs reticence to provide specific guidance in this case is understandable because of the extreme paucity of relevant data on which to base it.

...

Conclusions

...

There is clearly increased concern, particularly in the USA about the practical problem of skin irradiation. Following considerable

technical development methods are now available to calculate or measure a range of dosimetric parameters relevant to skin, even at depths of 20 microns associated with the thinnest human epidermis. However, fundamental radiobiological uncertainties remain concerning the most appropriate parameter to measure. Current ICRP recommendations are inadequate, particularly when exposure is highly non-uniform (in depth and area). A growing body of biological data on beta exposure of animal skin is becoming available which should allow more meaningful protection criteria to be developed and would aid the design of personal skin dosemeters. NCRP Committee 80 on the Radiobiology of Skin is evaluating the basis of skin dosimetry and is currently suggesting a major role for dermal damage in the induction of skin cancer, a view which runs counter to current ICRP recommendations. It is necessary that an international consensus is reached on the most relevant biological end-point for radiological protection applications for the skin. Only when the relative importance, in terms of health detriment, of stochastic and early and late non-stochastic effects is determined will a decision regarding the most appropriate design of personal dosemeter be possible. In the interim period the current practice of estimating skin dose in the vicinity of the basal layer of the epidermis, averaged over an area in the region of square centimetre for comparison with the annual dose limit is almost certainly a conservative procedure. This may considerably over estimate the actual health detriment in many cases of beta exposure."

IE Comments on Revision of 10 CFR Part 20

Based on considerations of the information outlined above, as well as other considerations, IE staff has provided the following comment on the proposed revision to 10 CFR Part 20:

"§20.201(a)(3)(ii) reads as follows: "The annual dose equivalent limit to the skin and to each of the extremities in 50 rem. This limit applies to the dose equivalent averaged over 10 square centimeters in the region of highest exposure."

Comment: (a) The second sentence in §20.201(a)(3)(ii) should be deleted because it specifies an area for averaging for external exposure when no such area is needed, and because there is no adequate basis for using the 10 cm^2 value for averaging in cases of skin contamination. A more detailed discussion follows.

(b) The Statement of Considerations for the final rule should explain the reason for the change recommended in (a) above. The Statement of Considerations also should state that, until NCRP or ICRP provides suitable new guidance, the staff intends to continue its existing position on calculating skin doses from small particles. That position is that this dose should be assessed at a depth of 7 mg/cm^2 and averaged over an area of 1 cm^2. (See following discussion.)..."

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J. D. Buchanan
December 1986