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STANDARDS AND GUIDELINES PERTINENT TO THE DEVELOPMENT OF DECOMMISSIONING CRITERIA FOR SITES CONTAMINATED WITH RADIOACTIVE MATERIAL

H. W. Dickson

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H. W. Dickson

ABSTRACT

A review of existing health and safety standards and guidelines has been undertaken to assist in the development of criteria for the decontamination and decommissioning of property contaminated with radioactive material. During the early years of development of the nuclear program in the United States, a number of sites were used which became contaminated with radioactive material. Many of these sites are no longer useful for nuclear activities, and the U. S. Department of Energy (DOE) desires to develop criteria for the management of these sites for future uses. Radiation protection standards promulgated by the International Commission on Radiological Protection (ICRP), the National Council on Radiation Protection and Measurements (NCRP), and the American National Standards Institute (ANSI) have been considered. Government regulations, from the Code of Federal Regulations and the legal codes of various states, as well as regulatory guidelines with specific application to decommissioning of nuclear facilities also have been reviewed. In

addition, recommendations of other scientific organizations such as the National Academy of Sciences/National Research Council Advisory Committee on the Biological Effects of Ionizing Radiations and the United Nations Scientific Committee on the Effects of Atomic Radiation were considered. Finally, a few specific recommendations and discussions from current literature were included.

INTRODUCTION

There are many properties throughout the United States which had been licensed for various operations under the Manhattan Engineering District (MED) and/or the Atomic Energy Commission (AEC). The DOE currently has a program to resurvey the formerly licensed sites and to develop complete documentation of the radiological status. In addition there are several inactive uranium mill sites that are being studied for possible remedial action. Remedial actions will be undertaken with the intent to permit release of the sites for totally unrestricted use so that no continual or periodic surveillance will be required in future years. In the case of the inactive uranium mill sites, it may not be feasible or even desirable to undertake cleanup of all sites; thus, criteria for decommissioning of the inactive uranium mill sites criteria will be suggested to determine whether or not cleanup should be undertaken, the levels to which decontamination should proceed if undertaken, and the extent of future restrictions on site use for sites where cleanup is not undertaken. The goal of DOE in this program is to suggest criteria and guidelines for the management of contaminated real estate in a manner that will be cost-effective in protecting public health and environmental quality but which will permit further use of land and other resources.

In the development of criteria for decommissioning property contaminated with radioactive material, it is useful and instructive to review pertinent health and safety standards and guidelines which have been established over the years. Of particular interest are the radiological standards and guidelines; however, several non-radiological standards and guidelines may also have direct application for decommissioning criteria. While the terms regulation, standard, guideline and criteria are often used interchangeably, this report makes distinctions. A standard is established by "authority" as a rule to follow. Regulations are rules having the force of law issued by an executive authority or a government. A guideline is a recommended practice or guiding information supplied by an agent with implied intimate technical knowledge. In general, standards set forth limits or definitive ways of accomplishing an objective, whereas criteria provide a yardstick for comparison as a basis for judging the acceptability of a practice.

STANDARDS

The International Congress of Radiology established the International Commission on Radiological Units (ICRU) and the International Commission on Radiological Protection (ICRP). The recommendations of these two bodies have been recognized as authoritative and have constituted the internationally accepted standards for radiation protection purposes. As early as 1928 the ICRU adopted the roentgen as a unit of exposure and ICRP published the first set of international recommendations for protection from ionizing radiation. Over the years, there have been many changes in the permissible radiation exposure levels recommended by

ICRP, each resulting in a decrease in recommended exposure limits for workers and for the general population. The basic philosophy of ICRP is that any level of radiation is potentially harmful and any unnecessary exposure should be avoided. Thus, they admonish that radiation doses should be kept as low as reasonably achievable but, in any case, should not exceed the prescribed annual dose limits. The current ICRP radiation doses limits[1] are presented in Table 1.

Of particular concern for the uranium mills and excessed MED/AEC sites is Ra-226 contamination. The ICRP has established limits for the maximum permissible quantity of radium in the bone[2] based on studies of radium dial painters[3] and medical applications.[4] For occupational exposure, 0.1 μg of radium in equilibrium with its decay products has been recommended as the maximum permissible body burden (MPBB) of Ra-226. The corresponding MPBB for non-occupational exposure is 1/10 of the occupational MPBB or 0.01 μg of Ra-226.

In a recent paper by Stewart[5] the most recent ICRP recommendations[6] were discussed. The ICRP now considers total risk rather than risk to critical organs. This is accomplished by establishing a level of risk per unit of radiation dose received by each organ and using a weighting factor of relative risk for each organ compared to that of whole-body radiation doses. The risk factors are given in Table 2. Some values may be sex and/or age dependent, but the ICRP considers that these differences are insufficient to warrant separate risk factors. In using these values, the sum of risks is not to exceed the equivalent risk of the annual dose limits for whole-body doses. In effect, this provides a method for normalizing all types of radiation exposure. For instance, exposure to the lungs from radon daughter products should not exceed 0.5

rem ÷ 0.12 or 4.16 rem per year for a member of the general population assuming no other exposure occurred.

The NCRP is the recognized authority in the setting of radiation protection standards in the United States. The NCRP was formed in 1929 under the auspices of the National Bureau of Standards as the Advisory Committee on X-Ray and Radium Protection. The name was later changed and NCRP received its "official" charter by an Act of Congress in 1964. From its beginnning in 1929, NCRP has been closely associated with the ICRP. The current NCRP radiation dose standards[7] are summarized in Table 3. The NCRP continues to subscribe to the standard of 0.1 μg as the limiting body burden for Ra-226. The NCRP recommendations, like those of ICRP, are based on the principle that the lowest practicable radiation level is the fundamental basis for establishing radiation standards and that radiation health hazards do not have a dose threshold. The setting of radiation protection standards requires consideration of balances between currently assumed hazards and benefits. The NCRP considers the practice of balancing risks and benefits ideal but highly uncertain and imprecise at this time. The NCRP continues to hold the belief that risk estimates at low doses and low dose rates based on a linear extrapolation from effects at high doses and high dose rates are very conservative from a radiation protection standpoint.

The linear dose-effect hypothesis has been frequently used in analyses of population exposures which are expressed in the form of person-rem, including doses of the order of one millirem per year. The NCRP cautions that a significant variation in radiation effectiveness at different dose rates would make the current practice of summing doses at be individually identified.) Where potentially contaminated surfaces are not accessible for measurement (as in some pipes, drains, and ductwork), such property shall not be released according to the standard, but made the subject of a case-by-case evaluation. Credit may not be taken for coatings over contamination. This proposed standard is in essential agreement with Nuclear Regulatory Commissions (NRC) Regulatory Guide[9] 1.86 and other NRC guidelines.[10]

REGULATIONS

Government regulations which relate to decommissioning of nuclear sites appear in the Code of Federal Regulations (CFR) and in the legal codes of various states. While all the federal government regulations are contained in the CFR, different titles are associated with various government agencies, commissions, and administrations. For example, Title 10 - Atomic Energy pertains to the NRC. Title 40 - Protection of the Environment, includes regulations of the Environmental Protection Agency (EPA) and Title 29 - Labor, Chapter XVII, deals with regulations under the Occupational Safety and Health Administration (OSHA). Some of the regulations under these titles have immediate application in the decommissioning of real estate contaminated with radioactive material which shall henceforth be referred to as a nuclear site in this report. The term, nuclear site, may be troublesome to some since it implies a site used for deliberate nuclear endeavors, whereas some property has become contaminated inadvertently. Nevertheless, we shall use the term nuclear site to denote all sites contaminated with radioactive material regardless of its origin.

Pertinent Title 10 Regulations

The NRC's rules and regulations form a fundamental framework within which nuclear facilities must be designed, built, operated and decommissioned. The NRC regulations appear under Title 10 - Atomic Energy in the Code of Federal Regulations. Also, the NRC issues Regulatory Guides which are guidelines describing solutions to safety issues which are acceptable to the NRC. These will be discussed more fully in the section on regulatory guidelines.

The NRC's regulations have evolved with time, being established or modified as operational experience was gained and comments were received from other federal agencies, state agencies, scientific groups, industrial organizations and other interested parties. The NRC regulations in 10 CFR, including the appendices, are promulgated in accordance with the rule-making authority given in the Atomic Energy Act of 1954, as amended. These regulations have the force of law and, where applicable, compliance with them is required.

Standards for protection against radiation are contained in 10 CFR 20. Specifically, Part 20 discusses control of releases of radioactive materials to the environment and limitation of radiation doses to workers and members of the public from operations involving NRC-licensed nuclear facilities. The Part 20 regulation was made effective in 1957 and was based on recommendations of the NCRP and the ICRP. Subsequently, guidance on radiation protection was provided by the Federal Radiation Council (FRC) which has since been incorporated into the Environmental Protection Agency (EPA), the agency which currently has the authority to establish environmental radiation protection standards. The 10 CFR 20 provides limits on air and water effluent concentrations of approximately 250 radionuclides that must be met by all licensees. More restrictive limits may be applied, if necessary, to assure that exposures to the public from all sources (other than natural background and medical) do not exceed specified limits. Part 20 also sets limits of radiation exposure for individuals in both restricted (workers) and unrestricted (general public) areas. These exposure limits are summarized in Table 6.

Part 40 - Control of Source Material deals with the regulation of "source material" which means any material, except fissionable material, containing by weight 0.05% (500 ppm) or more of (1) uranium, (2) thorium or (3) any combination thereof. Unless authorized by an NRC license, no person may transfer or deliver, receive possession of or title to, or export from the U.S., any source material after removal from its place of deposit in nature. This includes the disposition of raw source material (which also includes uranium mill tailings) by dumping into streams or sewers, or in any other manner that precludes recovery.

A precedent for establishing remedial action criteria for a site contaminated with uranium mill tailings has been set in 10 CFR 712 - Grand Junction Remedial Action Criteria. These regulations establish the criteria for determination by DOE of remedial actions to limit radiation exposure of individuals in Grand Junction, Colorado, from the use of uranium mill tailings as construction fill. These criteria specifically consider external gamma radiation (EGR) levels and indoor radon daughter concentration (RDC) levels. A summary of the remedial action criteria for dwellings and schoolrooms is presented in Table 7, and the text of 10 CFR 712 is given in Appendix I. All action levels listed in Table 7 refer to levels above natural background. For structures other than dwellings or schoolrooms, an RDC less than 0.03 working levels* (WL) and an EGR less than 0.15 mR/h above background indicates no need for remedial action.

Measurement of average RDC levels is a difficult task due to the large diurnal and seasonal fluctuations in these levels. One technique to obtain a DOE-approved RDC level is to average the results of 6 air samples, each of at least 100-h duration, and taken at a minimum of 4-week intervals throughout the year.

Environmental Protection Agency

In the CFR, Title 40 deals with environmental regulations which fall in the domain of EPA. The EPA sets generally applicable environmental radiation standards for the protection of the general public from radioactive materials. These responsibilities were transferred to EPA from the FRC when EPA was established in 1970. The FRC established a guideline for permissible exposure of uranium miners at 4 working level months (WLM) per year[11] and the EPA continues to subscribe to this guideline. The FRC guidance for man-made sources of radiation limit whole-body doses to 500 millirem for an individual and to 170 millirem/person for any significant segment of the general population. This specifically excludes exposure to naturally-occurring sources such as radium as well as exposure from diagnostic and therapeutic medical applications of radiation. Among those regulations which have appli-

*A working level is any combination of short-lived radon daughter products in 1 liter of air which will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy.

cation to decommissioning criteria for nuclear sites are those dealing with drinking water standards and uranium fuel cycle dose standards.

A standard for radioactivity in drinking water was developed by EPA for the Safe Drinking Water Act, Public Law 93-523 (1974). The standard consists of four parts:

(1) maximum contamination levels,

(2) analytical methods,

(3) monitoring frequency, and

(4) reporting requirements.

In the section on maximum contamination levels, mixtures of radionuclides, compliance criteria and dose limits for natural and man-made radioactivity are discussed. The standard for natural radioactivity is limited to a combined Ra-226 and Ra-228 level of 5 pCi/liter and a gross alpha activity level (including Ra-226, but excluding radon and uranium) of 15 pCi/liter.[12] The dose limit was set at 4 millirem/year for a member of the general public from consumption of drinking water containing radioactivity.

The EPA also develops and promulgates non-radiological standards for the protection of the environment. At inactive uranium mill tailings sites, concentrations of such elements as selenium, arsenic, cadmium, lead and iron have been found[13] to exceed drinking water standards.[12] For this type of nuclear site, as well as others, the EPA drinking water standards should apply even though few individuals would use surface water from these sites as a drinking water supply.

The 40 CFR 190 Subpart B contains the regulations dealing with an environmental radiation dose standard for the uranium fuel cycle. In preparing this standard, EPA considered:

(1) total radiation dose to populations,

(2) maximum dose to individuals,

(3) risk of health effects including long-term health effects arising from the release of long-lived radionuclides to the environment,

(4) effectiveness and cost to mitigate these risks through effluent control, and

(5) findings of the Advisory Committee on Biological Effects of Ionizing Radiation (BEIR Committee) of the National Academy of Sciences/National Research Council.

The standard is scheduled to go into effect in December 1980, except for krypton and iodine levels which would go into effect on January 1, 1983.

In summary, the EPA fuel cycle standard[14] states that the annual dose equivalent to a member of the general public shall not exceed 25 millirem to the whole-body, 75 millirem to the thyroid or 25 millirem to any other organ as a result of exposure to radioactive discharges and radiation from uranium fuel cycle operations. Radon and radon daughter exposures are excluded from the standard. The uranium fuel cycle includes milling, conversion, enrichment, fuel fabrication, reactor operation, reprocessing and waste disposal, however, the standard does not apply to mining or waste disposal operations.

The Resource Conservation and Recovery Act of 1976, (Public Law 94-580) provides for development of criteria to define hazardous waste.

The EPA has established, for implementation of this law, that waste not covered by the Atomic Energy Act of 1954, as amended, be considered radioactive if it contains 5 pCi/g or more Ra-226.

The EPA also has proposed radiation dose limits for exposure from soil contaminated with plutonium.[15] This guidance limits the lung dose to one millirad per year and the bone dose to three millirad per year. The risk to an individual continuously exposed to these recommended dose limits is less than one chance in a million per year, and less than ten chances per 100,000 in a lifetime, of developing a cancer from this source of exposure.

Occupational Safety and Health Regulations

With regard to non-radiological standards, the Occupational Safety and Health Administration (OSHA) plays a major role. The OSHA has set standards limiting the concentration of various toxic materials to which a worker may be exposed. These standards were set forth as regulations in the Federal Register[16] and concern the concentrations of noxious gases that may be breathed by a worker. Since these standards do not extend to the public, they have limited application for decommissioning criteria except as they may be related to workers engaged in implementing remedial action.

State Regulations

Approximately one-half of the states have entered into an agreement with the NRC (or previously with the AEC) to assume some regulatory responsibilities, including the licensing of certain nuclear facilities, and the regulation of by-product, source and special nuclear material in quantities not sufficient to form a critical mass. The NRC retains regulatory responsibility for specific nuclear activities including, but not limited to, production and utilization facilities. These states, as well as some of the others, issue regulations dealing with radiation exposure, effluent concentration limits, licensable quantities of radioactivity, etc. In general, it can be stated that these regulations are at least as stringent as the corresponding NRC regulations. Some of the states have chosen to impose even stricter regulations and, in addition, to regulate radiation sources such as Ra-226 over which the NRC has no specific control. As an example, a number of states[17] require licensing of sources containing Ra-226 in concentrations in solids exceeding 0.1 pCi/g. This level, incidentally, is exceeded in a number of natural situations including soil and foodstuffs such as Brazil nuts.

REGULATORY GUIDELINES

In addition to regulations which carry the force of law, regulatory bodies such as NRC and EPA prepare regulatory guides which, among other things, suggest solutions to problems which would be acceptable to the issuing agency.

The NRC Regulatory Guide[9] (RG) 1.86 has application to decommissioning criteria. This guideline deals with the termination of a license for a nuclear reactor and provides specific guidance on the disposal of radioactive material and extent of decontamination required before property can be released for unrestricted use. Radioactive materials may be secured on the site, but a license "to possess" and continued surveillance are required. If it is desired to terminate a license and eliminate the surveillance requirements, the facility has to be decontaminated to a level which minimizes risk to public health and safety. This level has been defined in RG 1.86 and the guidance is reproduced in Table 8. The licensee may not take credit for coverings which would attenuate weakly penetrating alpha and beta radiations. In addition, the interior surfaces of pipes, drains, and ductwork should be assumed to be contaminated in excess of the limits unless the radiological status can be documented.

Another guideline[10] issued by the NRC provides similar guidance but differs in that it extends to all contaminated facilities and equipment and the termination of licenses for by-product, source and special nuclear material. This guideline specifies the limits for surface contamination and radiation exposure rates associated with the surface contamination which should be met prior to abandonment or release for unrestricted use. These limits do not apply to premises, equipment or scrap containing induced radoactivity for which the radiological considerations may be different. The release of such items from regulatory control will be considered on a case-by-case basis. The text of this guideline is included in Appendix II.

The EPA has also prepared some provisional guidelines which are directly applicable to decommissioning criteria.[18,19] In order to expedite the engineering assessments of alternative remedial actions applicable to uranium mill tailings piles, EPA developed interim radiological criteria for decontamination of inactive uranium mill sites.

These criteria are applicable to the sites proper, the surrounding area which has become contaminated, and buildings in which the tailings material has inadvertently been used as construction-related material. A report by Fitzgerald et al.[19] explores the critical radiation exposure pathways from inactive uranium mill sites to members of the general population and identifies these as:

(1) radon emanating from the tailings pile and being transported to habitable areas,

(2) tailings material used for construction of habitable structures,

(3) direct external gamma radiation exposure from tailings material,

(4) Ra-226, Th-230, and other radionuclides leaching into water supplies, and

(5) windblown radioactive particulate material.

In order to restore the environmental quality and provide for public protection, EPA recommends decontamination by the removal of radioactive material or providing sufficient earth cover to reduce gamma radiation levels to less than 40 μR/h above background. Also, cleanup should reduce soil concentrations to less than twice the radium background level. If residual gamma levels are less than 10 μR/h above background, the land may be released for unrestricted use. These gamma radiation levels are the net, corrected measurements at 3 ft above the ground. For structures, the lower limits of the Surgeon General, as given in 10 CFR 712, apply. (See Appendix I).

RECOMMENDATIONS OF OTHER SCIENTIFIC ORGANIZATIONS

In addition to the standards setting bodies and regulatory agencies, recommendations on protection of human health and environmental quality are also made by other scientific organizations.

Biological Effects of Ionizing Radiation Committee

A report[20] by the National Academy of Sciences/National Research Council Advisory Committee on the Biological Effects of Ionizing Radiation (BEIR Committee) deals with the scientific basis for the establishment of radiation protection standards. The BEIR Committee reviewed existing scientific data concerning radiation exposure of human populations and determined risk estimates for such exposures. The estimates for genetic risk were expressed in four ways:

1. risk relative to natural background radiation,
2. risk estimates for specific genetic conditions,
3. risk relative to current prevalence of serious disabilities, and
4. risk in terms of overall ill health.

One of the conclusions of the BEIR Committee is that the 170 millirem/year Radiation Protection Guide as given by the FRC is too high.

Some of the other recommendations of the BEIR Committee are noteworthy:

1. Large sums of money should not be expended to reduce a small risk from radiation when the same amount spent otherwise would produce greater benefit.
2. There should be a limit to man-made non-medical radiation exposure for individuals in the general population such that the

risk is small compared to risks that are normally accepted. (This limit would essentially define a "de minimus" level, i.e., a level below which the risk is acceptable.)

3. Guidance for the nuclear power industry should be established on the basis of cost-benefit analysis.
4. If radiation standards are adequate to protect man, it is unlikely that populations of other living organisms would be perceptibly harmed.

United Nations Scientific Committee on the Effects of Atomic Radiation

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) reviews levels of radiation man receives from all sources and considers the genetic effects, the effects on the immune response and the induction of malignancies in man and animals. The UNSCEAR was established by the General Assembly of the United Nations in 1955. This committee has published several reports, one of which[21] has significant application to decommissioning criteria.

The UNSCEAR report[21] makes estimates of risk from radiation only in the region of doses where effects have been observed rather than extrapolating to low doses as the BEIR Committee did. The UNSCEAR report stresses the uncertainty associated with extrapolations, such as those made by the BEIR Committee in these words:

"Estimates of risk per unit dose derived from epidemiological investigations are valid only for the doses at which they have been

> estimated and they can be applied to a range of doses only if there is a linear relationship between dose and incidence since extrapolations beyond that range may lead to gross errors.

The UNSCEAR estimates of the radiation dose required to double the spontaneous mutation rate in man are about 30 rad for high dose rates and about 100 rad for low dose rates. A doubling dose of about 100 rad corresponds to a 1 percent increase in mutation frequency per rad.

PERTINENT STANDARDS AND GUIDELINES IN THE LITERATURE

Several authors have attempted to analyze radiation hazards associated with decontamination, cleanup or decommissioning of nuclear sites. Of particular significant in the development of decommissioning criteria are papers by Healy[22,23] on soil contaminaton standards, by Goldsmith et al.[24] on uranium tailings cleanup and by Schiager[17] on the risk from radium-bearing radioactive waste.

Soil Standards

In this review of pertinent standards and guidelines having applicability to decontamination and decommissioning criteria, it has become clear that one of the greatest deficiencies is the availability of accepted soil contamination standards. Healy[22,23] has proposed a standard for plutonium in soil, but this standard has little direct bearing on the types of contamination found at the majority of the nuclear sites which now require decommissioning. However, the logic and formalism that Healy used for arriving at a soil standard does have applicability for a number of the commonly-occurring radionuclides in soil including radium.

Healy's reports examine the pathways of exposure for people living in an area where soils are contaminated with plutonium. He treats the subjects of resuspension, deposition velocity of particles and effectiveness of radioactive particulates in producing lung cancer. Some of this information can be applied directly to other radionuclides. Healy[23] proposes a guide of 100 pCi ^{239}Pu/g soil.

Cleanup of Uranium Tailings

A recent paper by Goldsmith et al.,[24] presents the rationale and the procedures used in reviewing the adequacy of proposed criteria for remedial action at inactive uranium mill tailings sites. Exposures due to aquatic, terrestrial, airborne, and direct gamma radiation were analyzed to determine that the most hazardous components of the tailings are Ra-226 and Th-230. Goldsmith determined that the most restrictive pathway for exposure is the diffusion of Rn-222 into enclosed structures and the subsequent inhalation of radon and its daughter products.

Goldsmith[24] contends that a residual contamination level of Ra-226 of 0.5 pCi/g above natural background does not represent any specific health hazard. This can be interpreted to be a recommendation for a "de-minimus" level. Goldsmith cautions that the conservative assumptions used in deriving this general guideline may not be applicable to all sites and that no thought has been given to the practicality of achieving this level in actual clean-up operations.

In Schiager's[17] discussion of risk from radium-bearing radioactive waste, he uses the term "acceptable risk," indicating that it can be defined only with reference to the reason for taking the risk. Following a technical discussion of the risks associated with radium-bearing wastes and the exposure pathways, Schiager concludes that a "de-minimus" concentration of radium contamination is in the range of 4 to 40 pCi/g. For radium-contaminated construction materials, soils and other non-edible media, the concentration of radium that can be considered safe and acceptable depends on the exposure from gamma radiation and radon daughter products.

Canadian Cleanup Criteria

Due to the great similarity between radioactive contamination cleanup situations experienced here and in Canada, it is informative to consider the criteria[25] that the Canadians have developed for their cleanup operations. Contaminated nuclear sites in Canada associated with the mining and/or processing of uranium ore such as Port Hope and Elliot Lake in Ontario and Uranium City in Saskatchewan have remarkable similarity to uranium tailings sites and contaminated excess nuclear sites in the United States. In Canada, a Federal-Provincial Task Force on Radioactivity was established to coordinate a national program of radioactive contamination assessment and remedial measures. One of the working groups of this Task Force developed criteria which can be applied to existing and potentially contaminated property.

The brief criteria that were developed considered only:

1. radiation exposure due to radon and radon daughter products, and
2. direct external gamma radiation exposure.

These criteria are summarized in Table 9.

These cleanup criteria are intended for application in actual or potential living or occupied areas of homes and other structures. It is interesting to note that once remedial measures have been started, the Canadians propose to continue until the radiation and radon levels are reduced to the range of background or below the action level, whichever is lower.

SUMMARY AND CONCLUSIONS

In this review of pertinent standards and guidelines having application to the development of decommissioning criteria for nuclear sites, several trends have become obvious. Radiation protection standards have tended to become more stringent over the years. Each new recommendation or guideline has been lower than the previous one dealing with the same subject. It even appears that there might exist some one-upmanship among standards-setting organizations in setting of tighter standards. There also is some confusion about which scientific committee's report is the most authoritative.

Recently there has been an effort to define "de-minimus" levels of radiation and radioactivity below which the hazard should be acceptable to the general public. At this level the risk would be only a small fraction of the risk associated with everyday events in people's lives. The "acceptable" risk is probably of the order of 10^{-6} health effects per person per year.[26-28] This level of risk was selected by the EPA in arriving at a proposed guideline for plutonium in soil.[15] As expected, scientists disagree on exactly what the "de-minimus" level is for particular radiation concerns. For example, Schiager[17] proposes that a "de-minimus" level for radium in soil is in the range of 4 to 40 pCi/g whereas Goldsmith[24] suggests a level of 0.5 pCi/g. These are within an order of magnitude at the extremes, however, and it might be expected that a reasonable compromise would put this "de-minimus" level at 5 pCi/g (which is approximately background for many locations in the United States). This lends support to the EPA interim decontamination criteria[18] for the engineering assessment of inactive uranium mill sites which is twice background for soil contamination.

Nearly all state and federal regulations and all scientific and technical organizations dealing with radiation protection standards indcate that the philosophy of maintaining radiation and radioactivity levels as low as practicable (ALAP) or as low as reasonably achievable (ALARA) should be applied in all cases. Obviously this philosophy should be extended to the development of decommissioning criteria.

The current practice of performing cost (risk)/benefit analyses is widespread. This practice, in all likelihood, will have to be included in decommissioning criteria. The problem with this approach is that risks and benefits are not well defined and the methodology will have to be applied on a case-by-case basis. Above the "de-minimus" level there will be a range of exposures and/or radionuclide concentrations which will require that consideration be given to each nuclear site to determine the necessity and level of remedial action. This concept of graded action levels will follow the pattern established by the Grand Junction Remedial Action Criteria in 10 CFR 712 and emulated by the Canadians in their clean-up criteria.[25]

Increasingly, concern has been expressed for exposure of future generations to pollutants that have been created by the present generation. While it is unlikely that the risk in the future from present-day pollutants can be expected to exceed the current risk*, it is equally unlikely that future generations will derive much in the way of benefits from present-day activities. This question has not been adequately addressed in currently available standards and guidelines. In spite of the lack of specific guidance, this question will have to be addressed in the decommissioning criteria.

There is a trend toward the consideration of real or potential health effects as the basis for the setting of health and safety standards and guidelines. Many scientific reports[20,21] deal with the determination of risk factors that might be appropriate for the evaluation of the number of health effects that can be expected to occur per unit insult, be it radiation or some other noxious agent. Confusion has occurred in the past due to the fact that many insults are specific to a particular organ or portion of the body. As an example, it is difficult to compare radiation insults on any kind of meaningful scale that could equate health effects. With the proposed ICRP methodology,[5,6] it may be possible to compare lung exposures with thyroid exposures, for instance. The ICRP approach is to consider all radiation insults on a whole-body equivalent dose basis. Once the whole-body equivalent dose is determined, it may be multiplied by a single risk factor to obtain the total risk.

*There may be some exceptions due to the ingrowth of particularly hazardous daughter products from rather innocuous, present-day radioactive contamination.

There seem to be adequate standards available for preparing decommission criteria on surface contamination and direct radiation exposure. Guidance on radon and radon daughter levels is also probably adequate. The remaining deficiencies are in the areas of radioactive contamination in soils, specific non-nuclear pollutants for which standards have not been developed, and cost (risk)/benefit input parameters.

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Table 1. Current ICRP dose limits

Organ or tissue	Maximum permissible doses for adults exposed in the course of their work	Dose limits for members of the public
Gonads, red bone-marrow	5 rem in a year	0.5 rem in a year
Skin, bone, thyroid	30 rem in a year	3 rem in a year
Hands and forearms feet and ankles	75 rem in a year	7.5 rem in a year
Other single organs	15 rem in a year	1.5 rem in a year

Table 2. ICRP recommended risk factors

Organ	Risk Sv^{-1}	Relative risk
Gonads	0.01	0.25
Breast	0.0025	0.15
Red bone marrow	0.002	0.12
Lung	0.002	0.12
Thyroid	0.0005	0.03
Bone surfaces	0.0005	0.03
All others	0.005	0.30

Table 3. Current NCRP dose limits

Groups at risk	Maximum permissible dose equivalent
Occupational Exposure	
Combined whole-body occupational exposure	
Prospective annual limit	5 rem in any one year
Retrospective annual limit	10-15 rem in any one year
Long term accumulation	(N - 18) X 5 rem, where N is age in years
Skin	15 rem in any one year
Hands	75 rem in any one year (25/qtr)
Forearms	30 rem in any one year (10/qtr)
Other organs, tissues and organ systems	15 rem in any one year (5/qtr)
Fertile women (with respect to fetus)	0.5 rem in gestation period
Dose Limits for the Public, or Occasionally Exposed Individuals	
Individual or occasional	0.5 rem in any one year
Students	0.1 rem in any one year
Population Dose Limits	
Genetic	0.17 rem average per year
Somatic	0.17 rem average per year
Emergency Dose Limits-Life Saving	
Individual (older than 45 if possible)	100 rem
Hands and forearms	200 rem, additional (300 rem, total)
Emergency Dose Limits-Less Urgent	
Individual	25 rem
Hands and forearms	100 rem, total
Family of Radioactive Patients	
Individual (under age 45)	0.5 rem in any one year
Individual (over age 45)	5 rem in any one year

Table 4. Surface Contamination Limits

The levels may be averaged* over the 1 m^2 provided the maximum activity in any area of 100 cm^2 is less than 3 times the limit value.

Nuclide	Limit (Activity) dpm/100 cm^2 Total	Removable
Group 1: Nuclides for which the nonoccupational MPC_a** is 2×10^{-13} Ci/m^3 or less or for which the nonoccupational MPC_w*** is 2×10^{-7} Ci/m^3 or less; includes Ac-227; Am-241; -242m, -243; Cf-249; -250, -251, -252; Cm-243, -244, -245, -246, -247, -248; I-125, -129; Np-237; Pa-231; Pb-210; Pu-238, -239 -240, -242, -244; Ra-226, -228; Th-228, -230.****	100	20
Group 2: Those nuclides not in Group 1 for which the nonoccupational MPC_a** is 1×10^{-12} Ci/m^3 or less or for which the nonoccupational MPC_w*** is 1×10^{-6} Ci/m^3 or less; includes Es-254; Fm-256; I-126, -131, -133; Po-210; Ra-223; Sr-90; Th-232; U-232.****	1,000	200
Group 3: Those nuclides not in Group 1 or Group 2.	5,000	1000

*See note following Table 5 on application of limits.

**MPC_a: Maximum Permissible Concentration in Air applicable to continuous exposure of members of the public as published by or derived from an authoritative source such as NCRP, ICRP or NRC (10 CFR Part 20 Appendix B Table 2, Column 1.)

***MPC_w: Maximum Permissible Concentration in Water applicable to members of the public.

****Values presented here are obtained from 10 CFR Part 20. The most limiting of all given MPC values (e.g. soluble vs. insoluble) are to be used. In the event of the occurence of mixture of radionuclides, the fraction contributed by each constituent of its own limit shall be determined and the sum of the fractions must be less than 1.

Source: Proposed American National Standard, ANSI N328-1976, "Control of Radioactive Surface Contamination on Materials, Equipment, and Facilities to be Released for Uncontrolled Use," 1976.

Table 5. Alternate Surface Contamination Limits

(All alpha emitters, except U-nat and Th-nat are considered as a group)

The levels may be averaged over 1 m^2* provided the maximum activity in any area of 100 cm^2 is less than 3 times the limit value.

Nuclide	Limit (Activity) $dpm/100\ cm^2$ Total	Removable
If the contaminant cannot be identified; or if alpha emitters other than U-nat and Th-nat are present; or if the beta emitters comprise Ac-227, Ra-226, Ra-228, I-125 and I-129.	100	20
If it is known that all alpha emitters are generated from U-nat and Th-nat; and beta emitters are present which, while not identified, do not include Ac-227, I-125, I-129, Ra-226 and Ra-228.	1,000	200
If it is known that alpha emitters are generated only from U-nat and Th-nat; and the beta emitters, while not identified, do not include Ac-227, I-125, I-129, Sr-90, Ra-223, Ra-228, I-126, I-131 and I-133.	5,000	1,000

*NOTE ON APPLICATION OF TABLES 4 AND 5 TO ISOLATED SPOTS OR ACTIVITY:

For purposes of averaging, any m^2 of surface shall be considered to be contaminated above the limit, L, applicable to 100 cm^2 if:

a. From measurements of a representative number, n, of sections, it is determined that $1/n \sum_n Si \geq L$, where Si is the dpm/100 cm^2 determined from measurement of section i; or

b. On surfaces less than 1 m^2, it is determined that $1/n \sum_n Si \geq AL$, where A is the area of the surface in units of m^2; or

c. It is determined that the activity of all isolated spots or particles in any area less than 100 cm^2 exceeds 3L.

Source: Proposed American National Standard, ANSI N328-1976, "Control of Radioactive Surface Contamination on Materials, Equipment, and Facilities to be Released for Uncontrolled Use," 1976.

Table 6. Radiation exposure limits in 10 CFR 20

Exposure	Restricted area[a]	Unrestricted area[b]
Whole-body, head and trunk active blood-forming organs, lens of eye, or gonads	1.25 rem/qtr on average 3 rem/qtr max	0.5 rem/year 2 millirem in 1 h 100 millirem in 7 consecutive days
Hands and forearms, feet and ankles	18.75 rem/qtr	-
Skin of whole body	7.5 rem/qtr	-

[a]Restricted area means any area in which access is controlled for purposes of radiation protection.

[b]An unrestricted area is an area which is not controlled for radiation protection purposes. This refers to an area open to the general public.

Table 7. Grand Junction Remedial Action Criteria

EGR[a]	RDC[b]	Recommendation
Greater than 0.1 mR/h	Greater than 0.05 WL	Remedial action indicated
From 0.05 to 0.1 mR/h	From 0.01 to 0.05 WL	Remedial action may be suggested
Less than 0.05 mR/h	Less than 0.01 WL	No remedial action indicated

[a]External gamma radiation exposure rate.

[b]Radon daughter concentration in working level (WL) which means any combination of short-lived radon daughter products in 1 liter of air that will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy.

Table 8. Acceptable surface contamination levels

Nuclide[a]	Average[b,c]	Maximum[b,d]	Removable[b,c,e]
U-nat, U-235, U-238, and associated decay products	5,000 dpm α/100 cm^2	15,000 dpm α/100 cm^2	1,000 dpm α/100 cm^2
Transuranics, Ra-226, Ra-228, Th-230, Th-228, Pa-231, Ac-227, I-125, I-129	100 dpm/100 cm^2	300 dpm/100 cm^2	20 dpm/100 cm^2
Th-nat, Th-232, Sr-90, Ra-223, Ra-224, U-232, I-126, I-131, I-133	1000 dpm/100 cm^2	3000 dpm/100 cm^2	200 dpm/100 cm^2
Beta-gamma emitters (nuclides with decay modes other than alpha emission or spontaneous fission) except Sr-90 and others noted above	5000 dpm β-γ/100 cm^2	15,000 dpm β-γ/100 cm^2	1000 dpm β-γ/100 cm^2

[a]Where surface contamination by both alpha- and beta-gamma-emitting nuclides exists, the limits established for alpha- and beta-gamma-emitting nuclides should apply independently.

[b]As used in this table, dpm (disintegrations per minute) means the rate of emission by radioactive material as determined by correcting the counts per minute observed by an appropriate detector for background, efficiency, and geometric factors associated with the instrumentation.

[c]Measurements of average contaminant should not be averaged over more than 1 square meter. For objects of less surface area, the average should be derived for each such object.

[d]The maximum contamination level applies to an area of not more than 100 cm^2.

[e]The amount of removable radioactive material per 100 cm^2 of surface area should be determined by wiping that area with dry filter or soft absorbent paper, applying moderate pressure, and assessing the amount of radioactive material on the wipe with an appropriate instrument of known efficiency. When removable contamination on objects of less surface area is determined, the pertinent levels should be reduced proportionally and the entire surface should be wiped.

Source: Regulatory Guide 1.86, Termination of Operating Licenses for Nuclear Reactors, June 1974.

Table 9. Criteria for radioactive clean-up in Canada

EGR(mR/h)[a]	RDC(WL)[b]	Action indicated
-	> 0.01	Investigation
> 0.01	> 0.02	Clean-up indicated
> 0.05 (in bldgs)	> 0.15	Prompt interim action
> 0.10 (outdoors)		Prompt interim action

[a]External gamma radiation exposure rate at 1 m above the surface existing over the course of a year.

[b]Annual average radon daughter concentration expressed in working levels (WL) which is any combination of short-lived radon progeny in 1 liter of air that will release 1.3×10^5 MeV of potential alpha energy.

APPENDIX I

SURGEON GENERAL'S GUIDELINES
Part 712
Grand Junction Remedial Action Criteria

Federal Register, Vol. 41, No. 253, pp. 56777-8, Thursday, December 30, 1976

PART 712 - GRAND JUNCTION REMEDIAL ACTION CRITERIA

712. 1 Purpose

(a) The regulations in this part establish the criteria for determination by ERDA of the need for, priority of and selection of appropriate remedial action to limit the exposure of individuals in the area of Grand Junction, Colo., to radiation emanating from uranium mill tailing which have been used as construction-related material.

(b) The regulations in this part are issued pursuant to Publ. L. 92-314 (86 Stat. 222) of June 16, 1972.

713.2 Scope

The regulations in this part apply to all structures in the area of Grand Junction, Colo., under or adjacent to which uranium mill tailings have been used as a construction-related material between January 1, 1951, and June 16, 1972, inclusive.

712.3 Definitions

As used in this part:

(a) "Administrator" means the Administrator of the Energy Research and Development Administration or his duly authorized representative.

(b) "Area of Grand Junction, Colo.," means Mesa County, Colo.

(c) "Background" means radiation arising from cosmic rays and radioactive material other than uranium mill tailings.

(d) "ERDA" means the Energy Research and Development Administration or duly authorized representative thereof.

(e) "Construction-related material" means any material used in the construction of a structure.

(f) "External gamma radiation level" means the average gamma radiation exposure rate for the habitable area of a structure as measured near floor level.

(g) "Indoor radon daughter concentration level" means that concentration of radon daughters determined by: (1) Averaging the results of 6 air samples, each of at least 100 hours duration, and taken at a minimum of 4-week intervals throughout the year in a habitable area of a structure, or (2) utilizing some other procedure approved by the Commission.

(h) "Milliroentgen (mR) means a unit equal to one-thousandth (1/1000) of a roentgen which roentgen is defined as an exposure dose of X or gamma radiation such that the associated corpuscular emission per 0.001293 gram of air produces, in air, ions carrying one electrostatic unit of quantity of electricity of either sign.

(i) "Radiation" means the electromagnetic energy (gamma) and the particulate radiation (alpha and beta) which emanate from the radioactive decay of radium and its daughter products.

(j) "Radon daughters" means the consecutive decay products of radon-222. Generally, these include Radium A (polonium-218), Radium B (lead-218), Radium C (bismuth-214), and Radium C (polonium-214).

(k) "Remedial action" means any action taken with a reasonable expectation of reducing the radiation exposure resulting from uranium mill tailings which have been used as construction-related material in and around structures in the area of Grand Junction, Colo.

(l) "Surgeon General's guidelines" means radiation guidelines related to uranium mill tailings prepared and released by the Office of the U.S. Surgeon General, Department of Health, Education and Welfare on July 27, 1970.

(m) "Uranium mill tailings" means tailings from a uranium mill operation involved in the Federal uranium procurement program.

(n) "Working Level" (WL) means any combination of short-lived radon daughter products in 1 liter of air that will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy.

712.4 Interpretations

Except as specifically authorized by the Administrator in writing, no interpretation of the meaning of the regulations in this part by an officer or employee of ERDA other than a written interpretation by the General Counsel will be recognized to be binding upon ERDA.

712.5 Communications

Except where otherwise specified in this part, all communications concerning the regulations in this part should be addressed to the Director, Division of Safety, Standards, and Compliance, U.S. Energy Research and Development Administration, Washington, D.C. 20545.

712.6 General radiation exposure level criteria for remedial action

The basis for undertaking remedial action shall be the applicable guidelines published by the Surgeon General of the United States. These guidelines recommend the following graded action levels for remedial action in terms of external gamma radiation level (EGR) and indoor radon daughter concentration level (RDC) above background found within dwellings constructed on or with uranium mill tailings:

EGR	RDC	Recommendation
Greater than 0.1 mR/hr.	Greater than 0.05 WL.	Remedial action indicated
From 0.05 to 0.1 mR/hr.	From 0.01 to 0.05 WL.	Remedial action may be suggested.
Less than 0.05 mR/hr.	Less than 0.01 WL.	No remedial action indicated.

712.7 Criteria for determination of possible need for remedial action

Once it is determined that a possible need for remedial action exists, the record owner of a structure shall be notified of that structure's eligibility for an engineering assessment to confirm the need for remedial action and to ascertain the most appropriate remedial measure, if any. A determination of possible need will be made if as a result of the presence of uranium mill tailings under or adjacent to the structure, one of the following criteria is met:

(a) Where ERDA approved data on indoor radon daughter concentration levels are available:

(1) For dwellings and schoolrooms: An indoor radon daughter concentration level of 0.01 WL or greater above background.

(2) For other structures: An indoor radon daughter concentration level of 0.03 WL or greater above background.

(b) Where ERDA approved data on indoor radon daughter concentration levels are not available:

(1) For dwellings and schoolrooms:

(i) An external gamma radiation level of 0.05 mR/hr. or greater above background.

(ii) An indoor radon daughter concentration level of 0.01 WL or greater above background (presumed).

(A) It may be presumed that if the external gamma radiation level is equal to or exceeds 0.02 mR/hr. above background, the indoor radon daughter concentration level equals or exceeds 0.01 WL above background.

(B) It should be presumed that if the external gamma radiation level is less than 0.001 mR/hr. above background, the indoor radon daughter concentration level is less than 0.01 WL above background and no possible need for remedial action exists.

(C) If the external gamma radiation level is equal to or greater than 0.001 mR/hr. above background but is less than 0.02 mR/hr. above background, measurements will be required to ascertain the indoor radon daughter concentration level.

(2) For other structures: (i) An external gamma radiation level of 0.15 mR/hr. above background averaged on a room-by-room basis.

(ii) No presumptions shall be made on the external gamma radiation level/indoor radon daughter concentration level relationship. Decisions will be made in individual cases based upon the results of actual measurements.

712.8 Determination of possible need for remedial action where criteria have not been met

The possible need for remedial action may be determined where the criteria in 712.7 have not been met if various other factors are present. Such factors include, but are not necessarily limited to, size of the affected area, distribution of radiation levels in the affected area, amount of tailings, age of individuals occupying affected area, occupancy time, and use of the affected area.

712.9 Factors to be considered in determination of order or priority for remedial action

In determining the order or priority for execution of remedial action, consideration shall be given, but not necessarily limited to, the following factors:

(a) Classification of structure. Dwellings and schools shall be considered first.

(b) Availability of data. Those structures for which data on indoor radon daughter concentration levels and/or external gamma radiation levels are available when the program starts and which meet the criteria in 712.7 will be considered first.

(c) Order of application. Insofar as feasible remedial action will be taken in the order which the application is received.

(d) Magnitude of radiation level. In general, those structures with the highest radiation levels will be given primary consideration.

(e) Geographical location of structures. A group of structures located in the same immediate geographical vicinity may be given priority consideration particularly where they involve similar remedial efforts.

(f) Availability of structures. An attempt will be made to schedule remedial action during those periods when remedial action can be taken with minimum interference.

(g) Climatic conditions. Climatic conditions or other seasonable considerations may affect the scheduling of certain remedial measures.

712.10 Selection of appropriate remedial action

(a) Tailings will be removed from those structures where the appropriately averaged external gamma radiation level is equal to or greater than 0.05 mR/hr. above background in the case of dwellings and schools and 0.15 mR/hr. above background in the case of other structures.

(b) Where the criterion in paragraph (a) of this section is not met, other remedial action techniques, including but not limited to sealants, ventilation, and shielding may be considered in addition to that of tailings removal. ERDA shall select the remedial action technique or combination of techniques, which it determines to be the most appropriate under the circumstances.

APPENDIX II

GUIDELINES FOR DECONTAMINATION OF FACILITIES AND EQUIPMENT PRIOR TO RELEASE FOR UNRESTRICTED USE OR TERMINATION OF LICENSES FOR BYPRODUCT, SOURCE, OR SPECIAL NUCLEAR MATERIAL

U. S. Nuclear Regulatory Commission
Division of Fuel Cycle and
Material Safety
Washington, D.C. 20555

November 1976

The instructions in this guide in conjunction with Table IV-1 specify the radioactivity and radiation exposure rate limits which should be used in accomplishing the decontamination and survey of surfaces or premises and equipment prior to abandonment or release for unrestricted use. The limits in Table I do not apply to premises, equipment, or scrap containing induced radioactivity for which the radiological considerations pertinent to their use may be different. The release of such facilities or items from regulatory control will be considered on a case-by-case basis.

1. The licensee shall make a reasonable effort to eliminate residual contamination.

2. Radioactivity on equipment or surfaces shall not be covered by paint, plating, or other covering material unless contamination levels, as determined by a survey and documented, are below the limits specified in Table I prior to applying the covering. A reasonable effort must be made to minimize the contamination prior to use of any covering.

3. The radioactivity on the interior surfaces of pipes, drain lines, or ductwork shall be determined by making measurements at all traps, and other appropriate access points, provided that contamination at these locations is likely to be representative of contamination on the interior of the pipes, drain lines, or ductwork. Surfaces of premises, equipment, or scrap which are likely to be contaminated but are of such size, construction, or location as to make the surface inaccessible for purposes of measurement shall be presumed to be contaminated in excess of the limits.

4. Upon request, the Commission may authorize a licensee to relinquish possession or control of premises, equipment, or scrap having surfaces contaminated with materials in excess of the limits specified. This may include, but would not be limited to, special circumstances such as razing of buildings, transfer or premises to another organization continuing work with radioactive materials, or conversion of facilities to a long-term storage or standby status. Such request must:

    a. Provide detailed, specific information describing the premises, equipment or scrap, radioactive contaminants, and the nature, extent, and degree of residual surface contamination.

    b. Provide a detailed health and safety analysis which reflects that the residual amounts of materials on surface areas, together with other considerations such as prospective use of the premises, equipment or scrap, are unlikely to result in an unreasonable risk to the health and safety of the public.

5. Prior to release of premises for unrestricted use, the licensee shall make a comprehensive radiation survey which establishes that contamination is within the limits specified in Table I. A copy of the survey report shall be filed with the Division of Fuel Cycle and Material Safety, USNRC, Washington, D.C. 20555, and also the Director of the Regional Office of the Office of Inspection and Enforcement, USNRC, having jurisdiction. The report should be filed at least 30 days prior to the planned date of abandonment. The survey report shall:

    a. Identify the premises.

    b. Show that reasonable effort has been made to eliminate residual contamination.

    c. Describe the scope of the survey and general procedures followed.

    d. State the findings of the survey in units specified in the instruction.

Following review of the report, the NRC will consider visiting the facilities to confirm the survey.

ACCEPTABLE SURFACE CONTAMINATION LEVELS

NUCLIDES[a]	AVERAGE[b c f]	MAXIMUM[b d f]	REMOVABLE[b e f]
U-nat, U-235, U-238, and associated decay products	5,000 dpm α/100 cm^2	15,000 dpm α/100 cm^2	1,000 dpm α/100 cm^2
Transuranics, Ra-226, Ra-228, Th-230, Th-228, Pa-231, Ac-227, I-125, I-129	100 dpm/100 cm^2	300 dpm/100 cm^2	20 dpm/100 cm^2
Th-nat, Th-232, Sr-90 Ra-223, Ra-224, U-232, I-126, I-131, I-133	1,000 dpm/100 cm^2	3,000 dpm/100 cm^2	200 dpm/100 cm^2
Beta-gamma emitters (nuclides with decay modes other than alpha emission or spontaneous fission) except SR-90 and other noted above.	5,000 dpm $\beta\gamma$/100 cm^2	15,000 dpm $\beta\gamma$/100 cm^2	1,000 dpm $\beta\gamma$/100 cm^2

[a] Where surface contamination by both alpha- and beta-gamma-emitting nuclides exists, the limits established for alpha- and beta-gamma-emitting nuclides should apply independently.

[b] As used in this table, dpm (disintegrations per minute) means the rate of emission by radioactive material as determined by correcting the counts per minute observed by an appropriate detector for background, efficiency, and geometric factors associated with the instrumentation.

[c] Measurements of average contaminant should not be averaged over more than 1 square meter. For objects of less surface area, the average should be derived for each such object.

[d] The maximum contamination level applies to an area of not more than 100 cm^2.

[e] The amount of removable radioactive material per 100 cm^2 of surface area should be determined by wiping that area with dry filter or soft absorbent paper, applying moderate pressure, and assessing the amount of radioactive material on the wipe with an appropriate instrument of known efficiency. When removable contamination on objects of less surface area is determined, the pertinent levels should be reduced proportionally and the entire surface should be wiped.

[f] The average and maximum radiation levels associated with surface contamination resulting from beta-gamma emitters should not exceed 0.2 mrad/hr at 1 cm and 1.0 mrad/hr at 1 cm, respectively, measured through not more than 7 milligrams per square centimeter of total absorber.

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