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BACKGROUND INFORMATION ON FEMA-REP-22: CONTAMINATION MONITORING GUIDANCE FOR PORTABLE INSTRUMENTS USED FOR RADIOLOGICAL EMERGENCY RESPONSE TO NUCLEAR POWER PLANT ACCIDENTS

FEDERAL EMERGENCY MANAGEMENT AGENCY

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I. INTRODUCTION:

This document provides technical support for the Federal Emergency Management Agency (FEMA) *"Contamination Monitoring Guidance for Portable Radiation Instruments Used for Emergency Response to Nuclear Power Plant Accidents (FEMA-REP-22)."* It is a companion to the FEMA guidance for portal monitors "*Contamination Monitoring Standard for a Portal Monitor used for Radiological Emergency Response (FEMA-REP-21)"* (Reference 1) which provides procedures and decision criteria for using a portal monitor to evaluate the need for decontamination of individuals who are potentially contaminated from a release of airborne, beta-gamma emitting, radioactive material from a nuclear power plant accident, or from short term exposure to widespread contamination deposited from such airborne radioactive material.

I.A. Basis for Guidance:

Acceptable levels of risk of health effects under emergency conditions were used as the basis for developing the decontamination decision criteria for portal monitors in Reference 1. This concept is also used in this document as the primary basis for decision criteria for portable instruments with hand-held detectors (commonly referred to as portable instruments). A secondary basis is to limit the spread of contamination. Acceptable levels of risk under emergency conditions have been defined by the Environmental Protection Agency (EPA) in their *"Manual of Protective Action Guides and Protective Actions for Nuclear Incidents"* (Reference 2). Since portable instruments are used during emergency response to identify the location and intensity of contamination on individuals, vehicles, equipment, and other possessions, it is appropriate to develop guidance for their use that is compatible with that already developed for portal monitors.

I.B. Existing Guidance for Portable instruments:

EPA, in Reference 2, provided Contamination Screening Levels for use with portable radiation instruments to support decisions on the need for decontamination of individuals exposed to accidental releases of radioactive material from nuclear power plants. However, those screening levels are based only on the ability to detect and measure contamination using CD V-700 instruments or other portable instruments with similar detection capability. They did not take into account the EPA general guidelines in Reference 2 for using acceptable levels of risk of health effects as a basis for establishing contamination limits.

I.C. Purpose:

The main purpose of this document is to present the results of experiments conducted by FEMA in order to develop monitoring procedures and decontamination decision criteria for portable instruments that result in risk levels comparable to those deemed acceptable for developing the Portal Monitor Standard (Reference 1). The monitoring procedures and decontamination criteria developed here do **not** apply to non emergency situations such as an individual or worker, as defined in 10 CFR 19.3 that could be exposed to contamination under controlled conditions such as in a work-place environment.

Implementation of monitoring and decontamination in accordance with the procedures and criteria developed in this document will provide reasonable assurance that risk of skin cancer and other detrimental radiation effects to the skin of an individual due to radiation exposure from undetected contamination on the skin and clothing will not exceed general guidelines established by the Environmental Protection Agency (EPA) in Reference 2 regarding adequate protection of public health under emergency conditions.

Monitoring procedures and decontamination decision criteria may be based on considerations other than acceptable risk of health effects, (e.g., controlling the spread of contamination or minimum detectable levels of the radiation instruments to be used). However, since the procedures and criteria developed here represent maximum acceptable levels of risk of health effects under emergency conditions, any alternative procedures or decision criteria should result in equal or lower levels of risk.

II. TECHNICAL BASIS:

Risk-based decision criteria for decontamination of individuals were published in Reference 1. That guidance is supported by technical information in the FEMA Document, *Background Information on FEMA-REP-21: Contamination Monitoring Standard for a Portal Monitor used for Radiological Emergency Response (Reference 3).* Portions of that document are applicable to guidance for portable instruments, and those portions are repeated in this Section for convenience.

II.A. Contamination Type and Distribution:

Individuals who have been exposed in areas where inhalation of accidentally released airborne radioactive materials would have warranted evacuation may be contaminated. This contamination may consist of “loose,” “fixed,” or a combination of "loose” and "fixed" contamination. (For purposes of this study, loose contamination is that which is removable by bathing or decontamination and fixed contamination is that which remains after bathing or attempted decontamination.) In addition, contamination is unlikely to be uniformly distributed. Therefore, contamination monitoring instruments should be capable of detecting and measuring both widespread and spot contamination at the threshold levels that warrant decontamination for both fixed and loose contamination. Hot particles could occur, but there is no evidence that they would occur from an accident at a nuclear power facility.

II. B. Health Effects:

The potential health effects for an individual exposed to radioactive surface contamination on the skin are (1) acute exudative radiodermatitis, (2) skin ulcers with fibrosis, (3) skin ulceration from a hot particle, or (4) skin cancer. In addition, skin erythema may occur. However, this is considered to be only a minor radiation effect; <u>not</u> a health effect. This is because it is only a short-term cosmetic effect (similar to sunburn) and should not require medical attention for full recovery.

II B.1. Deterministic Health Effects:

A deterministic health effect is one for which there is a threshold dose below which the effect does not occur. The deterministic effects of concern from skin contamination are acute exudative radiodermatitis, ulcers with fibrosis, skin ulceration from a hot particle, and skin erythema. Deterministic effects occur only to specific areas of the skin where the dose exceeds a threshold value.

For persons contaminated from an airborne plume or from widespread contamination resulting from a plume as previously assumed, it is not credible to assume that all of the contamination on skin and clothing will be confined to a small area of skin with no contamination on other parts of the skin or clothing. It is assumed that contamination on an individual will be widespread and non uniformly distributed and that small spots of concentrated contamination may be present. Small Spots of contamination would be of concern for specific deterministic health effects as discussed below.

II.B.2. Stochastic Health Effects:

Stochastic effects are those for which there is no threshold dose below which the effect will not occur and the probability of occurrence is directly (but not necessarily linearly) proportional to the dose received. The stochastic effect of concern from surface contamination on skin and clothing is skin cancer. Since there is no threshold dose for this effect, a limiting dose to the skin must be selected at a level for which the corresponding increase in risk of skin cancer is within established guidelines.

II.C. Factors Affecting Threshold Levels for Detection:

Using information on (1) assumed area of the exposed skin, (2) assumed duration of exposure, (3) dose rate per unit of activity on the skin, and (4) the threshold dose for specific health effects, one can calculate the amount (µCi), or concentration (µCi/cm^2) of contamination on an individual that must be detected and measured by the radiation instrument. Assumptions must be made regarding both the size of the area of exposed skin and the duration of exposure. Dose to the skin per unit of activity on the skin and the threshold doses for specific health effects can be found in Reference 2. The assumptions on spot size and duration of exposure are presented in the following section.

II.C.1. Spot Size:

The activity (μCi) needed to produce a deterministic health effect on a spot of skin is directly proportional to the size of the contaminated spot. Therefore, a determination must be made regarding an acceptable size of a spot of skin where a deterministic health effect could be allowed to rarely occur under emergency conditions. This determination is necessary because, as the size of the area is reduced, smaller and smaller amounts of contamination will produce the effect, and eventually the amount of contamination is reduced to where the time needed to detect it becomes unreasonably long, or detection becomes impossible using typical contamination monitoring equipment. Spot size, therefore, becomes a trade-off between risk of a possible small deterministic health effect from undetected contamination and time needed to monitor a large number of individuals possibly exposed from an accidental release. A spot not larger than 0.2 cm^2 (i.e., approximately 0.5 cm diameter circle) is judged to be a limiting acceptable size of an area of skin for the rare occurrence of the deterministic health effect that occurs from undetected contamination. As will be shown later, this effect is "acute exudative radiodermatitis."

II.C.2. Duration of Exposure:

For a particular quantity or concentration of contamination on the skin, the dose and consequent risk of health effects is directly proportional to the time the contamination remains on the skin (duration of exposure). Therefore, a determination of duration of exposure must be made. Duration of exposure is assumed to be either 36 hours (12 hours before being monitored plus 24 hours after being monitored) for loose contamination (contamination that is removable by washing and changing clothing) and 336 hours (14 days) for fixed contamination (contamination that is not removable by washing and changing clothing).

Twelve hours is the FEMA limit for completion of the monitoring effort, and 24 hours is assumed to be an adequate amount of time for evacuees who have been monitored and found to have no detectable contamination to wash and change clothes. This takes into account the difficulties that evacuees may have in getting access to bathing facilities and in getting non-contaminated clothes. Fourteen days is the approximate time needed for the skin to replace itself by natural processes. It is assumed that all contamination (except for hot particles) may initially include some fraction of radioactive material that is fixed. For hot particles, it is assumed that the same process that combined the radioactive material into particles rendered them unlikely to be attached to or absorbed by the skin. Thus, it is assumed that hot particles (should they occur) will be removed by bathing and changing clothes and that the maximum exposure period will be 36 hours.

II.D. Calculation of Threshold Levels for Detection:

Dose to skin is the quantity of interest for evaluation of risk of health effects. Dose and risk are both proportional to the time-integrated activity (µCi h) or time-integrated concentration (µCi h/cm^2) on the skin. Therefore, in the sections that follow, the time-integrated activity or time integrated concentration that will produce the dose of concern for each health effect is calculated; this number is then divided by the assumed duration of exposure in hours (h) to get the amount of activity (radioactive contamination) needed to produce the dose of concern for each effect.

II.D.1 Acute Exudative Radiodermatitis:

Acute Exudative Radiodermatitis is characterized by inflamed skin with redness, pain, and oozing body fluids. Medical care may be needed. This is the deterministic **health effect** of greatest concern because it occurs at the lowest level of concentrated surface contamination.

Based on information in Appendix B of Reference 2, the threshold dose to the skin for acute exudative radiodermatitis is in the range of 1,200 to 2,000 rad (as used here, 1 rad = 1 rem). The lower end of the range (1,200 rem) is conservatively assumed.

Based on dose conversion factors in Appendix B of EPA 520/1-89-016 *Evaluation of Skin and Ingestion Exposure Pathways* (Reference 4) for the mix of radionuclides assumed to be associated with a major reactor accident, the factor to convert skin contamination to skin dose at a skin depth of 7 mg/cm^2, is about 7 rem/h per µCi/cm^2 (may also be expressed as 7 rem per µCi h/cm^2). Therefore, if the activity is concentrated in a 0.2 cm^2 area, then the threshold MDL of activity on the spot to **avoid** acute exudative radiodermatitis is **34 µCi h** (i.e., 1,200 rem)7 rem per µCi h/cm^2 x 0.2 cm^2). Dividing 34 µCi h by 36 h and 336 h of exposure yields **0.95 µCi** and **0.10 µCi** for loose and fixed contamination respectively.

II.D.2. Ulceration with Fibrosis:

Ulceration with fibrosis is characterized by an open sore in the skin with pain, pus, redness and swelling. Medical care may be needed. Based on information in Appendix B of Reference 2, ulcers with fibrosis of the skin may occur in the range of 5,500 to 7,000 rad (as used here, 1 rad = 1 rem). Using the lower end of the range (5,500 rem), the threshold level of contamination for **avoiding** ulcers with fibrosis of the skin is 5,500/1,200 times higher than the threshold for acute exudative radiodermatitis as calculated in Section II.D.1 above. This is **155.8 µCi h** (i.e., 55/12 x 34 µCi h). Dividing 156 µCi h by 36 h and 336 h of exposure yields **4.3 µCi** and **0.46 µCi** for loose and fixed contamination respectively.

II.D.3. Ulceration from a Hot Particle:

A hot particle is a tiny chemically or physically bound fragment of highly radioactive material. It may be too small to be seen without magnification. A hot particle on the skin could cause a single small ulceration that is treatable as an ordinary thermal burn. If hot particles occur, it is assumed that the mechanism that bound the material into a particle will prevent their adsorption by the skin so that they will be removed by ordinary bathing and thus can be considered as "loose" contamination. In its Report No. 106 (Reference 5) the National Council on Radiation Protection and Measurement (NCRP) recommended a time-integrated activity for exposure to hot particles of **75 µCi h** per particle, which is considered to be a threshold exposure below which ulceration does not occur. Therefore, the minimum detectable level for avoiding ulceration from a single hot particle is **75 µCi h.** Dividing 75 µCi h by 36 hours of exposure yields **2.1 µCi** for loose contamination.

II.D.4. Skin Erythema:

Skin erythema is a redness of the skin similar to sunburn. It is a visual, temporary, cosmetic, effect but not a significant effect impacting an individual's health at the threshold level of dose and, as such, **requires no medical treatment** for recovery.

The most **conservative** estimate found in the literature (*Health Effects Model for Nuclear Power Plant Accidence Consequence Analysis. Part 2, Scientific Basis for Health Effects Models* (Reference 9, page II-68) of the **threshold dose** below which erythema **does not occur** is 200 rad (as used here, 1 rad = 1 rem). Other references (e.g., Reference 2) estimate the threshold to be in the range of 300 to 800 rad (depending on the literary reference used). Based on the literature, keeping the dose to any portion of the skin to less than 200 to 800 rem will **avoid** skin erythema.

Based on the factor of 7 rem per µCi h/cm^2 and the range of dose thresholds (200 to 800 rem), a time-integrated concentration in the range of 29 to 114 µCi h/cm^2 would represent a threshold exposure for erythema, depending on the reference used. Since erythema is **not** considered to be a health effect, a median value (as opposed to a minimum value as used for health effects) of 70 µCi h/cm^2 is assumed to be a reasonable threshold value. It is also assumed that a spot of erythema larger than 5 cm^2 (i.e., approximately a 2.5 cm diameter circle) from undetected contamination would be unacceptable. Thus, based on a threshold concentration of 70 µCi h/cm^2, the minimum detectable level for preventing skin erythema is **350 µCi h** (i.e., 70 µCi h/cm^2 x 5 cm^2). Dividing 350 µCi h by 36 h and 336 h of exposure yields **9.7 µCi** and **1.0 µCi** for loose and fixed contamination respectively.

II.D.5. Skin Cancer:

Since skin cancer is a stochastic effect, it is assumed that there is no threshold dose below which the effect will not occur and the probability of occurrence is directly proportional to the dose received. In this case, a dose to the skin must be selected at a level for which the corresponding risk of skin cancer is within established guidelines.

Based on guidance in Reference 2, the health risk from skin contamination should not be allowed to exceed 20 percent of the risk that would warrant evacuation of the public. The Protective Action Guides (PAG) in Reference 2 limit skin dose to 50 times the numerical 1 rem evacuation PAG, or 50 rem. Twenty percent of 50 rem (10 rem), is, therefore, used as the limiting dose to the skin of the whole body from a single exposure to limit the risk of skin cancer.

To determine the upper limit for whole body skin contamination, it is necessary to calculate the time-integrated concentration on the skin that would produce a dose of 10 rem. The factor to convert from time-integrated skin contamination to a dose of 10 rem is **1.4 µCi h/cm^2** (i.e., 10 rem)7 rem per µCi h/cm^2). To determine the time-integrated activity necessary to yield a dose of 10 rem to the skin of the whole body, it is necessary to multiply the time-integrated concentration per square centimeter that will yield a dose of 10 rem times the area of the skin on the whole body (about 18,000 cm^2 for an adult). Although the area of a child's skin would be smaller, the margin of safety in the activity threshold for cancer compared to the activity threshold for the controlling deterministic health effects is so large that no adjustment to the area of the skin is needed. Based on the above data, the threshold level corresponding to adequate protection of the public from skin cancer under emergency conditions is a time-integrated activity of **25,200 µCi h** (i.e., 1.4 µCi h/cm^2 x 18,000 cm^2). This is independent of the distribution of the contamination on the skin. Dividing 25,200 µCi h by 36 h and 336 h of exposure yields rounded values of **700 µCi** and **75 µCi** for loose and fixed contamination respectively. Since a portable instrument would view only a small area of skin, the threshold level in activity per unit area (µCi/cm^2) is of interest. This is calculated by dividing the activity on the total body by the area of the skin of the total body (18000 cm^2). This yields **0.039 µCi/cm^2** and **0.0042 µCi/cm^2** as the concentrations of concern regarding risk of cancer from loose and fixed widespread contamination respectively.

II.E. Summary of Calculated Minimum Detectable Levels:

Table 1 summarizes the calculated minimum detectable levels (MDL) of contamination on individuals that, if not detected and removed, would not cause unacceptable risk of health effects from exposure during the time periods assumed. The minimum detectable levels (MDL) in Table 1 are expressed in units of activity (µCi) or concentration (µCi/cm^2) of contamination. Although these units are appropriate for relating contamination levels to risk of health effects, they cannot be **measured** by portable radiation instruments. Each instrument/detector type must be evaluated to determine its numerical response in counts per minute (cpm) to the threshold levels of contamination (µCi or µCi/cm^2) that would warrant decontamination. This document will provide the results of experiments that were conducted to identify the instrument readings for typically-used portable radiation instrument/detector combinations and appropriate **procedures** for detecting and measuring contamination at the levels identified in Table 1 for the most restrictive deterministic health effect, acute exudative radiodermatitis, and for the only stochastic health effect of concern, skin cancer.

TABLE 1

Derived Minimum Detectable Levels for Health Effects

Effect	Assumed Maximum Acceptable Area of the Condition from Undetected Contamination	Derived Minimum Detectable Level (μCi)[a]			
		Small spot of Contamination		Total Body Contamination	
		Loose[b]	Fixed[c]	Loose[b]	Fixed[c]
Acute Exudative Radiodermatitis	0.2 cm^2	0.95	0.10	N.A.[d]	N.A.
Ulceration with Fibrosis	0.2 cm^2	4.3	0.46	N.A.	N.A.
Ulceration from a Hot Particle	N.A.	2.1	N.A.[e]	N.A.	N.A.
Erythema	5 cm^2	9.7	1.0	N.A.	N.A.
Skin Cancer	N.A.	N.A.	N.A.	694	74

a. *The Minimum Detectable Levels were derived for each health or radiation effect based on the calculated μCi h of exposure needed to cause the effect. These values were then divided by the expected hours of exposure (see Section II.D).*

b. *Loose contamination that is not detected by monitoring is assumed to be removed by bathing within 36 hours after its deposition on the skin.*

c *Fixed contamination is assumed to be removed by natural processes within 336 hours (14 days) after deposition on the skin.*

d. *N.A. means not applicable.*

e. *Hot particles are assumed to be removable by bathing (i.e., loose contamination).*

The data in Table 1 show the following:

- In terms of required minimum detectable level, acute exudative radiodermatitis is controlling.
- Ulceration from a hot particle (if they should occur) will not be the leading consideration for detection of contamination.
- If the criteria for acute exudative radiodermatitis are used, the threshold for skin erythema will be avoided by a factor of 10.

- The calculated areas are small in which spots of activity on the skin would have to be concentrated for any deterministic health effects to occur. This indicates that the probability is very low for the occurrence of such a distribution of contamination from exposure to an airborne plume or to widespread deposited radioactive material. If a detected spot of contamination is larger than the specified size and the exposure time does not exceed the assumed value, the threshold dose to the skin will not be reached and no health effect will occur. If the detected spot is smaller than the specified size, then the size of the health effect will be smaller and possibly more severe, (e.g., ulceration with fibrosis).

- The MDL for skin cancer appears deceivingly high. The value shown is for total body contamination, but a portable instrument would see only a fraction of that. So the portable instrument detector will be less sensitive than the portal monitor to widespread contamination.

II.F. Assumptions for Derived Minimum Detectable Levels:

The derived minimum detectable levels shown in Table 1 are based on assumptions which, in some cases, cause the values to be on the conservative side. Each assumption is discussed below:

F.1. All contamination that is detected is assumed to be on the skin.

This is a conservative assumption with regard to health effects to skin because clothing would be exposed to air or surface contamination to the same degree as skin and the dose to skin from unit contamination on clothing will be less than that from unit contamination on skin.

F.2. The assumed distribution of the contamination on the skin and the small area used for calculating dose to the skin result in a low probability of deterministic health effects to the skin.

For any detectable level of contamination, an area can be calculated, which if contaminated to that level for a specified period of time, a particular health effect to the skin will occur. The probability that contamination will occur in a quantity equal to or greater than the derived MDLs shown in Table 1 and also be concentrated into an area smaller than indicated is indeterminate but is assumed to be extremely remote. This remote chance of occurrence and small area of effect are used in lieu of the commonly used principle of keeping the dose below the threshold for deterministic health effects. This guidance attempts to strike a balance between risk of health effects and the potential need to complete screening of large numbers of evacuees for contamination in a short period of time. However, as discussed later in Section V.A., other factors such as instrument capability may affect this balance.

F.3. Threshold doses for deterministic health effects were selected as the lower end of ranges of values given in the literature.

Except for the case of hot particles, the threshold dose values for specific deterministic health effects vary from one literature source to another. The range of threshold dose values for a particular health effect may vary by up to a factor of 4 depending on the literature reference used. Since erythema is not considered to be a health effect, a median value was used instead of the lowest value as was used for the deterministic health effects. For the controlling acute health effect, acute exudative radiodermatitis, the threshold dose values in the literature vary from 1200 to 2000 rem. Use of the 1200 rem value introduces the possibility of a small conservatism in the derived MDLs.

F.4. The time period of exposure is assumed to be 36 hours for loose contamination and 14 days for fixed contamination.

It has been assumed that persons who have been in areas where evacuation would have been justified based on total effective dose equivalent (TEDE), and who have been monitored and loose-plus-fixed contamination in excess of the derived MDL was not detected, will be advised to wash and change clothes at their first opportunity and preferably within 24 hours after being monitored. Since emergency response plans call for completion of the monitoring within about 12 hours of all residents and transients in the plume exposure emergency planning zone arriving at relocation centers, the total duration of exposure to loose contamination is assumed to be 36 hours or less. This appears to be conservative for most evacuees because monitoring, bathing, and changing clothes will likely take place within about 36 hours or less. However, these actions may take longer for some evacuees because of the time needed to set up monitoring centers and because of lack of opportunities for them to bathe and/or lack of available uncontaminated clothing, thus causing this assumption to be non conservative in some cases.

The assumption of removal of fixed contamination by normal skin replacement within approximately 14 days is a conservative assumption. Since skin replacement is a gradual process (not a step process that happens at the end of 14 days), the average contamination level over the period will be much less than the initial level. This effect is also enhanced by radioactive decay of short lived radionuclides. Radioiodines are expected to be the primary source of potential fixed contamination on the skin due to the ability of the skin to absorb them. Their half lives range from a few hours to about 8 days. Therefore, the exposure rate would decrease significantly over a 14 day period due to radioactive decay.

F.5. Hot particles are assumed to be removed by washing.

It is assumed that the same process that combined the radioactive material into particles rendered them unlikely to be attached to or absorbed by the skin. The accuracy of this assumption is unknown. However, there is no data indicating that hot particles would be a significant exposure pathway for reactor accidents.

Although none of these separate processes can be predicted accurately, when combined, they will **significantly** reduce the dose to the skin. These factors contribute to conservatism in the analysis for fixed contamination. Based on the above discussion of the assumptions, the derived minimum detectable levels are acceptable for maintaining risk of radiation effects to the skin, including health effects, within established guidelines.

III. INSTRUMENT RESPONSE:

Section II provided threshold levels of contamination corresponding to decision criteria for decontamination. This Section evaluates the response (audible for detection and counts per minute [cpm] for measurements) of a variety of portable radiation instruments that are typically used for contamination monitoring. The evaluation is based on empirically derived data on detection and measurement of contamination levels corresponding to decision criteria for decontamination shown in Table 1. Although beta radiation will be the most abundant form of radiation detected, all instruments were calibrated using either gamma radiation from Cs/Ba-137, or were calibrated by the instrument manufacturer to respond at 3000 to 4000 cpm per mR/h when equipped with a pancake detector.

III.A. Monitoring Process:

Monitoring of individuals for detection and measurement of contamination using radiation instruments that incorporate a movable beta-gamma detector is a four-step process as follows:

1. A speaker or earphone(s) attached to the instrument is used to audibly announce the presence of contamination as the detector, with the beta shield open, is passed over the potentially contaminated surface at a specified,
   - probe speed,
   - distance between the probe and the contaminated surface, and
   - distance between passes of the probe (path-width).
2. When contamination is detected, the earphone(s) or speaker is used to find either, the location of spot(s) of contamination, or the location of the highest concentration(s) of widespread contamination.
3. A meter reading is then taken with the detector in a fixed position at the location of the highest audible response and at a specified distance (one inch was used in this study) from the monitored surface.
4. The meter reading is compared to the decontamination decision criteria.

Step 1 above (detection) would likely take place at a monitoring center established for this purpose. Steps 2, 3 and 4, could also take place at the monitoring center, in which case only those with contamination equal to or greater than the decontamination criteria would be sent to decontamination while others found to be not contaminated would be released. (If the criteria for loose-plus-fixed contamination are used, released persons should be advised to bathe and change clothes within 24 hours.) Alternatively, those with detectable contamination would be sent to decontamination prior to steps 2, 3, and 4. After decontamination they would be monitored again to determine whether the decontamination was successful. Additional variations on this process are discussed in Section V.B.

III.B. Experimental Objectives:

Experiments were conducted using spot and widespread Cs/Ba-137 beta-gamma sources with radiation instruments that incorporate a movable detector (probe) and audio (speaker or earphone[s]) plus visual (meter) output. The objectives were to determine the following for a variety of commonly used instrument/detector combinations:

1. The optimum combination of probe speed, distance from probe to contaminated surface, and maximum distance off-center between the detector and the spot source for clearly audible detection of spot contamination at the 0.1 and 1.0 μCi decision criteria for fixed and loose contamination respectively,

2. The counts per minute (cpm) or exposure rate (mR/h) corresponding to the decontamination criteria for loose and fixed contamination and for spot and widespread contamination when a specific instrument/detector combination is in a fixed position and at a designated distance (one inch was chosen) from the contaminated surface,

3. The effect of typically used probe covers on detection and measurement of contamination and,

4. The effect of increased background gamma radiation levels on the detection of spot contamination.

III.C. Equipment Used:

C.1. Sources:

Thin-window sources of Cs/Ba-137 were used for the experiments. These were judged to have average beta energies similar to the average energies of radionuclides predicted to be released from major accidents at nuclear power facilities. This type of source was also used for checking adequacy of response of portal monitors used for emergency response, and they are convenient to use because of their long (30 year) half life.

C.1.a Spot Sources:

Special Cs/Ba-137 sealed sources with thin (0.9 mg/cm^2) windows on one side were used. These consisted of two spot sources and one widespread source. All sources were calibrated by, or are traceable to, the National Institute of Standards and Technology. The two spot sources had approximately 0.1 and 1.0 µCi of activity on a circle 0.5 cm in diameter (0.2 cm^2). Since the source activities were not exactly equal to these threshold values for decontamination decisions, measured counts per minute (cpm) were multiplied by appropriate factors to yield the counts per minute that would have been indicated if the sources had activities of exactly 0.1 and 1.0 µCi respectively. The factors were calculated as follows:

The original activity and calculated current activity of the two Cesium/Barium 137 spot sources used for evaluating the response of portable instruments are:

SOURCE NUMBER	2-6-95 ACTIVITY	CALCULATED 2-6-99 ACTIVITY
471-66-1	0.0923 µCi	0.0841 µCi
471-66-2	0.965 µCi	0.880 µCi

The current activity of each source was calculated using the following equation:

$$I = I_0 e^{-\left(\frac{0.693t}{T}\right)} = 0.0923e^{-\left(\frac{0.693x4}{30}\right)} = 0.0923x0.9117 = 0.0841\mu Ci$$ for source #471-66-1

Where:

“I” is the calculated current activity (µCi),
“I_0” is the activity at the time of calibration (.0923 µCi)
“t” is the elapsed time since calibration (4 years), and
“T” is the half life (30 years).

The decay factor for four years as shown in the above equation is 0.9117. This factor can be multiplied by the original activity of the second source to determine its present activity as follows:

0.965 µCi x 0.9117 = 0.880 µCi.

To adjust measured count rates to values that would have resulted had the two sources been full strength of 0.1 and 1.0 µCi, multiply the count rates by 0.1/0.0841 = 1.189 and by 1/0.880 = 1.136 respectively.

C.1.b. Widespread Source

The widespread source is rectangular with an active area of 8 inches by 10 inches and with an NIST-traceable activity of 0.00845 µCi/cm^2 as adjusted (same procedure as above for spot sources) to the time of the experiments. The factors used to adjust the measured count rates were 0.47 and 4.7. Measured count rates were multiplied by these factors to convert count rates to those that would be read from sources with activities of 0.004 and 0.04 µCi/cm^2 respectively, the slightly rounded decontamination threshold criteria for fixed and loose widespread contamination as derived in Section II.D.5. The adjustment factors were calculated as follows:

Let:

x = desired activity (0.004 µCi/cm^2 for the fixed contamination threshold and 0.04 µCi/cm^2 for the loose contamination threshold),

y = the actual activity (0.0085 µCi/cm^2), and

f = the calculated adjustment factor.

Then: x = fy or x/y = f and,

$$\frac{0.004 \mu Ci / cm^2}{0.0085 \mu Ci / cm^2} = f = 0.47 \quad \text{and} \quad \frac{0.04 \mu Ci / cm^2}{0.0085 \mu Ci / cm^2} = f = 4.7$$

C.1.c. Other Sources:

Additional small gamma-only Cs/Ba-137 sources were arranged to create background gamma radiation of 0.1 mR/h at the detector location. This level was assumed to be representative of possible operational field conditions.

III.C.2. Instruments:

The specific types of instruments that were tested are shown in Table 2. All instruments had been recently calibrated to respond correctly to gamma radiation from Cs/Ba-137.

TABLE 2

Instrument/Detector Types Evaluated

Instrument Model or Type	Detector Type	Number Tested
CD V-700 (standard FEMA issue)	GM – side window	2
CD V-700 (modified to accept a pancake detector)	GM – pancake	2
Nuclear Research Corporation Model CD V-718	GM – thin end-window	1
Nuclear Research Corporation Model CD V-718-A	GM – pancake	1
Nuclear Research Corporation Model ADM 300-A	GM – pancake	1
Eberline Instruments, Model E-600	GM – pancake	1
Ludlum Measurements, Inc Model 14-C	GM – pancake	1
Ludlum Measurements, Inc. Model 3	1” x 1” NaI (TI) detector and no beta window	1
SE International, Inc. - Model Radiation Alert – Inspector	GM pancake	1
Technical Associates Model TBM-15	GM pancake	1
Victoreen – Model-190	GM pancake	1

III.C.3. Transport System:

To test the capability of instrument/detector combinations for detecting spots of contamination, it was necessary to develop a transport system in which the variables could be controlled. The variables are, (1) Speed of the detector past the spot source, (2) vertical distance between the source and the detector housing and (3) the horizontal off-set from the center of the source to the center of the detector. Devices were built to hold detectors at selected positions relative to the source and to move the source along a track at constant speeds ranging from 1 to 24 inches per second.

Figure 1 is a sketch of the devices that were used for transporting the source past the detector at selected speeds, and at selected distances horizontally and vertically between the source and detector. The hydraulic hoisting shaft was used to adjust the vertical distance between the spot source and the detector, and the swing arm was used to adjust the horizontal distance. The motor drive mechanism for the tow lines is not shown. Transporting the source under the detector was unconventional but was more convenient than transporting the detector. However, the instrument response would be the same.

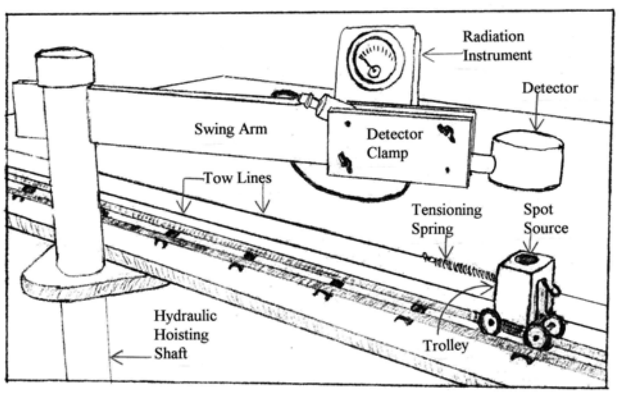

Figure 1 - Transport Mechanism

III.C.4. Miscellaneous Equipment:

- Probe covers consisting of a surgeon's glove, condom, sandwich bag, and thin plastic wrap of the type commonly used to wrap food were used to evaluate the beta shielding effect from these products.
- One-eighth inch thick plastic beta-shields with different size rectangular openings in the center and a detector-height positioning device were used to determine whether the 8 inch by 10 inch widespread source was viewed as an infinite plane when the detector was at one inch above the source. The openings in the beta shields were the following sizes (inches): 0x0, 1x3, 2x4, 3x5, 4x6, 5x7, 6x8, and 7x9. The detector-height positioning device for the widespread source is shown in Figure 2. Figure 3 shows the detector-height positioning device with the detector in place at 4 inches above the source and with one of the beta shields

covering the source, except for where the 4 x 6 inch window exposes the source. Measurements were made at one inch and other heights.

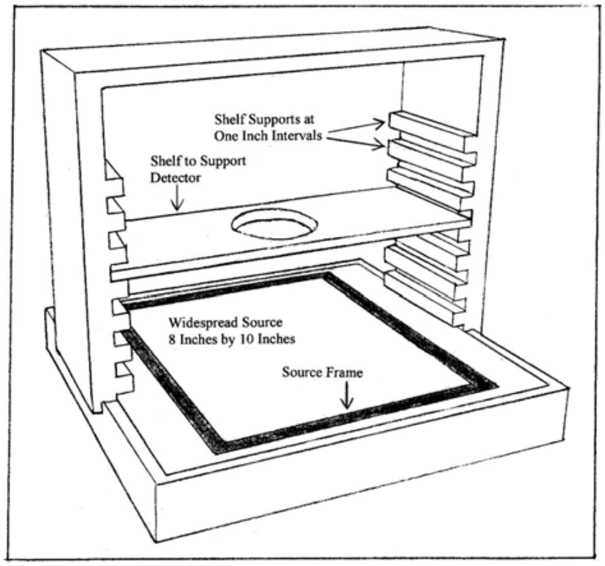

FIGURE 2

Widespread Source with Detector-Height Positioning Device

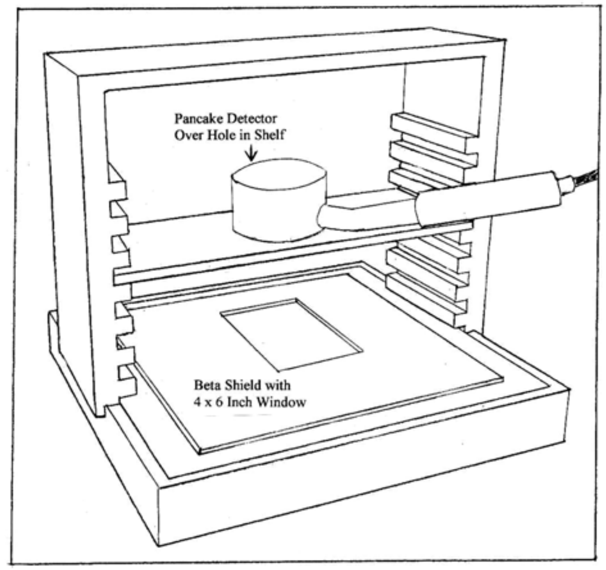

FIGURE 3

Widespread Source Covered by an Example Beta Shield and a Detector Positioned at Four Inches Above the Source

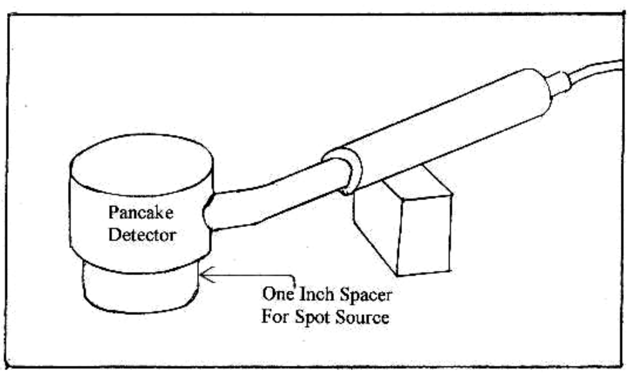

Figure 4

Detector Positioning Device Used for Measuring Response to a Spot Source

A plastic spacer was used to hold the detector at one inch directly above a spot source for measurements of cpm at a fixed position. (The selection of one inch height for measurements was arbitrary). Figure 4 is a sketch of the spot source positioning device (spacer). For measurements, the source was centered in the bottom of the device so that the distance from the source to the frame of the detector was one inch.

IV. TEST PROTOCOL:

IV.A. Determination of the Optimum Combination of Probe Speed, Distance from Probe to Contamination, and Path Width for Detecting Spot Contamination:

As shown in Figure 1, the detector, with the beta window facing downward, was secured to a vertically and horizontally adjustable support stand and near the detector transport device (trolley). The portable radiation instrument was placed on a table next to the transport device where the speaker could be heard by the observers. (For some instruments, earphones were used instead of speakers.)

A spot source was placed on the transport device. As the source was transported under the detector at a selected speed, height, and distance off-center, the observer(s) would determine whether the response was clearly audible. The distance off-center from the detector was increased for successive passes of the source until the response was not clearly audible. When the maximum distance off-center for clearly audible detection was determined, the repeatability of the detection was tested for several passes of the source. This entire process was repeated for increasing heights and for selected speeds appropriate for the sensitivity of the detector and for both of the nominal 0.1 µCi and 1.0 µCi sources.

Data were recorded regarding the probe speed, probe height, and maximum distance off-center where detection of the source was clearly audible. Since the detector can be assumed to detect a spot source at equal distances on either side of the center line of the path of the detector, twice the distance off-center was considered to be the path-width (PW) of detection. The above detection process was conducted with and without a probe cover and in the presence of a slightly elevated background gamma radiation level (about 0.02 mR/h) and a higher background level of 0.1 mR/h. These tests were used to determine the effect these conditions would have on path-width of detection.

IV.B. Determination of Instrument Response to Spot Contamination at Levels Equal to the Decision Criteria for Decontamination (0.1 µCi and 1.0 µCi)

After a spot of contamination is detected on a person or equipment, the next step is to take a measurement (usually in cpm) with the detector centered at a fixed height above the spot. This measurement is then compared to the decision criteria for decontamination. For uniformity, one inch from the housing of the detector to the source was arbitrarily selected as the distance to be used for the experiments. Using the positioning device, (see Figure 4) measurements were made for each instrument/detector combination both with and without two layers of plastic vegetable wrap as a probe cover. (See Section VII for discussion of probe cover experiments). Measured values were corrected for the differences in actual source strength compared to the threshold decontamination criteria (see Section C.1.a).

IV.B.1. Determination of Instrument Response to Widespread Contamination

For determining instrument/detector response to widespread contamination, measurements were made with the detector in a fixed position at one inch above the center of the widespread source. (See Figures 2 and 3 for the equipment used conduct these measurements, except, in the sketch, the support shelf is shown in these figures at four inches from the source instead of one inch). Since the activity of the widespread source was mid-range between the decontamination thresholds for fixed and loose contamination, the instrument readings were adjusted linearly as discussed in Section III.C.1.b to produce the two readings that would occur at source strengths equal to the decision criteria for decontamination (i.e., 0.004 and 0.04 $\mu Ci/cm^2$).

Using the widespread sources and beta shields with variable size openings to adjust the area of the source viewed by the detector, measurements were made at one inch height. These measurements confirmed the minimum source area where beta radiation appeared to the detector to be coming from an infinite plane.

IV.B.2. Influences on the Detection of Spot Contamination

When moving a spot source past the detector, the ability to distinguish the boundary between "clearly audible" and "not clearly audible" is subjective and is somewhat influenced by background noise levels relative to the volume of the speaker or earphone(s). Background noise from the transport device and air circulation was significant in the experimental area and was judged to be about at the level that might be expected in a busy area with several people close by. Some instruments had the advantage of louder or more distinct speakers or earphone(s) than others, and some had volume adjustments. In cases where instruments had speakers, two persons listened with one person at about two feet from the speaker and the other about four feet away. The person nearest to the audio source listened with eyes closed to avoid being influenced by knowledge of when the detection should occur.

Another potential effect on the ability to detect the spot sources is that each of the sources contained slightly less activity than the threshold they represented. Therefore the maximum path widths measured may be slightly conservative. Calculations were performed as follows to determine the expected reduction in path width due to this effect:

IV.B.2.a. Calculation of Correction Factors for Adjusting the Path Width Over Which Spot Source Detection Would Be possible if Source Activities Were 0.1 and 1.0 µCi.

Let: R = count rate

A = constant (count rate at unit distance [inch] and unit activity [µCi]). This factor will cancel in the calculations.

C = source activity (µCi)

D = distance from source to detector (inches)

Then:

$$R = \frac{AC}{D^2}$$

By assigning two values (case 1, and case 2) to AC@ and keeping AR@ a constant, one can calculate

a ratio of AD@ values where the same flux would reach the detector for the different values of AC@ as follows:

$$R_1 = \frac{AC_1}{D_1^2} \quad \text{and} \quad R_2 = \frac{AC_2}{D_2^2}$$

If $R_1 = R_2$, then , $\frac{C_1}{D_1^2} = \frac{C_2}{D_2^2}$ and $\frac{D_1}{D_2} = \sqrt{\frac{C_1}{C_2}}$ and $D_2 = \frac{D_1}{\sqrt{\frac{C_1}{C_2}}}$

If , C_1 = actual source strength, and C_2 = desired full strength source, then, D_1 is the measured distance of detection and D_2 is the calculated distance of detection for a full strength source. For the present situation regarding the small source, C_1 = 0.0841 and C_2 = 0.1 µCi. For the large source, C_1 = 0.88 and C_2 = 1.0 µCi.

Therefore, **in the case of the small source**, $D_2 = \frac{D_1}{\sqrt{\frac{0.0841}{0.10}}} = \frac{D_1}{0.917}$

or**, $D_2 = D_1 \times 1.090$**

In the case of the large source, $D_2 = \frac{D_1}{\sqrt{\frac{0.88}{1.0}}} = \frac{D_1}{0.938}$

Or, $D_2 = D_1 \times 1.066$

Based on these calculations, the increased distance at which the source would have been detectable if the source were exactly equal to the decision criteria for decontamination is, 9 percent for the small source and 6.6 percent for the larger source. Therefore, use of the available sources that contain slightly less activity than the decontamination threshold value added less than ten percent more conservatism to the already conservative distances recommended for probe height and path width.

V. EXPERIMENTAL RESULTS:

Table 3 provides the results from evaluation of parameter values for the different detector types used for detecting the presence of spot contamination. In general, all of the tested instruments that employed the same type of detector responded similarly for audible detection of spot sources. Therefore, the data on audible detection of spots of contamination in Table 3 for specific instrument/detector types are categorized primarily by detector type for the two decontamination thresholds, 0.1 µCi and 1.0 µCi. Probe speed is expressed as inches/second (in./s) while probe height and path width are expressed as inches (in.).

TABLE 3

Experimental Results on Audible Detection of a Spot Source Using a Moving Probe

DETECTOR TYPES: GM Side Window, GM End-Window, and Scintillation with no Window **SOURCE STRENGTH:** 0.1µCi **BACKGROUND:** 0.02 mR/h

INSTRUMENT	PROBE SPEED (in./s)	MAXIMUM PATH-WIDTH (PW) FOR THE BEST HEIGHTS		REDUCTION IN MAX. PATH WIDTH DUE TO 0.1 mR/h BACKGROUND[c]	CONSERVATIVE[d] COMBINATION
		HEIGHT[a] (in.)	PW[b] (in.)		
MANUFACTURER - Anton Electronics Laboratories, Inc. MODEL – CD V-700[e] – with side window detector SERIAL # - 320	2	0.25 to 0.5	0.5	100% (i.e., the source was not detectable at any speed)	Speed (in./s) 4 Height (in.) 0.25 to 0.5 Path Width (in.) 0.6
	3	0.25 to 0.75	1		
	4	0.25 to 0.5	1		
	6	0.25	N.D.		
MANUFACTURER - Victoreen, Inc. MODEL – CD V-700[e] – with side window detector SERIAL # - 56497	2	0.25 to 0.75	0.5 to 1.5	25%	Speed (in./s) 4 Height (in.) 0.25 to 0.5 Path Width (in.) 0.6
	3	0.25 to 0.5	0.5 to 1		
	4	0.25 to 0.5	1		
	6	0.25 to 0.5	1		
MANUFACTURER - Nuclear Research Corporation MODEL – CD V-718[e] with end window detector SERIAL # - 30436	1	0.5 to 1	2 to 3	50%	Speed (in./s) 3 Height (in.) 0.5 to 1 Path Width (in.) 1.0
	2	0.5 to 2	1.5 to 2		
	3	0.5 to 1	1 to 1.5		
	6	0.5	0.5		
MANUFACTURER - Ludlum Measurements, Inc. MODEL – 3 with 1" x 1" NaI(TI) scintillation detector SERIAL # - 154154	1	This detector has no beta window. Due to its strong audible response to background gamma radiation, this instrument could not detect the source at any height or speed.			Speed (in./s) Height (in.) Path Width (in.)
	2				
	3				
	6				

TABLE 3 (CONTINUED)

DETECTOR TYPES: GM Side Window GM End-Window, and Scintillation with no Window **SOURCE STRENGTH:** 1.0 µCi **BACKGROUND:** 0.02 mR/h

INSTRUMENT	PROBE SPEED (in./s)	MAXIMUM PATH-WIDTH (PW) FOR THE BEST HEIGHTS		REDUCTION IN MAX. PATH WIDTH DUE TO 0.1 mR/h BACKGROUND[c]	CONSERVATIVE[d] COMBINATION
		HEIGHT[a] (in.)	PW[b] (in.)		
MANUFACTURER - Anton Electronics Laboratories, Inc. MODEL – CD V-700[e] – with Side window detector SERIAL # - 320	6	1 to 2	3	10%	Speed (in./s) 6 Height (in.) 1 to 2 Path Width (in.) 2
	12	1 to 2	3 to 3.5		
MANUFACTURER - Victoreen, Inc. MODEL – CD V-700[e] – with Side window detector SERIAL # - 56497	6	1 to 2	3 to 4	10%	Speed (in./s) 6 Height (in.) 1 to 2 Path Width (in.) 2
	12	0.5 to 1.5	1 to 2		
MANUFACTURER - Nuclear Research Corporation MODEL – CD V-718[e] with end window detector SERIAL # - 30436	3	1 to 5	5 to 6	10%	Speed (in./s) 6 Height (in.) 1 to 4 Path Width (in.) 3
	6	1 to 4	4 to 6		
	24	1 to 3	2 to 4		
MANUFACTURER - Ludlum Measurements, Inc. MODEL – 3 with 1” x 1” NaI(TI) scintillation detector SERIAL # - 154154	3	This detector has no beta window. Due to its strong audible response to background gamma radiation, this instrument could not detect the source at any height or speed.			Speed (in./s) Height (in.) Path Width (in.)
	6				
	24				

TABLE 3 (CONTINUED)

DETECTOR TYPE: GM Pancake **SOURCE STRENGTH:** 0.1µCi **BACKGROUND:** 0.02 mR/h

INSTRUMENT	PROBE SPEED (in./s)	MAXIMUM PATH-WIDTH (PW) FOR THE BEST HEIGHTS		REDUCTION IN MAX. PATH WIDTH DUE TO 0.1 mR/h BACKGROUND[c]	CONSERVATIVE[d] COMBINATION
		HEIGHT[a] (in.)	PW[b] (in.)		
MANUFACTURER - Lionel Electronic Laboratories	6	1 to 3	2.5 to 3	0%	Speed (in./s) 6
MODEL – CD V-700[e]– with Pancake detector by S.E. International	12	1 to 3	2 to 3		Height (in.) 1 to 3
SERIAL # - 13121	24	1 to 2	3		Path Width (in.) 2
MANUFACTURER – Victoreen Instrument Co.	6	1 to 3	2.5 to 3.5	15%	Speed (in./s) 6
MODEL – CD V-700[e]– with pancake detector by Nuclear Research Corp.	12	1 to 3	2 to 2.5		Height (in.) 1 to 3
SERIAL # - 71665	24	1 to 2	2 to 2.5		Path Width (in.) 2
MANUFACTURER - Eberline Instruments	6	1 to 3	5 to 6	15%	Speed (in./s) 6
MODEL – E-600	8	2 to 4	2 to 4		Height (in.) 1 to 3
SERIAL # - 00199	12	2 to 3	2 to 3		Path Width (in.) 3.5
MANUFACTURER - Ludlum Measurements, Inc.	6	2 to 3	4.5 to 5	25%	Speed (in./s) 6
MODEL – 14-C	8	1 to 2	3 to 4		Height (in.) 2 to 3
	12	2 to 3	3 to 4		
SERIAL # - 154154	24	1 to 2	4		Path Width (in.) 3
MANUFACTURER - Nuclear Research , Corp.	6	1 to 3	3 to 4	25%	Speed (in./s) 6
MODEL – ADM-300-A[f]	12	1 to 2	3		Height (in.) 1 to 3
SERIAL # - 691053	24	1 to 2	2 to 3		Path Width (in.) 2
MANUFACTURER - Nuclear Research , Corp.	6	1 to 3	4 to 5	20%	Speed (in./s) 6
MODEL – CD V-718 A[f]	12	1 to 2	2 to 2.5		Height (in.) 1 to 3
SERIAL # - 90337					Path Width (in.) 3

TABLE 3 (CONTINUED)

DETECTOR TYPE: GM Pancake **SOURCE STRENGTH:** 0.1 µCi **BACKGROUND:** 0.02 mR/h

INSTRUMENT	PROBE SPEED (in./s)	MAXIMUM PATH-WIDTH (PW) FOR THE BEST HEIGHTS		REDUCTION IN MAX. PATH WIDTH DUE TO 0.1 mR/h BACKGROUND[c]	CONSERVATIVE[d] COMBINATION
		HEIGHT[a] (in.)	PW[b] (in.)		
MANUFACTURER - S.E. International, Inc. MODEL – Inspector[g] SERIAL # - 06139	6	1 to 4	3 to 4	15%	Speed (in./s) 12
	12	2 to 4	3 to 4		Height (in.) 1 to 4
					Path Width (in.) 2
MANUFACTURER - Technical Associates MODEL – TBM-15 SERIAL # - 003507	6	1 to 3	5 to 6	25%	Speed (in./s) 6
	12	2 to 3	4 to 6		Height (in.) 1 to 4
	24	2 to 3	3 to 6		Path Width (in.) 3.5
MANUFACTURER - Victoreen, Inc. MODEL – 190 SERIAL # - 944	6	1 to 4	4.5 to 5.5	100%[h] (i.e., the source was not detectable at any speed)	Speed (in./s) 6
	8	1 to 4	4 to 5.5		Height (in.) 1 to 4
	18	1 to 3	3.5 to 4		Path Width (in.) 3

TABLE 3 (CONTINUED)

DETECTOR TYPE: GM Pancake **SOURCE STRENGTH:** 1.0 µCi **BACKGROUND:** 0.02 mR/h

INSTRUMENT	PROBE SPEED (in./s)	MAXIMUM PATH-WIDTH (PW) FOR THE BEST HEIGHTS		REDUCTION IN MAX. PATH WIDTH DUE TO 0.1 mR/h BACKGROUND[c]	CONSERVATIVE[d] COMBINATION
		HEIGHT[a] (in.)	PW[b] (in.)		
MANUFACTURER - Lionel Electronic Laboratories MODEL – CD V-700[e] – with Pancake detector by S.E. International SERIAL # - 13121	6	2 to 6	8 to 12	5%	Speed (in./s) 24
	12	2 to 6	9 to 12		Height (in.) 2 to 6
	24	2 to 6	10 to 12		Path Width (in.) 7
MANUFACTURER - Victoreen, Instrument Co. MODEL – CD V-700[e] – with pancake detector by Nuclear Research Corp. SERIAL # - 71665	6	2 to 6	9 to 10	10%	Speed (in./s) 24
	12	2 to 6	9 to 10		Height (in.) 2 to 6
	24	2 to 6	9 to 12		Path Width (in.) 7
MANUFACTURER - Eberline Instruments MODEL – E-600 SERIAL # - 00199	12	2 to 6	11 to 12	15%	Speed (in./s) 24
	24	2 to 6	11 to 13		Height (in.) 2 to 6
					Path Width (in.) 8
MANUFACTURER - Ludlum Measurements, Inc. MODEL – 14-C SERIAL # - 154154	12	2 to 6	9 to 11	15%	Speed (in./s) 24
	24	2 to 6	9 to 11		Height (in.) 2 to 6
					Path Width (in.) 7
MANUFACTURER - Nuclear Research , Corp. MODEL – ADM-300-A[f] SERIAL # - 691053	12	2 to 6	10 to 11	15%	Speed (in./s) 24
	24	2 to 6	9 to 11		Height (in.) 2 to 6
					Path Width (in.) 7
MANUFACTURER - Nuclear Research , Corp. MODEL – CD V-718 A[f] SERIAL # - 90337	12	2 to 6	8 to 12	15%	Speed (in./s) 24
	24	2 to 6	9 to 11		Height (in.) 2 to 6
					Path Width (in.) 7

TABLE 3 (CONTINUED)

DETECTOR TYPE: GM Pancake **SOURCE STRENGTH:** 1.0 µCi **BACKGROUND:** 0.02 mR/h

INSTRUMENT	PROBE SPEED (in./s)	MAXIMUM PATH-WIDTH (PW) FOR THE BEST HEIGHTS		REDUCTION IN MAX. PATH WIDTH DUE TO 0.1 mR/h BACKGROUND[c]	CONSERVATIVE[d] COMBINATION
		HEIGHT[a] (in.)	PW[b] (in.)		
MANUFACTURER - S.E. International , Inc. MODEL – Radiation Alert Inspector[g] SERIAL # - 06139	12	2 to 6	10 to 14	15%	Speed (in./s) 24
	24	2 to 6	13 to 16		Height (in.) 2 to 6
					Path Width (in.) 8
MANUFACTURER - Technical Associates MODEL – TBM-15 SERIAL # - 003507	12	4 to 6	16	25%	Speed (in./s) 24
	24	4 to 6	14 to 16		Height (in.) 4 to 6
					Path Width (in.) 8
MANUFACTURER Victoreen, Inc. MODEL – 190 SERIAL # - 944	12	2 to 6	12 to 14	100%[h] (i.e., the source was not detectable at any speed)	Speed (in./s) 24
	24	2 to 6	10 to 14		Height (in.) 2 to 6
					Path Width (in.) 8

---

a. *The range of heights includes those that are associated with the greatest path widths for the indicated probe speed.*
b. *The maximum path widths that appear as single values indicate that the path width was constant within the range of specified heights.*
c. *Because of the subjective nature of these percentages, they have been rounded to the nearest 5 percent.*
d. *Conservative path widths (column 6) were selected to be about 65 to 80 percent of the lowest value or the range of measured maximum path widths (column 4) for best combination of probe speed and range of heights.*
e. *Ear phones are needed with this instrument.*
f. *This instrument has a low-volume internal speaker. However, earphones are available and are recommended in areas where competing sounds are present.*
g. *This instrument has no external probe to house the detector. The detector is in the back of the instrument. Due to the compact size of the instrument, lack of a probe was not a problem. However, the lack of a handle increased the probability of dropping the instrument.*
h. *In the presence of 0.1 mR/h background gamma radiation, this instrument changes scales when the spot source approaches the detector, and it simultaneously changes the audio tone fom shrill beeps to a low-volume buzz. This gives the user the false impression that less radiation is being detected. Internal adjustment of the alarm did not help.*

Data in the last column of Table 3 show trends related to the type of detector used. In general, the type of instrument to which the detector is attached is not important for detection of contamination so long as the audible response is crisp and loud enough to be prominent in the presence of the ambient background noise. As would be expected, the data also show that the presence of increased background radiation levels reduces the detectability of spot sources, especially when detecting the smaller of the two sources. Although not shown in the table, **detectability** was not affected to a measurable degree by two layers of plastic vegetable wrap around the detector. However, the **measured count rate** at one inch was slightly affected as shown in Section VII.

V.A. Summary of Derived Detection Parameters for Individuals:

Table 4 summarizes the derived parameters (probe speed, probe height, and path width) from the data in Table 3. The recommended path-width values shown in Table 3 have been reduced from the maximum measured values by about 20 to 35 percent. In the process of summarizing the data from Table 3 into Table 4, the path widths have been reduced again by 10 to 15 percent. Except as noted below, this provides path widths that are sufficiently conservative to allow for the effect of background gamma radiation levels up to 0.1 mR/h. The exceptions are, one of the two CD V-700 instruments with the side window detector, the CD V-718 with the end window detector, and the Victoreen 190 with the pancake detector. One of the CD V-700s with the side window detector and the CD V-718 were successful in detecting the large spot source (1.0 µCi) but not the small spot source (0.1 µCi) in a 0.1 mR/h background gamma radiation level. The Victoreen 190, due to a change in the audible response as the source approached the detector, was not successful in audibly detecting either of the spot sources in the presence of the higher (0.1 mR/h) background. However, as shown in Table 3, it responded well for detection of spot sources in the 0.02 mR/h background level.

Table 4 shows the estimated time needed to monitor an adult for spot contamination using the four instrument detector combinations when using the recommended probe speed and path width. It should be noted that monitoring times derived for the CD V-700 with the side window detector (see Table 3) are significantly increased from prior guidance which indicated that an individual could be monitored in 90 seconds. See Section V.B. for a discussion of possible adjustments to monitoring procedures to decrease the monitoring times.

TABLE 4

Derived Parameter Values For Contamination Detection[a]

Instrument/ Detector Combination	Fixed Contamination (0.1 µCi Threshold)				Loose-Plus-Fixed Contamination (1.0 µCi Threshold)			
	Probe Speed (inches/s)	Height Of Probe (inches)	Path Width (inches)	Time Needed to Monitor an Adult[b] (minutes)	Probe Speed (inches/s)	Height of Probe (inches)	Path Width (Inches)	Time Needed to Monitor an Adult[b] (minutes)
CD V-700 with side window detector	4	0.25 to 0.5	0.6[c]	19	6	1 to 2	2	3.9
CD V-718 with end window detector	3	0.5 to 1	1	16	6	1 to 4	3	2.6
All tested instruments with pancake detector except the Victoreen 190	6	1 to 3	2	3.9	24	2 to 6	7	0.28
Victoreen 190 with pancake detector	6	1 to 4	3[c]	2.6	24	2 to 6	8[c]	0.24

a. The values shown were derived with the detector protected by two layers of plastic vegetable wrap and in the presence of 0.1 mR/h gamma radiation background, except as noted.

b. These are calculated values assuming a skin area of 18,000 cm^2 = 2790 in^2.

c. Audible detection was not possible in the presence of 0.1 mR/h background. This value was derived in the presence of 0.02 mR/h background.

V.B. Instrument Response to Derived Decontamination Criteria:

Table 5 provides the beta-plus-gamma response (cpm with the detector in a fixed position at one inch above the source) of the various instrument/detector combinations to both spot and widespread contamination at the threshold levels for decontamination based on limitations associated with health effects. Measurements were made in background radiation levels of about 0.02 mR/h. A level of 0.1 mR/h would add about 50 cpm to the readings taken with the CD V-700s with side window or pancake detectors and about 250 to 300 cpm to readings taken with other instruments using pancake detectors. For purposes of collecting empirical data, the reported values are averages of about 5 to 10 readings. However, such multiple readings would not be practical in an emergency response situation.

Under some circumstances it may be appropriate to adjust emergency response plans and procedures for monitoring evacuees to assure the best protection of the public. This may require adjustments that take into account equipment shortcomings and time constraints for completing the monitoring more rapidly. The monitoring times shown in Table 4 may be an example of the need for adjustments if a large number of evacuees need to be monitored. FEMA will approve justified changes to monitoring procedures to reduce monitoring times.

Examples of alternative approaches that might be used to permit faster monitoring are:

1. Initially scan areas on evacuees where contamination would most likely be found (e.g., head, hands, elbows, thighs in areas where the hands would naturally contact, knees and shoe soles. If the numerically higher decision criteria for loose-plus-fixed contamination are used, those for which no contamination was found would be released and advised to bathe and change clothes at their first opportunity within the next 24 hours. Those found to be contaminated would be referred to decontamination followed by a complete monitoring of areas that were not protected by clothing. Removed clothing would be monitored only for widespread contamination which would require only a few quick passes.

2 Identify geographical areas where contaminated evacuees may have been exposed to contamination and send individuals from those areas directly to decontamination (e.g., showers) without prior monitoring but with follow up monitoring after decontamination .

3. Separate the evacuees into two groups, (1) those who have not bathed, changed clothes or been decontaminated since evacuating, and (2) those who have bathed, changed clothes or been decontaminated. Group 1 could be monitored using the faster detection parameters derived for loose-plus-fixed contamination (see Table 4). Group 2 should be monitored using the detection parameters derived for fixed contamination .

4. Some of the above suggestions might be combined to further increase monitoring speed.

Based on assumed areas for monitoring, the calculated times needed for monitoring using example 1 above, would be about a factor of 5 less than the times listed in Table 4. The assumed areas and their size (square inches) are: head – 154, hands – 112, elbows – 18, thighs – 128, knees – 32, and shoe soles – 96. This is a total of 540 in^2 compared to 2790 in^2 for the skin of the whole body.

V.C. Conclusions from Table 5:

1. Instrument responses to fixed and loose contamination at threshold levels for decontamination are similar for both spot and widespread contamination. Therefore, it is reasonable to have the same decision criteria for spot and widespread contamination on individuals.

2. Considering only the risk of health effects to individuals under emergency conditions, decontamination criteria of 300 and 3,000 cpm above background for fixed and loose-plus-fixed contamination respectively can be justified for CD V-700 instruments with side-window detectors. These criteria correspond to full scale readings on the X-1 and X-10 scales. The 300 cpm over background corresponds to the guidance in FEMA-REP-14 (Reference 6).

3. Based on the data, decontamination criteria for individuals when using CD V-700s that have been retrofitted with a pancake detector could be conservatively set at 1,000 cpm above background for fixed contamination and 10,000 cpm above background for loose-plus-fixed contamination.

4. It is apparent that the cpm for CD V-700 instruments outfitted with a pancake detector are much lower than other tested instruments that use the pancake detector. This difference can be attributed in part to the inherent ratio of cpm to mR/h. All of the tested instruments had been calibrated to respond accurately to gamma radiation from a sealed Cs/Ba-137 source. However, CD V-700s are designed for one mR/h to correspond to 600 cpm whereas, the other instruments are designed for one mR/h to correspond to 3000 to

TABLE 5

Response of Portable Radiation Instruments to Contamination Levels Equal to the Decontamination Decision Criteria

INSTRUMENT/ SERIAL NUMBER	DETECTOR TYPE	RESPONSE (CPM) AT ONE INCH HEIGHT			
		Spot Sources[a]		Widespread Sources[b]	
		Fixed[c]	Loose[d]	Fixed[e]	Loose[f]

Anton CD V-700 #320	GM Side Window	360	4,800	510	5,100
Victoreen CD V-700 #56497	GM Side Window	430	5,000	490	4,900
Victoreen CD V-700 #71665	Nuc. Res. Corp. GM Pancake	1,900	16,400	2,570	25,700
Eberline Mod. E-600 #00199	GM Pancake	16,000	184,000	19,700	197,000
Ludlum Mod. 14-C #154154	GM Pancake	14,000	136,000	16,400	164,000
Nuc. Research Corp. ADM-300 #691053	GM Pancake	17,800	170,000	18,800	188,000
Nuc. Research Corp. CD V-718-A #90337	GM Pancake	14,300	147,000	17,800	178,000
S.E. International Mod. Inspector #06139	GM Pancake (no probe)	14,300	170,000	17,400	174,000
Technical Associates Mod. TBM-15 #003507	GM Pancake	13,100	Off Scale[g]	15,000	Off Scale[g]
Victoreen Mod. 190 #944	GM Pancake	14,300	136,000	17,400	174,000
Nuc. Research Corp. CD V-718 #30436[h]	GM End-Window	1.3 mR/h	14.5 mR/h	1.1 mR/h	11.0 mR/h

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a. *Readings were taken in a background radiation level of about 0.02 mR/h. The detector was protected by two layers of plastic vegetable wrap and was centered in a fixed position with the detector housing at one inch above the surface of the source. The measured values (cpm) have been multiplied by 1.189 and 1.136 to correct the readings to what they would have been had the source activities been exactly 0.1 and 1.0 µCi respectively. (These correction factors were derived in Section III.C.1.a.)*

b. *Only one widespread source was used. The readings (cpm) were adjusted up or down proportionally to yield the readings associated with 0.04 or 0.004 µCi/cm^2 of contamination as discussed in Section III.C.1.b..*

c. *The readings are those associated with 0.1 µCi of Cs/Ba-137 on a 0.2 cm^2 spot.*

d. *The readings are those associated with 1.0 µCi of Cs/Ba-137 on a 0.2 cm^2 spot.*

e. *The readings are those associated with 0.004 µCi/cm^2 of widespread Cs/Ba-137 contamination.*

f. *The readings are those associated with 0.04 µCi/cm^2 of widespread Cs/Ba-137 contamination.*

g. *This instrument has a maximum range of 50,000 cpm.*

h. *This instrument reads only in mR/h.*

4000 cpm, depending on the instrument. For the application discussed here, it is fortunate that the response (cpm) by CD V-700s that have been retrofitted with pancake detectors is less than for more modern instruments. Otherwise, the threshold for loose contamination would be much higher than the CD V-700 maximum reading of 30,000 cpm. "More modern" means more recent than the CD V-700 instruments which were last manufactured in 1962.

5. When using the more modern (non CD V-700) instruments with pancake detectors of the types tested, 10,000 cpm for fixed spot and fixed widespread contamination and 100,000 cpm for loose-plus-fixed spot or widespread contamination could be conservatively selected as health-risk based decontamination decision criteria for individuals.

6. Although not recommended, low range instruments that read in mR/h can be used for monitoring for contamination. Since mR/h is the unit for gamma exposure rate, it is technically not a suitable unit for measuring contamination where beta radiation is the primary type of radiation being detected. However, count-rate instruments that read in mR/h (e.g., the CD V-718) can be used for this purpose if their open-beta-window response is evaluated against a calibrated source of beta radiation (Cs/Ba-137 is recommended for response to nuclear power plant accidents). Conservative criteria for the CD V-718 with the end window detector are open window readings of 1 and 10 mR/h above background for fixed and loose-plus-fixed contamination respectively.

V.D. Summary of Findings for Four Portable Instrument/Detector Combinations:
Table 6 summarizes the derived maximum decontamination decision criteria for individuals based on acceptable risk of health effects under emergency conditions. Such criteria derived on a different basis (e.g., instrument capability or contamination control objectives) may have similar or lower values, depending on the instrument detector combination. In any case, the values should not be higher than those in Table 6.

TABLE 6

Recommended Decontamination Decision Criteria Summarized from Table 5 for Selected Portable Instrument/Detector Combinations

Instrument Type	Detector Type	Response at One Inch from the Surface[a]	
		Fixed Decontamination Criteria	Loose-Plus-Fixed Decontamination Criteria
CD V-700	Standard GM Side Window	300 cpm	3000 cpm
CD V-700	GM Pancake	1000 cpm	10,000 cpm
CD V-718	Standard GM End Window	1 mR/h	10 mR/h
Count Rate Instruments That Calibrate at 3000 To 4000 cpm/mR/h	GM Pancake	10.000 cpm	100,000 cpm

a. All cpm values are above background. These values have been substantially reduced and rounded from the measured values shown in Table 5.

V.E. Comparison of Portal Monitor Response to Portable Instrument Response:

One objective of this document was to develop procedures for contamination monitoring guidance for portable instruments that would be compatible with existing guidance for portal monitors. Stated another way, decisions on the need for decontamination based on findings using portable instruments should be essentially the same as decisions based on portal monitor findings. As was done for this document, the background information document for portal monitoring (see reference 3) evaluated all of the potential radiation effects and the corresponding levels of fixed and loose contamination (for both spot and widespread contamination) that would represent thresholds for acceptable levels of health effects under emergency conditions. Both documents have concluded that for spot contamination, the controlling threshold would be from the lowest level of contamination that could cause acute exudative radiodermatitis. For widespread contamination, it concluded that the controlling factor would be the lowest levels of contamination that could cause unacceptable risk of skin cancer. From the analyses performed, it was concluded that the ability to detect 0.1 µCi and 1.0 µCi of contamination on a small spot would meet the criteria for fixed and loose contamination respectively. Similarly, it was concluded that the ability to detect and measure widespread contamination at levels of 75 µCi and 700 µCi (rounded from derived values of 74 and 694 µCi) distributed over the entire body would meet the guidance for adequate protection from skin cancer. However, since a portal monitor cannot distinguish between spot and widespread contamination, it was determined that a portal monitor would need to be able to detect 1 µCi of total (spot plus widespread) contamination to confirm the absence of more than 0.1 µCi of spot contamination. (This is because of the arbitrary but believed-to-be conservative assumption that a small spot of contamination would be accompanied by at least 10 times as much widespread contamination). When the Portal Monitor Standard was derived from the associated Background Information Document, fixed spot contamination was determined to be controlling, and a portal monitor was determined to meet the Standard if it could detect the beta radiation from a 1 µCi thin-window spot-source of Cs/Ba-137 located anywhere between the frames that support the detectors. That would confirm the possibility that the 1 µCi detected could possibly include 0.1 µCi of spot contamination.

V.E.1. Detection Levels:

As discussed above, a portal monitor that meets the Portal Monitor Standard would be able to detect 1 µCi of contamination regardless of its distribution over an individual. For uniform distribution (the most difficult distribution for detection by a portable instrument), this is 1 $\mu Ci/18{,}000\ cm^2 = 5.6\ E\text{-}5\ \mu Ci/cm^2$. This detection limit is a factor 71 lower than the 0.004 $\mu Ci/cm^2$ derived as a minimum detectable level for widespread contamination based on an acceptable risk of skin cancer. This low concentration of widespread contamination cannot be detected by a CD V-700, even when outfitted with a pancake detector. More modern instruments with pancake detectors would be able to detect this level at about 220 to 260 cpm over background. This analysis shows that all typically-used portable instruments can <u>detect</u> both spot and widespread contamination at the levels of concern for health effects but, control of contamination spread with the less sensitive portable instruments would be much less effective than when using a portal monitor. It also shows that decisions on the need for decontamination based on measurements made with either a portable instrument or a portal monitor would be sufficiently protective of public health for emergency response.

V.E.2. Lower Proposed Decision Criteria:

Since the risk of skin cancer is proportional to dose to the skin from widespread contamination, decontamination decisions based on measurements made with CD V-700 instruments, or other instruments with similar sensitivity to beta radiation, would not provide as much protection from skin cancer as would be provided by decisions based on measurements made with a portal monitor. Since monitoring speed would not be adversely affected, it would be prudent to reduce the decision criteria from those suggested in Table 6 in order to reduce the risk of skin cancer from undetected contamination. Also, since "loose," widespread contamination would be the overwhelming source of the spread of undetected contamination to other areas, lowering the decision criteria for portable instruments would also reduce this problem. For purposes of simplifying the decision process, it would be conservative to assume that all contamination on individuals is "fixed." However, selecting fixed contamination limits (0.1 μCi for spot and 0.004 $\mu Ci/cm^2$ for widespread) as the basis for detection of both fixed and loose contamination will greatly increase the time needed for monitoring individuals compared to the time that would be needed to monitor for loose-plus-fixed contamination (see Table 4).

The present decontamination decision criteria in FEMA-REP-14 (Reference 6) is 300 cpm over background for a CD V-700 without specifying the type of detector or the height above the contaminated surface for taking the reading. Some States have adopted decision criteria lower than 300 cpm over background. For purposes of lowering the risk of skin cancer and the chances of contamination spread, consideration should be given to lowering the decision criteria to 300 cpm over background at one inch from the contaminated surface for all portable instruments of the type tested. Selection of the lower decision criteria (cpm) would not interfere with the detector speed, path width, and detector height for detection of spot contamination as derived in Section III and presented in Table 4. Decision criteria lower than 300 cpm could be selected if this doesn't interfere with the State's capability to monitor all persons in the evacuation Emergency Planning Zone (EPZ) within 12 hours.

Just for information, Table 7 provides a comparison of existing and proposed decontamination decision criteria for individuals.

TABLE 7

Comparison of Decontamination Decision Criteria for Individuals

Source of Guidance	Instrument/ Detector	Decontamination Criteria[a]	
		Loose-Plus-Fixed	Fixed
EPA Screening Levels (Reference 2)	CD V-700/ Standard	2 x bkgd., where bkgd does not exceed 0.1mR/h[b]	2 x bkgd., not to exceed 0.5 mR/h[c] including bkgd
FEMA-REP-14, (Reference 6)	CD V-700/Std.	300 cpm.	5000 to 10,000 cpm[d]
FEMA Reference 1	Portal monitor	Alarm at 1 µCi for any distribution[e]	Alarm at 1 µCi for any distribution[e]
FEMA – Suggested values in this document based on limiting the spread of contamination and reducing the risk of skin cancer where instrumentation capability permits.	All instrument/ detector combinations reported in this document.	300 cpm	300 cpm
FEMA – Derived values in this document based only on limiting the risk of health effects to acceptable levels for emergency response	CD V-700/Std	3,000 cpm	300 cpm
	CD V-700/ Pancake	10,000 cpm	1,000 cpm
	CD V-718	10 mR/h[f]	1 mR/h[f]
	Modern/Pancake	100,000 cpm	10,000 cpm

a. *All readings are above background except as noted, and all readings expressed in cpm are open window readings.*
b. *Reading taken with open beta shield. The 0.1mR/h background corresponds to 60 cpm.*
c. *Reading taken with closed beta shield. The 0.5 mR/h reading corresponds to 300 cpm.*
d. *The guidance does not specify open or closed beta window, but since the reading is expressed in cpm, open window is assumed.*
e. *This corresponds to an assumed 0.1 µCi of spot contamination which would produce an open window reading on a CD V-700 with a Standard detector of 300 cpm over background or greater and about 7 cpm (non detectable) from uniformly distributed widespread contamination. Portable instruments with pancake detectors would read about 5 times (for the CD V-700) to 33 times (for modern instruments) higher than these values.*
f. *Open window readings.*

VI. VEHICLES, EQUIPMENT AND OTHER POSSESSIONS

The data in Tables 3 through 6 and the associated conclusions in Section V pertain to the detection and measurement of spot and widespread contamination (fixed or loose) on individuals. This section addresses contamination on vehicles, equipment, and other possessions. Contamination on vehicles, equipment, and other possessions is a problem only to the extent that it may ultimately expose individuals or processes (e.g., photographic film) to radiation directly from the contaminated surface or, if the contamination is "loose," it may transfer to individuals or processes. The data discussed here apply only to the possibility of exposing individuals; not processes.

Spot versus widespread contamination is not an issue for vehicles and equipment. Therefore, the criteria developed for probe speed, probe height, and path width for detecting spot contamination on individuals are not applicable for monitoring vehicles, equipment, and other possessions. However, the use of audible detection is applicable when scanning to verify the presence or absence of contamination.

Widespread (fixed or loose) contamination would be of concern for contaminated vehicles and equipment. Contrary to the situation with contamination on individuals, loose contamination on vehicles or equipment fosters greater risk than fixed contamination. This is because of the possibility of the loose contamination being transferred to individuals where it will be in continuous direct contact with the skin so the exposure rate will be greater.

VI.A. Loose Contamination:

The transfer coefficient for loose contamination from surfaces to individuals is usually arbitrarily assumed to be an average of 10 percent. However, since the possibility exists for average contamination levels to become concentrated by mechanical action, it would not be prudent to establish decontamination criteria for loose contamination that is ten times higher on vehicles, equipment, and other possessions than would be allowed on individuals. Also, loose contamination may be transferred to an individual after monitoring has been completed and at a time when there will be no advice to wash and change clothes. <u>Therefore, the decision criteria</u>

used for loose contamination on individuals should also be used for monitoring vehicles and equipment that have not been decontaminated. Detection parameters suitable for widespread contamination (loose-plus-fixed and fixed) are shown in Table 10.

VI.B. Fixed Contamination:

Fixed contamination is, by definition, contamination that is not removed by decontamination. Since fixed contamination cannot be transferred to individuals, it is a problem on vehicles, equipment, and other possessions only if it may expose someone directly. External beta radiation from a beta-gamma source that is nearby may provide a dose to the skin that is much higher than the whole body dose from the accompanying gamma radiation. Calculations by the Environmental Protection Agency (Reference 4) show that, for widespread contamination with a mixture of radionuclides that might be characteristic of an accidental release from a nuclear power plant, the skin dose from beta radiation (unshielded by clothing) at one foot from the contaminated surface would be about 7 times the whole body dose from the accompanying gamma radiation. However, the risk of health effects from whole body gamma dose is about 50 to 100 times higher than from an equal beta radiation dose to the skin of the whole body. Therefore, except in cases where fixed contamination is on surfaces that will be in contact with skin for extended periods of time, whole body dose from gamma radiation would be of greater concern than the accompanying beta radiation.

VI.C. Dose Limitations:

This Section provides an analysis of dose limitations from fixed contamination on vehicles, equipment and other possessions from both gamma and beta radiation. Based on calculations in Sections VI.C.1, VI.C.2.a, and VI.C.2.b below, the limiting concentration for cancer (other than skin cancer) from gamma radiation is 0.022 $\mu Ci/cm^2$, for erythema from beta radiation 0.052 $\mu Ci/cm^2$, and skin cancer from beta radiation 0.0083 (rounded to 0.0085) $\mu Ci/cm^2$. From this, it is concluded that **0.0085 $\mu Ci/cm^2$ for protection from skin cancer is the controlling concentration and is the technical basis for decision criteria for fixed contamination on vehicles, equipment, and other possessions.**

VI.C.1. Dose Limitations from Gamma Radiation:

Since fixed contamination on vehicles, equipment, and other possessions may expose persons outside the emergency response zone, consideration should be given to limiting the whole body dose to individual members of the public from this pathway to levels established for licensed radioactive material. These limits are provided in 10 CFR 20 Section 20.1301 (Reference 8) as 2 millirem in any one hour and 100 mrem in one year for continuous occupancy.

To calculate the surface concentration that would correspond to these exposure rates, it is necessary to make assumptions regarding (1) the size of the contaminated surface, (2) the average distance from the contaminated surface to the whole body, and (3) the duration of exposure. Conservative values for these parameters, are arbitrarily assumed to be (1) a circle 4 feet in diameter for the contaminated surface, (2) one foot from the surface to a point representative of the whole body, and (3) an average exposure time of 40 hours per week for calculating the one year exposure. Since a large fraction of the deposited material from a major nuclear power plant accident would initially be short-lived radionuclides, consideration of radioactive decay is important. Weathering or wear would also affect the long-term dose. For purposes of calculating the gamma exposure rate, the gamma energy from Cs/Ba-137 is assumed.

First we need a relationship between the initial exposure rate (mR/h) at a given point and the first year exposure at that same point from a mix of radionuclides representative of a major accident at a nuclear power plant. Chapter 7, Section 7.6.2 of Reference 2, provides this relationship. These data show that, for the reactor accident type analyzed (SST-2) and considering radioactive decay and weathering, areas with readings of 2 to 5 mR/h during the first few days after the accident can be expected to produce a whole body dose of 2000 mrem in the first year after the accident and less than 500 mrem in the second year at the point of the reading. Using the lower value of 2 mR/h resulting in 2000 mrem in the first year for continuous exposure, an exposure time of 40 hours per week would produce a first year gamma dose of about 1/4 of that value or 500 mrem. Therefore, the exposure rate that would produce 100 mrem in the first year would be 100/500 x 2 mR/h = 0.4 mR/h. Now the question becomes “what level of contamination will produce

0.4 mR/h at one foot from a four foot diameter circle."   This can be calculated as follows using procedures from pages 757 to 763 of Reference 7:

$$R = \frac{q\Gamma}{a^2}\ln\frac{h^2 + a^2}{h^2}$$ is the model for calculating the centerline gamma dose from a flat disk.

Where:

R = Roentgens per hour = 0.0004

q = total mCi of contamination

э = Dose factor read from graph = 3.6 for Cs/Ba-137

a = radius of contaminated surface = 61 cm

h = height of calculated dose rate = 30.5 cm

Solving the above equation for q:

$$q = \frac{Ra^2}{\Gamma \times \ln\frac{h^2 + a^2}{h^2}}$$

Inserting the values:

$$q = \frac{0.0004 \times 61^2}{3.6 \times \ln 4.84} = 0.26\, mCi = 260\, \mu Ci$$

The concentration "C" on the 4 ft diameter disk is:

$$C = \frac{260\ \mu Ci}{\pi a^2} = 0.022\ \mu Ci / cm^2$$

Therefore, a concentration of 0.022 µCi/cm^2 of Cs/Ba-137 distributed uniformly on a 4 foot diameter disk will yield an initial gamma exposure rate at one foot above the surface of 0.4 mR/h and an exposure of 100 mR in the first year if the average exposure time is 40 hours per week. This should be fairly representative of the initial exposure rate from contamination deposited from an airborne plume from a major reactor accident. For the assumptions made, this concentration should not result in exposure rates in excess of 2 mR/h or 100 mR in one year as permitted for individuals in the general public from licensed radioactive material.

VI.C.2 Dose Limitations from Beta Radiation:

Health effects from external beta radiation are a concern only for the skin, and the greatest dose will be from contamination in contact with the skin. As discussed in Section II.B, two types of radiation effects are of concern from beta radiation; deterministic effects and stochastic effects. Although previous analyses of deterministic effects were based on avoiding small spots of acute exudative radiodermatitis, this analysis will consider erythema which occurs at a lower dose than acute exudative radiodermatitis. Erythema is chosen in this case because of the potential for the effect to occur over a large area of skin from near-contact exposure to fixed contamination on vehicle seats or the steering wheel. The stochastic effect of concern is skin cancer; also from near-contact exposure from contaminated vehicle seats or the steering wheel.

VI.C.2.a. Protection from Erythema:

Section II.D.4 concluded that skin dose less than 200 rad (rad = rem) will avoid erythema and that the beta dose rate to skin from contamination on the skin is 7 rad/h per μCi/cm^2. Therefore, 28 μCi h/cm^2 (i.e., 200 rad) 7 rad/μCi h/cm^2) is the limiting time integrated concentration. Assuming 2080 hours exposure per year and no radioactive decay, the limiting concentration to avoid erythema is 0.013 μCi/cm^2 (i.e., 28 μCi h/cm^2) 2080 hours). However, as developed in Section VI.C.1 for gamma radiation, radioactive decay will reduce the one-year dose to ¼ the dose that would result if radioactive decay were not considered. **Therefore, the threshold concentration for erythema is 4 x 0.013 = 0.052 μCi/cm^2**

VI.C.2.b. Protection from skin cancer

Section II.D.5 concludes that limiting the dose to the skin of the whole body to 10 rem will adequately limit the risk of skin cancer. This relationship is assumed to hold true regardless of the distribution of the contamination on the body. Since less than 1/3 of the body skin (back of legs and back of torso) would be exposed at close range from sitting on a car seat, 30 rem to 1/3 of the skin of the whole body is assumed to provide the same risk as 10 rem to the skin of the whole body. Based on the calculations above for erythema, the limiting time integrated concentration without considering radioactive decay is 4.29 μCi h/cm^2 (i.e., 30 rad) 7 rad/μCi h/cm^2). Dividing 4.29 μCi h/cm^2 by the assumed exposure time (2080 h) and multiplying by 4 to account for radioactive decay, **the limiting concentration for skin cancer is 0.0083 µCi/cm^2. This is rounded to 0.0085µCi/cm^2.**

VI.D. Contamination Levels Versus Instrument Response:

The relationship between surface contamination (µCi/cm^2) and instrument response can be determined from experimental data compiled using apparatus shown in Figures 3 and 4 of Section III.C.4. These data are presented in columns 1 through 4 of Table 8. They show relationships between measured gamma exposure rates and beta-plus-gamma exposure rates with the detector housing at one inch above a widespread surface containing 0.0085 µCi/cm^2 of Cs/Ba-137 for four instrument/detector combinations. Column 3 shows the measured values with the beta shield in place and column 4 shows the values with no beta shield. In cases where data were available for more than one instrument of a particular type, average values were used. These data show the measured responses by 4 instrument/detector combinations to a specific concentration of widespread contamination. These responses can be scaled to responses expected from other concentrations.

Note that the threshold concentration of 0.0083 µCi/cm^2 derived in the previous section as the technical basis for releasing vehicles and equipment is almost the same as the concentration of activity on the source that was used for measurements reported in Table 8 (0.0085 µCi/cm^2). Therefore, the data in columns 3 and 4 of Table 8 are used without adjustment as the derived threshold criteria for releasing vehicles, equipment, and other possessions that have fixed contamination.

Measurements were also made to determine whether the area of the widespread (8 x 10 inch) source that was used was large enough to be viewed by the beta radiation detectors as an infinite plane. This was done by taking successive measurements with each detector in a fixed position at one inch above the source while inserting beta shields with variable size windows over the source (see Figure 3). The size of the rectangular beta window was increased in one-inch increments from no window until a window size was reached where the instrument reading did not increase. As shown in column 6 of Table 8, all instrument/detector combinations, when held at one inch above the 8 inch by 10 inch source, viewed the source as an infinite area for beta radiation.

TABLE 8

Average Instrument Response to Widespread Contamination of 0.0085 µCi/Cm^2 at One Inch Height

Instrument Type	Detector Type	Average Gamma Response	Average Beta-Plus-Gamma Response	Ratio[a] of Average Responses	Size[b] of Infinite Beta Source (in.)	Number of Instruments Tested
CD V-700	Standard	126 cpm	1,065 cpm	8.5	5 x 7	2
CD V-700	Pancake	132cpm	5,460 cpm	41	5 x 7	1
CD V-718	End Window	0.19 mR/h	2.3 mR/h	12	4 x 6	1
Modern[c]	Pancake	725	36,400 cpm	50	7 x 9	6

a. *This is a ratio of the average measured beta-plus-gamma exposure rate to the average measured gamma exposure rate.*
b. *These data show that the 8 inch by 10 inch source used for the experiments was viewed as an infinite plane for beta radiation by all of the detectors when placed at one inch from the source.*
c. *Modern refers to tested instruments that are more modern than the CD V-700 which was last manufactured in 1962.*

Note that the data in columns 3 and 4 of Table 8 vary depending on the type of instrument/detector combination that was used. Since adequate protection from deterministic effects and the risk of cancer are provided by using these criteria, and the control of the spread of contamination is not an issue with fixed contamination, decision criteria can logically be expressed as a function of the specific instrument/detector combination. However, if one wishes to choose a single count rate to simplify the criteria regardless of the instrument/detector type, 1000 cpm above background for beta-plus-gamma radiation would be a good choice for instruments that read in cpm. Otherwise, **Table 9 provides a summary of derived beta-plus-gamma count rates above background that could be recommended as decision criteria for fixed contamination on vehicles, equipment and other possessions.** These criteria have been rounded from the technically derived values in column 4 of Table 8.

TABLE 9

Recommended Decision Criteria for Releasing Vehicles, Equipment, and Other Possessions With Fixed Contamination

Instrument Type	Detector Type	Decision Criteria for Release[a] Beta-Plus-Gamma
CD V-700	Standard Side Window	1,000 cpm
CD V-700	Pancake	5,400 cpm
CD V-718	Standard End Window	2.3 mR/h[b]
Modern	Pancake	36,000 cpm

a. *These criteria are based on widespread fixed contamination of 0.0085 µCi/cm^2. All values are above background.*

b *With the beta shield open, this is not an actual exposure rate in mR/h. It is only a derived meter indication. This instrument does not have a read-out in cpm.*

VI.E. DETECTION OF WIDESPREAD CONTAMINATION ON VEHICLES, EQUIPMENT, AND OTHER POSSESSIONS

Since spot contamination is not an issue for vehicles and equipment, the detection parameters listed in Table 4 for individuals do not apply. Empirical data have been collected regarding maximum probe speed and maximum distance from the probe to contaminated surface for widespread contamination. Data were collected for 4 instrument/detector combinations and for the various decision criteria (cpm) derived for widespread contamination as designated in Section VI.A for loose-plus-fixed contamination and in Table 9 for fixed contamination.

To collect the data, the 0.0085 µCi/cm^2 widespread source was shielded with sheets of paper until the instrument, with the detector fixed at 1 inch above the source, showed a reading (cpm or mR/h) equal to the selected decision criteria. With the gamma background level at 0.1 mR/h, the detector was moved over the source at different heights and at different speeds while listening for clearly audible indication of the presence of radiation from the source. Maximum values for combinations of distance and speed were recorded. These data are summarized in Table 10 for the contamination levels of concern on vehicles, equipment and other possessions. The data show that probe speed can be relatively fast. Therefore, care should be taken when monitoring small objects or areas to assure that the probe speed will permit adequate time for the instrument to audibly respond (usually about 2 seconds) while the probe is being passed over the potentially contaminated object or area. Appropriate path width is a judgment call depending on the size of the surface being monitored and whether it represents the portion the item that is most likely to be contaminated. Instead of monitoring an entire large object, judgment should be used to determine the most likely areas to be contaminated and then concentrate on those areas. For example, on automobiles, the tires, bumpers, inside the fenders, door handles, air filter, steering wheel, floor, and seats would be the most likely parts to be contaminated. If those most likely areas are found to be not contaminated in excess of the criteria, the item can be released.

TABLE 10

Recommended Detection Parameters for Widespread Contamination on Vehicles, Equipment and Other Possessions.

Instrument/ Detector Type	Decision Criteria	Detection Parameters	
		Maximum Probe Height (inches)	Maximum Probe Speed (inches/second)
CD V-700 with side Window detector	300 cpm[a]	1	6
	1,000 cpm[b]	2	12
CD V-700 with pancake detector	300 cpm[a]	1	12
	5400 cpm[c]	4	24
CD V-718 with end window detector[d]	1.0 mR/h[e]	1	6
	2.3 mR/h[f]	3	12
Modern instruments w/pancake detector	300 cpm[a]	10	24
	36,000 cpm[g]	10	24

a. This is the release criterion at one inch recommended for widespread loose-plus-fixed contamination for all instrument/detector combinations that read out in cpm.

b. This is the release criterion at one inch recommended for the CD V-700 with a side window detector for widespread fixed contamination.

c. This is the reading at one inch from the derived decision criterion concentration of 0.0085 µCi/cm^2 for fixed contamination when using the CD V-700 with a pancake detector.

d. This instrument reads out only in mR/h.

e. This is the release criterion at one inch recommended for widespread loose-plus-fixed contamination for this CD V-718 instrument/detector combination.

f. This is the reading at one inch from the derived decision criterion concentration of 0.0085 µCi/cm^2 for fixed contamination for the CD V-718 with the end window detector.

g. This is the reading at one inch from the derived decision criterion concentration of 0.0085 µCi/cm^2 for fixed contamination when using modern instruments with pancake detectors.

VI.F. Instrument Response to Various Decision Criteria

Table 11 shows the count rates that would be associated with some historical decision criteria for fixed contamination on vehicles and equipment. The count rates are based on the CD V-700 with

TABLE 11

Comparison of Various Alternative Decontamination Decision Criteria

Possible Decision Criteria	Source of Criteria	Corresponding Beta-Plus-Gamma Count Rate (cpm) At One Inch Above the Surface[a]
5 mR/h	Proposed as interim decision criteria for vehicles and equipment in FEMA-REP-14 .	3,000[b]
0.5 mR/h	Release criteria recommended in EPA 400-92-001 for releasing animals and equipment having fixed contamination.	300[b]
0.04 to 0.1 $\mu Ci/cm^2$	The level of contamination near, but outside, the restricted zone within a few days after an accident where contaminated areas could be authorized for unrestricted use based on EPA Protective Action Guides.	5,000[c] to 12,500[c]
0.0085 $\mu Ci/cm^2$	The level of fixed widespread contamination on vehicles and equipment derived as acceptable based on limiting the first year skin dose to 33 rem from beta radiation.	1,062[d]
0.004 $\mu Ci/cm^2$	The level of fixed widespread contamination on individuals derived on the basis of acceptable risk of health effects under emergency conditions.	500[c]
300 cpm of Beta Plus Gamma	The level of loose and/or fixed contamination on individuals derived as acceptable based on limiting the risk of health effects and limiting the spread of loose contamination.	300

a. *Based on measurements using a CD V-700 with a standard detector.*
b. *Based on the CD V-700 meter face which shows both mR/h and cpm.*
c. *Derived by multiplying the criteria concentration in column 1 times the cpm for the CD V-700 from Table 8 and dividing by the concentration that was measured (0.0085 $\mu Ci/cm^2$).*
d. *From Table 8, column 4.*

a standard detector. Estimates of corresponding readings on other instrument/detector combinations can be scaled from data in Table 8.

VII. PROBE COVERS:

Experiments were conducted to determine the reduction in count rate for the different detector types when covered by typically used probe covers. Error bands of 5 to 10% in ability to read the meter displays (due to pointer fluctuations or digital roving) caused some variations in the results. However, the readings used are, in each case, the average of 6 readings. Table12 provides experimentally determined average percent reductions in count rate due to probe covers when used with the standard CD V-700 side window detector, pancake detector, and end window detector. Window thicknesses were 30 mg/cm^2 for the side window, 1.5 to 2 mg/cm^2 for the pancake window, and 3 to 4 mg/cm^2 for the end-window detector.

TABLE 12

Effects of Probe Covers on Measurements

Type of Probe Cover	Density Thickness (mg/cm^2)	Average Reduction In Count Rate (Percent)		
		CD V-700 Side-Window Detector	Pancake Detector	CD V-718 End-Window Detector
One Layer of Store Brand Plastic Vegetable Wrap	1.2	1.1	3.6	4.7
Two Layers of Store Brand Plastic Vegetable Wrap	2.4	2.2	7.7	8.6
One Layer of Store Brand[a] Plastic Fold-Over Sandwich Bag	1.5	2.2	6.7	6.3
Two Layers of Store Brand[a] Plastic Fold-Over Sandwich Bag	3.0	3.8	14	11
Latex Surgeon's Glove (*Health Shield* Brand)	16	13	35	33
Latex Condom (*Life Styles Vibra-Ribbed* Brand)	14	10	32	29

a. Other brands were not found.

Based on the data in Table 12, the effectiveness of the tested materials in reducing an instrument's response (cpm) to beta radiation varies with the type of material used for the cover and with the detector type. These data show that the best probe cover for protection of the detector from contamination is 1 or 2 layers of plastic vegetable wrap. The one tested was a store brand with a density thickness of 1.2 gm/cm^2. For comparison, national brands of this material, *Saran Cling Wrap* and *Glad Cling Wrap* have densities of 1.3 and 1.1 gm/cm^2 respectively. This type of material provides minimal shielding of beta radiation, is easy to install, provides the best fit with no sagging, and is transparent for observing the position of the beta shield.

Tests were also run to determine whether the use of two layers of plastic vegetable wrap as a probe cover would significantly reduce the detectability of spot contamination from a moving probe. The procedure for these tests was to first determine the maximum path width for each probe speed and height without the use of a probe cover. Then an additional observation was made at the maximum path width settings with two layers of vegetable wrap shielding the probe from the source. In each case, no reduction was clearly observable. In other words, any reduction in path width that may have occurred due to using the probe cover was less significant than that introduced by the subjective decision as to whether detection was clearly audible.

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