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MINIMUM DETECTABLE ACTIVITIES OF CONTAMINATION CONTROL SURVEY EQUIPMENT

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DISCLAIMER

INTRODUCTION

The Instrumentation & External Dosimetry (I&ED) Section of the Health Physics Department at the Pacific Northwest Laboratory (PNL)[a] has performed a series of tests to determine the ability of portable survey instruments used at Hanford to detect radioactive contamination at levels required by DOE 5480.11. This semi-empirical study combines instrumental, statistical, and human factors as necessary to derive operational detection limits. These threshold detection values have been compared to existing contamination control requirements, and detection deficiencies have been identified when present.

Portable survey instruments used on the Hanford Site identify the presence of radioactive surface contamination based on the detection of α-, β-, γ-, and/or x-radiation. However, except in some unique circumstances, most contamination monitors in use at Hanford are configured to detect either α-radiation alone or β- and γ-radiation together. Testing was therefore conducted on only these two categories of radiation detection devices. Nevertheless, many of the results obtained are generally applicable to all survey instruments, allowing performance evaluations to be extended to monitoring devices which are exclusively γ- and/or x-ray-sensitive.

The ability of a survey instrument to detect radioactive surface contamination of a particular type is conveniently characterized by a minimum detectable activity (MDA) parameter. For the purposes of this study, MDA has been defined as that activity which can be detected 67% of the time under standard survey conditions, in which a detector is scanned over the contaminated surface at 5 cm/s with a constant ¼-in. separation. Under these conditions an instrument's MDA will be a function of

- background counting rate
- operator recognition factors
- detection efficiency
- source and surface characteristics.

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[a] Operated for the U.S. Department of Energy by Battelle Memorial Institute under Contract DE-AC06-76RLO 1830.

With a zero background counting rate, which is characteristic of α-monitoring instruments, operator recognition of contamination depends primarily upon the probability of a single decay event being detected when the detector is positioned over the activity. Decay detection, on the other hand, is dependent upon four additional factors: absolute detection efficiency, an energy- and geometry- dependent function; the residence time of the detector over the source, a geometric factor; the physical nature contaminated surface, a highly variable and unpredictable condition; and the quantity of surface contamination present. For ideal surface conditions, which are assumed throughout this study, the MDA for α-detection can therefore be estimated from purely statistical considerations once the physical size and energy-dependent efficiency of the candidate detector are determined; this approach is precisely the one used in this study.

Unlike α-monitors, instruments used for β/γ-detection typically have background count rates of 50 to 500 counts per minute (cpm) when no contamination source is present. In this type of situation, a purely statistical approach to determining an instrument's ability to find contamination in a scanning mode is not appropriate, since detection relies greatly on the ability and judgment of the technician using the instrument. Therefore, both instrument efficiency and operator response need to be accounted for in establishing MDAs for β/γ-monitoring systems. To accomplish this, the energy-dependent efficiencies of survey instruments were combined with background-dependent operator recognition thresholds.

MDA EVALUATIONS

Alpha Detection MDAs

Instrumental α-detection sensitivities were evaluated for three detection systems: the ~50 cm^2 (4.5 W x 11.1 L) Hanford portable alpha monitor (5PAM), a 100-cm^2 (8.5 W x 11.8 L) large-area scintillation monitor (LASM), and a commercial (8.7 W x 11.5 L) gas proportional monitor (GPM). Detection efficiencies were determined over an α-energy range of 4.68 to 5.5 MeV using nominal 1-in.-diameter electroplated sources of ^{230}Th, ^{239}Pu, and ^{241}Am at a reference distance of ¼ in. The characteristic residence time of each

individual α-contamination survey instrument over a source was calculated from the standard survey scan speed and the width of the instrument probe. In the case of the instruments tested, residence times of 0.9, 1.7, and 1.74 s were established for the PAM, LASM, and GPM, respectively.

Using these measured efficiencies and detector-specific residence times, energy-dependent MDAs were determined for each of the α-instruments studied using the statistical methods established in draft ANSI Standard 13.12.[b] Figure 1 summarizes the results of these α-MDA evaluations. Because all three instruments exhibited higher detection efficiencies with increasing α-energy, MDAs are found to decrease with increasing α-energy. Although testing did notquantify instrument performance for α-energies below 4.68 MeV, most α-emitting radionuclides of concern are included within the energy range covered in this study.

In interpreting the graphical results presented in Figure 1, it is important to keep in mind that these data are highly idealized, and that the performance of these instruments may differ considerably under field conditions. For example, under non-ideal field conditions, where contaminated surfaces are rarely uniform flat planes, a larger (wider) probe face may not increase the likelihood of α-detection as is suggested by Figure 1. Indeed, for complex three-dimensional objects, the physical size of the detector may limit the operator's ability to maintain the standard detector-to-surface separation, and thus severely affect detection efficiency and resultant instrumental MDAs. Thus a large detector will only be an advantage if it does not impact an operator's ability to maintain a fixed detector-to-surface separation over the entire object being monitored.

Although instrumental MDAs illustrated in Figure 1 are only appropriate for point sources, the same statistical approach can be used to estimate detection thresholds for uniformly distributed surface activities. As in the previous case, detector dimensional and efficiency parameters are used with the detector residence time over the contamination zone to establish a total localized activity that can be detected with 67% certainty. However, in the

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[b] Draft ANSI Standard 13.12. December 1985. "Control of Radioactive Surface Contamination on Materials, Equipment, and Facilities to be Released for Uncontrolled Use." American National Standards Institute, Inc., New York.

case of extended sources, this derived threshold activity is the average value the detector is exposed to during the scan. This average value is then used with detector and contamination geometries to establish a corresponding total surface activity, which is the desired detector MDA parameter. For the purposes of this evaluation a square, 100-cm^2 contamination zone was assumed. If it is further assumed that the detector spans one dimension of the contamination zone while scanning across the other, which is certainly possible for all detectors being evaluated, the resultant instrumental MDAs are found to be nominally the same as if all surface contamination was concentrated in a single point (i.e., the point source MDA). This result stems from the fact that the increased residence time of the detector over the extended source during a scan compensates for the lower surface concentration of the distributed activity.

Since α-MDAs for distributed contamination are dependent upon specific geometric conditions encountered, which in general will not be limited to a localized 10 cm x 10 cm square field, the condition in which the detector entirely spans one of the dimensions of the extended source does not represent an absolute worst-case situation. However, it is a reasonable model to use for this evaluation, as distributed surface contamination would rarely be restricted to a highly localized 100-cm^2 field under actual field conditions. Therefore, the point source MDA data presented in Figure 1 will also be used to represent instrumental detection limits associated with distributed sources.

Beta/Gamma-Detection MDAs

Instrumental β/γ-detection sensitivities were evaluated for three detection systems: the LASM, the GPM, and the Hanford "Pancake" GM (Geiger Müller) probe. To empirically establish operator recognition thresholds, 23 radiation protection technologists were asked to survey a surface that had many discrete contamination (U-nat) sites of varying activity. The Pancake GM detection system used for these tests was operated under the three background counting rate conditions (50, 250, and 500 cpm) characteristic of the three detection systems being evaluated (GM, LASM, and GPM). The results of these recognition tests, which are graphically summarized in Figures 2-4,

demonstrated that activities producing net instrument responses of 305 cpm, 310 cpm, and 475 cpm could be statistically recognized 67% of the time in 50-cpm, 250-cpm, and 500-cpm background fields, respectively when standard survey conditions were employed. These data show that under dynamic survey conditions the large fractional instrumental response variations characteristic of low count rate conditions in combination with short exposure times ($t<RC$) inhibit an operators ability to recognize the influence of source activities which would otherwise be considered significant under static, integrating counting conditions. Although exposure times will be greater for the LASM and GPM survey systems, the count rate dependent threshold response data generated by the GM will be used to estimate minimum detectable activities for all detectors in this study.

The energy-dependent detection efficiencies of the LASM, GPM, and Pancake GM were determined for a series of β/γ point and distributed activity sources over a decay energy range of 0.15 to 2.3 MeV at the standard (¼ in.) source-to-detector separation. These data revealed that the γ-sensitivities of the instruments under study are insufficient to qualify them as useful contamination control devices for x- and/or γ-ray-emitting radionuclides (e.g., ^{125}I). In addition, instrumental detection efficiencies were also found to be marginal for low-energy (<220 keV) β-emitters.

To derive energy-dependent β-MDAs, the point and distributed source efficiency data were combined with appropriate operator recognition threshold information (previously described) for all three detection systems under study. These MDA results are graphically summarized in Figures 5 and 6.

The point source data presented in figure 5 demonstrate the nominal equivalence of the β survey instruments, if the source of surface contamination is confined to discrete radioactive particles. Instrumental MDAs in this type of situation represent the activity of highly localized hot spots that can be detected 67% of the time using standard monitoring techniques. If, on the other hand, the surface contamination is a uniformly distributed activity, instrumental MDAs are found to be strongly influenced by active detector surface area.

As shown in Figure 6, distributed source detection sensitivity was found to be roughly equal for the 100 cm^2 GPM and LASM detectors, but the Pancake

probe exhibited considerably lower sensitivity due to the GM's small active surface area (15.5 cm^2). At low ß-energies (~300 keV), the two large-area detectors could detect nominal surface contamination levels of 1,500 dpm/100 cm^2. Because of improved detection sensitivities, these instrumental MDAs are found to decrease to ~1000 dpm/100 cm^2 at high ß-energies.

Since the Pancake GM is exposed to only a small portion of uniformly distributed large-area sources, its MDA ranged from 9000 dpm/100 cm^2 to as high as 34,000 dpm/100 cm^2 at low energies. The Pancake GM clearly lacks sensitivity for detecting non-localized, low-energy ß-emitter contamination. However, this type of source, although producing worst-case detection conditions, is not necessarily a good representation of the type of surface contamination commonly encountered in the field. To the extent that this is true, the data presented in Figure 6 significantly underestimates the capabilities of the Pancake GM.

Gamma-Detection MDAs

Routine β/γ-survey instrumentation used on site has been shown to be too insensitive to be used for identifying x- and γ-ray-emitting activities and low-energy β-emitters. In most cases in which this type of contamination can be present, a high-efficiency NaI detection system can be successfully used to measure secondary x- and/or γ-ray emissions accompanying the decay process. For point source, low-energy photon emitters (~30 keV), detection efficiencies can range between 10% and 20%. Since pulse height analysis can be used to reduce NaI background counting rates to between 25 and 50 cpm, operator recognition thresholds for x- and/or γ-ray survey instrumentation should be nominally the same as that encountered with the Pancake GM monitor, ~300 cpm. Using this value and a detection efficiency of 15%, an MDA for ^{125}I and/or ^{126}I surface contamination can be estimated at 2000 dpm for a point source. Since common NaI-based Hanford pool instruments have only a 5-cm^2 effective surface area, this type of instrument is not well suited for identifying uniformly distributed surface contamination. In the case of the previously mentioned iodine isotopes, portable NaI-based field instruments could only expected to detect surface activity levels greater than 40,000 dpm/100 cm^2. The use of larger area detectors could reduce this surface contamination detection limit by as much as an order of magnitude if background counting rates were adequately controlled. However, there has been no apparent need to demonstrate this capability as most radionuclides requiring this mode of detection are short lived and do not present a general contamination threat at the Hanford site.

INSTRUMENTAL MDAs AND SITE MONITORING REQUIREMENTS

DOE 5480.11 provides guidelines for Allowable Total Residual Surface Contamination Levels for various groups of radionuclides. The following discussion compares these requirements with the capabilities of plant survey instruments evaluated in this study.

Group I

Surface contamination limits for the members of this group, which include the transuranics, ^{125}I, ^{129}I, ^{226}Ra, ^{227}Ac, ^{228}Ra, ^{228}Th, ^{230}Th, and ^{231}Pa, have

been established at 300, 900, and 20 dpm/100 cm^2 for average, maximum, and smearable activities.

For α-emitting radionuclides in this group (^{228}Th, ^{230}Th, ^{226}Ra, and α-emitting transuranics), point and distributed source detection is difficult at the required average levels even under laboratory conditions. Detection at 300 dpm with the GPM probe was demonstrated over the entire range of α-energies tested. However, the LASM-based system was found to be only marginally acceptable at these contamination levels, and the Hanford PAM failed to meet sensitivity requirements under all testing conditions. For the α-emitters in this group, the Hanford PAM could be expected to reliably detect ~750-dpm/100 cm^2 67% of the time under controlled conditions. This is twice required value.

On the other hand, because of near zero detector backgrounds, detection of smearable α-activity at 20 dpm/100 cm^2 is potentially achievable by all the detection systems studied if sample self-absorption is negligible and static, long-term (scalar) counting of the smear sample is conducted. However, since less-than-ideal monitoring conditions can and will increase threshold detection levels in unpredictable ways, it seems apparent that overall surface contamination control of Group I α-emitting radionuclides cannot be routinely achieved at existing required levels with the portable survey instruments under consideration.

As discussed earlier, radionuclides decaying by electron capture such as ^{125}I can only be effectively detected by their low-energy photon emissions. Plant NaI detectors with relatively small active surface areas can, with difficulty, be used to survey equipment suspected of being contaminated with these radionuclides. However, routine instrumental ^{125}I MDAs for point and distributed sources estimated at 2,000 and 40,000 dpm/100 cm^2, respectively, are much greater than the contamination control criteria established for these radionuclides. The use of larger area detectors could significantly reduce the distributed contamination detection limit to ~5,000 dpm/100 cm^2, but this is hardly necessary, as ^{125}I (because of its short half-life) does not present a sitewide contamination control problem that needs to be addressed by routine plant survey instrumentation. Special purpose methods and counting equipment should be employed by laboratories using this isotope to ensure DOE contamination monitoring requirements are met at the user site.

Unlike ^{125}I, ^{129}I is a long-lived, ß-emitting fission product that presents a significant surface contamination potential across the Hanford Site. Like its lower mass isotope, ^{129}I contamination can be detected using secondary low-energy photon emissions accompanying its decay with, unfortunately, very similar sensitivities. Although ^{129}I is a ß-emitter, it has a relatively low (0.19 keV) decay energy; consequently, its MDA's using ß-survey instrumentation are not much better than those achievable using γ-sensitive detection equipment. Specifically, ^{129}I MDAs for point and distributed sources are estimated at 5,000 and ~40,000 dpm/100 cm^2 for ß-monitoring vs. 2,000 and 40,000 dpm/100 cm^2 for photon detection using routine plant survey instrumentation. For either approach, the use of large area detectors can improve ^{129}I extended source MDAs to ~5,000 dpm/100 cm^2, if flat surfaces possessing unattenuated contamination activities are encountered; however, this sensitivity improvement is still insufficient to meet existing contamination control limits.

Detection of ^{228}Ra is also very difficult with routine field survey equipment due to its very low ß-decay energy (0.055 MeV). However, this 6-year activity decays to ^{228}Ac, which is a short-lived (6 h), high-energy (2.1 MeV) ß-emitter. Since ^{228}Ac quickly grows into the ^{228}Ra parent, ^{228}Ra surface contamination is easily detected by the ß-survey instruments characterized in this study unless special circumstances allow for surface contamination with a freshly separated parent fraction - a very unlikely event! Using the decay energy of ^{228}Ac as a basis, average Pancake GM MDAs for point and distributed surface contamination of ^{228}Ra have been estimated at 1,500 and 10,000 dpm/100 cm^2, respectively, which again are much greater than all administrative contamination control limits established for this radionuclide. Although LASM and GPM distributed source MDAs are an order of magnitude less than the Hanford Pancake GM (1000 Vs 10,000 dpm/100 cm^2, under ideal conditions), they are also incapable of detecting (Group I) surface contamination at the mandated release limits.

Identification of removable ß- and/or γ-activity at levels specified for this group would necessitate sample counting in the scalar mode. Under field conditions it is assumed that ß/γ activities equivalent to instrumental background rates can be routinely (67%) recognized. Under this assumption, release criteria for removable ß/γ activity cannot be met with the survey

instruments that have been evaluated. Although recognition at removable β/γ release limits can be achieved using conventional laboratory counting methods, these methods are not currently available for routine field use.

Group II

Control limits for natural thorium, ^{90}Sr, ^{126}I, ^{131}I, ^{133}I, ^{223}Ra, ^{224}Ra, ^{232}U, and ^{232}Th have been set to 1000, 3000, and 200 dpm/100 cm^2 for average, maximum, and smearable surface activity contamination.

^{90}Sr, ^{131}I, and ^{133}I are all β-emitting fission products. Unlike ^{90}Sr, however, the iodine isotopes in this group are not credible surface contamination sources at the Hanford Site due to their relatively short half-lives. Like ^{125}I, contamination control of these iodine isotopes is largely a local issue which can be adequately addressed at the laboratory level where these radionuclides are being used.

As mentioned earlier, control of ^{90}Sr is a sitewide issue which has to be addressed using routine plant survey instrumentation. Like the Group I ^{228}Ra activity, ^{90}Sr has an energetic (2.27 MeV) short-lived (64 h) daughter, ^{90}Y, which quickly grows into the parent activity that significantly enhances detection. Since decay chain equilibrium is expected for all plant sources of ^{90}Sr, both parent and daughter β activities were used as the basis for estimating ^{90}Sr MDAs for the instruments tested. Instrumental MDAs, for point $^{90}Sr/(^{90}Y)$ sources, ranged from ~550 dpm/100 cm^2 for large-area monitors to 900 dpm/100 cm^2 for the Hanford Pancake GM. For distributed sources, MDAs were significantly influenced by active detector area. An order of magnitude separated the MDAs of the large area instruments (~600 dpm/100 cm^2) from those of the 15.5 cm^2 Pancake GM (6,000 dpm/100 cm^2).

Although $^{90}Sr/(^{90}Y)$ MDAs for the large area monitoring systems meet existing control levels, it must be kept in mind that all assessments are based upon ideal monitoring conditions. Consequently, one would have to assume that, under actual field conditions, the total surface contamination guideline could not be met 67% of the time with any of the surveying instruments evaluated in this study, and sample monitoring in the scalar mode would certainly have to be used to survey wipes at 200 dpm/100 cm^2 smearable levels. Because of the assumed dependence of detection upon background, the

Pancake GM is the only survey instrument with sufficient sensitivity to recognize removable activity at the specified release limit.

For the α-emitting radionuclides in Group II (^{223}Ra, ^{224}Ra, ^{232}U, and ^{232}Th), point source detection at 1000 dpm/100 cm^2 is possible with all survey instruments tested. Because of zero detector backgrounds, detection of smearable activity at the 200 dpm/100 cm^2 control limit is achievable if sample self-absorption is negligible and if static, long-term (scalar) counting conditions are assumed. Non-ideal field conditions can of course significantly degrade performance of any of the detectors tested in this study.

Like the iodine isotopes in Group I, ^{126}I can most easily be monitored by detecting its low-energy photon emissions. As with the other iodine isotopes, plant instrumental MDAs for point and distributed contamination are estimated at 2,000 and 40,000 dpm/100 cm^2, respectively. Although ^{126}I cannot be detected at the required contamination control limits using standard plant monitoring equipment, this short-lived (13 d) isotope does not represent a credible plant contamination source except at specific laboratories generating or using it. Consequently, ^{126}I is not a contamination source which should be addressed by routine site survey equipment; rather, local methods and/or controls need to be established ensure all applicable plant contamination control limits are met at the user/generator location.

Group III

Natural uranium, ^{235}U, ^{238}U and associated decay products, and other α-emitters are limited by DOE 5480.11 guidelines to 5000, 15,000, and 1000 dpm/100 cm^2 for average, maximum, and smearable surface contamination activities.

For the α-emitting radionuclides in this group, required detection sensitivities can be achieved under all specified conditions with all survey instruments tested. This result assumes a reasonable detector efficiency energy dependence and, more importantly, ideal surface conditions. Self-absorption and surface irregularities can easily and significantly degrade performance of any of the detectors tested in this study.

Group IV

For all ß/γ-emitters not included in Groups I through III, DOE 5480.11 requires contamination control at 5000, 15,000, and 1000 dpm/100 cm^2 for average, maximum, and smearable surface activities.

For ß-emitting radionuclides with maximum ß-energies greater than 0.22 MeV, it should be possible to detect point or distributed surface contamination under all stated conditions with all ß-sensitive instruments tested except the Pancake GM. However, since ^{90}Sr and is dominant fission product activity in this group and is the principal activity in high- and low-level plant waste streams, this isotope will, in most situations, determine the detectability of Group IV contamination sources. Assuming this to be the case, the Pancake GM will exhibit adequate sensitivity to meet control requirements if the contamination is confined to hot particles with activities > 1,500 dpm. For distributed Group IV contamination, the Pancake GM, unfortunately, lacks required detection sensitivity. Its Group IV MDA (6,000 dpm/100 cm^2) was estimated to be a factor of 5 greater than that of the large area monitors (1200 dpm/ 100 cm^2) evaluated in this study. Although the 15.5-cm^2 active surface area of the Pancake probe limits instrumental sensitivity for distributed sources relative to large-area instruments (LASM and GPM), it is much easier, under field applications, to maintain standard surveying conditions using a smaller probe. Because of this, the apparent advantage of the large-area detection systems may not be realizable under actual field operating conditions. The monitoring of wipes at the 1000 dpm/100 cm^2 level may require use of the probes in a scalar mode, especially if the levels of smearable contamination are close to the stated limit.

The above Group IV MDA analysis assumes relatively ideal surveying conditions. Self-absorption and/or non-uniform surface conditions can significantly affect response data, making detection at 5000 dpm difficult, especially for low-energy ß-emitters. As mentioned previously, non-standard plant activities need to establish techniques and/or procedures to ensure that contamination limits are achieved on the local level if special ß-emitting waste products are produced.

For x- and/or γ-ray-emitting isotopes, photon-sensitive survey instruments must be used. However, for routine plant monitoring conditions,

x- and/or γ-activity without β-emissions from accompanying activities (i.e., ^{90}Sr) is difficult to conceive of. Since β-activities should dominate all contamination sites produced from plant waste sources as previously explained, and β-MDAs are generally lower than photon MDAs, monitoring of x- and/or γ-emitting radionuclides will be satisfied by routine β-ray monitoring techniques.

ACHIEVABLE SURFACE CONTAMINATION CONTROL LEVELS

The ability of radiation protection technologists to detect α-, β-, γ-, and x-ray emissions from contaminated surfaces at required control levels using routine portable survey instrumentation has been evaluated. The results obtained from this study suggest that some DOE 5480.11 surface contamination requirements cannot be met with existing field survey instrumentation and, consequently, some contamination control limits may need to be adjusted to reflect limitations imposed by human and/or instrumental detection thresholds. The MDA limits derived from this study and summarized in Table 1 are, necessarily, based upon relatively ideal surveying conditions, as worst-case conditions would preclude identifying contamination at any reasonable level. Therefore, before these limits can be meaningfully applied to survey results, the physical state of the surface to be monitored needs to be specifically addressed and properly prepared, if necessary. Table 2 compares requirements of DOE 5480.11 with the capabilities of Hanford monitoring equipment if standard survey methods are used under ideal surface contamination conditions. The MDAs listed in this table are best achievable values; the effects of adverse field conditions upon detection limits have not been taken into account in estimating these values. However these estimates are also based upon uniformly distributed surface contamination conditions which are probably not representative of actual circumstances encountered in the field. For β-surface contamination confined to localized hot spots (point sources), the sensitivity of the Pancake GM will nominally improve by a factor 6, which will significantly reduce resultant estimated MDAs.

TABLES

TABLE 1. MINIMUM DETECTABLE SURFACE ACTIVITIES OF CONTROLLED RADIONUCLIDES

NUCLIDE	MINIMUM DETECTABLE ACTIVITY (dpm/100 cm^2) REQUIREMENT REMOVE/TOTAL	REMOVABLE PAM/GM	FIXED PLUS REMOVABLE PAM	GM	LASM	GPM	COMMENTS
GROUP I:	20/300						
^{226}Ra, ^{230}Th, and alpha transuranics		20	750	-----	360	230	MDA at 4.7 MeV assumed for all alpha transuranics.
^{228}Th		20	510	-----	250	200	
^{125}I		N/A	-----	N/A	N/A	N/A	Not a routine site source.
^{129}I		1000	-----	40,000	5,000	5,000	MDA removable, 250 dpm/100 cm^2 for photon detection methods.
$^{228}Ra/(^{228}Ac)$		200	-----	10,000	1,000	1,100	
GROUP II:	200/1000						
^{223}Ra, ^{224}Ra, and ^{232}U		20	510	-----	250	200	
^{232}Th		20	750	-----	360	230	MDA at 4.7 MeV assumed.
$^{90}Sr/(^{90}Y)$		140	-----	6,000	410	700	
^{126}I, ^{131}I and ^{133}I		N/A	-----	N/A	N/A	N/A	Not routine site sources.
GROUP III:	1000/5000						
U(Nat), ^{235}U, ^{238}U and decay products.		20	750	----	360	230	
GROUP IV:	1000/5000						
Other fission products		360	----	6,000	1,100	1,300	Mixed fission product MDA based on ^{90}Cs.

TABLE 2. ACHIEVABLE PLANT SURFACE CONTAMINATION CONTROL LIMITS

NUCLIDE	CONTAMINATION DETECTION LIMITS (dpm/100 cm^2) REMOVABLE MEASURED	REMOVABLE REQUIRED	FIXED PLUS REMOVABLE MEASURED	FIXED PLUS REMOVABLE REQUIRED
GROUP I:				
^{226}Ra, ^{228}Th, ^{230}Th, and α-transuranics	20	20	750	300
^{125}I	N/A	20	N/A	300
^{129}I	1000	20	40,000	300
$^{228}Ra/(^{228}Ac)$	200	20	10,000	300
GROUP II:				
^{223}Ra, ^{224}Ra, ^{232}U, and ^{232}Th	20	200	750	1,000
^{126}I, ^{131}I, and ^{133}I	N/A	200	N/A	1,000
$^{90}Sr/(^{90}Y)$	140	200	6,000	1,000
GROUP III:				
U(Nat), ^{235}U, ^{238}U, and decay products	20	1000	750	5,000
GROUP IV:				
Other β/γ/x-emitters	360	1000	6,000	5,000

FIGURES

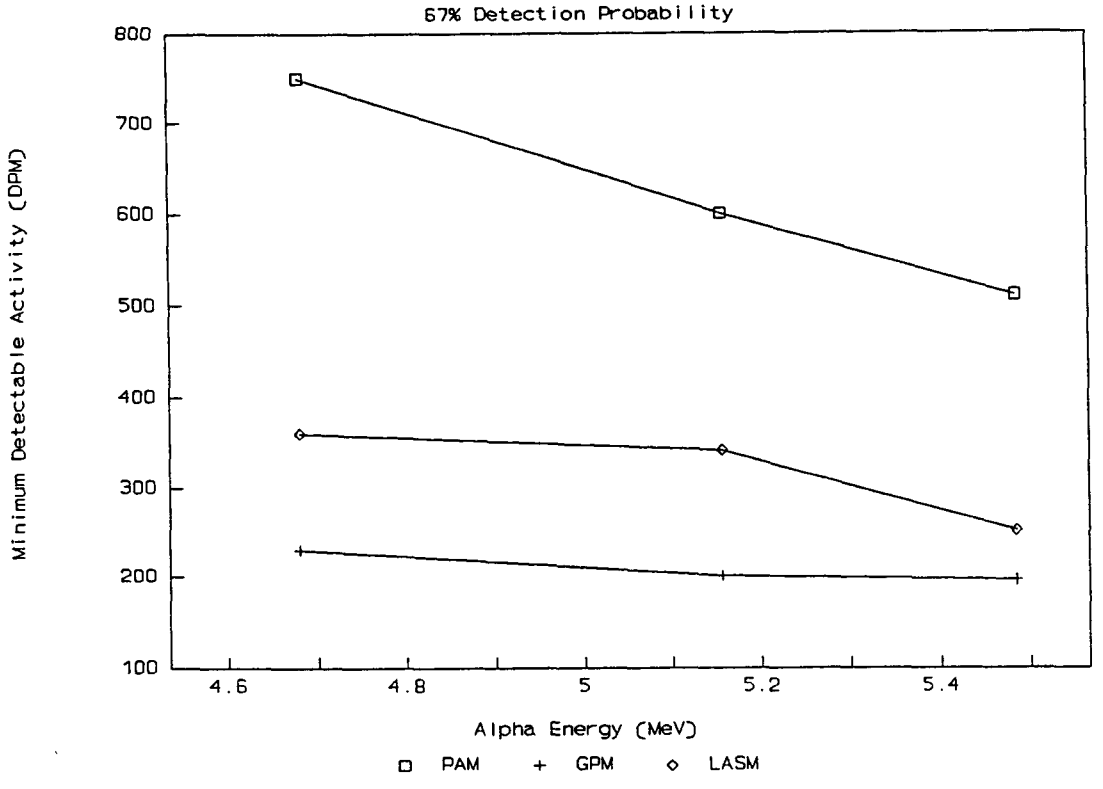

Figure 1 MDAs For α-Contaminated Surfaces

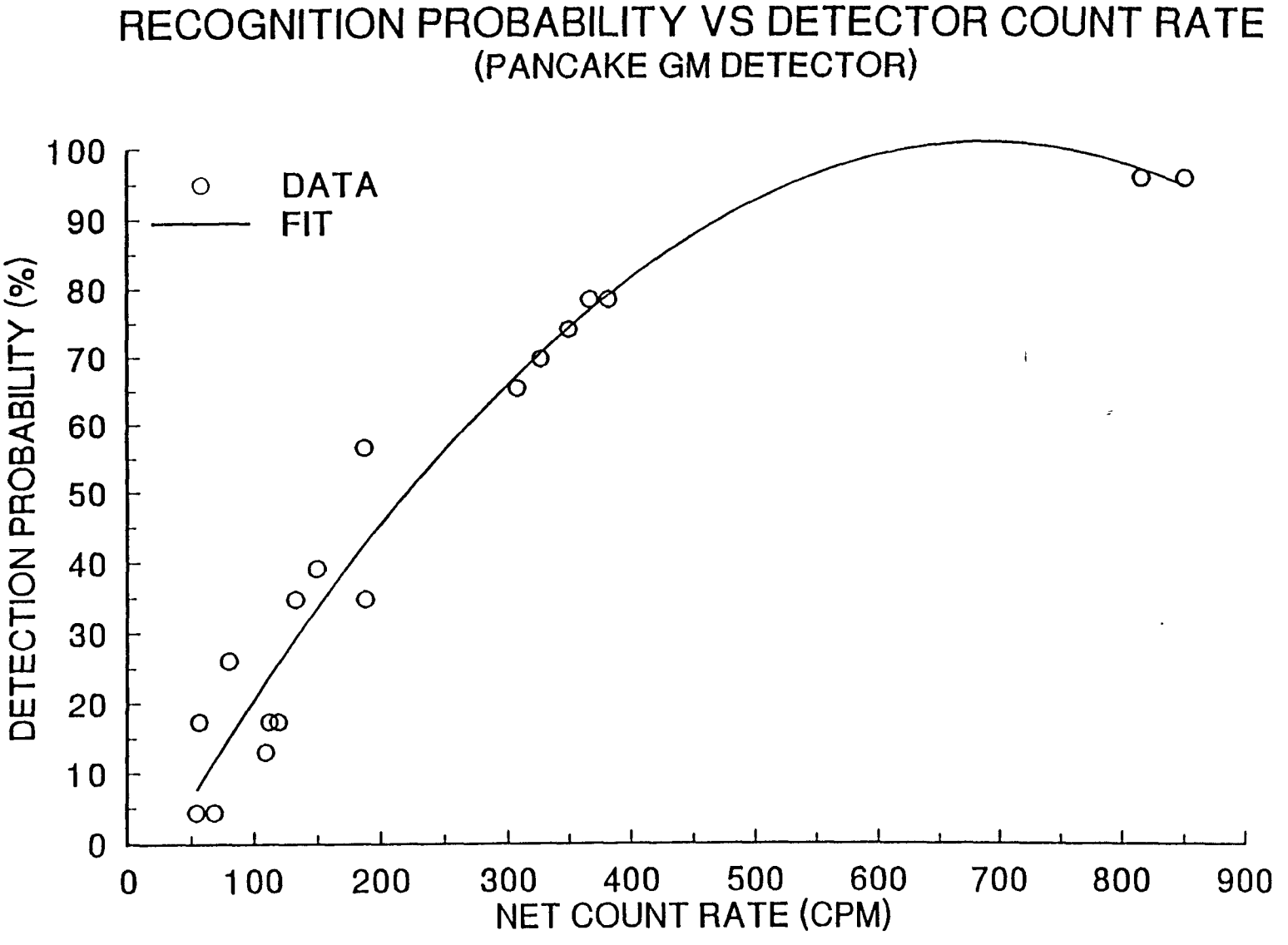

Figure 2. Detection Probability as a Function of Instrumental Response (50 cpm Background)

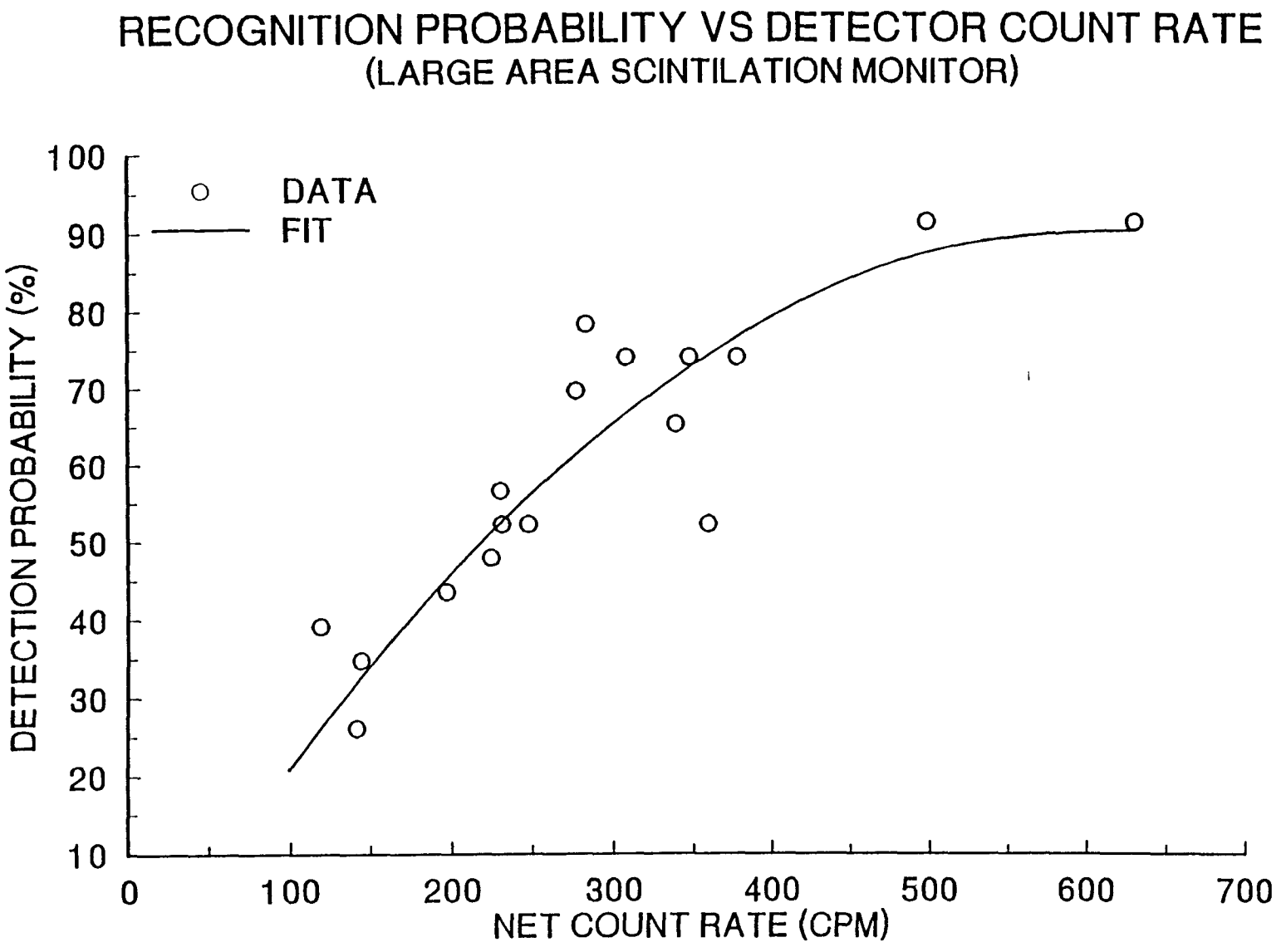

Figure 3. Detection Probability as a Function of Instrumental Response (250 cpm Background)

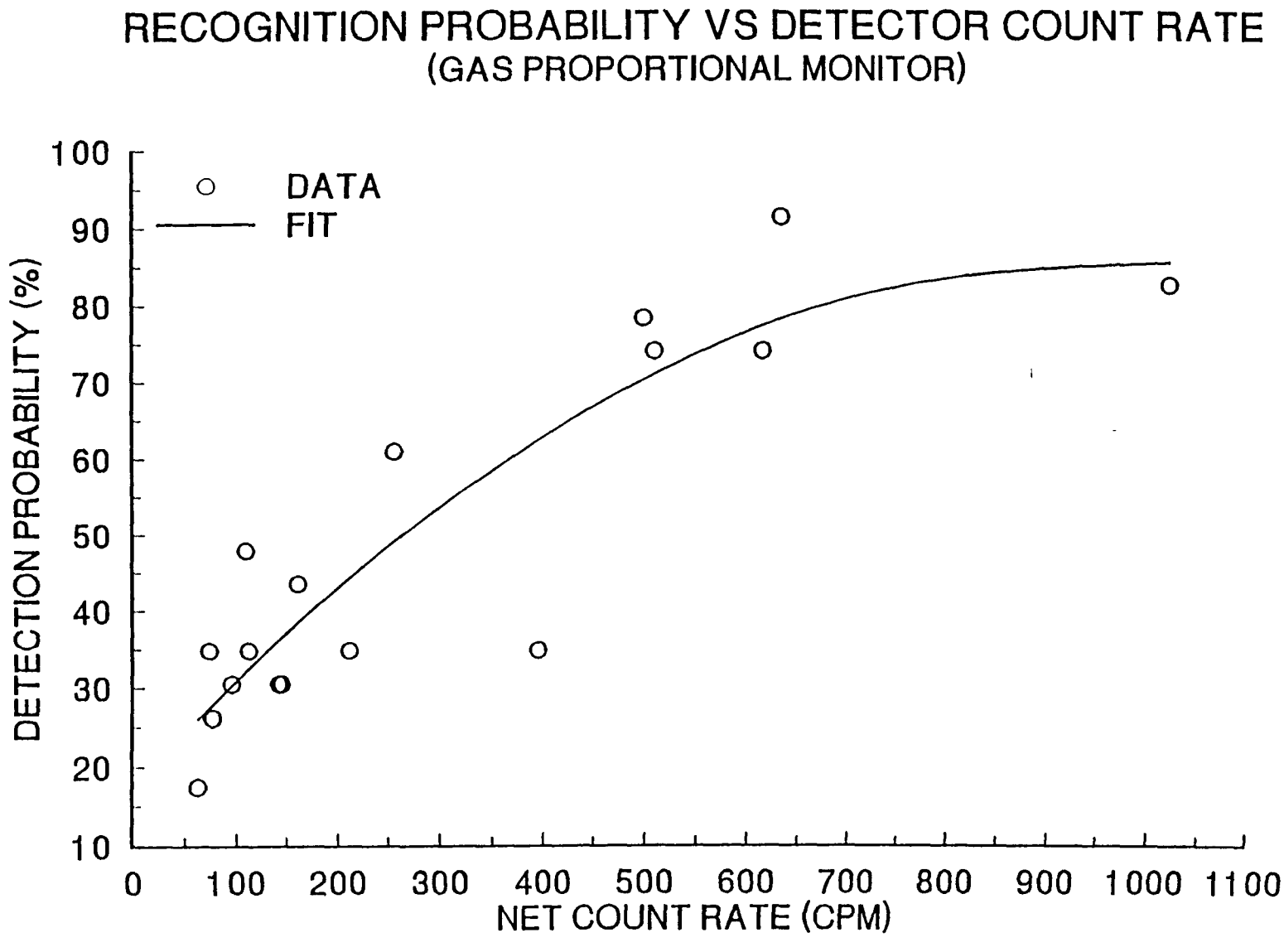

Figure 4. Detection Probability as a Function of Instrumental Response (500 cpm Background)

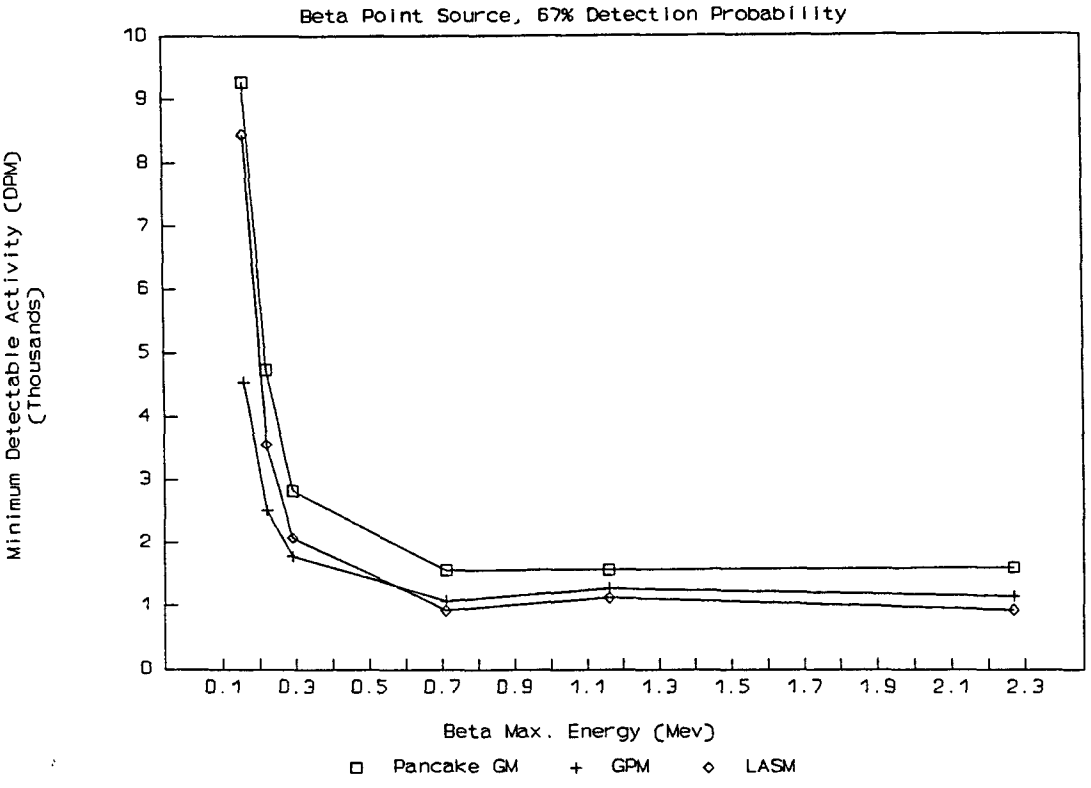

Figure 5 MDAs For β-Point Source Surface Contamination

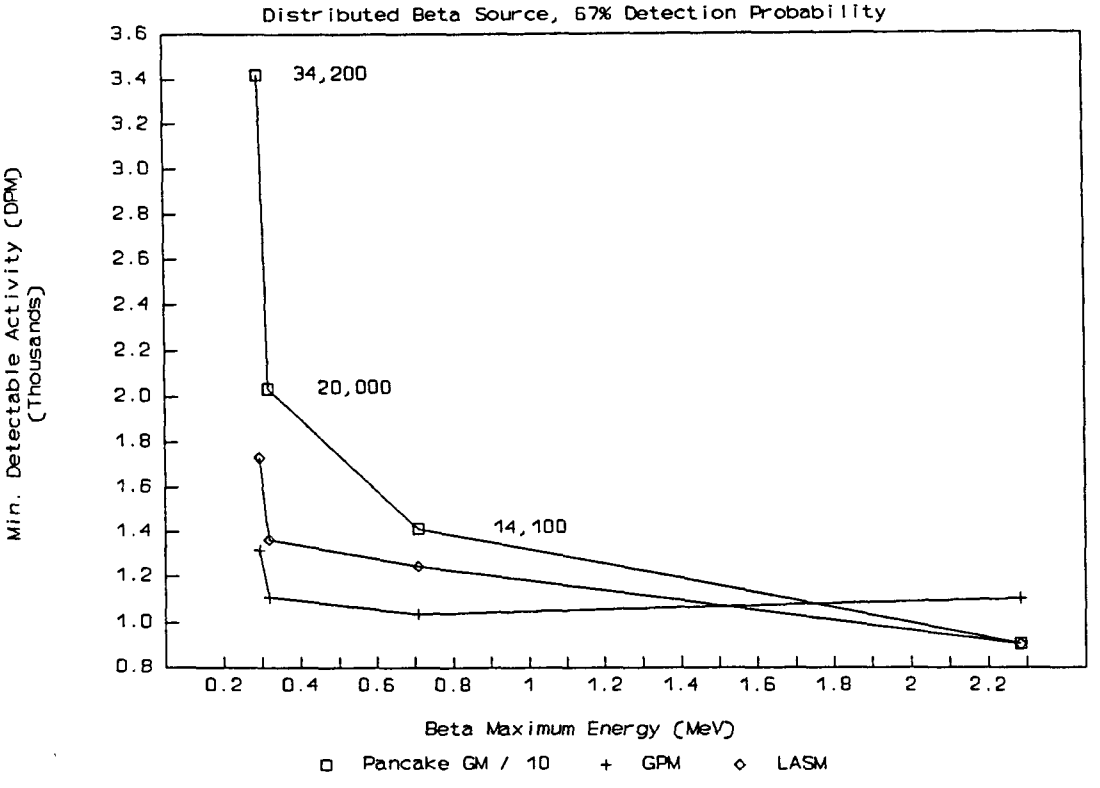

Figure 6 MDAs For Distributed ß-Surface Contamination