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TITLE: "Radiological Survey of the T056 Landfill; Area From 23rd Street to Building T100; And An Area Across From Building T011"

-APPROVALS-

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## ABSTRACT

A radiological survey was performed at three SSFL areas used to support nuclear-related facilities as storage areas for materials, components, drums, and barrels; dump sites for dirt and rubbish; and as access pathways from facility to facility. These primarily natural terrain areas include: 1) T056 Landfill/Dump Site, 2) a field between 23rd Street and Building T100, and 3) a field south of Building T011. These areas were identified in the "Radiological Survey Plan for SSFL," (Reference 4) as being potential candidate locations for residual radioactivity because of operations performed there. Two of these subject areas were noted in findings by a recent survey performed by a DOE team in May of 1988, (Reference 24). These findings apply in these areas primarily to suspect chemical contaminants; residual radioactivity is unlikely in these areas because of radiological controls imposed for dispositioning of radioactive materials and radioactively contaminated material. The areas are clear of debris, except for a small storage yard east of Building T100. Buried debris in the T056 Landfill, however, is likely. No known contamination incidents occurred at nearby facilities or within these areas to such a magnitude that would result in contaminating these inspected areas. The radiological survey was performed to determine if any radioactive material has been accidentally left behind to such an extent that further surveying or decontamination is warranted.

All combined, a 4-acre area was inspected. Ambient gamma exposure rate measurements were performed on a 6-m square plot plan. Soil sample collection and analysis was not required and not performed. A water sample collected from the T056 pit, in close proximity to the T056 Landfill, was analyzed for radioactivity.

Results of this survey and analysis show that all three inspected areas are not contaminated with residual radioactivity. Gamma exposure rate measurements plotted against cumulative probability show Gaussian distributions with no outliers or anomalies. All sample lots, when corrected for

ambient "background" radiation, pass acceptance criteria for unrestricted use. Water sample analysis shows no detectable activity. No further investigation is necessary in these locations; however, if extensive subsurface sampling is performed at the T056 Landfill and debris is recovered, surveys for radioactivity should be performed concurrently.

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## 1.0 INTRODUCTION

The T056 Landfill/Dumpsite (cleaned-up and inactive since the late 1970s), a field between 23rd Street and Building T100, and a field across from Building T011 were surveyed and analyzed for residual radioactive material. These areas were used as landfills, storage yards, dirt dumps, and pathways between nearby facilities. No known placement or dumping of radioactive materials or radioactively contaminated items is known to have occurred in these areas. However, because of the nuclear-related facilities these areas served and the operations which were conducted, this radiological survey was performed to ensure that no radioactivity has been accidentally left behind or previously undetected. The goal of this survey was to determine whether insignificant quantities of contamination exist, further investigation is required, or remedial action is necessary. This radiological survey was conducted as prescribed in the "Radiological Survey Plan for SSFL," (Reference 4, sections 5.4.17, 5.4.19, and 5.4.25).

These areas are located in Area IV of Rockwell International's Santa Susana Field Laboratories (SSFL) in Ventura County, California. SSFL has been used to develop and test nuclear reactors; fabricate nuclear reactor fuels; and disassemble irradiated fuel elements. These programs were funded by the AEC, ERDA, and DOE. Many of these government-sponsored nuclear-related programs have ended, and the facilities that supported these programs have been reassigned and modified for other non-nuclear DOE programs. The areas covered in this survey supported these programs. The site used as a dumpsite and landfill during the 1960s and 1970s was cleaned up and is no longer in use; it is commonly referred to today as the T056 Landfill because of its proximity to an excavated pit where Building T056 was to have been built. The pit elevation is about 40 ft below groundwater-table elevation and is consequently full of water. An area bordered by 23rd Street, Building T100, "F" Street, and "G" Street is partially in use as a storage yard. Miscellaneous debris has been on site: wood scrap, concrete, sodium cold traps, pipes, vessels, junked trucks, barrels, large system components, and sheet metal. A location recently identified by a DOE Environmental Survey Team (Reference 24) as suspect for chemical contaminants was a trench located just northeast of Building T100 in the 1960s.

This trench was used by contractors for burning rubbish and miscellaneous debris; it is not suspected of residual radioactivity. An area south of Building T011 was used very rarely for storing items and dumping dirt. Currently all of these areas are natural terrain, except for a portion of the field between 23rd Street and Building T100 used as a storage yard. Radioactive contamination is not likely in these areas, but because of the activities performed here and the uncertainty that accidental disposition of radioactive materials might have occurred, a radiological survey was performed to document current radiological condition.

As part of the DOE SSFL Site Survey, a radiation survey was performed in these areas to determine if any residual contamination exists. Ambient gamma exposure rates were measured on a 6-m by 6-m grid. These radiation measurements are sensitive to radiation emitted from radioactive materials handled or produced at the nuclear facilities: mixed fission products and activation products. If radioactive contamination was indicated during performance of the gamma measurements, samples were to be collected and analyzed for radioactivity. Further sampling inspection was not required for this particular survey. A water sample from the T056 pit was required by the Plan and performed.

All ambient gamma exposure rate data were input into a Personal Computer (PC) graphics program which plots the radiation measurement value against its cumulative probability. The software also calculates a test statistic using inspection by variables techniques. This test statistic is that value greater than the mean value of the distribution, which corresponds to a consumer's risk of acceptance of 10% probability with a Lot Tolerance Percent Defective (LTPD) of 0.10. This method assumes the data follow a Gaussian probability density function. Inspection by variables techniques allows a thorough, understandable, and conclusive study for assessing the contamination level in an area.

Radiation measurements are compared against DOE residual radioactivity limits specified in "Guidelines for Residual Radioactivity at FUSRAP and Remote SFMP Sites," (Reference 1). This guide generally agrees with previously published guides and standards, including ANSI Standard

N13.12 (Reference 7), Regulatory Guide 1.86, and USNRC License SNM-21 (Reference 2). Limits for acceptable ambient gamma exposure rates differ between the DOE and NRC. DOE specifies 20 μR/h above background while NRC specifies 5 μR/h above background as acceptable gamma exposure rate limits. Natural "background" at SSFL is very difficult to determine because of a large observed variability in the measurements. Because of this large variation, total-gross gamma measurements made in a survey area are plotted and compared against three independent "natural" background distributions. Then the average "background" exposure rate of the three "natural background" distributions is subtracted from each data set to compare the results against the 5 μR/h above background criteria.

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# 2.0 IDENTIFICATION OF FACILITY PREMISES

## 2.1 Location

The three areas covered in this report are identified in the "Radiological Survey Plan for SSFL," (Reference 4) as follows:

1. Old Dumpsite - Southwest of Building T059 and T056 Pit (Section 5.4.17);
2. Field From 23rd Street West to Building T100 Fence, North to Rock Outcropping (Section 5.4.19); and
3. Area Across "G" Street From Building T011 (Section 5.4.25).

Throughout this report abbreviated terms are used to refer to each inspected area; the first area is called the T056 Landfill; the second area is the T100 Storage Yard; and the third area is the T011 Field.

These areas are located in the same general vicinity of Rockwell International's Santa Susana Field Laboratory (SSFL) in the Simi Hills of southeastern Ventura County, California. The site is adjacent to the Los Angeles County line, and is approximately 29 miles northwest of downtown Los Angeles. The SSFL location relative to the Los Angeles area and surrounding vicinity is shown in Figure 2.1. Figure 2.2 is an enlarged map of neighboring SSFL communities.

The three areas covered in this report are located in the western portion of SSFL, which is referred to as Area IV. Figure 2.3 is a plot plan of Area IV showing the locations of subject areas. All of the areas are located within or adjacent to the 90.26 acre Government-Optioned Area.

## 2.2 Topography, Utilization, and Present Radiological Condition

These sites are located on an irregular plateau in a mountainous area of recent geological age sprinkled with outcroppings above the more

Figure 2.1 Map of Los Angeles Area

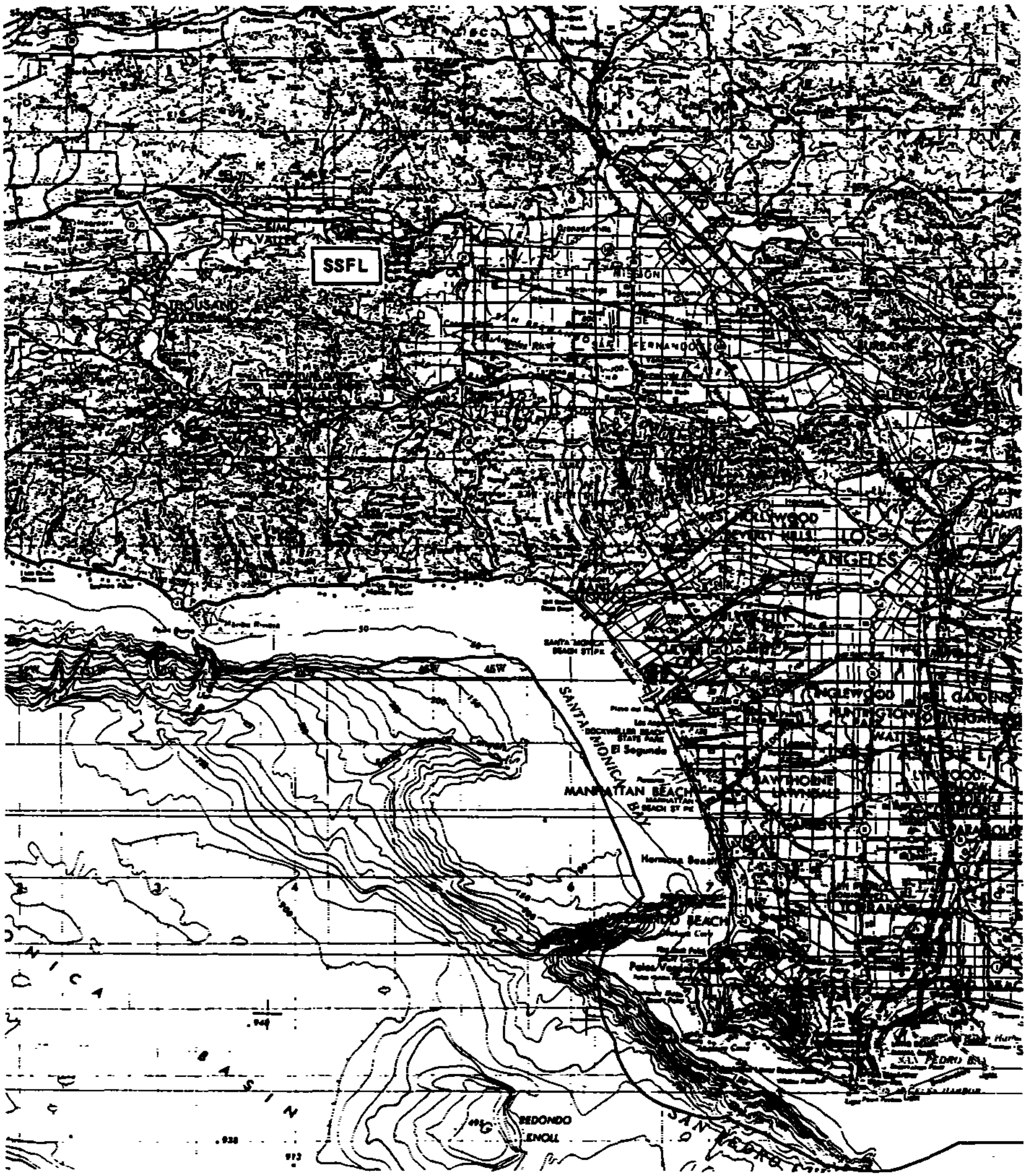


Figure 2.2 Map of Neighboring SSFL Communities

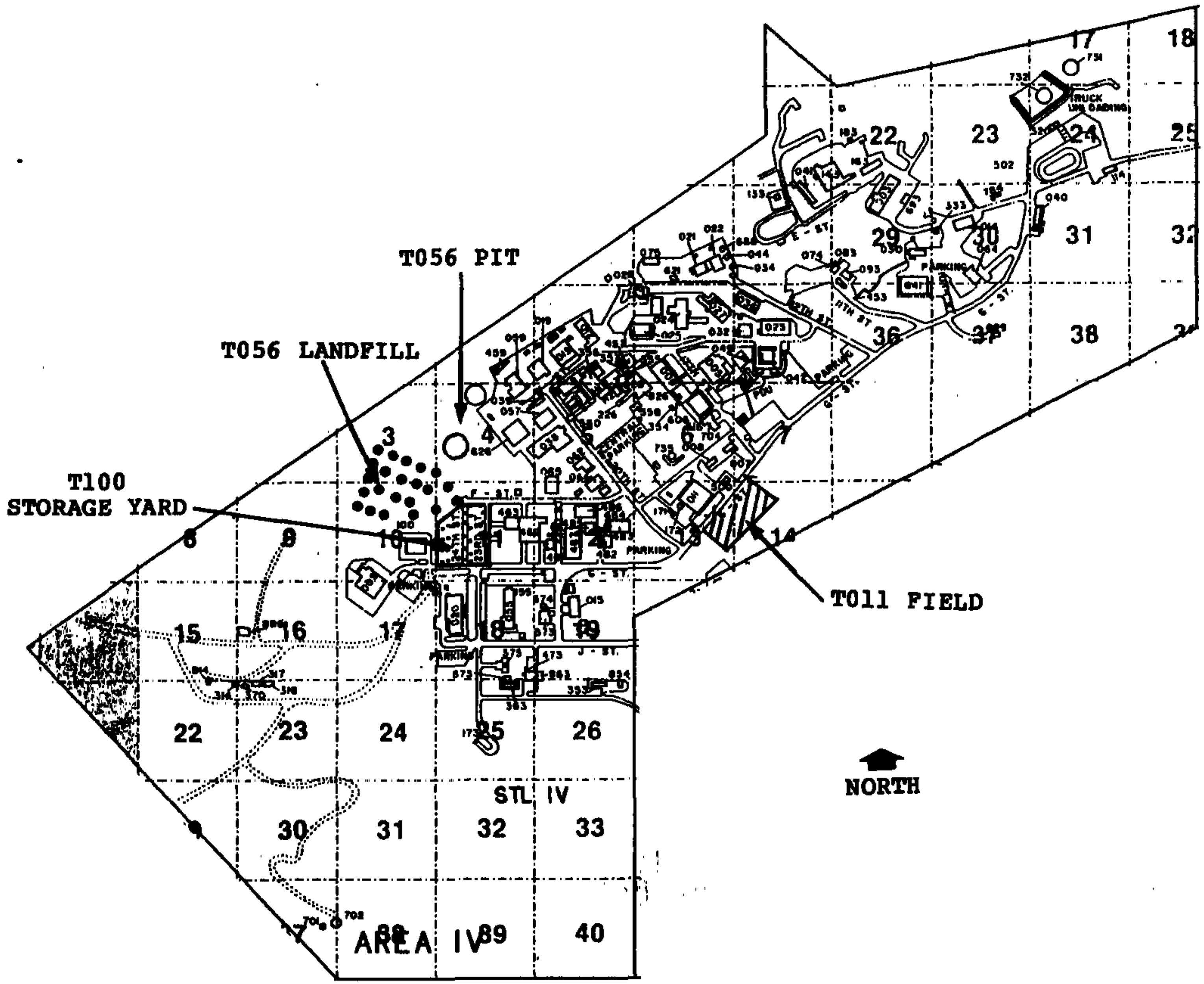



Figure 2.3 SSFL Layout, Showing Locations of
the T056 Landfill, T100 Storage Yard, and T011 Field

level patches. Outcroppings of Chico sandstone formation are numerous near the T056 Landfill. The T100 Storage Yard and T011 Field are relatively flat areas covered with natural vegetation or gravel. Large outcroppings border the northern side of the T100 Storage Yard. Topographic maps of these areas are presented in Figures 2.4, 2.5, and 2.6.

The general slope of Area IV is in a southerly direction. Water runoff is directed to the retention reservoirs which are part of the SSFL industrial effluent control system. Liquid effluent discharge from the property into the Bell Canyon drainage occurs only after controlled effluent hold-up and sampling. Because the T056 Landfill borders the northern property line, however, some surface drainage is northerly to Simi Valley via a large, deep ravine.

Most of the subject areas consist of natural terrain. Parts of the T100 Storage Yard are covered with gravel. Figure 2.7 is an aerial photograph of the areas surveyed. None of these inspected areas are highly suspect of radiological contamination. The only possible contaminants are mixed fission products and activation products. Activation products in concrete, rebar, and metal components are probably the most likely contaminants. These radionuclides are readily detectable at relatively large distances and through soil. The following sections describe in more detail each area's terrain, use, and present radiological condition.

### 2.2.1 T056 Landfill

The T056 Landfill is located southwest of a large pit which was excavated in the early 1960s as a foundation for Building T056 that was to be used for Systems for Nuclear Auxiliary Power (SNAP) 8 flight reactor tests. Shortly after the pit was excavated and before the facility foundation was set, the program was canceled. T056 was never built. This large pit, excavated in Chico sandstone, was then fenced-in and never backfilled. It is in the same condition as in the 1960s. The T056 Landfill, which is

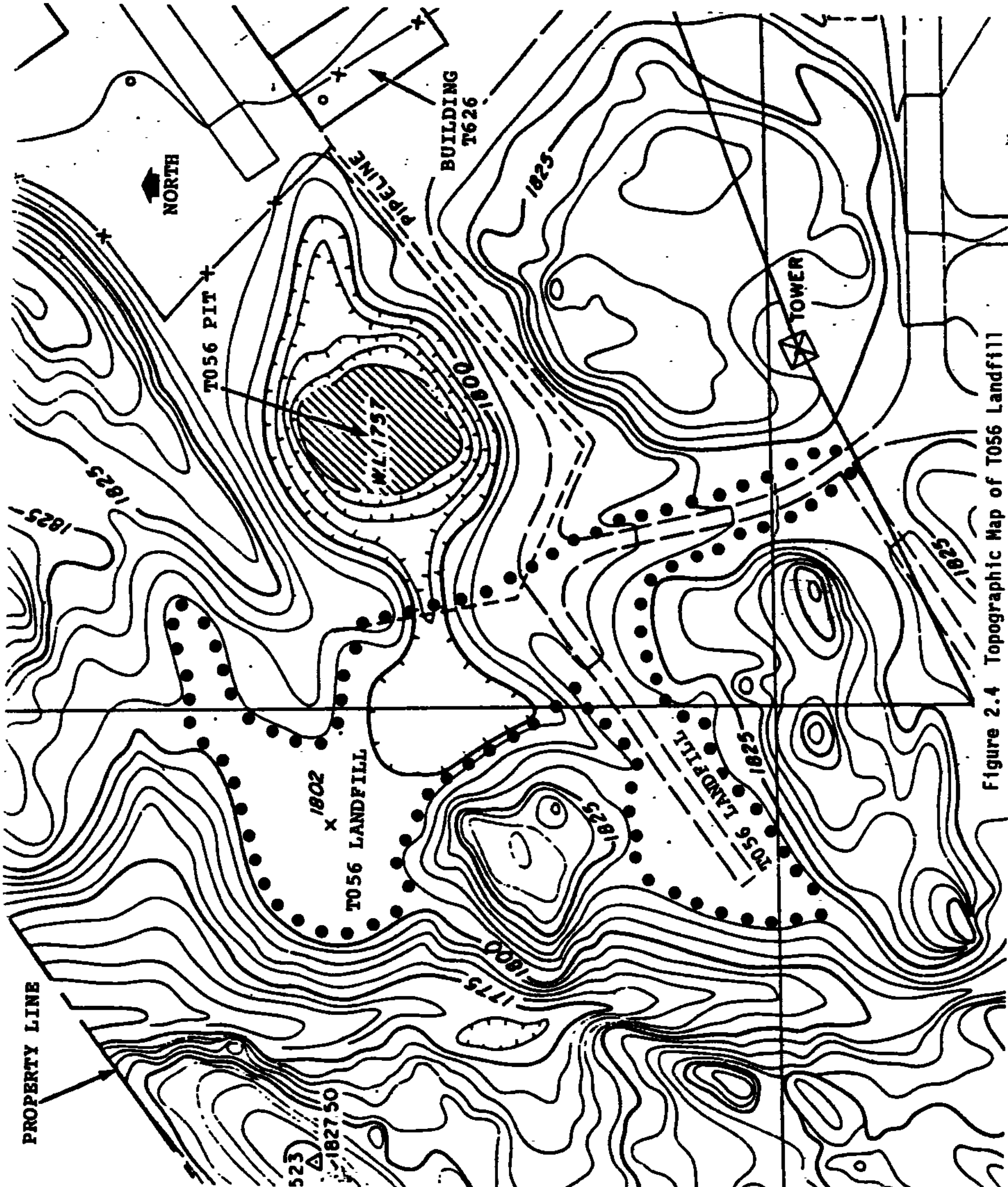



Figure 2.4 Topographic Map of T056 Landfill

Figure 2.5 Topographic Map of T100 Storage Yard

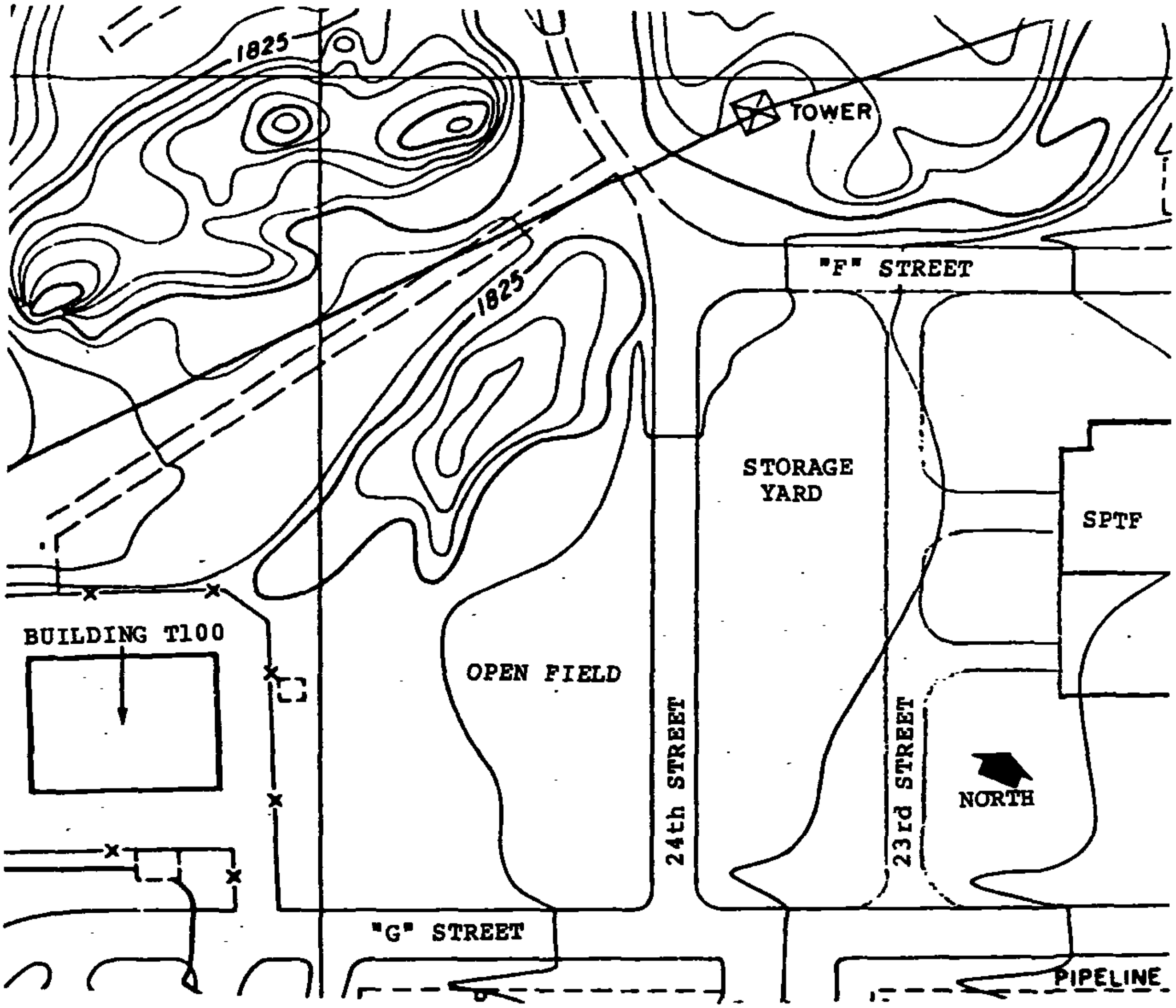
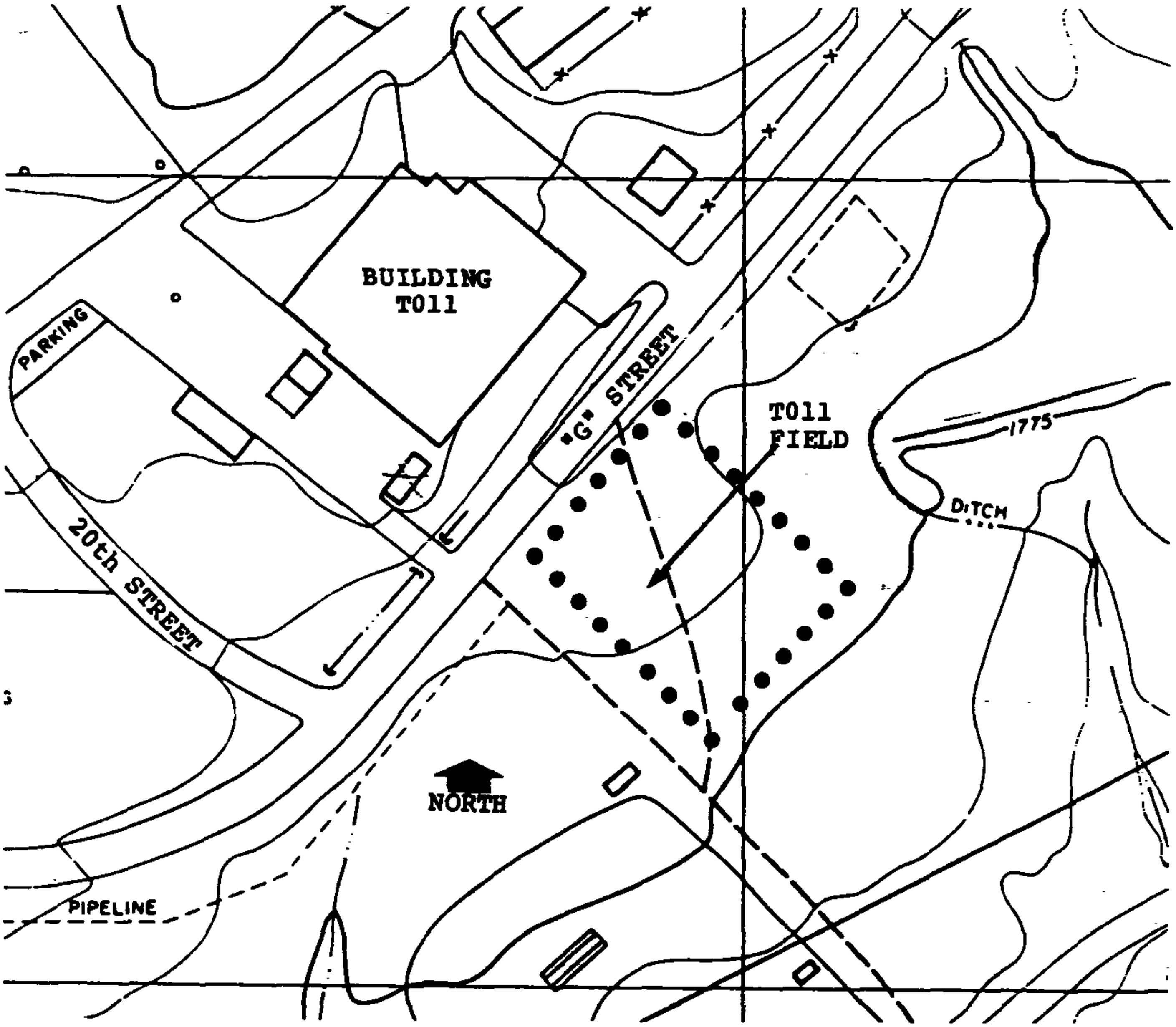


Figure 2.6  Topographic Map of T011 Field



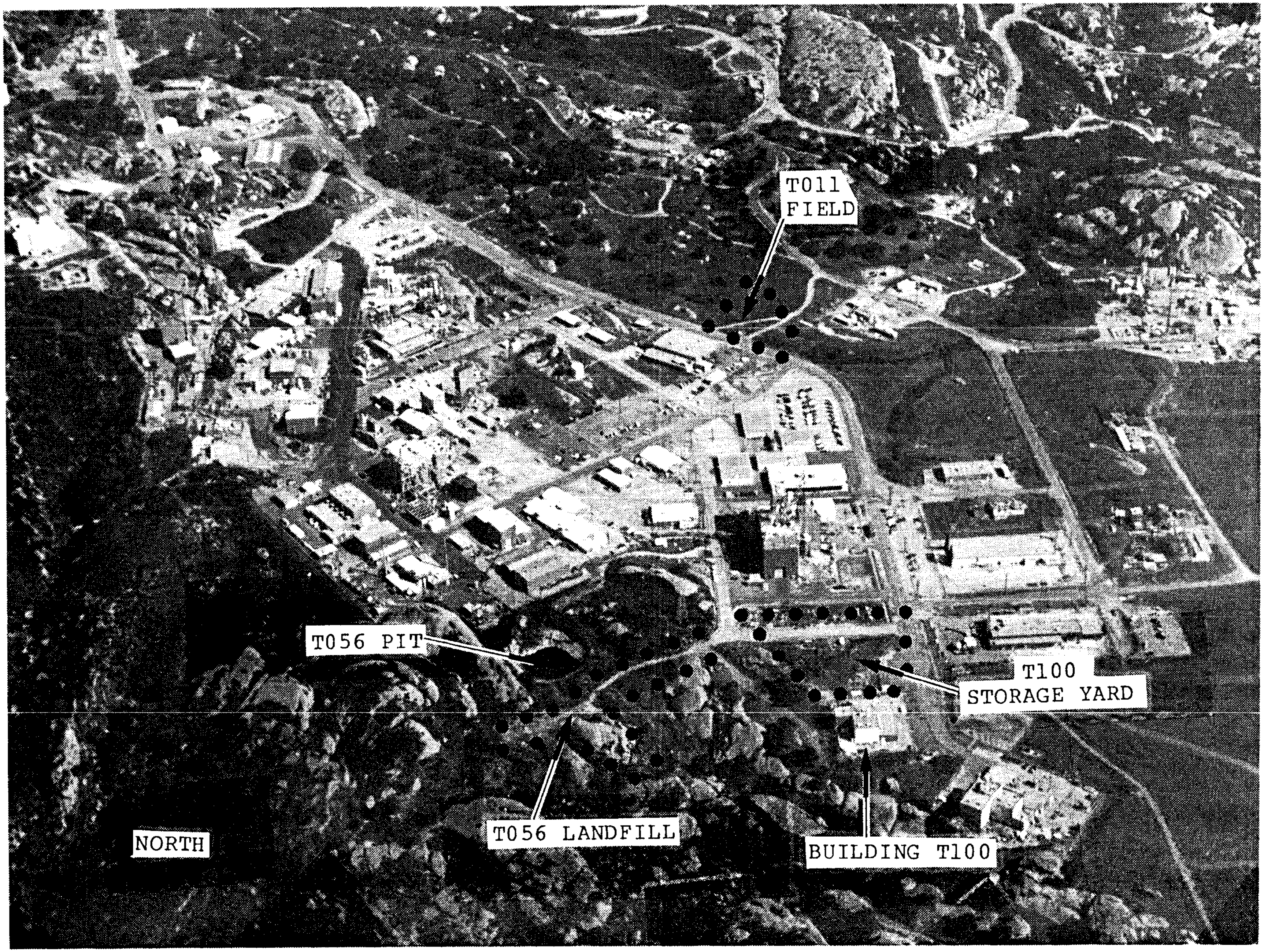



Figure 2.7 Aerial Photograph Showing Locations Surveyed

the subject of this report, was immediately adjacent to the southwest fence-line of this pit within the DOE-optioned land and was designated on drawings as "loose fill." Because of its proximity to what was to have been Building T056, this landfill is commonly referred to as the T056 Landfill. It was referred to by the DOE Environmental Appraisal team (Reference 24) as the B-56 Landfill. The T056 pit is the primary landmark.

Figure 2.8 is a 1975 photograph of the pit and the T056 landfill showing dumped scrap at the end of the road. The landfill is accessible from the intersections of 24th and "F" streets through a gated chain-link fence. This dirt road runs slightly downgrade until it plateaus in the landfill area. The landfill forms a "Y" shape with large sandstone out-croppings bordering the southern side and in between the arms of the "Y," (see Figure 2.8). To the northwest, at the landfill edge, is a significant drop in elevation (about 60 ft) into a deep ravine. Rainwater runs from the landfill north, down this ravine past the property-line, into Simi Valley. Figure 2.8 shows the landfill to be well groomed and in use, with loose dirt piled up along the edges among junk and waste materials.

The landfill was created in the early 1960s from the material excavated from the T056 pit. Earth from a Sodium Component Test Installation (SCTI) excavation was also dumped here. At various periods from the mid 1960s to mid 1970s this landfill became a dumping ground for garbage, trash, scrap, drums, and barrels. No radioactively contaminated items are known to have been deposited in this area. Radiation surveys were performed periodically. No radioactivity problems are known. From personal communications, the landfill became a fairly abused dumping ground; items were being pushed over the northern edge into the deep ravine. Finally, in the late 1970s a decision was made to remove all items from the landfill (and the ravine) and disposition them off-site. Currently the area is natural terrain overgrown with natural vegetation. A few scrap objects are still scattered about the surface. The landfill is no longer in use. Construction debris was encountered during the drilling of well RD-7, so some subsurface debris is likely to exist throughout the area (Reference 24).


Figure 2.8 1975 Photograph of T056 Pit and Landfill

Preliminary findings of the DOE Environmental Survey performed at SSFL on May 16-26, 1988 (Reference 24), assign the landfill as a Category III. This category relates only to potential sources of soil and ground water contamination. The suspect contamination here is chemical, not radiological. Based on operational history of this landfill and periodic radiation surveys which were performed, radioactive contamination in this area is not highly suspect. Because chemical contamination is suspect in this area, further subsurface sampling and chemical analysis is scheduled to be performed. As an additional assurance, radioactivity analysis will be performed concurrent with chemical analysis of subsurface samples. This report covers only surface radiological contamination.

### 2.2.2 T100 Storage Yard

The storage yard and open-field area is located between 23rd Street and Building T100. The storage yard is specifically located between 23rd and 24th streets and is covered with loose gravel. From 24th Street to Building T100 is an open, natural-terrain field. Bounding the northern side of this area is large Chico sandstone outcropping. The slope of this entire area is such that rain water runoff is into the SSFL controlled reservoir system. Because of its proximity to Building T100, this storage yard and open-field area is referred to as the T100 Storage Yard; it is not necessarily related to Building T100 activities.

The area between 23rd and 24th streets was covered with gravel in the early 1960s and used as a material storage and scrap yard for non-nuclear components only. No known radioactive contamination incidents have occurred. This yard is still in use.

The field between 24th Street and Building T100 was never used as a storage yard. Residual radioactive material is not suspect. This area is currently an open field.

1960 photos show the presence of debris and drums in a trench located near what is now the intersection of "F" and 24th streets. This trench, referred to by the DOE Environmental Appraisal team (Reference 24) as the Trench in the B-100 Area, was a Category III finding in that subject report. This category relates only to potential sources of soil and ground water contamination. This trench was used by contractors for burning and disposal of construction debris and possibly hazardous substances. The possibility of radioactive material existing in this old trench is extremely unlikely. The trench was cleaned out and backfilled in the late 1960s to early 1970s. This trench location is now covered by asphalt concrete of 24th Street. Subsurface sampling for radioactivity is not required based on the small possibility of residual contamination existing there.

### 2.2.3 T011 Field

This area is a flat, natural terrain, open field covered with natural vegetation. It has been observed to be used by operations personnel for storing/staging materials and equipment temporarily. This field was used in a small capacity -- it was never an officially recognized and operated equipment yard. The major use of this area was for dumping small truck loads of dirt; so it was referred to as the dirt dump. This area is not suspect of residual radioactivity and is not currently in use for anything.

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## 3.0 SURVEY SCOPE

The following areas were radiologically inspected by measuring ambient gamma exposure rates 1 meter above the ground in locations specified by the "Radiological Survey Plan for SSFL," (Reference 4):

1. <u>T056 Landfill (Reference 4, Section 5.4.17)</u>

   * Surface survey from entrance gate over bank and down drain line from T056 pit fence to rock outcroppings.
   * Water sample from T056 pit.

2. <u>T100 Storage yard (Reference 4, Section 5.4.19)</u>

   * Survey surface.

3. <u>T011 Field (Reference 4, Section 5.4.25)</u>

   * Survey surface for mixed fission products. On indication perform gamma spectrometry on soil samples.

These areas are shown in Figures 2.4., 2.5, and 2.6, topographic maps; and Figure 2.7, an aerial photograph.

Gamma exposure rate measurements were made at 487 locations in the combined areas: 140 (T056 Landfill); 308 (T100 Storage Yard); and 39 (T011 Field). Soil samples were not collected and analyzed because no indication of radioactive contamination occurred. Ambient gamma exposure rates are reported in micro-roentgens per hour ($\mu$R/h). Radioactivity in a water sample collected from the T056 pit was analyzed for radioactivity. The results are reported in $\mu$Ci/ml for each radionuclide identified by gamma spectrometry.

## 3.1 Unrestricted-use Acceptable Contamination Limits

A sampling inspection plan using variables, discussed in Section 4.2, was used to compare radiological contamination quantities against unrestricted-use acceptable contamination limits prescribed in DOE guidelines (Reference 1), Regulatory Guide 1.86, NRC license SNM-21, and other references. The limits shown in Table 3.1 have been adopted by Rocketdyne.

Limits for soil and water radioactivity concentrations are applicable on an as-required basis. The limits used here for alpha contamination in soil, are based on Ra-226 (Reference 1).

Three specific action levels were established for the survey. These are proactive action levels initiated when the surveyor detects radiation according to the following criteria:

1. Characterization Level - that level of radioactivity which is below 50% of the maximum acceptable limit. This level is typical of natural background levels, or slightly above, and requires no further action.

2. Reinspection Level - that level of radioactivity which is above 50% of the maximum acceptable limit. A general resurvey of the area and a few additional samples are required in this case.

3. Investigation Level - that level of radioactivity which exceeds 90% of the maximum acceptable limit. Specific investigation of the occurrence is required in this case.

Table 3.1 Maximum Acceptable Contamination Limits

| Criteria | Alpha | Beta |
|---|---|---|
| Ambient Gamma Exposure Rate* | 5 μR/h above background | |
| Soil Activity Concentration** | 21 pCi/g<br>31 pCi/g | 100 pCi/g |
| Water Activity Concentration*** | $1x10^{-4}$ μCi/ml | $1x10^{-5}$ μCi/ml |

* Although DOE Guide (Reference 1) recommends a value of 20 μR/h above background for ambient gamma exposure rate, NRC has required 5 μR/h. For conservatism, we use 5 μR/h above background to compare survey results.

** The alpha activity concentration limit for Ra-226 is 5 pCi/g (Reference 1) plus that contribution from naturally occurring radioactivity, (about 16 pCi/g from Reference 17, p. 93) averaged over the first 15 cm of soil below the surface. At a depth greater than 15 cm below the surface, 15 pCi/g averaged over 15-cm-thick layers of soil plus "background" is the limit. The total beta activity concentration limit is 100 pCi/g, including background which is about 24 pCi/g.

*** The most restrictive alpha/beta water radioactivity concentrations for a restricted area taken from DOE Order 5480.1 Chapter XI, Table 1, Column 2. Alpha corresponds to Pu-239, beta to Sr-90.

## 3.2 Sample Lots

For purposes of this radiological survey, each of the three areas was treated as a single sample lot for characterization and interpretation. Some of the areas, as demonstrated by the topographic maps, are surrounded by sandstone outcroppings. Figures 2.4, 2.5, and 2.6 show the survey sampling lot plan.

6-m square grids were superimposed over the terrain. One ambient gamma exposure rate measurement was made in each $36\text{-m}^2$ cell. Location (1,1) was the northwestern-most grid in each area. Each measurement location was marked on a map with its corresponding two figure Cartesian coordinate indicating the location from a local benchmark. The sampling inspection plan used was based upon a uniform 6-meter square grid superimposed on a uniform inspection area. Radiological conditions and physical surroundings fell into two categories: 1) Gravel cluttered with metal parts (portion of T100 Storage Yard); or 2) natural terrain (remaining test-areas).

The T056 pit was treated separately from other sample lots. A water sample was collected and analyzed for radioactivity.

### 3.3 Ambient Gamma Exposure Rate Measurements

In each 36-$m^2$ cell, a gamma exposure rate measurement was made 1 m from the surface. The particular location in each cell was chosen randomly, and identified on a map. A tripod was used to support a 1 in. x 1 in. NaI crystal coupled to a photomultiplier tube and fed to a Ludlum 2220-ESG scaler, at 1 m from the ground. In each cell, a 1-min. count was collected and converted to $\mu$R/h. The measurement location and exposure rate were recorded in tabular form. 487 1-min. measurements were acquired over the total area.

### 3.4 Surface Soil Samples

Soil sampling was required by the Site Survey Plan (Reference 4) only if gamma exposure rate measurements indicated possible radioactivity. Exposure rate measurements did not indicate possible contamination. Soil samples were not collected.

### 3.5 Water Sampling from T056 Pit

A water sample was collected and analyzed for radioactivity as required by the Site Survey Plan. Analysis was by gamma spectrometry. Positively identified isotopes (see library in Appendix E) are reported in activity concentrations of $\mu$Ci/ml. No Detectable Activity (NDA) is used to indicate that no isotopes, other than naturally-occurring ones, were identified by gamma spectrometry.

## 3.6 Goals and Limitations of Survey Scope

These landfills, storage yards, pathways, and dirt dumps cover an extensive territory; about 4 acres. Certain locations were used for many years and were used quite actively in the 1960s and early 1970s for storing scrap and dumping materials. Limited inventory controls were used during these periods; however, radiological controls were well-known and were complied with. Radioactive materials and radioactively contaminated equipment were prohibited from these areas. Radiation surveys were performed randomly throughout these SSFL sites on a regular basis to ensure compliance with this policy. We believe that no contaminated items or debris were ever discovered in these areas, and that includes access paths and roadways to various facilities. Radioactivity is not suspect. The goal of this survey is to determine if contamination exists to such an extent that further surveying or remedial action is warranted.

Ambient gamma exposure rate measurements are sensitive enough to detect contaminants left behind. Most probable contaminants are mixed-fission products and activation products. Subsurface (greater than a foot) debris is currently known to exist at the T056 Landfill. However, the likelihood of that debris being contaminated with radioactive material is thought to be small. If any contaminants do exist on-site, they are most likely still on the surface, or buried slightly below the surface at the T056 Landfill.

Because of the large area surveyed, exposure rates were measured every 36 $m^2$. This sampling plan is sufficient for two reasons:

1) gamma measurements made on a 6-m square would detect Cs-137, a fission product, at 100 pCi/g (the beta activity limit) if the surface layer was thicker than 1 cm. A 1 mCi Cs-137 source would be detectable at the greatest separation distance of 6 meters. These sensitivities meet the requirements of this survey; and

2) By applying Lot Tolerance Percent Defective techniques, we can determine with a statistical confidence of 0.90, that there is a probability of 90% that radioactive contamination does not exceed some predetermined acceptance limit. This determination varies inversely to the number of samples taken. This technique, along with the graphical representations of cumulative distribution functions will identify trends, anomalies, outliers, and perturbations in the radiation levels.

We are able to conclude whether:

1. Any surface deposition, migration, or dispersion of radioactive materials has occurred; and

2. Any relatively intense gamma-emitting debris is buried (see Section 5.4.4).

We cannot conclude whether:

1. Any slight subsurface migration has occurred; or

2. Any buried debris with low intensity radiation is present.

The likelihood for occurrence of the above two conditions is small. First, migration periods of contaminants below the surface are typically very long. It is much easier for surface water flowing downslope to carry any contaminants with it. The settling out of these contaminants into the subsurface also takes a long time. Second, no known burial or debris dumping activities took place at the T100 Storage Yard or T011 Field. At the T056 Landfill, however, buried debris is thought to be present; however, the likelihood of radioactive contamination on subsurface debris is small. The sensitivity of these measurements is discussed in detail in Section 5.4.4.

Radioactivity, other than ambient fallout, is not suspected in the T056 pond. A surface sample collected is representative of the pit because water mixes well due to daily ambient temperature changes. Gamma spectrometry gives us the desired sensitivity for detecting most probable radioactive contaminants mentioned previously.

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# 4.0 STATISTICS

## 4.1 Counting Statistics

The emission of atomic and nuclear radiation obeys the rules of quantum theory. As a result of this, only the probability that an emission will occur is determined. The absolute number of particles emitted by a radioactive source in a unit of time, is not constant in time; it has a statistical variability because of the probabilistic nature of the phenomenon under study. The number of particles emitted per unit time is different for successive units of time. Therefore, only the average number of particles emitted per unit time and per unit area or mass can be determined. The number of particles, x, emitted by a radiation source in time, T, obeys the Poisson distribution:

$$P_x = \frac{m^x e^{-m}}{x!} \qquad \text{(Eq. 4-1)}$$

where m is the average number of emissions in that time. x is what we measure each time an area or sample is surveyed. The standard deviation is the square root of the average squared deviation of x from its mean, m. For the Poisson distribution, the standard deviation is given by:

$$s = \sqrt{x}\ , \qquad \text{(Eq. 4-2)}$$

the square root of the counts observed, $(x \approx \overline{x} = m)$. Since background radiation is always inherent in a given sample measurement, propagation of errors tells us that the total standard deviation is:

$$s = \frac{\sqrt{C + B}}{T} \qquad \text{(Eq. 4-3)}$$

where C = the number of counts recorded in time, T, of the sample

B = the number of counts recorded in time, T, of the background radiation environment

Equal values of the time, T, must be used for the sample and background counts for equation 4-3 to apply. This Poisson distribution and standard deviation applies for single radiation measurements, of the discrete random variable, x, and is applicable only when the observation times are short compared with the half-life. This is the case for the site survey.

Because of the probabilistic nature of particles emitted by radioactive elements, repeated measurements of the average number of emissions per unit time shows a distribution approximated by the Gaussian (or normal) probability density function (pdf); this is known as the central limit theorem. This theorem holds for any random sample with finite standard deviation. If measurements are made at many similar locations, these measurements will show a greater variability, but the distribution will remain adequately represented by a Gaussian function. This Gaussian approximation is good when the number of samples collected is at least 30. Thus the number of occurrences of particular mean radiological contamination values, g(x), shows a Gaussian pdf relative to the contamination value, and the data can be plotted accordingly. Subsequently, based on the results of the data analysis, a conclusion can be made regarding the amount of radioactive material in an area, and any anomalous values can be identified.

The Gaussian probability density function, g(x), is given by:

$$g(x)dx = \frac{1}{(\sqrt{2\pi})\sigma} \exp\left(\frac{-(x-m)^2}{2\ \sigma^2}\right) dx \qquad \text{(Eq. 4-4)}$$

where g(x)dx = probability that the value of x, lies between x and x+dx

m = average, or mean of the population distribution

$\sigma$ = standard deviation of the population distribution.

A graph of x vs. g(x) gives the following bell-shaped curve:

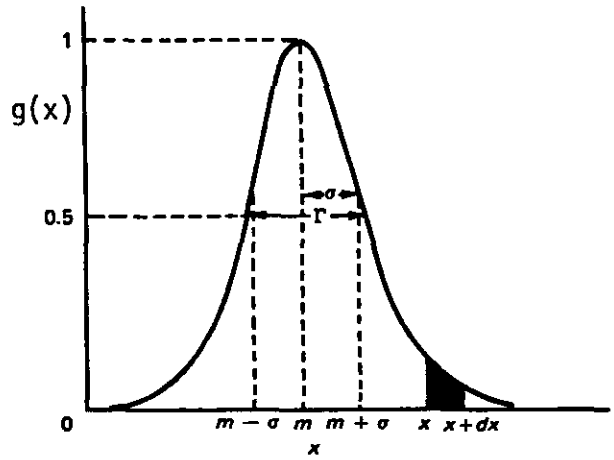


Figure 4.1 The Gaussian Probability Density Function

The cumulative distribution function (cdf), G(x), is equal to the integral of the pdf, for a continuous random variable, hence:

$$G(x) = \int_{\infty}^{X} g(x)dx \qquad \text{(Eq. 4-5)}$$

$$= P(x < X)$$

This function is commonly referred to as the error function, (erf). The graph of the Gaussian cdf is:

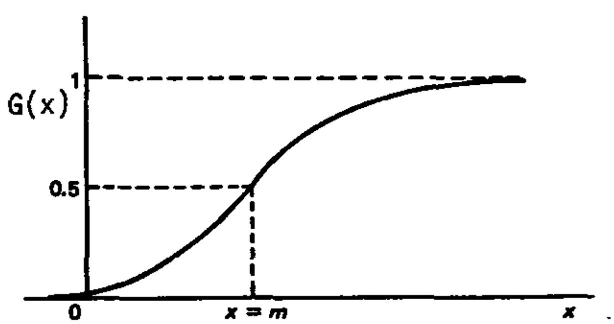


Figure 4.2 The Gaussian Cumulative Distribution Function

By plotting multiple measurements we make in the field; i.e. the average contamination values approximated by the Poisson distribution, as a cdf of the Gaussian distribution, we can identify whether the entire area is unacceptably contaminated, part of the area is contaminated more than the rest, or further radiological measurements are necessary. Furthermore, by making use of the Gaussian approximation, we can easily calculate the mean contamination value with its associated standard deviation, and apply inspection by variables techniques to either accept the area as clean or reject the area as contaminated.

This statistical summary presents fundamental principles used to reduce and analyze radiological measurement data from the site survey.

## 4.2 Sampling Inspection

### 4.2.1 By Variables

Acceptance inspection by variables is a method of judging whether a lot of items is of acceptable quality by examining a sample from the lot, or population. In the case of determining the extent of contamination in an area, it would be unacceptably time consuming and not cost effective to measure 100% of the population. However, by applying sampling inspection by variables methods, the accuracy of the conclusion made about the level of contamination is not sacrificed because of a decrease in number of sampling locations. We estimate the level of contamination in an area by making at least 30 measurements. This allows us to approximate a Gaussian distribution through the Central Limit Theorem. The entire area must have similar radiological characteristics and physical attributes. In acceptance inspection by variables, the result is recorded numerically and is not treated as a Boolean statistic, so fewer areas need to be inspected for a given degree of accuracy in judging a lot's acceptability.

### 4.2.2 By Attributes

By contrast, in acceptance inspection by attributes, the radiation measurement in a given area is recorded and classified as either being defective or nondefective, according to the acceptance criteria. A defect means an instance of a failure to meet a requirement imposed on a unit with respect to a single quality characteristic. Second, a decision is made from the number of defective areas in the sample whether the percentage of defective areas in the lot is small enough for the lot to be considered acceptable. More areas need to be inspected to obtain the same level of accuracy using this method. Consequently, we use inspection by variables.

## 4.3 Sampling Inspection by Variables

### 4.3.1 Calculated Statistics of the Gaussian Distribution

The test statistic for each sample area, $\overline{x} + ks$, is compared to the acceptance limit U, where:

- $\overline{X}$ = average (arithmetic mean of measured values) of sample
- s = observed sample distribution standard deviation
- k = tolerance factor calculated from the number of samples to achieve the desired sensitivity for the test
- U = acceptance limit.

The sample mean is given by:

$$\overline{x} = \frac{\sum_{i=1}^{n} x_i}{n} \qquad \text{(Eq. 4-6)}$$

where: $x_i$ = individual measurement values
n = number of measurement values

The standard deviation, s is given by:

$$s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - x)^2}{n-1}} \qquad \text{(Eq. 4-7)}$$

The sample mean, standard deviation, and acceptance limit are easily calculable quantities; the value of k, the tolerance factor, bears further discussion. Of the various criteria for selecting plans for acceptance sampling by variables, the most appropriate is the method of Lot Tolerance Percent Defective (LTPD), also referred to as the Rejectable Quality Level (RQL). The LTPD is some chosen limiting value of percent defective in a lot. Associated with the LTPD is a parameter referred to as consumer's risk ($\beta$), the risk or probability of accepting a lot with a percentage of defective items equal to the LTPD. It has been standard practice to assign a value of 0.10 for consumer's risk ($\beta$). Conventionally, the value assigned to the LTPD has been 10%. These a priori determinations are consistent with the literature and regulatory position, and are the same values used by the State of California (Reference 2). Thus, based on sampling inspection, we are willing to accept the hypothesis that the probability of accepting a lot as not being contaminated which is in fact 10 percent defective (i.e. above the test limit, U) is 0.10. The value of k, which is a function of the a priori determinations made for $\beta$ and LTPD is given by equation 4-8.

Figure 4.3 demonstrates this principle. The operating characteristics curve of a Gaussian sample distribution shows the principles of consumer's and producer's risk, LTPD (or RQL), and acceptable quality level, (AQL). The criteria for acceptance of a lot are presented in section 4.3.3.

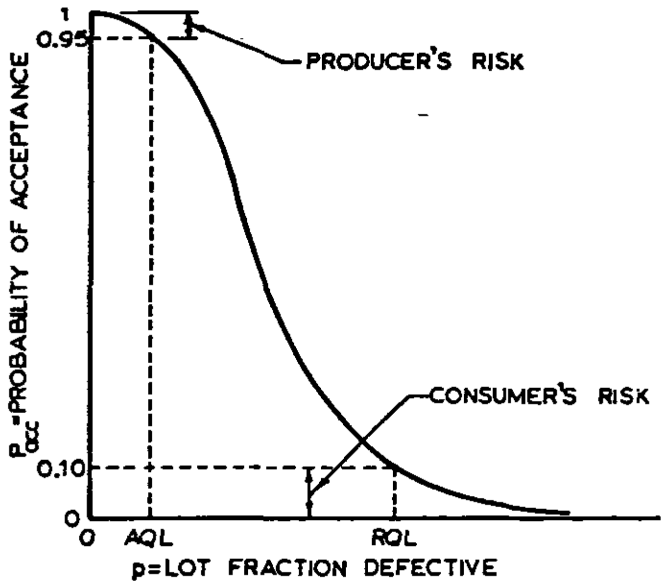


Figure 4.3 Operating Characteristics Curve

The value of k, and thus the value of $\bar{x} + ks$, on which ultimately a decision is made whether the area is acceptably clean, is based on the conditions chosen for the test. k is calculated in accordance with the following equations, (Reference 8):

$$k = \frac{K_2 + \sqrt{K_2^2 - ab}}{a} \; ; \; a = 1 - \left(\frac{K_\beta^2}{2(n-1)}\right); \; b = K_2^2 - \frac{K_\beta^2}{n} \quad \text{(Eq. 4-8)}$$

where:

k = tolerance factor
$K_2$ = the normal deviate exceeded with probability of $\beta$, 0.10 (from tables, $K_2 = 1.282$)
$K_\beta$ = The normal deviate exceeded with probability equal to the LTPD. 0.10 (from tables, $K_\beta = 1.282$)
n = number of samples

As mentioned previously, the State of California has stated that the consumer's risk of acceptance ($\beta$) at 10% defective (LTPD) must be 0.1. For these choices of $\beta$ and LTPD, $K_\beta = K_2 = 1.282$.

The coefficients $K_\beta$ and $K_2$ are equal because of the choice for the values of both $\beta$ and LTPD as 0.10. Refer to statistics handbooks listed in the reference section for additional description of this sampling principle. The values chosen for the sampling coefficients are consistent with industrial sampling practice and regulatory guidance.

### 4.3.2 Graphical Display of Gaussian Distribution

When the cdf G(x), the integral of the Gaussian pdf, (Eq. 4-4), is plotted against x, the measurement value, a graph of the error function is generated (Fig. 5.2) on a linear-grade scale. For convenience of this survey and for readability, G(x) is plotted as the abscissa (x-axis) on a probability grade scale and the measurement value, x, is plotted as the ordinate (y-axis). G(x) values arranged in order of magnitude from left to right form a straight line on probability-grade paper, when the sample lot contamination is normally distributed. Figure 4.4 shows this output.

The power of this graphical display is that it permits identification of values with significantly greater contamination than expected for that lot. Calculated statistics numerically indicate the average and dispersion of the distribution, but are not effective for identifying trends or anomalies. For instance, identification of an isolated area in a sample lot which is contaminated at levels significantly greater than the fitted Gaussian line are easily observable in the plot, but $\overline{x}$ + ks may still show acceptability. Upon further inspection and analysis, these graphical displays are used to show contamination level differences between areas or structures in a sample lot. The power of the fitted Gaussian graphical display is important in assessing significant variations in the contamination levels within sample lots.

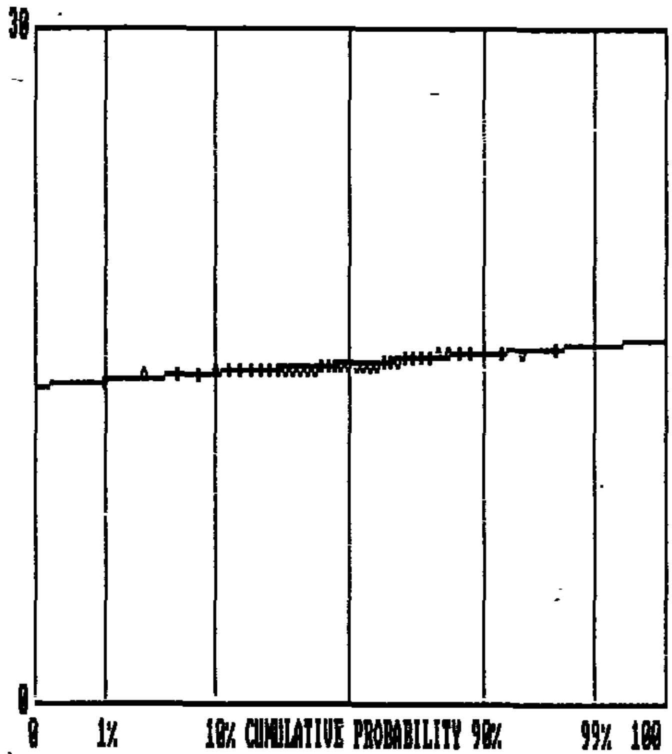


Figure 4.4 Gaussian cdf Plotted on Probability-Grade Paper

4.3.3 Acceptance Criteria for an Uncontaminated Area

Once the test statistic, $\overline{x} + ks$, is calculated and the Gaussian cdf probability plot is generated, a decision is made as to the extent of contamination in the area. Is the area clean? Is part of the area contaminated? Is the entire area contaminated? Are additional measurements necessary to make a determination?

First, the Gaussian distribution will identify significant variations in the radiological measurements. The sample output, if it represents the entire area well, should approximate a straight line. Measurements made which represent radiological conditions in a separate population from the one assumed, are easily observable as severe deviations in the straight line. The location of these anomalous measurements can be determined and subsequent follow-up is applied.

Second, the test statistic, $\overline{x} + ks$, is calculated for the distribution. The criteria for acceptance are presented as a plan of action. The action plan is:

1) Acceptance: If the test statistic ($\overline{x}$ + ks) is less than or equal to the limit (U), accept the region as clean. (Any single value, x, less than 50% of the limit is considered the <u>Characterization Level</u>, which requires no further action. If any single measured value, x, exceeds 50% of the limit, reinspect that location and take a few additional samples in the immediate area for the analysis. This is the <u>Reinspection Level</u>. If any single measured value, x, exceeds 90% of the limit, investigate the source of occurrence. This is the <u>Investigation Level</u>. These proactive action levels were presented in section 3.1.)

2) Collect additional measurements: If the test statistic ($\overline{x}$ + ks) is greater than the limit (U), but $\overline{x}$ itself is less than U, independently resample and combine all measured values to determine if $\overline{x} + ks <= U$ for the combined set; if so, accept the region as clean. If not reject the region.

3) Rejection: If the test statistic ($\overline{x}$ + ks) is greater than the limit (U) and $\overline{x} >= U$, reject the region. Investigate the source of occurrence.

# 5.0 ANALYTICAL TECHNIQUES

The statistical methods presented in Section 4.0 were used to judge whether an area is not contaminated, slightly contaminated, contaminated above acceptance limits, or whether additional investigation is required. For this particular survey, that judgement is based on one type of radiological measurement: ambient gamma exposure rate. A water sample collected from the T056 pit was analyzed "for indication" of contaminants; this data was not treated statistically and no special analytical techniques apply.

Analytical techniques used to acquire, evaluate, and interpret these radiological measurements are presented in detail in this section. These techniques include instrument calibration, determination of "background" radiation, and computerized data analysis through inspection by variables.

## 5.1 Data Acquisition

In each designated 6-m square grid, ambient gamma exposure rate was measured. Each square grid was stepped-off from a local benchmark and marked with its coordinates. The exact location within that square grid where the measurement was made was left to the surveyor's judgement: it was to be the area that, in his judgement, was most likely to have retained the greatest amount of contamination in that square grid. This decision is based on discoloration, debris, crevices, or cracks in the soil; a low settling spot for rain water; or loosely packed earth. The use of a predetermined grid with discretion for the exact location provides a uniform survey biased towards the high end of the distribution. Locations of noticeably greater exposure rates were to be reinspected. Reinspection was not required for this particular survey.

## 5.2 Data Reduction Software Program

Each gamma exposure rate measurement value was input into SMART SPREADSHEET. This is an off-the-shelf computer software package which allows multiple computations to be performed on raw data values. Columns were established to calculate the surface ambient gamma exposure rate and its standard deviation in μR/h. Software was developed in a program language called Quick Basic by Microsoft to read data from a SMART file into a graphics program which plots the radiological measurements against the Gaussian cdf. For convenience, the distribution function, G(x) is plotted as the abscissa (probability grades), and x, the measurement value, is plotted as the ordinate (linear grades).

Input for data reduction of these measurements was:

1) Grid location, ex. (10,6)
2) Ambient Gamma Exposure Rate (counts in 1 min.; cpm);
3) Gamma survey instrument background (1 min.); and
4) Efficiency factor (μR/h/cpm).

Output for Gaussian plots of these measurements:

1) Ambient gamma exposure rate and standard deviation (μR/h).

## 5.3 Data Analysis

An arithmetic mean and standard deviation of the radiological measurement values is calculated for each data set. The test statistic, $\overline{X}$ + ks, based on a consumer's risk of acceptance of 0.10 at 10% defective, is also calculated for each distribution. The acceptance criteria presented in Section 4.3.3 is applied to each sampling distribution using the acceptance limits in Table 3.1.

From the plot of measurement values vs. cumulative probability, the mean radiological value of the lot is the point on the ordinate axis where the fitted-distribution intersects the 50% cumulative probability. In test cases where an acceptance limit has been established for acceptably clean, a vertical line is plotted corresponding to the test statistic, $\overline{x}$ + ks. When an acceptance limit is applied to a test case, horizontal lines are displayed on the graph at 0 (zero), 50% of the acceptance limit (Reinspection), 90% of the acceptance limit (Investigation), and at the acceptance limit. The figures display the results on an expanded scale so that the variations in the data can be seen in detail.

5.4 Ambient Gamma Exposure Rate

Measurements of ambient gamma exposure rate were made by use of a 1 in. x 1 in. NaI scintillation crystal coupled to a Ludlum Model 2220 portable scaler, (Appendix A). This device was mounted on a tripod so that the sensitive crystal was 1 meter from the ground. The detector is nearly equally sensitive in all directions, i.e. 4-$\pi$ geometry, and can show variations in exposure rate down to one-half of a $\mu$R/h, using the digital scaler for a 1-min. count time. Because of the natural variability of ambient radiation, however, a 3 to 5 $\mu$R/h exposure rate above "background" is considered the instrument sensitivity in practice. At this level, a surveyor would decide to collect additional measurements.

5.4.1 Instrument Calibration

This detector is calibrated quarterly by the calibration laboratory using Cs-137 as the calibration source. A voltage plateau is plotted and the voltage is set at a nominal 800 V. The detector is placed on a calibration range and readings taken at 5, 2, 1, 0.9, 0.5, 0.4, 0.3, and 0.2 mR/hr. A detector efficiency plot as a function of exposure rate is generated in this regard, ($\mu$R/h/cpm).

Because of an exposure rate-dependent effect and because our calibration range does not read less than 200 μR/h (0.2 mR/h), this instrument was cross-calibrated against a Reuter Stokes High Pressure Ion Chamber (HPIC). Count rates were converted to exposure rates by the relationship that about 215 cpm = 1 μR/h, at background exposure rates. This calibration was performed several times.

Instrument response was checked three times a day using a Ra-226 source. The source was placed 1 ft from the detector and counted for 1 min. If the scaler reading fell within ± 5% of the nominal value, then the instrument was qualified as operable for the day, under the calibration conditions previously described. Recalibration because of "instrument out of tolerance" was never necessary.

### 5.4.2 Data Acquisition and Reduction

Each location where a gamma measurement was made was identified on a map and in matrix notation. The gross number of counts recorded in 1 min. along with the matrix notation location was input into SMART SPREADSHEET. Columns were established to calculate the total exposure rate (μR/h) and its standard deviation according to equations 5-1 and 5-2. Gamma scintillations produced by a NaI detector were converted from gross counts to exposure rate (μR/h) by:

$$R = \frac{(C) * (EF)}{1 \text{ min.}} \qquad \text{(Eq. 5-1)}$$

where R = exposure rate (μR/h)

C = gross counts in 1 min.

EF = efficiency factor (0.0047 μR/h/cpm) based on cross calibration with HPIC.

The standard deviation of a single measurement then becomes by Eq. 4-3:

$$s = \frac{\sqrt{C} *(EF)}{1 \text{ min.}} \qquad \text{(Eq. 5-2)}$$

### 5.4.3 Data Analysis

Analysis and interpretation of gamma exposure rate data is a five step process:

1. Plot, in order of magnitude from left to right, total-gross exposure rates in μR/h against cumulative probability for three independent areas considered to be "natural background" at SSFL. These survey locations should be from areas where no radioactive material has ever been used, handled, stored, or disposed. These areas should be of similar geologic characteristics to those of the inspected areas. Calculate the average, standard deviation, and range for each distribution. These three distributions give the baseline for "natural" variability of exposure rate as a function of SSFL terrain.

2. Plot total-gross exposure rates in μR/h against cumulative probability for each subject sampling lot. Calculate the average, standard deviation, and range for each distribution. Compare these statistics and probability distributions against "natural background" distributions.

3. Determine if there are any trends indicated by the probability plots of each subject sampling lot which show a potentially contaminated area. If necessary, explain elevated measurements and/or trends in the distribution.

4. Determine whether the "natural background" distributions adequately represent "ambient background" for the tested areas. Determine if any nuclear-related operations in the local area are influencing "ambient background" in the test-areas. If so, make corrections.

5. Subtract "natural background" from each test-area measurement and compare the results against acceptance criteria in Table 3.1 and Section 4.3.3. Use inspection by variables techniques to test for acceptance. Calculate the average, standard deviation, and test statistic, $\bar{X}$ + ks, for each test-area distribution. If "ambient background" in the test-areas exceeds "natural background," correct the data accordingly and retest.

The most critical step in the analysis of gamma exposure rate measurements is assessing what true "ambient background" radiation is for a test area. "Ambient background" accounts for three effects which result in the production of an electronic pulse of the instrument (a count), which under ideal measurement conditions would not occur:

1. "Natural background" radiation from the cosmos, and primordial radionuclides;

2. Secondary influence of gamma exposure rate due to nearby facilities which handle radioactive materials or radiation producing machines; and

3. Instrument noise.

These individual contributions to "ambient background" play havoc with data interpretation against acceptable limits because both the NRC and DOE criteria for acceptance for unrestricted use are given in $\mu$R/h above background, 5 and 20, respectively. During the survey we observed significant deviations in "natural background" radiation as a function of landscape geometry. For example, when the detector is placed near a large sandstone outcropping, the exposure rate may increase by almost 4 $\mu$R/h. This increase is due to primordial radionuclides in the sandstone, and a change in source geometry, from a planar $2\pi$-steradian surface to a rocky $3\pi$-steradian surface. "Natural background" is also more variable when measurements are made over, at, or near large metal pieces, scrap components, and other objects -- such as those stored in equipment yards. Fortunately, no secondary influence of gamma exposure rate occurred in these sampling locations. Instrument noise is fairly uniform.

The best solution for evaluating the potential or existence of residual contamination in an area where the radiation field varies naturally by swings as large as the acceptance limit, is to compare test-area total-gross exposure rates against "natural background" total-gross exposure rates. "Natural background" measurements were taken on flat and rugged terrain, with Chico Formation sandstone, similar to conditions of each test-area. Additionally, an assessment of other contributors to "ambient background" should be performed. These quantities should be estimated.

Once all the best corrections for "ambient background" have been made, resulting distributions are compared against the 5 μR/h above "background" acceptance limit. The test statistic, $\overline{X}$ + ks, is calculated for each distribution. Statistical acceptance criteria presented in section 4.3.3 apply.

### 5.4.4 Sensitivity of Gamma Exposure Rate Measurements

The purpose of performing these exposure rate measurements is to detect any significant quantity of gamma-emitting radionuclides. Operational history and surveys performed years ago show that the most probable radiological contaminant in these areas is Cs-137, associated mixed-fission-products, and activation products. Since Cs-137 is a gamma emitter, it is detectable with the NaI detector.

The sensitivity of these measurements, or rather, the amount of contamination which could be there and which would not be detected, is based on two possibilities:

1) A uniformly contaminated region of soil; a layer on the surface, or a layer several feet below the surface; (this scenario is unlikely in these inspected areas); or

2) A piece of contaminated debris located on the surface, or buried several feet below (this is the more credible scenario for residual radioactivity in these areas).

Our acceptance criteria specify that no soil activity exceeding 100 pCi/g-beta is acceptable for unrestricted-use. In comparison, 10 $\mu$Ci of Cs-137, total, is the limit for exempt quantity according to 10CFR30, Schedule B. If only Cs-137 were contained in the soil, 10 $\mu$Ci of activity would be present in 100 kg of soil, or about 70,000 $cm^2$ of surface area, if the layer were 1 cm thick.

Natural ambient gamma "background" radiation is about 12-16 $\mu$R/h at 1 meter from the ground, so the radioactive material would have to produce an exposure rate of about 3 $\mu$R/h above background in order to detect it to such an extent that further investigation would commence. Table 5.1 shows theoretical exposure rates calculated for some uniformly contaminated soil and miscellaneous contaminated debris. The contaminant is assumed to be Cs-137. Condition (1) assumes a uniformly distributed layer of soil with 100 pCi/g Cs-137. Condition (2) assumes a point source of Cs-137 with total activity equal to 1 mCi.

For condition (1), 100 pCi/g Cs-137 layer of contaminated soil, these measurements would detect a surface layer greater than one cm thick, but would not detect a small thickness of soil (10 cm) buried much more than a half-foot from the surface. This is very good sensitivity, particularly since the likelihood of a thin layer of contaminated soil located more than 6 in. below the surface is small. For condition (2), contaminated debris, whose activity exceeded 1 mCi Cs-137 activity could be seen if it wasn't buried much deeper than about a foot. 10 mCi could probably be seen down to 2 feet. The likelihood of buried or scattered debris occurring in these

Table 5.1 Exposure Rates of Cs-137 Contaminated Soil and Debris

| (1) Contaminated Soil (100 pCi/g) | Exposure Rate (μR/h) 1 meter above surface | |
|---|---|---|
| Infinite Slab on the Surface | | |
| 0.3 meters thick | 72 | |
| 1 meter thick | 74 | |
| Infinite Slab, 20 cm thick/10 cm thick | | |
| at Surface | 68 | 55 |
| at 5 cm depth | 32 | 25 |
| at 10 cm depth | 17 | 13 |
| at 15 cm depth | 9 | 7 |
| at 30 cm depth | 2 | 1 |
| Rectangular Volume, 20 cm thick/10 cm thick | | |
| 1 square meter, surface | 6.5 | 4.2 |
| 36 square meters, surface | 47 | 34 |
| (2) Contaminated Debris, (1 mCi total activity) | | |
| at Surface | 155 | |
| at 15 cm depth | 36 | |
| at 30 cm depth | 8 | |

areas is very small; however, this is probably the most likely scenario of the two for residual contamination. Concerning suspect activation products and their sensitivity levels, Co-60 is the most significant activation product. It is more easily detectable than Cs-137 because of higher energy gamma rays. Thus, this Cs-137 analysis gives the most conservative sensitivities for suspect contaminants.

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# 6.0 PROCEDURES

The following radiological procedures were used in performing this survey.

## 6.1 Sample Selection Gridding

Three sample lots should be established, one for each of the subject test-areas. Superimpose 6-meter square grids on each surface to be radiologically characterized. Designate each square meter in matrix notation with location (1,1) being the northwestern-most square in a sample lot. From this northwestern-most location, mark a location off every 6 meters east, and south. Where it is not convenient to make a measurement because of rock outcroppings, step to the nearest clear area.

## 6.2 Calibration and Instrument Checks

Instruments are calibrated and checked every morning, noon, and evening for the duration of the project as follows.

Portable Ludlum 2220-ESG Survey Instruments coupled to a 1 in. x 1 in. NaI crystal:

1) Turn the instrument 'ON' and allow to warm up for 5 min.

2) Check high voltage (800V gamma).

3) Check threshold (400 gamma).

4) Set window in/out switch to "out."

5) Check battery (greater than 500).

6) Set range selector to 1, response to fast, and count time for ambient gamma exposure rate measurements to 1 min.

7) Take and record a 1 min. background count in an uncontaminated area which typifies the area to be surveyed. Verify that ambient background falls within ± 20% of daily-averaged background measurements.

8) Use a Ra-226 check source located 1 ft from the NaI detector to check operability of the gamma instrument. The count rate should not vary by more than ± 5% from the initially established standard. The gamma calibration efficiency factor is determined by comparison against a Reuter Stokes High Pressure Ion Chamber (HPIC).

Gamma Spectrometer (for water sample analysis):

1) Check to make sure that the MCA has been calibrated for energy and efficiency.

2) If machine is not calibrated, refer to user's manual for proper calibration of device.

## 6.3 Radiological Measurements

### 6.3.1 Ambient Gamma Exposure Rate Measurements

1) Mount the detector on a tripod which centers the detector 1 meter from the ground.

2) Set the count time to 1 min. and take a measurement at each applicable location for that length of time.

3) *If any single reading exceeds about 400 cpm above normal readings, recount.*

4) Record the location, total counts, background, and efficiency factor (μR/h/cpm).

5) Enter the data into SMART SPREADSHEET.

6) Take at least 30, 1-min. counts in an area of similar topography where no radioactive materials were ever handled, stored, or used. This is the background distribution. Enter data in SMART SPREADSHEET.

6.3.2 Gamma Spectrometry Measurements

1) Place the water in a 1-liter Marinelli beaker.

2) Place the beaker over the calibrated high purity germanium (HPGE) detector and collect counts for 10,000 seconds. Use the MCA to qualify and quantify radioactive material in the water sample.

3) Evaluate and correct MCA calculated activities and reduce to units of μCi/ml.

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# 7.0 SURVEY RESULTS

A radiological survey of three outdoor areas was performed using the survey plan previously described:

1. T056 Landfill;
2. T100 Storage yard; and
3. T011 Field.

Each inspected test-area was treated as a sample lot for analyzing and interpreting radiological data. Uniform 6-m square grids were established to measure ambient gamma exposure rates. Analytical interpretation of gamma exposure rate measurements and probability plots with corrections for changes in "natural background," show that all areas are uncontaminated. Variability of "natural background" was observed for all test-areas. A water sample collected from the T056 pit and analyzed by gamma spectrometry showed no detectable activity above naturally-occurring "background."

*In this section, the format used for presenting data, analyzing* probability plots, and interpreting results is presented first. Then the gamma exposure rate measurement results are presented according to this format. Each sampling lot is discussed separately.

## 7.1 Statistical Results Format

Gamma exposure rate data collected for this survey are displayed as Gaussian cumulative distribution functions in Figures 7.1 through 7.15. Figures 7.1 through 7.3 are distributions of gamma exposure rate measurements made at 3 independent SSFL locations to demonstrate the variability of "natural background" radiation. Figures 7.4, 7.6, 7.8, and 7.10 are distributions of gross-total gamma exposure rates for each test-area including a division of the T100 Storage Yard measurements. Figures 7.5, 7.7, 7.9, and 7.11 are distributions of the same four data sets corrected for "natural background" based on the average of results presented in Figures 7.1 through

7.3, (i.e. the "natural background" data). These figures show each measurement value, arranged in order of magnitude from left to right, and a straight line representing the derived fitted-Gaussian distribution.

The mean of each distribution is approximately that value of the fitted-Gaussian on the ordinate which corresponds to a 50% cumulative probability on the abscissa. The measurement value at 50% cumulative probability is the median. For a theoretical Gaussian, the median is equal to the mean. For a well-fitted Gaussian, the median is very close to the mean. One, two, and three standard deviations above the mean correspond to 84%, 97.7%, and 99.8% cumulative probability for a one-sided test, respectively. Inspection by variables is used to test only "background-corrected" data sets against the NRC acceptance limit of 5 $\mu$R/h. The value of k used in the inspection test is very nearly 1.5 for each case; thus, the Test Statistic (TS) line ($\bar{X}$ + ks) will run perpendicular to the abscissa corresponding to about a 93.3% cumulative probability. The Gaussian distribution line must pass below the intersection of the "TS" line (about 93%) and the horizontal line showing the acceptance limit at that point in order to accept the lot as being uncontaminated. "k" and thus the "TS" line increase as the number of samples in a lot decrease.

At the top left hand corner of each output is the data file name for the sample lot. For "uncorrected" data sets, 30 $\mu$R/h is normally used for convenience, as the maximum ordinate value. If measurements exceed 30 $\mu$R/h, then the greatest measurement value is the upper bound of the ordinate axis. In cases where the measurements have been corrected for "natural background," 5 $\mu$R/h (the NRC acceptance limit) is used as the maximum ordinate value. The lower bound of the ordinate is either the smallest measured value (minus background, if applicable) or the smallest value calculated for a Gaussian fit. Negative numbers result when the measured value is less than background. Cumulative probability (abscissa) is plotted in probability grades, i.e. the distance between any two successive points increases as the distance from the 50% cumulative probability line increases. If an acceptance limit is applicable, four horizontal lines extending across each plot show, from top to bottom, 100% of the test limit, 90% of the test limit (Investigation), 50% of the test limit (Reinspection), and zero; see Section 4.3.3.

In cases where an acceptance limit is not appropriate, for example, gamma exposure rate measurements not corrected for "natural background," the four horizontal lines are not shown. Furthermore, a test statistic is not calculated because we were not testing the data against an acceptance limit. Since the variability in naturally occurring ambient gamma exposure rates at SSFL is wide, background was not subtracted at first. In these cases, the mean is calculated and the shape of the distribution is observed to identify any areas of increased radioactivity. Then the shape of the curve is compared against three "background" distributions. Finally, "natural background" and contributions to "ambient background," if applicable, are subtracted and inspection by variables techniques are applied to prove or disprove the hypothesis that the area is not contaminated.

## 7.2 Ambient Gamma Exposure Rates

Ambient gamma exposure rate measurements were made at 502 locations. Appendix C shows the data sets. Appendix D shows measurement locations. Table 7.1 shows the computed statistics for each data set compared against data from three independent areas where no radioactive material was ever handled, used, or stored. These areas are considered "natural background" at SSFL. This type of comparison is necessary for two reasons: 1) to demonstrate variability of "natural background" gamma radiation at SSFL; and 2) to estimate "natural background" at SSFL because the limits for unrestricted-use by which we use to demonstrate an "acceptable" area are based on above "background" criteria. So, unless we confidently know what "ambient background" is, the area under study may be found incorrectly acceptable if the background used was too high, or incorrectly unacceptable if the background used was too low.

Table 7.1 Natural Background Gamma Radiation at SSFL Compared to Survey Data

| Location | No. of Measurements | Mean Exposure Rate (μR/h) | Expected Standard Deviation at the Mean (μR/h)* | Standard Deviation of the Distribution (μR/h)** | Range μR/h |
|---|---|---|---|---|---|
| T056 Landfill | 140 | 14.9 | 0.26 | 0.80 | 5.6 |
| T100 Storage Yard | 308 | 13.5 | 0.25 | 1.35 | 9.1 |
| T100 Storage Yard (Greatest Measurements) | 40 | 15.7 | 0.27 | 0.88 | 2.8 |
| T011 Field | 39 | 13.0 | 0.24 | 0.34 | 1.3 |
| Background | | | | | |
| Building 309 Area (1/19/88) | 36 | 15.6 | 0.27 | 0.82 | 3.4 |
| Well #13 Road (Dirt) (4/29/88) | 43 | 16.2 | 0.27 | 0.49 | 2.2 |
| Incinerator Road (Dirt) (4/29/88) | 35 | 14.0 | 0.25 | 0.36 | 1.4 |

* The expected standard deviation at the mean is calculated based on counting statistics, equation 4.2.

** The standard deviation of the data points accounts for dispersion in the measurements, equation 4.7.

Descriptive statistics presented in Table 7.1 show that average exposure rates calculated for each test-area are within one standard deviation of each of the three "natural background," control-group areas. The standard deviations of each test-area, except for the T100 Salvage Yard, are comparable to "natural background" in natural terrain. The greater variance observed in the T100 Salvage Yard (1.35 μR/h) is attributed to interference of exposure rate due to stored equipment items. The range in this case is also greater than expected. Because of this difference in range and standard deviation, the 40 greatest measurements were extracted from the entire data-set and analyzed separately. These results are presented in the third row, and show that the range and standard deviation have dropped to "natural background" levels. By observation of these descriptive statistics, these test-areas appear uncontaminated. However, before any judgments can be made about the existence of residual contamination, we must investigate the probability plots to determine outliers in each distribution and to formulate an understanding of the greater variations and ranges observed in some test-cases.

### 7.2.1 Non-Radiological Areas

Because the "natural background" gamma-radiation environment is quite variable at SSFL and because the limits for unrestricted use are based on limits above background, further demonstration of this natural variability is necessary. For comparison against test-area measurements, three independent areas were surveyed, all in locations where no radioactive material was ever handled, used, stored, or disposed. All three areas are located on the eastern side of SSFL: (1) Area surrounding building 309 on Area I Road; (2) well #13 Road; and (3) Incinerator Road. Table 7.1 shows the results of these measurements. These "natural background" areas are similar in characteristics and topography to the areas inspected for this report. A few minor differences are worth mentioning: 1) The T100 Salvage Yard was cluttered with scrap materials and junk; and 2) the terrain of the T011 Field is very flat and covered only with natural vegetation -- no outcroppings. The purpose these distributions serve is to show "natural" variability of gamma radiation on natural terrain at SSFL.

Figures 7.1 through 7.3 are probability plots of these three independent "background" areas. At least 30 measurements were made in each area on the same day. In the plots, a uniform background rate (unbiased by spatial effects), would appear as a straight line with a minimal slope. That slope would show that 1 standard deviation from the mean of values would be equivalent to the mean-value standard deviation (i.e. the square root of the counts of the mean multiplied by an appropriate efficiency

Figure 7.1 Ambient Gamma Radiation at Area Surrounding Building 309
(Background Distribution)

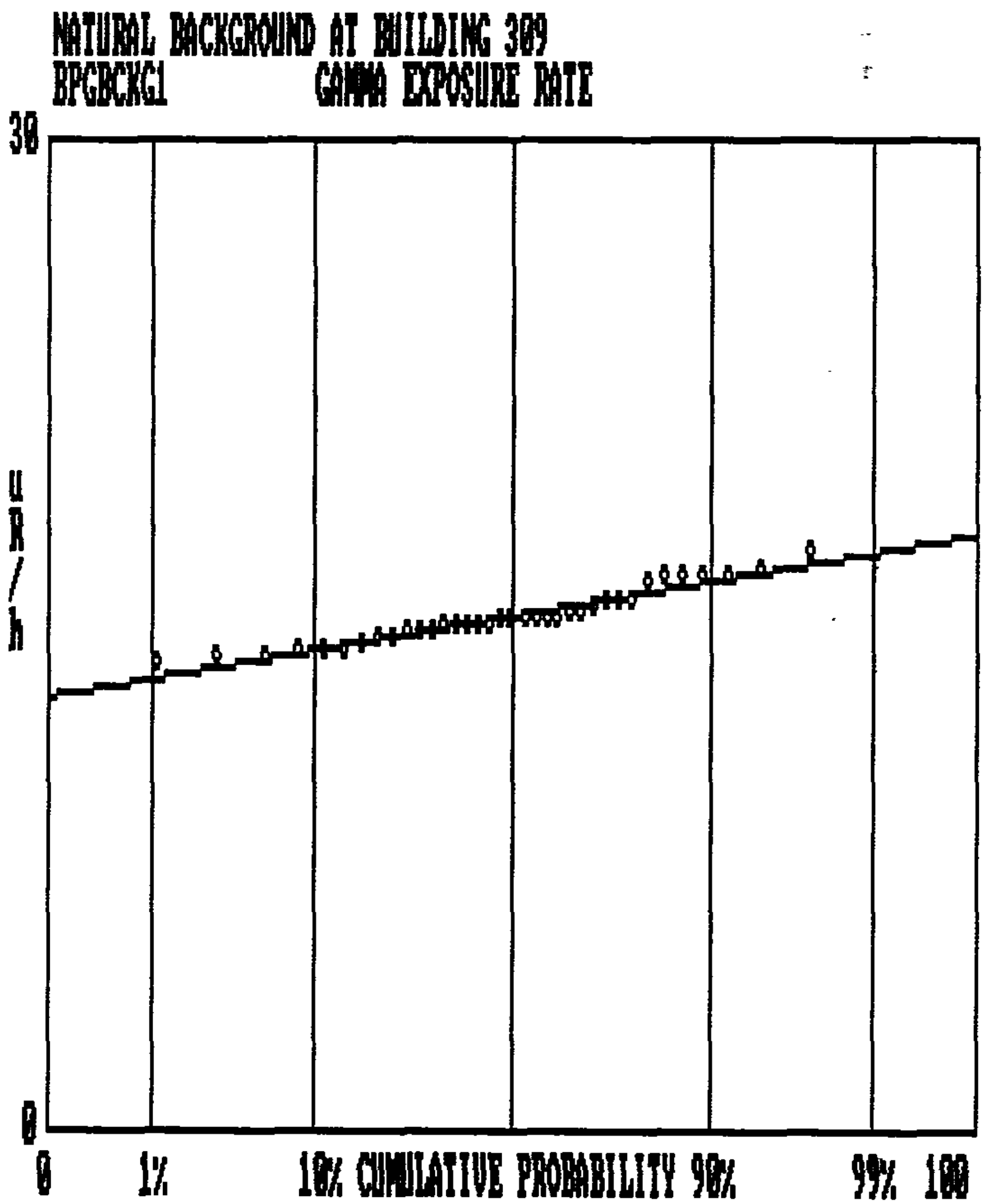


Figure 7.2 Ambient Gamma Radiation at Area Well #13 Road
(Background Distribution)

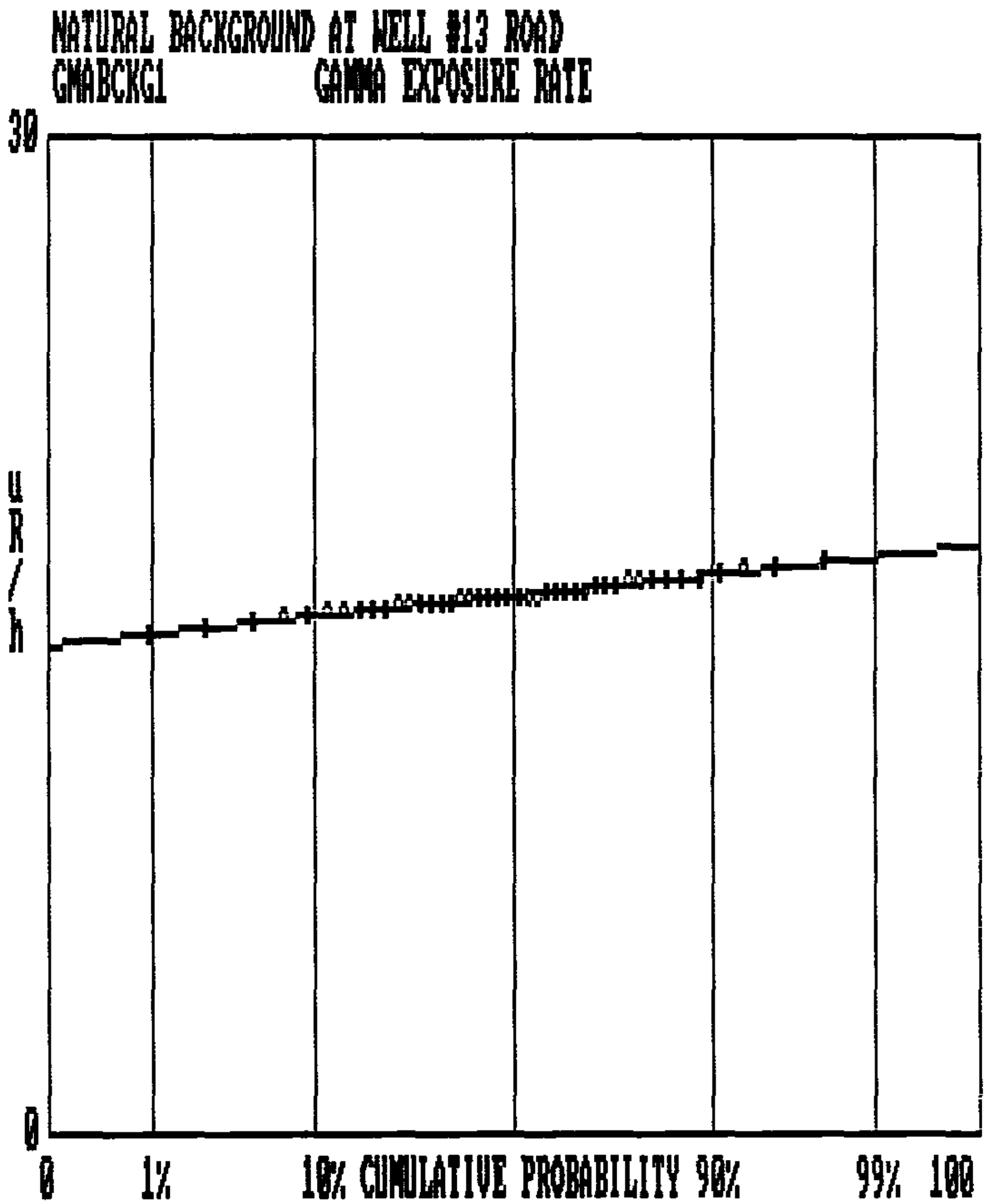
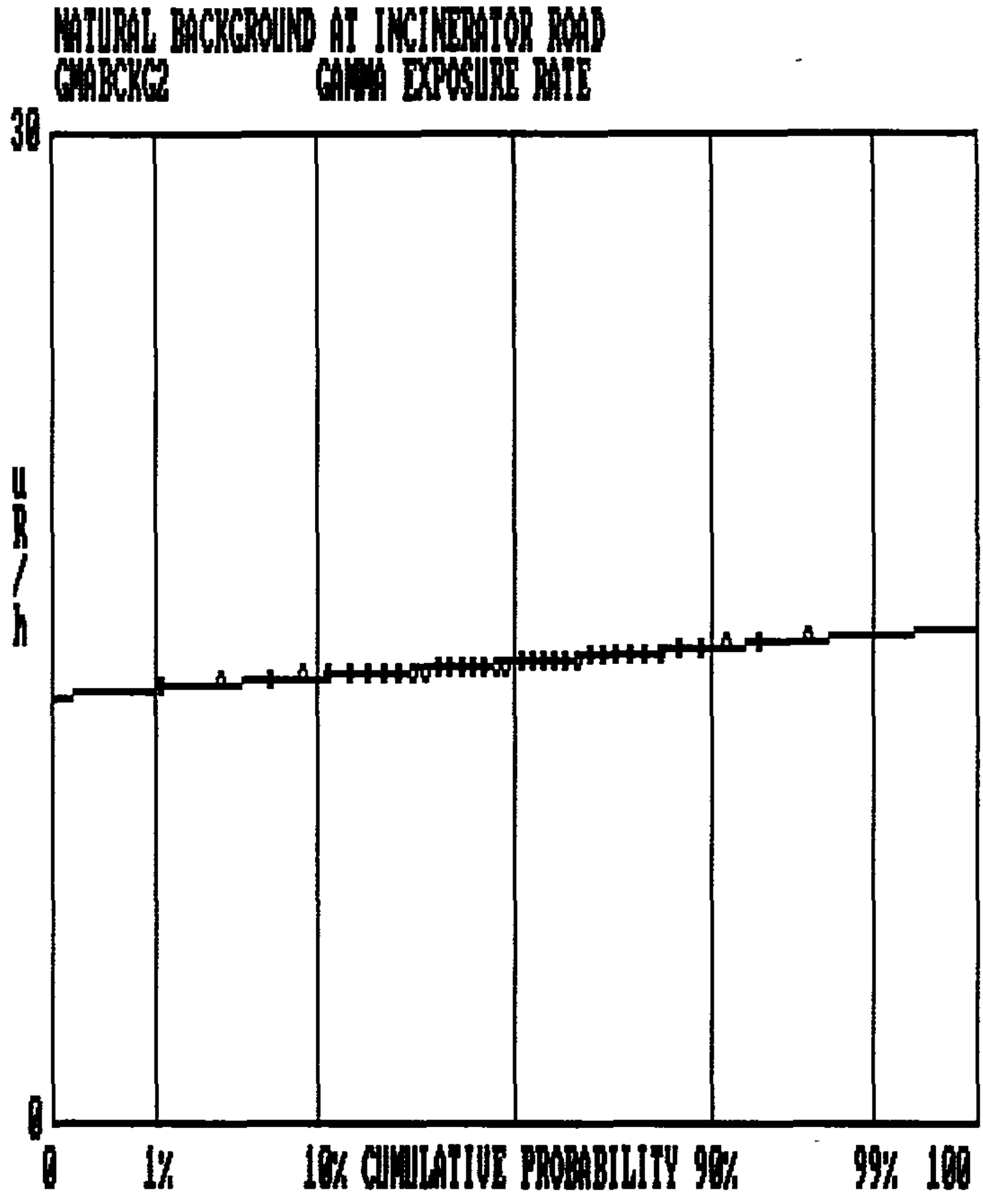


Figure 7.3 Ambient Gamma Radiation at Incinerator Road
(Background Distribution)



factor). If this was the case, the values in columns 4 and 5 of Table 7.1 would be equivalent. Obviously, this ideal condition is impossible to achieve in this terrain at SSFL. All three plots show model Gaussian distributions, but with greater variability than would be expected from unaffected measurements. Variability is greatest near Building 309.

Measurements from the area surrounding Building 309 show the most variability of all three background areas. This is attributed to large sandstone outcroppings in the area; the spatial dependency of each measurement is observable in this case. The variability of each distribution depends on the number of measurements made directly against the rock versus the number made many feet from the rock. Also of importance here is the range of measurement values with a maximum of 3.4 μR/h. "Natural background" variability approaches the NRC limit.

This "natural background" analysis shows the great difficulty in assessing whether an area is contaminated based on the NRC acceptance limit of 5 μR/h above background. The DOE limit of 20 μR/h is more reasonable. Natural gamma radiation is significantly variable at SSFL. We'll now compare this "natural" variability against the three test-area measurements presented in this report.

### 7.2.2 T056 Landfill

Figure 7.4 shows the statistical distribution of gross-total gamma exposure rate measurements plotted against cumulative probability for the T056 Landfill. This test-area on natural terrain is somewhat lightly packed (because of the landfill activities which took place there). The outlier at the high end and inlier at the low end of the distribution are not significant. These are normal expected deviations. The data follow a well-fitted Gaussian distribution with a mean value comparable to "natural background." No trends indicating a contaminated area are observed.

Figure 7.4 Total-Gross Ambient Gamma Exposure Rates at the T056 Landfill

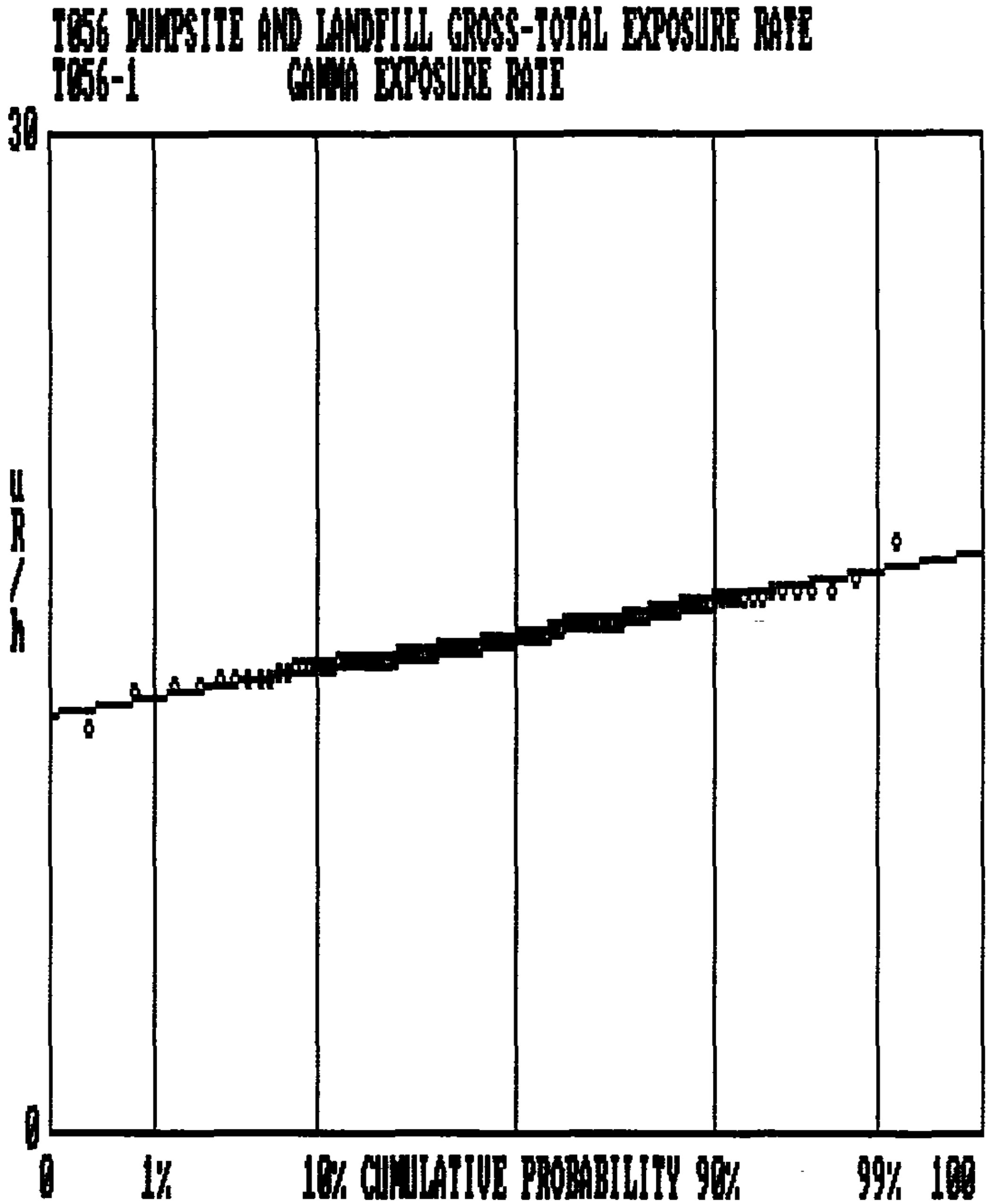


Figure 7.5 shows the same data set, in which case a correction for "natural background" was made uniformly to each measurement value. 15.30 μR/h was used for "background" subtraction, corresponding to the average of all three "natural background" data set measurements in Figures 7.1, 7.2, and 7.3.

Deviations observed in the measurements, although slight, are pronounced in this figure because the ordinate scale has been expanded. An average of $-0.30 \pm 0.80$ μR/h is less than the 5 μR/h acceptance limit and all action levels. The inspection test statistic, 0.85 μR/h, is less than 5 μR/h. We accept this area as uncontaminated by this inspection method. No further investigation is required.

### 7.2.3 T100 Storage Yard

Figure 7.6 shows the statistical distribution of gross-total gamma exposure rate measurements plotted against cumulative probability for the T100 Storage Yard. This test-area is half gravel, cluttered with system components, scrap, and junk; and half natural terrain surrounded by sandstone outcroppings. These objects perturb ambient exposure rates; the sample lot is not uniform. Even though the sample lot is not uniform, the data follow a well represented Gaussian distribution. A few points at the high end slightly deviate from the fitted function and the standard deviation of these measurements is greater than expected. Although no trends indicating a contaminated area are observed, these greatest measurements should be analyzed separately.

Figure 7.7 shows the same data set, in which case a correction for "natural background" was made uniformly to each measurement value. 15.30 μR/h was used for "background" subtraction, corresponding to the average of all three "natural background" data set measurements in Figures 7.1, 7.2, and 7.3.

Figure 7.5 Background-Corrected Ambient Gamma Exposure Rates at the T056 Landfill

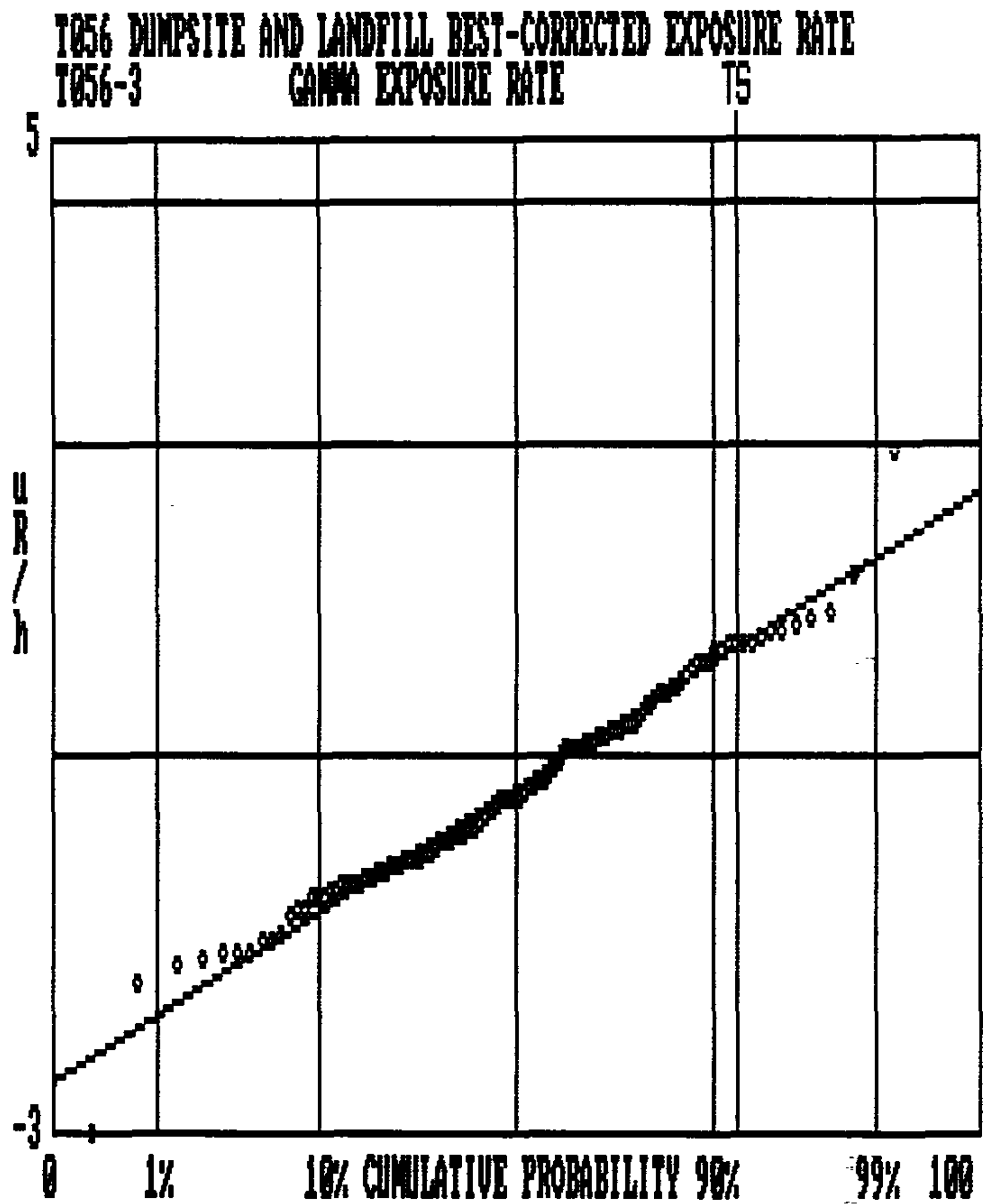


Figure 7.6 Total-Gross Ambient Gamma Exposure Rates at the T100 Storage Yard

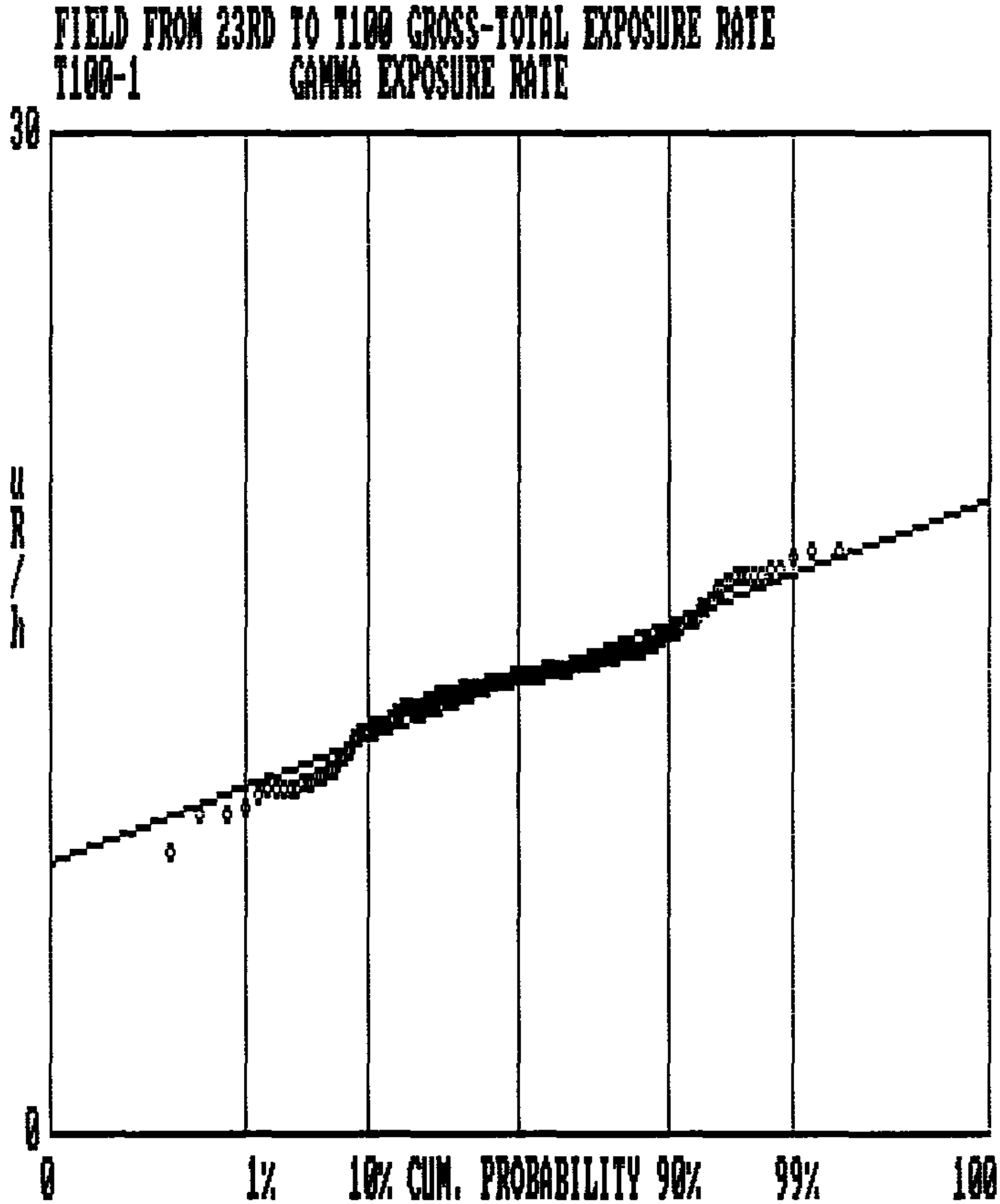
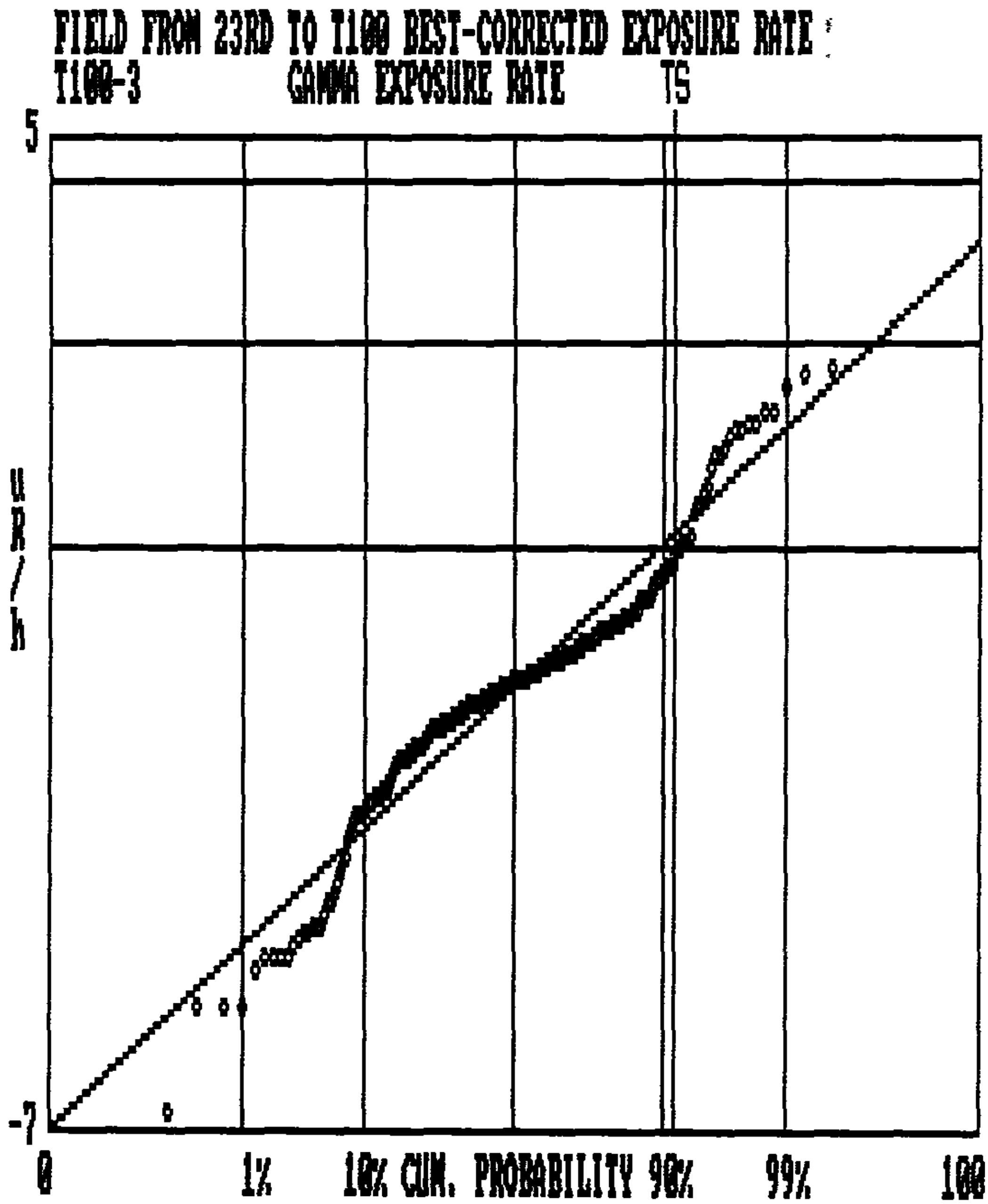


Figure 7.7 Background-Corrected Ambient Gamma Exposure Rates at the T100 Storage Yard



Deviations observed in exposure rate measurements because of stored scrap materials and surface obstructions are pronounced in this figure because the ordinate scale has been expanded. An average of -1.71 $\pm$ 1.35 $\mu$R/h is less than the 5 $\mu$R/h acceptance limit and all action levels. The inspection test statistic, 0.16 $\mu$R/h, is less than 5 $\mu$R/h. We accept this area as uncontaminated by this inspection method; however because of the unexpectedly large standard deviation and 30 or so outliers observed, these measurements are analyzed and interpreted separately in the following figures.

Figure 7.8 shows the statistical distribution of gross-total gamma exposure rate measurements plotted against cumulative probability for the 40 greatest measurements extracted from the T100 Storage Yard sample lot. The data show a well-represented Gaussian with no outliers. The average of this distribution is slightly greater than that of the entire data set, but certainly within the boundary limits established for "natural background." Most of the greatest measurements were made in the scrap yard. See Appendix D. No trends indicating a contaminated area are observed.

Figure 7.9 shows the same data set, in which case a correction for "natural background" was made uniformly to each measurement value. 15.30 $\mu$R/h was used for "background" subtraction, corresponding to the average of all three "natural background" data set measurements in Figures 7.1, 7.2, and 7.3.

Deviations observed in exposure rate measurements are much more pronounced in this figure because the ordinate scale has been expanded. This figure shows the great variability observed when making exposure rate measurements over various materials and terrain conditions. This is "natural." The inspection test statistic, 1.86 $\mu$R/h, is less than 5 $\mu$R/h. We accept this area as uncontaminated by this inspection method. No further investigation is required.

Figure 7.8 Total-Gross Ambient Gamma Exposure Rates at the 40 Greatest Measurements made at the T100 Storage Yard

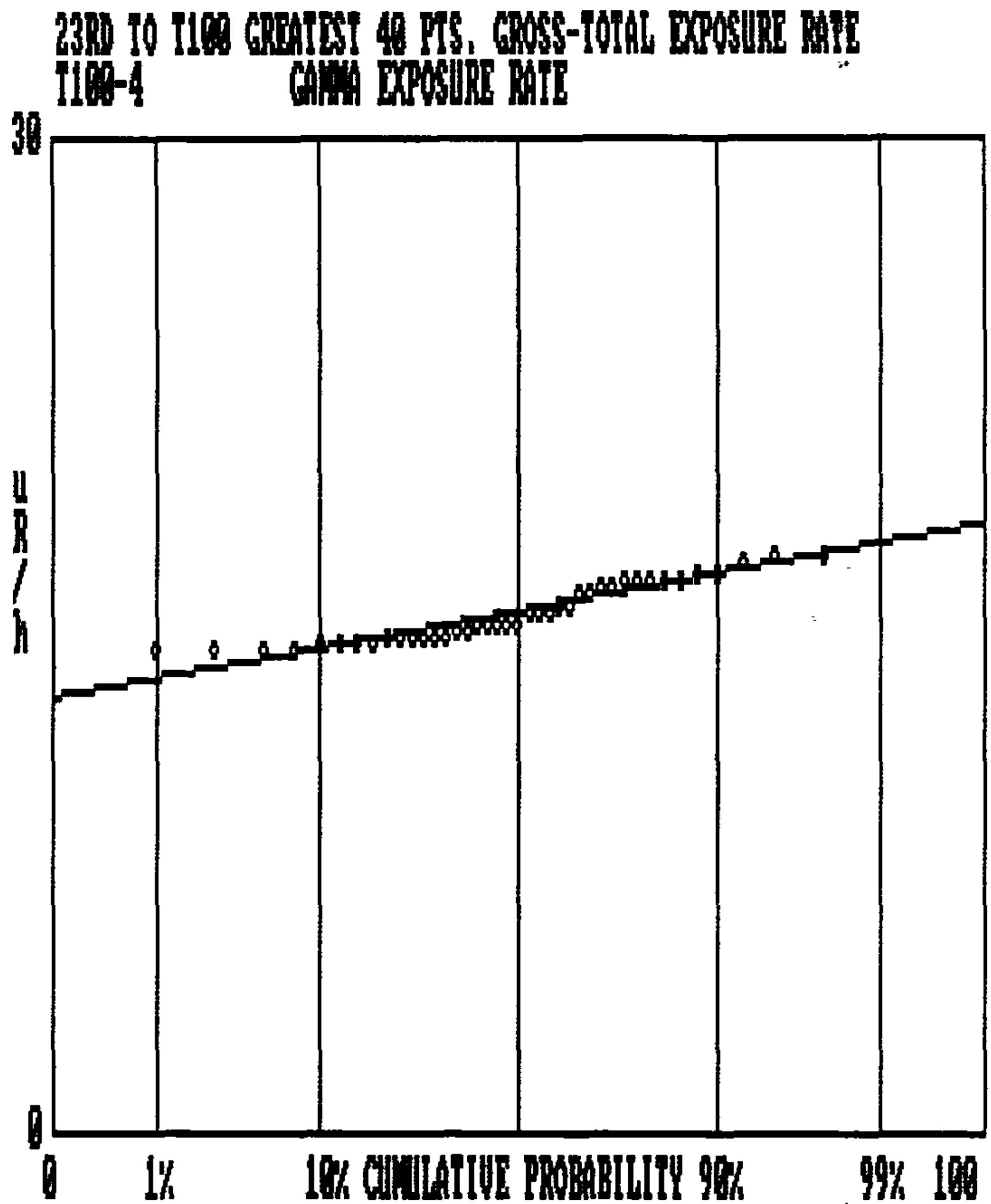
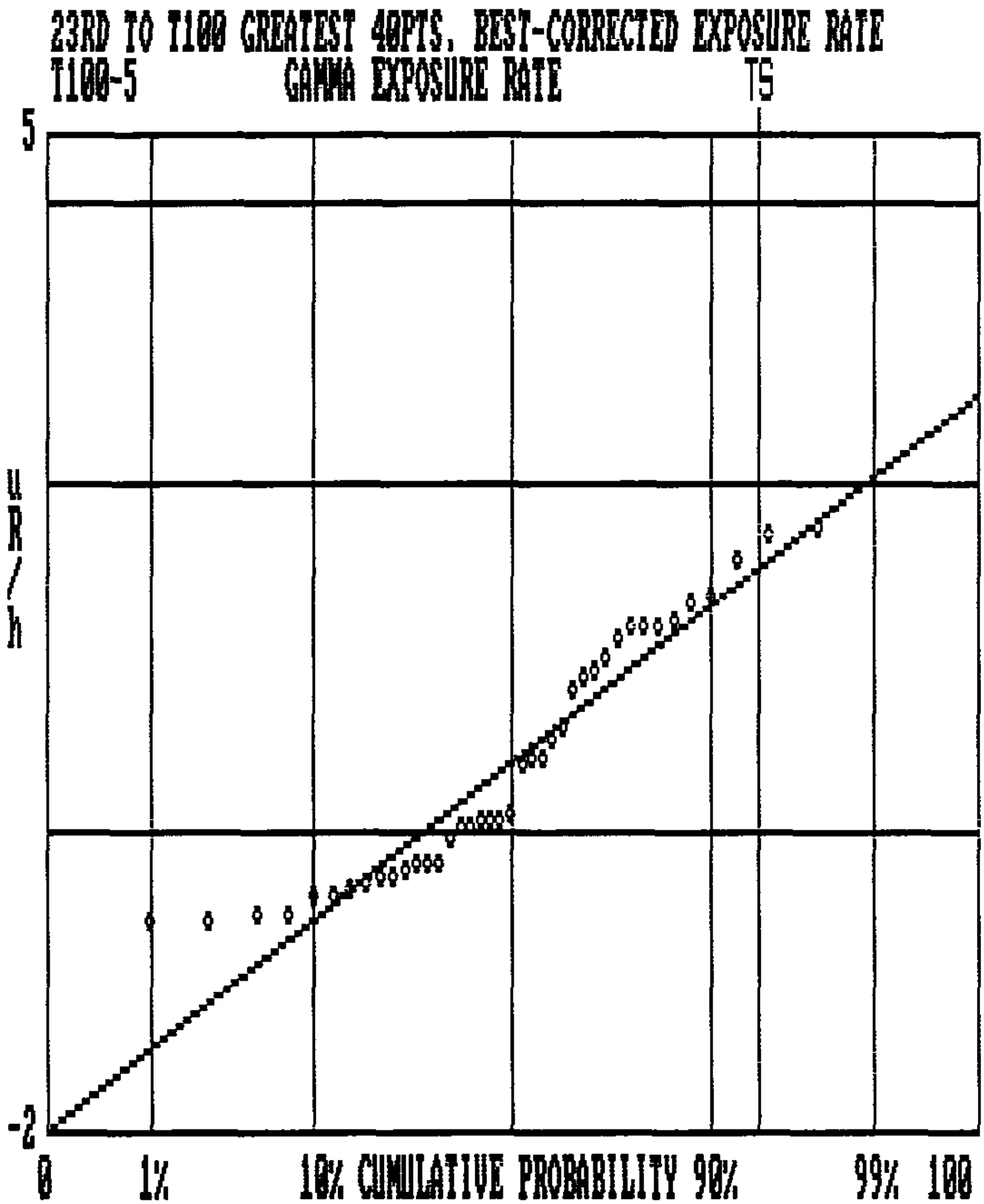


Figure 7.9 Background-Corrected Ambient Gamma Exposure Rates of the 40 Greatest Measurement at the T100 Storage Yard



7.2.4 T011 Field

Figure 7.10 shows the statistical distribution of gross-total gamma exposure rate measurements plotted against cumulative probability for the T011 Field. This test-area is flat natural terrain with no outcroppings. This figure shows an excellent experimental Gaussian distribution. In this distribution the standard deviation of the distribution (0.34 μR/h) is nearly equivalent to the expected standard deviation of the mean (0.24 μR/h); see Table 7.1. No trends indicating a contaminated area are observed.

Figure 7.11 shows the same data set, in which case a correction for "natural background" was made uniformly to each measurement value. 15.30 μR/h was used for "background" subtraction, corresponding to the average "natural background." Obviously, this value for "natural background" over-estimates background in this field area. This field was the most uniform area surveyed.

The inspection test statistic, -1.69 μR/h, is less than 5 μR/h. We accept this area as uncontaminated by this inspection method. No further investigation is required.

7.3 Results of Water Sample Analysis from T056 Pit

A 1-liter surface sample of water was collected from the T056 pit and analyzed by gamma spectrometry for 10,000 seconds. No detectable activity was found.

7.4 Assessment of Radiological Condition

Best-estimate corrections which account for ambient variations in "natural background" were applied specifically to each sample lot. Application of these corrections for "ambient background" and statistical analyses

Figure 7.10 Total-Gross Ambient Gamma Exposure Rates at the T011 Field

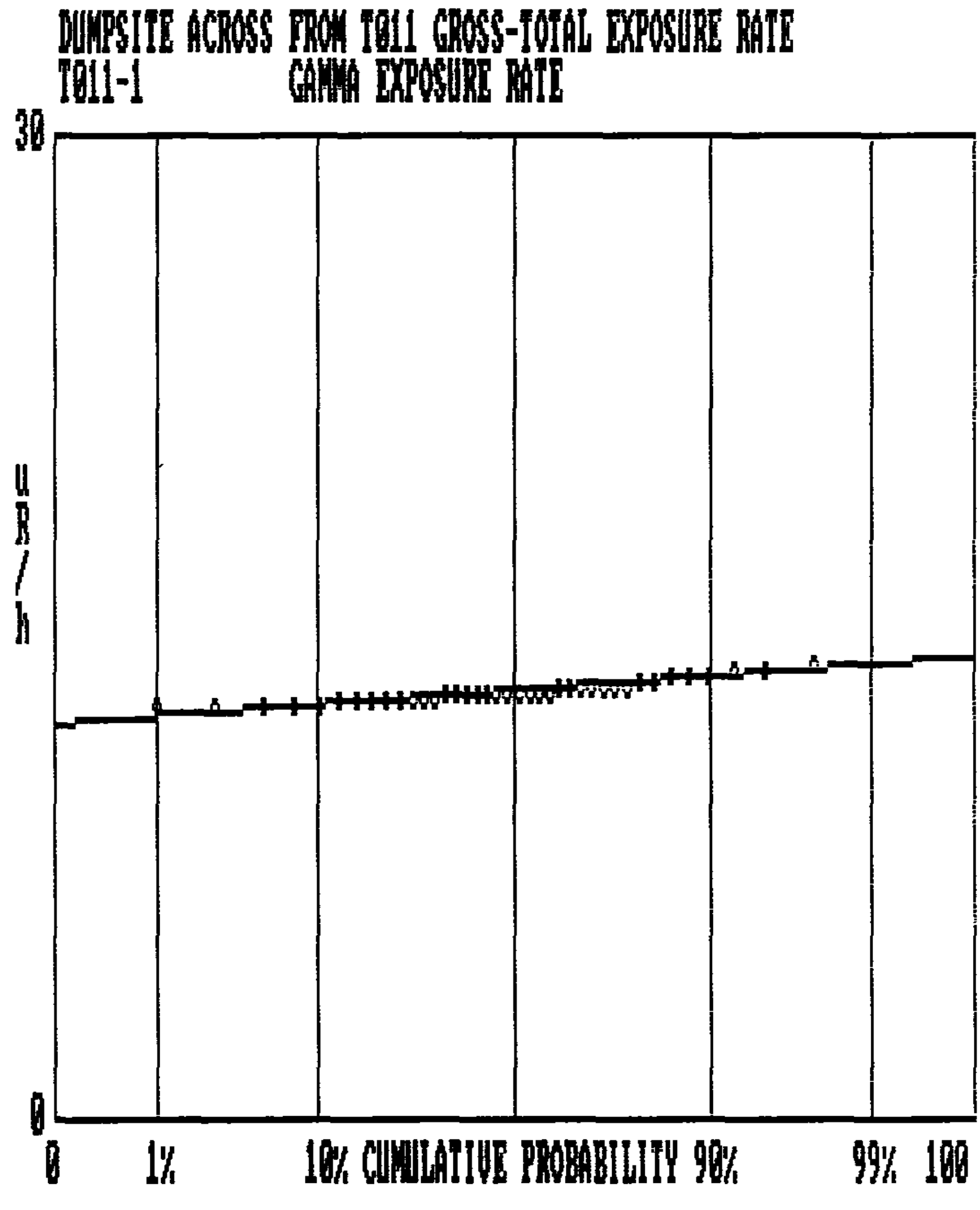
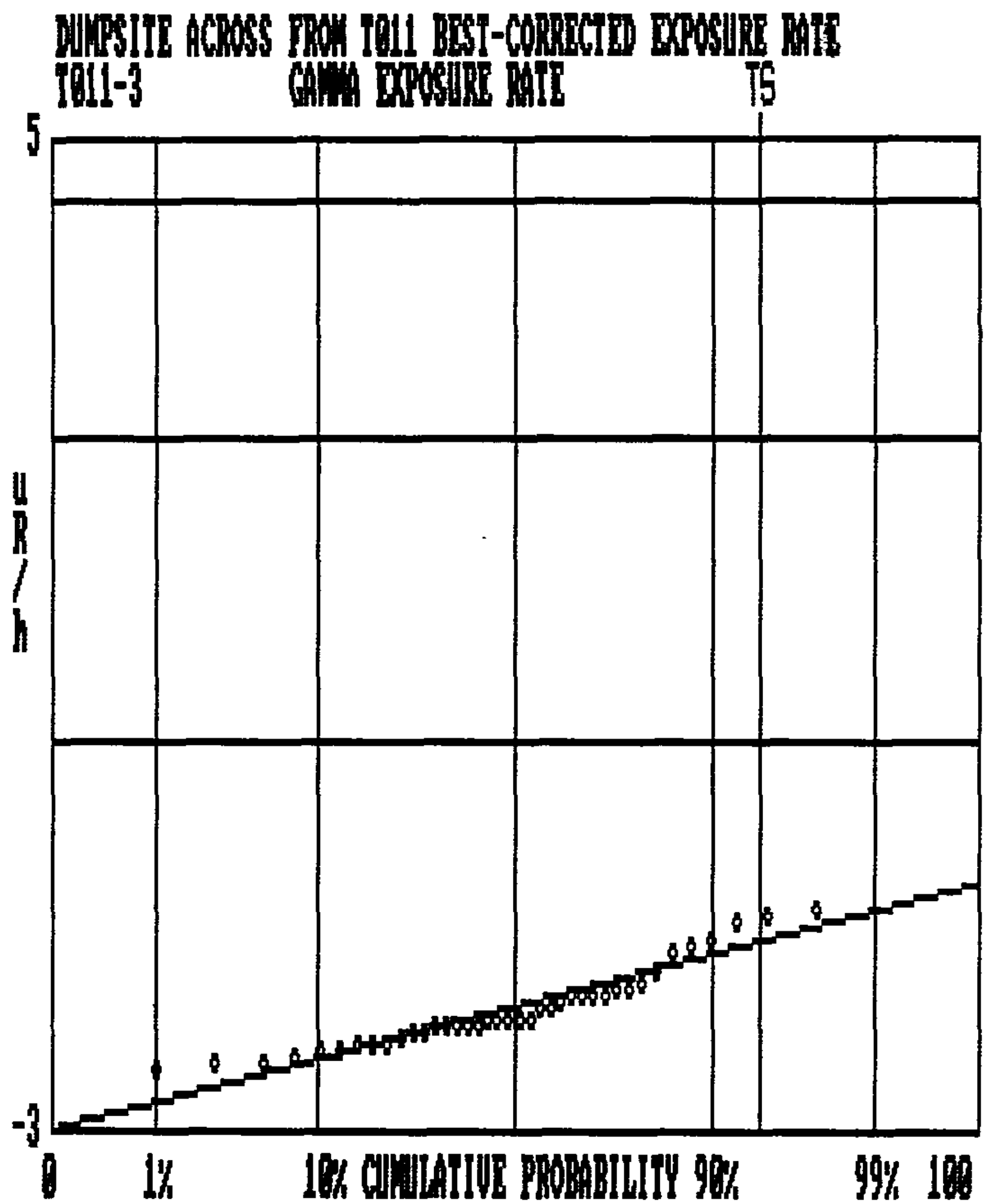


Figure 7.11 Background-Corrected Ambient Gamma Exposure Rates at the T011 Field



show that all sampled areas are acceptably clean. A summary of background-corrected statistics for these data sets is presented in Table 7.2. All areas pass criteria for unrestricted use. We are confident that the sensitivity and sampling frequency of exposure rate measurements is sufficient for identifying suspect contamination.

Table 7.2 Summary of Gamma Exposure Rate Data Corrected for Background and Statistically Tested Against Acceptance Limits

| Sample Lot | Ambient Background Value (μR/h) | Average Value (μR/h) | Standard Deviation (μR/h) | Maximum Value (μR/h) | Inspection Test Statistic (μR/h) | Acceptance Limit (μR/h) |
|---|---|---|---|---|---|---|
| T056 Landfill | 15.30 (1) | -0.30 | 0.80 | 2.44 | 0.85 | 5 |
| T100 Storage Yard | 15.30 (1) | -1.71 | 1.35 | 2.16 | 0.16 | 5 |
| T100 Storage Yard (40 Greatest Measurements) | 15.30 (1) | 0.47 | 0.88 | 2.16 | 1.86 | 5 |
| T011 Field | 15.30 (1) | -2.24 | 0.34 | -1.5 | -1.69 | 5 |

(1) Ambient background based on average "natural background" calculated from the three "background" distributions. Topography is similar in all areas.

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## 8.0 CONCLUSIONS

The T056 Landfill, T100 Storage Yard, and T011 Field were inspected for radioactive contaminants. Gamma exposure rate measurements were made on a 6-m square sampling grid, according to the Site Survey Plan (Reference 4). Exposure rate measurements plotted against cumulative probability show that "natural background" radiation in these areas varies depending on local topography, natural landscape conditions, and vicinity of large structures, equipment, or scrap components. The deviations observed in data collected for these inspected areas are attributed to ambient radiation conditions. When proper adjustments are made to the data to account for "natural background," the distributions show no trends indicating possible contamination. These locations pass as acceptably clean by our test criteria.

Based on these statistical distributions of exposure rate measurements corrected for what we found to be "ambient background" in each sample lot, we conclude through inspection by variables, that all locations surveyed do not contain residual radioactivity. This statistical test assumes a consumer's risk of acceptance of 0.1 at an LTPD of 10%. Analysis of a water sample from the T056 pit shows no detectable activity. Reinspection during performance of this survey was not necessary. No further inspection is required in these locations. It is recommended, however, that during excavation of debris at the T056 Landfill or subsurface sampling for volatile organics, items be surveyed for radioactivity.

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## 9.0 REFERENCES

1. "Guidelines for Residual Radioactivity at FUSRAP and Remote SFMP Sites," U.S. DOE, March 5, 1985.

2. "Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for By-product, Source, or Special Nuclear Material," Annex B, USNRC License SNM-21, Docket 70-25, Issued to Energy Systems Group of Rockwell International, last revision June 5, 1984.

3. "State of California Guidelines for Decontaminating Facilities and Equipment Prior to Release for Unrestricted Use," DECON-1, Revised March 24, 1983.

4. "Radiological Survey Plan for SSFL," 154SRR000001, F. H. Badger and R. J. Tuttle, Rockwell International, September 25, 1985.

5. "Long Range Plan for Decommissioning Surplus Facilities at the Santa Susana Field Laboratories," N001TI0000200, W.D. Kittinger, Rockwell International, September 30, 1983.

6. "Final Radiation Survey of the NMDF," N704SRR990027, J. A. Chapman, Rockwell International, December 19, 1986.

7. "Draft American National Standard Control of Radioactive Surface Contamination on Materials, Equipment, and Facilities to be Released for Uncontrolled Use," ANSI N13.12, August 1978, American National Standards Institute, Inc.

8. "Selected Techniques of Statistical Analysis," Statistical Research Group, Columbia University, McGraw-Hill Book Co., Inc., 1947.

9. "Some Theory of Sampling," W. E. Deming, Dover Publications, Inc., New York, 1950.

10. "Statistics in Research," B. Ostle and R. Mensing, The Iowa State University Press, 1979.

11. "Measurement and Detection of Radiation," N. Tsoulfanidis, Hemisphere Publishing Corp., Washington D.C., 1983.

12. "Standards for Protection Against Radiation," Title 10 Part 20, Code of Federal Regulations, January 1, 1985.

13. "Rocketdyne Division Environmental Monitoring and Facility Effluent Annual report Desoto and Santa Susana Field Laboratories Sites 1986," RI/RD87-133, J. D. Moore, Rockwell International, March 1987.

14. "Sampling Procedures and Tables for Inspection by Variables for Percent Defective," MIL-STD-414, June 11, 1957.

15. "Lower Limit of Detection and Statistically Significant Activity for Radiologic Measurements," IL from R. J. Tuttle to Radiation and Nuclear Safety, RI, June 24, 1986.

16. "Radiological Survey of Building T005," GEN-ZR-0003, J. A. Chapman, Rockwell International, February 1, 1988.

17. "Radiological Survey of the Sodium Disposal Facility - Building T886," GEN-ZR-0004, J. A. Chapman, Rockwell International, June 3, 1988.

18. "Radiological Survey of the Source and Special Nuclear Material Storage Vault - Building T064", GEN-ZR-0005, J. A. Chapman, Rocketdyne/Rockwell International, August, 1988.

19. "Radiological Survey of the Old Calibration Facility - Building T029", GEN-ZR-006, J. A. Chapman, Rocketdyne/Rockwell International, August, 1988.

20. "Radiological Survey of Shipping/Receiving and Old Accelerator Area - Building T641 and T030", GEN-ZR-0007, J. A. Chapman, Rocketdyne/Rockwell International, August, 1988.

21. "Radiological Survey of the Old ESG Salvage Yard, Rocketdyne Barrel Storage Yard, and New Salvage Yard (T583)", GEN-ZR-0008, J. A. Chapman, Rocketdyne/Rockwell International, August, 1988.

22. "Radiological Survey of the T513 Parking Lot; Old R/A Laundry Area; Plot 333; and Areas Between the SRE-to-RMDF, and KEWB-to-RMDF", GEN-ZR-0009, J. A. Chapman, Rocketdyne/Rockwell International, September, 1988.

23. "Radiological Survey of Building T019 and T013; An Area Northwest of T059, T019, T013, and T012; and A Storage yard West of Buildings T626 and T038", GEN-ZR-0010, J. A. Chapman, Rocketdyne/Rockwell International, September, 1988.

24. "Status Report of the DOE Activities at the Santa Susana Field Laboratories Site Environmental Survey", USDOE Memorandum EH-24 from Randal S. Scott, June 30, 1988.

# APPENDIX A. DESCRIPTION OF NUCLEAR INSTRUMENTATION

During the radiological survey, direct radiation measurements were made by using portable instruments. Analytical laboratory equipment was required for water sample analysis.

## A.1 *Ambient Gamma Exposure Rate*

A Ludlum model 2220-ESG portable scaler/ratemeter was coupled to a Ludlum model 44-10 NaI gamma scintillator for detecting gamma radiation. The NaI (Tl) crystal is extremely sensitive to changes in gamma flux. The probe efficiency varies with exposure rate. At background ambient gamma exposure rates, the efficiency is about 215 cpm/$\mu$R/h. This determination was made by calibrating the 2220-ESG against a Reuter Stokes High-Pressure Ion Chamber (HPIC). The HPIC displays a digital readout every 3 to 4 seconds in $\mu$R/h.

## A.2 Gamma Spectrometry Analyzer

Gamma spectrometry of a water sample was performed with a Canberra Industries, Inc. Series 80 Multichannel Analyzer (MCA). The MCA is coupled to a planar high purity germanium (HPGe) radiation detector having about a 10% relative sensitivity (relative to the sensitivity of a 3" x 3" NaI detector for cesium-137 gamma radiation), and a photopeak resolution capability of about 2.5 keV (FWHM) for the higher energy line of cobalt-60. The Series 80 MCA used for soil analyses has a 8192 channel memory capacity with a 1E+06 counts per channel capacity. Functional operation options include integral, net area, strip, and energy calibration, all used for spectrum analysis. The Series 80 was calibrated both for gamma energy and for nuclide quantification with a Marinelli Beaker Standard Source (MBSS) as specified in document ANSI/IEEE Std 680-1978, "IEEE Standard Techniques for Determination of Germanium Semiconductor Detector Gamma-Ray Efficiency Using a Standard Marinelli (Reentrant) Beaker Geometry." All samples analyzed by gamma spectrometry were presented to the detector with the same geometric configuration as the MBSS.

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**APPENDIX B. COPY OF DOE REPORT,**

**"GUIDELINES FOR RESIDUAL RADIOACTIVITY AT**

**FUSRAP AND REMOTE SFMP SITES," March, 1985**

MAR 6 05 PM

**Department of Energy**
Richland Operations Office
P.O. Box 550
Richland, Washington 99352

MAR 05 1985

CORRESPONDENCE

Addressees

GUIDELINES FOR RESIDUAL RADIOACTIVITY AT FUSRAP AND REMOTE SFMP SITES

The attached guidelines, "U.S. Department of Energy Guidelines for Residual Radioactivity at Formerly Utilized Sites Remedial Action Program and Remote Surplus Facilities Management Program Sites," (January 1985) have been issued by the Division of Remedial Action Projects for implementation by FUSRAP and SFMP in order to establish authorized limits for remedial actions. While these Guidelines are specifically intended for "remote" SFMP sites (those located outside a major DOE R&D or production site), they should be taken into consideration when developing authorized limits for remedial actions on major DOE reservations. The guidelines provide specific authorized limits for residual radium and thorium radioisotopes in soil, for airborne radon decay products, for external gamma radiation, and for residual surface contamination levels on materials to be released for unrestricted use. These guidelines will be supplemented in the near future by a document providing the methodology and guidance to establish authorized limits for residual radioisotopes other than radium and thorium in soil at sites to be certified for unrestricted use. The supplement will provide further guidance on the philosophies, scenarios, and pathways to derive appropriate authorized limits for residual radionuclides and mixtures in soil. These guidelines are based on the International Commission on Radiation Protection (ICRP) philosophies and dose limits in ICRP reports 26 and 30 as interpreted in the draft revised DOE Order 5480.1A. These dose limits are 500 mrem/yr for an individual member of the public over a short period of time and an average of 100 mrem/yr over a lifetime.

The approval of authorized limits differing from the guidelines is described in Section D, last sentence of the attached document. If the urgency of field activity makes DRAP concurrence not cost effective, a copy of the approval and backup analysis should be furnished to DRAP as soon as possible, although not necessarily prior to beginning field activities. This does not remove the requirement for approval by SFMPO.

As a result of a recent court decision, the Environmental Protection Agency (EPA) has issued airborne radiation standards applicable to DOE facilities. These final standards, issued as revisions to 40 CFR 61, are:

02067RL

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- 25 mrem/yr-whole body
- 75 mrem/yr-organ
- waiver of these standards will be granted if DOE demonstrates that no individual would receive 100 mrem/yr continuous exposure whole body dose equivalent from all sources within 10 km radius, excluding natural background and medical procedures
- radon and radon daughters are excluded (these standards are covered in 40 CFR 192)

The attached guidelines were written to be consistent with the revision of the DOE Order 5480.1A now in draft at Headquarters and have received the concurrence of the Public Safety Division, Office of Operational Safety. The guidelines will be included in the SFMP Program Plan beginning with the next revision (for FY 1986-1990).

Please refer any questions to Paul F. X. Dunigan, Jr. (FTS 444-6667), of my staff.

Clarence E. Miller, Jr.

Clarence E. Miller, Jr., Director
Surplus Facilities Management
Program Office

SFMPO:PFXD

Attachment:
As stated

cc: R. N. Coy, UNC
E. G. DeLaney, NE-24, HQ

3

# U.S. DEPARTMENT OF ENERGY GUIDELINES FOR RESIDUAL RADIOACTIVITY AT FORMERLY UTILIZED SITES REMEDIAL ACTION PROGRAM AND REMOTE SURPLUS FACILITIES MANAGEMENT PROGRAM SITES

(February 1985)

## A. INTRODUCTION

This document presents U.S. Department of Energy (DOE) radiological protection guidelines for cleanup of residual radioactive materials and management of the resulting wastes and residues. It is applicable to sites identified by the Formerly Utilized Sites Remedial Action Program (FUSRAP) and remote sites identified by the Surplus Facilities Management Program (SFMP).* The topics covered are basic dose limits, guidelines and authorized limits for allowable levels of residual radioactivity, and requirements for control of the radioactive wastes and residues.

Protocols for identification, characterization, and designation of FUSRAP sites for remedial action; for implementation of the remedial action; and for certification of a FUSRAP site for release for unrestricted use are given in a separate document (U.S. Dept. Energy 1984). More detailed information on applications of the guidelines presented herein, including procedures for deriving site-specific guidelines for allowable levels of residual radioactivity from basic dose limits, is contained in a supplementary document--referred to herein as the "supplement" (U.S. Dept. Energy 1985).

"Residual radioactivity" includes: (1) residual concentrations of radionuclides in soil material,** (2) concentrations of airborne radon decay products, (3) external gamma radiation level, and (4) surface contamination. A "basic dose limit" is a prescribed standard from which limits for quantities that can be monitored and controlled are derived; it is specified in terms of the effective dose equivalent as defined by the International Commission on Radiological Protection (ICRP 1977, 1978). Basic dose limits are used explicitly for deriving guidelines for residual concentrations of radionuclides in soil material, except for thorium and radium. Guidelines for

*A remote SFMP site is one that is excess to DOE programmatic needs and is located outside a major operating DOE research and development or production area.

**The term "soil material" refers to all material below grade level after remedial action is completed.

residual concentrations of thorium and radium and for the other three quantities (airborne radon decay products, external gamma radiation level, and surface contamination) are based on existing radiological protection standards (U.S. Environ. Prot. Agency 1983; U.S. Nucl. Reg. Comm. 1982). These standards are assumed to be consistent with basic dose limits within the uncertainty of derivations of levels of residual radioactivity from basic limits.

A "guideline" for residual radioactivity is a level of residual radioactivity that is acceptable if the use of the site is to be unrestricted. Guidelines for residual radioactivity presented herein are of two kinds: (1) generic, site-independent guidelines taken from existing radiation protection standards, and (2) site-specific guidelines derived from basic dose limits using site-specific models and data. Generic guideline values are presented in this document. Procedures and data for deriving site-specific guideline values are given in the supplement.

An "authorized limit" is a level of residual radioactivity that must not be exceeded if the remedial action is to be considered completed. Under normal circumstances, expected to occur at most sites, authorized limits are set equal to guideline values for residual radioactivity that are acceptable if use of the site is not be restricted. If the authorized limit is set higher than the guideline, restrictions and controls must be established for use of the site. Exceptional circumstances for which authorized limits might differ from guideline values are specified in Sections D and F. The restrictions and controls that must be placed on the site if authorized limits are set higher than guidelines are described in Section E.

DOE policy requires that all exposures to radiation be limited to levels that are as low as reasonably achievable (ALARA). Implementation of ALARA policy is specified as procedures to be applied after authorized limits have been set. For sites to be released for unrestricted use, the intent is to reduce residual radioactivity to levels that are as far below authorized limits as reasonable considering technical, economic, and social factors. At sites where the residual radioactivity is not reduced to levels that permit release for unrestricted use, ALARA policy is implemented by establishing controls to reduce exposure to ALARA levels. Procedures for implementing ALARA policy are described in the supplement. ALARA policies, procedures, and actions must be documented and filed as a permanent record upon completion of remedial action at a site.

## B. BASIC DOSE LIMITS

The basic limit for the annual radiation dose received by an individual member of the general public is 500 mrem/yr for a period of exposure not to exceed 5 years and an average of 100 mrem/yr over a lifetime. The committed effective dose equivalent, as defined in ICRP Publication 26 (ICRP 1977) and calculated by dosimetry models described in ICRP Publication 30 (ICRP 1978), shall be used for determining the dose.

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## C. GUIDELINES FOR RESIDUAL RADIOACTIVITY

### C.1 Residual Radionuclides in Soil Material

Residual concentrations of radionuclides in soil material shall be specified as above-background concentrations averaged over an area of 100 $m^2$. If the concentration in any area is found to exceed the average by a factor greater than 3, guidelines for local concentrations shall also be applicable. These "hot spot" guidelines depend on the extent of the elevated local concentrations and are given in the supplement.

The generic guidelines specified below are for concentrations of individual radionuclides occurring alone. If mixtures of radionuclides are present, the concentrations of individual radionuclides shall be reduced so that the dose for the mixture would not exceed the basic dose limit. Explicit formulas for calculating residual concentration guidelines for mixtures are given in the supplement.

The generic guidelines for residual concentrations of Th-232, Th-230, Ra-228, and Ra-226 are:

- 5 pCi/g, averaged over the first 15 cm of soil below the surface

- 15 pCi/g, averaged over 15-cm-thick layers of soil more than 15 cm below the surface

The guidelines for residual concentrations in soil material of all other radionuclides shall be derived from basic dose limits by means of an environmental pathway analysis using site-specific data. Procedures for deriving these guidelines are given in the supplement.

### C.2 Airborne Radon Decay Products

Generic guidelines for concentrations of airborne radon decay products shall apply to existing occupied or habitable structures on private property that are intended for unrestricted use; structures that will be demolished or buried are excluded. The applicable generic guideline (40 CFR 192) is: In any occupied or habitable building, the objective of remedial action shall be, and reasonable effort shall be made to achieve, an annual average (or equivalent) radon decay product concentration (including background) not to exceed 0.02 WL.* In any case, the radon decay product concentration (including background) shall not exceed 0.03 WL. Remedial actions are not required in order to comply with this guideline when there is reasonable assurance that residual radioactive materials are not the cause.

### C.3. External Gamma Radiation

The level of gamma radiation at any location on a site to be released for unrestricted use, whether inside an occupied building or habitable structure or outdoors, shall not exceed the background level by more than 20 μR/h.

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*A working level (WL) is any combination of short-lived radon decay products in one liter of air that will result in the ultimate emission of $1.3 \times 10^5$ MeV of potential alpha energy.

## C.4 Surface Contamination

The following generic guidelines, adapted from standards of the U.S. Nuclear Regulatory Commission (1982), are applicable only to existing structures and equipment that will not be demolished and buried. They apply to both interior and exterior surfaces. If a building is demolished and buried, the guidelines in Section C.1 are applicable to the resulting contamination in the ground.

| Radionuclides†[2] | Allowable Total Residual Surface Contamination (dpm/100 cm²)†[1] | | |
|---|---|---|---|
| | Average†[3],†[4] | Maximum†[4],†[5] | Removable†[6] |
| Transuranics, Ra-226, Ra-228, Th-230, Th-228, Pa-231, Ac-227, I-125, I-129 | 100 | 300 | 20 |
| Th-Natural, Th-232, Sr-90, Ra-223, Ra-224, U-232, I-126, I-131, I-133 | 1,000 | 3,000 | 200 |
| U-Natural, U-235, U-238, and associated decay products | 5,000α | 15,000α | 1,000α |
| Beta-gamma emitters (radionuclides with decay modes other than alpha emission or spontaneous fission) except Sr-90 and others noted above | 5,000β-γ | 15,000β-γ | 1,000β-γ |

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

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

†[3] Measurements of average contamination should not be averaged over an area of more than 1 $m^2$. For objects of less surface area, the average should be derived for each such object.

†[4] The average and maximum dose rates associated with surface contamination resulting from beta-gamma emitters should not exceed 0.2 mrad/h and 1.0 mrad/h, respectively, at 1 cm.

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

†[6] The amount of removable radioactive material per 100 $cm^2$ of surface area should be determined by wiping that area with dry filter or soft absorbent paper, applying moderate pressure, and measuring the amount of radioactive material on the wipe with an appropriate instrument of known efficiency. When removable contamination on objects of surface area less than 100 $cm^2$ is determined, the activity per unit area should be based on the actual area and the entire surface should be wiped. Tha numbers in this column are maximum amounts.

## D. AUTHORIZED LIMITS FOR RESIDUAL RADIOACTIVITY

The remedial action shall not be considered complete unless the residual radioactivity is below authorized limits. Authorized limits shall be set equal to guidelines for residual radioactivity unless: (1) exceptions specified in Section F of this document are applicable, in which case an authorized limit may be set above the guideline value for the specific location or condition to which the exception is applicable; or (2) on the basis of site-specific data not used in establishing the guidelines, it can be clearly established that limits below the guidelines are reasonable and can be achieved without appreciable increase in cost of the remedial action. Authorized limits that differ from guidelines must be justified and established on a site-specific basis, with documentation that must be filed as a permanent record upon completion of remedial action at a site. Authorized limits differing from the guidelines must be approved by the Director, Oak Ridge Technical Services Division, for FUSRAP and by the Director, Richland Surplus Facilities Management Program Office, for remote SFMP--with concurrence by the Director of Remedial Action Projects for both programs.

## E. CONTROL OF RESIDUAL RADIOACTIVITY AT FUSRAP AND REMOTE SFMP SITES

Residual radioactivity above the guidelines at FUSRAP and remote SFMP sites must be managed in accordance with applicable DOE Orders. The DOE Order 5480.1A requires compliance with applicable federal, state, and local environmental protection standards.

The operational and control requirements specified in the following DOE Orders shall apply to both interim storage and long-term management.

a. 5440.1B, Implementation of the National Environmental Policy Act

b. 5480.1A, Environmental Protection, Safety, and Health Protection Program for DOE Operations

c. 5480.2, Hazardous and Radioactive Mixed Waste Management

d. 5480.4, Environmental Protection, Safety, and Health Protection Standards

e. 5482.1A, Environmental, Safety, and Health Appraisal Program

f. 5483.1, Occupational Safety and Health Program for Government-Owned Contractor-Operated Facilities

g. 5484.1, Environmental Protection, Safety, and Health Protection Information Reporting Requirements

h. 5484.2, Unusual Occurrence Reporting System

i. 5820.2, Radioactive Waste Management

### E.1 Interim Storage

a. Control and stabilization features shall be designed to ensure, to the extent reasonably achievable, an effective life of 50 years and, in any case, at least 25 years.

b. Above-background Rn-222 concentrations in the atmosphere above facility surfaces or openings shall not exceed: (1) 100 pCi/L at any given point, (2) an annual average concentration of 30 pCi/L over the facility site, and (3) an annual average concentration of 3 pCi/L at or above any location outside the facility site (DOE Order 5480.1A, Attachment XI-1).

c. Concentrations of radionuclides in the groundwater or quantities of residual radioactive materials shall not exceed existing federal, state, or local standards.

d. Access to a site should be controlled and misuse of onsite material contaminated by residual radioactivity should be prevented through appropriate administrative controls and physical barriers--active and passive controls as described by the U.S. Environmental Protection Agency (1983--p. 595). These control features should be designed to ensure, to the extent reasonable, an effective life of at least 25 years. The federal government shall have title to the property.

E.2 <u>Long-Term Management</u>

a. Control and stabilization features shall be designed to ensure, to the extent reasonably achievable, an effective life of 1,000 years and, in any case, at least 200 years.

b. Control and stabilization features shall be designed to ensure that Rn-222 emanation to the atmosphere from the waste shall not: (1) exceed an annual average release rate of 20 $pCi/m^2/s$, and (2) increase the annual average Rn-222 concentration at or above any location outside the boundary of the contaminated area by more than 0.5 pCi/L. Field verification of emanation rates is not required.

c. Prior to placement of any potentially biodegradable contaminated wastes in a long-term management facility, such wastes shall be properly conditioned to ensure that (1) the generation and escape of biogenic gases will not cause the requirement in paragraph b of this section (E.2) to be exceeded, and (2) biodegradation within the facility will not result in premature structural failure in violation of the requirements in paragraph a of this section (E.2).

d. Groundwater shall be protected in accordance with 40 CFR 192.20(a)(2) and 192.20(a)(3), as applicable to FUSRAP and remote SFMP sites.

e. Access to a site should be controlled and misuse of onsite material contaminated by residual radioactivity should be prevented through appropriate administrative controls and physical barriers--active and passive controls as described by the U.S. Environmental Protection Agency (1983--p. 595). These controls should be designed to be effective to the extent reasonable for at least 200 years. The federal government shall have title to the property.

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## F. EXCEPTIONS

Exceptions to the requirement that authorized limits be set equal to the guidelines may be made on the basis of an analysis of site-specific aspects of a designated site that were not taken into account in deriving the guidelines. Exceptions require approvals as stated in Section D. Specific situations that warrant exceptions are:

a. Where remedial actions would pose a clear and present risk of injury to workers or members of the general public, notwithstanding reasonable measures to avoid or reduce risk.

b. Where remedial actions--even after all reasonable mitigative measures have been taken--would produce environmental harm that is clearly excessive compared to the health benefits to persons living on or near affected sites, now or in the future. A clear excess of environmental harm is harm that is long-term, manifest, and grossly disproportionate to health benefits that may reasonably be anticipated.

c. Where the cost of remedial actions for contaminated soil is unreasonably high relative to long-term benefits and where the residual radioactive materials do not pose a clear present or future risk after taking necessary control measures. The likelihood that buildings will be erected or that people will spend long periods of time at such a site should be considered in evaluating this risk. Remedial actions will generally not be necessary where only minor quantities of residual radioactive materials are involved or where residual radioactive materials occur in an inaccessible location at which site-specific factors limit their hazard and from which they are costly or difficult to remove. Examples are residual radioactive materials under hard-surface public roads and sidewalks, around public sewer lines, or in fence-post foundations. In order to invoke this exception, a site-specific analysis must be provided to establish that it would not cause an individual to receive a radiation dose in excess of the basic dose limits stated in Section B, and a statement specifying the residual radioactivity must be included in the appropriate state and local records.

d. Where the cost of cleanup of a contaminated building is clearly unreasonably high relative to the benefits. Factors that shall be included in this judgment are the anticipated period of occupancy, the incremental radiation level that would be effected by remedial action, the residual useful lifetime of the building, the potential for future construction at the site, and the applicability of remedial actions that would be less costly than removal of the residual radioactive materials. A statement specifying the residual radioactivity must be included in the appropriate state and local records.

e. Where there is no feasible remedial action.

## G. SOURCES

| Limit or Guideline | Source |
|---|---|
| **Basic Dose Limits** | |
| Dosimetry Model and Dose Limits | International Commission on Radiological Protection (1977, 1978) |
| **Guidelines for Residual Radioactivity** | |
| Residual Radionuclides in Soil Material | 40 CFR 192 |
| Airborne Radon Decay Products | 40 CFR 192 |
| External Gamma Radiation | 40 CFR 192 |
| Surface Contamination | U.S. Nuclear Regulatory Commission (1982) |
| **Control of Radioactive Wastes and Residues** | |
| Interim Storage | DOE Order 5480.1A |
| Long-Term Management | DOE Order 5480.1A; 40 CFR 192 |

## H. REFERENCES

International Commission on Radiological Protection. 1977. Recommendations of the International Commission on Radiological Protection (Adopted January 17, 1977). ICRP Publication 26. Pergamon Press, Oxford. [As modified by "Statement from the 1978 Stockholm Meeting of the ICRP." Annals of the ICRP, Vol. 2, No. 1, 1978.]

International Commission on Radiological Protection. 1978. Limits for Intakes of Radionuclides by Workers. A Report of Committee 2 of the International Commission on Radiological Protection. Adopted by the Commission in July 1978. ICRP Publication 30. Part 1 (and Supplement), Part 2 (and Supplement), Part 3 (and Supplements A and B), and Index. Pergamon Press, Oxford.

U.S. Environmental Protection Agency. 1983. Standards for Remedial Actions at Inactive Uranium Processing Sites; Final Rule (40 CFR Part 192). Fed. Regist. 48(3):590-604 (January 5, 1983).

U.S. Department of Energy. 1984. Formerly Utilized Sites Remedial Action Program. Summary Protocol: Identification - Characterization - Designation - Remedial Action - Certification. Office of Nuclear Energy, Office of Terminal Waste Disposal and Remedial Action, Division of Remedial Action Projects. April 1984.

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U.S. Department of Energy. 1985. Supplement to U.S. Department of Energy Guidelines for Residual Radioactivity at Formerly Utilized Sites Remedial Action Program and Remote Surplus Facilities Management Program Sites. A Manual for Implementing Residual Radioactivity Guidelines. Prepared by Argonne National Laboratory, Los Alamos National Laboratory, Oak Ridge National Laboratory, and Pacific Northwest Laboratory for the U.S. Department of Energy. (In preparation.)

U.S. Nuclear Regulatory Commission. 1982. Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for Byproduct, Source, or Special Nuclear Material. Division of Fuel Cycle and Material Safety, Washington, DC. July 1982. [See also: U.S. Atomic Energy Commission. 1974. Regulatory Guide 1.86. Termination of Operating Licenses for Nuclear Reactors. Table I.]

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# APPENDIX C. RADIOLOGICAL SURVEY DATA

T056 Landfill Lot Sorted by Location

C.1

| T056.WS ROOM NUMBER | GRID NAME | SORTED BY LOCATION GAMMA TOTAL | uR/h TOTAL | STD DEV |
|---|---|---|---|---|
| | 2-14 | 3068 | 14.21 | 0.26 |
| | 2-16 | 3166 | 14.66 | 0.26 |
| | 3-10 | 3050 | 14.13 | 0.26 |
| | 3-11 | 3147 | 14.58 | 0.26 |
| | 3-12 | 3334 | 15.44 | 0.27 |
| | 3-13 | 3302 | 15.29 | 0.27 |
| | 4-8 | 3066 | 14.20 | 0.26 |
| | 4-10 | 3009 | 13.94 | 0.25 |
| | 4-12 | 3304 | 15.30 | 0.27 |
| | 4-13 | 3186 | 14.76 | 0.26 |
| | 4-14 | 3164 | 14.66 | 0.26 |
| | 4-15 | 3094 | 14.33 | 0.26 |
| | 5-3 | 2964 | 13.73 | 0.25 |
| | 5-4 | 3123 | 14.47 | 0.26 |
| | 5-5 | 3080 | 14.27 | 0.26 |
| | 5-6 | 3109 | 14.40 | 0.26 |
| | 5-10 | 2946 | 13.65 | 0.25 |
| | 5-12 | 3062 | 14.18 | 0.26 |
| | 5-13 | 3094 | 14.33 | 0.26 |
| | 5-14 | 3300 | 15.29 | 0.27 |
| | 6-6 | 3303 | 15.30 | 0.27 |
| | 6-7 | 2888 | 13.38 | 0.25 |
| | 6-8 | 3125 | 14.48 | 0.26 |
| | 6-9 | 3060 | 14.17 | 0.26 |
| | 6-13 | 2948 | 13.66 | 0.25 |
| | 7-2 | 3069 | 14.22 | 0.26 |
| | 7-4 | 2966 | 13.74 | 0.25 |
| | 7-9 | 3159 | 14.63 | 0.26 |
| | 7-12 | 3133 | 14.51 | 0.26 |
| | 7-14 | 3191 | 14.78 | 0.26 |
| | 8-3 | 3111 | 14.41 | 0.26 |
| | 8-5 | 3375 | 15.63 | 0.27 |
| | 8-9 | 3148 | 14.58 | 0.26 |
| | 8-11 | 3143 | 14.56 | 0.26 |
| | 9-1 | 3080 | 14.27 | 0.26 |
| | 9-2 | 3103 | 14.37 | 0.26 |
| | 9-3 | 3300 | 15.29 | 0.27 |
| | 9-8 | 3332 | 15.43 | 0.27 |
| | 10-3 | 3324 | 15.40 | 0.27 |
| | 10-5 | 3214 | 14.89 | 0.26 |
| | 10-8 | 3200 | 14.82 | 0.26 |
| | 11-1 | 3101 | 14.36 | 0.26 |
| | 11-3 | 3054 | 14.15 | 0.26 |
| | 11-4 | 3144 | 14.56 | 0.26 |
| | 11-5 | 3324 | 15.40 | 0.27 |
| | 11-6 | 3214 | 14.89 | 0.26 |
| | 11-8 | 3315 | 15.36 | 0.27 |
| | 12-2 | 3180 | 14.73 | 0.26 |
| | 12-3 | 3144 | 14.56 | 0.26 |
| | 12-7 | 3332 | 15.43 | 0.27 |
| | 12-9 | 3510 | 16.26 | 0.27 |
| | 12-10 | 3174 | 14.70 | 0.26 |
| | 13-2 | 3160 | 14.64 | 0.26 |
| | 13-6 | 3343 | 15.48 | 0.27 |
| | 13-8 | 3041 | 14.09 | 0.26 |

T056.WS SORTED BY LOCATION

| ROOM NUMBER | GRID NAME | GAMMA TOTAL | uR/h TOTAL | STD DEV |
|---|---|---|---|---|
| | 13-10 | 2626 | 12.16 | 0.24 |
| | 13-11 | 3216 | 14.90 | 0.26 |
| | 14-11 | 3406 | 15.78 | 0.27 |
| | 14-12 | 3237 | 14.99 | 0.26 |
| | 15-7 | 3042 | 14.09 | 0.26 |
| | 15-9 | 2978 | 13.79 | 0.25 |
| | 15-10 | 3092 | 14.32 | 0.26 |
| | 16-7 | 3239 | 15.00 | 0.26 |
| | 16-10 | 3333 | 15.44 | 0.27 |
| | 16-12 | 3488 | 16.16 | 0.27 |
| | 16-13 | 3418 | 15.83 | 0.27 |
| | 16-14 | 3424 | 15.86 | 0.27 |
| | 16-15 | 3343 | 15.48 | 0.27 |
| | 16-16 | 3154 | 14.61 | 0.26 |
| | 17-8 | 3512 | 16.27 | 0.27 |
| | 17-12 | 3461 | 16.03 | 0.27 |
| | 17-14 | 3212 | 14.88 | 0.26 |
| | 17-15 | 3291 | 15.24 | 0.27 |
| | 17-16 | 3230 | 14.96 | 0.26 |
| | 18-12 | 3461 | 16.03 | 0.27 |
| | 18-13 | 3488 | 16.16 | 0.27 |
| | 18-14 | 3537 | 16.38 | 0.28 |
| | 18-15 | 3357 | 15.55 | 0.27 |
| | 18-16 | 3077 | 14.25 | 0.26 |
| | 18-17 | 3230 | 14.96 | 0.26 |
| | 18-18 | 3528 | 16.34 | 0.28 |
| | 19-10 | 3415 | 15.82 | 0.27 |
| | 19-13 | 3345 | 15.49 | 0.27 |
| | 19-15 | 3269 | 15.14 | 0.26 |
| | 19-16 | 3609 | 16.72 | 0.28 |
| | 19-17 | 3255 | 15.08 | 0.26 |
| | 19-19 | 3829 | 17.74 | 0.29 |
| | 20-3 | 3070 | 14.22 | 0.26 |
| | 20-7 | 3540 | 16.40 | 0.28 |
| | 20-10 | 3439 | 15.93 | 0.27 |
| | 20-12 | 3212 | 14.88 | 0.26 |
| | 20-13 | 3317 | 15.36 | 0.27 |
| | 20-14 | 3321 | 15.38 | 0.27 |
| | 20-18 | 3307 | 15.32 | 0.27 |
| | 20-19 | 3392 | 15.71 | 0.27 |
| | 20-20 | 3449 | 15.98 | 0.27 |
| | 20-21 | 3381 | 15.66 | 0.27 |
| | 21-3 | 3280 | 15.19 | 0.27 |
| | 21-4 | 3066 | 14.20 | 0.26 |
| | 21-9 | 3123 | 14.47 | 0.26 |
| | 21-11 | 3313 | 15.35 | 0.27 |
| | 21-12 | 3210 | 14.87 | 0.26 |
| | 21-18 | 3499 | 16.21 | 0.27 |
| | 21-19 | 3283 | 15.21 | 0.27 |
| | 21-23 | 3365 | 15.59 | 0.27 |
| | 22-3 | 3174 | 14.70 | 0.26 |
| | 22-6 | 3254 | 15.07 | 0.26 |
| | 22-10 | 3250 | 15.05 | 0.26 |
| | 22-18 | 3316 | 15.36 | 0.27 |
| | 22-20 | 3478 | 16.11 | 0.27 |

T056.WS SORTED BY LOCATION

| ROOM NUMBER | GRID NAME | GAMMA TOTAL | uR/h TOTAL | STD DEV |
|---|---|---|---|---|
| | 23-5 | 3110 | 14.41 | 0.26 |
| | 23-7 | 3042 | 14.09 | 0.26 |
| | 23-9 | 3139 | 14.54 | 0.26 |
| | 23-12 | 3218 | 14.91 | 0.26 |
| | 24-3 | 3098 | 14.35 | 0.26 |
| | 24-6 | 3141 | 14.55 | 0.26 |
| | 24-10 | 3084 | 14.29 | 0.26 |
| | 24-18 | 3493 | 16.18 | 0.27 |
| | 24-19 | 3401 | 15.75 | 0.27 |
| | 25-4 | 2925 | 13.55 | 0.25 |
| | 25-8 | 3212 | 14.88 | 0.26 |
| | 25-9 | 3233 | 14.98 | 0.26 |
| | 25-20 | 3460 | 16.03 | 0.27 |
| | 26-2 | 3272 | 15.16 | 0.26 |
| | 26-7 | 3118 | 14.44 | 0.26 |
| | 26-18 | 3473 | 16.09 | 0.27 |
| | 26-19 | 3326 | 15.41 | 0.27 |
| | 27-5 | 3024 | 14.01 | 0.25 |
| | 27-6 | 3254 | 15.07 | 0.26 |
| | 27-19 | 3491 | 16.17 | 0.27 |
| | 27-21 | 3345 | 15.49 | 0.27 |
| | 28-2 | 3208 | 14.86 | 0.26 |
| | 28-3 | 2939 | 13.61 | 0.25 |
| | 28-4 | 3111 | 14.41 | 0.26 |
| | 28-20 | 3301 | 15.29 | 0.27 |
| | 29-3 | 3018 | 13.98 | 0.25 |
| | 29-4 | 2933 | 13.59 | 0.25 |
| | 29-20 | 3398 | 15.74 | 0.27 |
| | 29-21 | 3152 | 14.60 | 0.26 |
| | 29-22 | 3252 | 15.06 | 0.26 |

| | | |
|---|---|---|
| NO. OF MEASUREMENTS: | 140 | |
| AVG./SQRT(SUMSQ): | 14.96 | 3.11 |
| STD. DEV.: | 0.80 | |
| MAXIMUM | 17.74 | |
| MINIMUM | 12.16 | |
| RANGE | 5.57 | |

# T056 Landfill Sorted by Exposure Rate

| T056.WS | | SORTED BY EXPOSURE RATE | | |
|---|---|---|---|---|
| ROOM | GRID | GAMMA | uR/h | |
| NUMBER | NAME | TOTAL | TOTAL | STD DEV |
| | 19-19 | 3829 | 17.74 | 0.29 |
| | 19-16 | 3609 | 16.72 | 0.28 |
| | 20-7 | 3540 | 16.40 | 0.28 |
| | 18-14 | 3537 | 16.38 | 0.28 |
| | 18-18 | 3528 | 16.34 | 0.28 |
| C.2 | 17-8 | 3512 | 16.27 | 0.27 |
| | 12-9 | 3510 | 16.26 | 0.27 |
| | 21-18 | 3499 | 16.21 | 0.27 |
| | 24-18 | 3493 | 16.18 | 0.27 |
| | 27-19 | 3491 | 16.17 | 0.27 |
| | 16-12 | 3488 | 16.16 | 0.27 |
| | 18-13 | 3488 | 16.16 | 0.27 |
| | 22-20 | 3478 | 16.11 | 0.27 |
| | 26-18 | 3473 | 16.09 | 0.27 |
| | 17-12 | 3461 | 16.03 | 0.27 |
| | 18-12 | 3461 | 16.03 | 0.27 |
| | 25-20 | 3460 | 16.03 | 0.27 |
| | 20-20 | 3449 | 15.98 | 0.27 |
| | 20-10 | 3439 | 15.93 | 0.27 |
| | 16-14 | 3424 | 15.86 | 0.27 |
| | 16-13 | 3418 | 15.83 | 0.27 |
| | 19-10 | 3415 | 15.82 | 0.27 |
| | 14-11 | 3406 | 15.78 | 0.27 |
| | 24-19 | 3401 | 15.75 | 0.27 |
| | 29-20 | 3398 | 15.74 | 0.27 |
| | 20-19 | 3392 | 15.71 | 0.27 |
| | 20-21 | 3381 | 15.66 | 0.27 |
| | 8-5 | 3375 | 15.63 | 0.27 |
| | 21-23 | 3365 | 15.59 | 0.27 |
| | 18-15 | 3357 | 15.55 | 0.27 |
| | 19-13 | 3345 | 15.49 | 0.27 |
| | 27-21 | 3345 | 15.49 | 0.27 |
| | 13-6 | 3343 | 15.48 | 0.27 |
| | 16-15 | 3343 | 15.48 | 0.27 |
| | 3-12 | 3334 | 15.44 | 0.27 |
| | 16-10 | 3333 | 15.44 | 0.27 |
| | 9-8 | 3332 | 15.43 | 0.27 |
| | 12-7 | 3332 | 15.43 | 0.27 |
| | 26-19 | 3326 | 15.41 | 0.27 |
| | 11-5 | 3324 | 15.40 | 0.27 |
| | 10-3 | 3324 | 15.40 | 0.27 |
| | 20-14 | 3321 | 15.38 | 0.27 |
| | 20-13 | 3317 | 15.36 | 0.27 |
| | 22-18 | 3316 | 15.36 | 0.27 |
| | 11-8 | 3315 | 15.36 | 0.27 |
| | 21-11 | 3313 | 15.35 | 0.27 |
| | 20-18 | 3307 | 15.32 | 0.27 |
| | 4-12 | 3304 | 15.30 | 0.27 |
| | 6-6 | 3303 | 15.30 | 0.27 |
| | 3-13 | 3302 | 15.29 | 0.27 |
| | 28-20 | 3301 | 15.29 | 0.27 |
| | 5-14 | 3300 | 15.29 | 0.27 |
| | 9-3 | 3300 | 15.29 | 0.27 |
| | 17-15 | 3291 | 15.24 | 0.27 |
| | 21-19 | 3283 | 15.21 | 0.27 |

T056.WS SORTED BY EXPOSURE RATE

| ROOM NUMBER | GRID NAME | GAMMA TOTAL | uR/h TOTAL | uR/h STD DEV |
|---|---|---|---|---|
| | 21-3 | 3280 | 15.19 | 0.27 |
| | 26-2 | 3272 | 15.16 | 0.26 |
| | 19-15 | 3269 | 15.14 | 0.26 |
| | 19-17 | 3255 | 15.08 | 0.26 |
| | 22-6 | 3254 | 15.07 | 0.26 |
| | 27-6 | 3254 | 15.07 | 0.26 |
| | 29-22 | 3252 | 15.06 | 0.26 |
| | 22-10 | 3250 | 15.05 | 0.26 |
| | 16-7 | 3239 | 15.00 | 0.26 |
| | 14-12 | 3237 | 14.99 | 0.26 |
| | 25-9 | 3233 | 14.98 | 0.26 |
| | 17-16 | 3230 | 14.96 | 0.26 |
| | 18-17 | 3230 | 14.96 | 0.26 |
| | 23-12 | 3218 | 14.91 | 0.26 |
| | 13-11 | 3216 | 14.90 | 0.26 |
| | 10-5 | 3214 | 14.89 | 0.26 |
| | 11-6 | 3214 | 14.89 | 0.26 |
| | 20-12 | 3212 | 14.88 | 0.26 |
| | 17-14 | 3212 | 14.88 | 0.26 |
| | 25-8 | 3212 | 14.88 | 0.26 |
| | 21-12 | 3210 | 14.87 | 0.26 |
| | 28-2 | 3208 | 14.86 | 0.26 |
| | 10-8 | 3200 | 14.82 | 0.26 |
| | 7-14 | 3191 | 14.78 | 0.26 |
| | 4-13 | 3186 | 14.76 | 0.26 |
| | 12-2 | 3180 | 14.73 | 0.26 |
| | 12-10 | 3174 | 14.70 | 0.26 |
| | 22-3 | 3174 | 14.70 | 0.26 |
| | 2-16 | 3166 | 14.66 | 0.26 |
| | 4-14 | 3164 | 14.66 | 0.26 |
| | 13-2 | 3160 | 14.64 | 0.26 |
| | 7-9 | 3159 | 14.63 | 0.26 |
| | 16-16 | 3154 | 14.61 | 0.26 |
| | 29-21 | 3152 | 14.60 | 0.26 |
| | 8-9 | 3148 | 14.58 | 0.26 |
| | 3-11 | 3147 | 14.58 | 0.26 |
| | 11-4 | 3144 | 14.56 | 0.26 |
| | 12-3 | 3144 | 14.56 | 0.26 |
| | 8-11 | 3143 | 14.56 | 0.26 |
| | 24-6 | 3141 | 14.55 | 0.26 |
| | 23-9 | 3139 | 14.54 | 0.26 |
| | 7-12 | 3133 | 14.51 | 0.26 |
| | 6-8 | 3125 | 14.48 | 0.26 |
| | 21-9 | 3123 | 14.47 | 0.26 |
| | 5-4 | 3123 | 14.47 | 0.26 |
| | 26-7 | 3118 | 14.44 | 0.26 |
| | 8-3 | 3111 | 14.41 | 0.26 |
| | 28-4 | 3111 | 14.41 | 0.26 |
| | 23-5 | 3110 | 14.41 | 0.26 |
| | 5-6 | 3109 | 14.40 | 0.26 |
| | 9-2 | 3103 | 14.37 | 0.26 |
| | 11-1 | 3101 | 14.36 | 0.26 |
| | 24-3 | 3098 | 14.35 | 0.26 |
| | 4-15 | 3094 | 14.33 | 0.26 |
| | 5-13 | 3094 | 14.33 | 0.26 |

T056.WS SORTED BY EXPOSURE RATE

| ROOM NUMBER | GRID NAME | GAMMA TOTAL | uR/h TOTAL | uR/h STD DEV |
|---|---|---|---|---|
| | 15-10 | 3092 | 14.32 | 0.26 |
| | 24-10 | 3084 | 14.29 | 0.26 |
| | 9-1 | 3080 | 14.27 | 0.26 |
| | 5-5 | 3080 | 14.27 | 0.26 |
| | 18-16 | 3077 | 14.25 | 0.26 |
| | 20-3 | 3070 | 14.22 | 0.26 |
| | 7-2 | 3069 | 14.22 | 0.26 |
| | 2-14 | 3068 | 14.21 | 0.26 |
| | 21-4 | 3066 | 14.20 | 0.26 |
| | 4-8 | 3066 | 14.20 | 0.26 |
| | 5-12 | 3062 | 14.18 | 0.26 |
| | 6-9 | 3060 | 14.17 | 0.26 |
| | 11-3 | 3054 | 14.15 | 0.26 |
| | 3-10 | 3050 | 14.13 | 0.26 |
| | 15-7 | 3042 | 14.09 | 0.26 |
| | 23-7 | 3042 | 14.09 | 0.26 |
| | 13-8 | 3041 | 14.09 | 0.26 |
| | 27-5 | 3024 | 14.01 | 0.25 |
| | 29-3 | 3018 | 13.98 | 0.25 |
| | 4-10 | 3009 | 13.94 | 0.25 |
| | 15-9 | 2978 | 13.79 | 0.25 |
| | 7-4 | 2966 | 13.74 | 0.25 |
| | 5-3 | 2964 | 13.73 | 0.25 |
| | 6-13 | 2948 | 13.66 | 0.25 |
| | 5-10 | 2946 | 13.65 | 0.25 |
| | 28-3 | 2939 | 13.61 | 0.25 |
| | 29-4 | 2933 | 13.59 | 0.25 |
| | 25-4 | 2925 | 13.55 | 0.25 |
| | 6-7 | 2888 | 13.38 | 0.25 |
| | 13-10 | 2626 | 12.16 | 0.24 |

| | | |
|---|---|---|
| NO. OF MEASUREMENTS: | 140 | |
| AVG./SQRT(SUMSQ): | 14.96 | 3.11 |
| STD. DEV.: | 0.80 | |
| MAXIMUM | 17.74 | |
| MINIMUM | 12.16 | |
| RANGE | 5.57 | |

T100 Storage Yard Sorted by Location

T100.WS SORTED BY LOCATION

C.3

| ROOM NUMBER | GRID NAME | GAMMA TOTAL | uR/h TOTAL | STD DEV |
|---|---|---|---|---|
| AREA A | A3-4 | 2834 | 13.13 | 0.25 |
| AREA A | A3-6 | 2932 | 13.58 | 0.25 |
| AREA A | A3-8 | 2864 | 13.27 | 0.25 |
| AREA A | A3-10 | 2824 | 13.08 | 0.25 |
| AREA A | A3-12 | 2937 | 13.60 | 0.25 |
| AREA A | A3-14 | 2965 | 13.73 | 0.25 |
| AREA A | A3-18 | 2899 | 13.43 | 0.25 |
| AREA A | G4-6 | 2972 | 13.77 | 0.25 |
| AREA A | G4-8 | 2814 | 13.03 | 0.25 |
| AREA A | G4-10 | 2814 | 13.03 | 0.25 |
| AREA A | G4-12 | 3033 | 14.05 | 0.26 |
| AREA A | A5-2 | 2902 | 13.44 | 0.25 |
| AREA A | G5-5 | 2973 | 13.77 | 0.25 |
| AREA A | A5-18 | 3407 | 15.78 | 0.27 |
| AREA A | G6-8 | 2755 | 12.76 | 0.24 |
| AREA A | D6-15 | 3010 | 13.94 | 0.25 |
| AREA A | G7-4 | 3001 | 13.90 | 0.25 |
| AREA A | G7-6 | 2918 | 13.52 | 0.25 |
| AREA A | G7-10 | 1808 | 8.37 | 0.20 |
| AREA A | G7-12 | 2898 | 13.42 | 0.25 |
| AREA A | D7-17 | 3198 | 14.81 | 0.26 |
| AREA A | A7-18 | 3544 | 16.42 | 0.28 |
| AREA A | A8-2 | 2836 | 13.14 | 0.25 |
| AREA A | G9-4 | 2940 | 13.62 | 0.25 |
| AREA A | G9-6 | 2569 | 11.90 | 0.23 |
| AREA A | G9-8 | 2245 | 10.40 | 0.22 |
| AREA A | G9-10 | 2217 | 10.27 | 0.22 |
| AREA A | G9-12 | 2734 | 12.66 | 0.24 |
| AREA A | D9-15 | 2984 | 13.82 | 0.25 |
| AREA A | A10-2 | 2770 | 12.83 | 0.24 |
| AREA A | D10-17 | 3070 | 14.22 | 0.26 |
| AREA A | A10-18 | 3648 | 16.90 | 0.28 |
| AREA A | A11-2 | 2770 | 12.83 | 0.24 |
| AREA A | G11-8 | 2485 | 11.51 | 0.23 |
| AREA A | G11-10 | 2637 | 12.21 | 0.24 |
| AREA A | G12-4 | 2965 | 13.73 | 0.25 |
| AREA A | G12-6 | 2519 | 11.67 | 0.23 |
| AREA A | G12-12 | 2823 | 13.08 | 0.25 |
| AREA A | D12-15 | 2816 | 13.04 | 0.25 |
| AREA A | A13-2 | 2884 | 13.36 | 0.25 |
| AREA A | D13-17 | 3246 | 15.04 | 0.26 |
| AREA A | A13-18 | 3757 | 17.40 | 0.28 |
| AREA A | G14-4 | 3015 | 13.97 | 0.25 |
| AREA A | G14-6 | 3133 | 14.51 | 0.26 |
| AREA A | G14-8 | 2995 | 13.87 | 0.25 |
| AREA A | G14-10 | 3044 | 14.10 | 0.26 |
| AREA A | G14-12 | 2990 | 13.85 | 0.25 |
| AREA A | A15-2 | 2835 | 13.13 | 0.25 |
| AREA A | G16-4 | 2955 | 13.69 | 0.25 |
| AREA A | G16-6 | 3043 | 14.10 | 0.26 |
| AREA A | G16-8 | 3042 | 14.09 | 0.26 |
| AREA A | G16-10 | 3098 | 14.35 | 0.26 |
| AREA A | G16-12 | 2965 | 13.73 | 0.25 |
| AREA A | D16-17 | 3129 | 14.49 | 0.26 |
| AREA A | A16-18 | 3715 | 17.21 | 0.28 |

T100.WS SORTED BY LOCATION

| ROOM NUMBER | GRID NAME | GAMMA TOTAL | uR/h TOTAL | STD DEV |
|---|---|---|---|---|
| AREA A | A17-2 | 2810 | 13.02 | 0.25 |
| AREA A | D17-15 | 2890 | 13.39 | 0.25 |
| AREA A | A18-4 | 2870 | 13.29 | 0.25 |
| AREA A | A18-6 | 2277 | 10.55 | 0.22 |
| AREA A | D18-17 | 3067 | 14.21 | 0.26 |
| AREA A | A18-18 | 3770 | 17.46 | 0.28 |
| AREA A | A19-8 | 3014 | 13.96 | 0.25 |
| AREA A | G19-10 | 2935 | 13.59 | 0.25 |
| AREA A | G19-12 | 2856 | 13.23 | 0.25 |
| AREA A | D19-15 | 2879 | 13.34 | 0.25 |
| AREA A | A20-2 | 2900 | 13.43 | 0.25 |
| AREA A | G21-4 | 3003 | 13.91 | 0.25 |
| AREA A | G21-6 | 2755 | 12.76 | 0.24 |
| AREA A | G21-8 | 2970 | 13.76 | 0.25 |
| AREA A | G21-10 | 2292 | 10.62 | 0.22 |
| AREA A | G21-12 | 2216 | 10.26 | 0.22 |
| AREA A | D21-15 | 2892 | 13.40 | 0.25 |
| AREA A | D21-17 | 2737 | 12.68 | 0.24 |
| AREA A | A21-18 | 3623 | 16.78 | 0.28 |
| AREA A | A22-2 | 2879 | 13.34 | 0.25 |
| AREA A | G24-4 | 2951 | 13.67 | 0.25 |
| AREA A | G24-6 | 3101 | 14.36 | 0.26 |
| AREA A | G24-8 | 3053 | 14.14 | 0.26 |
| AREA A | G24-10 | 2277 | 10.55 | 0.22 |
| AREA A | G24-12 | 2189 | 10.14 | 0.22 |
| AREA A | D24-15 | 2837 | 13.14 | 0.25 |
| AREA A | D24-17 | 3130 | 14.50 | 0.26 |
| AREA A | A24-18 | 3562 | 16.50 | 0.28 |
| AREA A | A25-2 | 2890 | 13.39 | 0.25 |
| AREA A | G26-4 | 3005 | 13.92 | 0.25 |
| AREA A | G26-6 | 2962 | 13.72 | 0.25 |
| AREA A | G26-8 | 2613 | 12.10 | 0.24 |
| AREA A | G26-10 | 2355 | 10.91 | 0.22 |
| AREA A | G26-12 | 2336 | 10.82 | 0.22 |
| AREA A | D26-15 | 2828 | 13.10 | 0.25 |
| AREA A | A27-2 | 2849 | 13.20 | 0.25 |
| AREA A | D27-17 | 3155 | 14.61 | 0.26 |
| AREA A | A27-18 | 3610 | 16.72 | 0.28 |
| AREA A | G28-4 | 2950 | 13.66 | 0.25 |
| AREA A | G28-6 | 2692 | 12.47 | 0.24 |
| AREA A | G28-8 | 2363 | 10.95 | 0.23 |
| AREA A | A28-10 | 2888 | 13.38 | 0.25 |
| AREA A | G28-12 | 2386 | 11.05 | 0.23 |
| AREA A | D28-15 | 2954 | 13.68 | 0.25 |
| AREA A | A29-2 | 2848 | 13.19 | 0.25 |
| AREA A | D29-17 | 3086 | 14.29 | 0.26 |
| AREA A | A29-18 | 3539 | 16.39 | 0.28 |
| AREA A | A30-6 | 2218 | 10.27 | 0.22 |
| AREA A | A31-4 | 2727 | 12.63 | 0.24 |
| AREA A | A31-8 | 2617 | 12.12 | 0.24 |
| AREA A | G31-10 | 2417 | 11.20 | 0.23 |
| AREA A | G31-12 | 2625 | 12.16 | 0.24 |
| AREA A | D31-15 | 2870 | 13.29 | 0.25 |
| AREA A | A32-2 | 2771 | 12.84 | 0.24 |
| AREA A | D32-17 | 2746 | 12.72 | 0.24 |

T100.WS SORTED BY LOCATION

| ROOM NUMBER | GRID NAME | GAMMA TOTAL | uR/h TOTAL | STD DEV |
|---|---|---|---|---|
| AREA A | A32-18 | 3405 | 15.77 | 0.27 |
| AREA A | G33-4 | 2950 | 13.66 | 0.25 |
| AREA A | G33-6 | 2887 | 13.37 | 0.25 |
| AREA A | G33-8 | 2300 | 10.65 | 0.22 |
| AREA A | G33-10 | 2089 | 9.68 | 0.21 |
| AREA A | G33-12 | 2219 | 10.28 | 0.22 |
| AREA A | D33-15 | 2811 | 13.02 | 0.25 |
| AREA A | A34-2 | 2865 | 13.27 | 0.25 |
| AREA A | G35-4 | 2679 | 12.41 | 0.24 |
| AREA A | G35-6 | 2298 | 10.64 | 0.22 |
| AREA A | G35-8 | 2719 | 12.59 | 0.24 |
| AREA A | G35-10 | 2079 | 9.63 | 0.21 |
| AREA A | G35-13 | 2664 | 12.34 | 0.24 |
| AREA A | D35-15 | 2832 | 13.12 | 0.25 |
| AREA A | D35-17 | 3112 | 14.41 | 0.26 |
| AREA A | A35-18 | 3509 | 16.25 | 0.27 |
| AREA A | S36-2 | 2790 | 12.92 | 0.24 |
| AREA A | G37-4 | 2606 | 12.07 | 0.24 |
| AREA A | G37-6 | 2078 | 9.63 | 0.21 |
| AREA A | G37-8 | 2762 | 12.79 | 0.24 |
| AREA A | G38-10 | 2261 | 10.47 | 0.22 |
| AREA A | G38-13 | 2641 | 12.23 | 0.24 |
| AREA A | D38-15 | 2891 | 13.39 | 0.25 |
| AREA A | D38-17 | 3207 | 14.85 | 0.26 |
| AREA A | A38-18 | 3609 | 16.72 | 0.28 |
| AREA A | A39-2 | 2749 | 12.73 | 0.24 |
| AREA A | G40-4 | 2996 | 13.88 | 0.25 |
| AREA A | G40-6 | 2925 | 13.55 | 0.25 |
| AREA A | G40-8 | 2989 | 13.85 | 0.25 |
| AREA A | G40-10 | 2919 | 13.52 | 0.25 |
| AREA A | G40-12 | 2625 | 12.16 | 0.24 |
| AREA A | D40-15 | 3027 | 14.02 | 0.25 |
| AREA A | A41-2 | 2823 | 13.08 | 0.25 |
| AREA A | D41-17 | 3085 | 14.29 | 0.26 |
| AREA A | A41-18 | 3655 | 16.93 | 0.28 |
| AREA A | G42-4 | 3006 | 13.92 | 0.25 |
| AREA A | G42-6 | 2935 | 13.59 | 0.25 |
| AREA A | G42-8 | 3003 | 13.91 | 0.25 |
| AREA A | G42-10 | 2955 | 13.69 | 0.25 |
| AREA A | G42-12 | 2781 | 12.88 | 0.24 |
| AREA A | D42-15 | 2881 | 13.34 | 0.25 |
| AREA A | A43-2 | 2918 | 13.52 | 0.25 |
| AREA A | D44-17 | 3055 | 14.15 | 0.26 |
| AREA A | A44-18 | 3591 | 16.63 | 0.28 |
| AREA A | A45-2 | 2906 | 13.46 | 0.25 |
| AREA A | G45-4 | 3029 | 14.03 | 0.25 |
| AREA A | D45-4 | 3002 | 13.91 | 0.25 |
| AREA A | G45-6 | 2931 | 13.58 | 0.25 |
| AREA A | G45-8 | 2945 | 13.64 | 0.25 |
| AREA A | A45-8 | 2956 | 13.69 | 0.25 |
| AREA A | G45-10 | 3045 | 14.10 | 0.26 |
| AREA A | A45-10 | 2973 | 13.77 | 0.25 |
| AREA A | G45-12 | 2917 | 13.51 | 0.25 |
| AREA A | A45-12 | 3300 | 15.29 | 0.27 |
| AREA A | D45-15 | 2930 | 13.57 | 0.25 |

T100.WS SORTED BY LOCATION

| ROOM NUMBER | GRID NAME | GAMMA TOTAL | uR/h TOTAL | STD DEV |
|---|---|---|---|---|
| AREA A | A45-15 | 3025 | 14.01 | 0.25 |
| AREA A | G46-6 | 2914 | 13.50 | 0.25 |
| AREA A | G46-8 | 2951 | 13.67 | 0.25 |
| AREA A | G46-10 | 2881 | 13.34 | 0.25 |
| AREA A | G46-13 | 2927 | 13.56 | 0.25 |
| AREA A | G46-15 | 2992 | 13.86 | 0.25 |
| AREA A | D46-17 | 3011 | 13.95 | 0.25 |
| AREA A | A46-18 | 3614 | 16.74 | 0.28 |
| AREA A | A47-18 | 3453 | 15.99 | 0.27 |
| AREA B | D2-2 | 3310 | 15.33 | 0.27 |
| AREA B | D2-3 | 3307 | 15.32 | 0.27 |
| AREA B | D2-4 | 3396 | 15.73 | 0.27 |
| AREA B | D2-5 | 3299 | 15.28 | 0.27 |
| AREA B | R2-6 | 3226 | 14.94 | 0.26 |
| AREA B | D2-10 | 3104 | 14.38 | 0.26 |
| AREA B | D3-1 | 3242 | 15.02 | 0.26 |
| AREA B | D3-2 | 3241 | 15.01 | 0.26 |
| AREA B | D3-3 | 3306 | 15.31 | 0.27 |
| AREA B | D3-4 | 3160 | 14.64 | 0.26 |
| AREA B | R3-5 | 3284 | 15.21 | 0.27 |
| AREA B | D3-10 | 2881 | 13.34 | 0.25 |
| AREA B | D4-1 | 3160 | 14.64 | 0.26 |
| AREA B | D4-2 | 3222 | 14.92 | 0.26 |
| AREA B | D4-3 | 2994 | 13.87 | 0.25 |
| AREA B | R4-4 | 3324 | 15.40 | 0.27 |
| AREA B | D4-7 | 3041 | 14.09 | 0.26 |
| AREA B | D4-8 | 2737 | 12.68 | 0.24 |
| AREA B | D4-9 | 3108 | 14.40 | 0.26 |
| AREA B | D4-10 | 2946 | 13.65 | 0.25 |
| AREA B | D5-1 | 3091 | 14.32 | 0.26 |
| AREA B | D5-2 | 3085 | 14.29 | 0.26 |
| AREA B | D5-7 | 2840 | 13.15 | 0.25 |
| AREA B | D5-8 | 2839 | 13.15 | 0.25 |
| AREA B | M5-9 | 2838 | 13.15 | 0.25 |
| AREA B | A5-10 | 2550 | 11.81 | 0.23 |
| AREA B | D6-1 | 3163 | 14.65 | 0.26 |
| AREA B | D6-8 | 2890 | 13.39 | 0.25 |
| AREA B | M6-9 | 2763 | 12.80 | 0.24 |
| AREA B | A6-10 | 2648 | 12.27 | 0.24 |
| AREA B | D7-5 | 3004 | 13.91 | 0.25 |
| AREA B | D7-6 | 3000 | 13.90 | 0.25 |
| AREA B | D7-7 | 2982 | 13.81 | 0.25 |
| AREA B | D7-8 | 3083 | 14.28 | 0.26 |
| AREA B | M7-9 | 2824 | 13.08 | 0.25 |
| AREA B | D7-10 | 2741 | 12.70 | 0.24 |
| AREA B | D8-5 | 2990 | 13.85 | 0.25 |
| AREA B | D8-6 | 2980 | 13.80 | 0.25 |
| AREA B | D8-7 | 2990 | 13.85 | 0.25 |
| AREA B | D8-8 | 2920 | 13.53 | 0.25 |
| AREA B | W8-9 | 2773 | 12.84 | 0.24 |
| AREA B | A8-10 | 2860 | 13.25 | 0.25 |
| AREA B | D9-3 | 3113 | 14.42 | 0.26 |
| AREA B | D9-5 | 3136 | 14.53 | 0.26 |
| AREA B | D9-6 | 3088 | 14.30 | 0.26 |
| AREA B | D9-7 | 2962 | 13.72 | 0.25 |

T100.WS SORTED BY LOCATION

| ROOM NUMBER | GRID NAME | GAMMA TOTAL | uR/h TOTAL | STD DEV |
|---|---|---|---|---|
| AREA B | W9-9 | 2635 | 12.21 | 0.24 |
| AREA B | D9-10 | 2594 | 12.02 | 0.24 |
| AREA B | D10-1 | 3434 | 15.91 | 0.27 |
| AREA B | D10-2 | 3161 | 14.64 | 0.26 |
| AREA B | D10-3 | 3155 | 14.61 | 0.26 |
| AREA B | D10-4 | 3116 | 14.43 | 0.26 |
| AREA B | D10-5 | 3050 | 14.13 | 0.26 |
| AREA B | D10-6 | 3002 | 13.91 | 0.25 |
| AREA B | D10-7 | 3008 | 13.93 | 0.25 |
| AREA B | W10-9 | 2446 | 11.33 | 0.23 |
| AREA B | D10-10 | 2737 | 12.68 | 0.24 |
| AREA B | D11-1 | 3233 | 14.98 | 0.26 |
| AREA B | D11-2 | 3217 | 14.90 | 0.26 |
| AREA B | D11-3 | 3106 | 14.39 | 0.26 |
| AREA B | D11-4 | 2990 | 13.85 | 0.25 |
| AREA B | D11-5 | 3022 | 14.00 | 0.25 |
| AREA B | D11-6 | 3078 | 14.26 | 0.26 |
| AREA B | D11-7 | 3018 | 13.98 | 0.25 |
| AREA B | W11-9 | 2595 | 12.02 | 0.24 |
| AREA B | D11-10 | 2877 | 13.33 | 0.25 |
| AREA B | G12-1 | 2923 | 13.54 | 0.25 |
| AREA B | D12-2 | 3196 | 14.80 | 0.26 |
| AREA B | D12-3 | 3031 | 14.04 | 0.26 |
| AREA B | D12-4 | 3077 | 14.25 | 0.26 |
| AREA B | G12-5 | 2969 | 13.75 | 0.25 |
| AREA B | D12-6 | 2981 | 13.81 | 0.25 |
| AREA B | D12-7 | 2923 | 13.54 | 0.25 |
| AREA B | W12-9 | 2658 | 12.31 | 0.24 |
| AREA B | D12-10 | 2802 | 12.98 | 0.25 |
| AREA B | D13-1 | 3041 | 14.09 | 0.26 |
| AREA B | D13-2 | 3166 | 14.66 | 0.26 |
| AREA B | D13-3 | 3100 | 14.36 | 0.26 |
| AREA B | D13-4 | 3088 | 14.30 | 0.26 |
| AREA B | D13-5 | 2992 | 13.86 | 0.25 |
| AREA B | G13-6 | 2918 | 13.52 | 0.25 |
| AREA B | D13-7 | 2943 | 13.63 | 0.25 |
| AREA B | D13-8 | 2769 | 12.83 | 0.24 |
| AREA B | M13-9 | 2585 | 11.97 | 0.24 |
| AREA B | A13-10 | 2776 | 12.86 | 0.24 |
| AREA B | D14-1 | 3020 | 13.99 | 0.25 |
| AREA B | D14-2 | 3131 | 14.50 | 0.26 |
| AREA B | D14-3 | 3015 | 13.97 | 0.25 |
| AREA B | D14-4 | 3049 | 14.12 | 0.26 |
| AREA B | D14-5 | 3088 | 14.30 | 0.26 |
| AREA B | D14-6 | 3020 | 13.99 | 0.25 |
| AREA B | D14-7 | 2936 | 13.60 | 0.25 |
| AREA B | D14-8 | 2840 | 13.15 | 0.25 |
| AREA B | G14-9 | 2592 | 12.01 | 0.24 |
| AREA B | W14-10 | 2710 | 12.55 | 0.24 |
| AREA B | D15-1 | 3056 | 14.16 | 0.26 |
| AREA B | D15-2 | 3112 | 14.41 | 0.26 |
| AREA B | D15-3 | 3025 | 14.01 | 0.25 |
| AREA B | D15-4 | 3058 | 14.16 | 0.26 |
| AREA B | D15-5 | 3097 | 14.35 | 0.26 |
| AREA B | G15-6 | 3032 | 14.04 | 0.26 |

T100.WS SORTED BY LOCATION

| ROOM NUMBER | GRID NAME | GAMMA TOTAL | uR/h TOTAL | STD DEV |
|---|---|---|---|---|
| AREA B | G15-7 | 2848 | 13.19 | 0.25 |
| AREA B | D15-8 | 2919 | 13.52 | 0.25 |
| AREA B | W15-9 | 2455 | 11.37 | 0.23 |
| AREA B | M15-10 | 2649 | 12.27 | 0.24 |
| AREA B | D16-1 | 3028 | 14.03 | 0.25 |
| AREA B | D16-2 | 3098 | 14.35 | 0.26 |
| AREA B | D16-3 | 3099 | 14.35 | 0.26 |
| AREA B | D16-4 | 3080 | 14.27 | 0.26 |
| AREA B | D16-5 | 2941 | 13.62 | 0.25 |
| AREA B | D16-6 | 2920 | 13.53 | 0.25 |
| AREA B | D16-7 | 2951 | 13.67 | 0.25 |
| AREA B | D16-8 | 2944 | 13.64 | 0.25 |
| AREA B | D16-9 | 2647 | 12.26 | 0.24 |
| AREA B | D18-10 | 2665 | 12.34 | 0.24 |
| AREA B | D17-1 | 2862 | 13.26 | 0.25 |
| AREA B | D17-2 | 3068 | 14.21 | 0.26 |
| AREA B | D17-3 | 2987 | 13.84 | 0.25 |
| AREA B | D17-4 | 2967 | 13.74 | 0.25 |
| AREA B | D17-5 | 2901 | 13.44 | 0.25 |
| AREA B | D17-6 | 2926 | 13.55 | 0.25 |
| AREA B | D17-7 | 2780 | 12.88 | 0.24 |
| AREA B | D17-8 | 2744 | 12.71 | 0.24 |
| AREA B | D17-9 | 2826 | 13.09 | 0.25 |
| AREA B | D17-10 | 2898 | 13.42 | 0.25 |
| AREA B | D18-1 | 2848 | 13.19 | 0.25 |
| AREA B | D18-2 | 2760 | 12.78 | 0.24 |
| AREA B | D18-3 | 2887 | 13.37 | 0.25 |
| AREA B | D18-4 | 2856 | 13.23 | 0.25 |
| AREA B | D18-5 | 2909 | 13.47 | 0.25 |
| AREA B | D18-6 | 2817 | 13.05 | 0.25 |
| AREA B | D18-7 | 2854 | 13.22 | 0.25 |
| AREA B | D18-8 | 2867 | 13.28 | 0.25 |
| AREA B | D18-9 | 2953 | 13.68 | 0.25 |

| | | |
|---|---|---|
| NO. OF MEASUREMENTS: | 308 | |
| AVG./SQRT(SUMSQ): | 13.55 | 4.40 |
| STD. DEV.: | 1.35 | |
| MAXIMUM: | 17.46 | |
| MINIMUM: | 8.37 | |
| RANGE: | 9.09 | |

# T100 Storage Yard Sorted by Exposure Rate

C.4

T100.WS SORTED BY EXPOSURE RATE

| ROOM NUMBER | GRID NAME | GAMMA TOTAL | uR/h TOTAL | STD DEV |
|---|---|---|---|---|
| AREA A | A18-18 | 3770 | 17.46 | 0.28 |
| AREA A | A13-18 | 3757 | 17.40 | 0.28 |
| AREA A | A16-18 | 3715 | 17.21 | 0.28 |
| AREA A | A41-18 | 3655 | 16.93 | 0.28 |
| AREA A | A10-18 | 3648 | 16.90 | 0.28 |
| AREA A | A21-18 | 3623 | 16.78 | 0.28 |
| AREA A | A46-18 | 3614 | 16.74 | 0.28 |
| AREA A | A27-18 | 3610 | 16.72 | 0.28 |
| AREA A | A38-18 | 3609 | 16.72 | 0.28 |
| AREA A | A44-18 | 3591 | 16.63 | 0.28 |
| AREA A | A24-18 | 3562 | 16.50 | 0.28 |
| AREA A | A7-18 | 3544 | 16.42 | 0.28 |
| AREA A | A29-18 | 3539 | 16.39 | 0.28 |
| AREA A | A35-18 | 3509 | 16.25 | 0.27 |
| AREA A | A47-18 | 3453 | 15.99 | 0.27 |
| AREA B | D10-1 | 3434 | 15.91 | 0.27 |
| AREA A | A5-18 | 3407 | 15.78 | 0.27 |
| AREA A | A32-18 | 3405 | 15.77 | 0.27 |
| AREA B | D2-4 | 3396 | 15.73 | 0.27 |
| AREA B | R4-4 | 3324 | 15.40 | 0.27 |
| AREA B | D2-2 | 3310 | 15.33 | 0.27 |
| AREA B | D2-3 | 3307 | 15.32 | 0.27 |
| AREA B | D3-3 | 3306 | 15.31 | 0.27 |
| AREA A | A45-12 | 3300 | 15.29 | 0.27 |
| AREA B | D2-5 | 3299 | 15.28 | 0.27 |
| AREA B | R3-5 | 3284 | 15.21 | 0.27 |
| AREA A | D13-17 | 3246 | 15.04 | 0.26 |
| AREA B | D3-1 | 3242 | 15.02 | 0.26 |
| AREA B | D3-2 | 3241 | 15.01 | 0.26 |
| AREA B | D11-1 | 3233 | 14.98 | 0.26 |
| AREA B | R2-6 | 3226 | 14.94 | 0.26 |
| AREA B | D4-2 | 3222 | 14.92 | 0.26 |
| AREA B | D11-2 | 3217 | 14.90 | 0.26 |
| AREA A | D38-17 | 3207 | 14.85 | 0.26 |
| AREA A | D7-17 | 3198 | 14.81 | 0.26 |
| AREA B | D12-2 | 3196 | 14.80 | 0.26 |
| AREA B | D13-2 | 3166 | 14.66 | 0.26 |
| AREA B | D6-1 | 3163 | 14.65 | 0.26 |
| AREA B | D10-2 | 3161 | 14.64 | 0.26 |
| AREA B | D3-4 | 3160 | 14.64 | 0.26 |
| AREA B | D4-1 | 3160 | 14.64 | 0.26 |
| AREA A | D27-17 | 3155 | 14.61 | 0.26 |
| AREA B | D10-3 | 3155 | 14.61 | 0.26 |
| AREA B | D9-5 | 3136 | 14.53 | 0.26 |
| AREA A | G14-6 | 3133 | 14.51 | 0.26 |
| AREA B | D14-2 | 3131 | 14.50 | 0.26 |
| AREA A | D24-17 | 3130 | 14.50 | 0.26 |
| AREA A | D16-17 | 3129 | 14.49 | 0.26 |
| AREA B | D10-4 | 3116 | 14.43 | 0.26 |
| AREA B | D9-3 | 3113 | 14.42 | 0.26 |
| AREA A | D35-17 | 3112 | 14.41 | 0.26 |
| AREA B | D15-2 | 3112 | 14.41 | 0.26 |
| AREA B | D4-9 | 3108 | 14.40 | 0.26 |
| AREA B | D11-3 | 3106 | 14.39 | 0.26 |
| AREA B | D2-10 | 3104 | 14.38 | 0.26 |

T100.WS SORTED BY EXPOSURE RATE

| ROOM NUMBER | GRID NAME | GAMMA TOTAL | uR/h TOTAL | STD DEV |
|---|---|---|---|---|
| AREA A | G24-6 | 3101 | 14.36 | 0.26 |
| AREA B | D13-3 | 3100 | 14.36 | 0.26 |
| AREA B | D16-3 | 3099 | 14.35 | 0.26 |
| AREA A | G16-10 | 3098 | 14.35 | 0.26 |
| AREA B | D16-2 | 3098 | 14.35 | 0.26 |
| AREA B | D15-5 | 3097 | 14.35 | 0.26 |
| AREA B | D5-1 | 3091 | 14.32 | 0.26 |
| AREA B | D9-6 | 3088 | 14.30 | 0.26 |
| AREA B | D13-4 | 3088 | 14.30 | 0.26 |
| AREA B | D14-5 | 3088 | 14.30 | 0.26 |
| AREA A | D29-17 | 3086 | 14.29 | 0.26 |
| AREA A | D41-17 | 3085 | 14.29 | 0.26 |
| AREA B | D5-2 | 3085 | 14.29 | 0.26 |
| AREA B | D7-8 | 3083 | 14.28 | 0.26 |
| AREA B | D16-4 | 3080 | 14.27 | 0.26 |
| AREA B | D11-6 | 3078 | 14.26 | 0.26 |
| AREA B | D12-4 | 3077 | 14.25 | 0.26 |
| AREA A | D10-17 | 3070 | 14.22 | 0.26 |
| AREA B | D17-2 | 3068 | 14.21 | 0.26 |
| AREA A | D18-17 | 3067 | 14.21 | 0.26 |
| AREA B | D15-4 | 3058 | 14.16 | 0.26 |
| AREA B | D15-1 | 3056 | 14.16 | 0.26 |
| AREA A | D44-17 | 3055 | 14.15 | 0.26 |
| AREA A | G24-8 | 3053 | 14.14 | 0.26 |
| AREA B | D10-5 | 3050 | 14.13 | 0.26 |
| AREA B | D14-4 | 3049 | 14.12 | 0.26 |
| AREA A | G45-10 | 3045 | 14.10 | 0.26 |
| AREA A | G14-10 | 3044 | 14.10 | 0.26 |
| AREA A | G16-6 | 3043 | 14.10 | 0.26 |
| AREA A | G16-8 | 3042 | 14.09 | 0.26 |
| AREA B | D4-7 | 3041 | 14.09 | 0.26 |
| AREA B | D13-1 | 3041 | 14.09 | 0.26 |
| AREA A | G4-12 | 3033 | 14.05 | 0.26 |
| AREA B | G15-6 | 3032 | 14.04 | 0.26 |
| AREA B | D12-3 | 3031 | 14.04 | 0.26 |
| AREA A | G45-4 | 3029 | 14.03 | 0.25 |
| AREA B | D16-1 | 3028 | 14.03 | 0.25 |
| AREA A | D40-15 | 3027 | 14.02 | 0.25 |
| AREA A | A45-15 | 3025 | 14.01 | 0.25 |
| AREA B | D15-3 | 3025 | 14.01 | 0.25 |
| AREA B | D11-5 | 3022 | 14.00 | 0.25 |
| AREA B | D14-1 | 3020 | 13.99 | 0.25 |
| AREA B | D14-6 | 3020 | 13.99 | 0.25 |
| AREA B | D11-7 | 3018 | 13.98 | 0.25 |
| AREA A | G14-4 | 3015 | 13.97 | 0.25 |
| AREA B | D14-3 | 3015 | 13.97 | 0.25 |
| AREA A | A19-8 | 3014 | 13.96 | 0.25 |
| AREA A | D46-17 | 3011 | 13.95 | 0.25 |
| AREA A | D6-15 | 3010 | 13.94 | 0.25 |
| AREA B | D10-7 | 3008 | 13.93 | 0.25 |
| AREA A | G42-4 | 3006 | 13.92 | 0.25 |
| AREA A | G26-4 | 3005 | 13.92 | 0.25 |
| AREA B | D7-5 | 3004 | 13.91 | 0.25 |
| AREA A | G21-4 | 3003 | 13.91 | 0.25 |
| AREA A | G42-8 | 3003 | 13.91 | 0.25 |

T100.WS SORTED BY EXPOSURE RATE

| ROOM NUMBER | GRID NAME | GAMMA TOTAL | uR/h TOTAL | STD DEV |
|---|---|---|---|---|
| AREA A | D45-4 | 3002 | 13.91 | 0.25 |
| AREA B | D10-6 | 3002 | 13.91 | 0.25 |
| AREA A | G7-4 | 3001 | 13.90 | 0.25 |
| AREA B | D7-6 | 3000 | 13.90 | 0.25 |
| AREA A | G40-4 | 2996 | 13.88 | 0.25 |
| AREA A | G14-8 | 2995 | 13.87 | 0.25 |
| AREA B | D4-3 | 2994 | 13.87 | 0.25 |
| AREA A | G46-15 | 2992 | 13.86 | 0.25 |
| AREA B | D13-5 | 2992 | 13.86 | 0.25 |
| AREA A | G14-12 | 2990 | 13.85 | 0.25 |
| AREA B | D8-5 | 2990 | 13.85 | 0.25 |
| AREA B | D8-7 | 2990 | 13.85 | 0.25 |
| AREA B | D11-4 | 2990 | 13.85 | 0.25 |
| AREA A | G40-8 | 2989 | 13.85 | 0.25 |
| AREA B | D17-3 | 2987 | 13.84 | 0.25 |
| AREA A | D9-15 | 2984 | 13.82 | 0.25 |
| AREA B | D7-7 | 2982 | 13.81 | 0.25 |
| AREA B | D12-6 | 2981 | 13.81 | 0.25 |
| AREA B | D8-6 | 2980 | 13.80 | 0.25 |
| AREA A | A45-10 | 2973 | 13.77 | 0.25 |
| AREA A | G5-5 | 2973 | 13.77 | 0.25 |
| AREA A | G4-6 | 2972 | 13.77 | 0.25 |
| AREA A | G21-8 | 2970 | 13.76 | 0.25 |
| AREA B | G12-5 | 2969 | 13.75 | 0.25 |
| AREA B | D17-4 | 2967 | 13.74 | 0.25 |
| AREA A | G16-12 | 2965 | 13.73 | 0.25 |
| AREA A | G12-4 | 2965 | 13.73 | 0.25 |
| AREA A | A3-14 | 2965 | 13.73 | 0.25 |
| AREA A | G26-6 | 2962 | 13.72 | 0.25 |
| AREA B | D9-7 | 2962 | 13.72 | 0.25 |
| AREA A | A45-8 | 2956 | 13.69 | 0.25 |
| AREA A | G42-10 | 2955 | 13.69 | 0.25 |
| AREA A | G16-4 | 2955 | 13.69 | 0.25 |
| AREA A | D28-15 | 2954 | 13.68 | 0.25 |
| AREA B | D18-9 | 2953 | 13.68 | 0.25 |
| AREA A | G46-8 | 2951 | 13.67 | 0.25 |
| AREA A | G24-4 | 2951 | 13.67 | 0.25 |
| AREA B | D16-7 | 2951 | 13.67 | 0.25 |
| AREA A | G28-4 | 2950 | 13.66 | 0.25 |
| AREA A | G33-4 | 2950 | 13.66 | 0.25 |
| AREA B | D4-10 | 2946 | 13.65 | 0.25 |
| AREA A | G45-8 | 2945 | 13.64 | 0.25 |
| AREA B | D16-8 | 2944 | 13.64 | 0.25 |
| AREA B | D13-7 | 2943 | 13.63 | 0.25 |
| AREA B | D16-5 | 2941 | 13.62 | 0.25 |
| AREA A | G9-4 | 2940 | 13.62 | 0.25 |
| AREA A | A3-12 | 2937 | 13.60 | 0.25 |
| AREA B | D14-7 | 2936 | 13.60 | 0.25 |
| AREA A | G19-10 | 2935 | 13.59 | 0.25 |
| AREA A | G42-6 | 2935 | 13.59 | 0.25 |
| AREA A | A3-6 | 2932 | 13.58 | 0.25 |
| AREA A | G45-6 | 2931 | 13.58 | 0.25 |
| AREA A | D45-15 | 2930 | 13.57 | 0.25 |
| AREA A | G46-13 | 2927 | 13.56 | 0.25 |
| AREA B | D17-6 | 2926 | 13.55 | 0.25 |

T100.WS SORTED BY EXPOSURE RATE

| ROOM NUMBER | GRID NAME | GAMMA TOTAL | uR/h TOTAL | STD DEV |
|---|---|---|---|---|
| AREA A | G40-6 | 2925 | 13.55 | 0.25 |
| AREA B | G12-1 | 2923 | 13.54 | 0.25 |
| AREA B | D12-7 | 2923 | 13.54 | 0.25 |
| AREA B | D8-8 | 2920 | 13.53 | 0.25 |
| AREA B | D16-6 | 2920 | 13.53 | 0.25 |
| AREA A | G40-10 | 2919 | 13.52 | 0.25 |
| AREA B | D15-8 | 2919 | 13.52 | 0.25 |
| AREA A | G7-6 | 2918 | 13.52 | 0.25 |
| AREA A | A43-2 | 2918 | 13.52 | 0.25 |
| AREA B | G13-6 | 2918 | 13.52 | 0.25 |
| AREA A | G45-12 | 2917 | 13.51 | 0.25 |
| AREA A | G46-6 | 2914 | 13.50 | 0.25 |
| AREA B | D18-5 | 2909 | 13.47 | 0.25 |
| AREA A | A45-2 | 2906 | 13.46 | 0.25 |
| AREA A | A5-2 | 2902 | 13.44 | 0.25 |
| AREA B | D17-5 | 2901 | 13.44 | 0.25 |
| AREA A | A20-2 | 2900 | 13.43 | 0.25 |
| AREA A | A3-18 | 2899 | 13.43 | 0.25 |
| AREA A | G7-12 | 2898 | 13.42 | 0.25 |
| AREA B | D17-10 | 2898 | 13.42 | 0.25 |
| AREA A | D21-15 | 2892 | 13.40 | 0.25 |
| AREA A | D38-15 | 2891 | 13.39 | 0.25 |
| AREA B | D6-8 | 2890 | 13.39 | 0.25 |
| AREA A | A25-2 | 2890 | 13.39 | 0.25 |
| AREA A | D17-15 | 2890 | 13.39 | 0.25 |
| AREA A | A28-10 | 2888 | 13.38 | 0.25 |
| AREA A | G33-6 | 2887 | 13.37 | 0.25 |
| AREA B | D18-3 | 2887 | 13.37 | 0.25 |
| AREA A | A13-2 | 2884 | 13.36 | 0.25 |
| AREA A | G46-10 | 2881 | 13.34 | 0.25 |
| AREA B | D3-10 | 2881 | 13.34 | 0.25 |
| AREA A | D42-15 | 2881 | 13.34 | 0.25 |
| AREA A | D19-15 | 2879 | 13.34 | 0.25 |
| AREA A | A22-2 | 2879 | 13.34 | 0.25 |
| AREA B | D11-10 | 2877 | 13.33 | 0.25 |
| AREA A | D31-15 | 2870 | 13.29 | 0.25 |
| AREA A | A18-4 | 2870 | 13.29 | 0.25 |
| AREA B | D18-8 | 2867 | 13.28 | 0.25 |
| AREA A | A34-2 | 2865 | 13.27 | 0.25 |
| AREA A | A3-8 | 2864 | 13.27 | 0.25 |
| AREA B | D17-1 | 2862 | 13.26 | 0.25 |
| AREA B | A8-10 | 2860 | 13.25 | 0.25 |
| AREA A | G19-12 | 2856 | 13.23 | 0.25 |
| AREA B | D18-4 | 2856 | 13.23 | 0.25 |
| AREA B | D18-7 | 2854 | 13.22 | 0.25 |
| AREA A | A27-2 | 2849 | 13.20 | 0.25 |
| AREA A | A29-2 | 2848 | 13.19 | 0.25 |
| AREA B | G15-7 | 2848 | 13.19 | 0.25 |
| AREA B | D18-1 | 2848 | 13.19 | 0.25 |
| AREA B | D5-7 | 2840 | 13.15 | 0.25 |
| AREA B | D14-8 | 2840 | 13.15 | 0.25 |
| AREA B | D5-8 | 2839 | 13.15 | 0.25 |
| AREA B | M5-9 | 2838 | 13.15 | 0.25 |
| AREA A | D24-15 | 2837 | 13.14 | 0.25 |
| AREA A | A8-2 | 2836 | 13.14 | 0.25 |

T100.WS SORTED BY EXPOSURE RATE

| ROOM NUMBER | GRID NAME | GAMMA TOTAL | uR/h TOTAL | STD DEV |
|---|---|---|---|---|
| AREA A | A15-2 | 2835 | 13.13 | 0.25 |
| AREA A | A3-4 | 2834 | 13.13 | 0.25 |
| AREA A | D35-15 | 2832 | 13.12 | 0.25 |
| AREA A | D26-15 | 2828 | 13.10 | 0.25 |
| AREA B | D17-9 | 2826 | 13.09 | 0.25 |
| AREA B | M7-9 | 2824 | 13.08 | 0.25 |
| AREA A | A3-10 | 2824 | 13.08 | 0.25 |
| AREA A | G12-12 | 2823 | 13.08 | 0.25 |
| AREA A | A41-2 | 2823 | 13.08 | 0.25 |
| AREA B | D18-6 | 2817 | 13.05 | 0.25 |
| AREA A | D12-15 | 2816 | 13.04 | 0.25 |
| AREA A | G4-10 | 2814 | 13.03 | 0.25 |
| AREA A | G4-8 | 2814 | 13.03 | 0.25 |
| AREA A | D33-15 | 2811 | 13.02 | 0.25 |
| AREA A | A17-2 | 2810 | 13.02 | 0.25 |
| AREA B | D12-10 | 2802 | 12.98 | 0.25 |
| AREA A | S36-2 | 2790 | 12.92 | 0.24 |
| AREA A | G42-12 | 2781 | 12.88 | 0.24 |
| AREA B | D17-7 | 2780 | 12.88 | 0.24 |
| AREA B | A13-10 | 2776 | 12.86 | 0.24 |
| AREA B | W8-9 | 2773 | 12.84 | 0.24 |
| AREA A | A32-2 | 2771 | 12.84 | 0.24 |
| AREA A | A10-2 | 2770 | 12.83 | 0.24 |
| AREA A | A11-2 | 2770 | 12.83 | 0.24 |
| AREA B | D13-8 | 2769 | 12.83 | 0.24 |
| AREA B | M6-9 | 2763 | 12.80 | 0.24 |
| AREA A | G37-8 | 2762 | 12.79 | 0.24 |
| AREA B | D18-2 | 2760 | 12.78 | 0.24 |
| AREA A | G6-8 | 2755 | 12.76 | 0.24 |
| AREA A | G21-6 | 2755 | 12.76 | 0.24 |
| AREA A | A39-2 | 2749 | 12.73 | 0.24 |
| AREA A | D32-17 | 2746 | 12.72 | 0.24 |
| AREA B | D17-8 | 2744 | 12.71 | 0.24 |
| AREA B | D7-10 | 2741 | 12.70 | 0.24 |
| AREA B | D10-10 | 2737 | 12.68 | 0.24 |
| AREA B | D4-8 | 2737 | 12.68 | 0.24 |
| AREA A | D21-17 | 2737 | 12.68 | 0.24 |
| AREA A | G9-12 | 2734 | 12.66 | 0.24 |
| AREA A | A31-4 | 2727 | 12.63 | 0.24 |
| AREA A | G35-8 | 2719 | 12.59 | 0.24 |
| AREA B | W14-10 | 2710 | 12.55 | 0.24 |
| AREA A | G28-6 | 2692 | 12.47 | 0.24 |
| AREA A | G35-4 | 2679 | 12.41 | 0.24 |
| AREA B | D18-10 | 2665 | 12.34 | 0.24 |
| AREA A | G35-13 | 2664 | 12.34 | 0.24 |
| AREA B | W12-9 | 2658 | 12.31 | 0.24 |
| AREA B | M15-10 | 2649 | 12.27 | 0.24 |
| AREA B | A6-10 | 2648 | 12.27 | 0.24 |
| AREA B | D16-9 | 2647 | 12.26 | 0.24 |
| AREA A | G38-13 | 2641 | 12.23 | 0.24 |
| AREA A | G11-10 | 2637 | 12.21 | 0.24 |
| AREA B | W9-9 | 2635 | 12.21 | 0.24 |
| AREA A | G40-12 | 2625 | 12.16 | 0.24 |
| AREA A | G31-12 | 2625 | 12.16 | 0.24 |
| AREA A | A31-8 | 2617 | 12.12 | 0.24 |

T100.WS SORTED BY EXPOSURE RATE

| ROOM NUMBER | GRID NAME | GAMMA TOTAL | uR/h TOTAL | STD DEV |
|---|---|---|---|---|
| AREA A | G26-8 | 2613 | 12.10 | 0.24 |
| AREA A | G37-4 | 2606 | 12.07 | 0.24 |
| AREA B | W11-9 | 2595 | 12.02 | 0.24 |
| AREA B | D9-10 | 2594 | 12.02 | 0.24 |
| AREA B | G14-9 | 2592 | 12.01 | 0.24 |
| AREA B | M13-9 | 2585 | 11.97 | 0.24 |
| AREA A | G9-6 | 2569 | 11.90 | 0.23 |
| AREA B | A5-10 | 2550 | 11.81 | 0.23 |
| AREA A | G12-6 | 2519 | 11.67 | 0.23 |
| AREA A | G11-8 | 2485 | 11.51 | 0.23 |
| AREA B | W15-9 | 2455 | 11.37 | 0.23 |
| AREA B | W10-9 | 2446 | 11.33 | 0.23 |
| AREA A | G31-10 | 2417 | 11.20 | 0.23 |
| AREA A | G28-12 | 2386 | 11.05 | 0.23 |
| AREA A | G28-8 | 2363 | 10.95 | 0.23 |
| AREA A | G26-10 | 2355 | 10.91 | 0.22 |
| AREA A | G26-12 | 2336 | 10.82 | 0.22 |
| AREA A | G33-8 | 2300 | 10.65 | 0.22 |
| AREA A | G35-6 | 2298 | 10.64 | 0.22 |
| AREA A | G21-10 | 2292 | 10.62 | 0.22 |
| AREA A | A18-6 | 2277 | 10.55 | 0.22 |
| AREA A | G24-10 | 2277 | 10.55 | 0.22 |
| AREA A | G38-10 | 2261 | 10.47 | 0.22 |
| AREA A | G9-8 | 2245 | 10.40 | 0.22 |
| AREA A | G33-12 | 2219 | 10.28 | 0.22 |
| AREA A | A30-6 | 2218 | 10.27 | 0.22 |
| AREA A | G9-10 | 2217 | 10.27 | 0.22 |
| AREA A | G21-12 | 2216 | 10.26 | 0.22 |
| AREA A | G24-12 | 2189 | 10.14 | 0.22 |
| AREA A | G33-10 | 2089 | 9.68 | 0.21 |
| AREA A | G35-10 | 2079 | 9.63 | 0.21 |
| AREA A | G37-6 | 2078 | 9.63 | 0.21 |
| AREA A | G7-10 | 1808 | 8.37 | 0.20 |

| | | |
|---|---|---|
| NO. OF MEASUREMENTS: | 308 | |
| AVG./SQRT(SUMSQ): | 13.55 | 4.40 |
| STD. DEV.: | 1.35 | |
| MAXIMUM: | 17.46 | |
| MINIMUM: | 8.37 | |
| RANGE: | 9.09 | |

T011 Field Sorted by Location

T011.WS SORTED BY LOCATION

| ROOM NUMBER | GRID NAME | GAMMA TOTAL | uR/h TOTAL | STD DEV |
|---|---|---|---|---|
| | 1-1 | 2780 | 12.88 | 0.24 |
| | 2-1 | 2974 | 13.78 | 0.25 |
| | 2-2 | 2716 | 12.58 | 0.24 |
| | 2-4 | 2810 | 13.02 | 0.25 |
| | 2-6 | 2830 | 13.11 | 0.25 |
| C.5 | 2-8 | 2724 | 12.62 | 0.24 |
| | 2-10 | 2859 | 13.24 | 0.25 |
| | 3-1 | 2916 | 13.51 | 0.25 |
| | 3-2 | 2732 | 12.65 | 0.24 |
| | 3-4 | 2749 | 12.73 | 0.24 |
| | 3-6 | 2931 | 13.58 | 0.25 |
| | 3-8 | 2760 | 12.78 | 0.24 |
| | 3-10 | 2783 | 12.89 | 0.24 |
| | 4-1 | 2971 | 13.76 | 0.25 |
| | 4-2 | 2824 | 13.08 | 0.25 |
| | 4-4 | 2844 | 13.17 | 0.25 |
| | 4-6 | 2737 | 12.68 | 0.24 |
| | 4-8 | 2790 | 12.92 | 0.24 |
| | 4-10 | 2764 | 12.80 | 0.24 |
| | 5-1 | 2985 | 13.83 | 0.25 |
| | 5-2 | 2704 | 12.52 | 0.24 |
| | 5-4 | 2716 | 12.58 | 0.24 |
| | 5-6 | 2751 | 12.74 | 0.24 |
| | 5-8 | 2786 | 12.90 | 0.24 |
| | 5-10 | 2775 | 12.85 | 0.24 |
| | 6-1 | 2928 | 13.56 | 0.25 |
| | 6-2 | 2829 | 13.10 | 0.25 |
| | 6-8 | 2794 | 12.94 | 0.24 |
| | 6-10 | 2788 | 12.91 | 0.24 |
| | 7-1 | 2809 | 13.01 | 0.25 |
| | 7-4 | 2790 | 12.92 | 0.24 |
| | 7-6 | 2742 | 12.70 | 0.24 |
| | 7-9 | 2773 | 12.84 | 0.24 |
| | 8-1 | 2883 | 13.35 | 0.25 |
| | 8-2 | 2770 | 12.83 | 0.24 |
| | 8-4 | 2841 | 13.16 | 0.25 |
| | 8-7 | 2836 | 13.14 | 0.25 |
| | 8-10 | 2778 | 12.87 | 0.24 |
| | 9-2 | 2832 | 13.12 | 0.25 |

| | | |
|---|---|---|
| NO. OF MEASUREMENTS: | 39 | |
| AVG./SQRT(SUMSQ): | 13.02 | 1.53 |
| STD. DEV.: | 0.34 | |
| MAXIMUM: | 13.83 | |
| MIMIMUM: | 12.52 | |
| RANGE: | 1.30 | |

T011 Field Sorted by Exposure Rate

T011.WS SORTED BY EXPOSURE RATE

| ROOM NUMBER | GRID NAME | GAMMA TOTAL | uR/h TOTAL | STD DEV |
|---|---|---|---|---|
| | 5-1 | 2985 | 13.83 | 0.25 |
| | 2-1 | 2974 | 13.78 | 0.25 |
| | 4-1 | 2971 | 13.76 | 0.25 |
| | 3-6 | 2931 | 13.58 | 0.25 |
| | 6-1 | 2928 | 13.56 | 0.25 |
| | 3-1 | 2916 | 13.51 | 0.25 |
| C.6 | 8-1 | 2883 | 13.35 | 0.25 |
| | 2-10 | 2859 | 13.24 | 0.25 |
| | 4-4 | 2844 | 13.17 | 0.25 |
| | 8-4 | 2841 | 13.16 | 0.25 |
| | 8-7 | 2836 | 13.14 | 0.25 |
| | 9-2 | 2832 | 13.12 | 0.25 |
| | 2-6 | 2830 | 13.11 | 0.25 |
| | 6-2 | 2829 | 13.10 | 0.25 |
| | 4-2 | 2824 | 13.08 | 0.25 |
| | 2-4 | 2810 | 13.02 | 0.25 |
| | 7-1 | 2809 | 13.01 | 0.25 |
| | 6-8 | 2794 | 12.94 | 0.24 |
| | 4-8 | 2790 | 12.92 | 0.24 |
| | 7-4 | 2790 | 12.92 | 0.24 |
| | 6-10 | 2788 | 12.91 | 0.24 |
| | 5-8 | 2786 | 12.90 | 0.24 |
| | 3-10 | 2783 | 12.89 | 0.24 |
| | 1-1 | 2780 | 12.88 | 0.24 |
| | 8-10 | 2778 | 12.87 | 0.24 |
| | 5-10 | 2775 | 12.85 | 0.24 |
| | 7-9 | 2773 | 12.84 | 0.24 |
| | 8-2 | 2770 | 12.83 | 0.24 |
| | 4-10 | 2764 | 12.80 | 0.24 |
| | 3-8 | 2760 | 12.78 | 0.24 |
| | 5-6 | 2751 | 12.74 | 0.24 |
| | 3-4 | 2749 | 12.73 | 0.24 |
| | 7-6 | 2742 | 12.70 | 0.24 |
| | 4-6 | 2737 | 12.68 | 0.24 |
| | 3-2 | 2732 | 12.65 | 0.24 |
| | 2-8 | 2724 | 12.62 | 0.24 |
| | 5-4 | 2716 | 12.58 | 0.24 |
| | 2-2 | 2716 | 12.58 | 0.24 |
| | 5-2 | 2704 | 12.52 | 0.24 |

| | | |
|---|---|---|
| NO. OF MEASUREMENTS: | 39 | |
| AVG./SQRT(SUMSQ): | 13.02 | 1.53 |
| STD. DEV.: | 0.34 | |
| MAXIMUM: | 13.83 | |
| MIMIMUM: | 12.52 | |
| RANGE: | 1.30 | |

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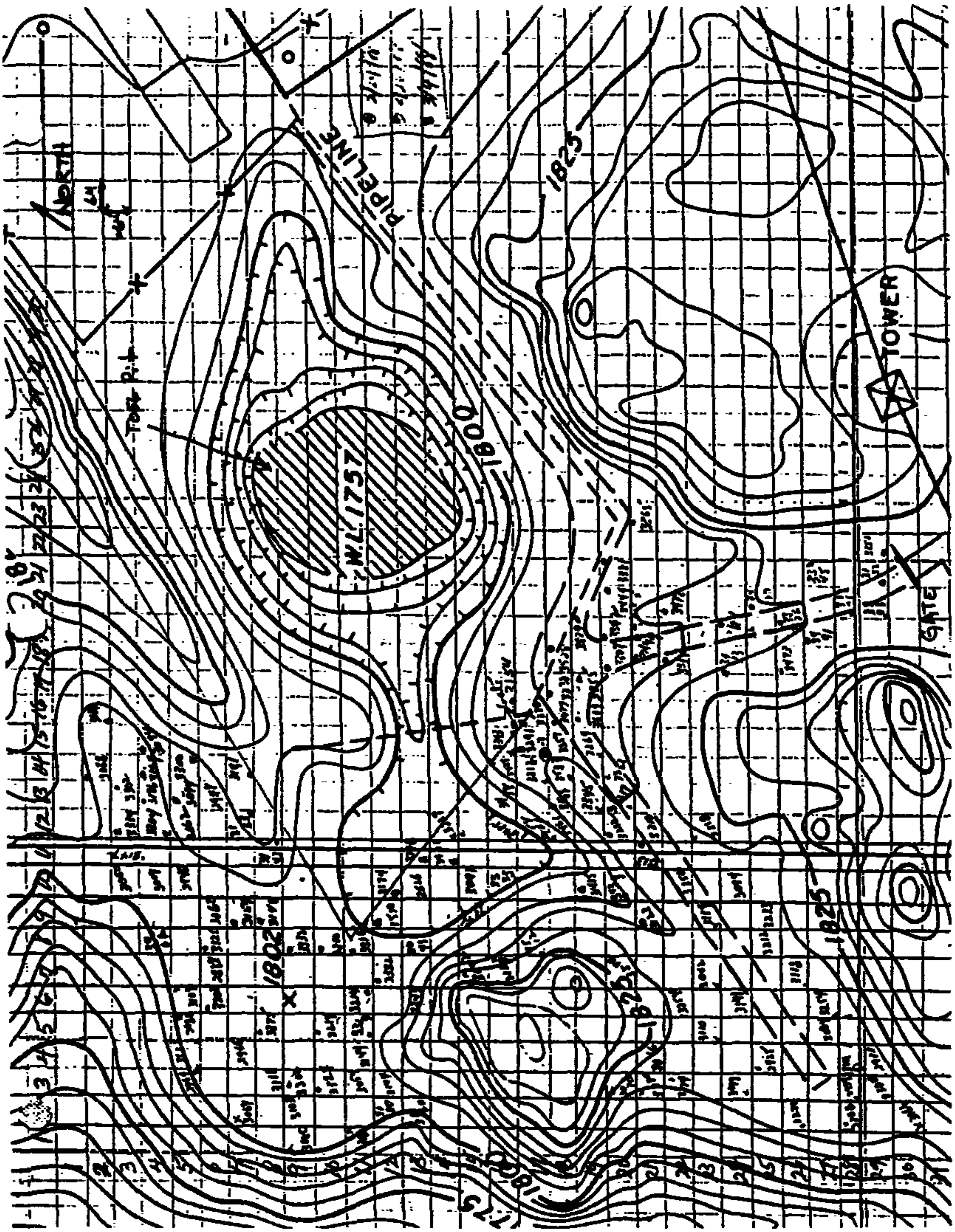
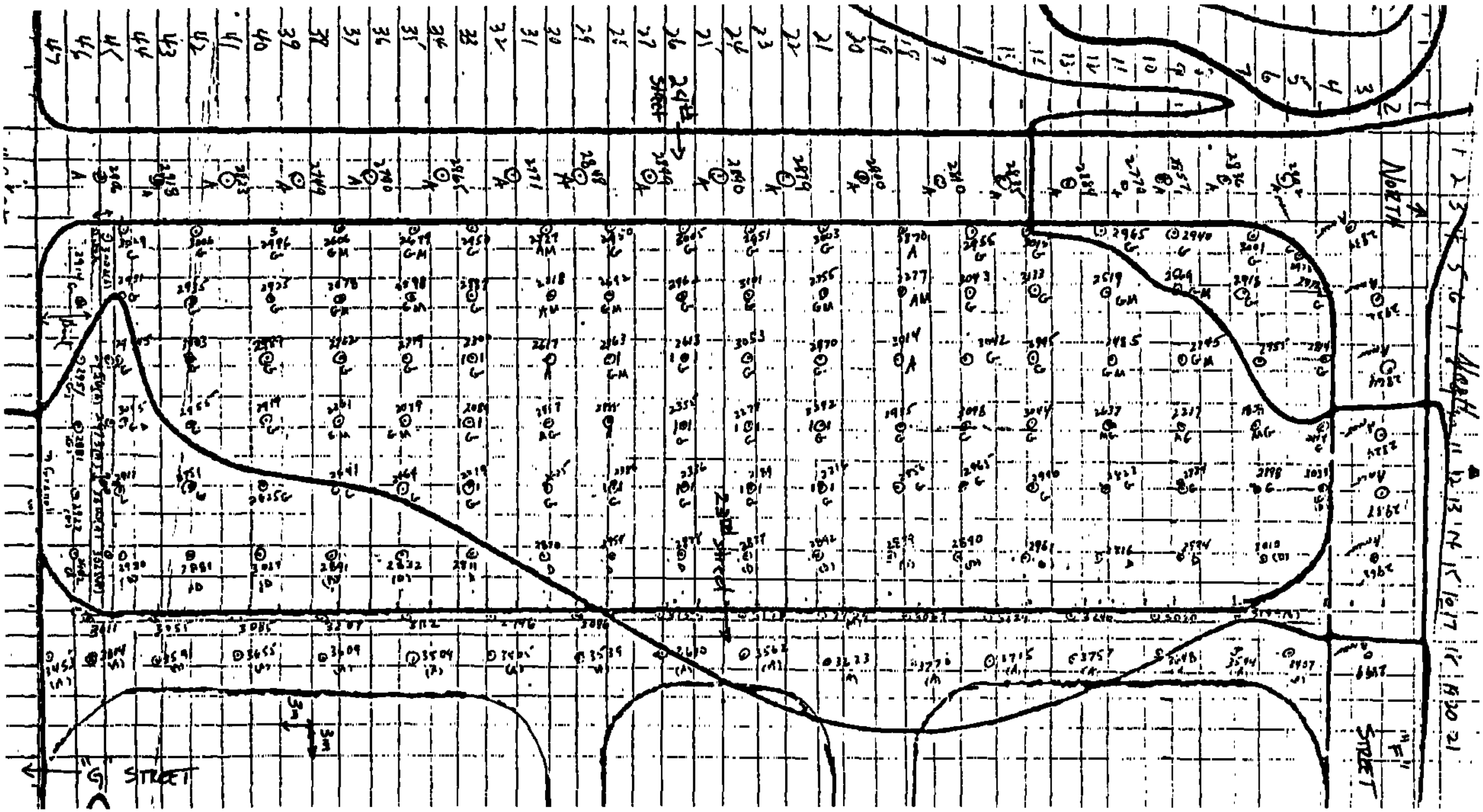
# APPENDIX D. SURVEYOR MAPS USED DURING RADIOLOGICAL SURVEY

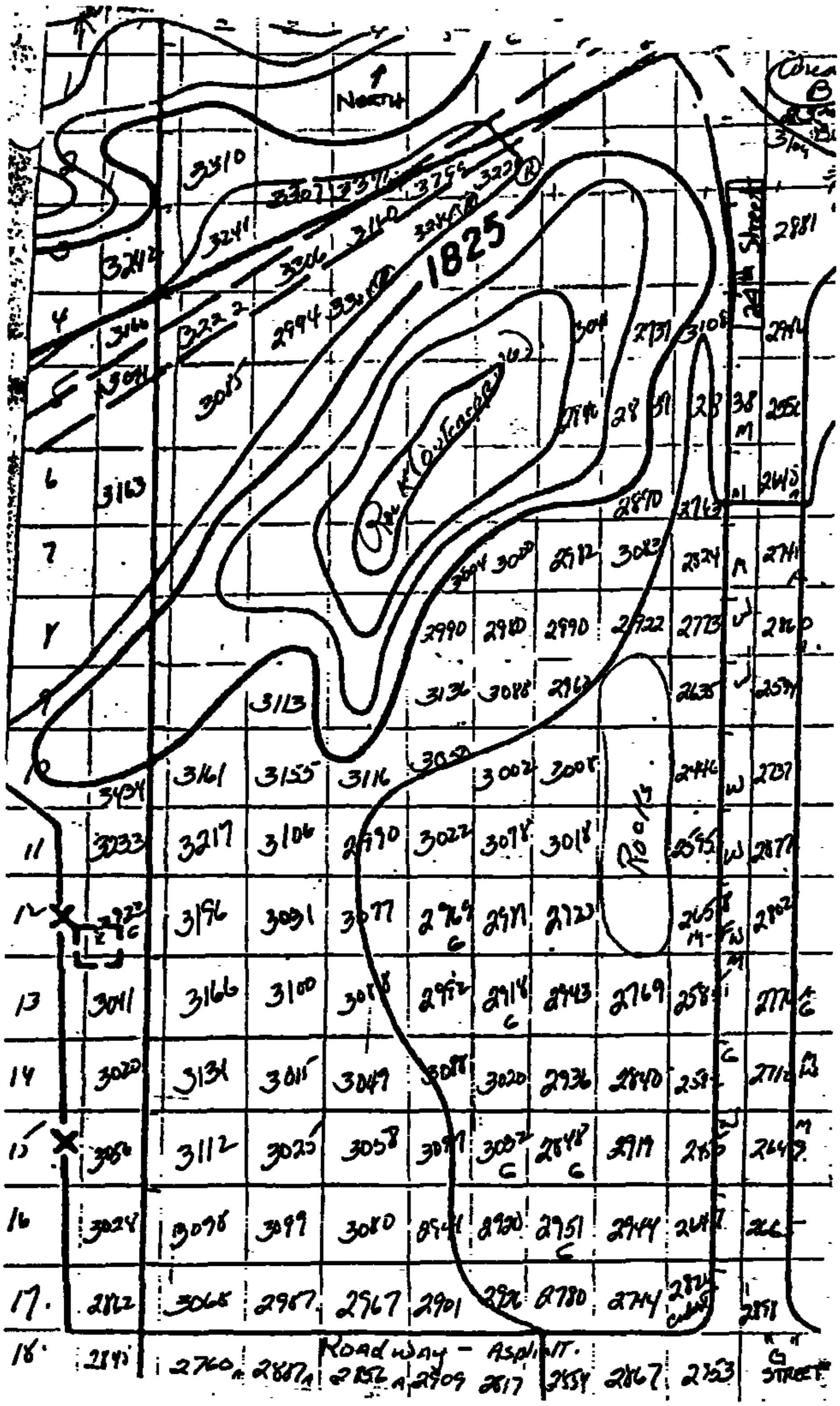



D.1 T056 Landfill

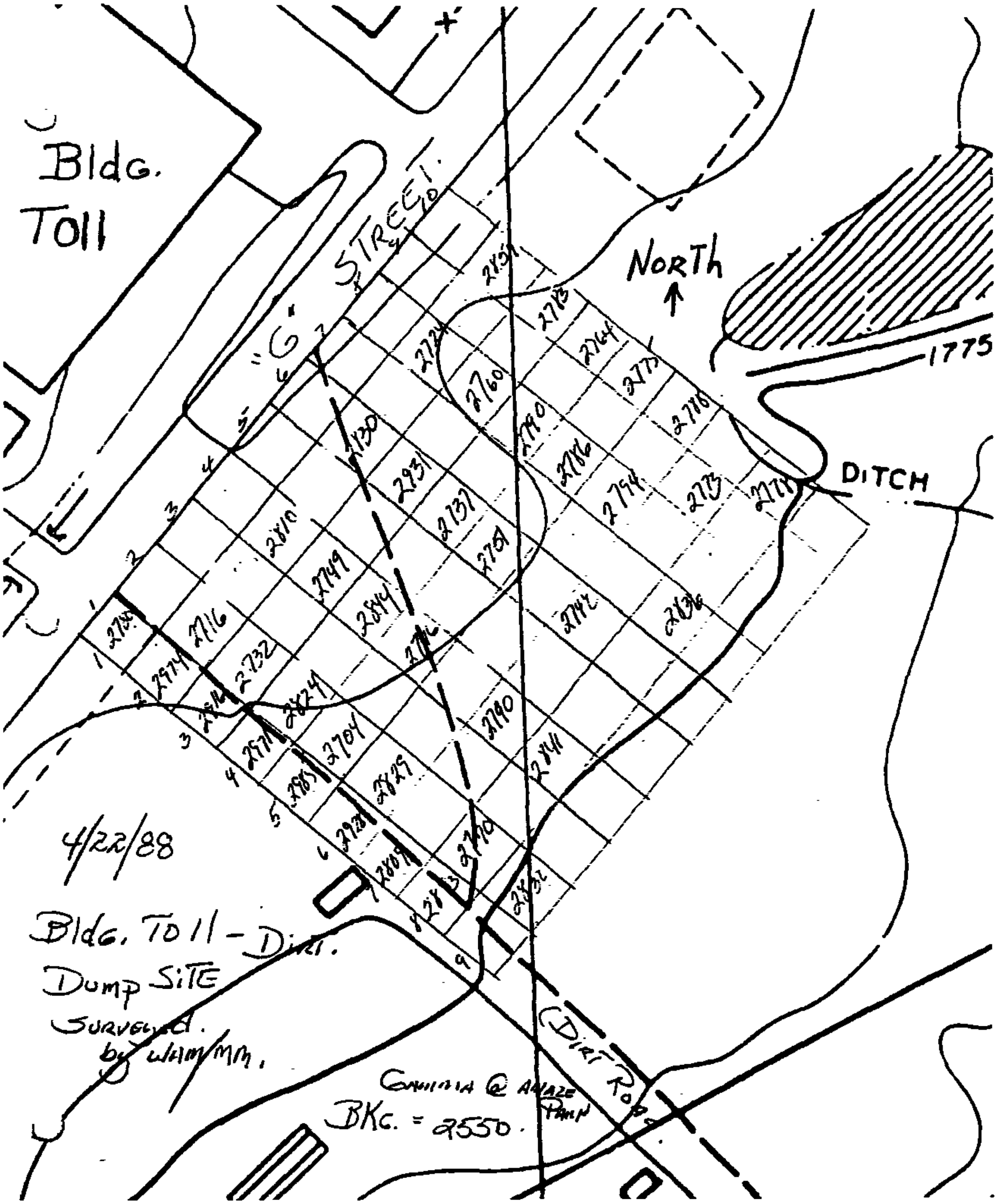



D.2 T100 Storage Yard (Area A)

D.3 T100 Storage Yard (Area B)



D.4 T011 Field



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# APPENDIX E. GAMMA SPECTROMETRY RADIONUCLIDE GAMMA-SIGNATURE LIBRARY

| | Isotope<br>Energy (keV) | Half-Life<br>% Yield | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | Zr-95 | 64.40 D | | | | | | | | |
| | 724.0 | 44% | 756.6 | 55% | | | | | | |
| 2. | Nb-95 | 35.15 D | | | | | | | | |
| | 765.7 | 99% | | | | | | | | |
| 3. | Ru-103 | 39.35 D | | | | | | | | |
| | 497.0 | 86% | 610.0 | 5% | | | | | | |
| 4. | Sb-125 | 0.1011E04 D | | | | | | | | |
| | 176.2 | 6% | 428.0 | 29% | 463.5 | 10% | 606.7 | 5% | 636.1 | 11% |
| 5. | I-131 | 8.04 D | | | | | | | | |
| | 284.2 | 6% | 364.5 | 81% | 636.9 | 7% | | | | |
| 6. | Cs-134 | 752.63 D | | | | | | | | |
| | 563.2 | 8% | 569.2 | 15% | 604.6 | 98% | 795.7 | 85% | 801.7 | 9% |
| 7. | Cs-136 | 12.98 D | | | | | | | | |
| | 66.8 | 12% | 86.2 | 6% | 153.1 | 7% | 176.5 | 14% | 273.5 | 13% |
| | 340.5 | 47% | 818.5 | 100% | 1048.0 | 80% | 1235.2 | 20% | | |
| 8. | Cs-137 | 0.1095E05 D | | | | | | | | |
| | 661.6 | 85% | | | | | | | | |
| 9. | Ba-140 | 12.80 D | | | | | | | | |
| | 162.5 | 5% | 537.3 | 20% | | | | | | |
| 10. | La-140 | 1.68 D | | | | | | | | |
| | 328.7 | 18% | 487.0 | 43% | 815.7 | 22% | 867.8 | 5% | 925.0 | 6% |
| | 1596.0 | 95% | | | | | | | | |
| 11. | Ce-141 | 32.50 D | | | | | | | | |
| | 36.0 | 8% | 145.1 | 48% | | | | | | |
| 12. | Ce-144 | 284.19 D | | | | | | | | |
| | 133.5 | 11% | | | | | | | | |
| 13. | Cr-51 | 27.70 D | | | | | | | | |
| | 320.0 | 9% | | | | | | | | |
| 14. | Mn-54 | 312.19 D | | | | | | | | |
| | 834.7 | 100% | | | | | | | | |
| 15. | Fe-59 | 45.10 D | | | | | | | | |
| | 1099.1 | 56% | 1291.5 | 43% | | | | | | |

| | Isotope<br>Energy (keV) | Half-Life<br>% Yield | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 16. | Co-58 | 70.78 D | | | | | | | | |
| | 511.0 | 30% | 810.7 | 99% | | | | | | |
| 17. | Co-60 | 0.1924E04 D | | | | | | | | |
| | 1173.1 | 100% | 1332.5 | 100% | | | | | | |
| 18. | Zn-65 | 243.80 D | | | | | | | | |
| | 511.0 | 3% | 1115.5 | 51% | | | | | | |
| 19. | Rh-102 | 0.1054E04 D | | | | | | | | |
| | 418.2 | 10% | 475.0 | 93% | 628.0 | 6% | 631.0 | 56% | 697.0 | 45% |
| | 766.7 | 33% | 1046.5 | 33% | 1112.6 | 17% | | | | |
| 20. | Rh-102M | 206.00D | | | | | | | | |
| | 475.0 | 44% | 511.0 | 23% | | | | | | |
| 21. | Sb-124 | 60.20 D | | | | | | | | |
| | 602.6 | 98% | 645.7 | 7% | 722.7 | 12% | 1691.0 | 50% | 2091.1 | 6% |
| 22. | Be-07 | 53.40 D | | | | | | | | |
| | 477.5 | 10% | | | | | | | | |
| 23. | Na-22 | 949.00 D | | | | | | | | |
| | 511.0 | 180% | 1274.5 | 100% | | | | | | |
| 24. | K-040 | 0.46E12 D | | | | | | | | |
| | 1460.7 | 11% | | | | | | | | |
| 25. | Ra-226 | 0.584E06 D | | | | | | | | |
| | 186.0 | 3% | | | | | | | | |
| 26. | Pb-214 | 0.02 D | | | | | | | | |
| | 74.7 6% | 77.0 11% | 241.8 | 7% | 295.1 | 19% | 352.0 | 37% | | |
| 27. | Bi-214 | 0.01 D | | | | | | | | |
| | 609.2 | 46% | 1120.2 | 15% | 1238.0 | 6% | 1764.5 | 15% | | |
| 28. | Ra-224 | 3.66 D | | | | | | | | |
| | 241.0 | 4% | | | | | | | | |
| 29. | Pb-212 | 0.44 D | | | | | | | | |
| | 74.7 | 9% | 77.0 | 18% | 87.1 | 6% | 238.5 | 43% | | |
| 30. | Bi-212 | 0.04 D | | | | | | | | |
| | 727.1 | 12% | 1620.5 | 3% | | | | | | |

| | Isotope<br>Energy (keV) | Half-Life<br>% Yield | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 31. | Tl-208 | 0.00 D | | | | | | | | |
| | 277.3 | 6% | 510.6 | 22% | 583.0 | 86% | 860.5 | 12% | | |
| 32. | Ac-228 | 0.25 D | | | | | | | | |
| | 338.3 | 12% | 911.0 | 29% | 964.5 | 5% | 968.8 | 17% | | |
| 33. | Th-234 | 24.10 D | | | | | | | | |
| | 63.2 | 4% | 92.3 | 2% | 92.7 | 3% | | | | |
| 34. | U-232 | 0.263E05 D | | | | | | | | |
| | 269.0 | 4% | | | | | | | | |
| 35. | U-235 | 0.26E12 D | | | | | | | | |
| | 93.3 | 2% | 143.7 | 11% | 163.3 | 5% | 185.6 | 54% | 205.2 | 5% |
| 36. | Am-241 | 0.158E06 D | | | | | | | | |
| | 59.5 | 36% | | | | | | | | |
| 37. | Np-237 | 0.7817E09 D | | | | | | | | |
| | 29.0 | 9% | 86.1 | 13% | | | | | | |
| 38. | Pu-242 | 0.1409E09 D | | | | | | | | |
| | 44.5 | 3% | | | | | | | | |
| 39. | Am-243 | 0.2699E07 D | | | | | | | | |
| | 74.6 | 66% | | | | | | | | |
| 40. | Np-239 | 2.35 D | | | | | | | | |
| | 99.5 | 15% | 103.6 | 24% | 106.0 | 23% | 117.6 | 8% | 228.1 | 11% |
| | 277.5 | 14% | | | | | | | | |
| 41. | Al-26 | 0.2612E10 D | | | | | | | | |
| | 511.0 | 164% | 1808.6 | 100% | | | | | | |
| 42. | Nb-94 | 0.7409E07 D | | | | | | | | |
| | 702.5 | 100% | 871.0 | 100% | | | | | | |
| 43. | Ag-108M | 0.4635E05 D | | | | | | | | |
| | 79.5 | 7% | 433.6 | 90% | 614.3 | 90% | 722.9 | 90% | | |
| 44. | Cd-109 | 453.00 D | | | | | | | | |
| | 88.0 | 3% | | | | | | | | |
| 45. | Ba-133 | 0.3906E04 D | | | | | | | | |
| | 81.0 | 33% | 276.2 | 7% | 302.6 | 19% | 355.8 | 62% | 383.6 | 9% |

| No. | Isotope<br>Energy (keV) | Half-Life<br>% Yield | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 46. | Eu-148 | 54.00 D | | | | | | | | |
| | 413.8 | 11% | 414.0 | 7% | 550.1 | 99% | 553.1 | 17% | 571.8 | 9% |
| | 611.2 | 19% | 629.8 | 71% | 725.6 | 12% | 1034.0 | 8% | | |
| 47. | Eu-152 | 0.4636E04 D | | | | | | | | |
| | 121.7 | 29% | 244.6 | 8% | 344.2 | 27% | 778.8 | 13% | 964.0 | 14% |
| | 1085.7 | 10% | 1112.0 | 13% | 1408.0 | 21% | | | | |
| 48. | Eu-154 | 0.3102E04 D | | | | | | | | |
| | 123.0 | 40% | 248.0 | 7% | 723.2 | 20% | 873.1 | 11% | 996.2 | 11% |
| | 1004.7 | 18% | 1274.7 | 35% | | | | | | |
| 49. | Eu-155 | 0.181E04 D | | | | | | | | |
| | 86.3 | 33% | 105.2 | 22% | | | | | | |
| 50. | Tb-158 | 0.5475E05 D | | | | | | | | |
| | 79.5 | 11% | 181.8 | 9% | 780.1 | 9% | 944.1 | 43% | 962.1 | 20% |
| 51. | Pt-193 | 0.1825E05 D | | | | | | | | |
| | 63.2 | 24% | 64.8 | 44% | 73.5 | 15% | | | | |
| 52. | Co-57 | 270.00 D | | | | | | | | |
| | 122.0 | 86% | 136.3 | 11% | | | | | | |
| 53. | Sr-85 | 64.73 D | | | | | | | | |
| | 513.9 | 99% | | | | | | | | |
| 54. | Y-88 | 106.60 D | | | | | | | | |
| | 898.0 | 94% | 1836.0 | 99% | | | | | | |
| 55. | Sn-113 | 115.10 D | | | | | | | | |
| | 391.6 | 64% | | | | | | | | |
| 56. | Ce-139 | 137.50 D | | | | | | | | |
| | 165.7 | 80% | | | | | | | | |
| 57. | Hg-203 | 46.59 D | | | | | | | | |
| | 72.8 | 6% | 279.1 | 81% | | | | | | |
| 58. | Ta-182 | 115.00 D | | | | | | | | |
| | 67.7 | 41% | 100.1 | 14% | 152.4 | 7% | 222.0 | 7% | 1121.2 | 35% |
| | 1189.0 | 16% | 1221.4 | 27% | 1230.9 | 11% | | | | |