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UPDATED ESTIMATES OF $^{239-240}Pu + ^{241}Am$ INVENTORY, SPATIAL PATTERN, AND SOIL TONNAGE FOR REMOVAL AT NUCLEAR SITE-201, NTS

by

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DISCLAIMER

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ABSTRACT

Updated estimates of $^{239-240}Pu$ + ^{241}Am inventory and spatial pattern in surface soil are given for Nuclear Site (NS)-201 in Area 18 of the Nevada Test Site (NTS). These new estimates are based on 712 ^{241}Am soil concentrations including 185 data values not previously available. Estimates were obtained using essentially the same Kriging techniques and the estimated average $^{239-240}Pu$ to ^{241}Am ratio of 7.5 used by Simpson and Gilbert (1980) to obtain previous results. (Henceforth, Pu and Am refer to $^{239-240}Pu$ and ^{241}Am, respectively.) Estimated concentration contours, 68% confidence bands for the contours and estimated median concentrations for 50 x 50 ft blocks are given. The total Pu + Am inventory estimated to be in the top 5 cm of soil over the 109 hectare study (an area 5.2 hectares larger than used by Simpson and Gilbert, 1980) is approximately 16.3 curies. The approximate 68% confidence interval on this inventory estimate is about 6.7 to 45.6 curies. It is estimated that about 58 acres (≃23 hectares) of land in the study are contaminated at levels greater than 40 pCi/g which includes about 40 acres (≃16 hectares) at levels greater than 160 pCi/g. Approximately 28,000 tons of soil would need to be removed (to 15 cm depth) to clean up all areas with estimated concentrates greater than or equal to 160 pCi/g. About 41,000 tons would require removal at the 40 pCi/g level. These new estimates of inventory and spatial patterns are within the range of sampling error of previous estimates obtained by Simpson and Gilbert (1980).

INTRODUCTION

This paper gives updated estimates of Pu + Am inventory, spatial pattern and soil tonnage for removal at NS-201 on the NTS. Previous estimates based on 185 fewer soil data points were reported by Simpson and Gilbert (1980). Their estimates are not greatly different from those reported here. For additional information on radionuclides in soil at NS-201, including the distribution of radionuclides between sieved soil fractions and with soil depth, as well as quality assurance aspects, the reader should consult Essington (1980). Simpson and Gilbert (1980) give some historical background and references concerning prior NAEG studies at NS-201.

The estimates of inventory given here do not include whatever Pu + Am may exist in the man-made earth mound near the ground zero (GZ) at NS-201. Soil samples have been collected on the surface of this mound. The results are given by Essington (1981). The sampling protocol for the mound is described by Essington (1980).

METHODS

The statistical estimation methods used here are essentially the same as used and discussed by Simpson and Gilbert (1980). A brief summary of some methods are discussed below, but the reader should consult Simpson and Gilbert for details. Also, the minor changes that were made to obtain updated estimates in this paper are discussed below.

Results presented here are based on 712 surface (0-5 cm) soil samples collected at the locations indicated in Figure 1. The 185 new data, not available when Simpson and Gilbert (1980) made initial estimates, are at locations removed from the immediate vicinity of GZ; most are greater than or equal to 600 ft north of GZ. Twenty are at various locations between about 200 and 800 ft south of GZ. The data are 100 minute Ge(Li) counts of the <10 mesh (2 mm) fraction of the dried, ball milled soil.

Kriging was used to obtain estimates of spatial patterns and inventory. An explanation of the technique and an example of its use are given by Barnes (1980). Other references on Kriging are given in Simpson and Gilbert (1980).

Our basic approach for obtaining estimates of Pu + Am inventory and spatial distribution was to first Krige the 712 Ge(Li) Am data to obtain estimates of Am spatial pattern and inventory. Estimates for Pu + Am were then obtained by using the average Pu to Am ratio for NS-201 to estimate the Pu component (discussed more fully by Simpson and Gilbert, 1980). The Pu and Am were then added together. Simpson and Gilbert estimated the average Pu (wet chemistry) to Am (Ge(Li)) ratio to be 7.51 (based on 110 pairs of data). This estimated average ratio is the geometric mean of the 110 ratios. The approximate 95% confidence interval on the true geometric mean ratio was estimated to be 6.9 to 8.2. A scatter plot of the 110 data pairs is given by Simpson and Gilbert (1980, Fig. 1). That figure illustrates the reasonably good fit of the data to the line Pu = 7.51 Am.

Kriging was done on the logarithms of the data, then the results were transformed back to the original scale. This means that the Kriging estimates are estimates of medians, and the standard errors are multiplicative. Also

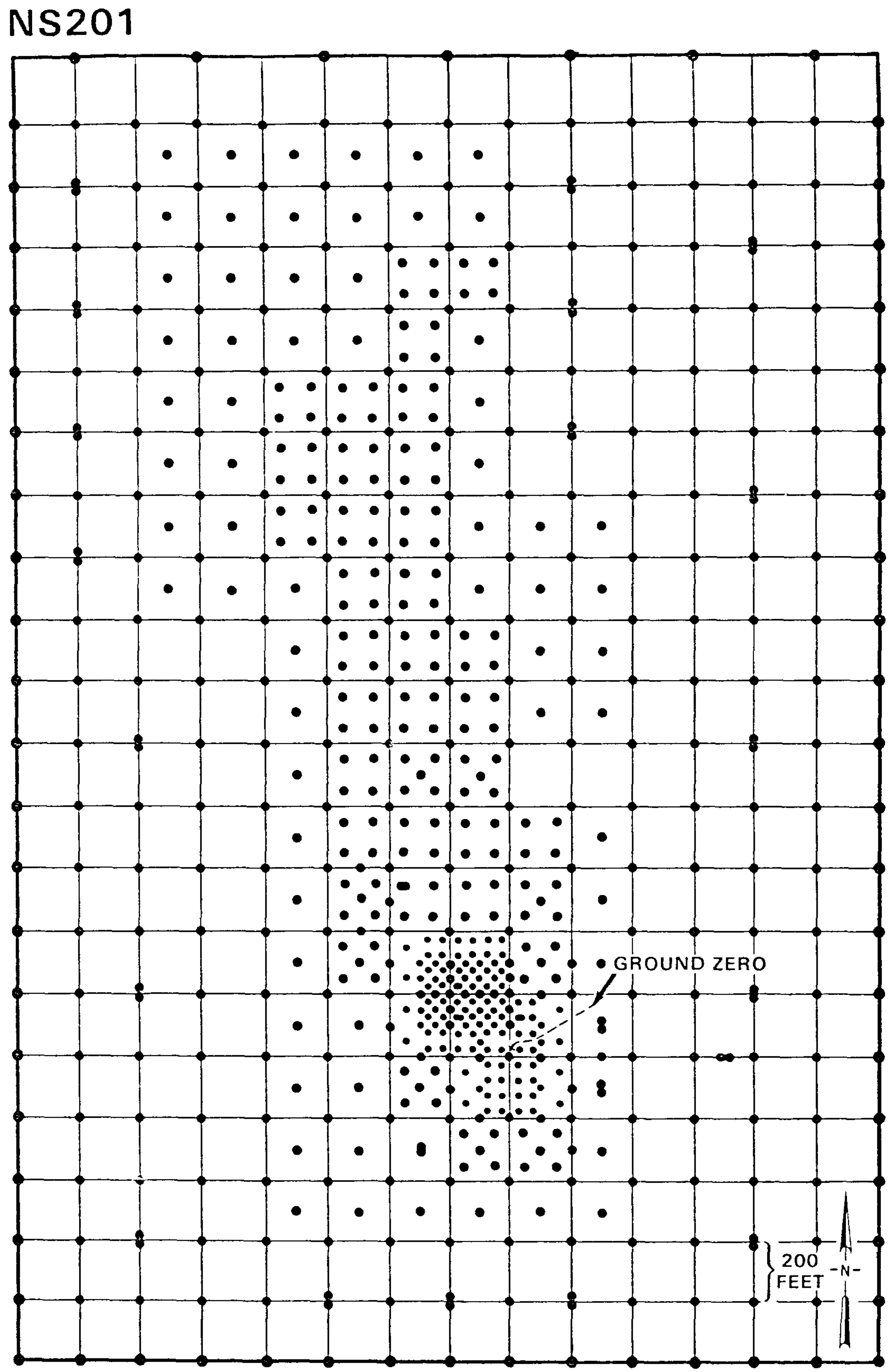

FIGURE 1. Locations (•) of 712 surface (0-5 cm) soil samples.

as noted above, Kriging was done on the <10 mesh soil. Hence, it is necessary to take account of the fact that at NS-201 the <10 mesh fraction is on the average 69% of the total weight of the sample, while it contains over 99% of the Am (Essington, 1980). Therefore, the final concentrations of Pu + Am per gram of total soil were obtained by multiplying the estimated Pu + Am concentrations in the 10 mesh soil by 0.69, as discussed by Simpson and Gilbert (1980).

Pu + Am concentration contours were obtained by applying Kriging as described above to the estimated median Pu + Am pCi/g concentrations for each 50 x 50 ft block of a grid system laid over the NS-201 study area. Then contours for selected concentration levels were drawn by hand.

Estimates of inventory for the defined study area (the 2800 x 4200 ft (853 x 1280 m) area bounded by the rectangle in Figure 1) were obtained by using Kriging to estimate the mean pCi of Pu + Am in the top 5 cm of each 50 x 50 ft block. The total surface inventory for the site is then the sum of these 4704 block estimates. In equation form we have

$$\hat{I} = K \sum_{i=1}^{4704} \hat{\mu}_i \tag{1}$$

where $\hat{I}$ = estimate of 0-5 cm Pu + Am inventory (in picocuries) over the defined study area

$\hat{\mu}_i$ = estimated mean pCi of Pu + Am per soil sample in the ith block

K = number of 12.7 cm diameter circle by 5 cm depth surface samples in a 50 x 50 ft block

= 18,334.

The estimates of the median, $\hat{M}_i$, were obtained by Kriging the sample estimates x_i, where

x_i = pCi/g of the ith sample * weight in grams of the ith sample

= estimated pCi in the ith sample.

The estimates of the mean, $\hat{\mu}_i$, were obtained from the median estimates using the following equation

$$\hat{\mu}_i = \hat{M}_i e^{\hat{\sigma}_i^2/2} \tag{2}$$

where

$\hat{\sigma}_i^2$ = the Kriging variance in the ith block.

This method for estimating inventory is different from that used by Simpson and Gilbert (1980). They estimated the median concentration (pCi/g) of Pu + Am in the ith 100 x 100 ft block, summed these over all blocks and multiplied by the average weight of soil in each 100 x 100 ft block to a depth of 5 cm. An average soil density of 1.06 g/cm^3 (standard error of 0.014 g/cm^3) was used to obtain the soil weight. The method used above (Equation 1) is believed to be superior since the soil density may change from sample to sample. This method also uses estimates of the mean instead of the median. Because of the skewed nature of the distribution, the use of the median causes the inventory to be underestimated. Therefore, the use of the mean should eliminate this bias.

The estimates of inventory given here assume all the Pu and Am in soil is in the top 5 cm. However, Essington (1980) demonstrates that for a substantial number of soil profile samples collected at NS-201, much of the radionuclide load is below the 5 cm depth. Hence, the estimates of inventory given here may need adjusting upward by an uncertain amount, yet to be accurately determined.

Finally, we note that the defined study area shown in Figure 1 is 5.2 hectares larger than the area used by Simpson and Gilbert (1980). The additional area is a 200 x 2800 ft strip at the top of Figure 1, added because of the seven samples located along the line 3200 feet north of GZ that became available during the past year.

RESULTS

Contours of Pu + Am Concentration

Figure 2 shows the estimated Pu + Am concentration contours obtained by the Kriging methods above. Figure 3 shows the approximate 68% confidence bands on the 100 pCi/g soil and 5000 pCi/g soil contours for Pu + Am. These confidence bands convey visual information about how well the location of the concentration contour line is known. The interpretation of the 68% confidence band in Figure 3 is as follows: approximately 68% of the total length of the true 100 pCi/g or 5000 pCi/g contours are expected to lie within their respective bands.

NS201

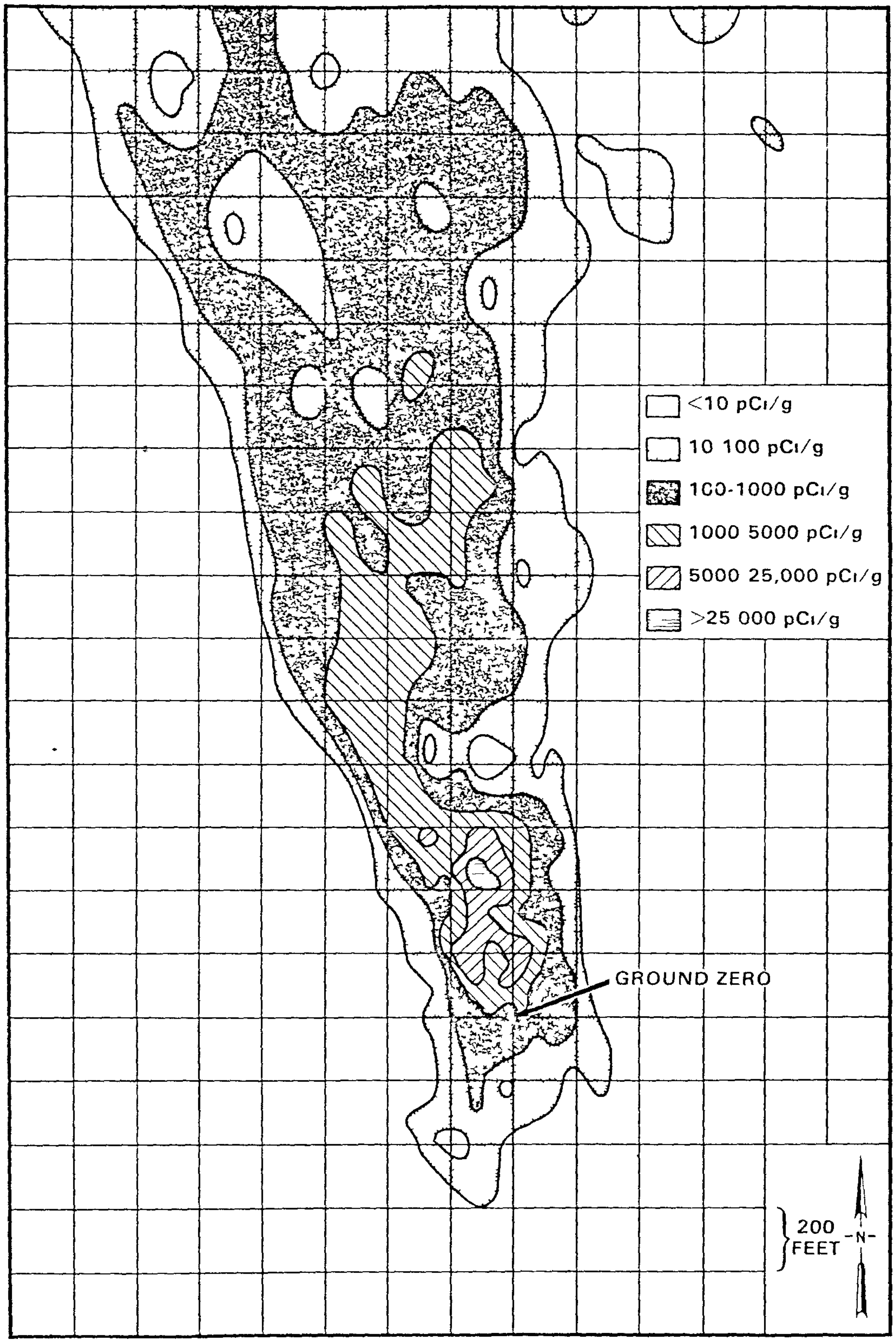

FIGURE 2. Estimated Pu + Am concentration contours obtained by Kriging.

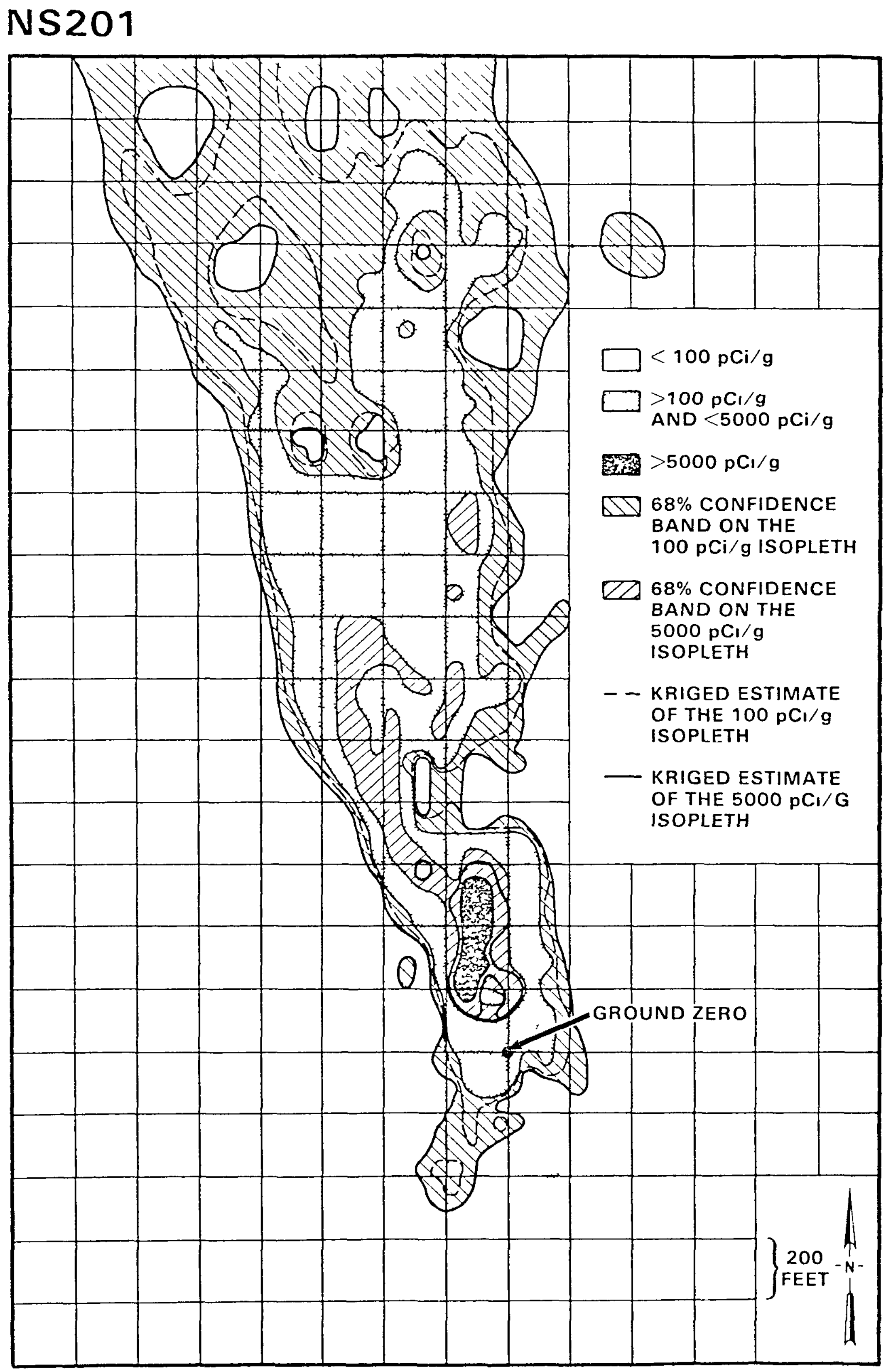

FIGURE 3. Approximate 68% confidence bands on the 100 pCi/g soil and 5000 pCi/g soil samples.

Areas of High Concentration and Estimates of Soil Removal for Cleanup

Figure 4 shows the estimated median concentrations of Pu + Am for each 50 x 50 ft block, i.e., this figure indicates which blocks were categorized as < 40 pCi/g, between 40 and 160 pCi/g, and >160 pCi/g. Figure 5 shows the upper 68% confidence limit on these median block estimates. This figure was obtained by estimating the upper 68% confidence limit on each block (by using the Kriging errors), then classifying a block as being < 40 pCi/g if the upper limit is < 40 pCi/g, and similarly for the 40 to 160 and the >160 regions.

An approximation of the amount of land associated with a given Pu + Am concentration can be computed by counting the blocks and then scaling to the particular units desired. We know that

$$1 \text{ block} = 2500 \text{ ft}^2 = 232 \text{ m}^2 = 0.0574 \text{ acre} = 0.0232 \text{ hectares.}$$

Estimates of soil volume and tonnage removal necessary to decontaminate NS-201 study area (Figure 1) to selected Pu + Am surface soil concentrations can be obtained by assuming a soil density and an average depth of soil removal. Such estimates are given in Table 1 for an average soil density of 1.06 g/cm^3 and a soil removal depth of 15 cm. We see, e.g., that to be approximately 68% confident that all surface soil with average Pu + Am concentrations greater than 40 pCi/g has been removed in a cleanup effort, about 64,000 cubic yards or 57,000 tons of soil would have to be removed. The use of 160 and 40 pCi/g limits in Table 1 is purely arbitrary and for illustration purposes only.

Estimates of Pu + Am Inventory

Using equations 1 and 2, the total estimated Pu + Am inventory in surface (0-5 cm) soil over the defined 4704 50 x 50 ft blocks is found to be

$$\hat{I} = 18{,}334 \sum_{i=1}^{4704} \hat{\mu}_i$$

$$= 18{,}334 \, (8.90 \times 10^8 \text{ pCi})$$

$$= 16.3 \text{ Ci.}$$

Using Kriging standard errors, we calculated an approximate 68% confidence interval for the average concentration in each block, and substituted the upper and lower limits of each block for $\hat{\mu}_i$ above. By doing so, we obtained an approximate 68% confidence interval for the total inventory. The lower and upper limits are 6.7 and 45.6 curies, respectively. Figure 6 shows graphically the estimated inventory at NS-201 on a block-by-block basis.

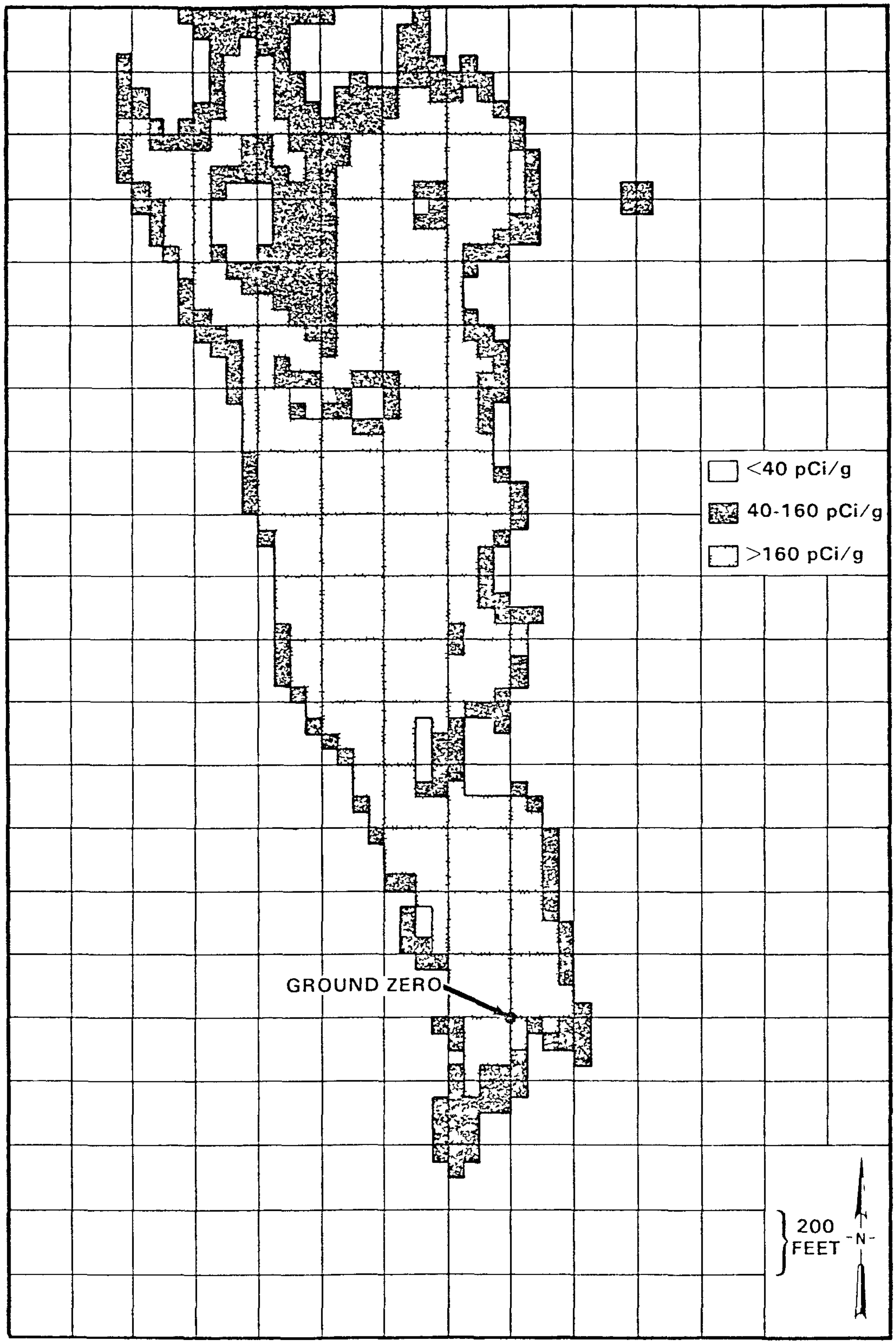

FIGURE 4. Estimated median concentrations of Pu + Am for each 50 x 50 ft block.

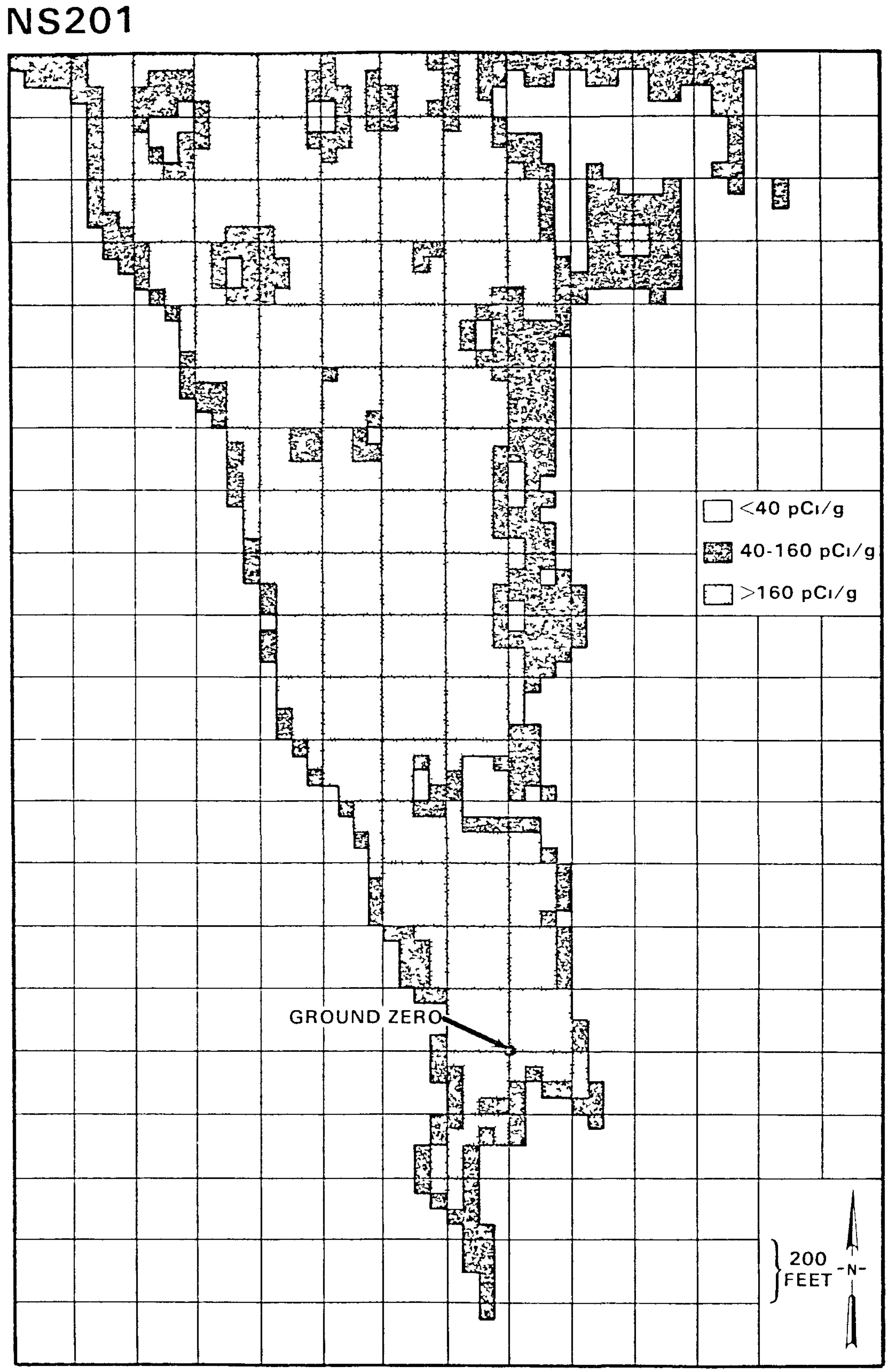

FIGURE 5. The upper 68% confidence limit on the 50 x 50 ft block estimates.

NS201

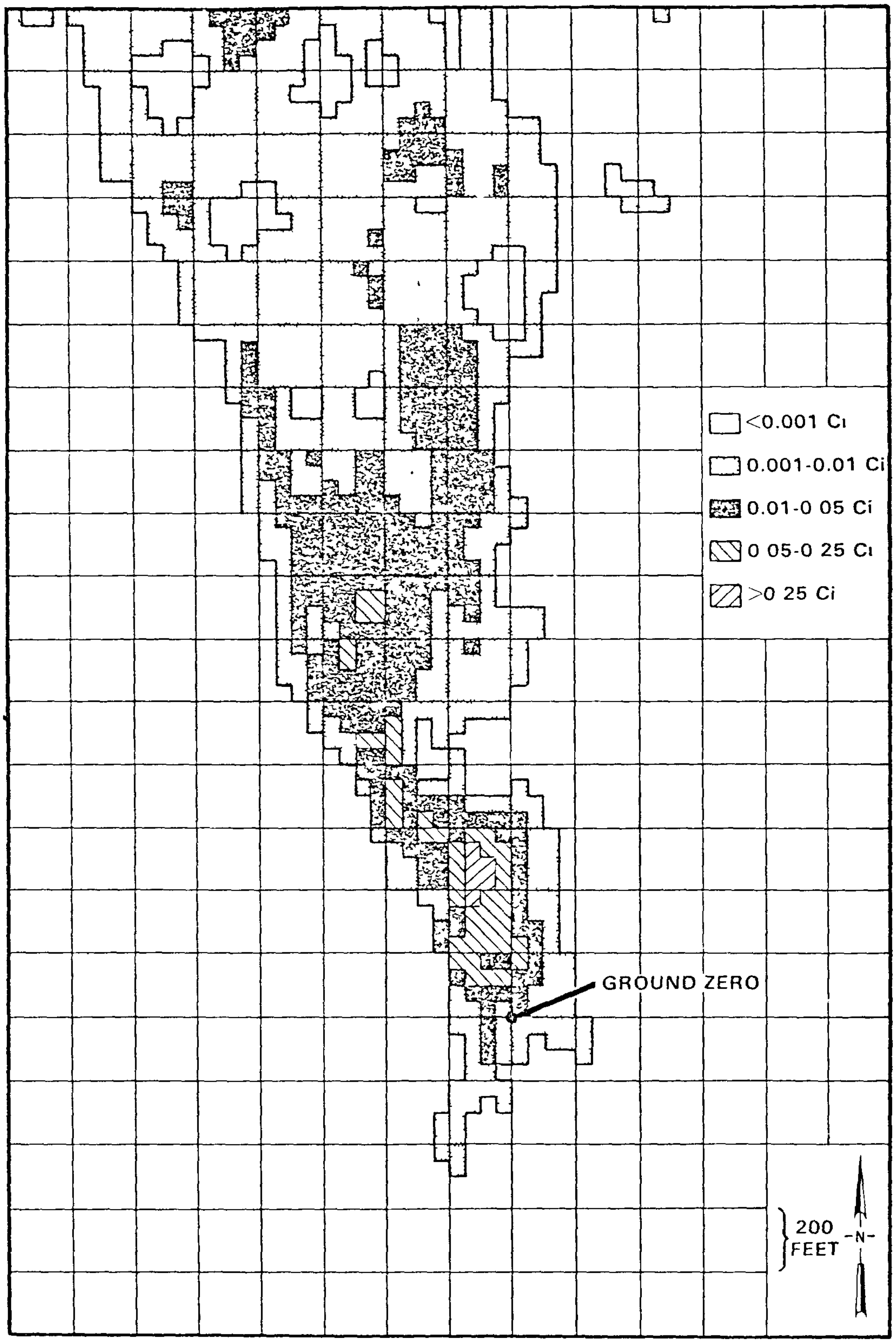

FIGURE 6. Estimated inventory for 50 x 50 ft blocks.

TABLE 1. Updated estimates of soil tonnage removal necessary to decontaminate NS-201 (area defined in Figure 1) to selected Pu + Am concentration levels.

Concentration	Number of 50x50 ft Blocks	Area			Volume[†]		Weight[††]	
		m^2	acres	hectares	m^3	yd^3	Kg Soil	Tons Soil
160 pCi/g	693	$161x10^3$	40	16	$24x10^3$	$32x10^3$	$2.6x10^7$	28,000
Upper 68% Confidence Limit on 160 pCi/g	1001	$232x10^3$	57	23	$35x10^3$	$46x10^3$	$3.7x10^7$	41,000
40 pCi/g	1007	$234x10^3$	58	23	$35x10^3$	$46x10^3$	$3.7x10^7$	41,000
Upper 68% Confidence Limit on 40 pCi/g	1408	$327x10^3$	81	33	$49x10^3$	$64x10^3$	$5.2x10^7$	57,000

[†] Assumes soil removal to 15 cm depth.

[††] Assumes a soil density of 1.06 g/cm^3.

Comparison of 1980 and 1981 Estimates

Table 2 compares estimates obtained by Simpson and Gilbert (1980) using 527 data values with estimates reported in this paper on 712 data values. The first column under 1981 gives estimates for the same land area (104 hectares) as used in 1980. The estimate of inventory increased from 9.4 as estimated in 1980 to 16.3 Ci, as reported in this paper. Most of this increase is due to using the mean, instead of the median, to estimate the inventory. (If the median had been used, the estimate of the inventory would be 10.3 Ci.) The estimated 68% confidence interval on the inventory was larger for 1981, a consequence of using the mean instead of the median. The number of hectares estimated to have concentrations greater than 40 or 160 pCi/g was somewhat larger in 1981 than in 1980 (~23% increase for 160 pCi/g; ~10% increase for 40 pCi/g). We note from Table 2 that the change from 1980 to 1981 estimates was not due primarily to the slightly larger study area used in 1981.

SUMMARY

Chemistry Pu and Ge(Li) Am data have been combined with 712 Ge(Li) Am data to obtain updated estimates of Pu + Am inventory, spatial distribution and soil tonnage for cleanup at NS-201 on NTS. The estimated total amount of Pu + Am in the top 5 cm of soil with the 109 hectare study area is about 16.3 curies, with an approximate 68% confidence interval of about 6.7 to 45.6 Ci. The estimate of 16.3 curies does not include any Pu + Am that may exist below the 5 cm depth, or outside the 109 hectare study area, or any that exists in the man-made earch mound close to GZ at NS-201. It is estimated that about 40 acres (~16 hectares) within the defined study area have Pu + Am levels of 160 pCi/g (top 5 cm) or more, and about 58 acres (~23 hectares) have levels of 40 pCi/g or more. Approximately 28,000 tons of soil would need to be removed (15 cm depth) to decontaminate areas on the study sites presently estimated to be greater than 160 pCi/g. About 41,000 tons on the site would need removal to decontaminate areas estimated to be above 40 pCi/g.

TABLE 2. Comparison of 1980 and 1981 estimates at NS-201.

	1980	1981	
	104 Hectares	104 Hectares†	109 Hectares††
Inventory	9.4 Ci	15.1 Ci	16.3 Ci
68% Confidence Interval on Inventory	4-30 Ci	6.6-42.1 Ci	6.7-45.6 Ci
Hectares >160 pCi/g	13	16.0	16.1
Hectares >40 pCi/g	21	23.0	23.4
Tons to Remove*			
At 160 pCi/g Level	23,000	27,900	28,200
At 40 pCi/g Level	36,000	40,300	41,000

*Assumes soil removal to 15 cm depth and a soil density of 1.06 g/cm^3.

†The same study area used by Simpson and Gilbert (1980).

††The larger study area used for the present report.

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