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Determining Cs-137 Background Body Burdens for Wild Pigs at Savannah River Site

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August 2019

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EXECUTIVE SUMMARY

In Gaines and Novak (2016), an effective method for determining the background ^{137}Cs body burden for the white-tailed deer population on the SRS was developed, using data collected during public hunts combined with gamma overflight data to determine the areas contaminated by site activities. However, a background ^{137}Cs body burden for the wild pigs present on the SRS has not been developed to date.

In this work, we applied the Gaines and Novak (2016) methods to determine the ^{137}Cs background concentration in wild pigs. The determination of a site-specific home range for wild pigs on SRS with establishing background hunt compartments for calculating the background body burdens of ^{137}Cs resulted in an upper bound concentration in wild pigs on SRS of 1.97 pCi/g. This value bounds 95% of the possible ^{137}Cs contamination value for wild pigs from the background compartments with 95% confidence. Therefore, it is recommended that 1.97 pCi/g be used in the SRS Hunter Dose Tracking System (Whiteside, 2017) as the background ^{137}Cs concentration for wild pigs on SRS. This concentration should be decay corrected from the year 2014.

It is also recommended that this assessment of background concentrations in SRS wild pigs (and white-tailed deer) be performed at least every five years.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ArcGIS	Arc Geographic Information System
Bq	becquerel
Bq/m2	becquerels per square meter
CDC/NCI	Centers for Disease Control and Prevention/National Cancer Institute
Ci	curie
CL	confidence limit
conc	concentration
cps	counts per minute
^{137}Cs	cesium-137 or radiocesium
DOE	Department of Energy
in	inch
km	kilometer
mi	mile
mrem	millirem
mt	megatons
pCI/g	pico curies per gram (wet weight)
P. R. China	Peoples Republic of China
Pu	plutonium
SC	South Carolina
SRNL	Savannah River National Laboratory
SRS	Savannah River Site
TBq	terabecquerel
US	United States
USFS	United States Forest Service
U.S.S.R.	Union of Soviet Socialists Republic (a.k.a. Soviet Union)

1.0 Introduction

The Savannah River Site (SRS) is a large (803 km^2) U.S. Department of Energy (DOE) facility located in the upper coastal plains, near Aiken, SC. The U.S. Atomic Energy Commission, a DOE predecessor agency, established SRS in early 1951, with its primary mission to produce special nuclear materials (such as ^{239}Pu and tritium) used in the production of nuclear weapons. Since 1951, public access has been strictly controlled at SRS.

A major source of residual radioactivity at SRS is global fallout of fission products from above ground weapons testing. As shown in Table 1-1, a worldwide total of about 480 megatons (mt) of nuclear weapons were detonated above ground.

Nation	Number of Above Ground Detonations	Years	Total Yield
United States	216	1945-1962	153.8 mt
U.S.S.R.	214	1949-1962	281.6 mt
United Kingdom	21	1952-1958	10.8 mt
France	46	1960-1974	11.4 mt
P.R.China	23	1964-1980	21.5 mt
South Africa	1	1979	0.003 mt

Table 1-1. The Worldwide Total of Detonated Nuclear Weapons in Above Ground Tests

Due to North American weather patterns and the relatively wetter weather conditions in the eastern US, the dry and wet deposition of relatively long-lived radionuclides with high fission yields (such as ^{137}Cs with about a 30-year half-life) was enhanced in this region of the United States (US) during the time of above ground weapons testing. A total of about 1.3 x 10^6 TBq (3.5 x 10^7 Ci) was introduced to the atmosphere during above ground testing (Eisenbud, 1987).

As shown in Fig. 1-1 (CDC/NCI, 2002), the deposition density of ^{137}Cs in this region of the US (including the SRS area) ranges between 4,000 and 6,000 Bq/m^2, with some localized areas receiving even higher deposition. Because of anthropogenic activities such as agriculture and suburban and urban developments, much of this cesium has been dispersed and is no longer bioavailable in the environment. However, at SRS, less than 10% of the site has been impacted by industrial activities and the rest has remained as managed forested areas by the US Forest Service (USFS) since the early 1950's. Because of this protection, a much larger fraction of the ^{137}Cs deposited on SRS during the 1950's and early 1960's remains bioavailable to higher trophic level animals, such as white-tailed deer (*Odocoileus virginianus*) and invasive wild pigs (*Sus scrofa*) on the site. This phenomenon also is observed at other large protected land areas such as military bases and national/state forests (Gaines and Novak, 2016).

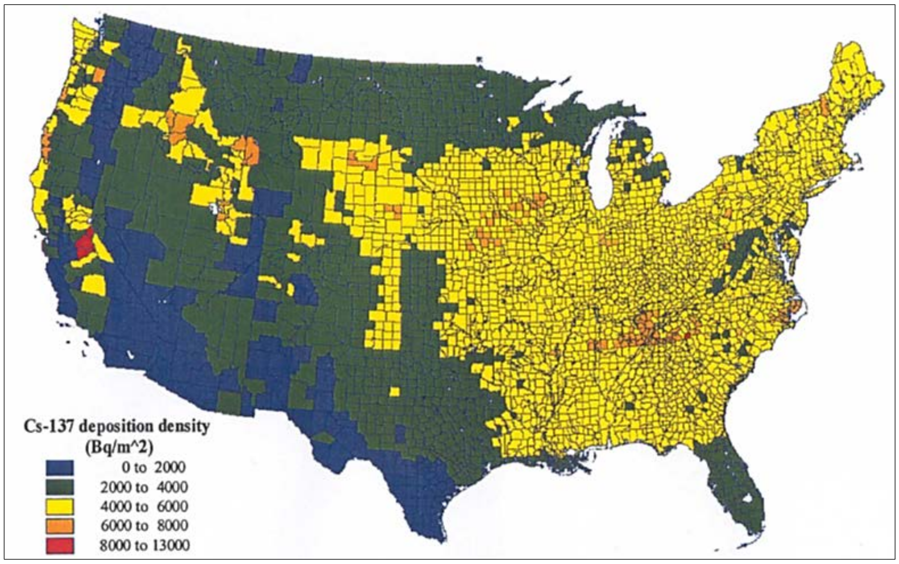


Figure 1-1. Deposition Density of ^{137}Cs in the United States

Because large portions of SRS are not industrialized, allowing for an abundant, undisturbed vegetation structure to develop, an increase in herd sizes among wildlife populations occurred, which eventually led to an increase in animal-vehicle accidents onsite (Gaines and Novak, 2016). To help decrease the number of these accidents and help the health of the animal populations, SRS began conducting annual wildlife hunts in 1965 by volunteer members of the pubic. These hunts were primarily for white-tailed deer and wild pigs.

Prior to release of any animal to a hunter, SRS personnel use portable sodium iodide detectors to perform field analyses for ^{137}Cs. For animals that have a ^{137}Cs concentration above the established background level (for deer this number is 2.59 pCi/g), a dose is assigned to that hunter. Annual and lifetime cumulative doses to each hunter are tracked (Whiteside, 2017). Since 2006, the administrative dose limit of 0.22 millisievert (22 mrem) has been established at SRS. The maximum annual dose from the onsite-hunter deer/hog consumption pathway typically exceeds all standard maximally exposed individual pathways combined, and it exceeds all other SRS sportsman dose scenarios (Jannik and Hartman, 2016).

The lands encompassing the SRS have had a wild pig presence since before the site began operations in 1953. Wild pigs are highly adaptable and intelligent animals, which makes managing the population on site difficult. The wild pigs on SRS are a non-native species and are intensively studied because of their destructive and intrusive nature (Mayer and Brisbin, 2012).

In Gaines and Novak (2016), an effective method for determining the background ^{137}Cs body burden for the deer population at SRS was developed, using data collected during hunts combined with gamma overflight data to determine the areas contaminated by site activities. However, a background ^{137}Cs body burden for the wild pigs on SRS has not been developed to date.

In this work, we apply the Gaines and Novak methods to determine the ^{137}Cs background concentration in wild pigs. The ^{137}Cs background body burden concentration in wild pigs on SRS was evaluated using data collected from 1) onsite hunts, 2) gamma overflights of SRS, and 3) studies of site-specific home range of wild pigs.

2.0 Methods and Materials

2.1 Determination of Appropriate Onsite Background Areas at SRS

SRS public annual hunts occur in the fall and early winter months, with hunters being allowed to harvest animals in specific areas, known as hunt compartments. Harvests within the hunt compartments vary from year to year and are based on population studies of the harvested animals performed by the USFS. SRS is divided into 50 hunt compartments as shown in Figure 2-1. When a hunter harvests an animal, the hunt compartment is recorded along with the hunter identification number and animal information, including weight, sex, and the measured ^{137}Cs concentration.

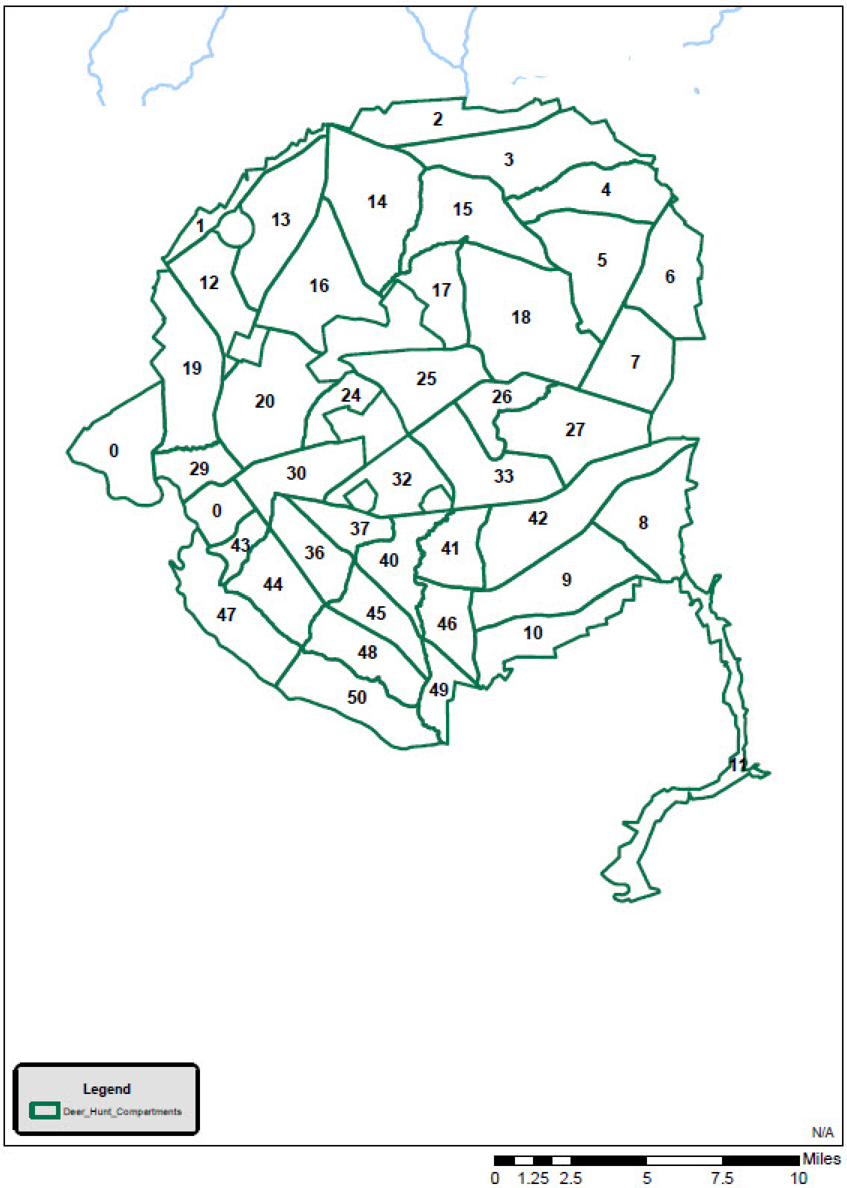


Figure 2-1. Hunt Compartment Locations on Savannah River Site

The development of a site-specific home range for wild pigs on the SRS was determined by using four studies conducted between 1969 and 1992 for the SRS wild pig population (Mayer and Brisbin, 2012).

Movements of wild pigs appear to be characteristic of general wandering or driving but show a general trend toward sedentary habits and are restricted to a defined area or home range over periods of time. However, these home ranges can vary over time. This variability is a product of habitat differences, interspersion of different habitats, seasonal shifts in food availability, varying population densities, and the social relationship of local individuals (Mayer and Brisbin, 2012).

Gamma overflight data maps from 1998 were used to identify legacy contaminated areas that were directly impacted by SRS operations. An Arc Geographic Information System (ArcGIS) was used to create buffer zones around the SRS legacy contaminated areas using the aforementioned home range data. Hunt compartments that were identified as being mostly (greater than 50% by area) outside the buffer areas were designated unimpacted by site operations and were used for background concentration determinations.

The field measured ^{137}Cs concentrations in wild pigs harvested in the background hunt compartments during recent annual hunts (2012-2018) were used to determine the upper 95% confidence level of the background concentration in wild pigs.

Figure 2-2. Sodium Iodide Detectors for ^{137}Cs Monitoring

To measure the ^{137}Cs concentrations in the animals, sodium iodide detectors are used. Until 2017, two small (2.5 in x 2.5 in) sodium iodide detectors were used. From 2017 to present, a single, large (2 in x 4 in x 16 in) sodium iodide detector is used that can also be placed into the ground to reduce field background (Whiteside, 2017).

3.0 Results and Discussion

3.1 Home Range Determination

Wild pigs on SRS are found in most of the terrestrial habitats; some activity has even been noted within boundaries of developed areas on site. Wild pigs prefer bottomland hardwood forests as their main habitat but have also been observed in pine habitats on site. The shift in location for the wild pigs often correlates with seasonal shifts in food availability (Mayer and Brisbin, 2012).

A summary of home range data compiled for the SRS wild pig population during four studies conducted between 1969 and 1992 is provided in Mayer and Brisbin (2012). The combined data from that report, with the range expressed as an area in hectares, are shown in Table 3-1.

Table 3-1. Combined Home Range Data for the Wild Pig Population at SRS

		Avg Range	**Variance**	**Std Dev**	**95% CL**	**Home Range Diameter**
	Count	**Hectares**				**Miles**
Female	11	837	221 - 2365	738.2	1240	2.5
Male	16	956	172 - 2443	703.9	1265	2.5

From Table 3-1, the upper 95% confidence limit (CL) for the home range of female wild pigs is 1,240 hectares and for males it is 1,265 hectares. This means the home range, on average, of the wild pigs studied is less than or equal to those 1,265 hectares with 95% confidence. To be conservative in defining the size of the possible home range, represented as a circle, a diameter of 2.5 mi was used in the determination of the background compartments.

The Buffer tool within ArcMap was used to visualize a home range of wildlife potentially contaminated by SRS operations. Using the 1998 SRS ^{137}Cs radiological gamma overflight survey, the home range was approximated to extend 2.5 miles radially from the 110 cps detection lines. Figure 2-2 shows overflight data and the overlay of the 2.5-mile diameter buffer zones.

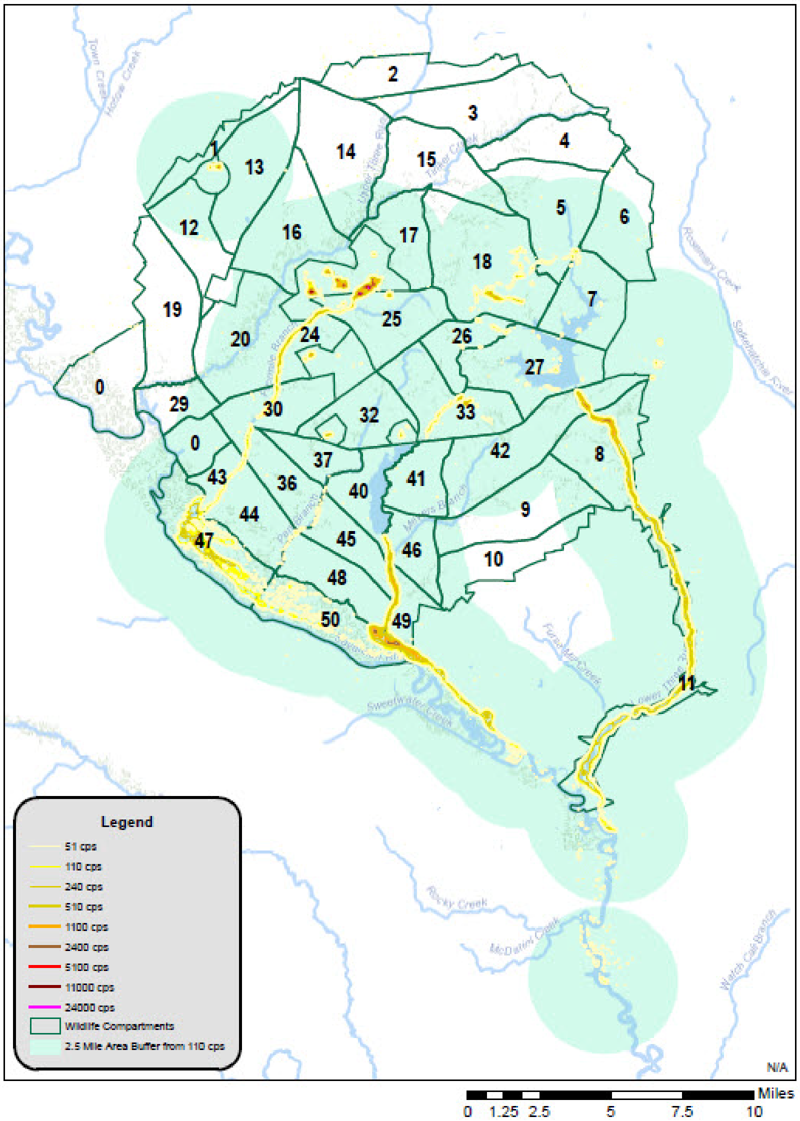


Figure 3-1. Gamma Overflight Map Showing Areas on Contamination and Home Range of Wild Pigs

From Figure 3-1, hunt compartments 2, 3, 4, 10, 14, 15, and 29 were identified as being more than 50% (by area) outside the designated buffer areas, and therefore, are considered unimpacted by site operations. These seven hunt compartments were used for SRS-specific background concentration determinations.

3.2 Wild Pig Background Calculations

With the background compartments identified (i.e., hunt compartments 2, 3, 4, 10, 14, 15, and 29), recent (2012-2018) ^{137}Cs concentration measurements (expressed relative to the edible meat portion) of wild pigs from these compartments were compiled and are shown in Table A-1 in Appendix A. These data are a random sample of possible ^{137}Cs concentration measurements representative of the background contamination at SRS. A tolerance limit method is used to determine an upper threshold for such contamination at the site.

A statistical tolerance method provides a bound or bounds that cover a specified percentage of the possible data from a population of interest with an identified level of confidence. The level of confidence is the reliability of the tolerance interval method to deliver correct results in repeated observations from the population. Tolerance intervals come in several forms: a two-sided interval that covers a certain percentage of the population between its lower and upper bounds, a lower one-sided tolerance interval which specifies that a certain percentage of the population will be above a stated lower bound, and an upper one-sided tolerance interval which specifies that a certain percentage of the population will be below a stated upper bound. The last of these tolerance intervals, the upper one-sided tolerance interval, is the appropriate form for establishing a threshold value for the background level for ^{137}Cs in the meat of wild pigs at SRS.

Another aspect of the method for developing a tolerance bound is whether the method depends on a specific probability distribution for the population of interest or relies on a distribution-free approach. A distribution-free approach depends only on the available data being a random sample of an unspecified probability distribution while the first approach relies also on the data being well-represented by a probability distribution with a specified form although it may have unknown values for associated parameters such as its mean and standard deviation.

The well-known normal (or Gaussian) probability distribution (i.e., the common, bell-shaped distribution) has been found to be applicable for many situations of practical interest. Tolerance limit methods for the normal distribution are also well known, and there are statistical tests that may be applied to judge the appropriateness of the normal distribution for representing the population from which a random sample has been taken. JMP Pro Version 11.2.1 was used to conduct evaluations to explore these possibilities for the data from the background compartments (JMP Pro Version, 2014).

Figure 3-2 provides a graphical display of the available data, since 2012, for the compartments seen as representative of the SRS background contamination. The data are color-coded by concentration value with the legend appearing on the far-right of the graphic. The information for each compartment is displayed as a column with the year of the data shown for each observation. Compartments 10 and 29 provided the bulk of the data available to represent the wild pig background at SRS.

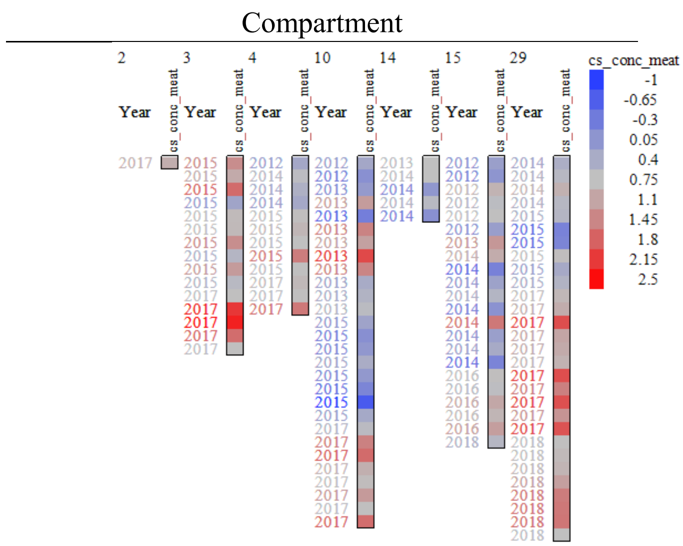
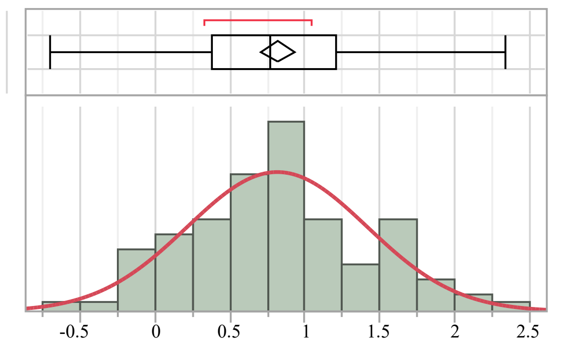


Figure 3-2. Cell Plot Showing ^{137}Cs Concentration Measurements (pCi/g) with Year

Negative concentration values were retained in the dataset because it is expected that some animals will have ^{137}Cs concentrations below the field background concentration taken in the area where the animals are measured.

Figure 3-3 provides a histogram and summary statistics for these data generated by the JMP software. Included in this figure are the average (0.815 pCi/g) and standard deviation (0.602 pCi/g). The bell-shaped curve superimposed on the histogram represents a normal probability distribution with this mean and standard deviation. Graphically, the approximation looks good.

Distribution
cs_conc_meat



Normal(0.81499,0.60243)

Quantiles

100.0%	maximum	2.341
99.5%		2.341
97.5%		2.04258
90.0%		1.6677
75.0%	quartile	1.20388
50.0%	median	0.766
25.0%	quartile	0.37275
10.0%		0.02122
2.5%		-0.2239
0.5%		-0.7039
0.0%	minimum	-0.7039

Summary Statistics

Mean	0.8149942
Std Dev	0.6024347
Std Err Mean	0.0569247
Upper 95% Mean	0.9277943
Lower 95% Mean	0.702194
N	112

Figure 3-3. Histogram and Summary Statistics for Background Data

Figure 3-4 provides the results of a more rigorous assessment of the question of representing these background data using a normal probability distribution. Included in this exhibit are the results of a Shapiro-Wilk test for the goodness of fit of a normal probability to these data. As indicated in the exhibit, the null hypothesis that these data are from a normal distribution would be rejected for a small p-value (i.e., one equal to or less than 0.05). From the exhibit, the significance level (or p-value) for the result of this test equals 0.4323, and thus, the null hypothesis of these data being from a normal distribution cannot be rejected at a 5% significance level. An additional feature available in the JMP software is the ability to request an upper tolerance bound on the data from a normal population. The result from the use of this feature to estimate an upper tolerance limit for the background contamination that covers 95% of the population values with 95% confidence is provided in Figure 3-4. The resulting value is 1.965 pCi/g, which indicates that 95% of the possible ^{137}Cs contamination values, expressed as pCi/g, for wild pigs from the background compartments are expected to be less than 1.965 pCi/gm with 95% confidence.

Fitted Normal					**Goodness-of-Fit Test**
Parameter Estimates					Shapiro-Wilk W Test
Type	**Parameter**	**Estimate**	**Lower 95%**	**Upper 95%**	0.988112 0.4323
Location	μ	0.8149942	0.702194	0.9277943	
Dispersion	σ	0.6024347	0.5325408	0.693614	Note: Ho = The data is from the Normal distribution. Small p-values reject Ho.
-2log(Likelihood) = 203.324392904381					
					One-sided Tolerance Interval
					Proportion **Lower TI** **Upper TI** **1-Alpha**
					0.950 . 1.965188 0.950

Figure 3-4. Results of the Applicability of the Normal Probability Distribution and an Upper Tolerance Bound on Background Contamination

4.0 Conclusions

In Gaines and Novak (2016), an effective method for determining the background ^{137}Cs body burden for the deer population at SRS was developed, using data collected during hunts combined with gamma overflight data to determine the areas contaminated by site activities. However, a background ^{137}Cs body burden for the wild pigs on SRS was not developed.

In this work, we applied the Gaines and Novak (2016) methods to determine the ^{137}Cs background concentration in wild pigs. The determination of a site-specific home range for wild pigs on SRS with establishing background hunt compartments for calculating the background body burdens of ^{137}Cs resulted in developing bounding concentration in wild pigs on SRS of 1.97 pCi/g. Therefore, it is recommended that 1.97 pCi/g be used in the SRS Hunter Dose Tracking System (Whiteside, 2017) as the background ^{137}Cs concentration for wild pigs on SRS. This concentration should be decay corrected from the year 2014.

5.0 Future Work/Recommendations

Now that a standard for background body burdens of ^{137}Cs has been established, future research and work will be conducted to determine if there is a correlation between the spatial or temporal data with the deer and the wild pigs and investigate why concentrations of the background body burdens of ^{137}Cs were higher in 2017 than in previous and subsequent years.

It is also recommended that this assessment of background concentrations in wild pigs (and deer) be performed at least every five years.

6.0 References

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Appendix A

Table_A-1. Concentration and Hunter Dose Tracking System Information

Year	Compartment	^{137}Cs Concentration in Meat
2017	2	0.992
2017	3	0.763
2017	3	2.165
2017	3	2.341
2017	3	1.695
2017	3	0.759
2015	3	1.378660814
2015	3	1.044937363
2015	3	1.708629942
2015	3	0.282835034
2015	3	0.828837752
2015	3	0.847985818
2015	3	1.358453233
2015	3	0.555293939
2015	3	1.214526909
2015	3	0.629150768
2017	4	0.867
2017	4	0.769
2017	4	1.588
2015	4	0.785070742
2015	4	0.891752828
2015	4	0.748680971
2015	4	1.534580788
2015	4	0.75771636
2014	4	0.678865662
2014	4	0.473977428
2014	4	0.338066168
2012	4	0.334516264
2017	10	0.647
2017	10	1.502
2017	10	1.714
2017	10	0.978
2017	10	0.81
2017	10	1.233
2017	10	0.758
2017	10	1.695
2015	10	0.267161123
2015	10	-0.032482455
2015	10	0.08609171
2015	10	0.408011323

2015	10	0.092093084
Year	Compartment	^{137}Cs Concentration in Meat
2015	10	-0.170508976
2015	10	-0.703919411
2015	10	0.349224267
2013	10	0.132891413
2013	10	1.211306511
2013	10	-0.257144129
2013	10	1.473683302
2013	10	1.149331239
2013	10	2.01661316
2013	10	1.454940693
2013	10	0.391753027
2013	10	0.513932771
2013	10	0.660636288
2012	10	0.327022528
2012	10	-0.024724229
2014	14	0.752657685
2014	14	0.075114105
2014	14	0.615679715
2014	14	-0.011402375
2013	14	0.748715209
2016	15	0.7841051
2016	15	0.7018327
2016	15	1.0815
2016	15	0.8948879
2016	15	1.18162
2014	15	1.023098172
2014	15	-0.216796492
2014	15	0.241215739
2014	15	0.547215794
2014	15	0.008885194
2014	15	1.58795082
2014	15	0.194675926
2014	15	0.366411305
2014	15	-0.178244724
2013	15	1.266516674
2012	15	0.053813974
2012	15	0.934371929
2012	15	0.66689146
2012	15	0.772293141
2012	15	0.178728135
2012	15	0.198073606
2018	15	0.576
2017	29	0.869
2017	29	1.013
2017	29	1.974

2017	29	1.103
Year	Compartment	^{137}Cs Concentration in Meat
2017	29	1.041
2017	29	0.941
2017	29	1.973
2017	29	1.506
2017	29	1.953
2017	29	1.296
2017	29	1.933
2015	29	0.557131319
2015	29	-0.206069672
2015	29	-0.170508976
2015	29	0.790054288
2015	29	0.360916165
2015	29	0.511972784
2014	29	0.440050967
2014	29	0.611151271
2014	29	0.953358988
2014	29	0.588013752
2018	29	0.763
2018	29	0.847
2018	29	0.911
2018	29	1.172
2018	29	1.55
2018	29	1.587
2018	29	1.604
2018	29	0.748