WSRC-MS-99-00481

Foodstuff Survey Around a Major Nuclear Facility, with Test of Satellite Images Application

Lawrence Koffman and Peter Fledderman
Westinghouse Savannah River Company
Aiken, SC 29808

Scot Twining, Johannes Strydom, Robert Rosson, and Bernd Kahn
Georgia Institute of Technology
Atlanta, GA 30332-0335

This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-96SR18500 with the U. S. Department of Energy.

Abstract

A foodstuff survey was performed around the Savannah River Site, Aiken SC. It included a census of buildings and fields within 5 km of the boundary and determination of the locations and amounts of crops grown within 80 km of SRS center. Recent information for this region was collected on the amounts of meat, poultry, milk, and eggs produced, of deer hunted, and of sports fish caught. The locations and areas devoted to growing each crop were determined in two ways: by the usual process of assuming uniform crop distribution in each county on the basis of agricultural statistics reported by state agencies, and by analysis of two LANDSAT TM images obtained in May and September. For use with environmental radionuclide transfer and radiation dose calculation codes, locations within 80 km were defined for 64 sections by 16 sectors centered on the Site and by 16-km distance intervals from 16 km to 80 km. Most locally-raised foodstuff was distributed regionally and not retained locally for consumption. For four food crops, the amounts per section based on county agricultural statistics prorated by area were compared with the amounts per section based on satellite image analysis. The median ratios of the former to the latter were 0.6 - 0.7, suggesting that the two approaches are comparable but that satellite image analysis gave consistently higher amounts. Use of satellite image analysis is recommended on the basis of these findings to obtain site-specific, as compared to area-averaged, information on crop locations in conjunction with radionuclide pathway modelling. Some improvements in technique are suggested for satellite image application to characterize additional crops.

Key words: Radionuclides, Foodstuff, Environmental surveillance, Satellite image analysis, Nuclear facility

Introduction

Nuclear facilities are required by Federal agencies to report annually the off-site maximum individual and collective radiation doses due to facility operation. A census of persons and foodstuff within 80 km of the facility center is necessary for this purpose. This report describes information collection concerning the location of nearest persons and the amounts and locations of foodstuff produced within the 80-km radius of the Savannah River Site (SRS), Aiken SC. Analysis of images obtained by satellite was tested for determining crop area and

location within 80 km to evaluate replacing agricultural statistics. To the extent that each foodstuff can be identified unambiguously by satellite image analysis, this procedure will provide more reliable information. County statistics depend on the accuracy of responses by selected farmers and their use is predicated on the assumption that these statistics apply uniformly throughout a county.

The SRS is roughly a circular 800-km^2 area on the east bank of the Savannah River that is operated for the Department of Energy by the Westinghouse Savannah River Company. Located on the site are nuclear reactors and production facilities that have generated and processed plutonium and tritium since 1953. To determine releases from operation, airborne and liquid radioactive effluent are monitored at points of discharge. Computer programs use this information to calculate concentrations of these radionuclides in ground-level air and surface water. Further transfer through the food chain and direct radiation exposure also are calculated. Annual radiation doses to persons are then estimated by this set of computer programs. Radiological surveillance is performed beyond the boundary to confirm calculated values where possible, and to assure that radioactivity and radiation levels are below regulatory limits.

To support calculation of the radiation dose to the maximum exposed individual off site, the locations of nearby persons are obtained periodically by surveys in the vicinity of the boundary. For this purpose and also to support calculation of the collective radiation dose, information on foodstuff produced within 80 km is obtained from Agricultural Statistics Services for Georgia and South Carolina.

Guidelines for state agencies in gathering and reporting agricultural data are provided by the US Dept. of Agriculture (USDA) Statistical Reporting Service (Barrowman 1983). Questionnaires are sent to selected farmers on the basis of an established data base for each crop to determine the crop area and yield. The amounts harvested are calculated from acreage and crop yield, and reported by county. Agencies for states such as Georgia use aerial photography to update the data base for crops and areas devoted to each, and select representative county sites for estimating crop yields. The state agencies also use questionnaires to compile by county the production of meat, poultry, milk, and eggs.

To calculate the annual radiation dose to persons from airborne radionuclides, the land around SRS is divided into 16 sectors centered on the cardinal directions. A further division into sections is based on 5 circles at 16-km intervals from the SRS center, of which the 4 more distant ones and slivers of the nearest one are outside the SRS boundary, as shown in Fig. 1. Average radionuclide deposition in each of these 64 grid sections beyond SRS is calculated on the basis of annual values for radionuclide release, wind frequency to each of the 16 sectors, deposition factors for dry conditions and precipitation, and atmospheric stability categories.

Currently, the amount of a specific crop in each grid section is estimated by prorating the acreage data for counties within the 80-km region for each section area. Eleven counties in South Carolina and 7 in Georgia lie either entirely or to a large extent within 80 km of the SRS center, and a total of 13 each are to some extent included, as shown in Fig. 1.

Aspects of the information gathered ancillary to radiological monitoring at SRS were described earlier (Hamby 1992; Hamby 1991). These reports delineated the drinking water and recreational exposure pathways via the Savannah River; meat and milk production; agricultural production in terms of leafy and "other" vegetables grown above ground; fishing in terms of sport, commercial, and invertebrate harvest; and model parameters for usage, human consumption and animal feed rates in the SRS environment. Radiological monitoring results and dose assessment from radionuclide releases are reported annually (Arnett and Mamatey 1998).

Satellite images have been used to identify crops, estimate the area devoted to their growth and place them in geographical information systems (Thomas 1986; van de Steene et al. 1992; Palacios and Gonzalez 1992; Bellow 1994). LANDSAT TM images were available for this purpose, and images from other satellites have become available. Suitable LANDSAT images can be selected for a 170 km x 185-km region that is revisited every two weeks. The pixel dimensions of 28.5 m x 28.5 m define the limits of spatial resolution. The extent to which the information content of the image identifies a crop depends on characteristic reflection intensities at seven wavelength regions, defined for the crop by observations at reference locations. Overlapping characteristic intensities limit the confidence with which crops can be distinguished from each other.

Presented here is a comparison of the two approaches for obtaining information on foodstuff grown in the vicinity of SRS: from 1994 county agricultural statistics and by analyzing LANDSAT images obtained May 22 and September 17, 1994. The crops that could be compared were grains, corn, soybeans, and peanuts. In addition, some of the food data reported earlier were updated, the area within 5 km of the SRS boundary was surveyed to locate every building and agricultural site, and food sales retailers and wholesalers were interviewed to determine the extent to which local foods are locally consumed.

Procedure

The survey in a 5-km strip outside the SRS boundary was performed on 5 occasions between Nov. 1994 and Aug. 1995. All nearby public roads were traversed by car, and paths were followed on foot as needed. Observed locations of residential and commercial structures, private gardens, farmland, dairies, and livestock were entered on USGS 1:24,000 maps for the 16 applicable quadrant maps (Twining et al. 1998).

Information concerning acreage harvested, density, and yield for various crops in each of the counties within 80 km of SRS center was obtained from South Carolina and Georgia Agricultural Statistics Services. Most information was for 1994, but some was for 1993, extrapolated from earlier years, or estimated for counties in which acreage for a specific crop was minimal. The data were entered by county into Arcinfo map files. The fractional acreage in the county devoted to the crop was represented by a polygon with the same fractional area within each grid section in that county, so that the crop acreage in the grid section is prorated for its area relative to that in the entire county. When a grid section includes two or more counties, county polygon data were united so that uniform weighted values of acreage and yield are recorded for the section.

Additional information was provided by state agencies and the USDA Agricultural Stabilization and Conservation Service in Georgia concerning meat, poultry, milk, and egg production. The South Carolina Wildlife Management Resources section in the Dept. of Natural Resources and the Georgia Dept. of Natural Resources provided deer hunting information: the former, for deer killed by licensed hunt clubs within the 80-km radius, and the latter for deer killed in 12 counties that include 5 counties within the 80-km radius. State agency staff suggested that the number of deer killed within 80 km could be estimated as 2.5 times the number killed by hunt clubs in South Carolina plus the number killed in the Georgia 12-county region. The sport fishing data by the Fish Management Section, Georgia Dept. of Natural Resources, is from a 1994 creel survey draft report for two reaches of the Savannah River. The upper reach is from the Savannah Bluffs Dam (River Mile 187) at Augusta above SRS to the US 301 bridge (RM 120.5) just below SRS; the lower reach is from that bridge to the US 17 bridge near the river mouth.

Two LANDSAT TM images approximately centered on SRS were purchased from the Earth Observation Satellite Company. They were selected on the basis of growing season and minimal cloud cover. Analysis was by Erdas Imagine (Version 8.1) for geographic rectification, image enhancement, supervised land-use classification, calculation of crop areas, and map production. Three of the seven channels of information -- #3 (620 - 690 nm, red), #4 (760 -900 nm, near infrared), and #5 (1,550 - 1,750 nm, mid infrared) -- were selected for display because they best distinguish the crops of interest. The images were rectified to Universal Transverse Mercator (UTM) coordinates whose source was ArcInfo coverage. The images were corrected to match the files by entering ground control points for readily identifiable locations such as road intersections.

Crop or feature object signatures were obtained by drawing polygons over several sufficiently large areas of known crops or objects depicted in aerial photographs provided by Georgia County Agricultural Surveillance and Conservation Services. Features included surface water, forests, forested wetlands, grasses, bare soil, clay, urban areas, cloud cover, and cloud shadows. The signatures are the reflection intensities in the utilized spectral regions. Signatures for the analyzed crops are listed in Table 1 on a scale of 0 to 1; all other signatures are listed in the report by Twining et al. (1998). These signature categories were used to divide the images into land cover classifications.

Acceptance or rejection of a crop signature was based on two statistical tools in Erdas Imagine. The first is a tool that produces a histogram for each reflectance band used as signature. A crop is recognized if clustered pixels

yield a distinctive single peak resembling a normal distribution curve with small coefficient of variation. Histograms that form broad or multiple peaks indicate badly defined or mixed ground covers. The second, "Feature Space Tool", permits plotting one reflectance band value against another for each pixel. Clusters at one location on the graph represent a particular ground cover class, while intermingling of pixels from two or more classes suggests difficulty in separating them. The statistics of the analyses provide the degree of reliability of these classifications.

Each pixel was given a distinguishing class color in the classified images, and the number of pixels per class was tabulated to calculate the area. The two images were analyzed separately and in merged form, but the merged images did not provide any enhanced information for the crops of interest. Based on crop planting and harvesting information, data for wheat, oats, and rye were taken from the May image; data for all other crops discussed below are from the September image.

The images were matched to the circular grid that SRS uses to calculate deposition of airborne radioactive materials and the resulting radiation doses to individuals and the population. The area devoted to each foodstuff class in each of 64 sections was calculated. Because the individual wheat, oats, and rye classes and the individual apple, peach, and pecan classes were not clearly distinguishable according to the statistics of analysis, they were merged into a grain class and a fruit tree class, respectively.

The tabulation of crop classes per grid section was compared with the data calculated from county statistics for the same section. No comparisons were performed for sections that had cloud cover over 25%, and for classes whose image analysis was highly uncertain. Such uncertainty was introduced by heavily watered grasses relative to certain crops, and for fruit orchards that had extensive grassy areas.

Results and Discussion

The summary of survey findings within 5 km of the SRS boundary, in Table 2, shows that persons live so close to the boundary in several directions that calculations of radiation doses at the boundary by various pathways are appropriate. Some home vegetable gardens that can constitute an ingestion pathway are located near the boundary, as are some individual beef cattle and milk cows. The nearest dairy to be considered for the milk intake pathway is 2.1 km NW.

County data made available for major crops and other foods by South Carolina and Georgia Agricultural Statistic Services were aggregated in Table 3 for the 80-km region around SRS. For brevity, only the total amounts, ranges of yields, and USDA mass conversions are listed here. The areas for the four crops also determined by satellite image analysis are tabulated by grid section in Tables 4a - 4d; areas for all other crops are given by Twining et al. (1998). Crop production was calculated from the area harvested and yield values reported by the state agencies.

Also given in Table 3 are the estimated annual fish catch from the reaches of Savannah River near SRS and downstream, and the estimated deer kill by hunters in the 80-km region. The fish catch is based on a creel survey. The deer kill is a number derived from compiled hunters' reports in some nearby Georgia counties and hunt club reports within this region in South Carolina. Values were not available for other game, such as rabbits, wild pigs and birds.

Inquiries at food stores (super markets, the Augusta Farmers' market, and roadside stands), a dairy, and a meat packing plant indicated that most crops, milk, eggs, meat and poultry from sources within 80 km of SRS are sold by regional distributors to retailers both outside and within the 80-km range. Comparison with food consumption rates (Hamby 1991) suggests that, by chance, the amounts of milk, eggs, beef, poultry and apples listed in Table 3 that are produced annually within 80 km approximately match intake by the 620,000 persons who live in this area according to the 1990 census. The wheat crop supplies food for considerably more persons, and the fish catch, for fewer.

Hence, persons within 80 km eat some foods produced beyond this area and persons living at greater distances consume some food grown near SRS. Roadside stands sell locally grown fruits and vegetables at harvest time, as well as some from outside the 80-km area. Local supermarkets sell a few locally grown foods, such as pecans, because they are in demand.

Analysis of the two LANDSAT images yielded the features shown in Fig. 2. Corn, soybeans, and peanuts were distinguishable crops. Oats, rye, and wheat could be distinguished as a class ("grains") from other crops. The areas attributed to these 4 categories are listed for each grid section in Tables 4a - 4d.

Cases of misclassification were observed where natural grasses with high water content (e.g., along river banks) and thoroughly watered ornamental vegetation (in lawns, gardens, and golf courses) were attributed to agricultural crops. Fruit tree orchards were misattributed due to confusion with other tree-filled areas or because grass surrounded the trees. Sorghum could not be sufficiently distinguished from grasses. Vegetables could not be identified as a class because of their variety.

The ratios in Tables 4a - 4d of the section area aggregated from county statistics to the section area obtained by analysis of the LANDSAT image are mostly less than unity. The ratios of grains, corn, and peanuts for the individual grid sections are log-normally distributed. Soybeans data appear to combine two log-normal distributions, one for Georgia and the other for South Carolina. Excluded from the calculations of mean ratios were 15 grid sections in which the cited problems in image analysis were known to occur, notably within the cities of Augusta and Aiken. The sections within 16 km of the SRS center were excluded because only slivers of land were outside the site boundary, and slivers of two sections to the north were not on the satellite image.

One correction to be made is that county statistics are for area harvested, while LANDSAT analysis yields the area planted. County agricultural statistics indicated that correction for crop planted but not harvested would increase the median ratio by about 36% for grains, and by 10% for the three other crops.

The median ratios for 49 sections, given below both corrected and uncorrected with the geometric standard deviations (g.s.d.), show that crop areas based on county statistics were only two-thirds of the crop areas based on LANDSAT image analysis, although all are within one standard deviation of unity:

corn	median	0.56	corrected media	0.62	g.s.d.	2.8
soybeans		0.65		0.72		---
grains		0.49		0.67		2.0
peanuts		0.58		0.64		3.0

More detailed examination of the ratios shows that corrected median values for soybeans, grains, and peanuts are closer to unity in Georgia than in South Carolina. They are, respectively, 0.80, 0.78, and 1.12 in 20 sections entirely or mostly in Georgia, compared to 0.40, 0.48, and 0.21 in 25 sections in South Carolina. Only for corn are the values of the median ratios reversed, being 0.50 in Georgia and 0.62 in South Carolina. The generally closer agreement in Georgia may be because Landsat image analysis was calibrated at Georgia sites. Another reason may be that aerial photography used in Georgia yielded better information on crop statistics than the questionnaires used in South Carolina.

A basic problem with county statistics is that they are, at best, approximations when only a part of the county is within the region of interest. The fraction of land planted with these crops within the 80-km region may well exceed the average for counties partially outside this region. County statistics concerning areas planted will inevitably lead to error for a specific section if major non-agricultural features such as rivers, towns and forests are distributed nonuniformly between the entire county and the section.

On the other hand, satellite image analysis can overestimate crop amounts if other categories are included erroneously with the crop of interest. Data on some listed crops were not included here when crop identification was ambiguous.

Conclusions and Recommendations

The information needed to update food pathway information for radiation doses to maximally exposed individuals was obtained by a survey within 5 km of the boundary. The nearest persons and sources of food were located on maps. Information for calculating the collective dose within 80 km was estimated from county crop data supplied by state agencies. Interviews with wholesale and retail food managers indicated that, with minor exceptions, the food grown within this region is mixed with food from other regions, so that only a fraction is consumed locally.

LANDSAT TM satellite images of the SRS environment obtained on two dates were analyzed to locate specific food crops and measure the areas devoted to them. Four food crops could be so located and measured. This source of information is advantageous because it locates each crop in each grid section related to SRS, rather than assuming that county agricultural statistics can be prorated by area for each section in a county.

The prorated county statistics for land devoted to the four food crops yielded only about two-thirds of the areas found by analysis of the LANDSAT images in terms of the geometric means of section ratios. This deviation from unity is within the uncertainty of each of the ratios, but its consistency suggests that county statistics underestimated production areas for these foods.

Analysis of satellite images for crop locations and areas can be particularly useful when combined with crop yield and coupled directly to computer programs to estimate radionuclide deposition and transfer, and radiation dose. It is suggested that the next effort be devoted to image analysis for distinguishing additional crops and determining crop yields. Feasible approaches include obtaining images that have better spatial resolution, classifying crops by using better spectral resolution, analyzing more images for better coordination with crop growth periods, and observing ground truth at the time of image collection.

At SRS, the currently low levels of radionuclides calculated for crops grown near the boundary do not require further efforts to delineate nearby foodstuffs. If radionuclide releases were significantly higher, surveys would be desirable to identify those foods that are both grown and consumed locally, especially crops grown in home vegetable gardens near the site boundary.

Acknowledgments

We thank Dr. Nicholas Faust, Diana Estrada, and Jairo Linares, Georgia Tech Research Institute, for guidance and assistance with the Erdas Imagine and Arcinfo programs; and Larry Snipes, GaASS, Robert Graham and Stephen Pavlasek, SCASS, Richard McDaniel, GaASCS, Allen York, SC ASCS, Todd Holbrook, GaFWS, and Dennis Schmitt, GaWRD for providing information on foodstuffs.

References

- Arnett, M.W.; Mamatey, A.R. Savannah River Site Environmental Report for 1997. Aiken SC. Savannah River Site; USDOE Report WSRC-TR-97-00322; 1998.
- Barrowman, D.W; Witzig, J;, Arends, W.; Buche,J; Frank, D. Scope and methods of the statistical reporting service Washington DC. USDA Miscellaneous Publication 1308; 1983.
- Bellow, M.E. Application of satellite data to crop area estimation at the county level. Washington DC. USDA Report STB-94-02; 1994.
- Hamby, D.M. Site-specific parameter values for the Nuclear Regulatory Commission's food pathway model. Health Phys. 62: 136 - 143; 1992.
- Hamby, D.M. Land and water use characteristics in the vicinity of the Savannah River Site. Aiken SC. Savannah River Site; USDOE Report WSRC-RP-91-017; 1991.
- Palacios, A.F.; Gonzalez, F. Cartography and statistics of crops under irrigation in the Donama area of Andalucia through the use of Landsat TM imagery and its incorporation in a GIS. Munich, Germany. Proceedings of Satellite Symposia 1 and 2, pp. 845 - 850; 1992.

- Thomas, R.W. Utility of remote sensing data in renewable resource sampling survey. Zurich, Switzerland. Proceedings of IGARS Symposium, pp. 755 - 758; 1986.
- Twining, S.; Strydom. J.; Rosson, R.; Kahn, B. Foodstuffs Monitoring at SRS. Environmental Resources Center Report, Georgia Institute of Technology, Atlanta GA 30332-0335; 1998.
- van de Steene, M.; Delince, J.; Lepoutre, D. Image treatment and geographical information systems at the service of the common agricultural policy. Munich, Germany. Proceedings of Satellite Symposia 1 and 2, pp. 281 - 285; 1992.

Table 1. Spectral signatures for food categories

Foodstuff		Reflectance (between 0 and 1)		
	Wave length, nm:	1550-1750	760-900	620-690
May Image				
Oats		0.596	0.927	0.775
Rye		0.612	0.913	0.804
Wheat		0.544	0.854	0.731
September Image				
Apple trees		0.673	0.709	0.682
Pecan trees		0.655	0.610.	0.617
Sorghum		0.838	0.618	0.661
Corn		0.771	0.996	0.868
Peanuts		0.982	0.719	0.733
Soybeans		0.909	0.600	0.659

Table 2. Dwellings and other features within 5 km of site boundary

Sector	Number of residential dwellings	Number of vegetable gardens	Number of commercial buildings	Number of livestock or dairy	Nearest residential dwelling(km)	Nearest vegetable garden(km)	Nearest livestock or dairy (km)
N	34	0	0	1	0.9	NA	3.0
NNE	92	2	3	4	0	2.4	0.3
NE	75	1	3	0	0	0.05	--
ENE	118	2	2	4	0.1	1.5	0.4
E	218	5	2	6	0.9	0.9	3.0
ESE	112	6	4	1	0	0.3	1.8
SE	89	3	2	4	0.05	4.8	0.3
SSE	56	0	2	9	0.3	NA	1.0
S	2	0	0	0	0.6	NA	--
SSW	37	1	2	5	1.5	1.5	2.4
SW	42	0	5	0	0.6	NA	--
WSW	123	0	4	2	0.9	NA	2.9
W	15	0	7	0	3.0	NA	--

WNW	876	62	61	0	0	0.1	--
NW	511	11	16	9(1)*	0	0.1	0.2(2.1)*
NNW	1,794	7	113	13	0	0.3	0.2
Total	4,194	100	226	58			

*Dairy location
NA: No gardens

Table 3. Foods within 80 km of SRS according to agricultural statistics

Item	Amount	Yield	Mass, kg/amount
Milk	9.40E+07 kg		
Eggs	2.00E+08		
Beef	1.13E+05		110.
Poultry	5.01E+07		
Hogs	1.23E+05		
Fish (lower reach)*	100,000		0.45
Fish (higher reach)*	38,100		0.23
Deer*	1.60E+05		
Apples	1.49E+06 kg	2.7 kg/m^2	
Corn	1.06E+07 bushels	0.014-0.032 bu/m^2	25.4
Oats	9.90E+05 bushels	0.014-0.020 bu/m^2	16.3
Peaches	4.78E+07 kg	0.71-1.36 kg/m^2	
Peanuts	4.06E+07 bushels	0.21-0.45 bu/m^2	
Rye	4.29E+05 bushels	0.0050-0.0076 bu/m^2	25.4
Sorghum	1.24E+05 bushels	0.0087-0.013 bu/m^2	25.9
Soybean	4.85E+06 bushels	0.0059-0.0078 bu/m^2	25.4
Wheat	4.97E+06 bushels	0.0098-0.0132 bu/m^2	26.3
Vegetables	4.14E+07 m^2		

* Data from surveys (see procedure section)