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April 8, 2010

Richard R. Bonczek, PhD.
U. S. Department of Energy
1017 Majestic Drive
Lexington, KY 40513

Subject: **FINAL AERIAL RADIOLOGICAL SURVEY REPORT OF THE PADUCAH GASEOUS DIFFUSION PLANT, PADUCAH, KENTUCKY**

Enclosed are seven copies of the final Remote Sensing Laboratory (RSL) summary report of the aerial radiological survey of the Paducah Gaseous Diffusion Plant. Also enclosed is two CD's entitled "An Aerial Radiological Survey of the Paducah Gaseous Plant, October 2009" which includes an electronic copy of the summary report and Meta data files.

The reports will be distributed as follows: One bound copy report and one CD to your office; six bound copy reports and one CD to the Paducah office to the attention of Mr. Craig Jones of the Paducah Remedial Services (PRS) office.

We appreciate the excellent relationship we have garnered with you and PRS and for the opportunity that RSL Aerial Measuring System (AMS) teams from Nellis and Andrews Air Force Base locations to support your organization

Should you require additional information, please contact Karen McCall, AMS Section Manager, at (702) 295-8089.

Brent K. Park
Director
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BKP:ead

Enclosure: as stated

See page 2 for cc's

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An Aerial Radiological Survey of the Paducah Gaseous Diffusion Plant and Surrounding Area

Survey Dates: October 28–November 2, 2009

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DOE/NV/25946—931
April 2010

An Aerial Radiological Survey of the Paducah Gaseous Diffusion Plant and Surrounding Area

Paducah, Kentucky

Survey Dates: October 28–November 2, 2009

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This document is UNCLASSIFIED

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ABSTRACT

An aerial radiological survey was conducted over the Paducah Gaseous Diffusion Plant (PGDP) and surrounding area in Paducah, Kentucky. The purposes of the survey were to 1) measure the terrestrial radiological environment within and around the PGDP in order to update previous radiological survey data from 1976 and 1990, and 2) provide information that will be used in the radiological verification for the PGDP's remedial closure effort. The survey was performed from October 28–November 2, 2009 utilizing a large array of helicopter-mounted sodium iodide gamma-ray detectors. The aerial survey was flown at an altitude of 150 feet (~46 meters) along a series of parallel lines spaced 250 feet (~76 meters) apart and encompassing an area of 24 square miles (62 square kilometers), bordered on the north by the Ohio River.

The results of the aerial survey are reported as implied exposure rate, man-made activity, and depleted uranium activity, which are presented in the form of contour maps superimposed on imagery of the surveyed area. Exposure rate measurements were acquired using a pressurized ionization chamber at 10 specific locations on the ground to validate the data derived from the aerial measurements.

Throughout most of the surveyed area, the detected radioisotopes and their associated gamma-ray exposure rates were consistent with those expected from normal background emitters. At specific locations within the PGDP, man-made activity was detected that was consistent with the operational history of the plant. In particular, protactinium-234m, a radioisotope indicative of uranium-238, was detected within the PGDP. The aerial survey data indicated no anomalies outside of the depleted uranium cylinder yards.

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ACRONYMS AND ABBREVIATIONS

AGL	above ground level
AMS	Aerial Measuring System
cps	counts per second
DGPS	Differential Global Positioning System
DOE	U.S. Department of Energy
DU	depleted uranium
ER	exposure rate
K-40	potassium-40
MMGC	man-made gross counts
NaI(Tl)	thallium-doped sodium iodide
NIST	National Institute of Standards and Technology
NORM	naturally occurring radioactive material
Pa-234m	protactinium-234m
PC-REDAC	PC-based Radiation and Environmental Data Analysis Computer
PGDP	Paducah Gaseous Diffusion Plant
PIC	pressurized ionization chamber
RA	radar altimeter
RF	radio frequency
REDAR-V	Radiation and Environmental Data Acquisition and Recorder, Version V
ROI	region of interest
RSL	Remote Sensing Laboratory
µR/h	microroentgens per hour

1. Introduction

At the request of the U.S. Department of Energy (DOE), an aerial radiological survey of the Paducah Gaseous Diffusion Plant (PGDP) in Paducah, Kentucky, was conducted from October 28–November 2, 2009. The survey covered a region of approximately 4 × 6 miles (~6.4 × 9.7 kilometers) for a total area of 24-square miles (~62-square kilometers) surrounding the Paducah plant. This region encompassed the PGDP, the West Kentucky Wildlife Management Area, and the nearby area extending north to the Ohio River. The survey was conducted by a team from the DOE National Nuclear Security Administration's Remote Sensing Laboratory (RSL), which is maintained and operated by National Security Technologies, LLC, at Nellis Air Force Base in Las Vegas, Nevada and Andrews Air Force Base, Maryland.

Radiological surveys of the PGDP were conducted in 1976[1] and 1990[2]. The purpose of those surveys was to determine the extent to which plant operations may have impacted the radiological signature of the plant surroundings. The purposes of the current survey were to (1) update the results of those earlier surveys to determine changes in the radiological signature of the PGDP and adjacent areas, and (2) provide information that will be used in the radiological verification for the PGDP's remedial closure effort. The RSL aerial survey data is presented in the form of contour maps superimposed on imagery of the surveyed area, which provide the gamma-ray exposure rates (ER) attributable to natural and man-made radionuclides.

The data were collected by the Aerial Measuring System (AMS) Radiation and Environmental Data Acquisition and Recorder, Version V (REDAR-V) using an array of twelve 2" × 4" × 16" sodium iodide detectors flown onboard a twin-engine Bell 412 helicopter. The data were geo-referenced using a differential Global Positioning System (DGPS). Gamma-ray energy spectra were collected continuously each second during the survey. This spectral data provides the capability to distinguish between ordinary fluctuations in natural background radiation levels and radiological signatures produced by man-made radioactive sources. Spectral data can also be used to identify specific radioisotopes and produce isotope-specific contour maps.

The current survey data is in general agreement with previous surveys of the PGDP and surrounding area[1, 2]. However, the anomalous radiation area detected outside the plant boundary during the 1990 survey[2] was not observed in the current survey because the NRC-licensed facility operating at that location in 1990 has since been decommissioned.

2. Survey Site Description

The PGDP, which is leased and operated by the United States Enrichment Corporation, is the only operational uranium enrichment facility in the United States. The plant is located on a large, government-owned reservation 4 miles (~6.4 kilometers) south of the Ohio River and 15 miles (24 kilometers) west of the city of Paducah, Kentucky. The PGDP is contained in a 1.2 square-mile (~ 3 square-kilometers) fenced area with an average elevation of approximately 375 feet (~114 meters) above sea level. The West Kentucky Wildlife Management Area borders the PGDP to the west, and the area surrounding the plant is primarily forest and farm land with some residential development to the east of the plant.

3. Survey Procedure

3.1 Aerial Survey

The aerial survey collected gamma radiation data over a 24-square mile (~62-square kilometer) area around the PGDP. The primary roads servicing the facility, as well as the facility perimeter, were taken into consideration when defining the survey boundaries.

The area was surveyed at a nominal ground speed of 70 knots (~36 meters per second) and a nominal altitude of 150 feet (~46 meters) above ground level (AGL). Parallel sets of flight lines spaced 250 feet (~76 meters) apart were flown. Due to flight restrictions over the PGDP, the survey area was broken into four regions, as shown in Figure 1. For the regions to the north and south of the restricted flight zone, the flight lines were flown in roughly an easterly or westerly direction. Conversely, the flight lines were flown in a generally northerly or southerly direction for the regions to the east and west of the restricted area. To assure data integrity and to monitor/correct for variations in detector background count rate due to aircraft, radon, and cosmic rays, measurements were made over a fixed test line and water line before and after each flight. The fixed test line was located along Ogden Landing Road, which is outside the eastern boundary of the survey area, and the fixed water line was over the Ohio River just to the northeast of the survey area.

3.2 Ground-Based Measurements

Ground-based pressurized ionization chamber (PIC) measurements were acquired at 10 locations within the survey area and two locations along the fixed test line. These measurements were taken to provide comparative exposure rates and support the integrity of the aerial data. The PIC measurements were averaged over a period of approximately 5 minutes at a height of 1 meter AGL.

Figure 1: Survey Setup for PGDP Aerial Survey. (The open region in the center of the survey area was a restricted flight zone.)

4. Survey Equipment

4.1 Aerial Survey

The aerial survey was conducted using AMS detection assets. The AMS detection system consists of a Bell-412 helicopter, a REDAR-V system, a Trimble DGPS and two large detector pods externally mounted on each side of the helicopter. Each pod contains six 2″ × 4″ × 16″ thallium-doped sodium iodide, NaI(Tl), gamma-ray detectors.

4.1.1 Data Recording

The preamplifier signal from each detector was calibrated using naturally occurring potassium-40 (K-40) and americium-241 (Am-241) gamma check sources. Normalized outputs from the 12 detectors were combined in a summing amplifier, and the signal was adjusted in the analog-to-digital converter so that the calibration photopeaks appeared in preselected channels in the REDAR-V multichannel analyzer. The data from the multichannel analyzer were used to produce time-stamped records that contain the number of gamma rays detected at each specific energy (channel) for each one-second sample. Each record, therefore, constitutes a geo-referenced gamma-ray spectrum. As every radioactive material, natural or man-made, has its own unique set of gamma rays, the spectra can be used to identify and distinguish the nature of the detected gamma radiation.

The REDAR-V, which produces the gamma-ray spectra described above, is a multi-processor data acquisition and real-time analysis system custom-designed by the RSL to operate in the severe environments associated with platforms such as helicopters, fixed-wing aircraft, and various ground-based vehicles. The system displays radiation and positional information to the operator in real time via video displays and multiple digital readouts. Gamma-ray spectra, aircraft position, meteorological parameters, real-time clock, and other data reference information are recorded at one-second intervals on digital data storage devices for post-flight analyses.

4.1.2 Helicopter Positioning

The helicopter's position was established by using two systems: a Trimble DGPS (utilizing OmniSTAR differential corrections) and a radar altimeter (RA). The DGPS provides continuous position information (latitude and longitude) using a constellation of satellites. The DGPS has a horizontal positional accuracy (1 sigma) of ±1 meter (3 feet). The RA determines the helicopter's altitude above the present terrain by measuring the round-trip propagation time of a RF signal reflected off the ground. The manufacturer's nominal accuracy of the RA is quoted as 2 feet or 2%, whichever is greater.

4.1.3 Data Processing

For each flight, the aerial survey data were downloaded into the PC-based Radiation and Environmental Data Analysis Computer (PC-REDAC) software package for processing. This RSL in-house-developed software package provided onsite preliminary analysis of the aerial data on a flight-by-flight basis and monitored pre- and post-flight quality assurance checks.

4.2 Ground-Based Measurements

Ground level exposure rates were measured at the PGDP using a portable, battery-powered Reuter-Stokes pressurized ion chamber (PIC) calibrated to the National Institute of Standards and Technology (NIST) standards. This instrument incorporates a 10-inch (25-centimeter) diameter metal sphere filled with 25 atmospheres of argon gas, a high voltage bias supply, an electrometer, and readout components. This unit has a sensitivity of approximately 3×10^{-14} amps per microroentgens per hour (µR/h) and has the capability of digitally and graphically displaying the total exposure rate data. The ground measurements were compared to the exposure rates inferred by the aerial measurements to validate the data analysis.

5. Analysis Procedures

5.1 Aerial Data Analysis

The photon radiation signal measured by the REDAR-V system is comprised of contributions from the naturally occurring terrestrial radionuclides, man-made radionuclides, naturally occurring airborne radon, cosmic rays, and trace amounts of radioactive materials present onboard the aircraft. Aerial data analysis techniques are used to distinguish and quantify each of these constituents using the measured radiation data. This section briefly describes some of the fundamental methodologies used to generate the data products for the aerial survey of the PGDP. The primary data products consist of contour maps overlaying satellite imagery of the survey area which depict the type and quantity of radiation sources present in the PGDP and surrounding area. Also included are the measured spectral signatures associated with radiological anomalies that were observed. These spectra indicate the source of the radiation giving rise to these anomalies.

5.1.1 Terrestrial Gamma Gross Count Rate

The terrestrial gamma gross count rate (GC_{terr}) is obtained by subtracting the estimated radon, cosmic, and aircraft contributions from the REDAR-V measured count rate. The remaining detected activity is then due to radioisotopes lying on or in the ground. A flight line over water conducted at the beginning and end of each survey flight provides an estimate of the count rate due to non-terrestrial sources. This water line is subsequently subtracted from the measured detection rate on a second-by-second basis. Additionally, a test line over an easily identified land feature is flown at the

start and end of each survey flight. This test line data is used to account for flight-to-flight variations, such as differences in the moisture content in the ground, and may be written as a scale factor appearing in the equation for GC_{terr}:

$$GC_{terr} = f\left(GC_{tot} - B_{wl}\right) \tag{1}$$

where

GC_{terr} = terrestrial gamma gross count rate from 38 to 3026 keV (cps)
f = inter-flight variability scale factor (unitless)
GC_{tot} = total measured count rate from 38 to 3026 keV (cps)
B_{wl} = water-line count rate measured from 38 to 3026 keV (cps).

The terrestrial gamma gross count rate is used as an indication of the presence of radiation on or in the vicinity of the ground throughout the survey area. This simple algorithm does not take into account natural fluctuations in background, nor does it yield information on the nature of radiation sources giving rise to the detector response. The algorithm is nonetheless effective for determining regions within the survey area where further analysis should be performed.

5.1.2 Man-Made Gross Counts

Naturally occurring radioactive materials (NORM) are present in the environment throughout the world. Because these materials are found in the soil, rocks, and building materials, the background radiation level associated with their presence may fluctuate significantly in different geographic locations. The man-made gross counts (MMGC) algorithm is a two-window extraction algorithm that is designed to suppress the natural variations in background radiation levels. This algorithm takes advantage of the fact that while background radiation levels may vary by a factor of two or more within a survey area, the background spectral shape remains relatively stable. More specifically, the ratio of natural components in any two regions (windows) of the energy spectrum will remain nearly constant.

In order to increase the sensitivity to detect man-made anomalies, the MMGC algorithm utilizes spectral energy extraction techniques. Application of the MMGC algorithm yields the portion of the gross counts that are directly attributable to gamma rays emitted from man-made radionuclides. In practice, virtually all man-made radioisotopes appear below 1394 keV in the gamma-ray energy spectrum. This is in contrast to the naturally occurring radioisotopes, which occur throughout the energy spectrum up to 3026 keV. The MMGC rate is calculated by integrating the detector response from 38 to 1394 keV and subtracting the NORM contribution, which is determined by taking a scaled response from the energy window extending from 1394 to 3026 keV. The *MMGC* rate can be expressed analytically in terms of the integrated count rates in these spectral windows:

$$MMGC = \sum_{E=38\text{keV}}^{1394\text{keV}} S(E) - K_{mm} \cdot \sum_{E=1394\text{keV}}^{3026\text{keV}} S(E) \tag{2}$$

$$K_{mm} = \left. \frac{\sum_{E=38\text{keV}}^{1394\text{keV}} S(E)}{\sum_{E=1394\text{keV}}^{3026\text{keV}} S(E)} \right|_{Background} \tag{3}$$

where

$MMGC$ = man-made gross count rate (cps)

$S(E)$ = measured energy dependent count rate (cps)

K_{mm} = mean energy window ratio, measured in area with only NORM (unitless).

This MMGC algorithm is sensitive to low levels of man-made radiation even in the presence of large variations in the natural background. In regions of background radiation the algorithm yields a distribution of values statistically centered about zero. When man-made radioactivity is indicated a detailed analysis of the gamma energy spectrum is conducted to ascertain which particular radionuclides are present.

5.1.3 DU-Specific Isotope Extraction Algorithm

As a decay product of uranium-238 (U-238), protactinium-234m (Pa-234m) is indicative of depleted uranium (DU, or U-238). Two common gamma rays emitted by Pa-234m result in photopeaks at 766 keV and 1,001 keV in the measured gamma-ray energy spectra. The variable natural background also contributes to these photopeaks, but a spectral extraction algorithm can remove the variable background contribution in a second-by-second operation. The DU-specific extraction algorithm employed for the PGDP survey may be written as:

$$DU = \sum_{E=936\text{keV}}^{1124\text{keV}} S(E) - K_{DU} \cdot \sum_{E=1140\text{keV}}^{1320\text{keV}} S(E) \tag{4}$$

$$K_{DU} = \left. \frac{\sum_{E=936\text{keV}}^{1124\text{keV}} S(E)}{\sum_{E=1140\text{keV}}^{1320\text{keV}} S(E)} \right|_{Background} \tag{5}$$

where

DU = net photopeak count rate from the 1001 keV photon arising from Pa-234m (cps)

$S(E)$ = measured energy dependent count rate (cps)

K_{DU} = mean energy window ratio, measured in area with only NORM (unitless).

The DU-specific extraction algorithm yields the net count rate in the 1001 keV photopeak. The net photopeak is obtained using a time-varying continuum subtraction that is formed by the background energy window extending from 1140 to 1320 keV. This window is selected to provide a satisfactory estimate of the baseline continuum while remaining unaffected by presence of depleted uranium. The DU extraction algorithm yields a statistical distribution of counts centered about zero in regions of NORM only. If a statistically significant amount of DU is present, its activity will be indicated as an anomaly outside the statistical bounds associated with the natural background activity.

5.1.4 Terrestrial Exposure Rate

One way of quantifying the total radiation level present in an environment is through use of the gamma exposure rate, which is related to the amount of charge separation in air created by the passage of ionizing radiation. The terrestrial exposure rate at ground level may be derived from the integral count rate in the gamma energy spectrum range between 38 and 3,026 keV. The terrestrial gamma gross count rate, measured in cps at survey altitude, is converted to exposure rate in µR/h at 1 meter AGL using the following equation:

$$ER = \frac{GC_{terr}}{C} \cdot e^{\mu(z - z_0)} \tag{6}$$

where

ER = derived exposure rate at ground level for sample (µR/hr)

GC_{terr} = terrestrial gamma gross count rate from 38 to 3026 keV from Eq. (1) (cps)

C = exposure rate conversion factor at nominal survey altitude (1712 cps/µR/hr)

μ = gamma ray air absorption coefficient (0.00176 ft^{-1})

z = actual altitude for sample (feet)

z_0 = nominal altitude for survey (feet).

The exponential appearing in Eq. (6) accounts for detector sensitivity changes associated with slight variations in the aircraft's altitude. The air absorption coefficient (μ) was determined from test line data at multiple altitudes to be 0.001761 $feet^{-1}$ (0.005778 $meter^{-1}$). The conversion factor (1,712 cps/µR/h) for 150 feet (46 meters) AGL was determined from documented calibration test lines located in Calvert County, Maryland[3]. The conversion factor assumes a uniformly distributed radiation source; i.e., 1) covering an area that is large in comparison with the field of view of the

detector system (a circle with a diameter roughly twice the altitude of the aircraft), and 2) having a gamma-ray energy distribution similar to that of the natural background of the calibration test line.

5.2 Ground-Based Measurements

A PIC is a device that directly measures the gamma exposure rate. Using a PIC, the gamma exposure rate at a height of 1 meter AGL was measured at 10 locations within the survey area and two locations along the test line. Most of these locations were not near any obvious radiation anomalies. The PIC measurements were collected to perform validation of the exposure rates inferred from the aerial data. A PIC measurement inherently includes contributions from airborne radon and cosmic rays. For direct comparison to aerial data, it is therefore necessary to account for these non-terrestrial contributions.

Given a sufficiently large data set, PIC measurements may be used to derive the exposure rate conversion factor appearing in Eq. (6). Such a procedure was outside the scope of the current survey. Instead, calibration data taken in a similar geographic location were used, and the PIC measurements collected at the PGDP were used to validate this assumption.

6. Results

6.1 Terrestrial Gamma Gross Counts Contour Map

Processing of the aerial measurement data removes radiological contributions from cosmic rays, radon, and the aircraft. The resulting gross counts are then due to terrestrial background radiation or man-made radioisotopes. The terrestrial gross count rate over the PGDP survey area, measured in counts per second at survey altitude, is shown in Figure 2.

The locations of five regions of interest (ROIs) are also indicated in Figure 2. The ROI labeled as “Background” is the region from which a representative spectrum of the terrestrial background was extracted. ROIs 1, 2, and 3 correspond to areas of elevated radiation levels where further spectral analysis was performed. ROI 4 is a region outside the plant boundary in which elevated radiation levels were detected during the 1990 survey[2] but were not observed in the current survey because the NRC-licensed facility operating at that location in 1990 has since been decommissioned.

6.2 Man-Made Gross Counts Map

The MMGC algorithm (discussed in the Section 5.1.2) was used to analyze the aerial data for man-made radionuclides in the survey area. The activity attributable to gamma radiation from man-made radioisotopes is shown on the MMGC map (Figure 3) with the variable natural background component removed. The magnitude of the count rates provides an indicator of the relative intensities for the radiation sources. There is evidence of elevated man-made radiation in ROIs 1, 2, and 3, as suggested

by the spectra in Figure 6. Note that the anomalous MMGC radiation area that was detected outside the plant boundary during the 1990 aerial survey[2] was not observed in the current survey (ROI 4).

6.3 DU (Pa-234m) Extracted Isotope Counts Map

The Pa-234m specific isotope extraction algorithm (discussed in Section 5.1.3) was used to analyze the aerial data for radiological signatures of DU. The activity due to Pa-234m is shown in Figure 4 with the variable natural background component subtracted. As with the MMGC, the magnitude of the count rates provides an indicator of the relative intensities for the radiation sources. The locations of elevated Pa-234m activity correspond to the cylinder yards (i.e., areas with cylinders containing DU) adjacent to the PGDP facilities.

6.4 Exposure Rate Contour Map

The terrestrial gamma exposure rate at 1 meter AGL inferred from the aerial data is shown in Figure 5 in the form of a contour map superimposed on imagery of the survey area. Using current processing techniques, data from the 1990 radiological aerial survey was reprocessed, and the results are included for comparison purposes. This ER map indicates elevated levels of radiation at the locations identified as cylinder yards within the plant. Over most of the survey area, the inferred terrestrial exposure rates are less than 7 µR/h and are typical for natural background in the Paducah area[4]. These background exposure rates are in good agreement with previous survey data[1, 2]. The exposure rates inferred at the cylinder yards confirm some changes in the configuration of the storage areas have occurred since the 1990 aerial survey[2]. In particular, the footprint of the elevated terrestrial exposure rate region at the southern cylinder yard has increased since 1990, while that of the western cylinder yard has decreased. Additionally, near the river on the northern side of the survey area, the low-lying regions give rise to low terrestrial exposure rates due to the presence of water. This effect is amplified in the current data due to high water levels resulting from precipitation during the survey period.

6.5 Net Spectral Extractions

For each anomaly observed on the GC contour map shown in Figure 2, a net-energy spectrum was produced by subtracting an appropriately scaled background spectrum from the measured energy spectrum associated with the spatial ROI. Spectral data extracted from the background region as well as net spectra corresponding to ROIs 1, 2, and 3 are shown in Figure 6. The representative background spectrum shown is indicative of the NORM present in this region. The origins of some of the prominent peaks are labeled for reference. The spectra from ROIs 1–3 clearly indicate the presence of Pa-234m. This is in agreement with the known operational history of the PGDP and previous surveys[1, 2].

6.6 Ground-Based Measurements

Ground-based PIC measurements are compared with the inferred aerial exposure rates in Figure 7. The ground-based point data is displayed as an overlay on the inferred exposure rate contour map. An estimated cosmic ray contribution[5] of 3.7 μR/h has been subtracted from the ground-based PIC measurements for comparison to the exposure rate inferred from the aerial data. It should be noted that the PIC measurements still include a radon contribution. The differences between PIC and aerial measurements are quite acceptable, being a maximum of 1.5 μR/h for background regions. The measurement taken in the region of high man-made activity is not expected to compare well, since the aerial system and the ground system have significantly different measurement footprints. The data confirms the exposure rate conversion factors used in the survey. The PIC measurements are tabulated and included in Appendix B.

7. Summary

An aerial radiological survey of the Paducah Gaseous Diffusion Plant and surrounding areas was conducted between October 28 and November 2, 2009. The gross count rate, terrestrial gamma exposure rate, man-made activity, and DU activity for the PGDP and surrounding area were documented. The aerial data were benchmarked to ground measurements and shown to match within the uncertainties involved. No significant man-made gamma activity was detected outside the boundary of the PGDP. Within the plant boundary the current survey indicates changes to the configuration of the depleted uranium cylinder yards since the 1990 aerial radiological survey documentation.

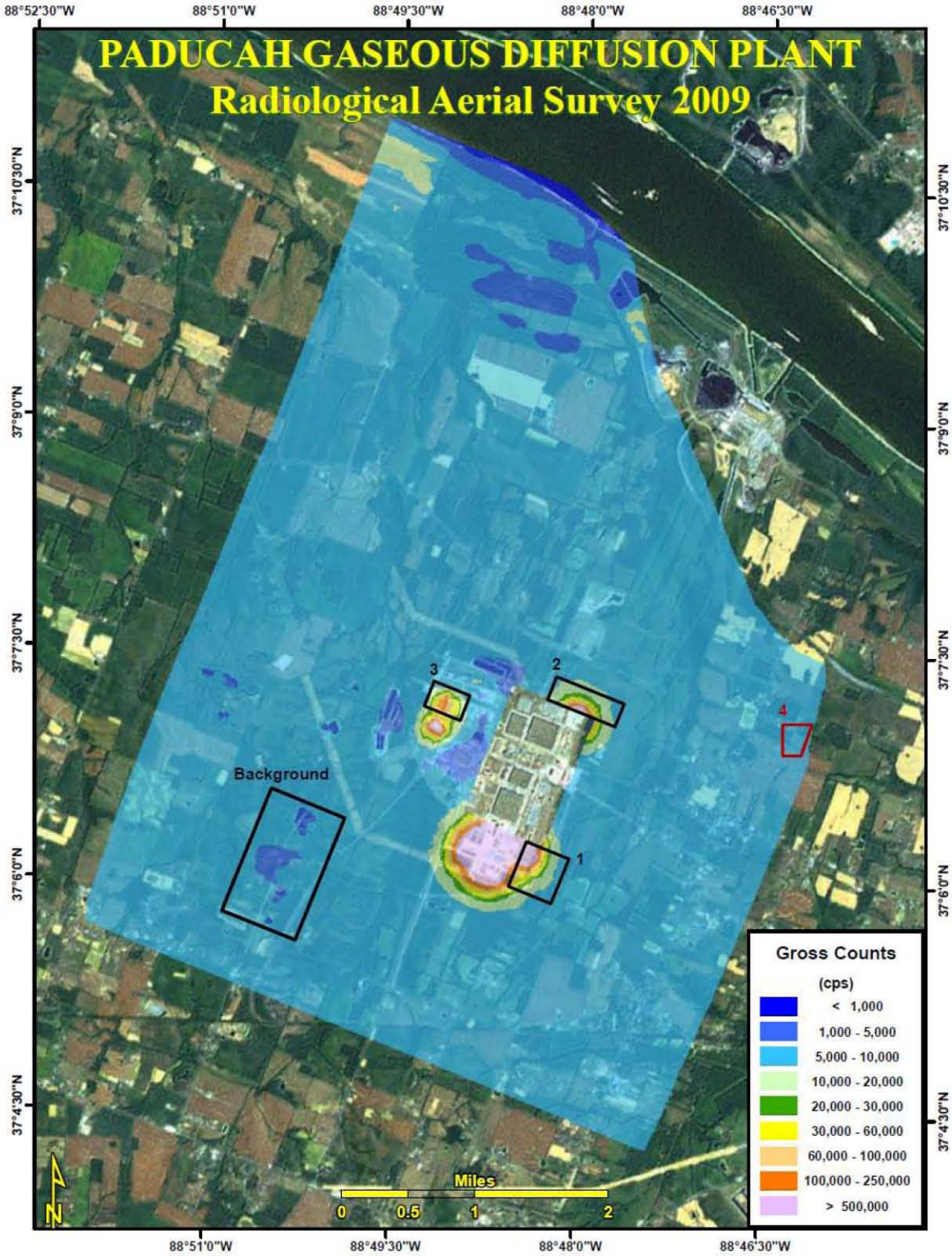

Figure 2: Gross Counts Contour Map with Regions of Interest Indicated.

ROIs 1-3 are areas of elevated radiation levels where further spectral analysis was performed. ROI 4 is a region in which elevated radiation levels were detected during the 1990 survey[2]. This anomaly was not observed in the current survey because the NRC-licensed facility operating at that location in 1990 has since been decommissioned.

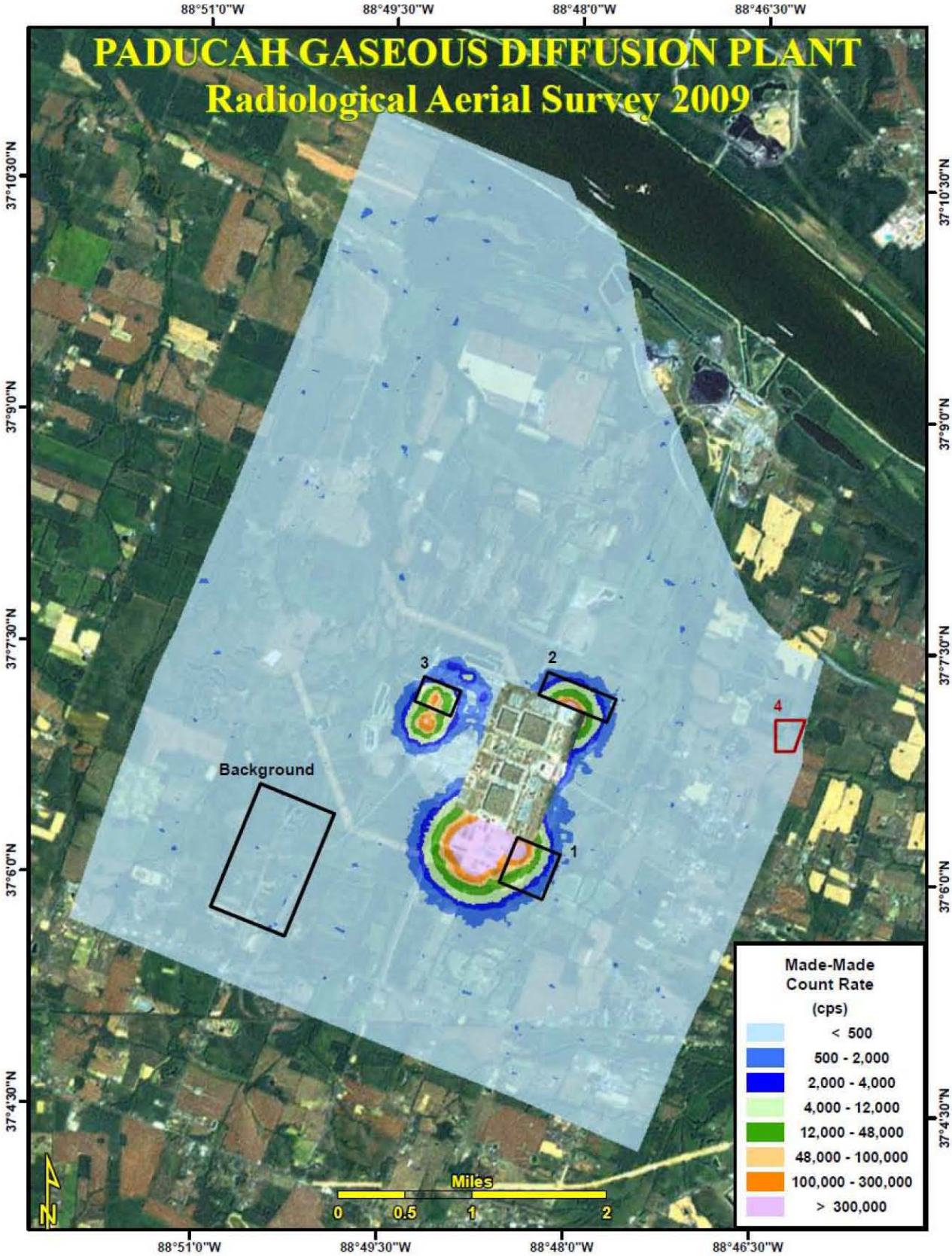

Figure 3: MMGC Count Rate Map with Regions of Interest Indicated (as in Figure 2).

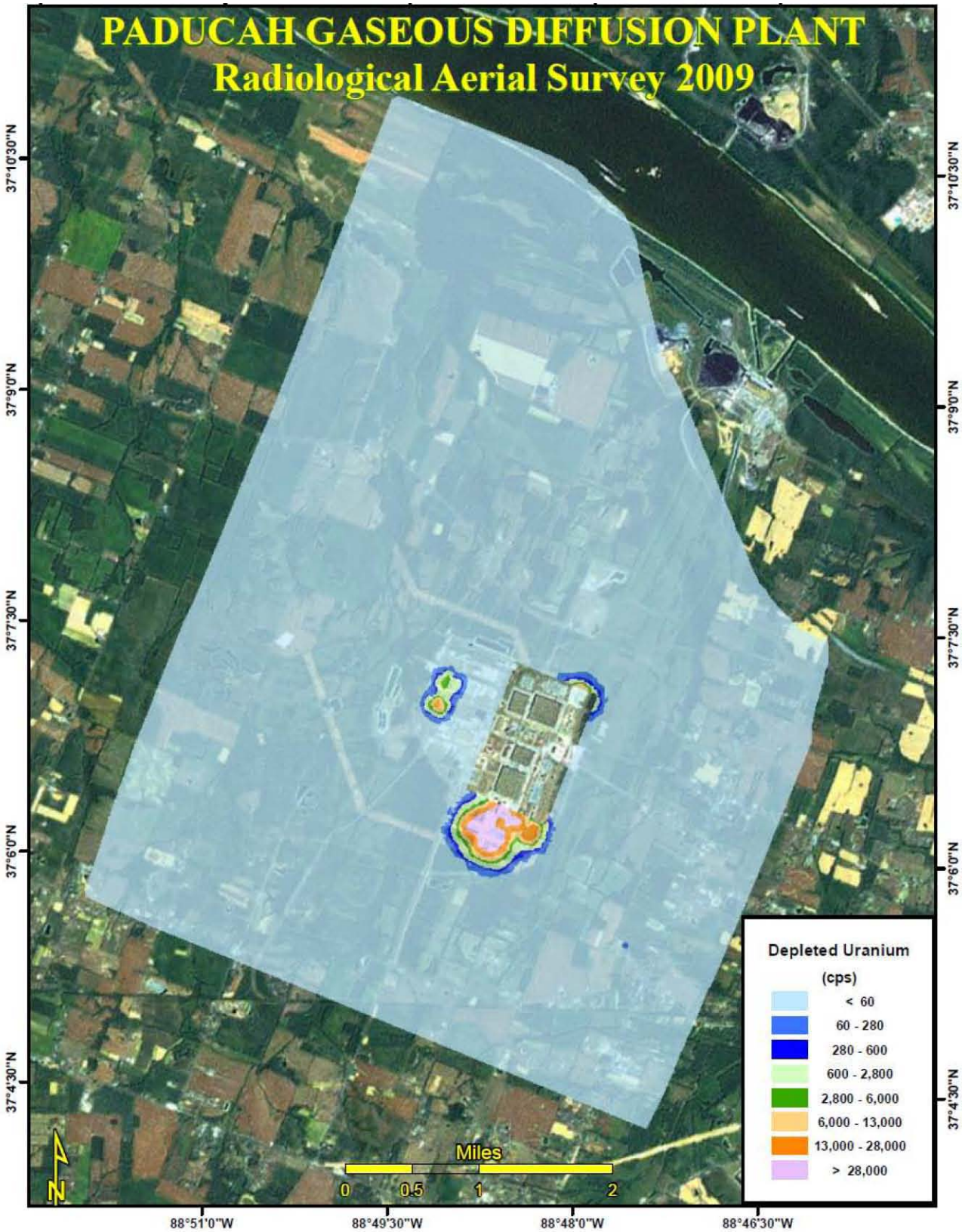

Figure 4: DU Extraction Count Rate Map

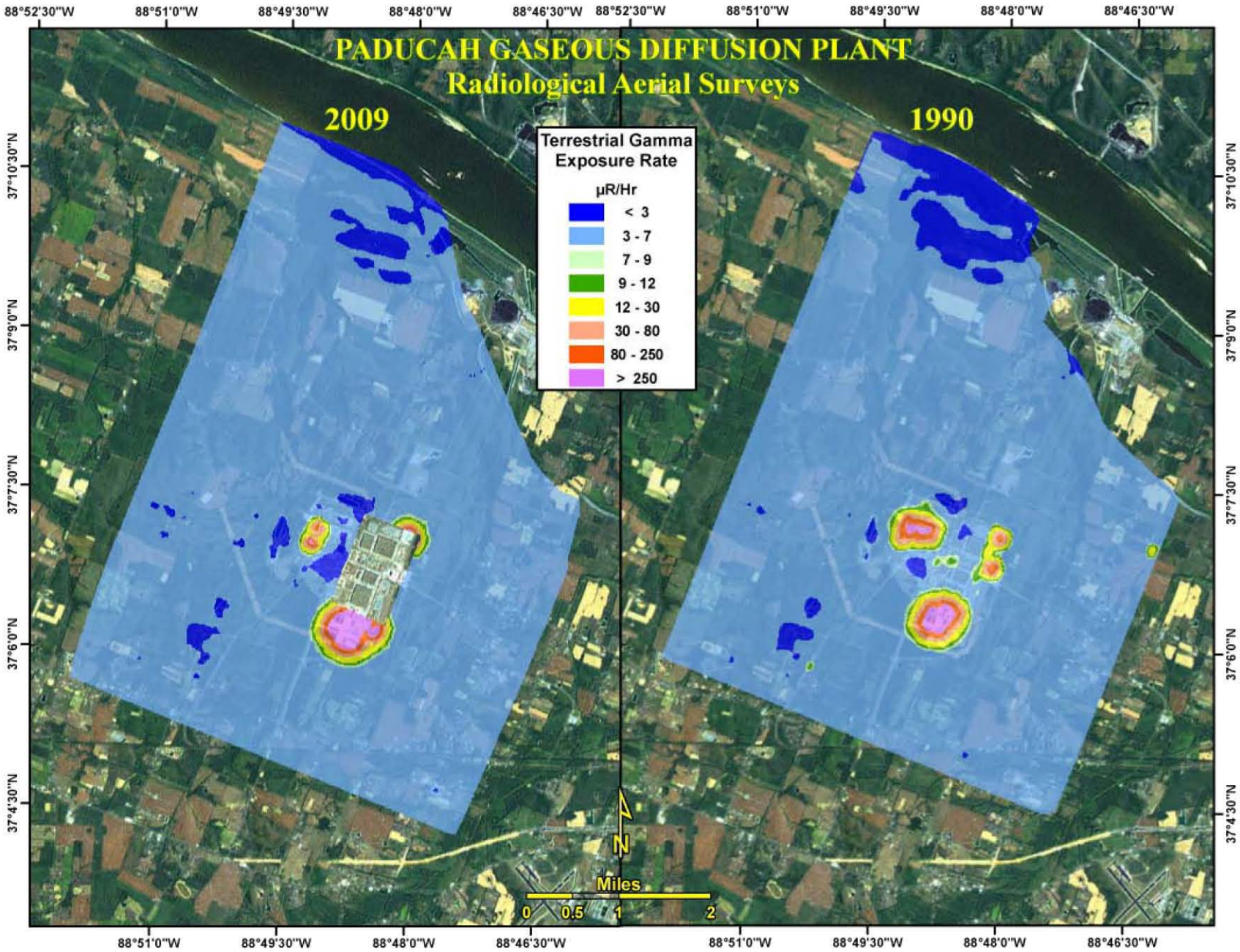

Figure 5: Terrestrial Gamma Exposure Rate Contour Map. Results from the previous survey[2](1990) are also shown for direct comparison.

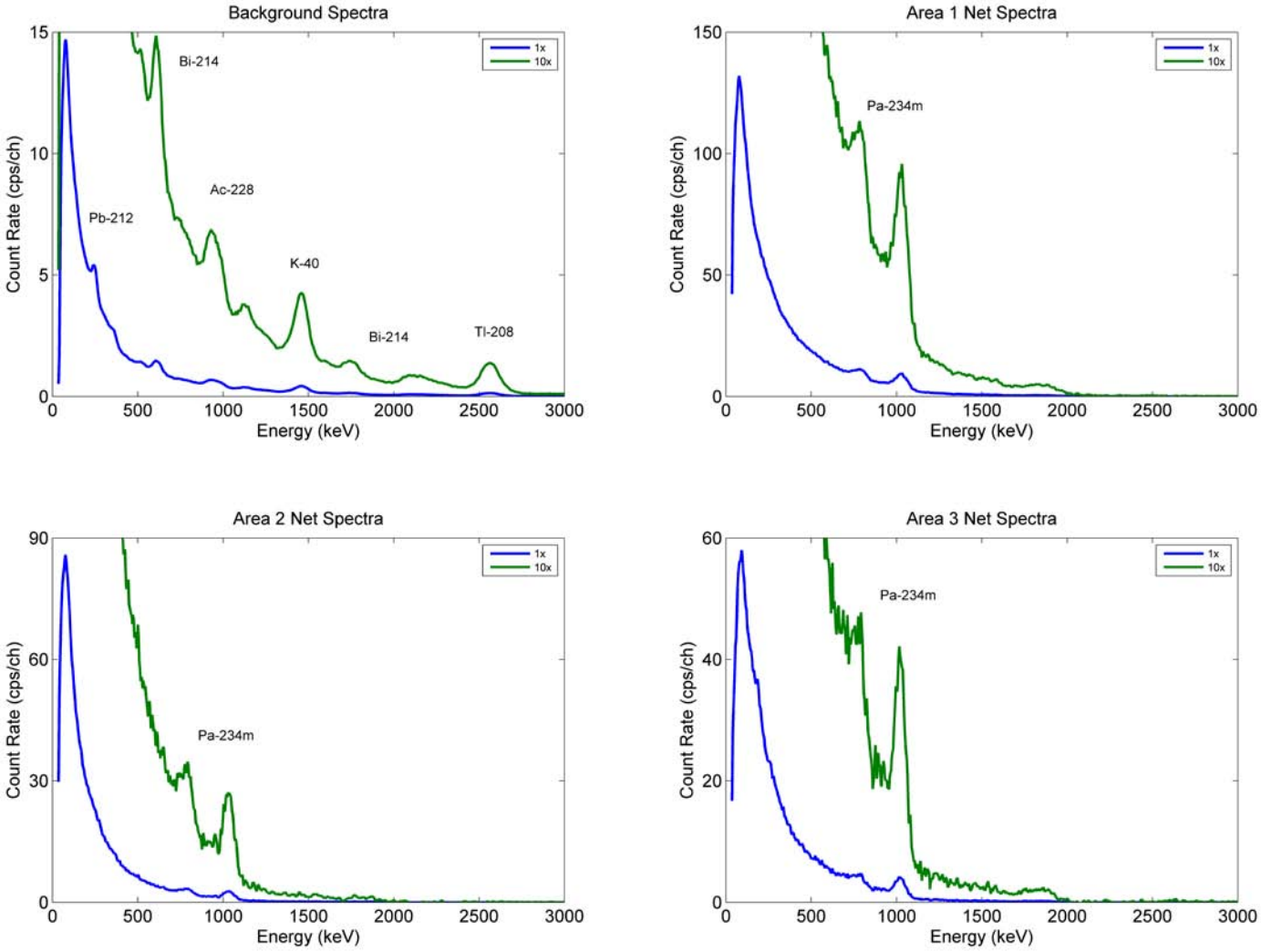

Figure 6: Spectra from Regions of Interest Indicated in Figures 2 and 3.

Each spectrum shows the counts per channel as a function of gamma-ray energy (where the energy conversion is 4 keV/channel) in a single 2”×4”×16” NaI(Tl) crystal.

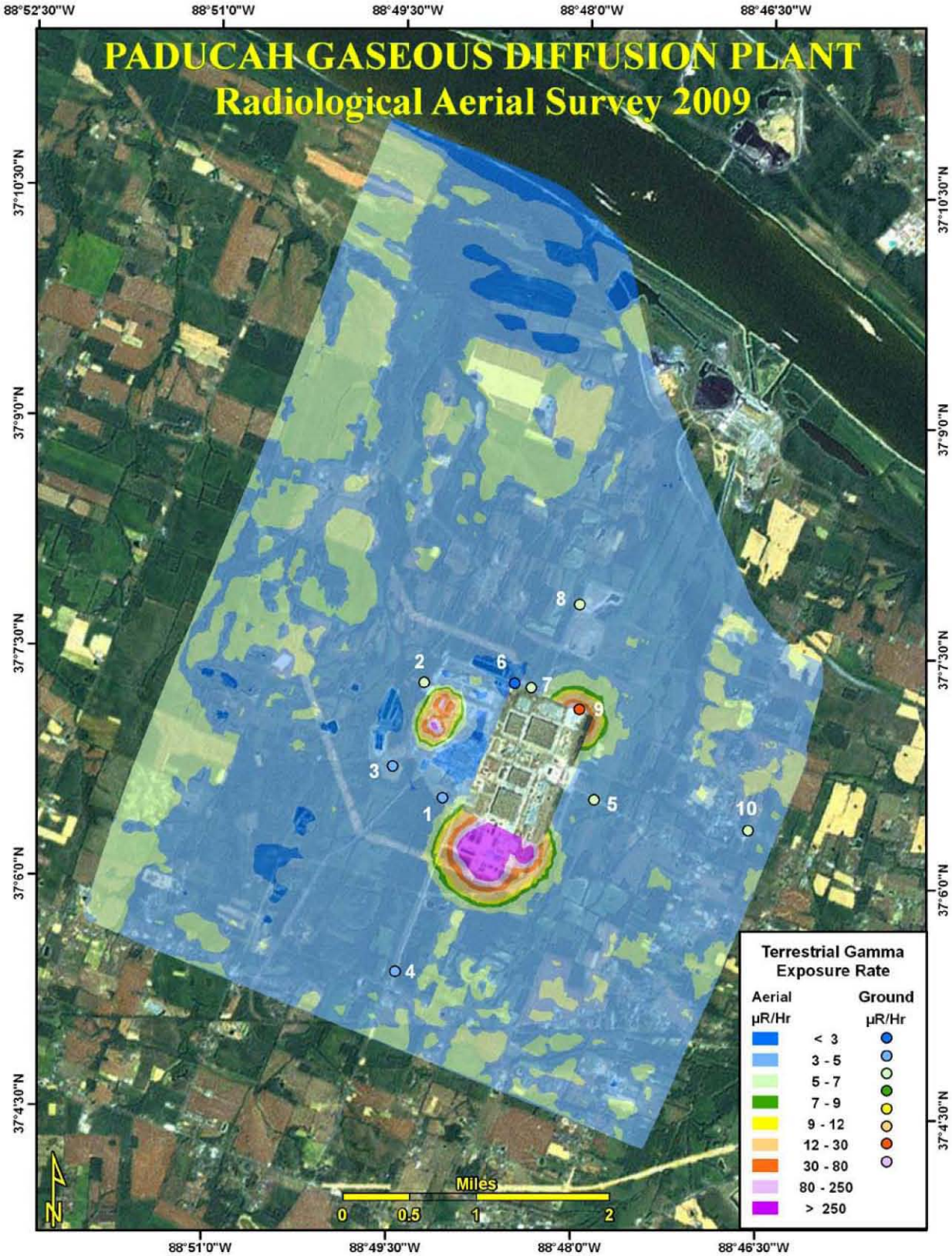

Figure 7: Comparison of PIC Ground-Based Measurements with Inferred Exposure Rate from Aerial Measurements. Values for the labeled data points are given in Appendix B

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APPENDIX A
Survey Parameters

Survey Site:	Paducah Gaseous Diffusion Plant, Paducah, Kentucky
Survey Coverage:	24 square miles (~62 square kilometers)
Survey Date:	October 28 – November 2, 2009
Survey Altitude:	150 feet (~46 meters)
Aircraft Speed:	70 knots (~36 miles per second)
Line Spacing:	250 feet (~76 meters)
Navigation System:	Trimble DGPS (OmniSTAR corrections)
Line Direction:	North-South and East-West
Detector Configuration:	Twelve 2″ × 4″ × 16″ NaI(Tl) detectors
Acquisition System:	REDAR-V
Conversion Factor:	1,712 cps/µR/h
Air Attenuation Coefficient:	0.001761/feet (0.005778/meters)
Aircraft:	Bell-412 Helicopter
Federal Team Lead:	Joe Ginanni
AMS Manager:	Karen McCall
Project Coordinator:	Elaine Hawkins
Project Manager:	Matthew Kiser
Project Scientist:	Michael Reed
Data Analysts:	Julia You Jezabel Stampahar Sonia Bonilla
Electronic Technicians:	Kevin Borders Tom Stampahar Dave Emery
Helicopter Pilots:	Jeff LeDonne Timothy Rourke
Aviation Mechanic:	Al Duncan

APPENDIX B

Ground-Based Measurements Compared to Inferred Aerial Measurements

Index	Latitude	Longitude	PIC Total (µR/h)	PIC Terrestrial (µR/h)	Aerial Terrestrial (µR/h)	PIC to Aerial Spread (µR/h)
1	37° 6’ 32.9”	-88° 49’ 5.8”	8.3	4.6	4.7	0.1
2	37° 7’ 17.7”	-88° 49’ 15.8”	8.9	5.2	4.0	1.2
3	37° 6’ 44.9”	-88° 49’ 30.5”	7.5	3.8	3.8	0.0
4	37° 5’ 24.5”	-88° 49’ 27.4”	8.2	4.5	4.1	0.4
5	37° 6’ 33.0”	-88° 47’ 51.8”	9.1	5.4	4.5	0.9
6	37° 7’ 18.1”	-88° 48’ 31.6”	6.4	2.7	2.6	0.1
7	37° 7’ 16.5”	-88° 48’ 23.5”	9.2	5.5	4.7	0.8
8	37° 7’ 49.4”	-88° 48’ 0.4”	9.2	5.5	4.0	1.5
9	37° 7’ 8.4”	-88° 47’ 59.7”	58.9	55.2	367.0	311.8
10	37° 6’ 22.1”	-88° 46’ 36.3”	9.0	5.3	4.1	1.2

The measured PIC data (PIC Total) intrinsically includes cosmic and radon contributions. An estimated cosmic ray contribution[5] of 3.7 µR/h was removed from the measured PIC value to get the PIC Terrestrial exposure rate. Note that this PIC Terrestrial exposure rate includes any radon contribution at the specific locations. Measured aerial data (Aerial Terrestrial) utilized test line and water line information to remove both the cosmic and radon contributions.