DOE-0335
Revision 0

An Aerial Radiological Survey of the Hanford Reservation Richland Washington

Date of Survey: February 29 to March 21, 1996

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

United States
Department of Energy
P.O. Box 550
Richland, Washington 99352

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A-6001-401 (REV 1)

Simmons, Sally A

DOE-0335
Rev. 0

From: Goldberg, Glenn I
Sent: Tuesday, October 16, 2007 9:07 AM
To: Leary, Kevin D; Simmons, Sally A
Subject: RE: RE: Security Clearance for OUO of the 1996 Aerial Radiological Survey of Hanford

Sally,

As long as the documents have been looked at by either RL (Kevin) or the Contractor (Aardal) I don't need to see them. The only reason I would need to see them is if the RL POC had some concerns or questions regarding OUO.

Since Kevin is OK with it, my approval is not necessary.

Thanks,

Glenn Goldberg
Security and Emergency Services
(509) 376-9552

From: Leary, Kevin D
Sent: Tuesday, October 16, 2007 8:59 AM
To: Simmons, Sally A
Cc: Goldberg, Glenn I
Subject: RE: Security Clearance for OUO of the 1996 Aerial Radiological Survey of Hanford

Sally--

I spoke with Glenn Goldberg this AM about doing a OUO review of the 1996 Aerial Radiological Survey of Hanford. Glenn stated since Nancy Hohman, Mark Williams, and Janice Aardall did a OUO review of the above-mentioned document, it is not necessary for him to review the document nor to sign-off on the clearance form. He said that he would send an e-mail to concur on this.

Thanks for your help.

Kevin D. Leary-*U-Plant Zone Closure/IS-1 Technical Lead*

U.S. Dept. of Energy-Richland

Certified Professional Soil Scientist/Hydrogeologist/Hydrologist

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"The only thing necessary for the triumph of evil is for good men to do nothing." --Sir Edmund Burke

"If you do the same thing over and over again, you cannot ever expect a different outcome." --Albert Einstein

National Security Technologies LLC
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September 2007

AN AERIAL RADIOLOGICAL SURVEY OF THE

HANFORD RESERVATION

RICHLAND, WASHINGTON

DATE OF SURVEY: FEBRUARY 29 TO MARCH 21, 1996

National Security Technologies LLC
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September 2007

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DATE OF SURVEY: FEBRUARY 29 TO MARCH 21, 1996

Prepared for the U.S. Department of Energy, Richland Site Office

ABSTRACT

An aerial radiological survey was conducted from February 29 to March 21, 1996, and covered a 1,450-square-kilometer (560-square-mile) area centered on the Hanford Reservation (HR) located northwest of Richland, Washington. Additional flights were conducted along the banks of the Columbia River extending from the Priest Rapids Dam in the northwest to Kennewick in the southeast. The results of the survey are reported as contours of the terrestrial exposure rate extrapolated to one meter above ground level, contours of the man-made gross count activity which is characteristic of all long-lived man-made radionuclides that emit gamma radiation with energies less than 1,400 keV, and contours of the cesium-137 activity. All data were scaled and overlaid on a United States Geological Survey (USGS) topographic map of the site and on aerial photographs of selected HR facilities and segments of the Columbia River. Excluding cosmic contributions, implied exposure rates for background areas (that is, areas undisturbed by Hanford radiological activities) ranged from 3 to 7 microroentgens per hour (μR/h) at one meter. In radiologically disturbed areas, implied exposure rates in excess of background levels (as high as 500 μR/h in some cases) were observed. Typical disturbed areas were: the nine deactivated graphite moderated plutonium production reactors in the 100 Areas, the Columbia Generating Station, Energy Northwest (Washington Public Power Supply System in 1996) Unit No. 2 reactor, and the facilities and radioactive storage sites within the 200 East/West and 300 Areas. Also, radioactive materials were detected within the perimeters of the Areva Nuclear Power, Inc (Siemens Power Corporation's Nuclear Division in 1996), the Perma Fix Environmental Services, Inc. (Allied Technology Group, Inc. in 1996), and the Pacific Northwest Service facilities, which are located in the city of Richland.

Pressurized ionization chamber measurements were collected by the Westinghouse Hanford Near-field Monitoring Group (NFM) at seven locations within the site boundaries. One of those measurements was collected onboard a boat on the Columbia River. These seven measurements were used to verify the aerial results and to check nominal radon background levels. The inferred aerial and ground-based exposure measurements were in excellent agreement with the average difference being only 0.3 μR.

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ACRONYMS

AGL	above ground level
AMS	Aerial Measuring System
ATG	Allied Technology Group
BWR	Boiling Water Reactor
CRT	cathode ray tube
DOE	U.S. Department of Energy
HR	Hanford Reservation
GC	gross count
GPS	Global Positioning System
MBB	Messerschmitt-Bolkow-Blohm
MDA	minimum detectable activities
MM	man-made
MMGC	man-made gross count
NaI(Tl)	thallium-activated sodium-iodide,
NFM	Near-field Monitoring
PIC	pressurized ionization chamber
PNNL	Pacific Northwest National Laboratory
PWR	pressurized water reactor
RDGPS	Real-time Differential Global Positioning System
REDAC	Radiation and Environmental Data Analysis Computer
REDAR IV	Radiation and Environmental Data Acquisition and Recorder, Model IV
RSL	Remote Sensing Laboratory
USGS	U.S. Geological Survey
WPPSS	Washington Public Power Supply System

PHYSICAL UNITS

^{137}Cs	cesium-137
^{60}Co	cobalt-60
^{152}Eu	europium-152
^{22}Na	sodium-22
^{234}Pa	protactinium-234
Ci	curie (a unit of activity)
cps	counts per second
ft	foot
h	hour
in	inch
kCi	kilocurie (a unit of activity)
keV	kiloelectronvolt (a unit of energy)
m	meter
$\mu Ci/m^2$	microcurie per square meter
μR	microroentgen (a unit of exposure)
pCi	picocurie (a unit of activity)
rem	roentgen equivalent man (a unit of radiation dose)
s	second

1.0 INTRODUCTION

An aerial radiological survey of the Hanford Reservation (HR) located northwest of Richland, Washington was conducted from February 29 to March 21, 1996, at the request of the U.S. Department of Energy (DOE) and covered a 1,450-square-kilometer (560-square-mile) area. Additional flights were conducted along the banks of the Columbia River extending from the Priest Rapids Dam in the northwest to Kennewick in the southeast. The survey was conducted by the DOE's Remote Sensing Laboratory–Nellis (RSL–N), currently maintained and operated by National Security Technologies [LLC] (NSTec) in Las Vegas, Nevada.

The purpose of the survey was to measure and map the natural and man-made gamma radiation emanating from the area within and surrounding the site boundaries. This survey was the fifth of its type at HR[1,2,3,4] and was conducted as a routine part of an on-going DOE research and environmental monitoring program.

Pressurized ionization chamber measurements were collected at a height of one meter above ground level (AGL) at seven locations within the site boundaries. One of these measurements was collected onboard the Pacific Northwest National Laboratory (PNNL) Ecology observation boat on the Columbia River. These measurements were used to verify the aerial radiological exposure rate results and to check nominal radon background levels.

2.0 SITE DESCRIPTION

The Hanford Nuclear Reservation, Figure 1, lies within the Pasco Basin of the Columbia Plateau in south central Washington state and covers an area of 1,450-square-kilometers (560-square-miles). This area is a semi-arid, shrub-steppe region with a normal annual rainfall of 16 centimeters (6.3-inches).[5] The Columbia River flows through the northern part of the HR and forms part of the site's eastern boundary. The Yakima River runs along the southern boundary and joins the Columbia River below the city of Richland, which is located at the site's southeastern boundary. Rattlesnake Mountain, Yakima Ridge, and Umtanum Ridge form the southwestern and western boundaries. The Saddle Mountains form the northern boundary. The nearest population center is the Tri-Cities area (Richland, Pasco and Kennewick), located directly downstream from the site.

Since the facility began operation in 1944, activities at the HR have centered on the nine graphite moderated plutonium production reactors, located along the southern bank of the Columbia River within the six 100-Areas. At the time of this survey, all nine of the reactors had been shutdown. Also, located in the center of the reservation are two large chemical separation areas (200-East and 200-West), where plutonium and uranium had been extracted from irradiated uranium fuel elements. These extractions were discontinued in 1984. Large quantities of liquid and solid radioactive wastes were stored at the underground tank farms and burial sites located within and around the 200-Areas.

Also, within the HR boundaries is the Washington Public Power Supply System (WPPSS), which is located approximately 27 kilometers (17 miles) north of the city of Richland in Benton County. At the time of this survey, only one of the three reactor units, Unit-2, was in operation. Unit 1 is a 1,250 megawatt pressurized water reactor (PWR) that was 80 to 90 percent completed. Unit 2 is a 1,150 megawatt boiling water reactor (BWR). Unit-4 was never in operation and has been dismantled.

Two commercial waste processing and repackaging plants (Allied Technology Group, Inc. [ATG, Inc.] and Siemens Power Corporation - Nuclear Division) are located immediately north of the Richland Airport and west of the 300 Area. Both of these plants had prior histories for the handling and storing of large quantities of radioactive materials. At the time of this survey, the ATG, Inc. was known to be in possession of a large activity beta source (168 kCi of strontium-90) plus additional gamma sources (cesium, cobalt, radium, and europium), which were being stored at the request of the U.S. Department of Defense.[6]

3.0 SURVEY PLAN

3.1 Aerial Survey

The aerial survey was conducted to collect gamma radiation data over a 1,450 square-kilometer (560 square-mile) area encompassing the HR. The boundary was selected to enclose the entire site, however due to the steepness of the terrain along the base of the Rattlesnake Mountain, the area in the southwestern portion of the HR was not flown. The south-eastern survey boundary was extended to the ATG, Inc. and Siemens Power Corporation plants in Richland and the east side of the river.

The radiation survey was flown at a constant ground speed of 80 knots (41 meters per second), at a nominal altitude of 61 meters (200 feet) AGL, and along a parallel set of flight lines spaced 122 meters (400 feet) apart, totaling approximately 12,900 flight line kilometers (~8,000 miles). The flight lines were oriented and flown in either a southerly or northerly direction. All data were scaled to overlay a USGS topographic survey map or selected aerial photographs (May 1996) of the HR site and the Columbia River shoreline. The aerial photographs were taken at nominally 4800 meters (16,000 feet) above ground level. In order to assure data integrity and to monitor/correct for variations in the detector's background count rate due to aircraft, radon, and cosmic rays, repeated measurements were made over a fixed test line before and after each flight. The fixed test line was located approximately 2.4 kilometers (1.5 miles) east of the Columbia River and 8 kilometers (5 miles) northeast of the Richland Airport. For the survey parameters cited, the minimum detectable activities (MDA) for the isotopes of interest are shown in Table 1. The isotopes of interest are: cesium-137 (^{137}Cs), from worldwide fallout attributed to the atmospheric nuclear weapons testing program as well as the HR operations, cobalt-60 (^{60}Co), europium-152 (^{152}Eu), sodium-22 (^{22}Na), and protactinium-234 (^{234}Pa). All of these isotopes had previously been detected by past radiation survey missions.

3.2 Ground-Based Measurements

On March 13, 1996, a set of ground-based pressurized ionization chamber (PIC) measurements were acquired at seven locations within the site's boundaries by the Westinghouse Hanford's Near-field Monitoring (NFM) Group.[6] These measurements were used verify to the inferred aerial data exposure rates. The locations selected were not near any obvious radiation anomalies and the majority were selected at known Hanford benchmark locations. Six of the seven total exposure rate measurements were collected at a height of one meter above the ground and were each integrated over a period of approximately 15 minutes. The seventh measurement was collected onboard the PNNL Ecology observation boat which was moored northwest of Locke Island, approximately 400 meters (1,310 feet) off-shore. The off-shore total exposure rate measurement was also integrated over a period of approximately 15 minutes.

4.0 SURVEY EQUIPMENT

4.1 Aerial Survey

The survey was conducted using two Aerial Measuring Systems (AMS) helicopters. Each helicopter-based detection system consists of a Messerschmitt-Bolkow-Blohm (MBB) BO-105 helicopter, a Radiation and Environmental Data Acquisition and Recorder, Version IV (REDAR-IV) system, and a Real-time Differential Global Positioning System (RDGPS), Figure 2

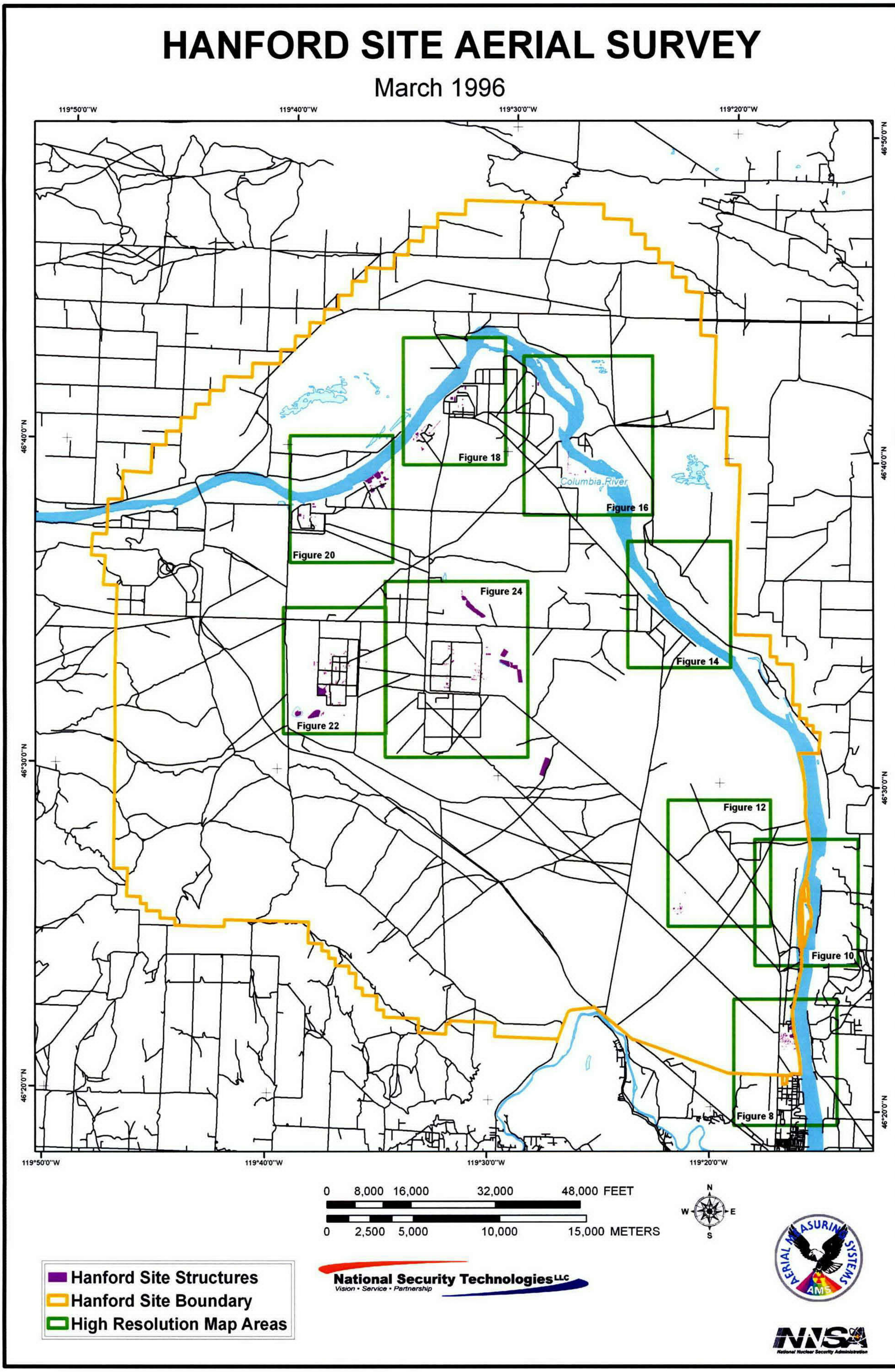


Figure 1. Area Map of the Hanford Nuclear Reservation

Table 1. Survey Minimum Detectable Activities (MDA) and Conversion Factors[a]

Isotope	Photopeak Energy (keV)	Minimum Detectable Activity Surface ($\mu Ci/m^2$)	Minimum Detectable Activity Exponential[b] (pCi/g)	Conversion Factors Surface ($\mu Ci/m^2$/cps)	Conversion Factors Exponential[b] (pCi/g/cps)
^{60}Co	1173/1332	0.022	0.11	0.00059	0.0029
^{137}Cs	662	0.074	0.47	0.0017	0.011
^{152}Eu	122	0.38	4.4	0.0061	0.072
^{152}Eu	1408	0.39	1.8	0.013	0.061
^{22}Na	1275	0.067	0.32	0.0024	0.012
^{234}Pa	1001	11.	56.	0.32	1.7

[a] Derived for a ground speed of 41 m/s, nominal altitude of 61 m, and line spacing of 122 m.
[b] Derived for a soil sample depth (z) of 3 cm and an inverse relaxation depth (α) of 0.1 cm^{-1}.

Figure 2. MBB BO-105 Helicopter with Detector Pods

Each helicopter was equipped with two large detector pods mounted on the helicopter landing skids. Each pod contained four 2- × 4- × 16-inch and one 2- × 4- × 4-inch thallium-activated sodium-iodide, NaI(T*l*), gamma ray detectors. The preamplifier signal from each detector was calibrated using ^{22}Na and americium-241 (^{241}Am) gamma check sources. Normalized outputs from eight large 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-IV multichannel analyzer.

4.1.1 REDAR-IV System

Data acquisition was performed using the REDAR-IV system, a multi-microprocessor, portable data acquisition and real-time analysis system, designed for use in aircraft. The REDAR-IV collects 1,024 channels (4 keV/channel) of gamma energy spectral data once every second and then records the spectral data, the aircraft altimeter and positioning data, and the environmental variables, such as ambient temperature and barometric pressure, to magnetic tape cartridges once every four seconds. The REDAR-IV is also equipped with multichannel analyzer and CRT display capabilities for in-flight monitoring of the gamma energy spectral data as well as other flight parameters. The detector and electronic system are described in detail in a separate publication.[7]

4.1.2 Helicopter Positioning

Each helicopter's position was established by using two systems: an RDGPS and a radar altimeter. The RDGPS is a navigation system providing continuous position information using a constellation of 24 satellites. At the time of this survey, the RDGPS had a positional accuracy of +/- 5 meters (16 feet). The radar altimeter determines the helicopter's altitude by measuring the round-trip propagation time of a signal reflected off the ground.

4.1.3 Data Processing

At the end of each flight, the aerial data were downloaded for processing from the magnetic tape cartridges into two mini-Radiation and Environmental Data Analysis Computer (REDAC) systems. The mini-REDAC systems were housed at the DOE Richland aerial operations hangar, which is located on the Tri Cities Airport in building #71 and is maintained and operated for the DOE by the Pacific Northwest National Laboratory. Each mini-REDAC system utilized: (1) a computer with 8-megabytes of memory for data manipulation, (2) two gigabytes of hard disk space for mass storage of data, (3) two 1/4-inch digital magnetic tape cartridge drives for reading the REDAR data tapes, (4) one Exabyte tape drive for data transfer and archiving, (5) a 36-inch-wide graphics plotter for data contouring, and (6) two video graphics display stations. Each system used an extensive library of software, which provided onsite preliminary analysis of the aerial data on a flight-by-flight basis and monitored pre- and post-flight quality assurance checks. The final data analysis for this survey was completed using a personal computer with 1 gigabyte of memory, a 36-inch-wide plotter, and a laser printer. The current software for the personal computer can perform all of the calculations that the mini-computer software used to perform.

Aerial count rate activity was converted to exposure rate at 1 meter above ground level by application of a conversion factor determined from a documented calibration range near Lake Mohave, Nevada. A number of ground-based measurements were also made at the Hanford Site. The Hanford measurements were taken to verify the inferred aerial measurements. They were not intended for nor were they used for calibrating the aerial system.

The total exposure rate measurements at Hanford were acquired using two Reuter-Stokes pressurized ionization chambers (PIC). These instruments are portable, battery-powered, and incorporate a 25-cm (10-inch) diameter metal sphere filled with 25 atmospheres of argon gas, a high voltage bias supply, an electrometer, and readout components. Both units have a sensitivity of ~3×10^{-14} amps per microroentgens per hour (μR/h) and have the capability of digitally and graphically displaying the total exposure rate data.

5.0 ANALYSIS PROCEDURES

5.1 Aerial Data Analysis

The aerial radiation data generally consist of contributions from the naturally occurring radionuclides, man-made radionuclides, airborne radon, cosmic rays, and aircraft-induced electronic noise. For this survey, contour maps were produced by processing the aerial data using the extraction methods discussed in this section. More detailed information can be found in a separate publication.[7]

5.1.1 Terrestrial Exposure Rate (Gross Count)

The terrestrial exposure rate or gross count method is based on the integral count rate in the gamma energy spectral range between 38 and 3,026 keV:

$$CR_{GC} = \sum_{E=38}^{3026} S(E) - NTB \qquad (1)$$

where

CR_{GC} = total terrestrial count rate or gross count, counts per second (cps).

$S(E)$ = energy spectrum containing the number of gamma rays collected at the given energy E per second.

E = the photon energy, keV.

NTB = non-terrestrial background count rate produced by the effects of airborne radon, cosmic rays, and the aircraft-induced electronic noise, cps.

The gross count, measured in cps at survey altitude, was converted to an exposure rate in μR/h at a height of one meter above the ground by the application of a conversion factor determined from documented calibration test lines located in Calvert County, Maryland[8] and Lake Mohave, Nevada. The conversion equation used is:

$$ER = \frac{CR_{GC}}{1113} e^{(A-61)\mu_{air}} \qquad (2)$$

where

ER = exposure rate extrapolated to one meter AGL, μR/h.

A = survey altitude, m.

μ_{air} = gamma ray air attenuation coefficient, m^{-1}.

The air attenuation coefficient, μ_{air}, deduced empirically from the altitude profile data acquired over the survey's test line, was 0.00633 m^{-1}. The derived conversion factor was 1,113 cps per μR/h for a survey altitude of 61 m AGL. The applicability of the conversion equation assumes a uniformly distributed radiation source: (1) covering an area which is large when compared to the field of view of the detection system (a circle with a diameter roughly twice the altitude of the aircraft), and (2) having a gamma energy distribution similar to that of the natural background radiation of the Lake Mohave calibration test line.

5.1.2 Man-Made Gross Count

The aerial data were also used to determine the location of nonnatural-occurring gamma sources (i.e., man-made radionuclides). The man-made gross count (MMGC) is the portion of the gross count which is directly attributed to the gamma rays from the man-made radionuclides. In general, evidence of man-made radionuclides can be found from increases in the gross count. However, slight variations in the gross count are generally not considered adequate proof to suspect the presence of a man-made anomaly since these variations can result naturally from geological fluctuations or changes in the ground coverage (i.e., rivers, vegetation, buildings).

In order to increase the sensitivity to detect man-made anomalies, a man-made gross count algorithm has been developed that uses differential spectral energy extraction techniques to denote changes in the gamma energy spectral shapes. This algorithm takes advantage of the fact that while background radiation levels often vary by a factor of two or more within a survey area, background spectral shapes remain essentially constant. More specifically, the ratio of natural components in any two sections (windows) of the energy spectrum will remain nearly constant.

Although this procedure can be applied to any region of the gamma energy spectrum, the most common practice is to place all counts below 1,394 keV into the man-made window (low energy sum), where most of the long-lived, man-made radionuclides emit radiation, and to place all counts above 1,394 keV into the natural window (high energy sum), where mostly the naturally occurring radionuclides emit radiation. The MMGC rate can be expressed analytically in terms of the integrated count rates in specific gamma energy spectral windows (keV):

$$MMGC = \sum_{E=38}^{1394} S(E) - K_{mm} \sum_{E=1394}^{3026} S(E) \qquad (3)$$

where K_{mm} is defined over an area that only contains gamma radiation from naturally occurring radionuclides as

$$K_{mm} = \frac{\sum_{E=38}^{1394} S(E)}{\sum_{E=1394}^{3026} S(E)} \qquad (4)$$

This MMGC algorithm has been found to be sensitive to low levels of man-made radiation even in the presence of large variations in the natural background. Once a region of man-made radioactivity has been identified, a detailed analysis of the gamma energy spectrum is conducted to ascertain which radionuclide(s) are present.

5.1.3 Isotope Extraction Algorithms

The determination of an individual isotope's contribution to the gross count requires an algorithm that can identify a specific photopeak's count rate. The simplest of these algorithms is the two-window strip, which is very similar to the algorithm used to extract the MMGC. The two-window stripping method assumes that the photopeak count rate from a specific isotope can be determined from the sum of the counts in the isotope's gamma energy source window minus a scaled background contribution. The equation for a two-window strip is similar to that shown in Equation 3, but the appropriate energy limits for both the source and background windows need to be inserted. The two-window proportionality factor, K_2, is similarly derived as was K_{mm} (Equation 4) from a region in the survey area that does not contain any of the isotopes of interest, so that the photopeak window contains only its background counts and therefore is directly related to the number of counts in the background window. If the principle source of background radiation in the photopeak window is from scattered gamma rays from photopeaks at higher energies, this is a good assumption. If there are isotopes other than the one of interest with photopeaks in the photopeak window, then this algorithm will likely fail.

If an area cannot be found that is free of the specific isotope of interest, or if the composition of the other isotopes drastically changes between the clean area and the rest of the survey area, then a simple multiplicative factor will not relate the counts in the photopeak window to the counts in the background window. To solve this problem, the three-window algorithm will be used that employs a background window on each side of the photopeak window. This algorithm assumes that, for any spectrum, the number of background counts in the photopeak window is linearly related to the number of counts in the two background windows. The equation for the three-window algorithm is given by:

$$CR_3 = \sum_{E=E_2}^{E_3} S(E) - K_3 \left[\sum_{E=E_1}^{E_2} S(E) + \sum_{E=E_3}^{E_4} S(E) \right] \qquad (5)$$

with

$$K_3 = \frac{\sum_{E=E_2}^{E_3} S_{bkg}(E)}{\sum_{E=E_1}^{E_2} S_{bkg}(E) + \sum_{E=E_3}^{E_4} S_{bkg}(E)} \qquad (6)$$

The three-window algorithm is also very useful in extracting low-energy photopeak counts where the shape of the Compton-scatter contributions from other isotopes is changing significantly.

Both the two- and three-window algorithms were applied to the Hanford data. For extracting the ^{137}Cs counts, the three window algorithm gave the most consistent results. The ^{137}Cs background energy limits that were used are shown in Appendix B. The extracted ^{137}Cs count rates, measured in cps at survey altitude, can be converted to soil activity in microcuries per square meter ($\mu Ci/m^2$) by application of a conversion factor, Table 1, which was derived from a radioactive transport matrix model developed by Beck, e*t al.*[9] This method mathematically models the gamma ray flux through a detector located at specific distances above a source distribution. A brief synopsis of this model will be discussed in the next section.

5.2 Conversion Factors

Conversion factors have been calculated which relate the photopeak count rate data to the radionuclide activity in the soil. The values are determined by combining a laboratory measurement of the detector efficiency to a given gamma ray energy with a theoretical calculation of the gamma ray flux arriving at the detector as a function of source distribution in the soil.

The unscattered gamma ray flux, φ, from a point source with activity *So* at a distance *r* from the source is given by

$$\phi = \frac{S_o}{4\pi r^2} e^{-r/\lambda_a} \qquad (7)$$

where λ_a is the gamma ray mean free path in air. This can also be written as

$$\phi = \frac{S_o}{4\pi r^2} e^{-(\mu/\rho)_a \rho_a r_a} \qquad (8)$$

where

$(\mu/\rho)_a$ = air mass attenuation coefficient, cm^2/g.

ρ_a = air density, g/cm^3.

This expression can be expanded to the more general case of a source distributed within the soil. In this case, the unscattered flux of gamma rays of energy *E* at a height *h* above a smooth air-ground interface due to an emitter distributed in the soil is given by

$$\phi = \int_0^\infty \int_0^\infty \frac{S_v}{4\pi r^2} e^{-(\mu/\rho)_a \rho_a r_a} e^{-(\mu/\rho)_s \rho_s r_s} 2\pi x dx dz \qquad (9)$$

where

S_v = activity per unit volume, $(\gamma/sec)/cm^3$

r = $r_a + r_s$ distance between detector and source, cm.

$(\mu/\rho)_a$, $(\mu/\rho)_s$ = air and soil mass attenuation coefficients, cm^2/g.

ρ_a, ρ_s = air and soil densities, g/cm^3.

This expression assumes a source distribution, which varies only with depth. This uniform distribution in the horizontal plane leads to results expressed in terms of an averaged value over the field of view of the detector.

The detector response to a given flux, φ, of gamma rays of energy *E* incident at an angle θ can be given in terms of an effective detector area, *A*, defined by

$$A = \frac{N_p}{\phi} \qquad (10)$$

where N_p is the net photopeak count rate, normally given in units of cps. The effective area, in general, varies as a function of the gamma ray angle of incidence and is usually written as

$$A = A_o R(\theta) \qquad (11)$$

where

A_o = detector photopeak count rate for a unit flux incident perpendicular to the detector face, $(cps)/(\gamma/cm^2\text{-sec})$.

$R(\theta)$ = ratio of the detector response at an angle θ to that at $\theta = 0°$.

Combining Equations 10 and 11 with Equation 9 yields an expression which relates the measured photopeak count rate to the source activity in the soil. This is given by

$$N_p = \int_0^\infty \int_0^\infty \frac{S_v A_o R(\theta)}{4\pi r^2} e^{-(\mu/\rho)_a \rho_a r_a} e^{-(\mu/\rho)_s \rho_s r_s} 2\pi x dx dz \qquad (12)$$

In order to evaluate Equation 12, it is necessary to make some assumptions on the source distribution depth. Three basic types of vertical source distributions are normally encountered in environmental measurements. Naturally-occurring background radiation is normally represented by a uniform volume distribution (i.e., distributed uniformly as a function of depth). Relatively fresh fallout activity is normally represented by a uniform surface distribution (i.e., the radioactivity lies in a thin layer of material on the ground). Fallout activity, which has aged into the soil over a period of time, is most often represented by an exponential distribution of the form

$$S_v = S_{vo} e^{-\alpha z} \qquad (13)$$

where

S_{vo} = activity per unit volume at the surface, $(\gamma/sec)/cm^3$.

α = reciprocal of the relaxation depth, cm^{-1}.

z = source distribution depth in the soil, cm.

This implies that the representative volume of soil at a depth of $1/\alpha$ is assumed to contain approximately 63% of the source's total activity. At a relaxation depth of $2/\alpha$ and $3/\alpha$, respectively, the representative volume of soil is assumed to contain approximately 86% and 95% of the total activity.

For the exponential soil depth distribution model, Equation 12 becomes

$$N_p = \frac{S_{vo} A_o}{2} \int_0^{\pi/2} \frac{R(\theta) \tan\theta \, e^{-(\mu/\rho)_a \rho_a h \sec\theta}}{\alpha + (\mu/\rho)_s \rho_s \sec\theta} d\theta \qquad (14)$$

This expression relates the measured photopeak count rate, N_p, to the activity per unit volume at the surface. The detector parameters, A_o and $R(\theta)$, are normally obtained empirically for a given system using standard calibration sources. Mass attenuation coefficients for air and typical soils can be found in standard reference tables. An average soil density of 1.5 g/cm^3 and air density of 0.001205 g/cm^2 at 20°C are normally assumed unless actual measured values are available. The detector height, *h*, can be measured in most cases.

In general, it is more useful to relate the photopeak net count rate data to an average concentration within a given depth rather than a surface concentration as given in Equation 14. The average concentration in the top *z* cm of soil, $S_v(z)$, for a source distributed exponentially with depth is given by

$$S_v(z) = \frac{1}{z}\int_0^z S_{vo}\, e^{-\alpha z}\, dz = \frac{S_{vo}}{\alpha z}(1 - e^{-\alpha z}) \qquad (15)$$

Another result often required is the total activity per unit area. This is given by

$$S_A = \int_0^\infty S_{vo}\, e^{-\alpha z}\, dz = \frac{S_{vo}}{\alpha} \qquad (16)$$

The conversion factors derived for all three source distribution types relate a measured photopeak net count rate, expressed in units of cps, to source activity expressed in units of gamma rays per second per unit area or unit volume. For a specific isotope, the source activity is normally changed to units of curies or becquerels. The average activity per unit volume can also be converted to average activity per unit mass by dividing by the soil density.

In the above model, the values for "α" and "z", which are normally measured in the field, are usually poorly known, and are highly dependent upon the actual soil conditions and isotopes present. Also, artificial soil disturbance (farming, construction, etc.) will affect the value of these parameters.

5.3 Interpretation of Contour Maps

The radiation field produced by a radioactive source extends well beyond the physical extent of the source. Therefore, for any remote measurement (aerial, hand-held survey meters, ion chambers, etc.), the presence of a radiation field does not necessarily indicate presence of radioactive material at the specific location where the radiation field is detected. Contour maps in this report present the measured radiation field at mapped locations. This field/source non-correlation is most apparent in the facilities along the river. The measured field extends well over the water even though the source of activity is entirely on the adjacent land surface. The contours show the extent of the field generated by the remote source. They do not imply the presence of radioactive materials in or on the water. While most evident in the water-adjacent facilities, the extended "bulls-eye" effect is also present around facilities entirely surrounded by land.

Contour maps in this report are generated by a standard procedure of linear interpolation within each facet of the triangulated irregular network formed by the measured points.

6.0 RESULTS

6.1 Terrestrial Gamma Exposure Rate Contour

Figure 3 presents the terrestrial gamma exposure rates inferred from the aerial data in the form of a contour map superimposed on a USGS map of the survey area. The levels shown do not include an estimated cosmic ray contribution of 3.7 μR/h.

Over most of the survey area, the inferred exposure rates represent normal fluctuations in the natural background radiation and range from 4 to 15 μR/h. Over the Columbia River and lake regions, the exposure levels typically were less than 4 μR/h. The inferred exposure rates over these natural background areas are well within the range, 1 to 20 μR/h, found throughout the United States.[10] A gamma energy spectrum of the natural background radiation in the survey area is shown in Figure 4. Areas exhibiting exposure levels greater than 15 μR/h are indicative of the presence of the man-made radionuclides, which will be presented in the next section.

6.2 Detected Anomalies

Figure 5 displays the nonnatural (man-made) radiation activity in the form of a contour map superimposed on a USGS map of the survey area. The levels shown are in counts-per-second units and are representative of the intensity of the detected radioactive materials.

Each of the nine areas depicted in Figure 1 have been enlarged and included in this report as separate figures. Also included are the net gamma energy spectra within each of the MMGC anomaly areas. The net gamma energy spectrum is the resultant spectrum after the natural background gamma energy spectrum has been removed. Figure 6 is an example of one of these spectra from Figure 7. It is identified as spectrum number ("Spectrum") 3 with a live time ("Live Time") of 38 seconds. The spectrum number appears on the corresponding MMGC contour map (Figure 8) to indicate the region over which the spectral data was collected.

Many of the spectra do not have readily identifiable photopeaks but rather a smear or continuum. This is often the case when the radioactive material is either well shielded or the radiation detection system experiences very high count rates. Spectra which have low count rates and no identifiable photopeaks are good examples of shielded sources. Spectra which have high count rates and no identifiable photopeaks are good examples of spectral distortion. In regions where the MMGC value is very low, the spectra may not exhibit any photopeaks because there are insufficient MMGC counts.

Figures 7 through 24 are the associated spectra and contours for the nine blocked areas depicted in Figure 1, proceeding in a counter-clockwise direction from the city of Richland.

Figure 25 displays the ^{137}Cs activity in the form of a contour map superimposed on a USGS map of the survey area. The cesium extraction algorithm removes the effect of the relatively uniform cesium from worldwide fallout, leaving only the excess cesium attributable to site operations. The ^{137}Cs activity levels shown are in counts-per-second units and are representative of the intensity of the detected radioactive materials. Since the actual distribution/shielding of the isotope strongly influences the relationship between count rate and concentration, conversions to concentration cannot be made.

At Hanford, many different situations exist. Activity may be spatially extended and near the surface (BC area), carried into the soil as liquid wastes, contained in underground tanks, or stored in buildings. Each situation is unique. Even for soil sites, there is a large range of conversion coefficients. For example, if the deposition is fairly recent and the isotope is on the surface, then a conversion factor of 570 cps per μCi/m^2 might be used. If the deposition is very old and the isotope has migrated uniformly into the soil, then a conversion factor of 77 cps per pCi/g might be appropriate. If the deposition is not very old and the distribution approximates an exponential distribution with a relaxation length of 3 cm, then a conversion factor of 91 cps per pCi/g could be used to calculate the average concentration in the top 2.5 cm of soil.

6.3 Columbia River Shore and Islands

The areas of interest along the river have been segmented into seventeen regions. The radiation results of the three river flights, Figures 26 to 42, are presented in the form of a color-coded path plot that has been superimposed on each of the river USGS map segments. Since much of the field-of-view of the detection system contains water, the terrestrial exposure rate data is not very useful. Therefore, only the MMGC data are shown.

The orgin of the man-made activity seen in the river plots is easily seen in the corresponding full-coverage survey plots. For example, river flight activity in Figures 29, 31, 32, and 38 in detailed in survey Figures 20, 18, 16, and 8, respectively.

6.4 Ground-based Measurements

Seven ground-based terrestrial exposure rate measurements were collected at the locations depicted in Figure 3 with their results tabulated in Table 2. The measured land exposure rates ranged from 7.7 to 8.5 μR/h, resulting in an average value of 8.1 μR/h. The integrated off-shore exposure rate was 4.6 μR/h.

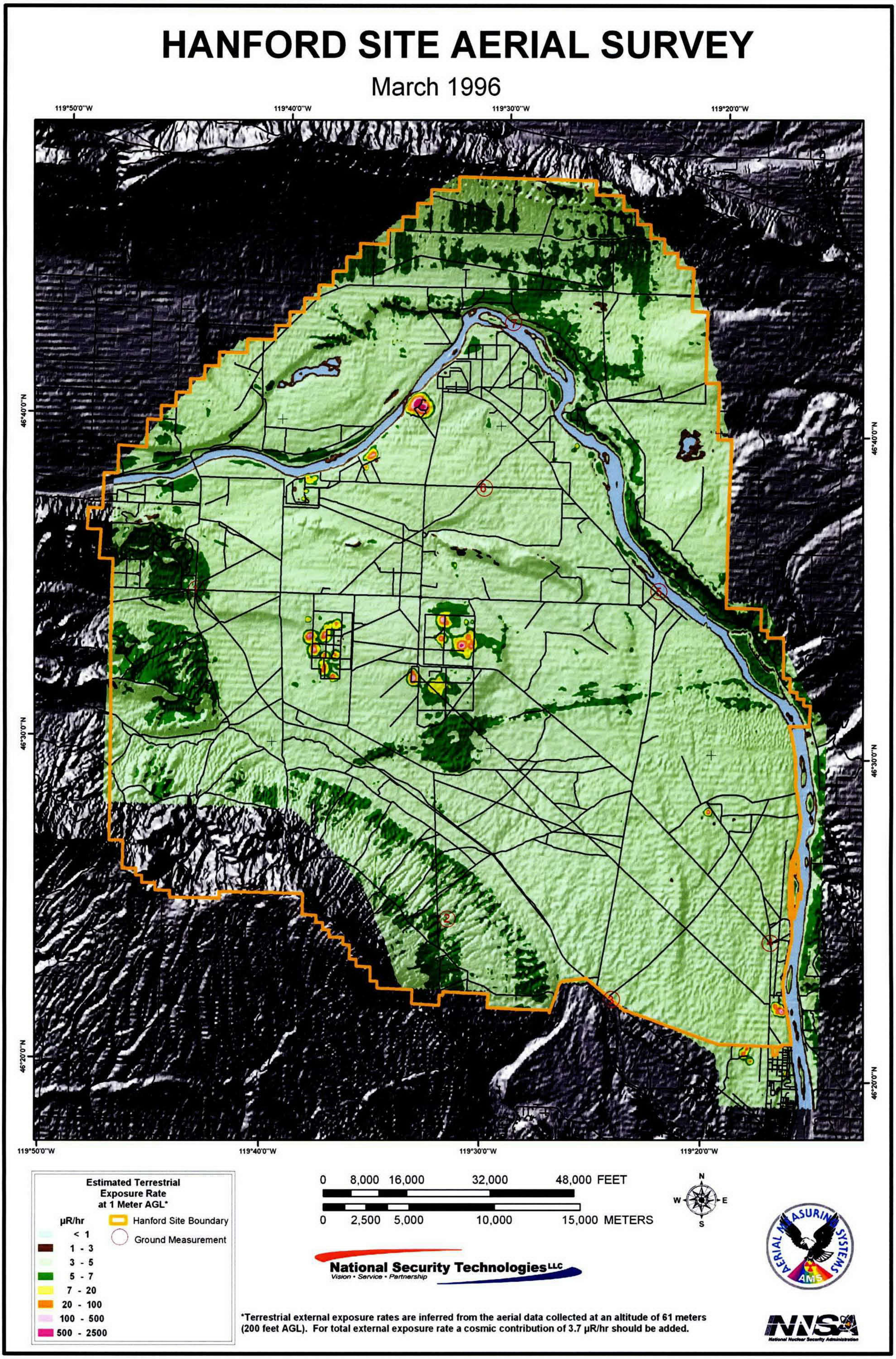


Figure 3. HR Terrestrial Gamma Radiation Exposure Rate Contours – Full Site

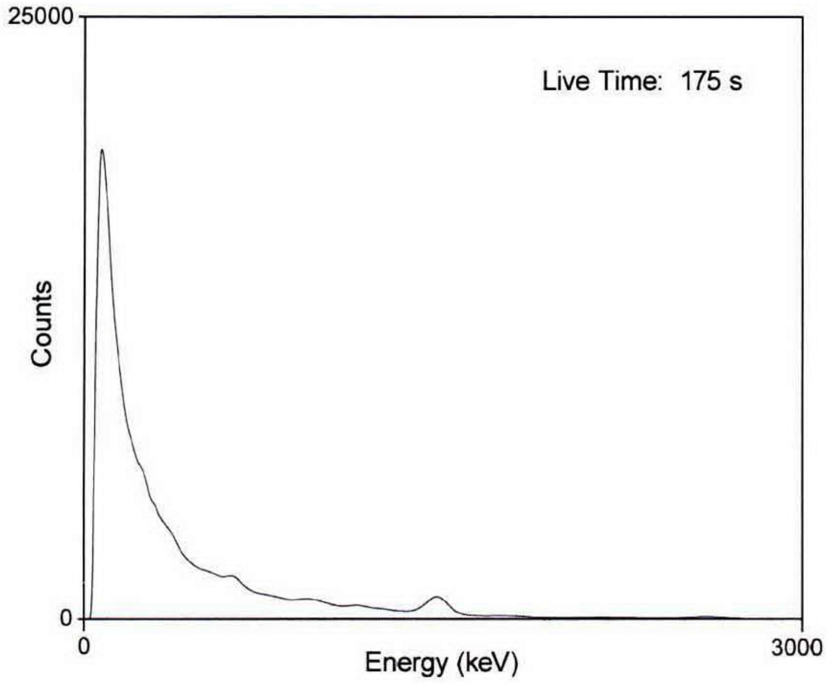


Figure 4. Background Gamma Energy Spectrum

Assuming an estimated cosmic ray contribution of 3.7 μR/h, the estimated radon exposure rate contribution during the survey period was approximately 0.9 μR/h.

A comparison of the ionization chamber exposure rates to the inferred aerial estimated exposure rates are also shown in Table 2. The inferred aerial exposure rates over land, which include an estimated cosmic ray contribution of 3.7 μR/h, ranged from 7.7 to 8.6 μR/h, resulting in an average value of 8.0 μR/h. The inferred off-shore exposure rate was 3.9 μR/h. The average difference between ground and aerial values was only 0.3 μR/h

The Hanford ground-based exposure rate measurements fall into a much narrower range than the inferred values from the aircraft. Because ground measurements were taken at locations that were convenient, they did not cover the entire range of background activity found at the site. From Figure 3, it is obvious that most of the background activity is within the range of 3 to 5 μR/h (6.7 to 8.7 including cosmic contribution). Ground measurements were not taken in geologically unique areas where background radioactivity is higher than the general site background.

The average difference between the inferred aerial exposure rate and the Hanford measured exposure rate at the selected locations shown in Table 2 is 0.3 μR, which is extremely good agreement. Any small disagreements between the aerial and ground data generally are attributed to differences between the fields of view of the detector systems. Each aerial data point covers an area several thousand times larger than data from a measurement made at one meter above the ground. Hence, the aerial system may detect radiation sources not seen by the ground-based system. Conversely, the aerial system may see a large region of low activity with one small "hot" area, whereas the ground-based system may be situated on the "hot" area.

7.0 CONCLUSION

An aerial radiological survey of the Hanford Nuclear Reservation was conducted from February 29 to March 21, 1996. The aerial survey was flown at an altitude of 61 meters (200 feet) AGL. The typical terrestrial exposure levels over the majority of the survey area were due to natural background radiation and ranged from 4 to 15 μR/h, which is well within the range found throughout the United States.

The non-naturally occurring (man-made) radionuclides that were detected within the survey area were a mixture of ^{137}Cs, ^{60}Co, ^{152}Eu, ^{241}Am, and ^{234m}Pa, with ^{137}Cs and ^{60}Co being the most predominant. A comparison of the present survey with the 1988 survey indicates a decrease of activity in most areas due to radioactive decay and cleanup activities, but it also revealed the locations of several new non-natural radiation activity areas that had not been detected in the 1988 survey. Visual comparisons of the plotted activity for the 1988 and 1996 surveys are presented in Appendix C. While the aerial survey can easily show changes in activity levels and location, only Hanford records can resolve why the levels have changed, especially in areas where increased activity is noted in 1996.

No detectable levels of man-made contamination existed on either bank of the Columbia River from the Priest Rapids Dam in the northwest to the periphery of the 100 B-C Area. The rest of the river shoreline showed decreased levels of ^{137}Cs activity at the locations consistent with past survey observations.

Figure 5. HR Man-Made Gross Count (MMGC) Contours – Full Site

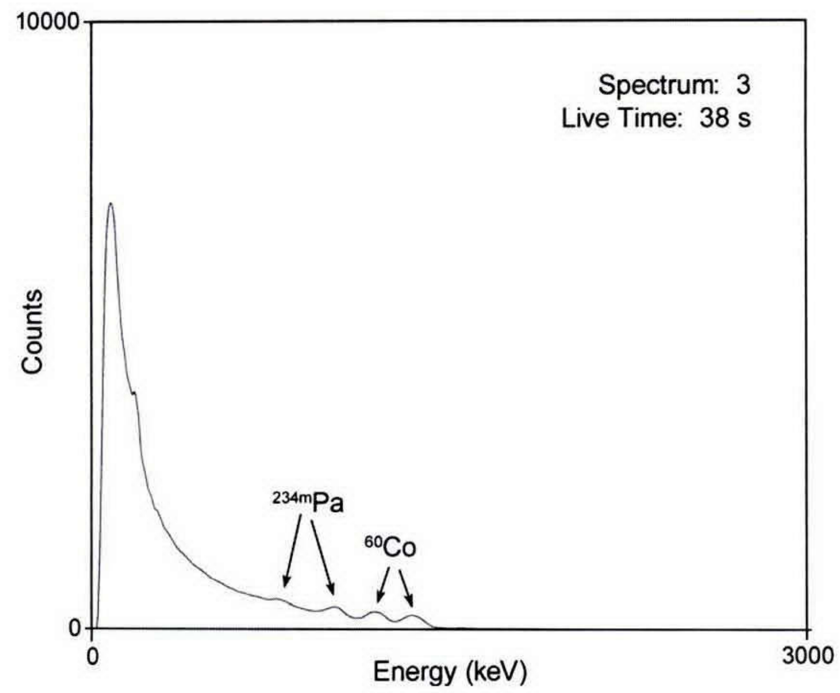


Figure 6. Sample Spectrum

Table 2. Comparison of Inferred-Aerial and Ground-Based Exposure Measurements

Site	Site Identifier	NAD83/WGS84 Coordinates Latitude (N)	Longitude (W)	Exposure Rates (μR/h at 1 m AGL)[a] Ion Chamber[b]	Inferred Aerial[c]
1	B-317	46° 34' 39.1"	119° 43' 38.8"	8.5 (0.4)	8.3 (0.1)
2	Z-321	46° 24' 41.1"	119° 31' 44.6"	8.4 (0.4)	8.6 (0.2)
3	H-324	46° 22' 21.5"	119° 24' 10.2"	8.1 (0.3)	7.7 (0.2)
4	N-323	46° 24' 14.6"	119° 17' 04.2"	8.1 (0.3)	7.7 (0.1)
5	T-317	46° 35' 03.0"	119° 22' 35.0"	7.8 (0.4)	7.7 (0.1)
6	Bleakley	46° 38' 05.4"	119° 30' 40.1"	7.7 (0.3)	7.8 (0.1)
7	Boat	46° 43' 15.0"	119° 29' 35.0"	4.6 (0.3)	3.9 (0.1)

[a] Measurement uncertainty (error) is enclosed in parenthesis and represents statistics only.

[b] Pressurized ionization chamber measurements were collected by Westinghouse Hanford NFM team on the morning of March 13, 1996, between 07:54 to 12:03.

[c] Includes an estimated cosmic ray contribution of 3.7 μR/h.

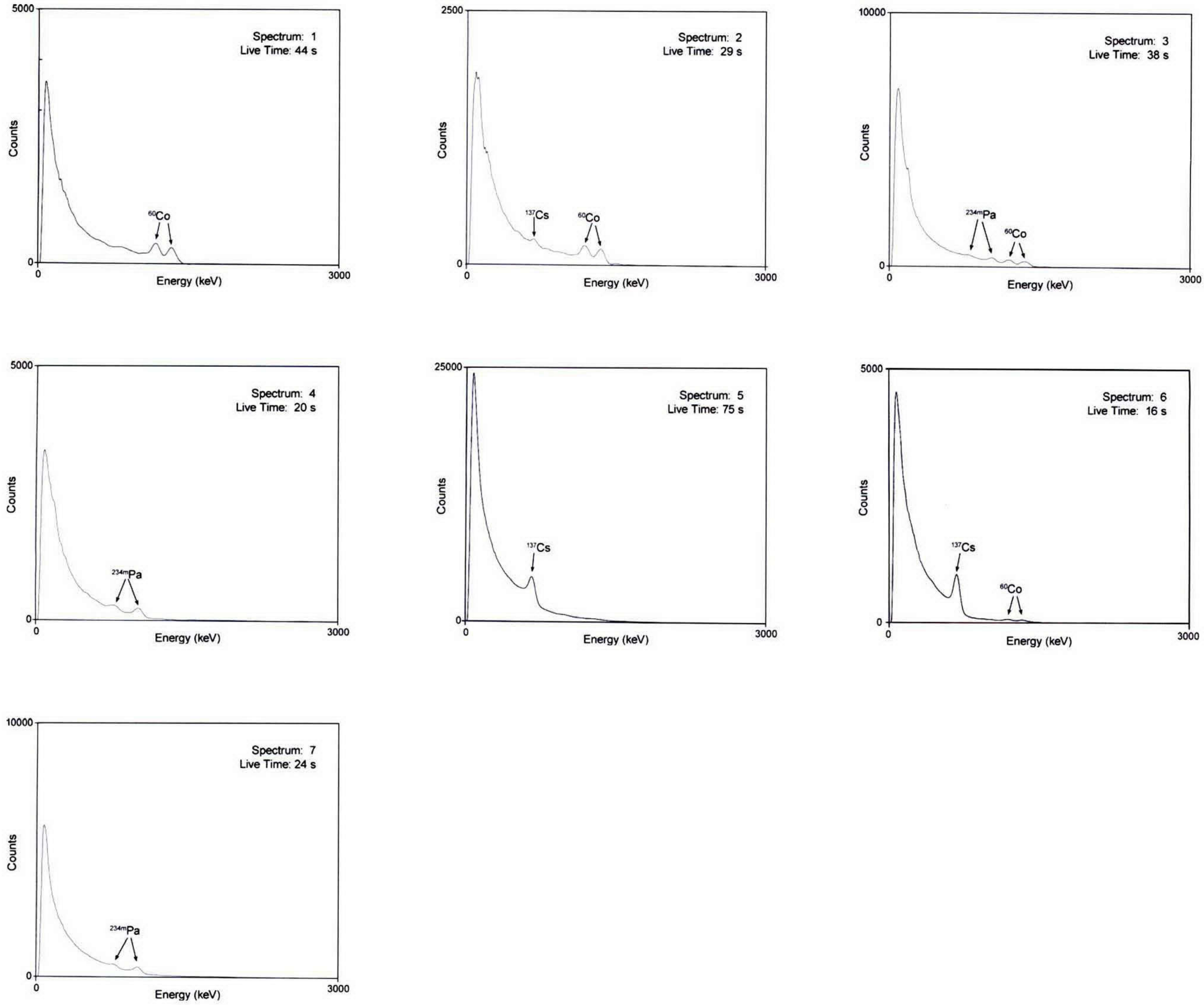


Figure 7. Spectra Corresponding to Regions of Interest on Figure 8

Figure 8. MMGC Contour of the 300 Area and Vicinity

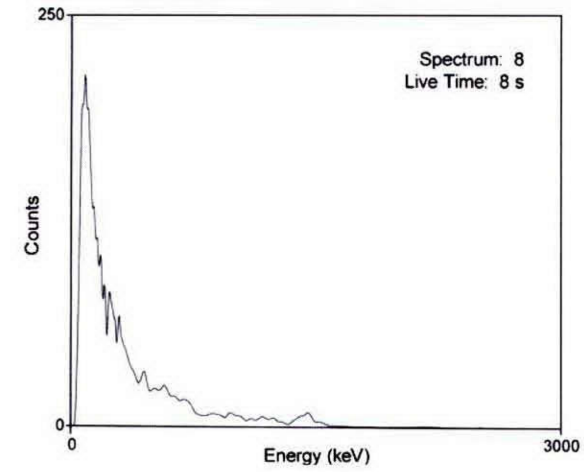


Figure 9. Spectra Corresponding to Regions of Interest on Figure 10

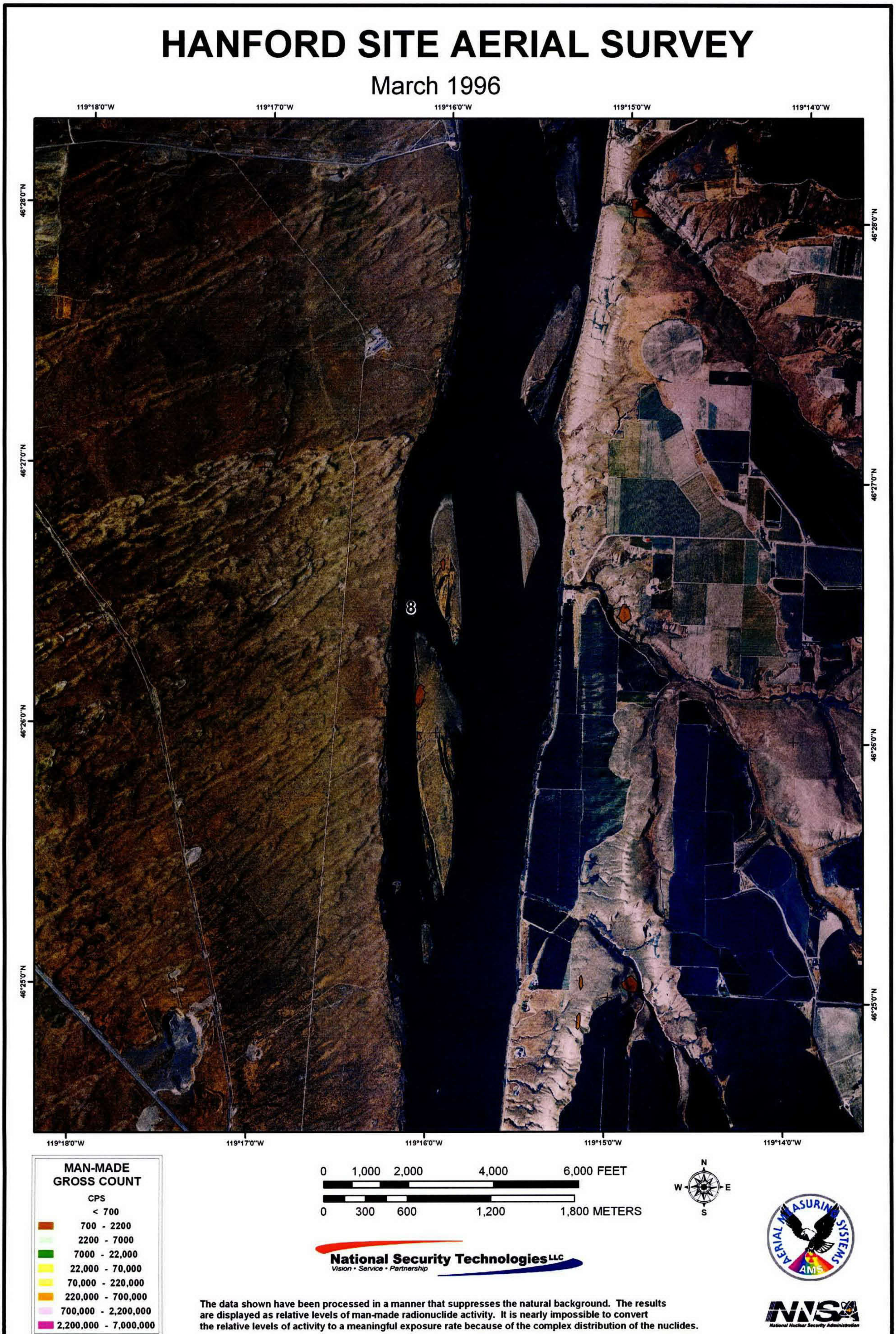


Figure 10. MMGC Contour of Wooded Island and Vicinity

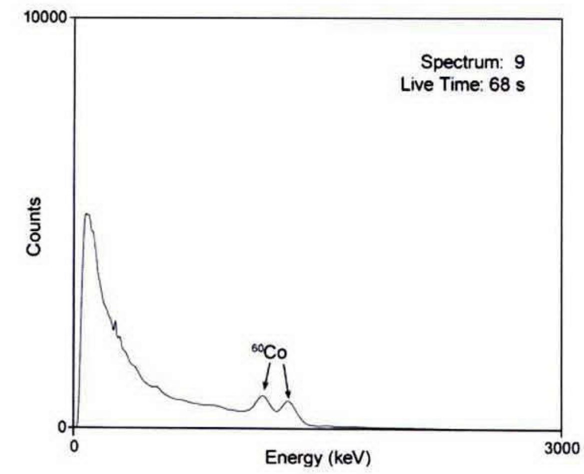


Figure 11. Spectra Corresponding to Regions of Interest on Figure 12

Figure 12. MMGC Contour of 400 Area and Columbia Generating Station (WPPSS in 1996)

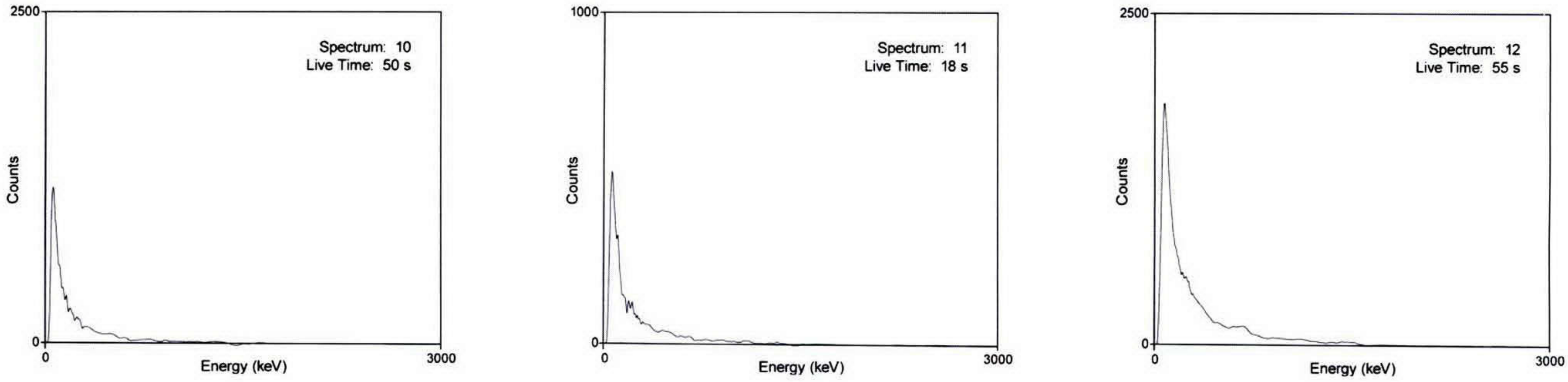


Figure 13. Spectra Corresponding to Regions of Interest on Figure 14

Figure 14. MMGC Contour of Old Hanford Townsite

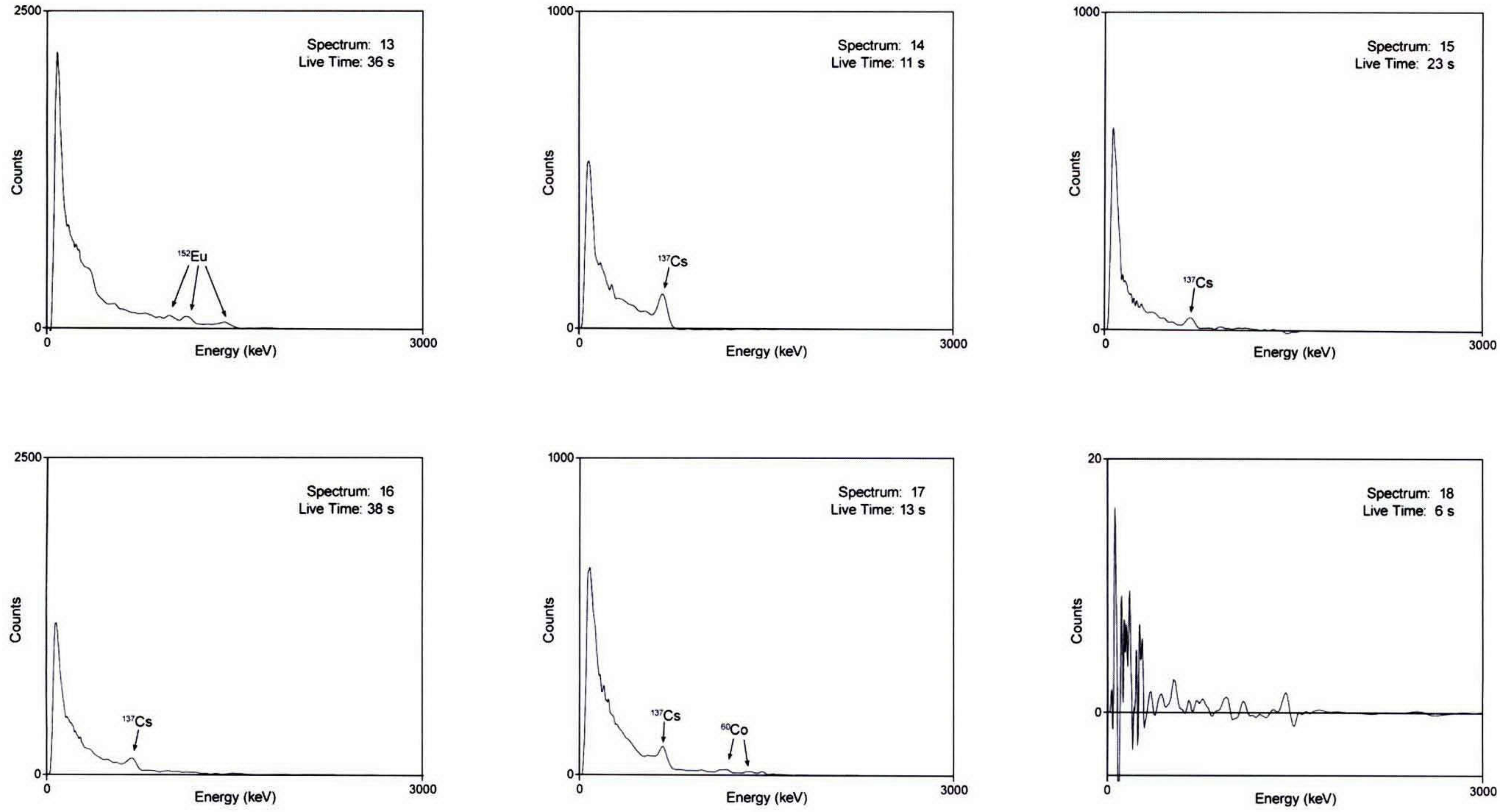


Figure 15. Spectra Corresponding to Regions of Interest on Figure 16

Figure 16. MMGC Contour of 100-F and 100-H Areas

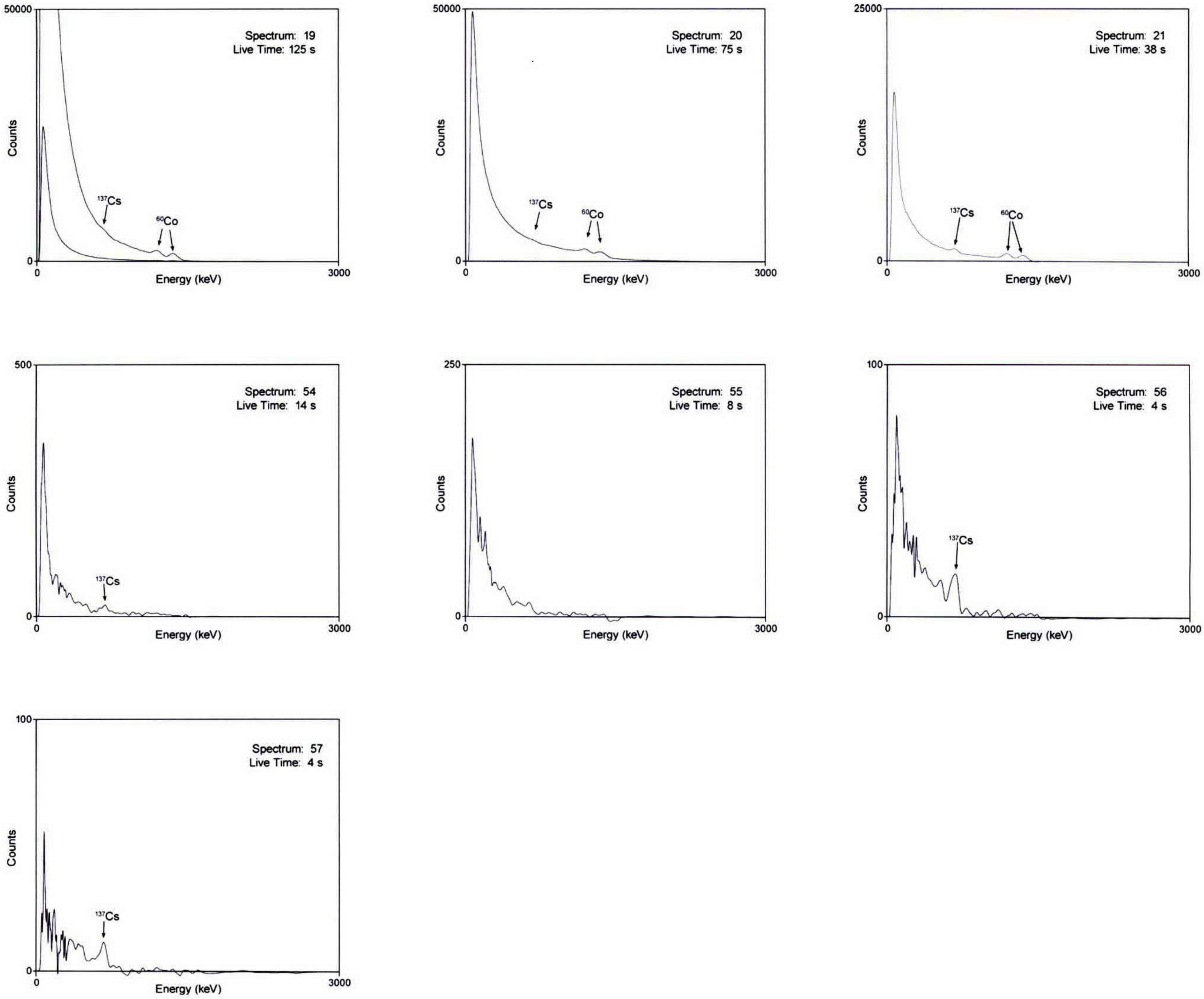


Figure 17. Spectra Corresponding to Regions of Interest on Figure 18

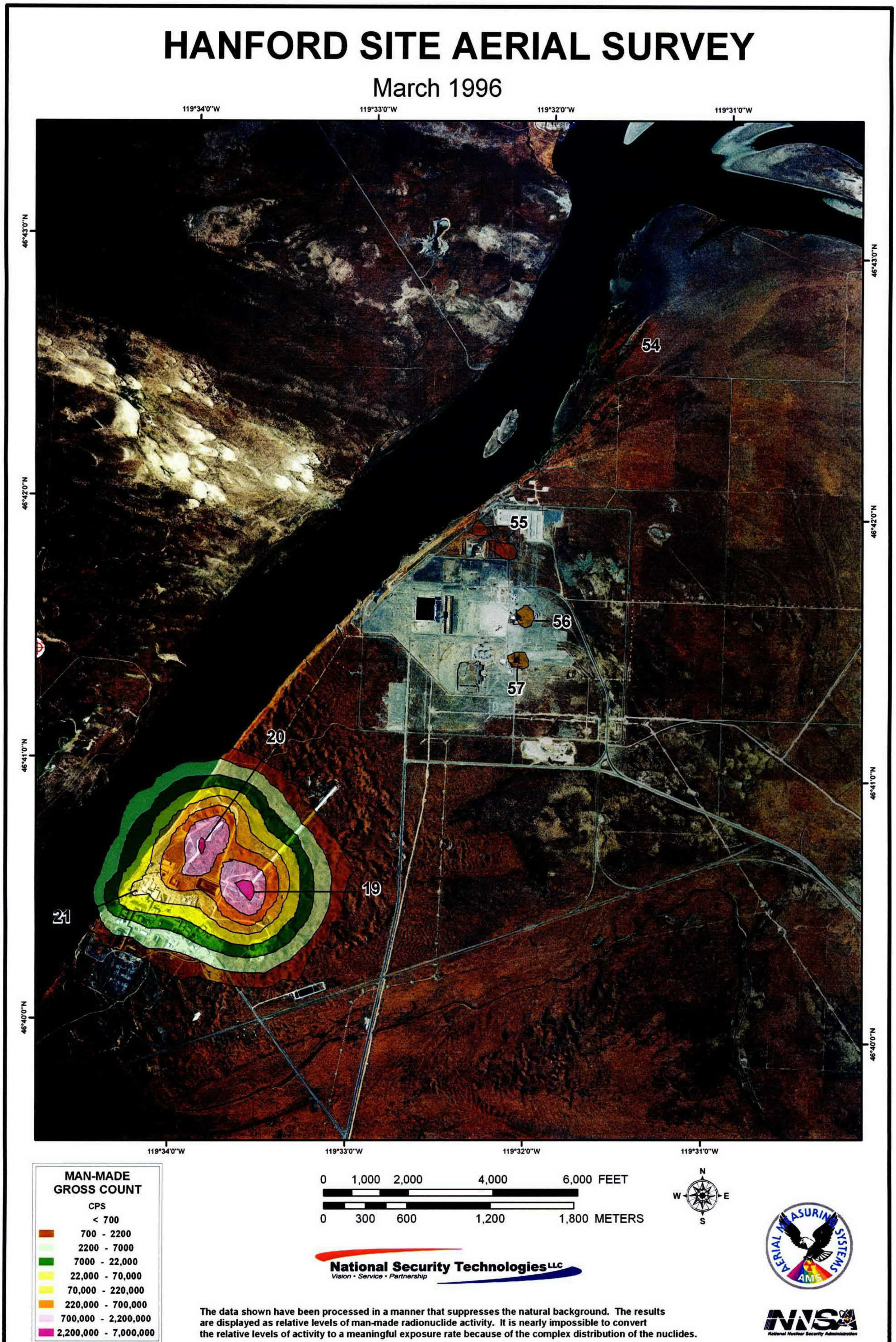


Figure 18. MMGC Contour of 100-D/DR and 100-N Areas

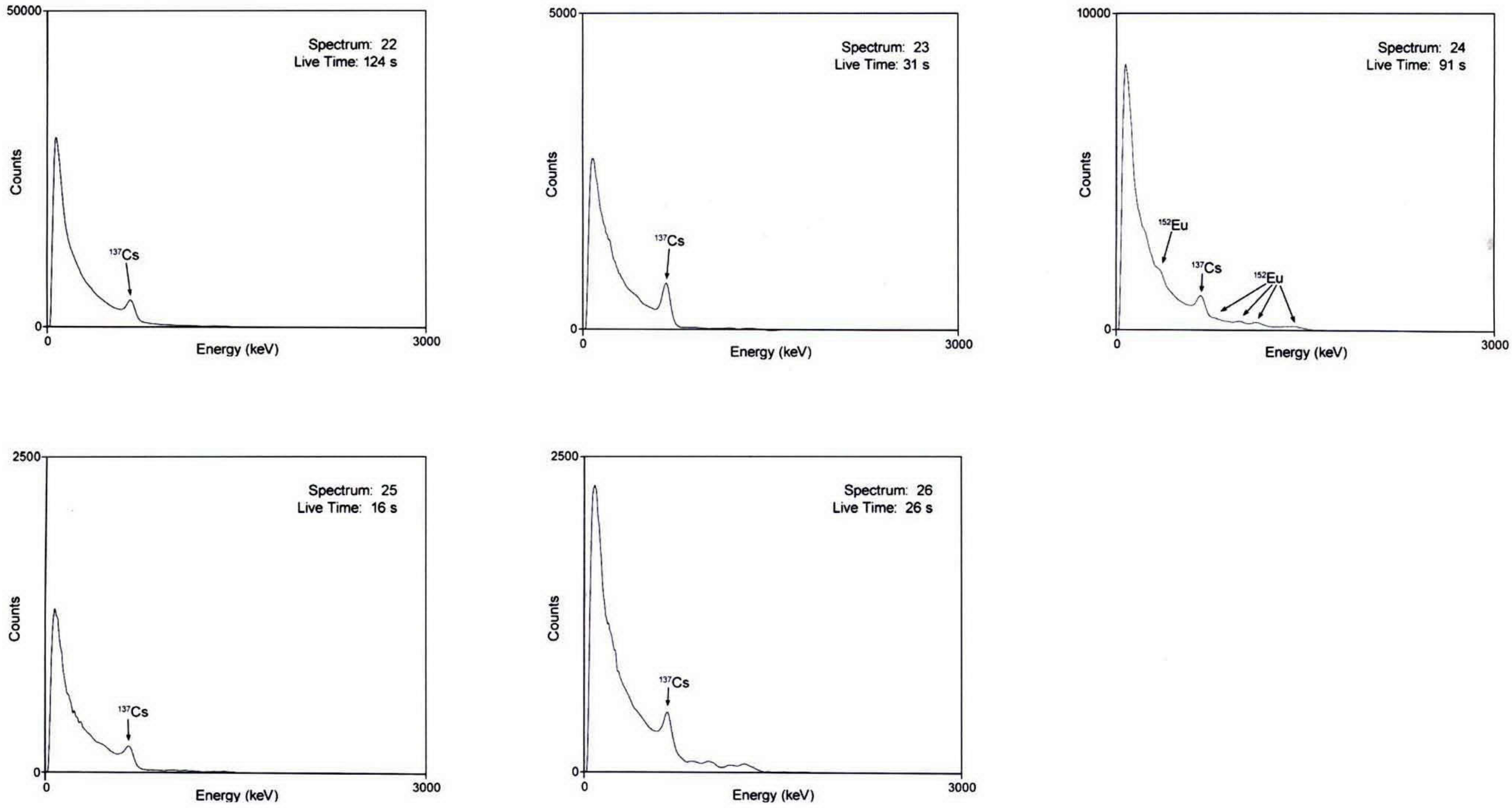


Figure 19. Spectra Corresponding to Regions of Interest on Figure 20

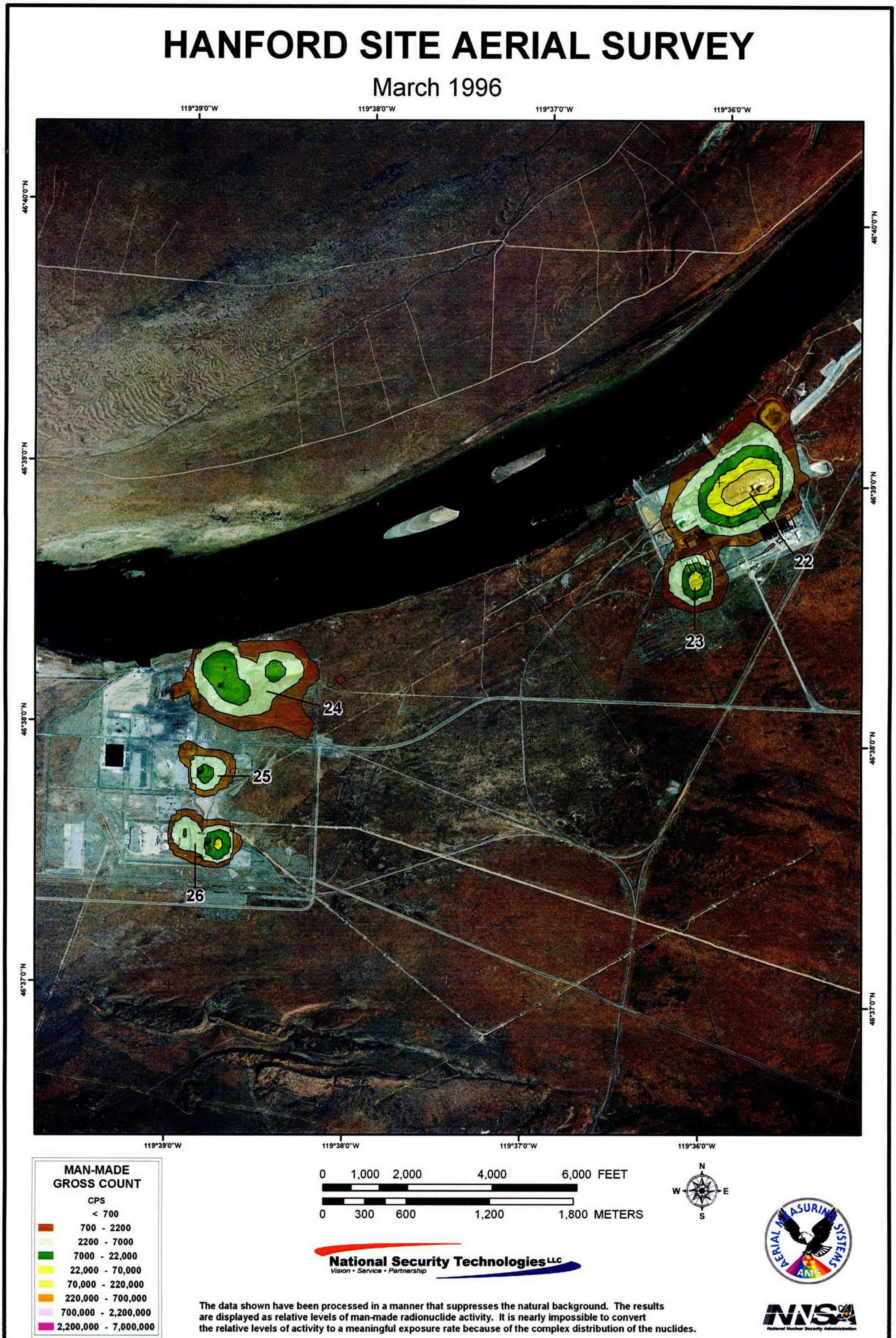


Figure 20. MMGC Contour of 100-K and 100-B/C Areas

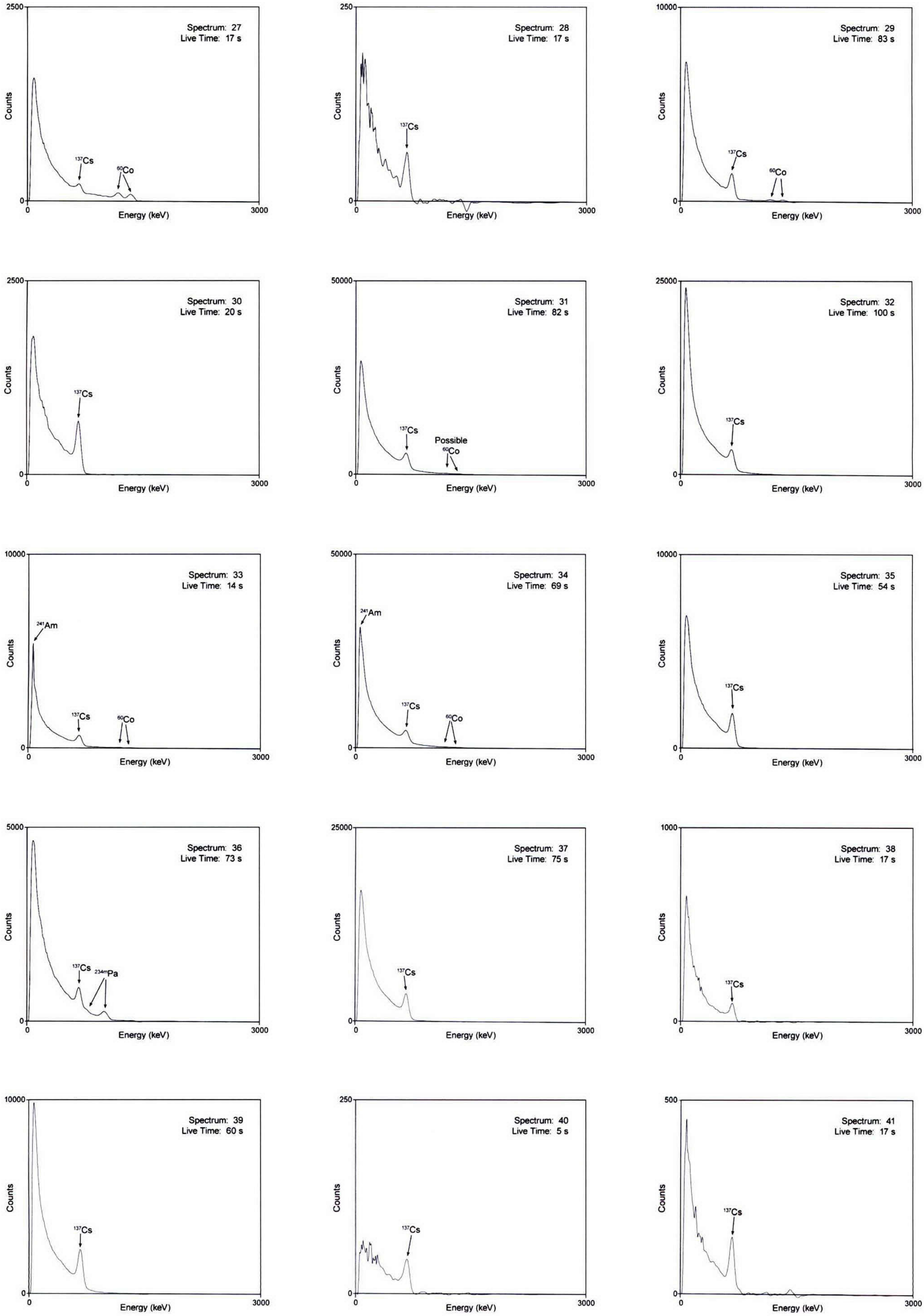


Figure 21. Spectra Corresponding to Regions of Interest on Figure 22

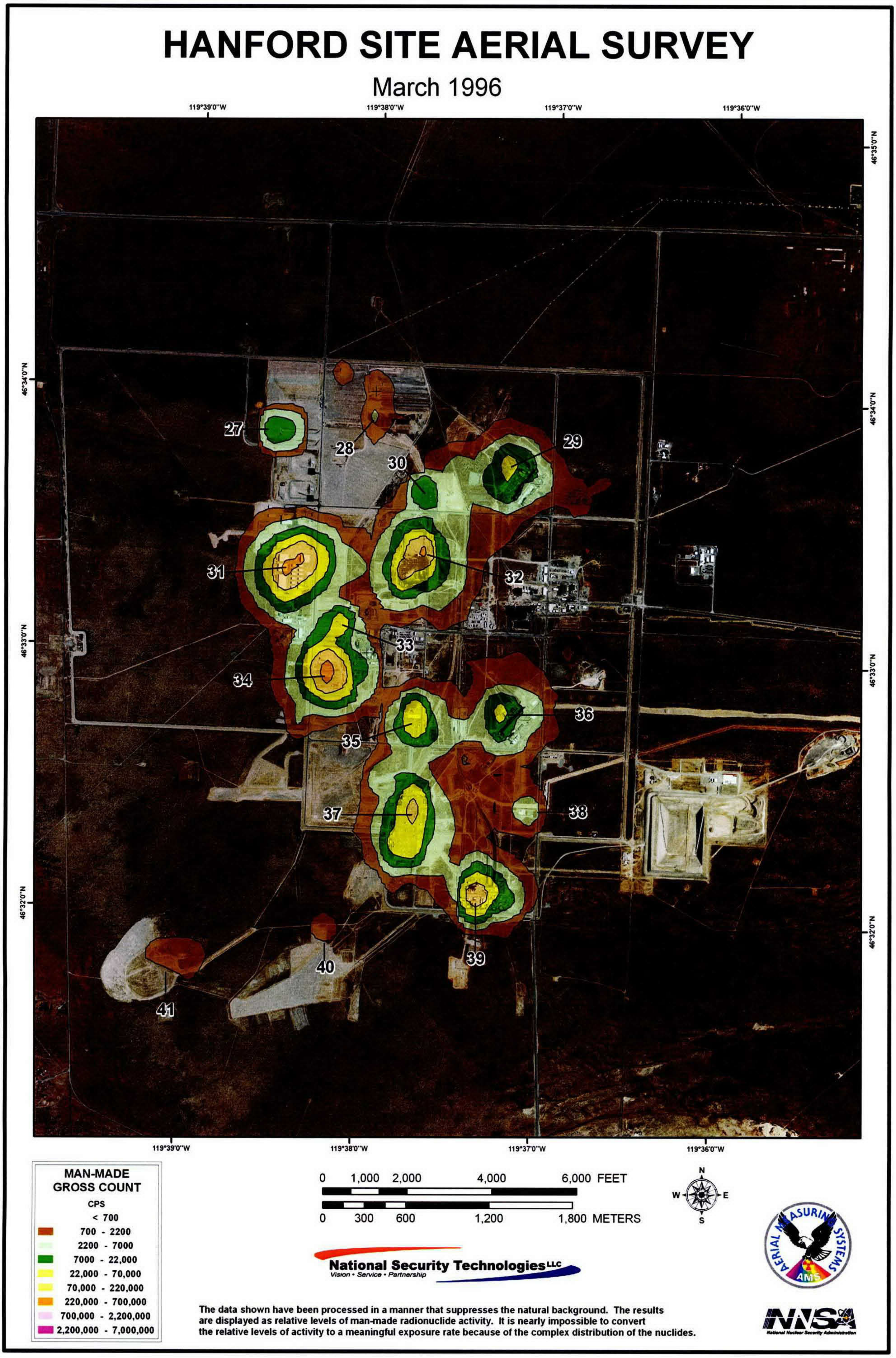


Figure 22. MMGC Contour of 200-West Area

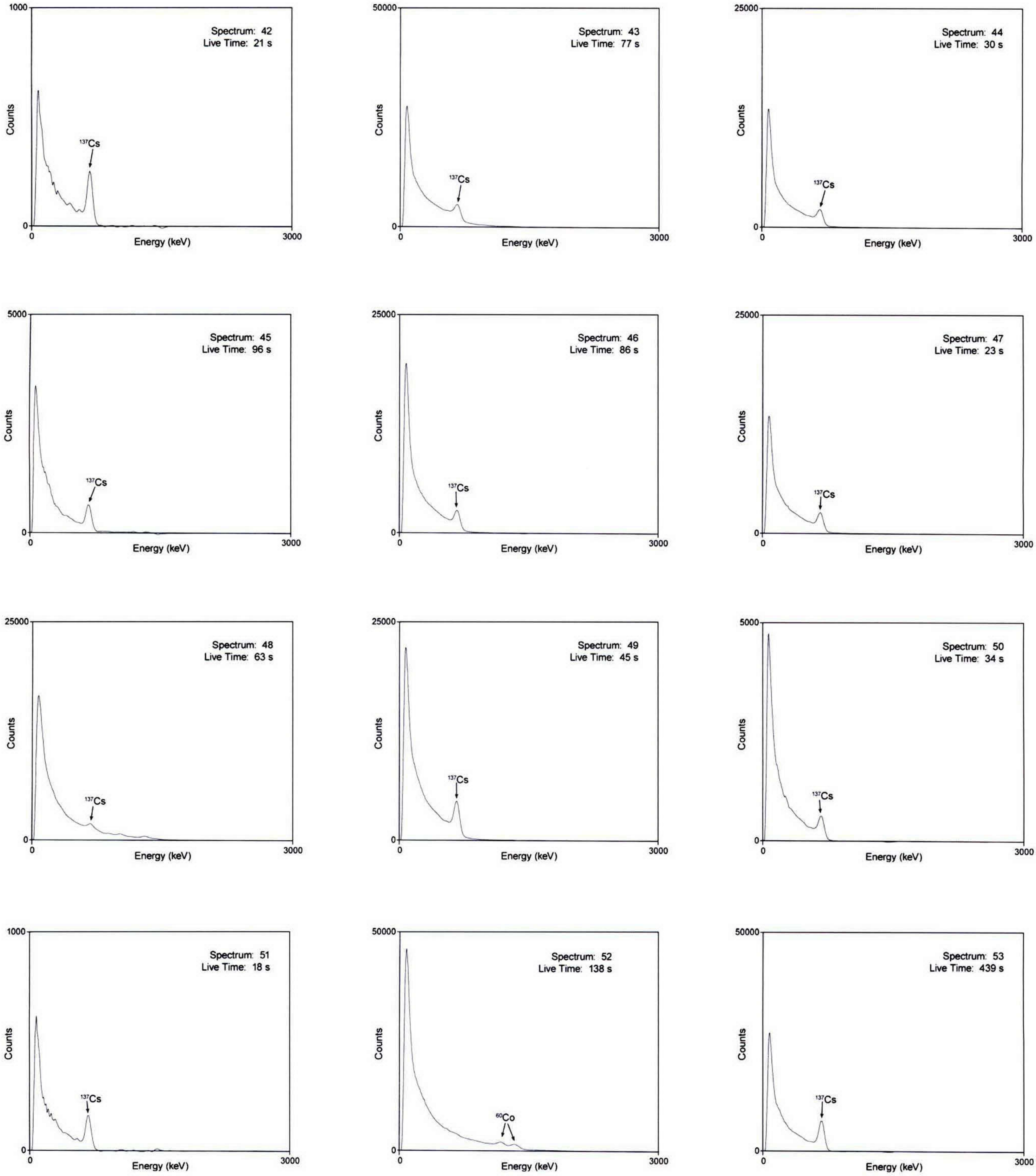


Figure 23. Spectra Corresponding to Regions of Interest on Figure 24

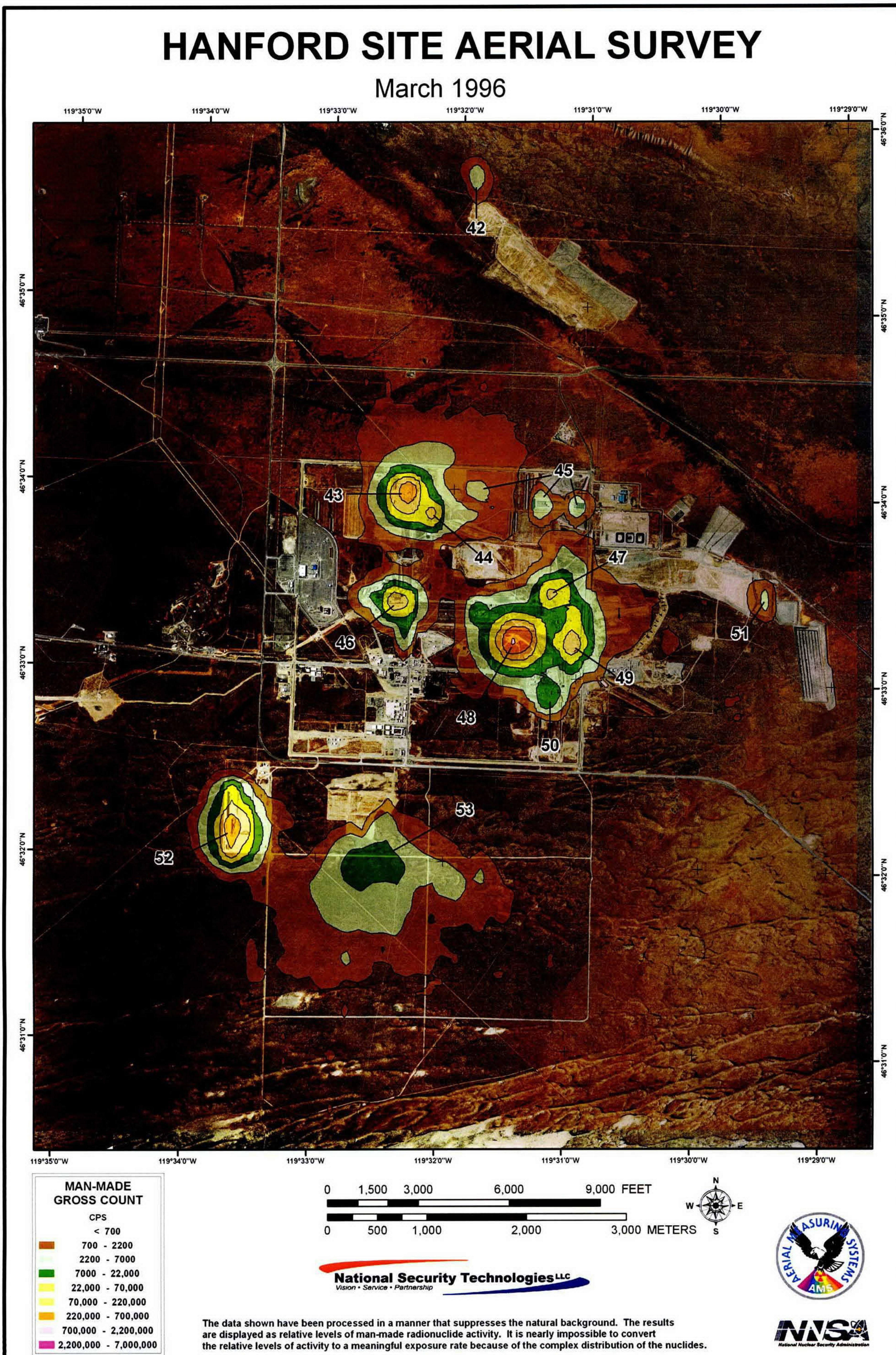


Figure 24. MMGC Contour of 200-East Area

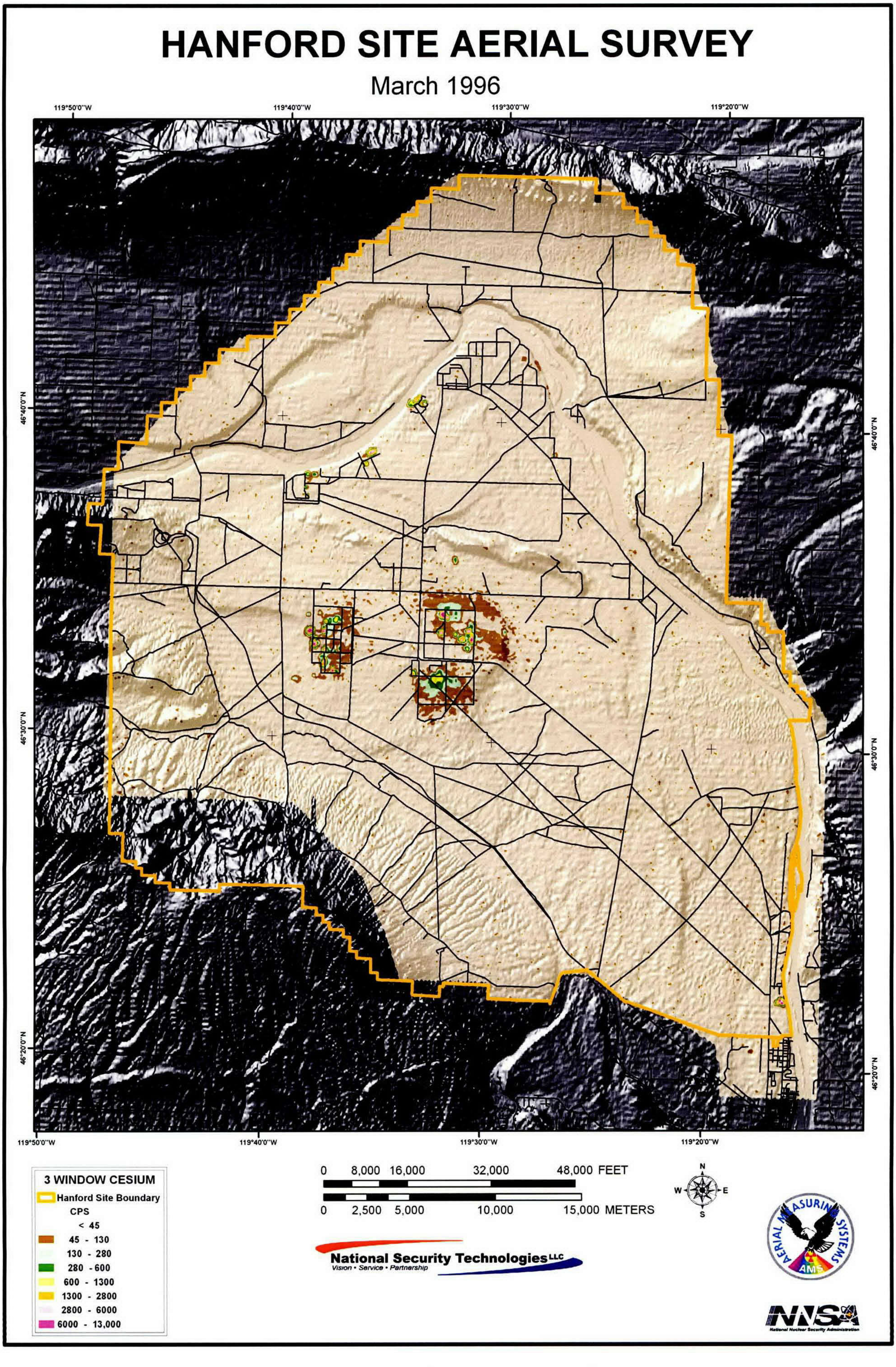


Figure 25. HR Cesium-137 Count Rate Contours – Full Site

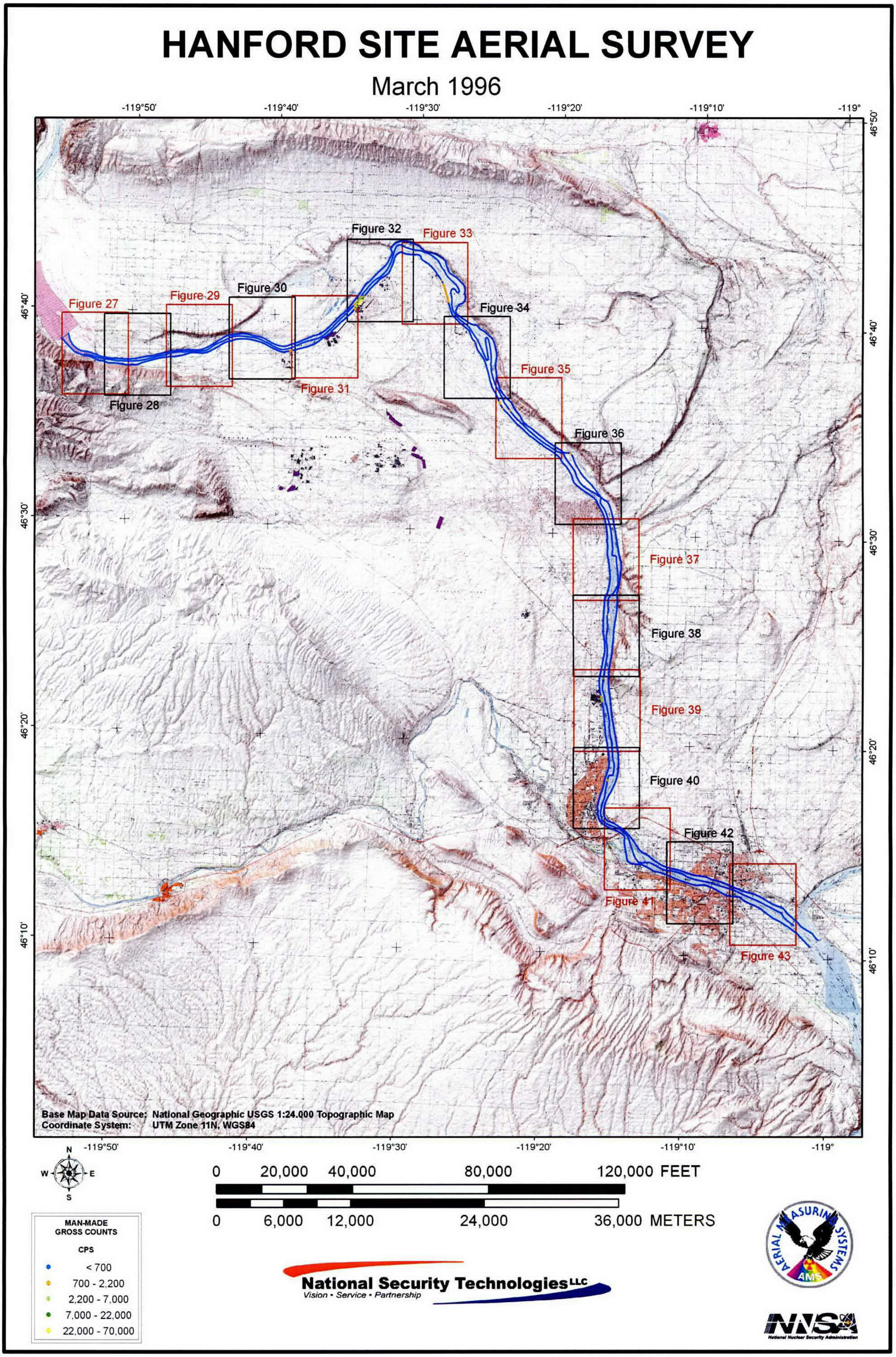


Figure 26. Man-Made Gross count (MMGC) Path Plot of Columbia River Flight Sections

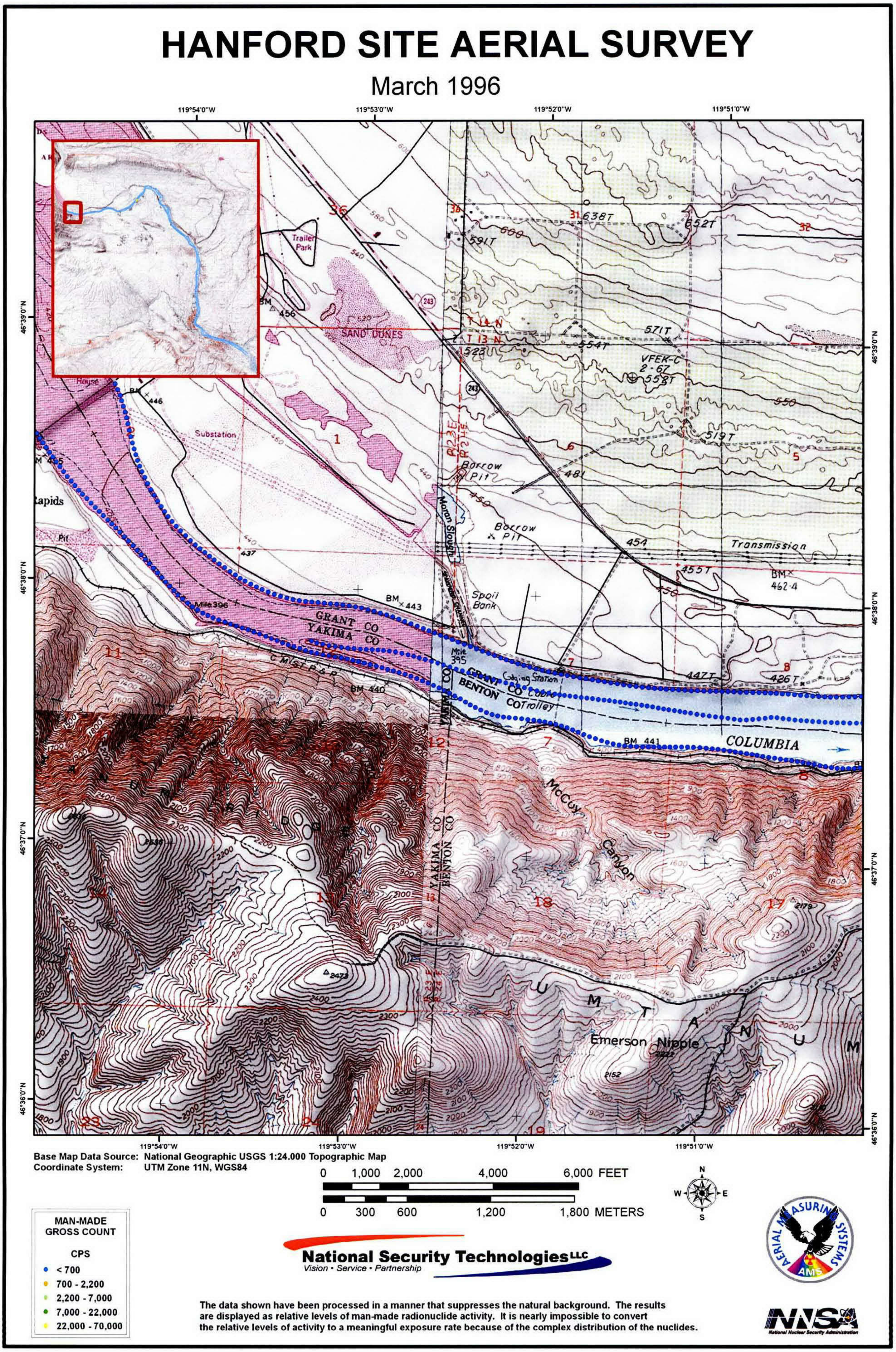


Figure 27. MMGC Path Plot of Columbia River Flight Section #1

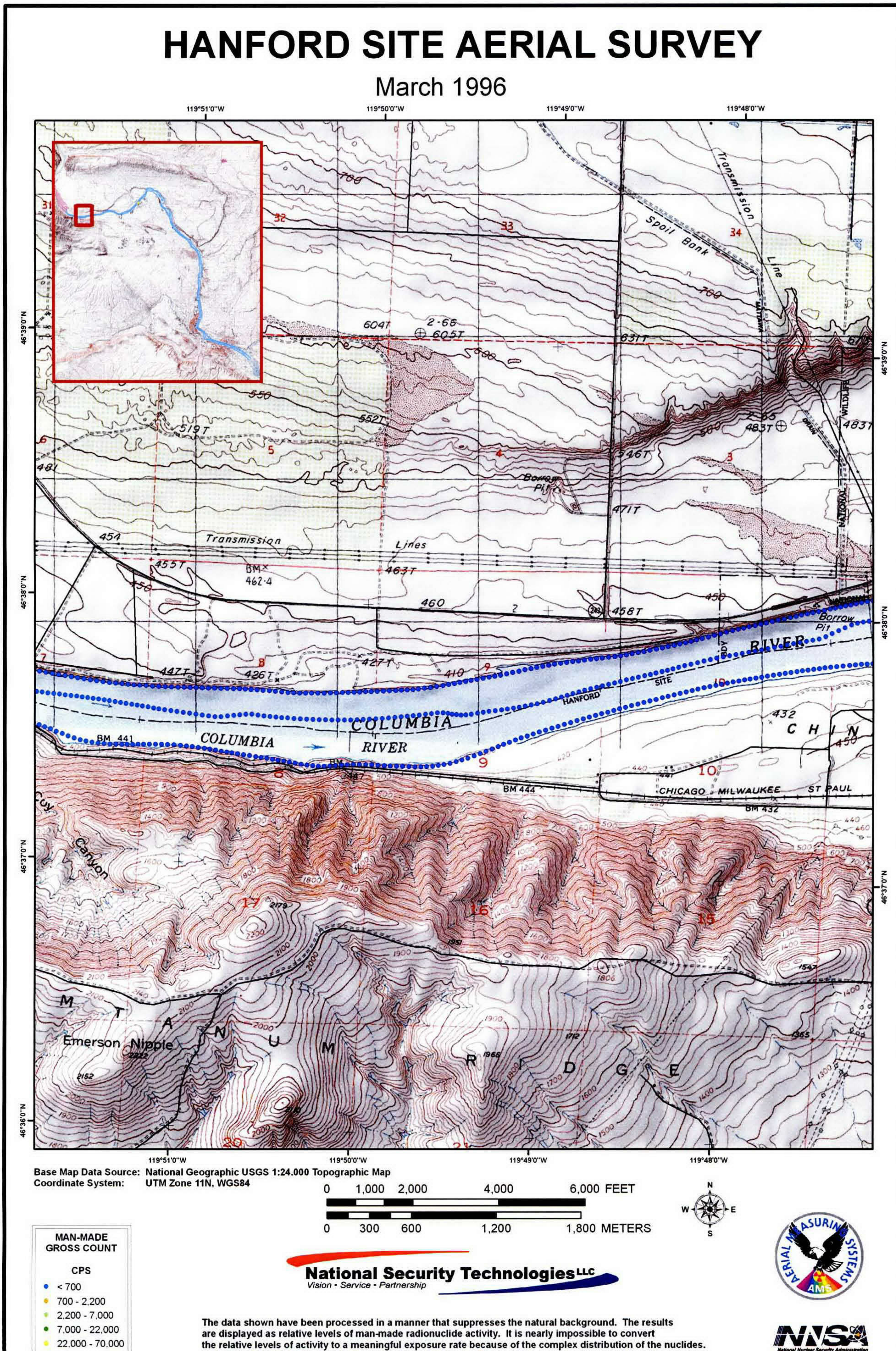


Figure 28. MMGC Path Plot of Columbia River Flight Section #2

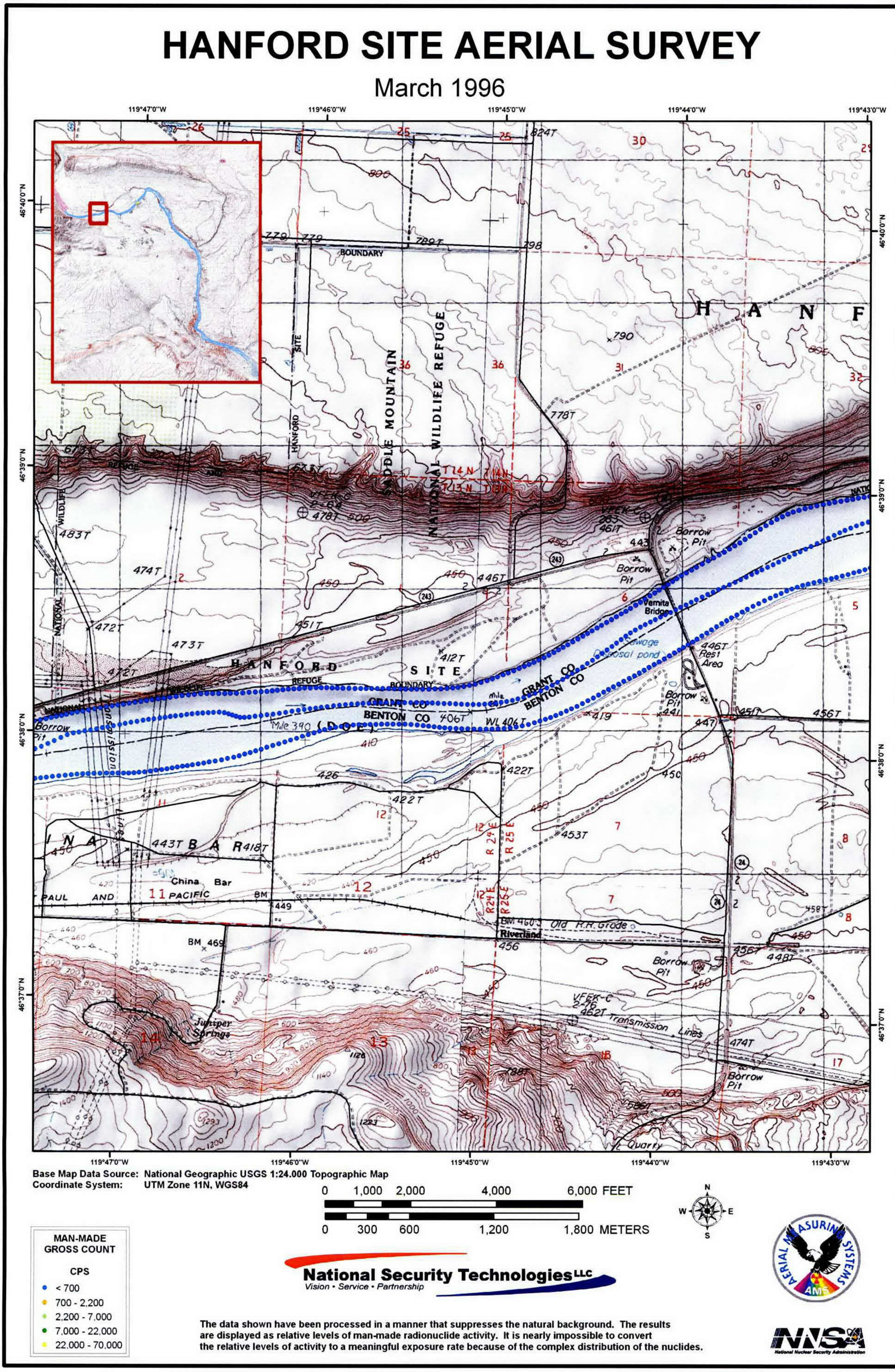


Figure 29. MMGC Path Plot of Columbia River Flight Section #3

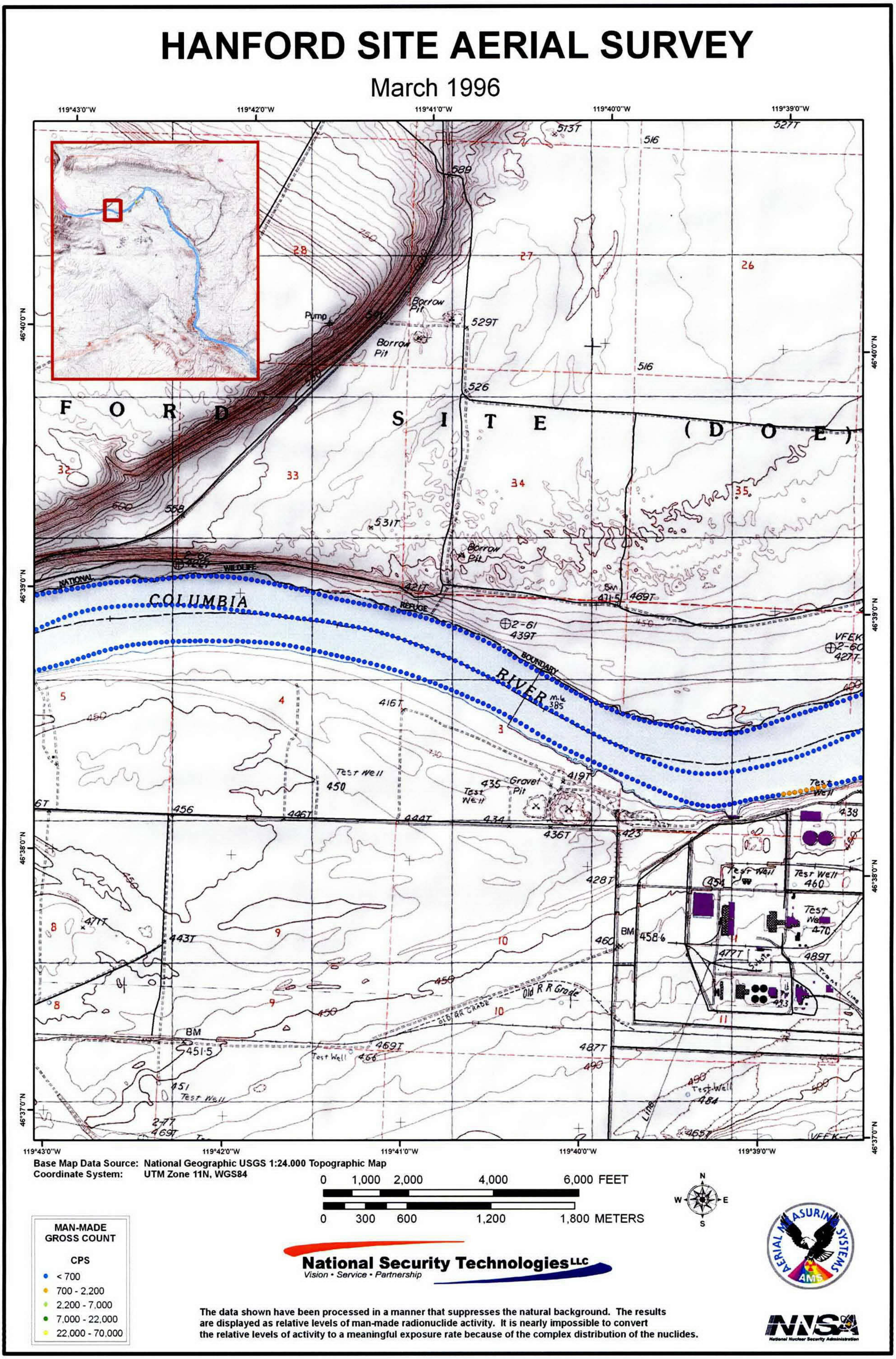
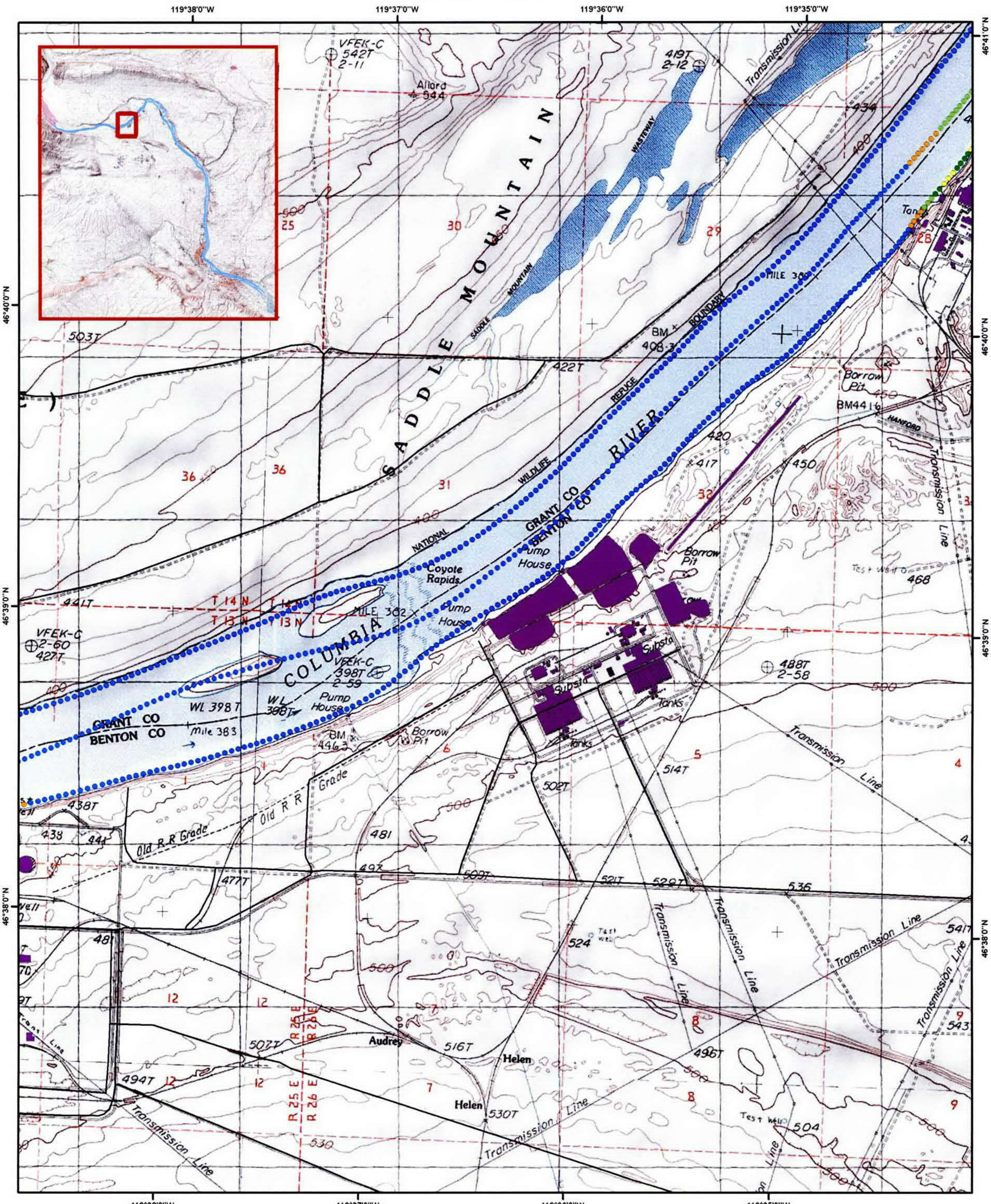


Figure 30. MMGC Path Plot of Columbia River Flight Section #4

HANFORD SITE AERIAL SURVEY

March 1996



Base Map Data Source: National Geographic USGS 1:24.000 Topographic Map
Coordinate System: UTM Zone 11N, WGS84

0 1,000 2,000 4,000 6,000 FEET

0 300 600 1,200 1,800 METERS

N W E S

MAN-MADE GROSS COUNT

CPS

- < 700
- 700 - 2,200
- 2,200 - 7,000
- 7,000 - 22,000
- 22,000 - 70,000

National Security Technologies LLC
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The data shown have been processed in a manner that suppresses the natural background. The results are displayed as relative levels of man-made radionuclide activity. It is nearly impossible to convert the relative levels of activity to a meaningful exposure rate because of the complex distribution of the nuclides.

AERIAL MEASURING SYSTEMS AMS

NNSA National Nuclear Security Administration

Figure 31. MMGC Path Plot of Columbia River Flight Section #5

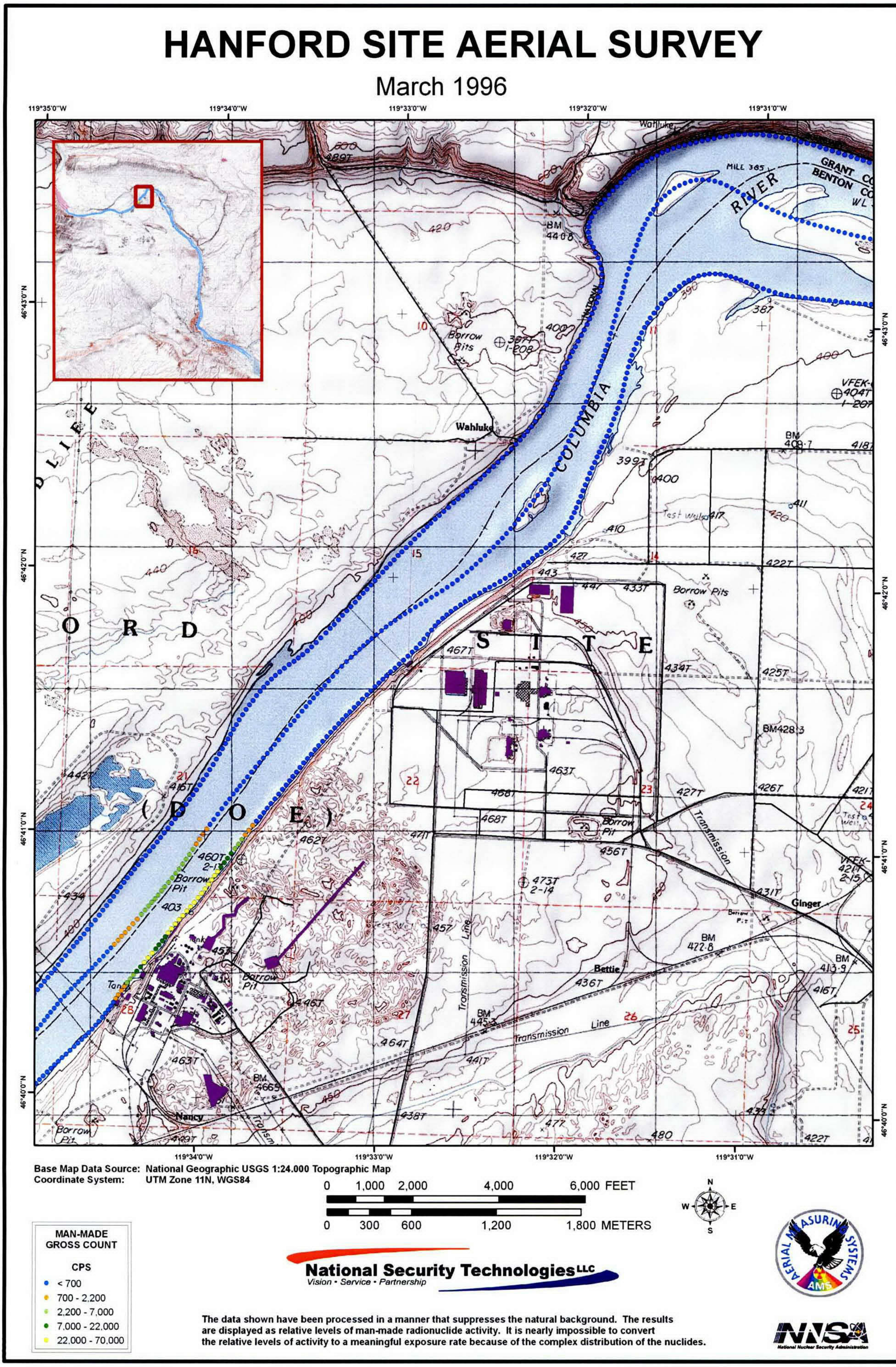


Figure 32. MMGC Path Plot of Columbia River Flight Section #6

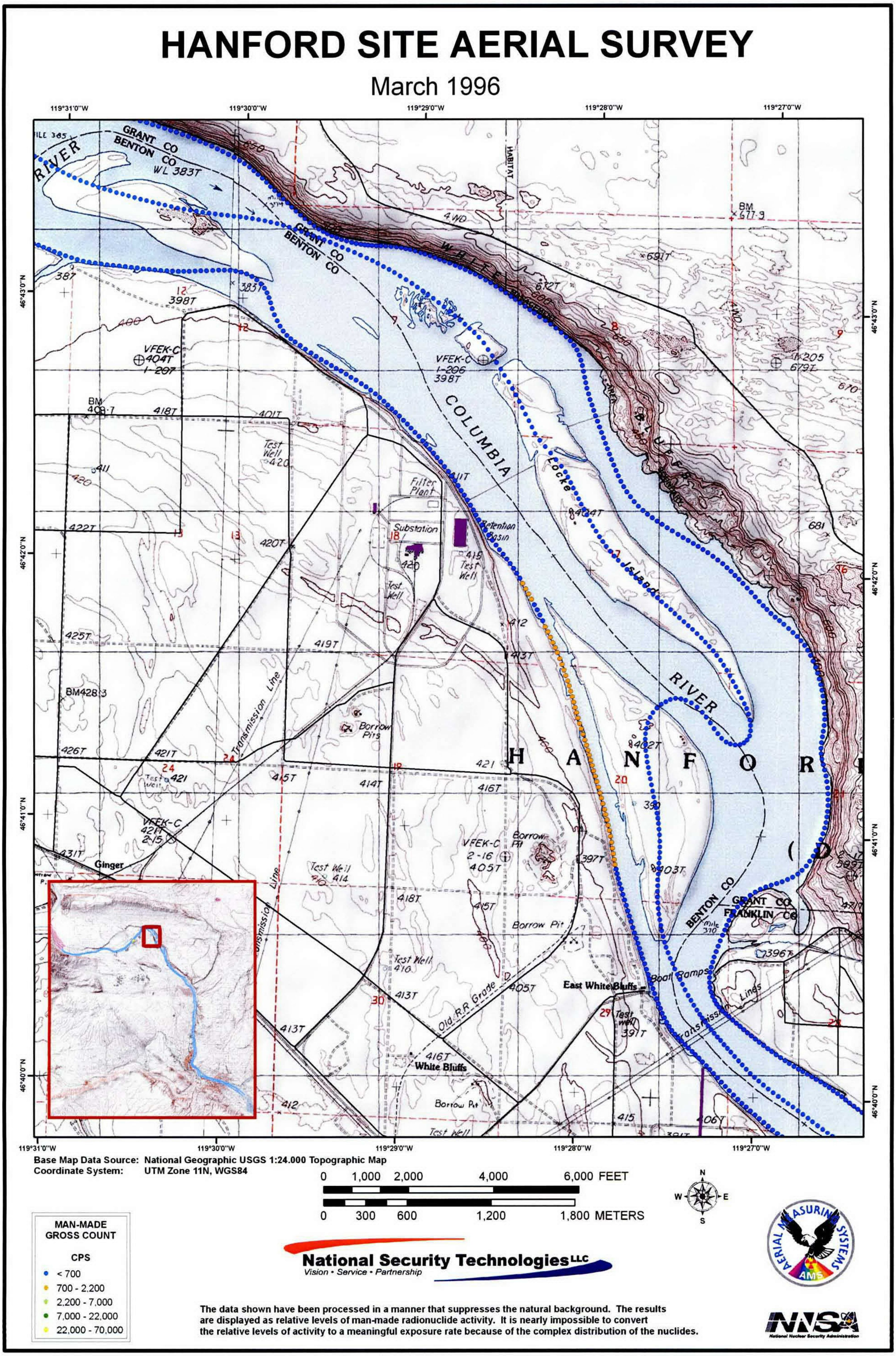


Figure 33. MMGC Path Plot of Columbia River Flight Section #7

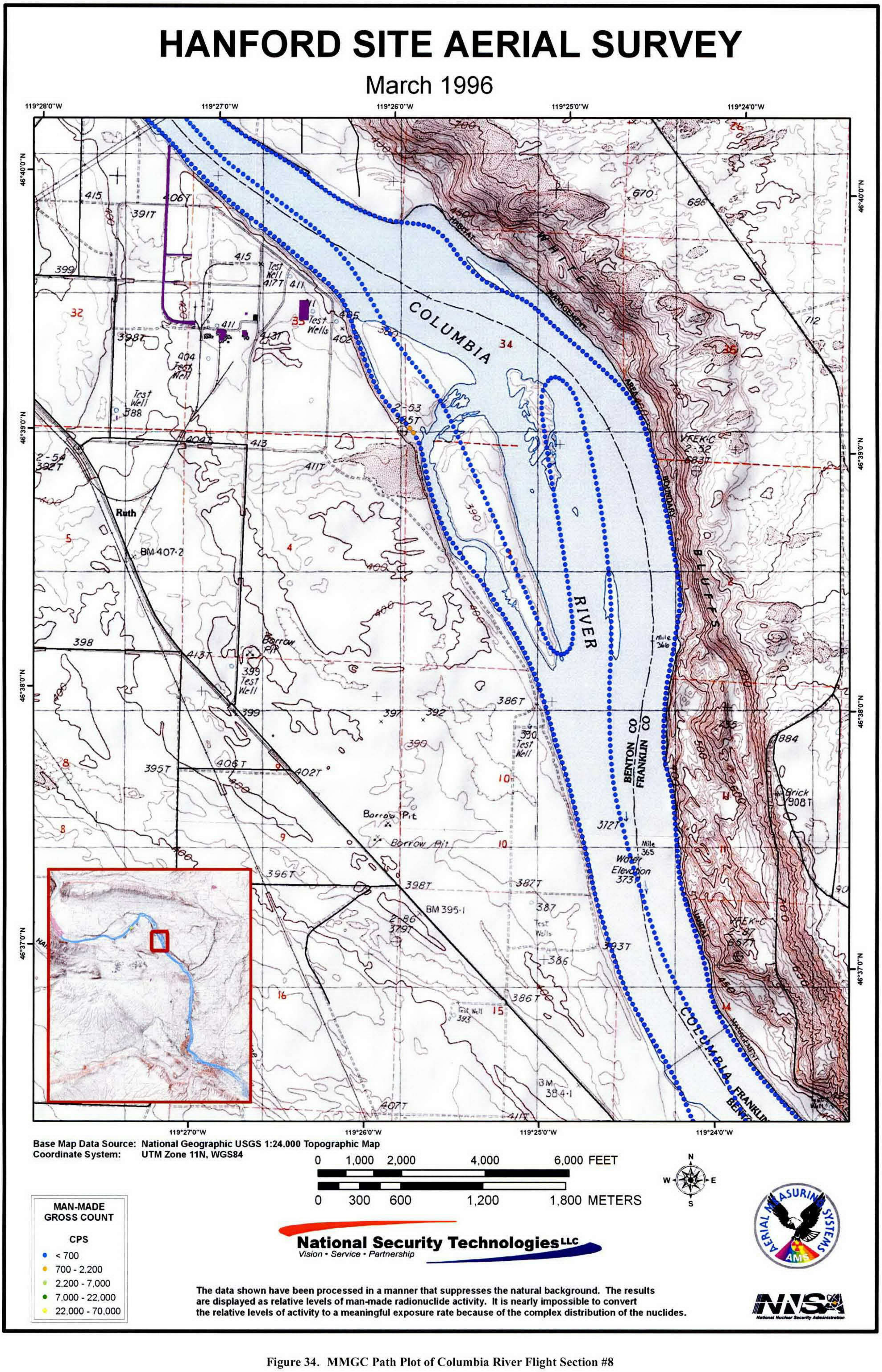


Figure 34. MMGC Path Plot of Columbia River Flight Section #8

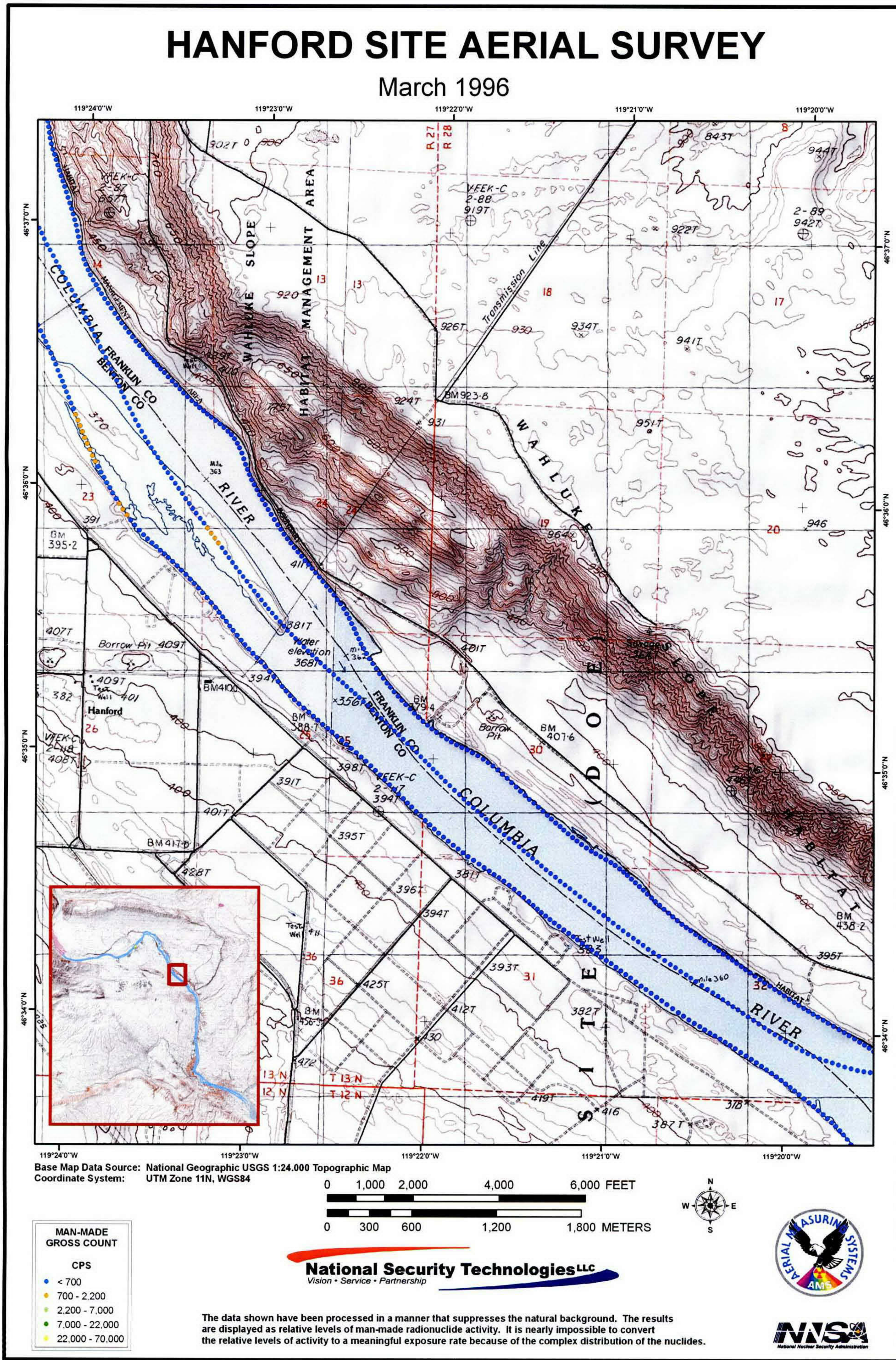


Figure 35. MMGC Path Plot of Columbia River Flight Section #9

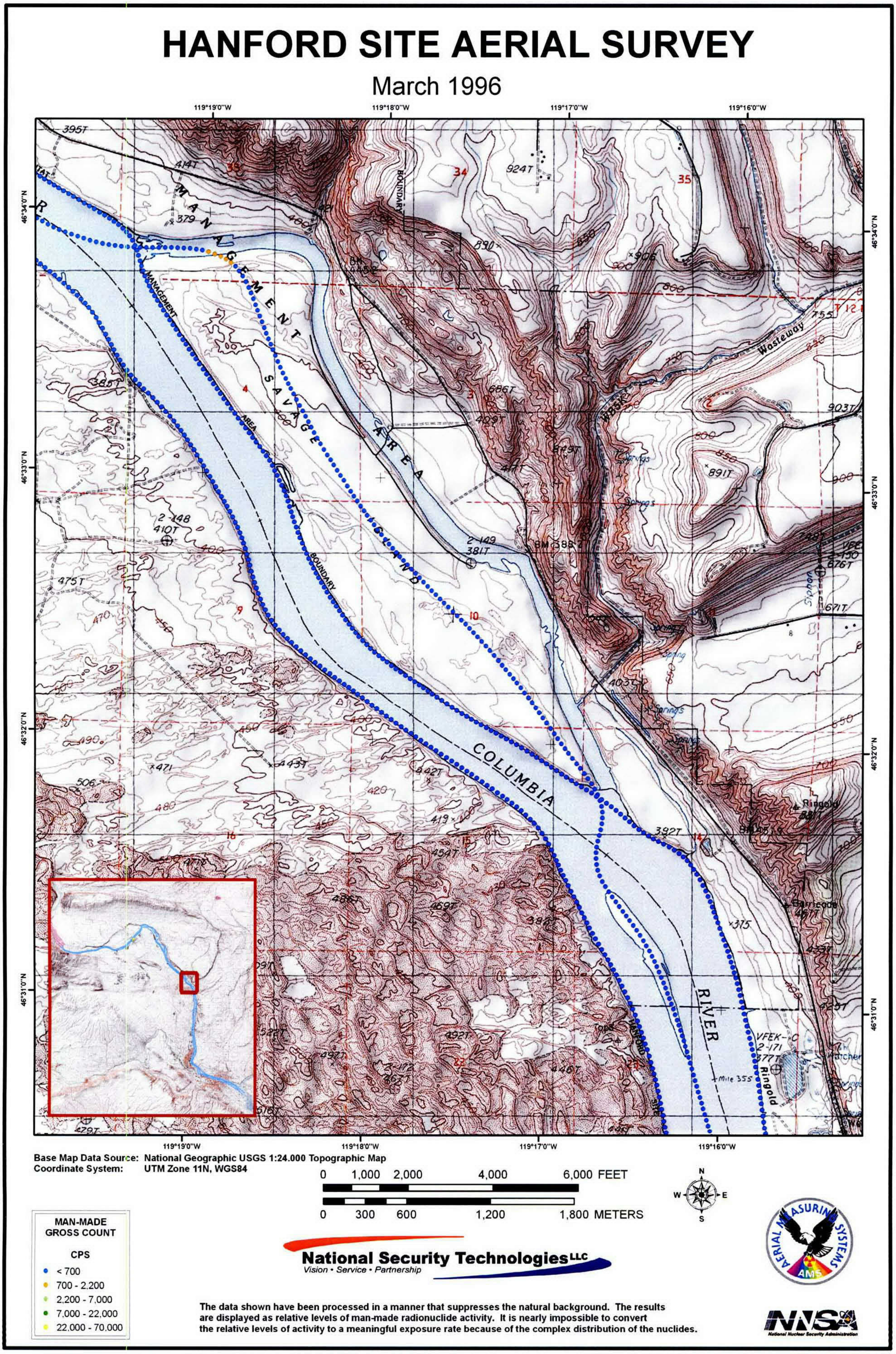


Figure 36. MMGC Path Plot of Columbia River Flight Section #10

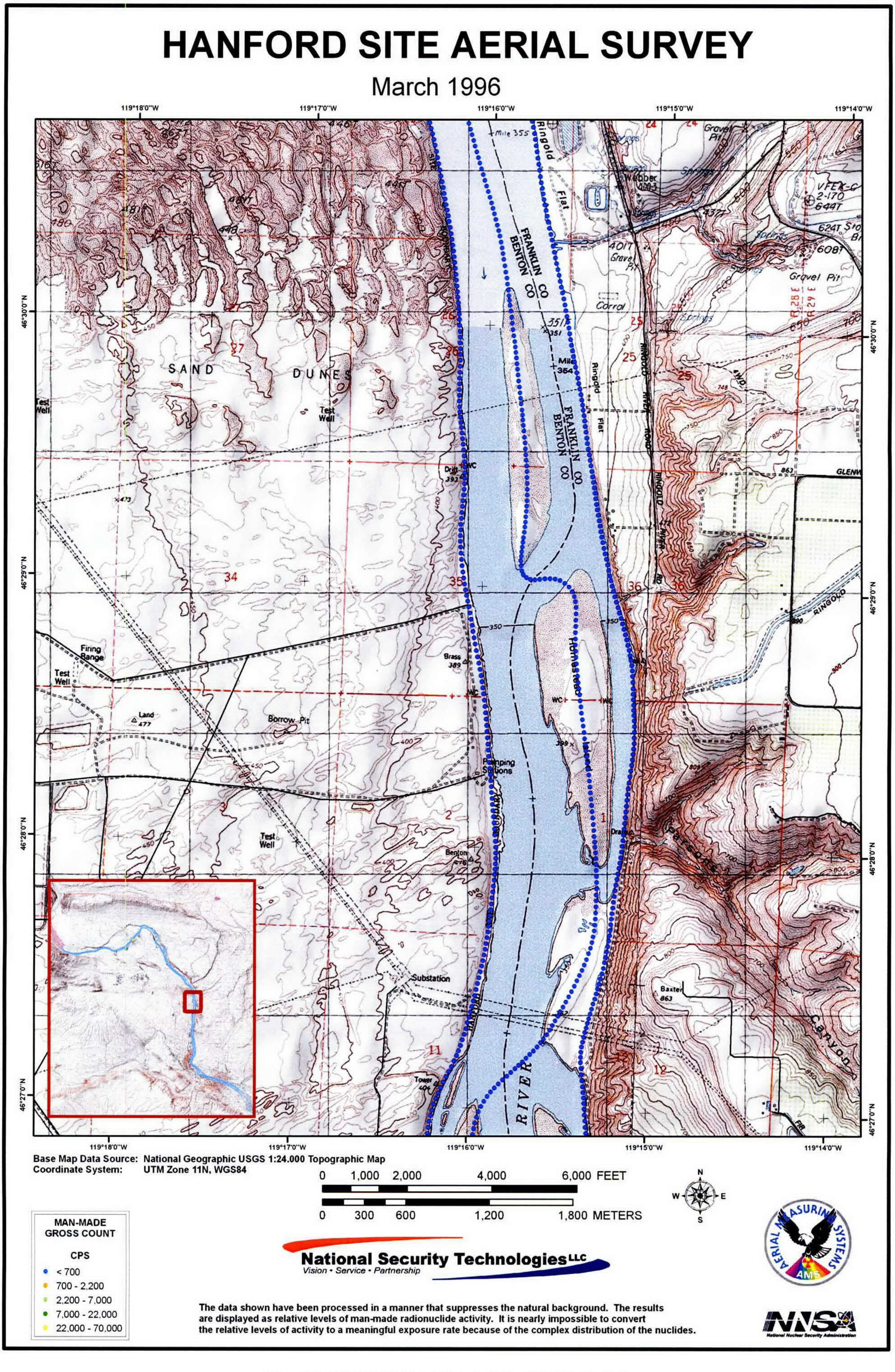


Figure 37. MMGC Path Plot of Columbia River Flight Section #11

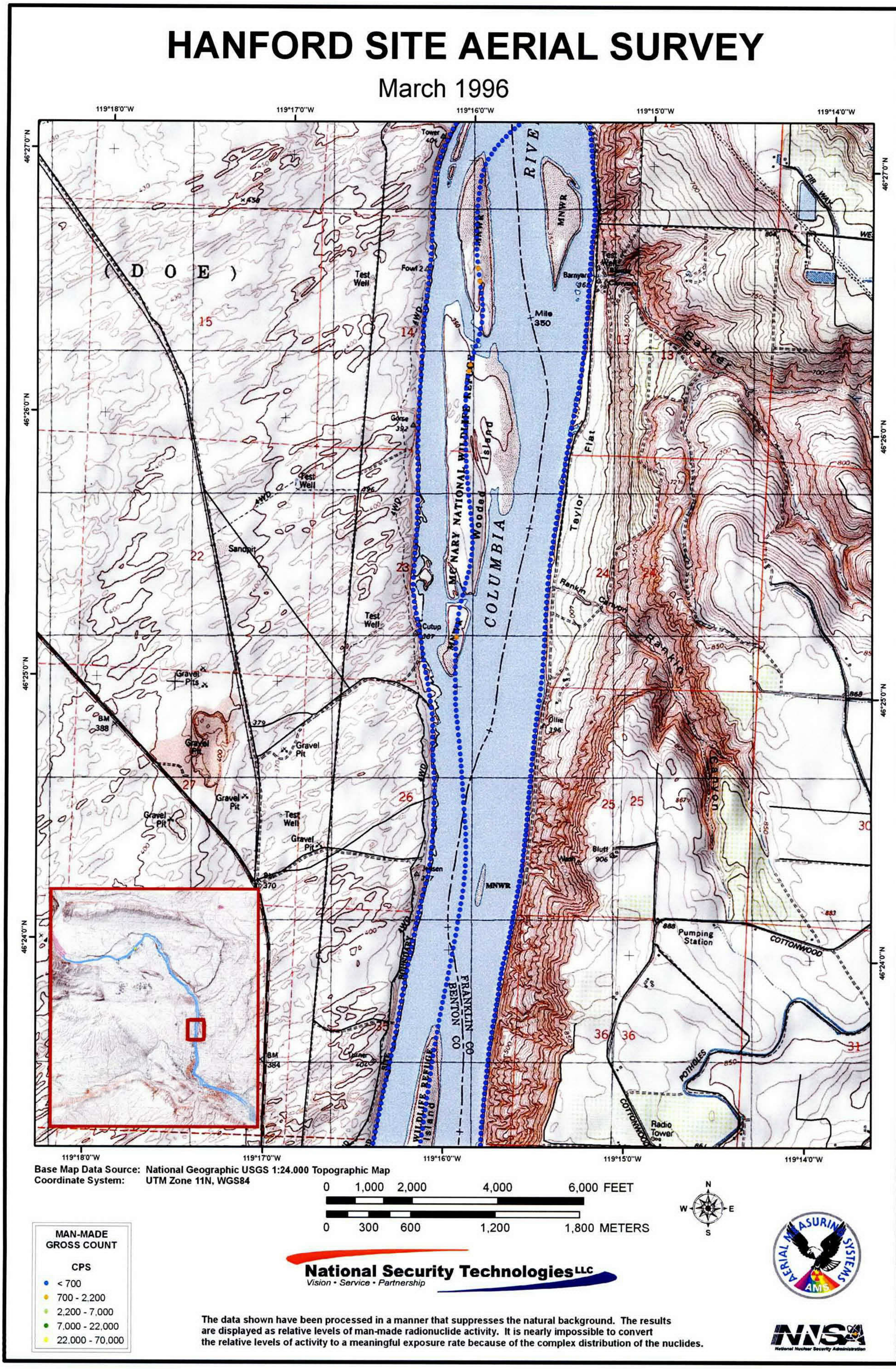
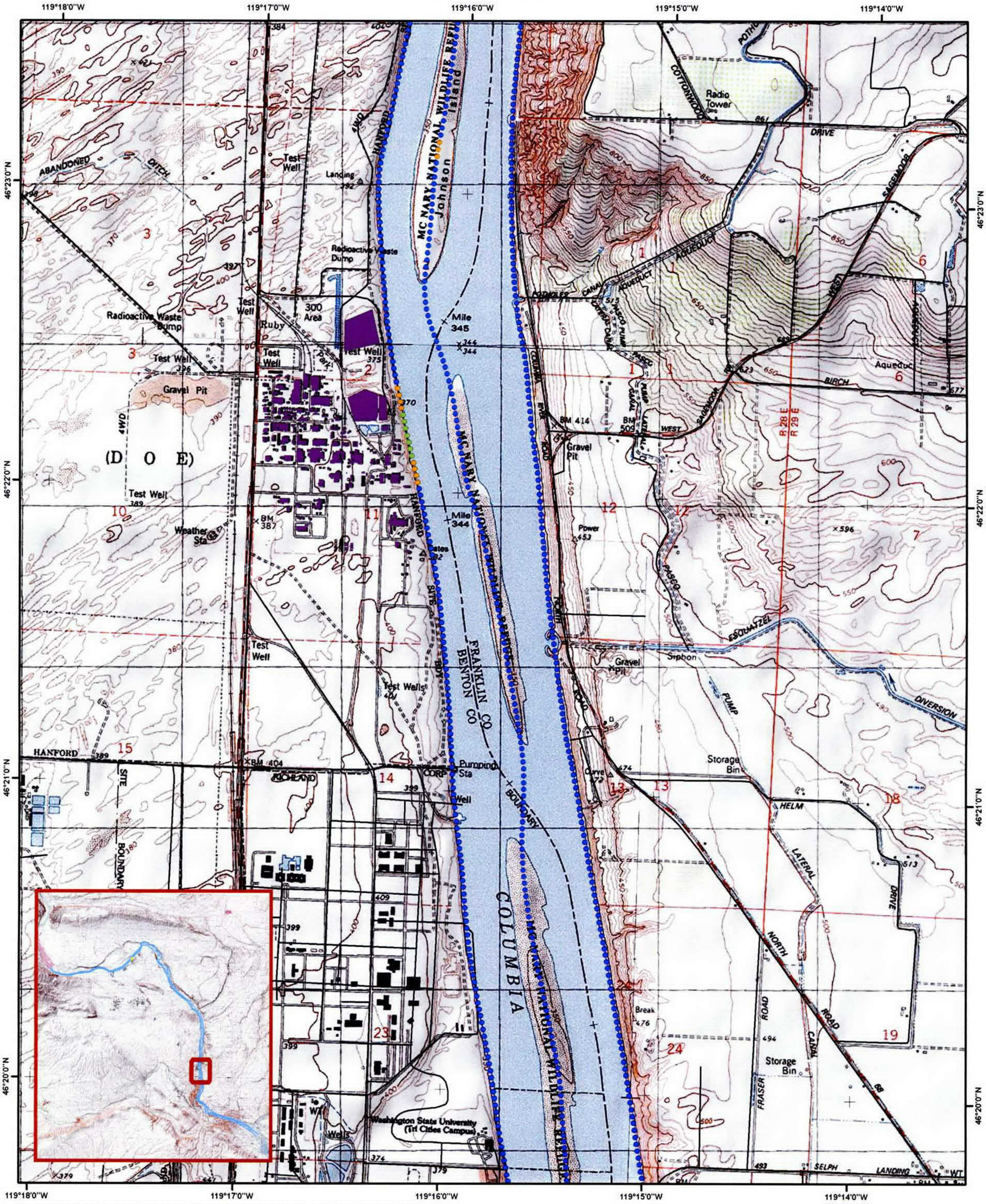


Figure 38. MMGC Path Plot of Columbia River Flight Section #12

HANFORD SITE AERIAL SURVEY

March 1996



Base Map Data Source: National Geographic USGS 1:24.000 Topographic Map
Coordinate System: UTM Zone 11N, WGS84

0 1,000 2,000 4,000 6,000 FEET

0 300 600 1,200 1,800 METERS

MAN-MADE GROSS COUNT

CPS

- < 700
- 700 - 2,200
- 2,200 - 7,000
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- 22,000 - 70,000

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The data shown have been processed in a manner that suppresses the natural background. The results are displayed as relative levels of man-made radionuclide activity. It is nearly impossible to convert the relative levels of activity to a meaningful exposure rate because of the complex distribution of the nuclides.

Figure 39. MMGC Path Plot of Columbia River Flight Section #13

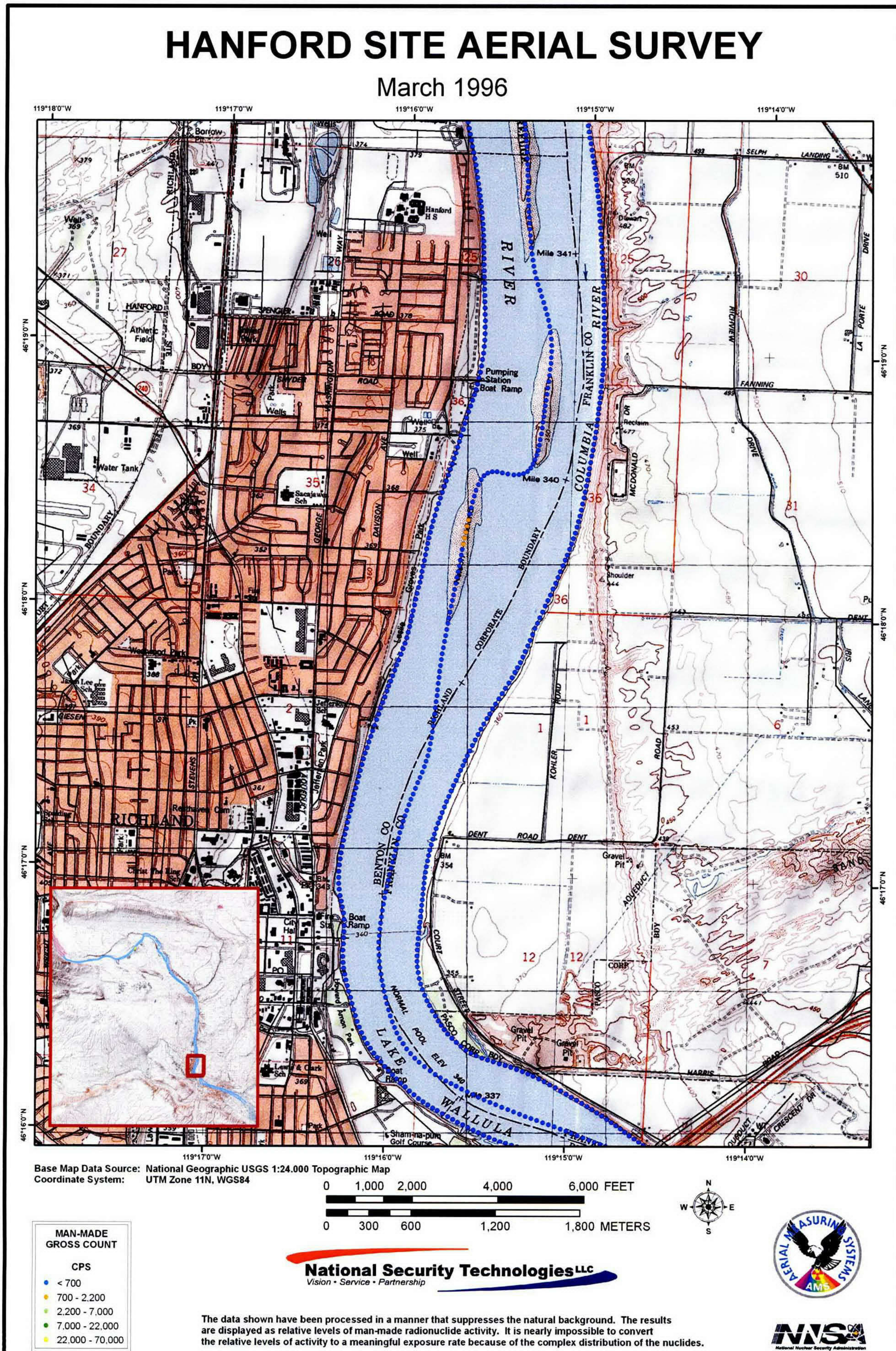

Figure 40. MMGC Path Plot of Columbia River Flight Section #14

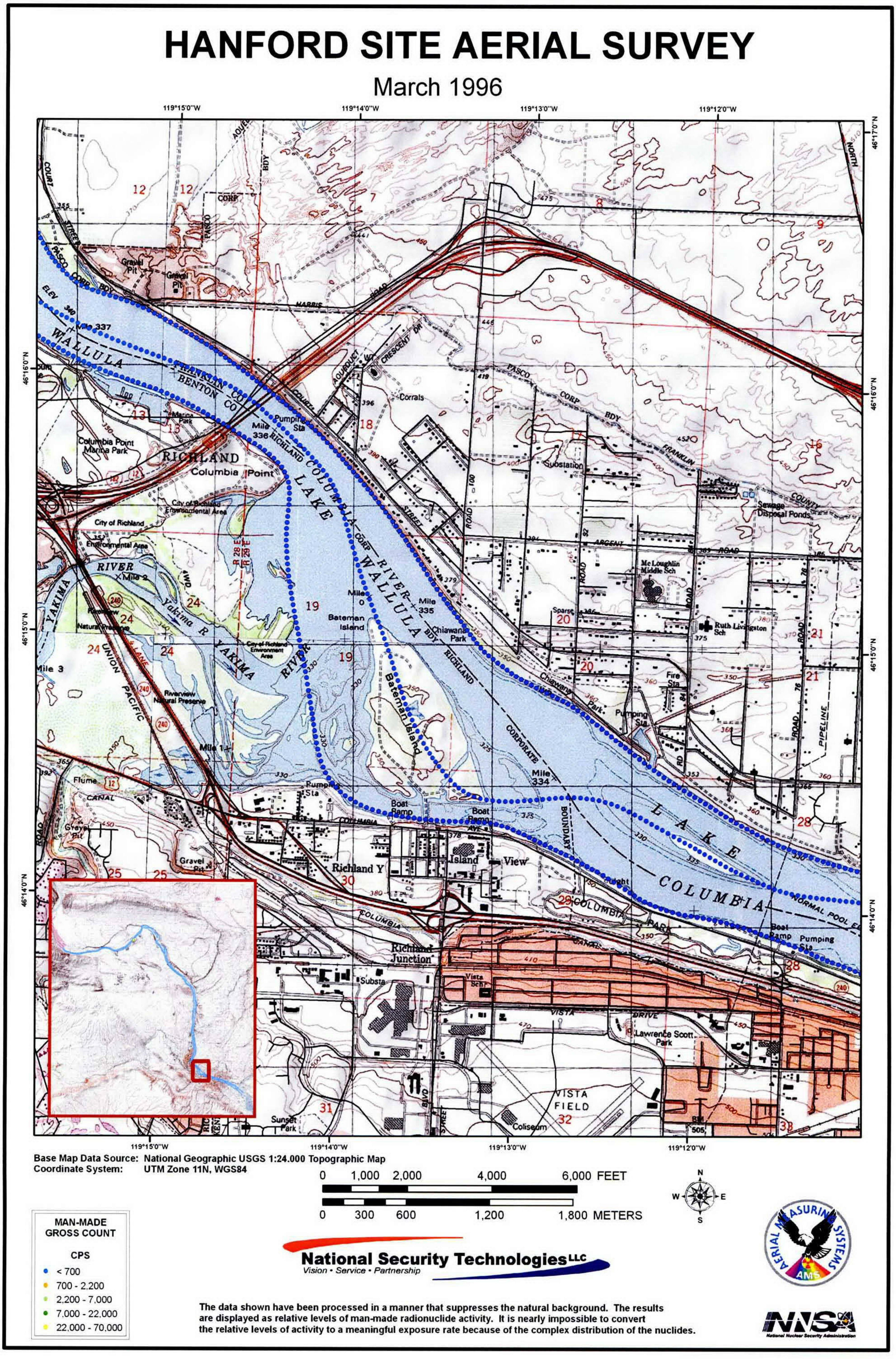

Figure 41. MMGC Path Plot of Columbia River Flight Section #15

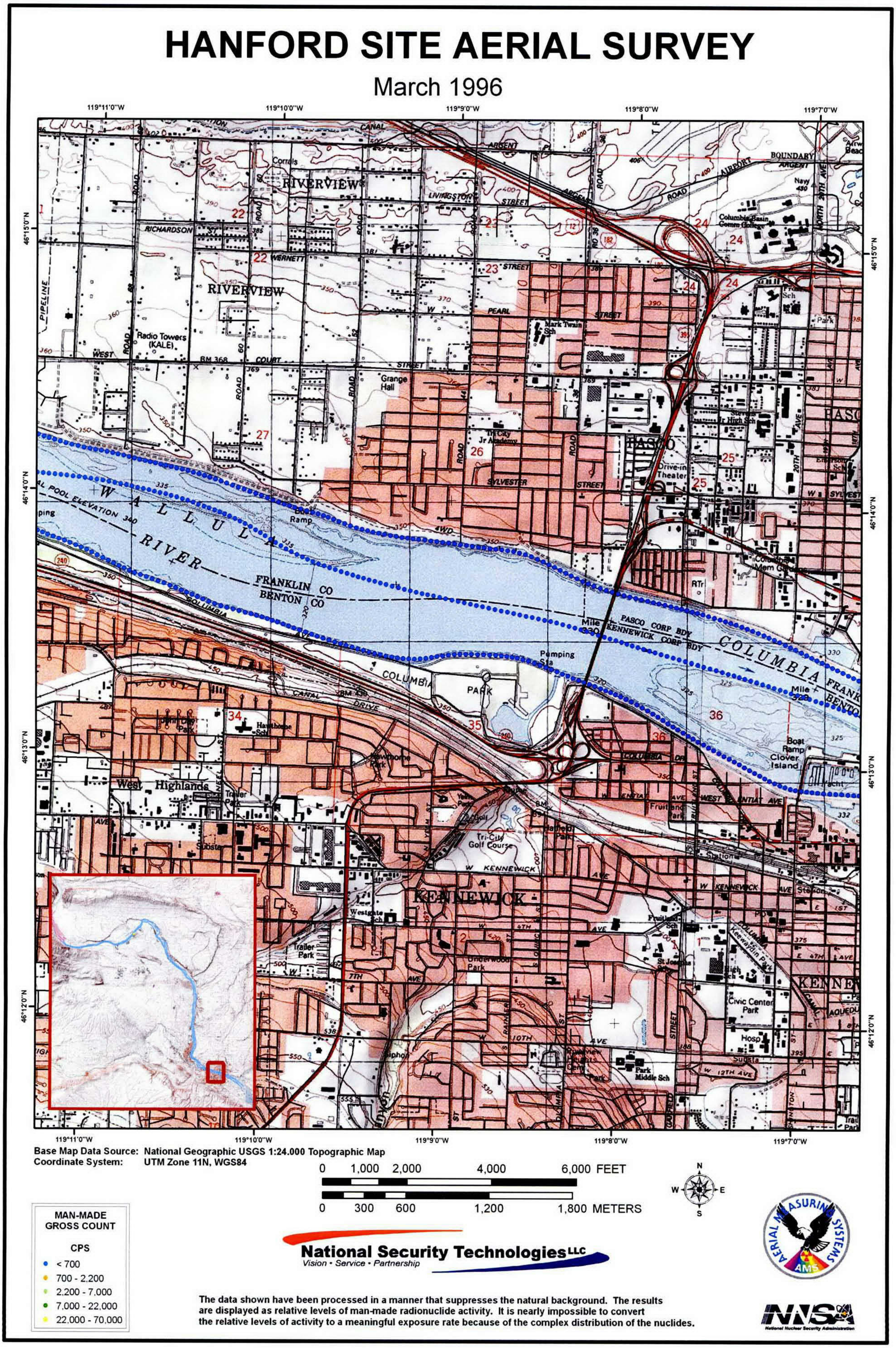

Figure 42. MMGC Path Plot of Columbia River Flight Section #16

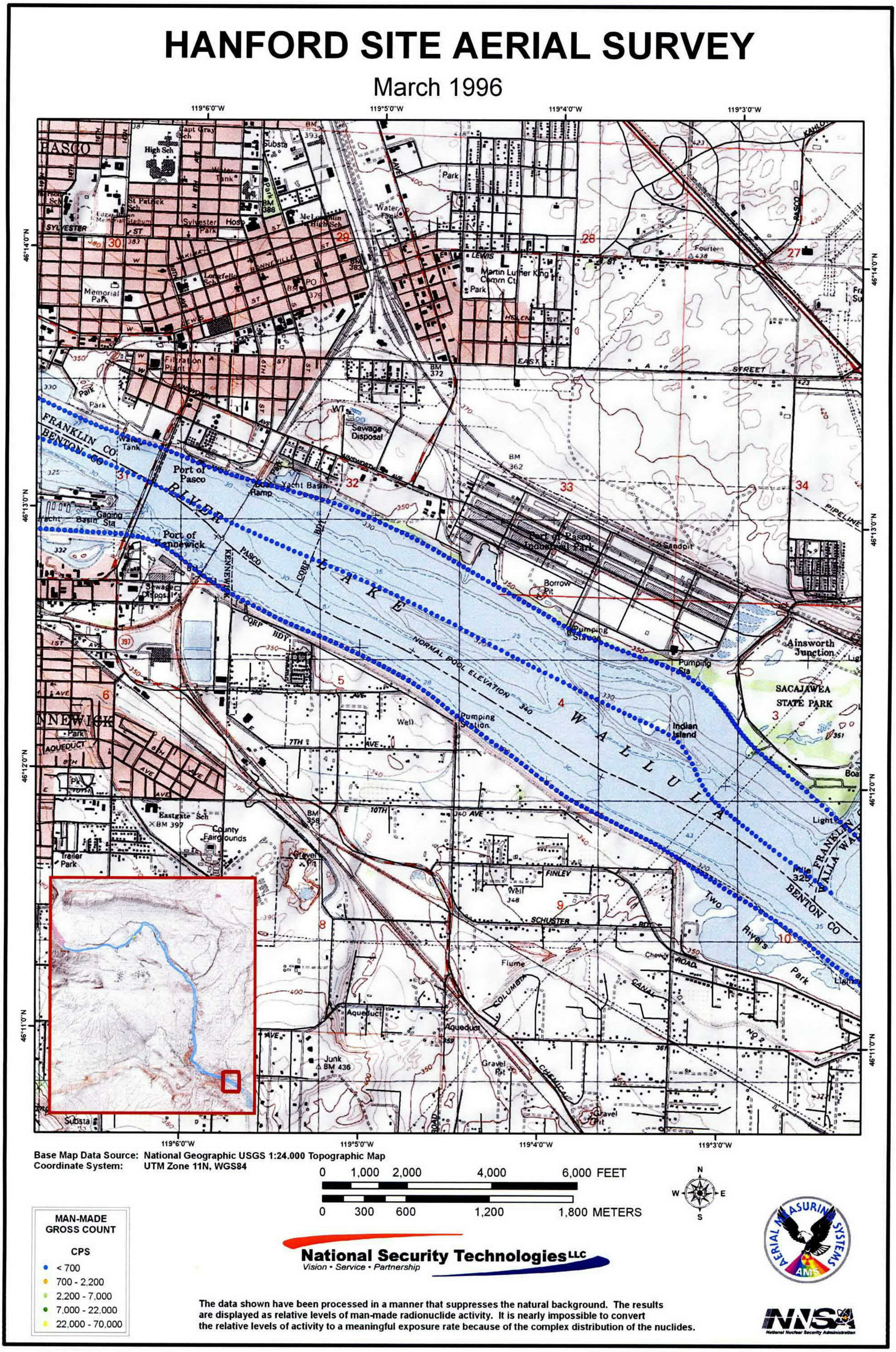

Figure 43. MMGC Path Plot of Columbia River Flight Section #17

APPENDIX A
AERIAL SURVEY PARAMETERS

Survey Site:	Hanford Nuclear Reservation
	Richland, Washington
Survey Coverage:	1,450 km^2 (560 mi^2)
Survey Dates:	February 29 to March 21, 1996
Survey Altitude:	61 m (200 ft)
Average Ground Speed:	41 m/s (80 knots)
Line Spacing:	122 m (400 ft)
Number of Survey Lines:	350
Navigation System:	Real-time Differential Global Positioning System
Line Direction:	South-North
Detector Configuration:	Eight 2- × 4- × 16-inch NaI (T*l*) detectors
	Two 2- × 4- × 4-inch NaI (T*l*) detectors
Acquisition System:	REDAR-IV
Aircraft:	Two MBB BO-105 Helicopters: N50EG and N70EG
Project Scientists:	D. Colton, T. Hendricks, S. Reidhauser
Data Analysts:	J. Stampahar, K. McCall, C. Bluitt, and J. Butler

APPENDIX B
AERIAL DATA PROCESSING

Total Terrestrial Exposure Rate (Gross Count)

Energy Window:	38 - 3,026 keV
Conversion Factor:	1,113 cps per μR/h
Cosmic Ray Contribution:	3.7 μR/h
Air Attenuation Coefficient:	0.00633 m^{-1} (0.001929 ft^{-1})

Man-Made Gross Count Rate (MMGC)

Source Energy Window:	38 - 1,394 keV
Background Energy Window:	1,394 - 3,026 keV

Cesium-137 Count Rate (^{137}Cs)

Source Energy Window:	590 - 734 keV
Background Energy Windows:	516 to 590 keV plus 734 to 806 keV
Conversion Factor (Surface):	570 cps per $\mu Ci/m^2$
Conversion Factor (Uniform):	77 cps per pCi/g
Conversion Factor (Exponential):	91 cps per pCi/g
- Inverse Relaxation Length (α):	0.1 cm^{-1}
- Soil Sample Depth (z):	3.0 cm

APPENDIX C

COMPARISON OF 1988 AND 1996 REGION OF INTEREST

Descriptor	Survey Year	Page	Figure	Spec	MMGC counts/sec	Comment
300 Area						
Pacific Nuclear Services	1988	8	9	1	7K - 22K	Co-60
	1996	12	8	1	22k - 70k	Co-60. Increased activity in 1996
U Fuel Fabrication	1988	8	9	2	22k - 70k	Pa-234m, Co-60
	1996	12	8	3	22k - 70k	Pa-234m, Co-60
Solid Waste Mixed Fission Products Burial Ground	1988	8	9	3	220k - 700k	Cs-137 +
	1996	12	8	5	220k - 700k	Cs-137, Co-60
U Fuel Fabrication	1988	8	9	4	22k - 70k	
	1996	12	8	7	22k - 70k	Pa-234m, Co-60
Liquid Waste Disposal, Burial U and Mixed Fission Products	1988	8	9	5	2.2k - 7.0k	Looks like gross natural spectrum rather than net spectrum.
	1996	12	8	n/a	0.7k - 2.2k	Low level, no report spectrum presented
Capp Island	1988	8	9	6	0.7k - 2.2k	Low level, no defined photopeaks
	1996	12	8	n/a		Very small spot, no report spectrum presented
??	1988	8	9	n/a		Not present in 1988
	1996	12	8	2	2.2k - 7.0k	Cs-137, Co-60, New in 1996
??	1988	8	9	n/a		Not present in 1988
	1996	12	8	4	22k - 70k	Pa-234m, New in 1996
400 Area						
Fast Flux Test Facility	1988	12	13	1	7k - 22k	Cs-137
	1996	16	12	n/a		Gone in 1996
Fast Flux Test Facility	1988	12	13	2	7k - 22k	Mn-54, Co-60
	1996	16	12	n/a		Gone in 1996
Fast Flux Test Facility	1988	12	13	3	7k - 22k	Na-22
	1988	16	12	n/a		Gone in 1996
Power Reactor	1988	12	13	4,5,6	2200k - 7000k	Na-22, Co-60?
	1996	16	12	9	70k - 220k	Co-60. Much reduced activity in 1996
Open Storage Pit	1988	12	13	7	2.2k - 7k	Co-60.
	1996	16	12	n/a	0.7k - 2.2k	Reduced activity, very small area in 1996
100N, 100D/DR Area						
1325 Liquid Waste Disposal Facility (LWDF)	1988	18	19	1	7m - 22m	Severely piled up spectrum, isotopes not identifiable
	1996	22	18	19	2.2m - 7m	Cs-137?, Co-60. Reduced activity in 1996
1301 LWDF	1988	18	19	2	7m - 22m	Severely piled up spectrum, isotopes not identifiable
	1996	22	18	20	2.2m - 7m	Cs-137?, Co-60. Reduced activity in 1996
Reactor Bldg	1988	18	19	3	220k - 700k	Cs-137?, Co-60
	1996	22	18	21	70k - 220k	Cs-137, Co-60 Reduced activity in 1996
LWDF and 107 Retention Basin	1988	18	19	4	2.2k - 7k	Cs-137
	1996	22	18	55	0.7k - 2.2k	Cs-137 Reduced activity in 1996
Reactor Bldg	1988	18	19	5,6	2.2k - 7k	Cs-137, Co-60
	1996	22	18	56,57	0.7k - 2.2k	Cs-137 Reduced activity in 1996
Slough	1988	18	19	7	0.7k - 2.2k	Cs-137
	1996	22	18	54	0.7k - 2.2k	Cs-137
100B/C, 100K Area						
Mixed Fission Products, Buried 15 Years	1988	20	21	1	7k - 22k	Cs-137, Eu-152
	1996	24	20	n/a	0.7k - 2.2k	No spec, Reduced activity in 1996
KE Reactor Building	1988	20	21	2	70k - 220k	Cs-137, Co-60
	1996	24	20	22	70k - 220k	Cs-137
107-KW Retention Basin	1988	20	21	3	22k - 70k	Cs-137, Co-60
	1996	24	20	n/a	2.2k - 7k	No spec, Reduced activity in 1996
107-C Retention Basin	1988	20	21	4	7k - 22k	Cs-137, Eu-152
	1996	24	20	24	7k - 22k	Cs-137, Eu-152
Reactor Building 105-B	1988	20	21	5	22k - 70k	Cs-137, Co-60?, Eu-152?
	1996	24	20	25	7k - 22k	Cs-137, Co-60?, Eu-152? Reduced Activity in 1996
Reactor Building 105-C	1988	20	21	6	22k - 70k	Cs-137, Co-60
	1996	24	20	26	22k - 70k	Cs-137

areas where activity is new or has increased since the 1988 aerial survey

Areas where activity is gone or has decreased since the 1988 aerial survey

200 West Area

Descriptor	Survey Year	Page	Figure	Spec	MMGC counts/sec	Comment
T Plant Area	1988	24	25	1	7k - 22k	Cs-137
	1996	26	22	29	22k - 70k	Cs-137, Co-60. Increased activity in 1996
U Plant Area	1988	24	25	2	7k - 22k	Cs-137, Pa-234m
	1996	26	22	36	22k - 70k	Cs-137, Pa-234m, Increased activity in 1996
Tank Farm U, Mixed Fission Products	1988	24	25	3	70k - 220k	Cs-137
	1996	26	22	35	70k - 220k	Cs-137
REDOX Complex	1988	24	25	4	220k - 700k	Cs-137
	1996	26	22	39	70k - 220k	Cs-137. Decreased activity in 1996
S/SX/SY Tank Farms	1988	24	25	5	70k - 220k	Cs-137
	1996	26	22	37	70k - 220k	Cs-137
S-10 Ditch	1988	24	25	6	2.2k - 7k	Cs-137
	1996	26	22			Gone in 1996
S-17 Pond	1988	24	25	7	2.2k - 7k	Cs-137
	1996	26	22	40	0.7k - 2.2k	Cs-137. Decreased activity in 1996
S-16 Pond	1988	24	25	8	2.2k - 7k	Cs-137
	1996	26	22	41	0.7k - 2.2k	Cs-137. Decreased activity in 1996
W-4C Burial Ground	1988	24	25	9	700k - 2,200k	Cs-137
	1996	26	22			Gone in 1996
W-4C Burial Ground	1988	24	25	10	70k - 220k	Cs-137, Co-60.
	1996	26	22	34	220k - 700k	Cs-137. Increased activity in 1996
Mixed Waste Storage Facilities	1988	24	25	11	22k - 70k	
	1996	26	22	31	220k - 700k	Cs-137. Increased activity in 1996
Solid Waste Buried Mixed Fission Products	1988	24	25	12	70k - 220k	Cs-137, Co-60
	1996	26	22	27	7k - 22k	Cs-137, Co-60. Decreased activity in 1996
T Pond	1988	24	25	13	22k - 70k	Cs-137, Co-60.
	1996	26	22	28	2.2k - 7k	Cs-137. Decreased activity in 1996
T Tank Farm	1988	24	25	14	22k - 70k	Cs-137
	1996	26	22	30	7k - 22k	Cs-137. Decreased activity in 1996
TX/TY Tank Farms	1988	24	25	15	220k - 700k	Cs-137
	1996	26	22	32	220k - 700k	Cs-137.

200 East Area

Descriptor	Survey Year	Page	Figure	Spec	MMGC counts/sec	Comment
10-15 Years Overflow From Pool, Mixed Fission Products	1988	22	23	1	2.2k - 7k	Cs-137
	1996	28	24	42	2.2k - 7k	Cs-137
A/AW/AX/AZ Tank Farms	1988	22	23	2	70k - 220k	Cs-137
	1996	28	24	49	70k - 220k	Cs-137
Fresh Fission Products Purex	1988	22	23	3	7k - 22k	Cs-137
	1996	28	24	50	7k - 22k	Cs-137
Equipment Contaminated with Fission Products	1988	22	23	4	220k - 700k	Cs-137, Co-60
	1996	28	24	48	700k - 2,200k	Cs-137, Eu-152? Increased activity in 1996
C Tank Farm	1988	22	23	5	70k - 220k	Cs-137
	1996	28	24	47	70k - 220k	Cs-137
BX/BY Tank Farm	1988	22	23	6	700k - 2,200k	Cs-137
	1996	28	24	43	220k - 700k	Cs-137. Decreased activity in 1996
B Tank Farm	1988	22	23	7	70k - 220k	Cs-137
	1996	28	24	44	70k - 220k	Cs-137
[East of BX/BY/B Tank Farm]	1988	22	23		2.2k - 7k	No spec in 1988.
	1996	28	24	45	2.2k - 7k	Cs-137. 3 locations, 2 new in 1996
Mixed Fission Products, B Plant Area	1988	22	23	8	70k - 220k	Cs-137
	1996	28	24		2.2k - 7k	No Spec. Decreased activity in 1996
B Plant Area	1988	22	23	9	220k - 700k	Cs-137
	1996	28	24	46	70k - 220k	Cs-137. Decreased activity in 1996
US Ecology Co	1988	22	23	10	700k - 2,200k	Co-60
	1996	28	24	52	220k - 700k	Co-60. Decreased activity in 1996
BC Controlled Area (Crib)	1988	22	23	11	7k - 22k	Cs-137
	1996	28	24	53	7k - 22k	Cs-137
??	1988	22	23			Not present in 1988
	1996	28	24	51	2.2k - 7k	New in 1996

areas where activity is new or has increased since the 1988 aerial survey

Areas where activity is gone or has decreased since the 1988 aerial survey

Descriptor	Survey Year	Page	Figure	Spec	MMGC counts/sec	Comment
100-F and 100-H Areas						
Lab Waste Burial, Mixed Fission Products	1988	16	17	1	7k - 22k	Eu-152
	1996	20	16	13	7k - 22k	Eu-152
Test Plot Burial	1988	16	17	2	2.2k - 7k	Cs-137, Eu-152
	1996	20	16	14	2.2k - 7k	Cs-137
Slough	1988	16	17	3	2.2k - 7k	Cs-137, Eu-152
	1996	20	16		0.7k - 2.2k	No spectrum taken in 1996. Decreased activity
Liquid Waste Burial, Mixed Fission Products	1988	16	17	4	2.2k - 7k	Eu-152
	1996	20	16		0.7k - 2.2k	No spectrum in 1996. Decreased activity in 1996
Reactor Building 100H	1988	16	17	5	2.2k - 7k	Cs-137, Co-60.
	1996	20	16	17	2.2k - 7k	
??	1988	16	17			Not present in 1988
East of river	1996	20	16	18	2.2k - 7k	New in 1996. Looks like instrument noise.
Downstream from 100-H	1988	16	17		0.7k - 2.2k	No spectrum taken in 1988
	1996	20	16	15	0.7k - 2.2k	Cs-137. Smaller area than in 1988
Downstream from 100-H	1988	16	17		0.7k - 2.2k	No spectrum taken in 1988
	1996	20	16	16	0.7k - 2.2k	Cs-137. Smaller area than in 1988
Old Hanford						
Slough	1988	14	15	1,2	2.2k - 7k	Eu-152
	1996	18	14	12	0.7k - 2.2k	Eu-152. Reduced activity in 1996
Shoreline	1988	14	15	3	0.7k - 2.2k	Eu-152
	1996	18	14		< 0.7k	Gone in 1996
Ridgeline	1988	14	15		< 0.7k	No spectrum taken. Background in 1988
	1996	18	14	10,11	0.7k - 2.2k	K-40? Looks like geological anomaly
Wooded Island and Vicinity						
Wooded Island	1988	10	11	1	0.7k - 2.2k	Eu-152?
	1996	14	10	8	0.7k - 2.2k	Eu-152? Smaller area than in 1996

areas where activity is new or has increased since the 1988 aerial survey

Areas where activity is gone or has decreased since the 1988 aerial survey

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