Idaho National Engineering Laboratory

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Idaho National Engineering Laboratory
Lockheed Martin Idaho Technologies
Physics Department
Idaho Falls, Idaho 83415

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ABSTRACT

The primary purpose of the gamma-neutron mapper (GNM) is to provide accurate and quantitative spatial information of the gamma-ray and neutron radiation fields as a function of position about the excavation of a radioactive waste site. The GNM is designed to operate remotely and can be delivered to any point on an excavation by the robotic gantry crane developed by the dig-face project at the Idaho National Engineering Laboratory (INEL). It can also be easily adapted to other delivery systems. The GNM can be deployed over a waste site at a predetermined scan rate and has sufficient accuracy to identify and quantify radioactive contaminants of importance.

The results reported herein are from a performance test conducted at the Transuranic Storage Area, Building 628, of the Radioactive Waste Management Complex located at the INEL. This building is an active interim-storage area for 55-gal drums of transuranic waste from the Department of Energy's Rocky Flats Plant. The performance test consisted of scanning a stack of drums five high by five wide. Prior to the test, radiation fields were measured by a health physicist at the center of the drums and ranged from 0.5 mR/h to 35 mR/h. Scans of the drums using the GNM were taken at standoff distances from the vertical drum stack of 15 cm, 30 cm, 45 cm, and 90 cm. Data were acquired at scan speeds of 7.5 cm/s and 15 cm/s. The results of these scans and a comparison of these results with the manifests of these drums are compared and discussed.

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ACKNOWLEDGMENTS

The authors wish to express their appreciation to Mark Sherick for arranging approvals, securing the radiation work permit, and scheduling the equipment operators and the health physics technician to operate the test in Building 628 on March 31 at the Radioactive Waste Management Complex. Steve Ingle and Jim Bishoff also helped in the arrangements. We wish to thank Leon Butler and Ted Mickelsen for operating the forklift, Mike Waters for providing continuous health physics coverage, and Skip Cline for serving as shift supervisor during off-shift hours. Also, we wish to thank Ervin Grafwallner for designing the wooden pallet and performing necessary machining.

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1. INTRODUCTION

Remediation of radioactive, hazardous, and mixed-waste sites involves unpredictable contact with unknown and potentially dangerous materials. When such materials are encountered, a complex sequence of events is often initiated, which includes waste assay, sorting, treating, and disposing of hazardous and/or radioactive materials. These follow-on activities strongly impact the speed, cost, and effectiveness of the remediation program. The dig-face characterization concept, initially proposed at the Idaho National Engineering Laboratory (INEL) in 1992, stresses safety and efficiency of remedial field operations by promoting unobtrusive, on-line characterization and monitoring during actual retrieval activities.

The dig-face characterization system developed at the INEL is composed of geophysical, radiological, and chemical sensors controlled by an automated data acquisition and analysis system. The gamma-neutron mapper (GNM) developed for the dig-face system is designed to rapidly monitor for γ-ray and neutron radiation fields during excavation of radioactive waste burial areas.

The primary focus of the GNM is to provide a spatially accurate, quantitative measurement of the γ-ray and neutron fields during a remediation program. The purpose is to avoid unanticipated exposure to high radiation fields, reduce process volume by identifying "clean" areas, pinpoint specific potentially radioactive objects of interest, and avoid the possibility of an unintentional nuclear criticality configuration. As with the other sensors, the GNM must be able to perform its scans rapidly so the excavation operation will not be delayed.

1.1 Gamma-Neutron Mapper Performance Tests

The initial evaluation of the GNM was performed during the summer of 1994 at the Test Reactor Area of the INEL. These tests were designed to assess the GNM and compare performance against procurement specifications. These initial tests also evaluated the Ge spectrometer and its analysis programs, and the capability of prompt gamma-neutron activation analysis (PGNAA) to assay chlorine-containing materials covered by side-burden (soil). The results of these tests are reported in Gehrke et al. (1995a).

As a result of this initial evaluation, a number of modifications were made to the GNM to improve its performance. A titanium window was added to the front of the detector, replacing the portion of the stainless steel front cover directly over the scintillation detectors. This was done to improve detector efficiency for low-energy gamma rays (e.g., ^{241}Am). Also, a number of internal electronic modifications were made to the pulse processing circuitry of the sensor to improve the signal-to-noise ratio of the scintillation detectors. This was done to improve detector sensitivity at the low-energy gamma-ray regime.

The next evaluation of the GNM was performed in accordance with the "Test Plan for a Live Drum Survey Using the Gamma-Neutron Sensor (Gehrke et al. 1995b). The results of the evaluation are reported herein.

1.2 Description of the Gamma-Neutron Mapper

The GNM consists of two large plastic scintillators 25.4 cm wide × 48.26 cm long × 3.81 cm thick located in front of two ^{3}He chambers of the same length and width. The ^{3}He chambers are 10 cm deep (outside dimension). These four detectors are located inside a protective stainless steel box as shown in Figure 1. A 1.0-mm-thick titanium window is located directly over the plastic scintillators to prevent the attenuation of low-energy γ-rays (e.g., the 60-keV γ-ray of ^{241}Am). As shown in Figure 2, the stainless steel box with detectors was fastened to a specially built pallet that fits on the tines of a forklift so that scans of vertically stacked 55-gal drums can be made. Also mounted on the pallet in an aluminum cylindrical container are the data acquisition and the sensor interface compartments. These compartments contain the central processing unit that controls all remote functions of the GNM. This includes the laser rangefinder that is used to determine sensor height above floor level, analog-to-digital conversion hardware, and RF communications with the base SUN workstation.

Located in the rear of a full-size van is the computer workstation as shown in Figure 3. The workstation consists of a Sun SPARCstation 10 computer, with 32 MB memory, 1 GB hard disk space, a Hewlett Packard Desk Jet 1200C color printer, and a floppy disk drive. The RF Ethernet communication link operates at 2.45 GHz frequency. This system displays and stores data generated by the rangefinder and the gamma-neutron sensor, and provides on-line data analysis functions in the form of color contour and a variety of three-dimensional plots. The system utilizes a 19-in. color display that is managed by the X-windows graphical user interface. Operator interaction with the system is through a series of pull-down menus and a custom graphics display using PV-Wave, which is a commercial software package designed specifically for data display.

2. TEST DESCRIPTION

The measurements from this test were made to ascertain the capability of the GNM under the simulated conditions expected during the excavation of 55-gal drums containing transuranic (TRU) and γ-ray emitting radionuclides. Although the drums were not covered with soil overburden, the waste drums in active interim storage contained TRU radioactive waste. For these measurements, the GNM was mounted to a specially designed wooden pallet, called the GNM assembly, to which the GNM and the sensor interface compartments were attached. The total weight of this assembly including the GNM, data acquisition module, sensor interface module, counter weight, and wooden pallet was about 180 kg. Acquired data was sent via an RF Ethernet link to the workstation computer. The GNM assembly was secured to an electric forklift and maneuvered in the vertical and horizontal directions to scan the stacked drums vertically. Gamma-ray and neutron radiation fields were recorded simultaneously along with data of the elevation above ground level. These data were time stamped and stored on the SUN workstation.

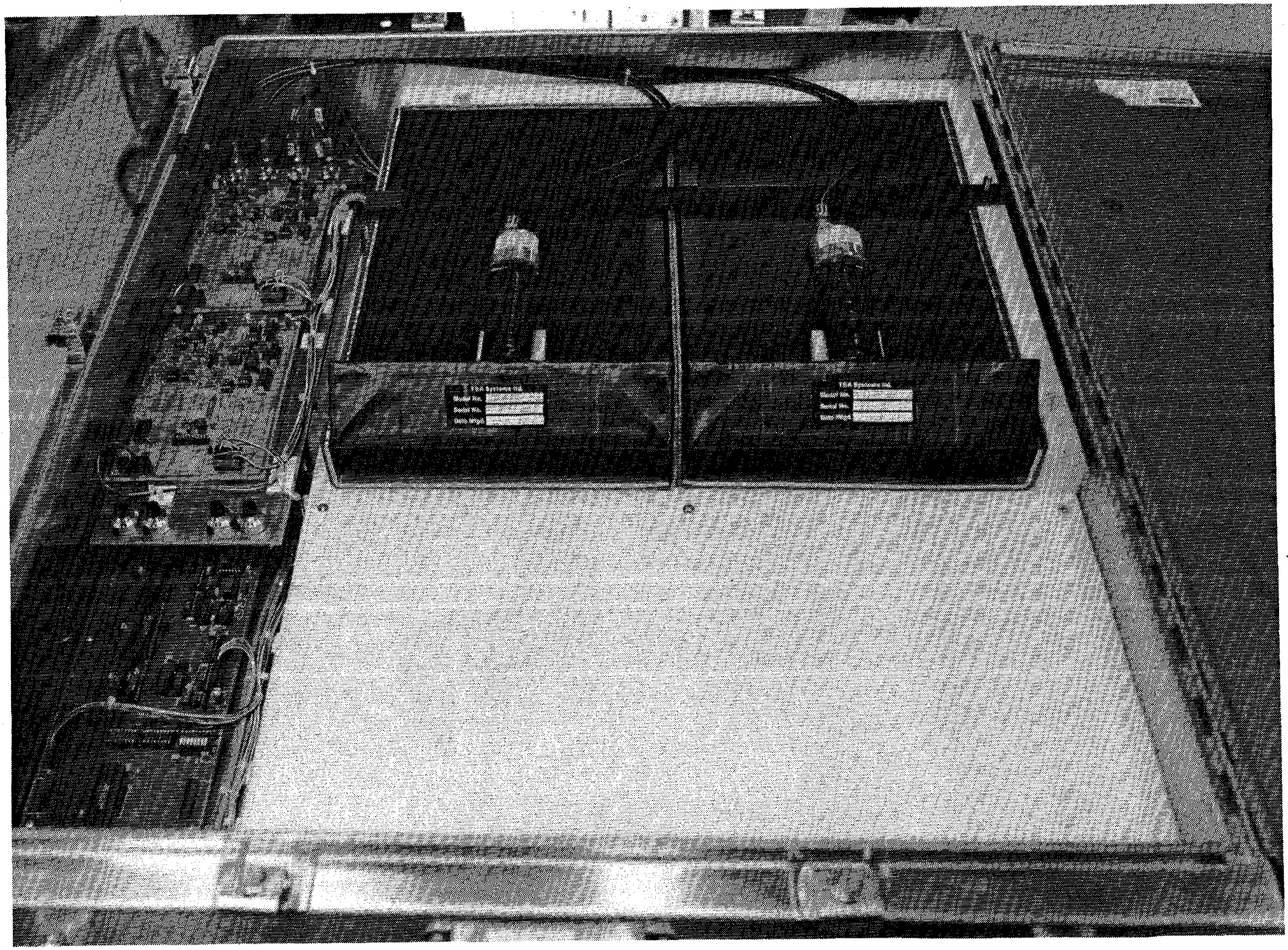

Figure 1. Plastic scintillation detectors inside stainless steel box of GNM.

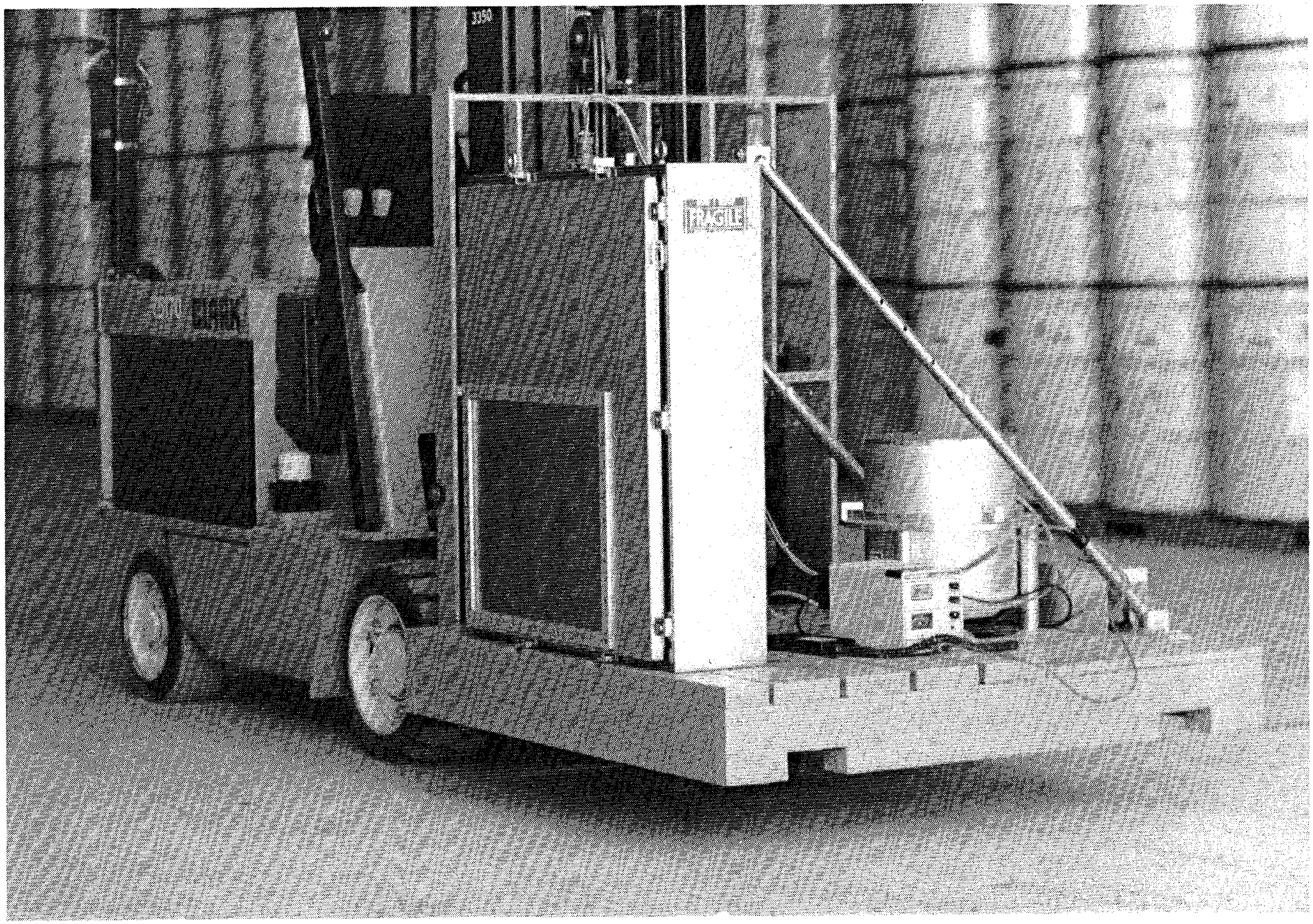

Figure 2. The GNM assembly preparing to make a vertical scan.

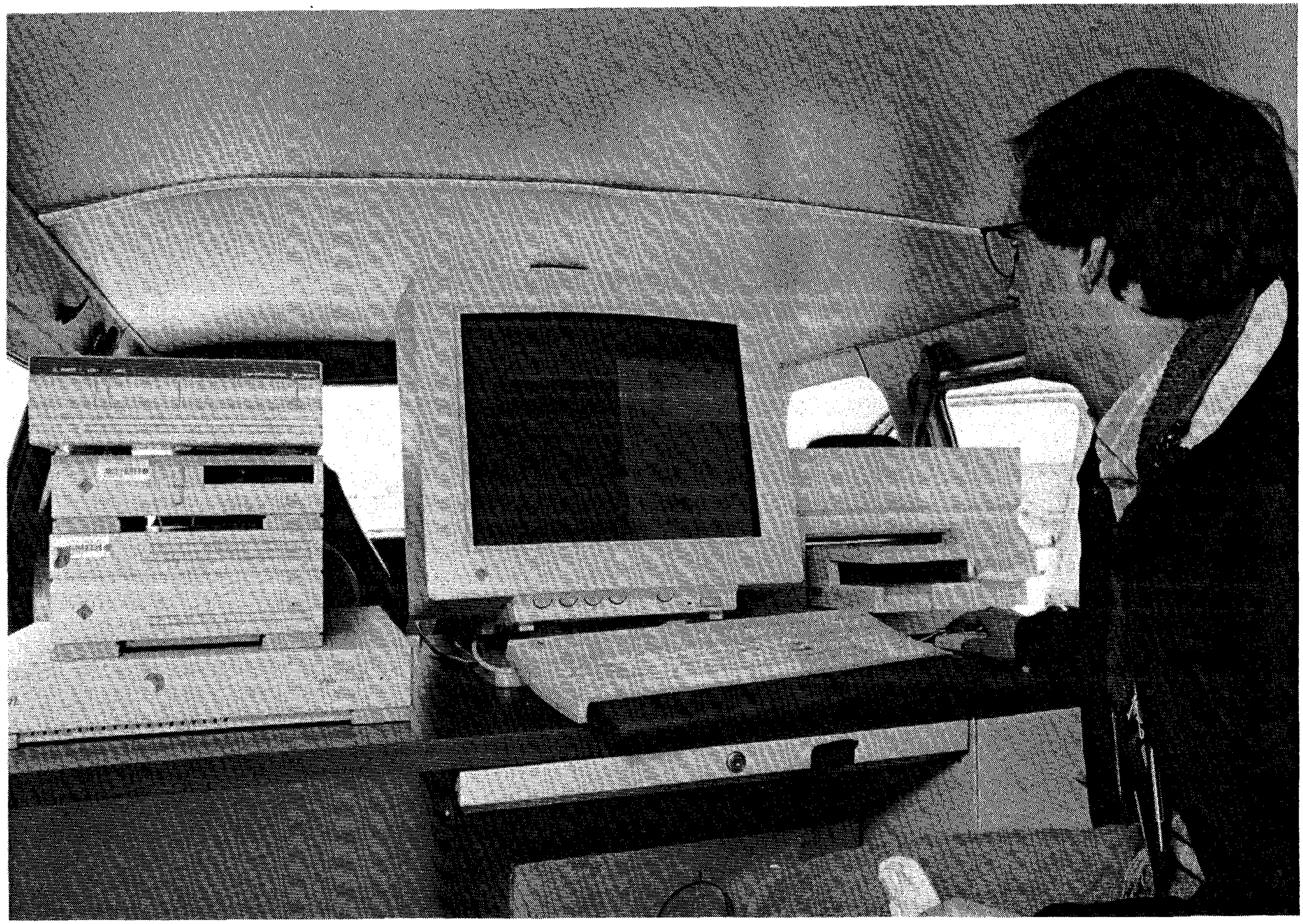

Figure 3. The Sun SPARC workstation as located in the rear cargo compartment of a full-size van. This van was located outside Building 628.

The test was performed at the Radioactive Waste Management Complex (RWMC) in Building 628 where 55-gal drums filled with TRU waste from the U.S. Department of Energy (DOE) Rocky Flats Plant are in active interim storage awaiting final disposal. This facility was chosen for the GNM performance tests because it is an actual storage facility with stacks of 55-gal waste drums representative of those that may be encountered at a below-grade burial area. The only difference between these drums and those buried at an excavation site is that these drums are neatly stacked, all intact, and not covered with soil overburden or sideburden.

The center of the detectors comprising the GNM was aligned visually with the center of each stack of drums, and the standoff distance of the GNM from the drum stack was physically measured and marked on the cement floor with adhesive tape. The uncertainty in horizontal standoff was estimated to be ±5 cm as required by the Test Plan. At no time were the sensor assembly, pallet, forklift, or support personnel in physical contact with the stacked drums. Figure 4 shows a picture of the GNM, data acquisition system, pallet, and forklift truck during a scan of a typical drum stack in Building 628.

The laser range finder was calibrated and checked to ensure that its distance measurement was accurate. This was accomplished by securing a metal tape to a position on the pallet, which is aligned with the range finder window. The pallet was raised to 450 cm (15 ft), and the measured rangefinder distance was recorded by the computer. The pallet was lowered in 30-cm steps until the pallet was within 30 cm of the floor while recording the distance measured by the range finder. The accuracy of these measurements was ±1.27 cm except at 30 and 60 cm, where they were in error by as much as 12 cm.

The GNM data were acquired over a 5 × 5 drum matrix (i.e., five stacks of drums with five drums per stack) at scan rates 7.5 cm/s and 15 cm/s. The analog signal was converted to counts per second and stored along with the time and vertical position as measured by the laser range finder. Horizontal standoff distances of 15, 30, 45, and 90 cm from the closest stack of drums were measured, and an adhesive tape was secured to the floor to provide the forklift operator with a guideline for maintaining a constant distance from the GNM to the nearest drum.

Seven experiments were performed in Building 628. All but the last experiment scanned the same 25-drum matrix using varying combinations of speed or horizontal standoff. The last experiment provided a continuous scan across a row of drums from left to right by driving the forklift in front of the stacked drums. Table 1 lists the parameters of each experiment.

Table 1. Conditions under which each experiment was performed.

Experiment number	Scan speed (cm/s)	Distance from drums (cm)
1	No scan, each drum counted ~10 s at its center	15.2
2	7.5	15.2
3	15	15.2
4	7.5	45.7
5	7.5	30.5
6	7.5	91.4
7	6.1	30.5

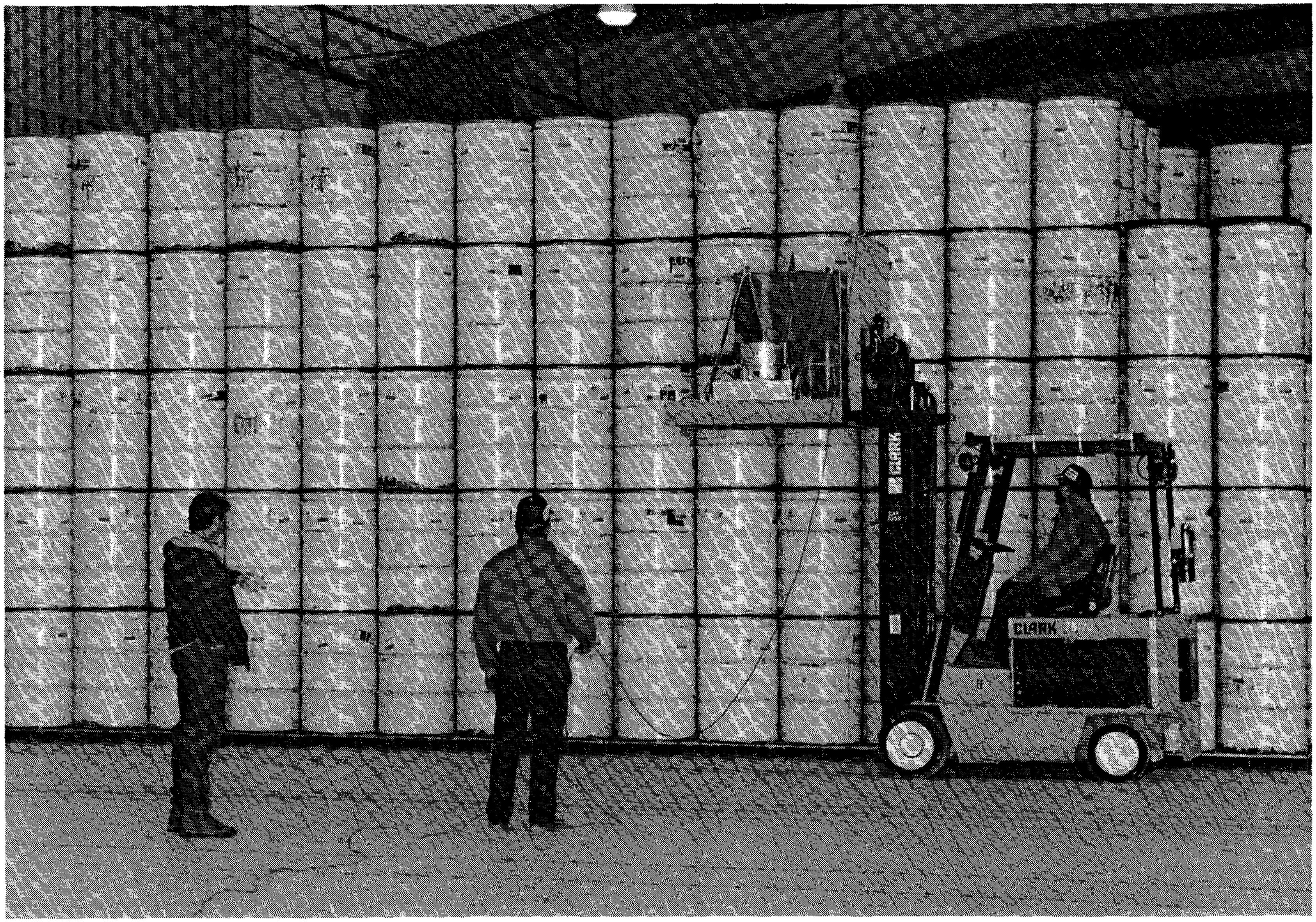

Figure 4. GNM during a typical scan sequence of the stacked 55-gal waste drums.

3. TEST AND DATA QUALITY OBJECTIVES

The primary objective of the RWMC test series was to evaluate the GNM in a TRU waste storage environment similar to the conditions that might be encountered at an actual radioactive remediation site.

3.1 Test Objectives

Specific objectives for the RWMC test series were:

1. Evaluate operation of the GNM under temperature, electrical, and mechanical noise conditions representative of a field environment.

2. Locate hot drums and measure the relative strengths of the radiation fields around the stacked drums. Produce contour maps of the gamma-ray and neutron fields using the acquisition system analysis tools.

3. Determine the effect of scan rate on the radiation field measurements.

4. Evaluate the effect of distance from the drums and sample spacing on spatial resolution of the composite data sets.

5. Evaluate the performance of the laser position sensor (range finder).

6. Estimate the sensitivity of the GNM for the detection of gamma-ray emitters such as ^{241}Am. If possible, estimate the neutron sensitivity of the plastic scintillation detectors.

7. Compare measurements with drum manifest and Stored Waste Examination Pilot Plant (SWEPP) measurements for selected drums.

3.2 Data Quality Objectives

Data quality objectives for the GNM performance tests are listed below. These were consistent with the performance objectives enumerated in Section 3.1.

1. Successful operation of equipment under field conditions. If proper equipment operation is not achieved due to the field environment, we will determine the offending condition and correct it.

2. Repeatability of the GNM detectors to within two standard deviations when counting a check source or a drum under repeatable counting conditions (i.e., distance and source position).

3. Reliable data collection using surface scan rates of 3 cm/s or greater. Faster scan speeds will be investigated consistent with forklift capability and safety considerations.

4. Repeatability of GNM detector counting rates to within three standard deviations when scanning stacked drums.

5. Standoff positioning of the sensor to within 5 cm of the desired horizontal standoff distance. The proposed standoff distances are 15, 30, 45, and 90 cm.

4. EXPERIMENTAL DESIGN AND PROCEDURES

This test was designed to determine the operability and capability of the GNM under conditions that closely represent those expected at an excavation site. Although a forklift would likely not be the method of choice for deploying the GNM at an actual site, it was available and expedient to use. Fortunately, the experienced forklift operator was able to maintain good control of the forklift, including the overall rate of travel and its repeatability, in spite of the inherent limitations of the forklift in this regard.

The temperature inside Building 628 is not controlled. Interior building temperatures during the winter typically are about 5°C (9°F) colder than the outside temperatures. On the day of the test, the outside temperature reached a high of about 10°C (50°F). With a little lag time, the air temperature inside the building tended to adjust to the outside temperature.

The GNM was calibrated for γ-ray and neutron efficiency prior to transporting the GNM assembly to the RWMC. The γ-ray scintillation efficiency for each detector at a distance of 30 cm (1 ft) was measured to be about 2% for ^{137}Cs. The neutron ^{3}He efficiency for each detector was measured at a distance of 30 cm (1 ft) to be ~0.23% for a bare ^{252}Cf source. The GNM was also checked to verify that the lower-level discriminators on the plastic scintillation detectors were set above the noise but below the 60-keV γ-rays emitted by ^{241}Am. Measurements with a ^{241}Am source verified that the titanium window efficiently transmitted 60-keV γ-rays.

The GNM pallet assembly was designed to fit snuggly on the tines of a forklift with the rangefinder positioned to view the floor through an opening in the pallet. The van containing the workstation computer was located outside of the metal building with the building truck door open sufficiently to allow straight-line RF transmission between the data acquisition compartment and the workstation. This arrangement allowed the system to communicate dependably over a typical distance of 23 m (75 ft). Communication, however, was achievable at distances up to 100 m (328 ft).

The center of the two scintillation detectors was aligned with the center of the stack of drums. The width of the two scintillation detectors and of the two ^{3}He detectors behind them was 50 cm. This was only 10 cm less than the diameter of a 55-gal drum.

The raw data from each experiment were collected as one file. Each record contained the time, horizontal position, vertical position, two γ-ray counts (one from each detector), and two neutron counts (one from each detector). Horizontal position was manually entered prior to each vertical scan of the drums and recorded in the project log book since there was no laser distance measurement for horizontal position.

4.1 Data Analysis Procedures

The data were collected and validated at the test site. This was done by visually examining the data as they were collected and comparing the count rate results with the expected count rates based on the preliminary hand survey done by the on-site health physics (HP) technician. The process of generating contour maps of the survey area was done in Idaho Falls using software specifically designed for this purpose. Prior to this, the position of the gamma-ray and neutron data from each detector on the sensor was corrected to correspond to the center of respective detectors. This was required because the data acquisition package simply recorded the overall position of the sensor and not the centroid of each of the detectors on the system. Future software modifications of the acquisition system will account for the actual detector locations within a sensor. Once these corrections were made, the data were gridded onto a regular grid, and contour lines were drawn based on grid values for each detector.

4.2 Experimental Procedures

The five experiments that were originally planned are listed below.

1. Count each drum at its center at a standoff distance of 15.2 cm for 10 seconds. Count from the top of a column to the bottom, step to the center of the next column of drums, and again scan from top to bottom. Repeat these steps until the entire matrix is scanned.

2. Scan five designated stacks of drums from top to bottom for each stack (column) at a scanning rate of 7.5 cm/s and at a standoff distance of 15.2 cm. Scan from the top of a column to the bottom, step to the center of the next column, and again scan from top to bottom. Repeat these steps until the entire matrix is scanned.

3. Repeat test 2 at a scanning rate of 15.2 cm/s.

4. Repeat test 2 at a scanning rate of 7.5 cm/s and at a distance of 45.7 cm from the closest drum.

5. Repeat test 2 at a scanning rate of 7.5 cm/s and at a distance of 30.5 cm from the closest drum.

During the test, two additional measurements were performed:

6. Repeat test 2 at a scanning rate of 7.5 cm/s and at a distance of 91.4 cm from the closest drum.

7. Perform a horizontal scan of one row of drums at a scanning rate of 7.5 cm/s and at a distance of 30.5 cm from the closest drum.

The stacks of drums were counted from top to bottom and from left to right until five columns were scanned. Each experiment collected the data as one file containing the time, distance, and four detector counts. All but the last experiment consisted of five scans of five columns of drums at standoff distances of 15.2, 30.5, 45.7, and 91.4 cm, respectively. The spotter for the forklift operator aligned the GNM detectors with respect to the center of the drum stack. The time required to complete an experiment, which scanned all 25 drums at a scan rate of 7.5 cm/s, was 6 minutes.

5. TEST RESULTS

The GNM operated flawlessly during the measurements in Building 628 of the RWMC. The temperature inside the building (~7.2°C) (45°F) did not appear to adversely impact any measurements. The forklift operators were able to repeatedly and uniformly scan the stacked drums at speeds of ~7.5 cm/s and at ~15 cm/s. The RF Ethernet transmission link between the sensor interface compartment of the pallet assembly and the workstation worked faithfully.

Although HP measurements were made on all 34 drums, only drums 6 through 30 were scanned with the GNM. Figure 5 shows the gamma-ray counts per second from the first stationary experiment, along with the drum number and the radiation field value recorded by HP personnel. The count rate limitation of the plastic scintillation circuitry was exceeded when the GNM scanned drums 7, 16, and 21. The count rate values at these areas saturated at ~600,000 counts/s. Actually, the count rates dropped within the 600,000-counts/s contour and were scaled to be 600,000 to show a high but unknown count rate. It is estimated that the actual count rate at drum 21 exceeded 5×10^6 counts/s. When the detector reached its saturation count rate, the circuitry was unable to properly handle the high radiation field, resulting in an analog voltage and corresponding measured count rate that is less than it should be. The count-rate capability of the detector continues to decline relative to the input count rate until it reaches approximately 600,000 counts/s, at which the count rate at the detector actually drops. This limitation is not inherent to the plastic scintillation detector; rather, it is due to limitation in the pulse processing circuitry and should be corrected. A comparison of the measured count rates from the first experiment compare favorably with the measured values taken at the center of each drum from the second experiment. Also shown in Figure 5 is the measured count rates for the neutron radiation fields from the first experiment (values from two detectors of each type were averaged).

The average γ and μ count rates measured by the GNM, the HP-measured γ-fields, and the manifest values for fissile mass in grams stored in the drums are given in Table 2 along with the drum content code. The GNM data over 25 drums (5×5 matrix) were acquired in 6 minutes while the data taken by the HP with his hand γ probe took about 20 minutes. Further, in 6 minutes, the GNM acquired both the γ and neutron data required to compose a two-dimensional contour plot. A comparison of the measured radiation fields are in qualitative agreement. However, in several cases, the passive assay results from the fissile passive/active neutron (PAN) system given in the generator manifest do not appear to correlate with either the γ or neutron measurements. Discussions with one of the technical staff responsible for oversight of the fissile operations at RWMC suggested that this is no surprise due to the limitations of the PAN passive coincidence counting method (e.g., α,n reactions caused by α-emitting radionuclides interacting with low Z materials interfere with the basic principle of PAN operation, reducing the accuracy of the method). Some of the PAN assay measurements that were made prior to hardware, software, and procedural improvements in the SWEPP assay system may also be questionable. Further, fissile assays cannot be performed under most conditions with a simple survey instrument as

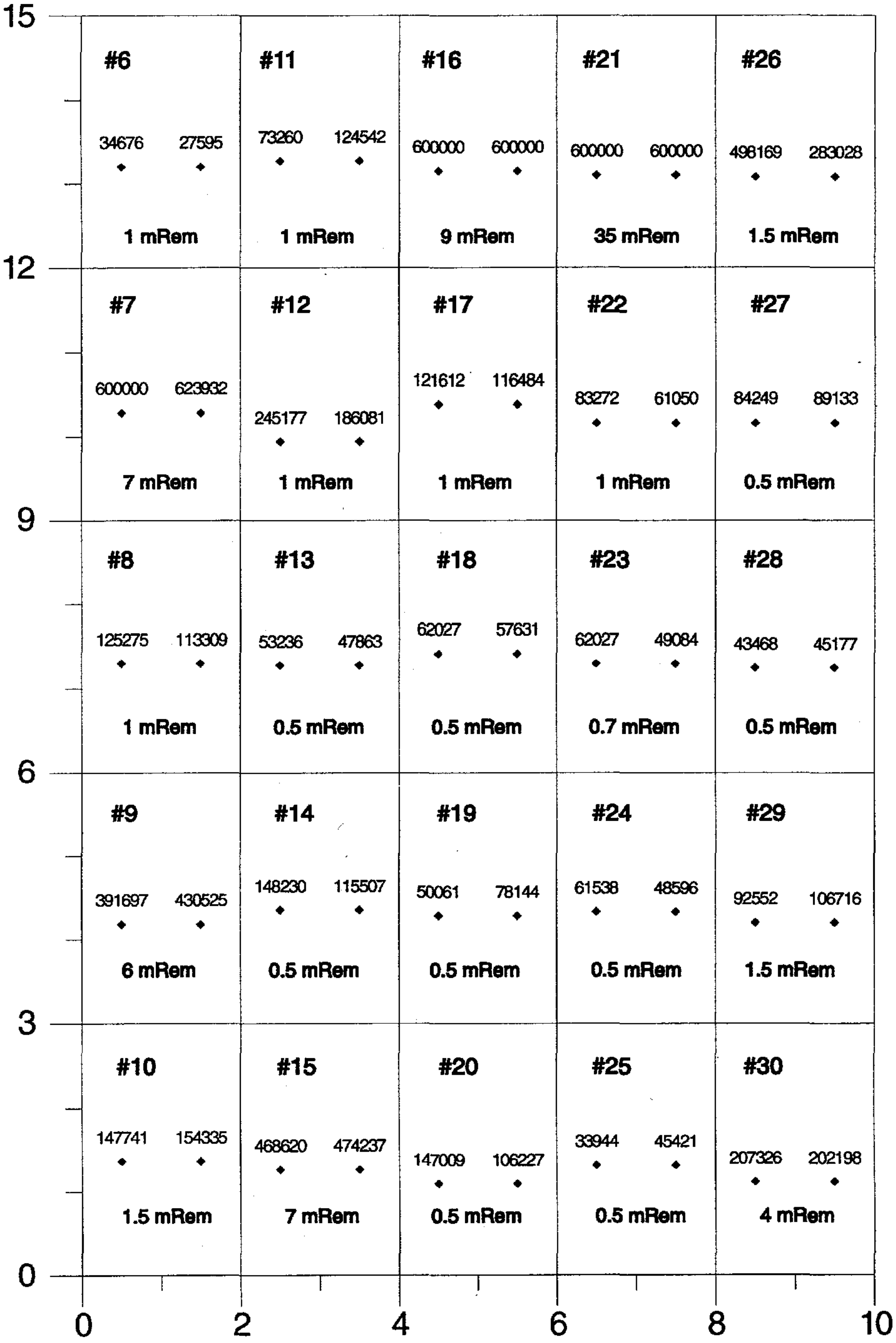

Figure 5. Outline of 25-drum test matrix with static gamma-ray and neutron measurements.

Table 2. Outline of 25-drum matrix with the GNM-measured γ-ray and neutron count rates, HP-measured γ-radiation fields at the center of each drum, passive fissile assays, and content codes.

Drum 6 (a) 1 (b) 31,140 (c) 49 (d) 1.2 (e) 7	Drum 11 (a) 1 (b) 98,900 (c) 82 (d) 17 (e) 7	Drum 16 (a) 9 (b) 600,000 (c) 108 (d) 16 (e) 1	Drum 21 (a) 35 (b) 600,000 (c) 146 (d) 0 (e) 1	Drum 26 (a) 1.5 (b) 390,600 (c) 102 (d) 9.5 (e) 7
Drum 7 (a) 7 (b) 612,000 (c) 114 (d) 0 (e) 1	Drum 12 (a) 1 (b) 215,630 (c) 132 (d) 3.2 (e) 480	Drum 17 (a) 1 (b) 119,050 (c) 142 (d) not available (e) 300	Drum 22 (a) 1 (b) 72,160 (c) 142 (d) 1.00 (e) 292	Drum 27 (a) 0.5 (b) 86,690 (c) 110 (d) 6.6 (e) 440
Drum 8 (a) 1 (b) 119,290 (c) 126 (d) not available (e) 337	Drum 13 (a) 0.5 (b) 50,550 (c) 148 (d) 1.4 (e) 7	Drum 18 (a) 0.5 (b) 59,830 (c) 182 (d) 32.9 (e) 480	Drum 23 (a) 0.7 (b) 55,560 (c) 122 (d) 5.0 (e) 1	Drum 28 (a) 0.5 (b) 44,320 (c) 105 (d) 1.4 (e) 7
Drum 9 (a) 6 (b) 411,110 (c) 172 (d) 117 (e) 1	Drum 14 (a) 0.5 (b) 131,870 (c) 134 (d) 2.0 (e) 4	Drum 19 (a) 0.5 (b) 64,100 (c) 134 (d) 0 (e) 7	Drum 24 (a) 0.5 (b) 55,070 (c) 176 (d) 1.0 (e) 334	Drum 29 (a) 1.5 (b) 99,630 (c) 164 (d) 24.8 (e) 300
Drum 10 (a) 1.5 (b) 151,040 (c) 95 (d) 0.66 (e) 1	Drum 15 (a) 7 (b) 471,430 (c) 105 (d) 7.5 (e) 1	Drum 20 (a) 0.5 (b) 126,620 (c) 92 (d) 1.1 (e) 7	Drum 25 (a) 0.5 (b) 39,680 (c) 174 (d) 0 (e) 7	Drum 30 (a) 4 (b) 204,760 (c) 310 (d) 0.13 (e) 320

a. HP γ-ray field measurement with telescoping probe. Measurement is of highest observed radiation field in mR/h.
b. GNM-measured γ-ray field from experiment #1 taken at center of drum. Units in counts/s. Value is the average of two detectors.
c. GNM-measured neutron field from experiment #1 taken at center of drum. Units in counts/s. Value is the average of two detectors.
d. Mass of fissile plutonium material from passive assay with a passive/active neutron assay (PAN) system.
e. Content code: 1 through 4, 7, and 292 = sludge; 300 = graphite molds; 320 = primarily tantalium crucibles; 330 to 335 = combustible waste; 337 = plastic and nonleaded rubber; 440 = glass; 480 = metals (including Fe, Al, Cu, and stainless steel). For further information, see T. L. Clements, DOE Report WM-F1-82-021, October 1982.

the GNM. Even so, it seems prudent that waste drums with high γ or neutron radiation fields (above 300,000 or 150 counts/s, respectively, for a standoff distance of 15.2 cm) should be reassayed for fissile content when improved technology becomes available. The use of the GNM to locate waste drums (e.g., drums 7, 19, 21, and 25) whose generator provided fissile content manifest values are believed to be questionably low due to high γ and neutron fields, may be an alternate use for this instrument since it can scan many drums in a relatively short time.

Figures 6 to 16 show the contour plots of the γ-ray and neutron data from each experiment with the physical dimensions of the drums also outlined over the plot. As shown in Figure 6, the hot drums identified in the contour plots of the scintillation data correspond to the hot drums identified by the HP with a telescoping probe. Further, little if any cross interference of radiation from drums appears to have occurred. Since there appears to be no cross interference of radiation between adjacent exposed drums, it is plausible that there are no cross interferences with the drums stored behind these exposed drums.

A comparison of Figures 6 and 8 to Figures 7 and 9 show that not all drums that had high γ radiation fields had high neutron radiation fields and vice versa. The differences in the peak intensities from the γ and the neutron scan data may result from several possible scenarios: (a) the source matrix contains, respectively, a combination of neutron moderators and high cross-section materials or of high Z material to prevent the neutrons or γ-rays from escaping the drum, (b) the source of neutrons may be produced by fission, an (α,n) reaction, or a combination of these production modes where the respective radionuclide emits only low-energy γ-rays or no γ-rays, (c) the waste contains γ-ray emitters but no corresponding (α,n) reactions. The drum content code can assist the γ-ray and neutron measurements in providing an assay of the radionuclide and fissile content of these drums.

Figure 17 shows three-dimensional plots of the drum matrix as a function of distance of the GNM from the stacked drums. Note that even at a distance of 45 cm, the resolution is sufficient to identify the drums with high radiation fields.

6. PROBLEMS AND ISSUES

The GNM performed without incident during the entire test. However, several minor problems were encountered prior to the test. First, the current limit adjustment on the 24-V power supply was inadvertently changed during shipment of the GNM assembly to the RWMC. This reduced the current output to below that required by the GNM. As a result, the power supply could not energize the GNM until the current control was increased. This adjustment was corrected prior to the test. Future uses of the GNM should have the 24-V power supply enclosed in the acquisition module with no voltage adjustment.

Second, it is difficult to attach the signal cable to the connector at the bottom of the sensor interface compartment when it is mounted on the wooden pallet. During hookup of the cables at the RWMC, the signal cable was attached to this connector when the interface may have been energized. This could have caused the digital-to-analog board to fail. In any case, the board was replaced prior to the test.

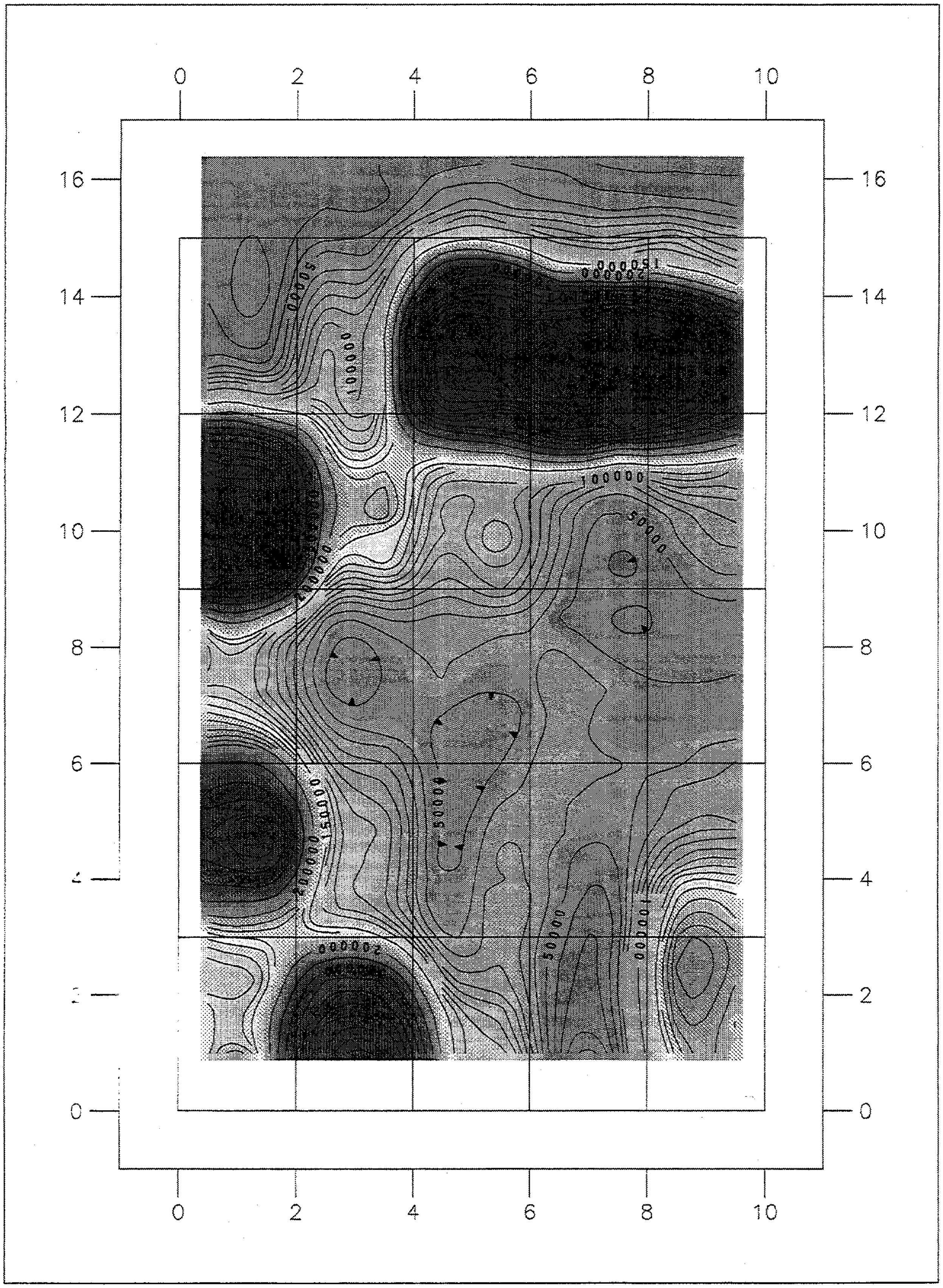

Figure 6. Contour plot of the γ-ray count rates from experiment 2 of the 25-drum matrix acquired at a standoff distance of 15.2 cm and a scan speed of 7.5 cm/s.

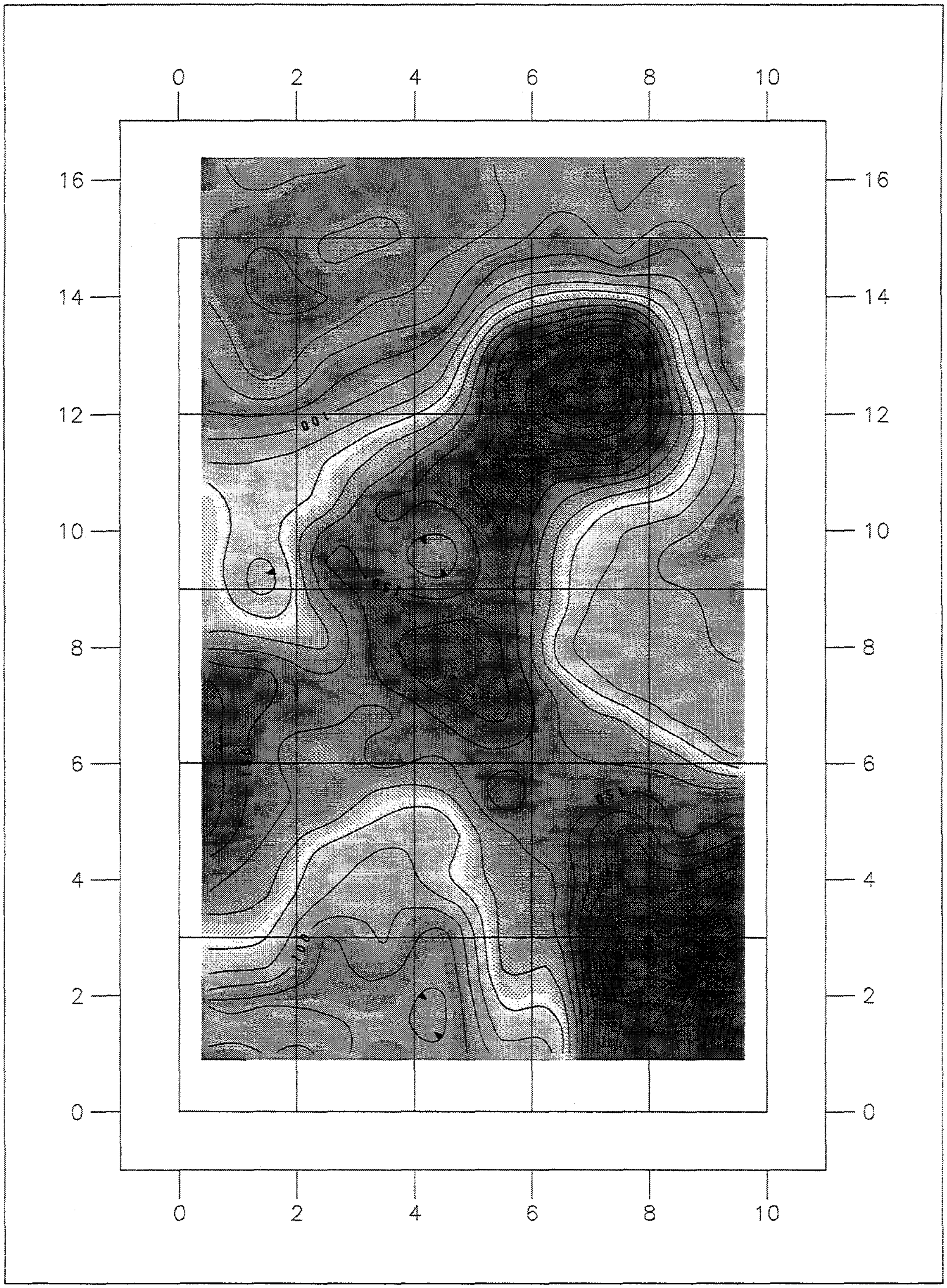

Figure 7. Contour plot of the neutron count rates from experiment 2 of the 25-drum matrix acquired at a standoff distance of 15.2 cm and a scan speed of 7.5 cm/s.

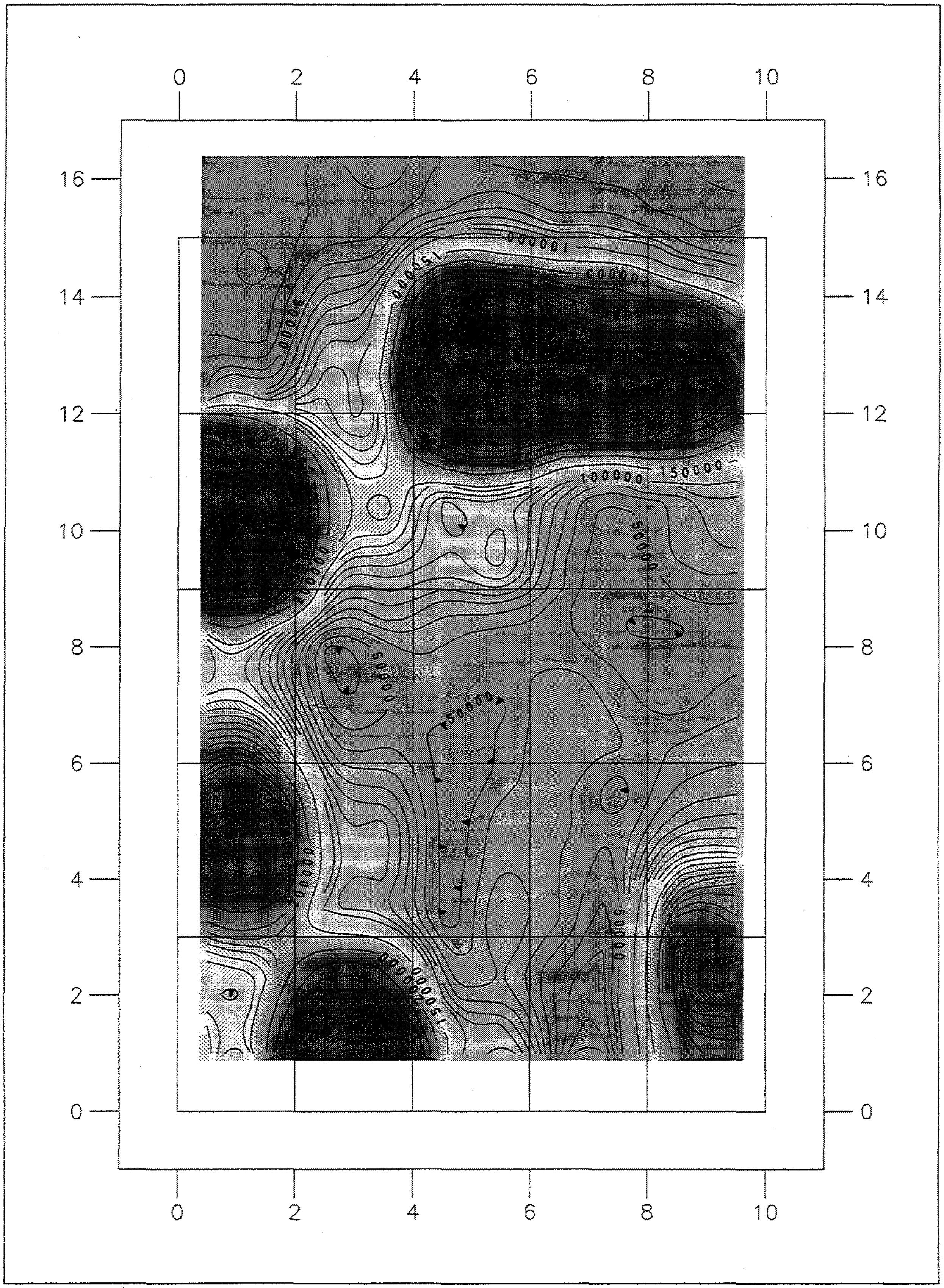

Figure 8. Contour plot of the γ-ray count rates from experiment 3 of the 25-drum matrix acquired at a standoff distance of 15.2 cm and a scan speed of 15 cm/s.

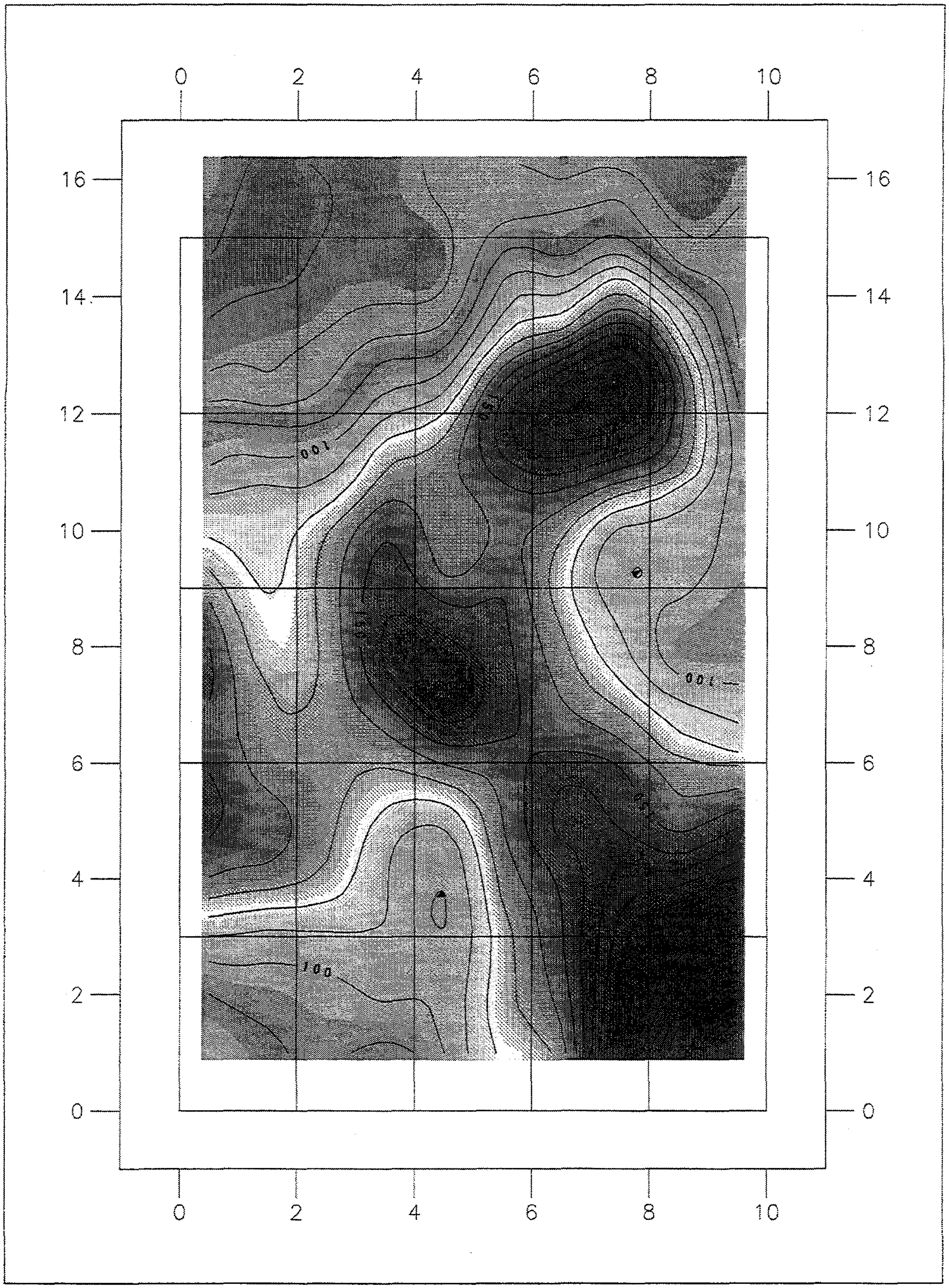

Figure 9. Contour plot of the neutron count rates from experiment 3 of the 25-drum matrix acquired at a standoff distance of 15.2 cm and a scan speed of 15 cm/s.

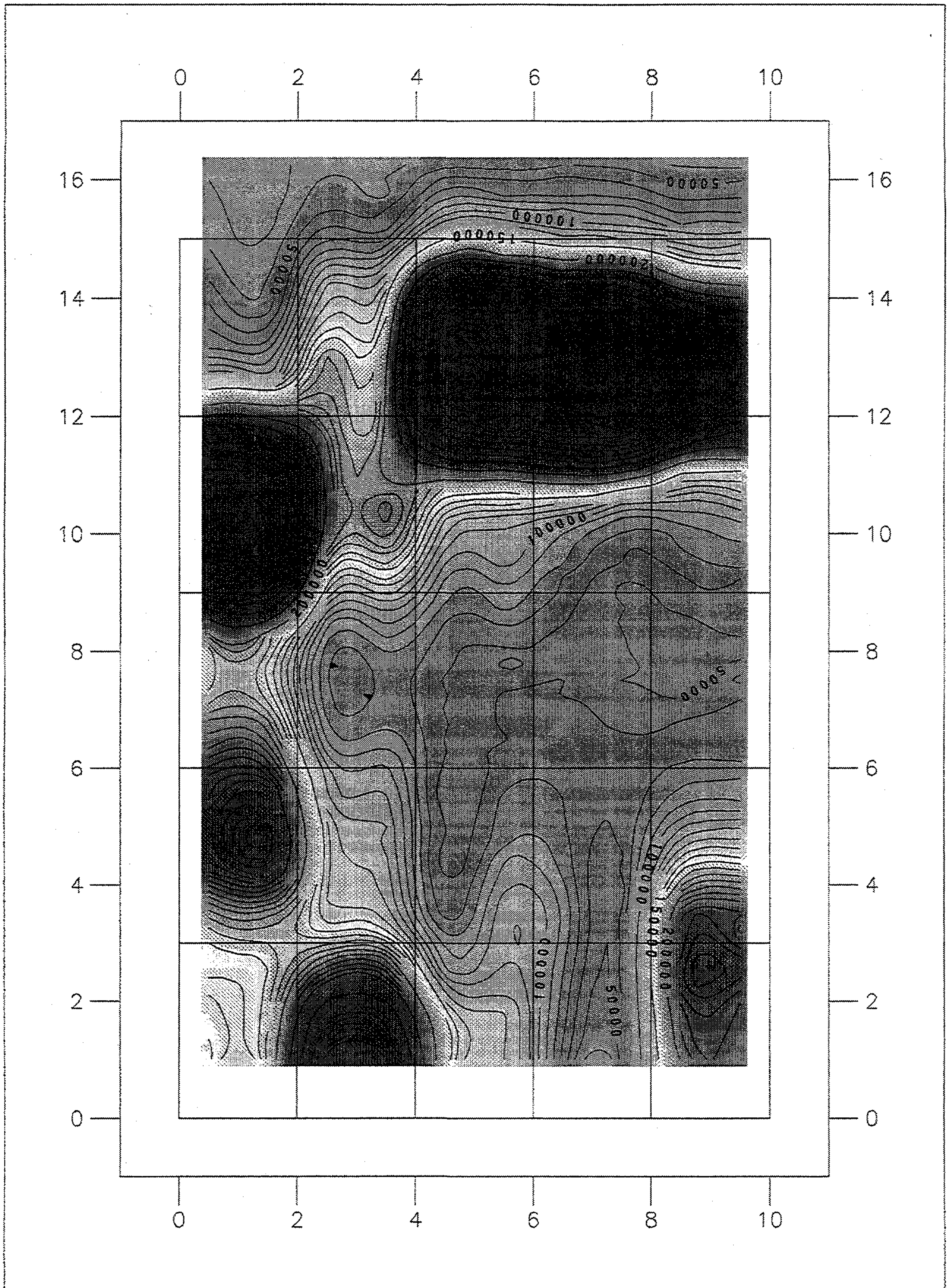

Figure 10. Contour plot of the γ-ray count rates from experiment 4 of the 25-drum matrix acquired at a standoff distance of 45.7 cm and a scan speed of 7.5 cm/s.

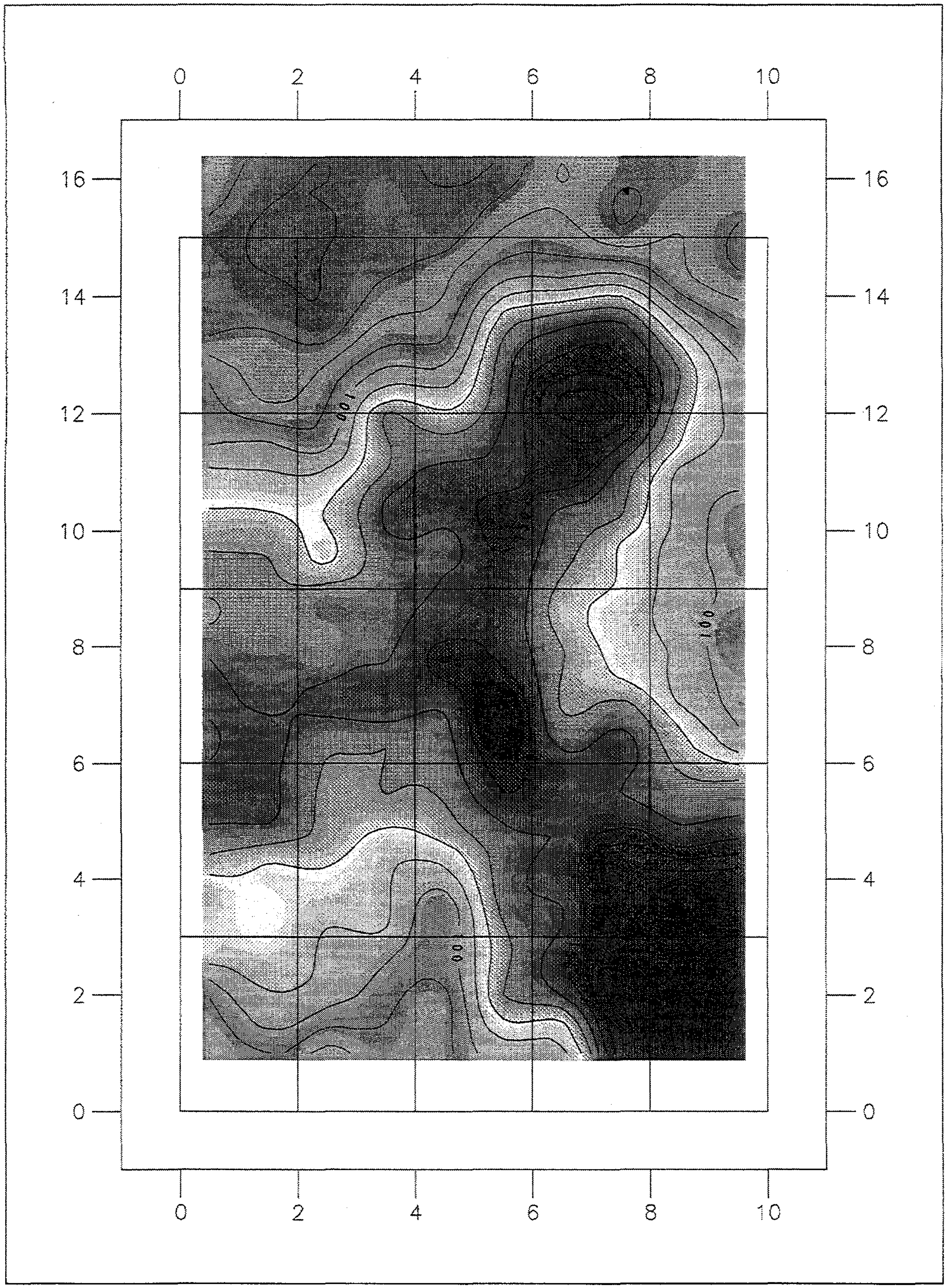

Figure 11. Contour plot of the neutron count rates from experiment 4 of the 25-drum matrix acquired at a standoff distance of 45.7 cm and a scan speed of 7.5 cm/s.

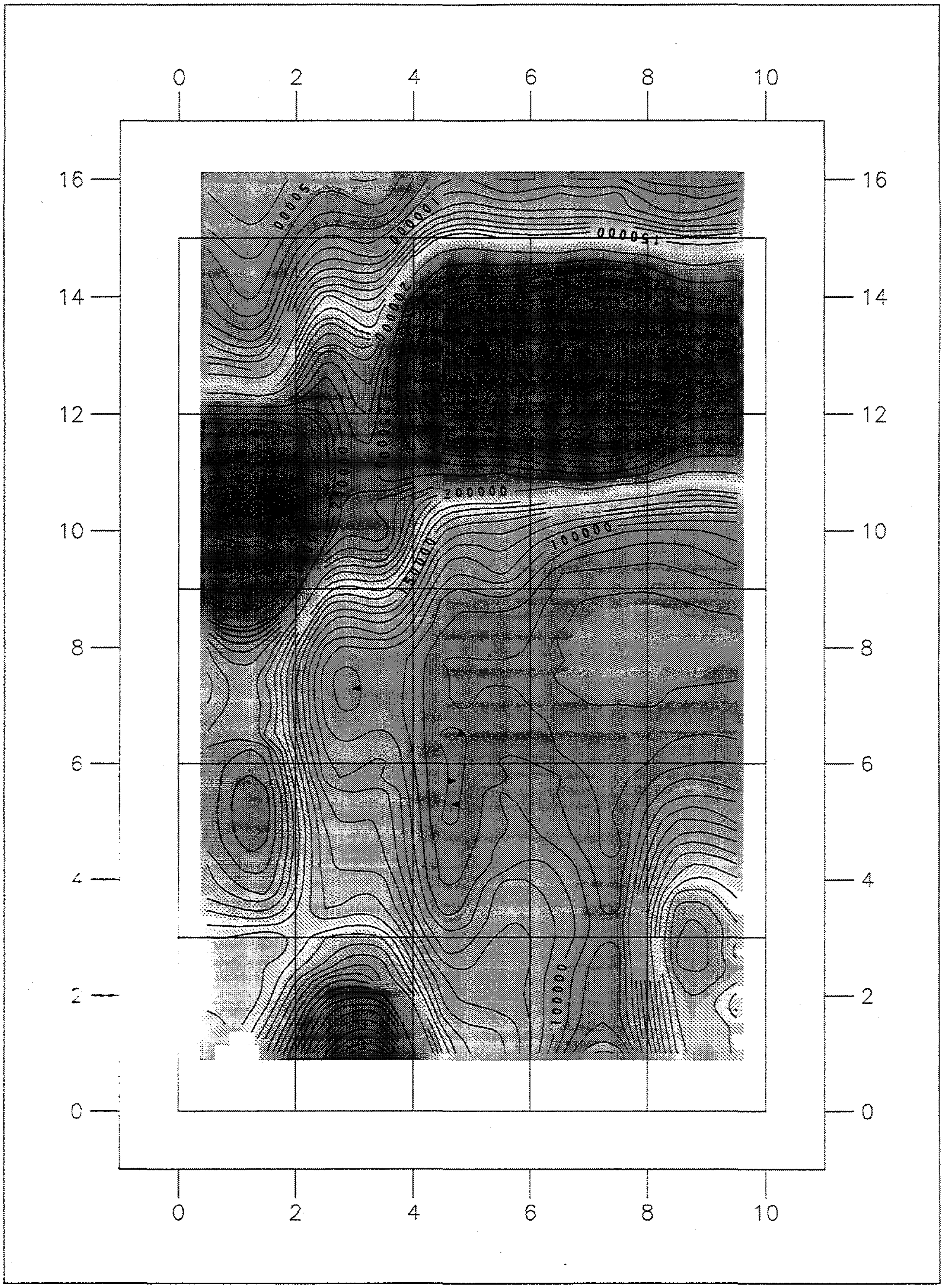

Figure 12. Contour plot of the γ-ray count rates from experiment 5 of the 25-drum matrix acquired at a standoff distance of 30.5 cm and a scan speed of 7.5 cm/s.

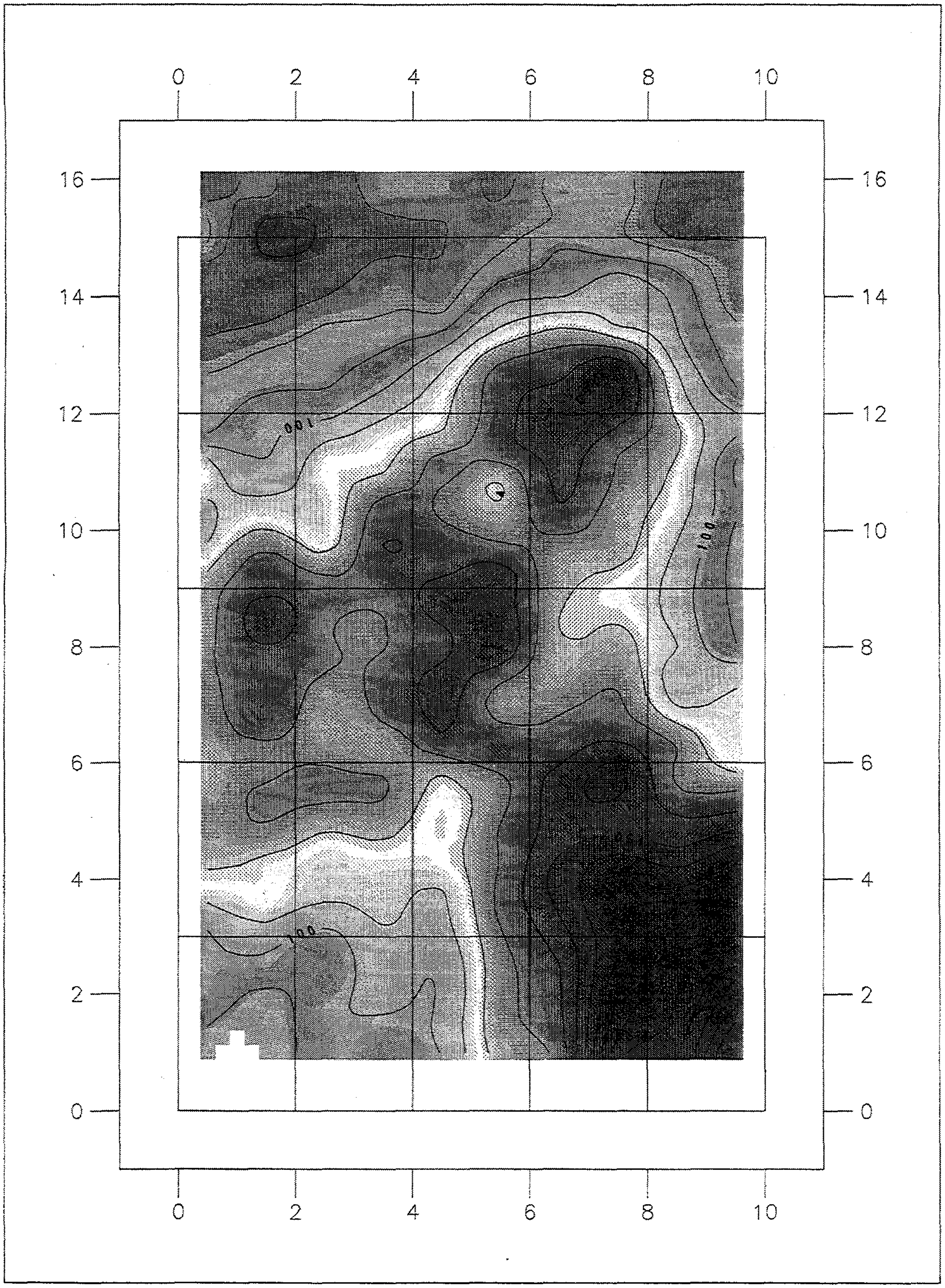

Figure 13. Contour plot of the neutron count rates from experiment 5 of the 25-drum matrix acquired at a standoff distance of 30.5 cm and a scan speed of 7.5 cm/s.

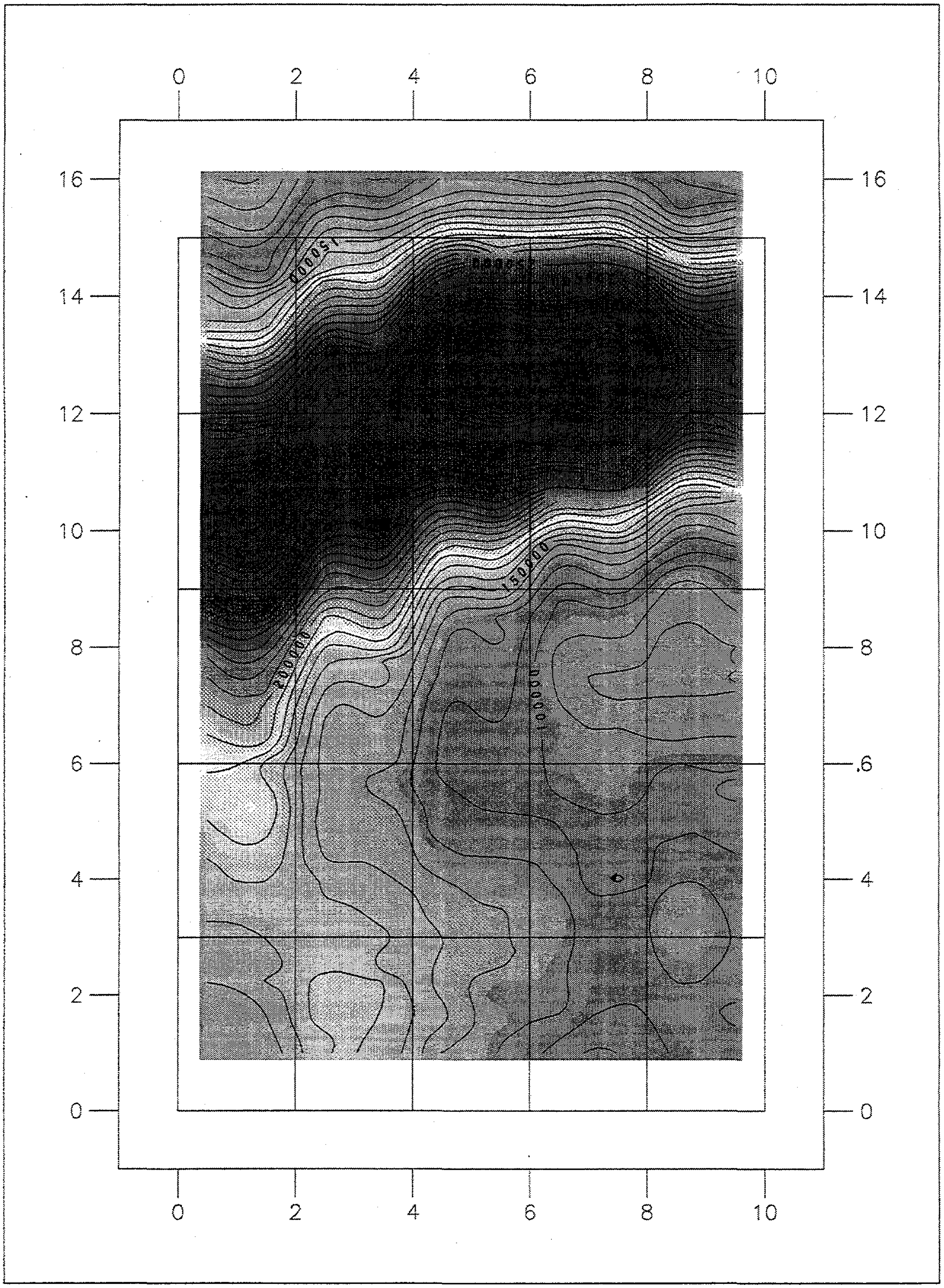

Figure 14. Contour plot of the γ-ray count rates from experiment 6 of the 25-drum matrix acquired at a standoff distance of 91.4 cm and a scan speed of 7.5 cm/s.

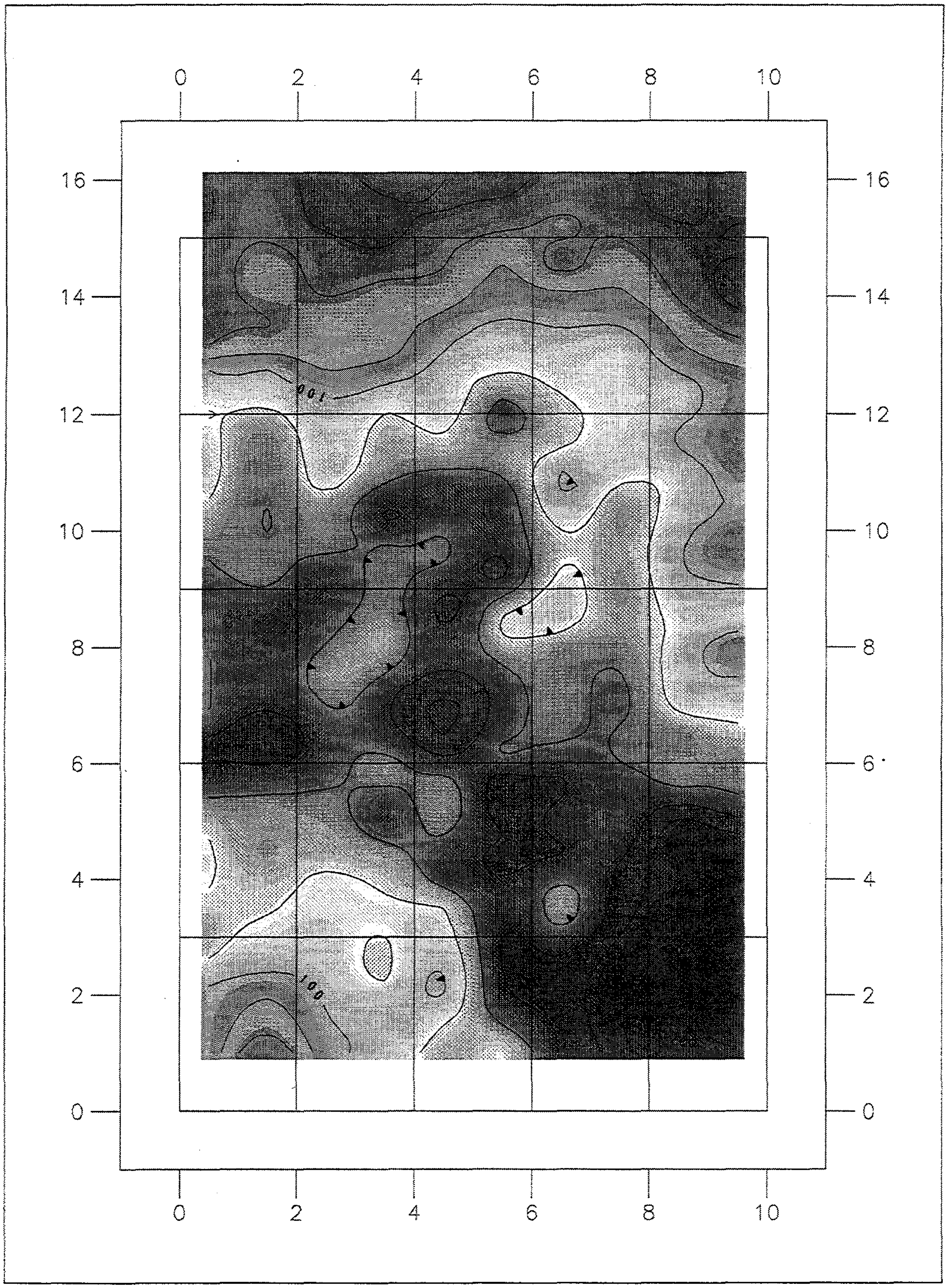

Figure 15. Contour plot of the neutron count rates from experiment 6 of the 25-drum matrix acquired at a standoff distance of 91.4 cm and a scan speed of 7.5 cm/s.

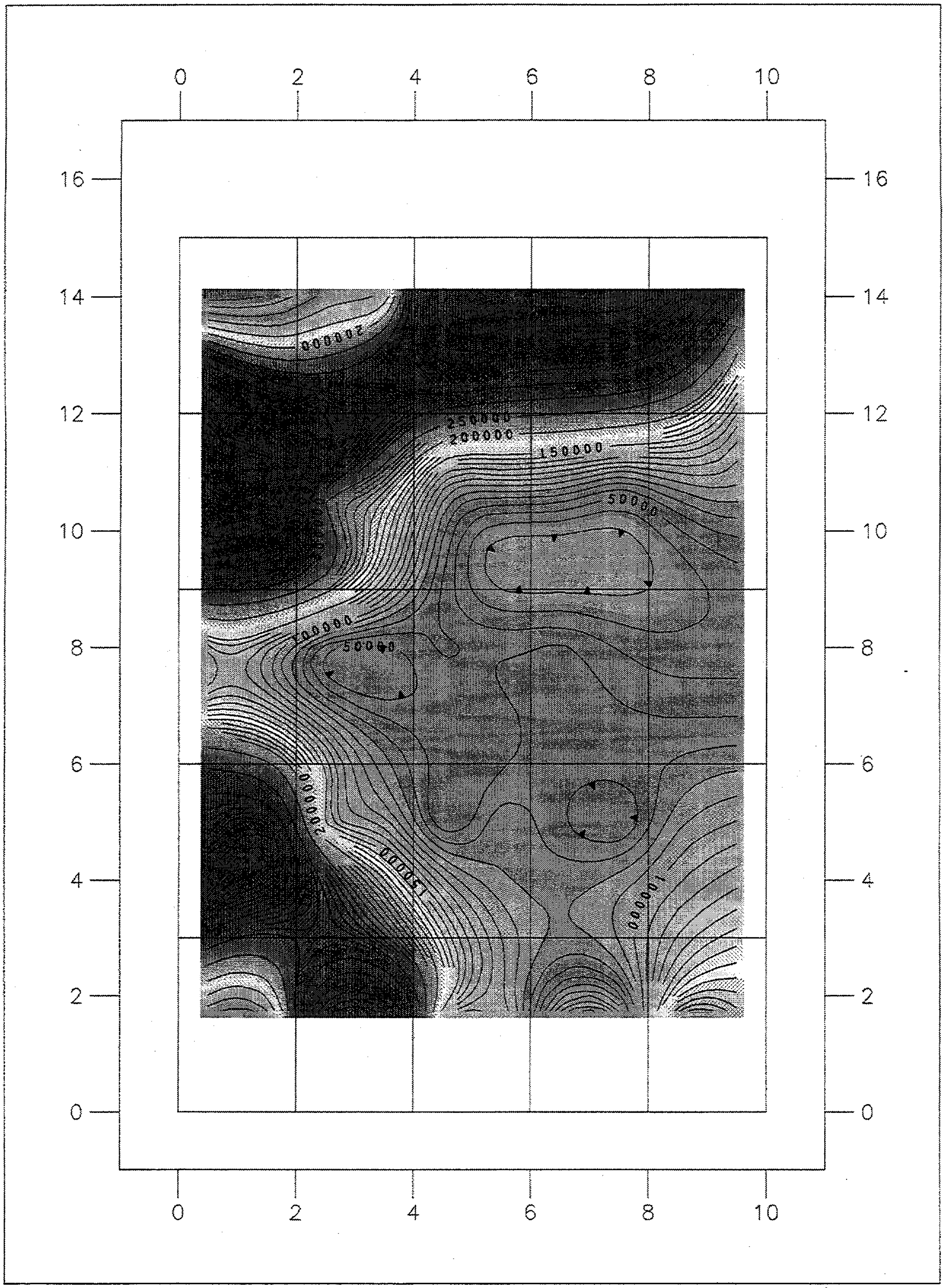

Figure 16. Horizontal scan of γ-ray count rates from experiment 7. Scan was across all five stacks at a height of 110 cm (center of second row of drums from the bottom), at a standoff distance of 30.5 cm, and a scan speed of 6.1 cm/s.

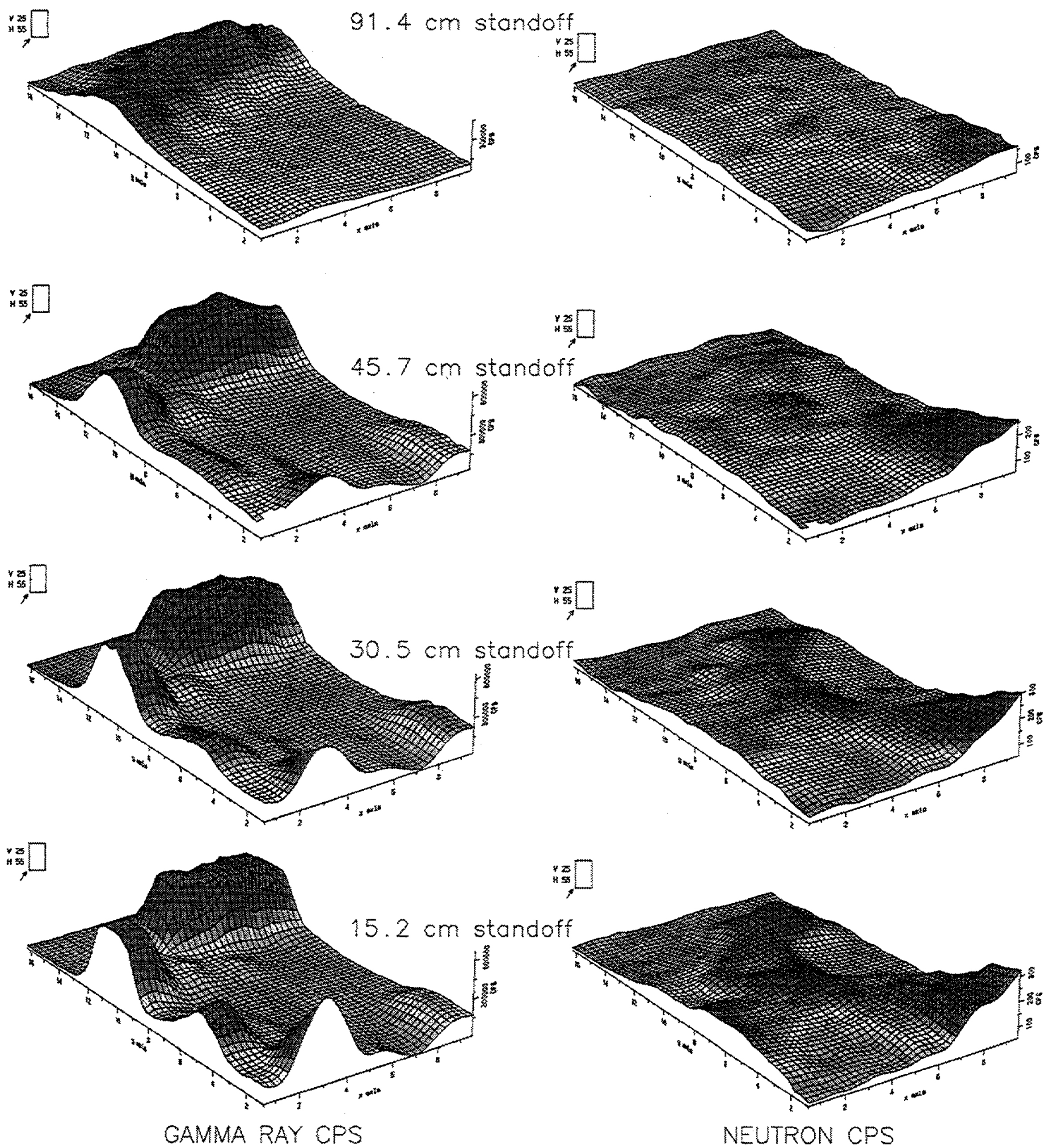

Figure 17. Three-dimensional plots of experiments 2, 5, 4, and 6 at standoff distances of 15.2, 30.5, 45.7, and 91.4 cm, respectively. Note that even at a 91.4-cm standoff distance, the "hot" drums can still be identified even though smearing of the contours has occurred.

The count rate limitation of the scintillation detector circuitry resulted in saturation when the 35-mR/h drum (No. 21) was scanned. This limitation will be corrected so that the scintillation detector can record count rates in excess of 1×10^6 counts/s with less than 10% counting losses as specified in the procurement specifications.

It should be noted that the dimensions of the scintillation and the ^{3}He detectors were chosen to provide high sensitivity to low levels of radiation. The radiation levels from the present test reached maximum levels much higher than original design specifications expected. Further, because the detector dimensions are quite large, the physical resolution of the GNM is less than it would be if the radiation detectors had smaller dimensions. In spite of this shortcoming, the GNM was effective in identifying specific drums with high γ or neutron radiation fields.

7. CONCLUSIONS AND RECOMMENDATIONS

All of the objectives of this performance test were achieved. The equipment performed flawlessly under the temperature, electrical noise, and mechanical noise conditions present during the test, and the personnel effectively carried out the planned measurements. As a result, all seven experiments were completed in about 6 hours. The temperature of the building, 10°C (50°F), did not cause any observable effect on the data. The RF Ethernet link worked well and was demonstrated to be operable even at distances of 100 m (328 ft).

The individual experiments all furnished useful data in a rapid and efficient manner with all 25 drums being scanned in 6 minutes or less. The radioactively "hot" drums were easily identified. Although the forklift is not intended to deliver a uniform speed for the purpose of scanning, the two operators assigned to this project for the day of the test did an excellent job of maintaining relatively uniform scan speeds.

The sensitivity of the plastic scintillators for the 60-keV ^{241}Am γ-rays was only indirectly demonstrated by the very high count rates encountered even with those drums emitting lower radiation fields. A 1-mR/h measurement corresponds roughly to 170,000 counts/s for each plastic scintillator. Prior to the test, the efficiency of the plastic scintillator detectors was measured to be 0.16% for the 60-keV γ-ray from ^{241}Am and 1.8% for the 661-keV γ-ray from ^{137}Cs at a 30.5-cm standoff distance. The ^{241}Am source used in the efficiency measurements is sealed in a small metal capsule, which may partially explain the low measured value. Transmission through the titanium window of the GNM for 60-keV γ-ray is about 70%.

As can be observed from a comparison of the GNM measurements with those taken by the HP, the drums with high-radiation fields are readily apparent. Further, the contour plots are very useful in identifying the location(s) in the waste drums of the highest levels of radiation.

As observed from Figure 6, the correlation between the γ radiation fields measured by the HP and the GNM γ scans was very high. The correlation between the GNM neutron-radiation scans and the fissile assays reported on the manifest is not as high. Discussions with one of the technical staff responsible for providing oversight of the fissile assay measurements made at SWEPP suggested that many of the generator-supplied assay values are questionable. In particular, the zero fissile content values reported for waste drums 7, 19, 21, and 25 are suspicious, and drums 7 and 21 are particularly so in light of the high γ and neutron radiation fields measured by the GNM. Use of the GNM for rapidly identifying potentially mislabeled waste drums actually containing high levels of fissile material should be considered.

Finally, we are pleased to report that because close attention was paid to the ALARA (as low as reasonably achievable) principle, the total cumulative whole-body radiation dose for all six workers (over 4.5 hours of work at Building 628) was less than 5 mRem, with no one receiving over 1 mRem.

8. REFERENCES

Gehrke, R. J., R. S. Lawrence, and R. J. Pawelko, 1995a, *Results of Performance Tests on Chemical and Radiation Measurement Systems for Use at a Dig-Face*, INEL-95/0036, April.

Gehrke, R. J., L. G. Roybal, and D. N. Thompson, 1995b, *Test Plan for a Live Drum Survey Using the Gamma-Neutron Sensor*, INEL-95/0171, April.