MALLINCKRODT CHEMICAL INC.

ST. LOUIS PLANT

BUILDING 235 EXPANSION PROJECT

WORK PLAN SUMMARY

FOR

SURFACE DECONTAMINATION AND FINAL SURVEY

October 9, 1996

BUILDING 235 DECONTAMINATION AND FINAL SURVEY

WORK PLAN SUMMARY

A. BACKGROUND

Building 235 is located in an area designated as Plant 5 at the Mallinckrodt St. Louis plant site. Mallinckrodt has developed a capital project to expand process capacity at building 235 for future product needs. This expansion involves installation of a new 20'x30'x2' deep concrete structure on the concrete pad immediately east of the building to support new process equipment. The attached sketch shows this pad along with the proposed location of the new process support structure. Mallinckrodt proposes to decontaminate the entire pad and perform a final status survey on the decontaminated surface prior to installing the new process support structure. Phase 1 characterization* net β measurement data have also shown portions of the building 235 east external wall to contain certain surface activity levels. Mallinckrodt also proposes to decontaminate this wall surface and perform a final status survey.

B. CONDITIONS AT THE SITE

The attached color-coded maps graphically show the present areal extent of surface contamination on the building 235 east pad and east external wall. The net β activity comparison shown on these maps is the surface release limit or criterion (1500 dpm/100 cm^2) derived using NUREG-1500 radionuclide 15 mrem/year limits. Comparison with the FC 83-23 (1100 dpm/100 cm^2) limit shows similar results.

The attached east pad sketch shows the locations of 8 boreholes drilled on this pad as part of the phase 1 characterization plan. As indicated on this sketch, the proposed new process support structure will be installed generally in the vicinity of boreholes 1 and 2. Attachment 1 contains the complete nuclide radioactivity concentrations and sum-of-ratio results for the 32 subsurface samples collected and analyzed from these 8 boreholes. Summarized below are radionuclide concentration averages and ranges in pCi/g for these borehole samples:

Nuclide	U^{238}	Th^{230}	Ra^{226}	Th^{232}	Ra^{228}	Th^{228}
Average	1.7	0.39	0.34	0.13	0.13	0.01
Range	0-6.4	0-2.9	0-1.8	0-0.69	0-0.8	0-0.4

B. CONDITIONS AT THE SITE - Con't.

As indicated on Table 1, Branch Technical Position Option 1 radionuclide limits of 5 pCi/g were used for each of the 6 nuclides to calculate the sum-of-ratio values. The average Table 1 sum-of-ratio value is <1.0 and none of the individual sum-of-ratio values exceed the 3.0 hot spot criterion. In addition, the few individual sample sum-of-ratio values that slightly exceed 1.0 comply with the NUREG/CR-5849 elevated area [$(100/A)^{½}$] criterion.

C. PLANNED DECONTAMINATION WORK

Enclosed concrete scarification with HEPA filtration will be employed on the east pad in a manner that will be protective of worker health and safety and in a manner to prevent the spread of contamination to adjacent areas and facilities. The scarifier unit will be enclosed in a 10'x10'x6' PVC containment with a connected blower to provide a negative air environment within the enclosure. This unit will remove up to ½" of concrete from the available pad area. Each decontaminated section of pad surface will be HEPA vacuumed and consolidated into suitable containers for storage prior to appropriate disposal. The scarifier containment is then moved to the next pad section for decontamination. Following completion of the work, the scarifier will be properly decontaminated prior to removal from the area.

The building east external wall (lower 8 foot section) will be decontaminated in a similar contained manner. The lower concrete footer section will be scabbled in conjunction with a HEPA filtered containment to prevent the spread of contamination. The radioactive contaminated bricks will be physically removed and replaced with new bricks. The removed bricks will be stored in suitable containers for ultimate disposal as radioactive waste.

Post-decontamination net β surveys will be conducted on both the east pad and building east external wall areas. Post-decontamination levels less than the FC 83-23 release limit will demonstrate the effectiveness of the decontamination method.

These surfaces will be decontaminated to below a background adjusted release limit of 1100 dpm/100 cm^2. This limit was derived using nuclide activities from 6 surface samples collected on the east pad and FC 83-23 individual radionuclide surface concentrations. The limit derivation equation used was reviewed with the NRC on November 3, 1994. This equation is equivalent to the sum-of-ratios equation and accounts for radionuclide series out of equilibrium.

D. WORKER AND ENVIRONMENTAL PROTECTION

Worker health and safety is of paramount importance to Mallinckrodt during the decontamination portion of this project. All workers will be radiation trained and will

D. WORKER AND ENVIRONMENTAL PROTECTION - Con't.

follow the provisions and requirements contained in the C-T plant health and safety plan* supplemented by the health physics requirements contained in Attachment 2.

Environmental protection is also of prime importance and will be given significant attention during the decontamination portion of this project. Continuous air sampling will be conducted adjacent to the scarifier tent. In addition, the site Radiation Safety Officer (or his delegate) will be at the site for the entire duration of the decontamination effort to assure the scarifier containment controls are working properly.

E. FINAL SURVEY PLAN

The final survey plan was developed using guidance in NUREG/CR-5849 and is presented in Attachment 3.

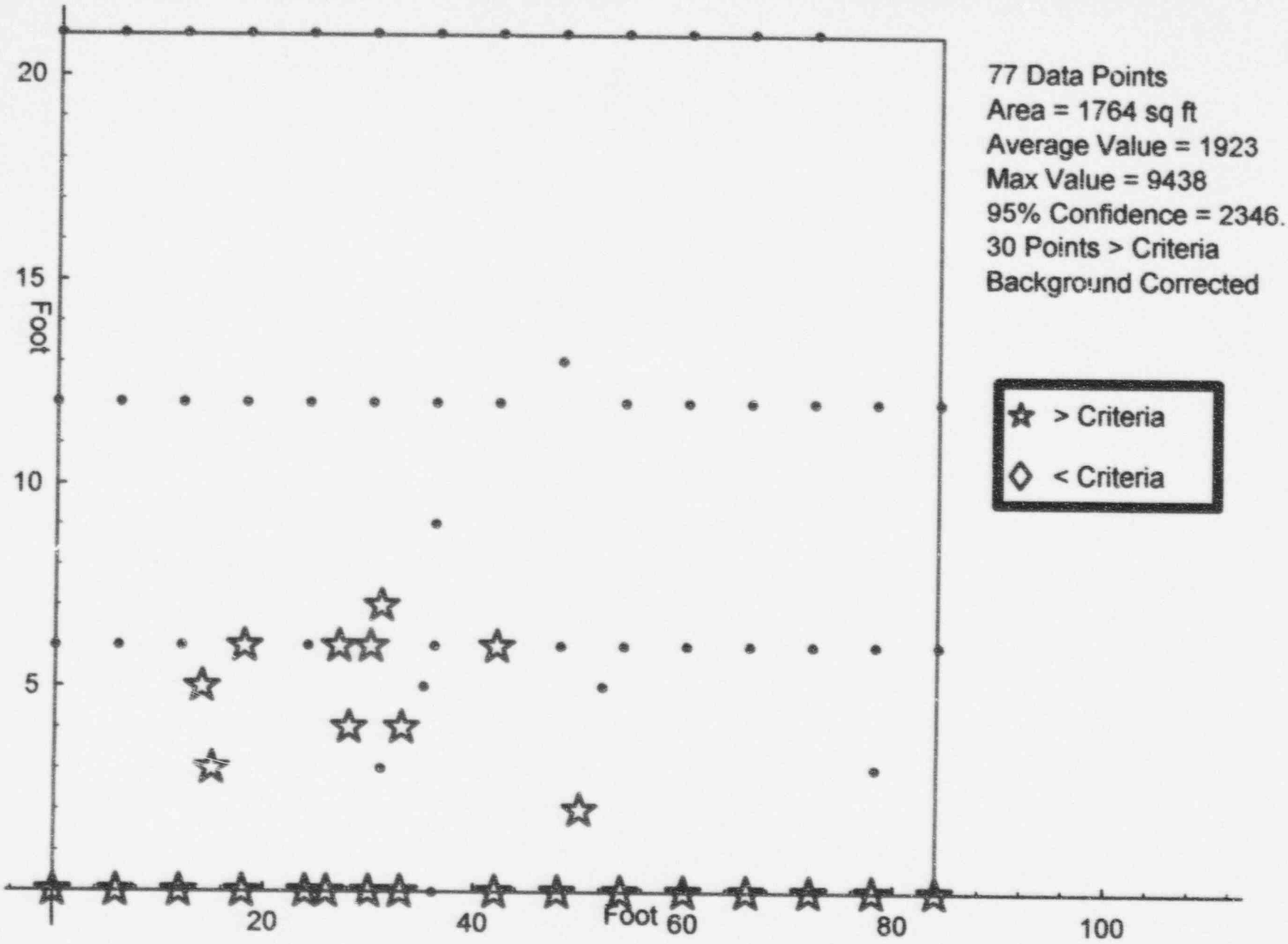
As indicated, this plan includes direct and removable net β surface measurements on the building 235 east external wall and adjacent east pad along with gamma exposure rate measurements on the decontaminated east pad surface. The plan also addresses field instrument MDA and final survey data interpretation criteria issues.

F. COST

The estimated cost for this decontamination/final survey project is $30,000 including anticipated NRC charges for the on-site verification survey work.

* C-T Characterization Plan dated January 10, 1994

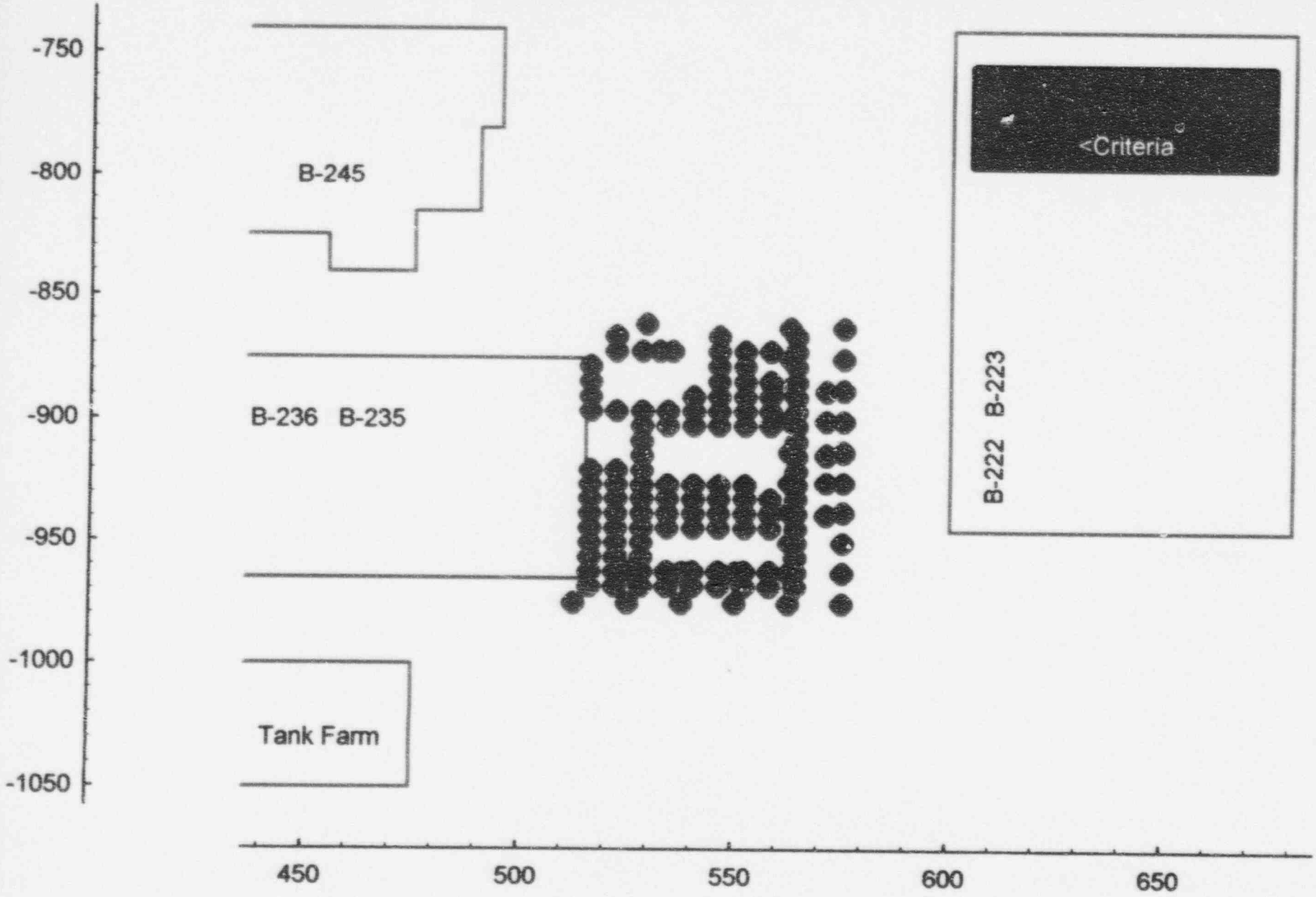
Building 235 East Exterior Wall NUREG 1500 Criteria 1500 Beta DPM/100 cm2



77 Data Points
Area = 1764 sq ft
Average Value = 1923
Max Value = 9438
95% Confidence = 2346.
30 Points > Criteria
Background Corrected

☆ > Criteria
◇ < Criteria

Street Scans - Beta Radiation Corrected for Background - NUREG 1500



BUILDING 235 EAST PAD LAYOUT

ATTACHMENT 1

07-Oct-96

Phase 1 Subsurface Data Sum of Ratios Tabulation

East	North	Depth	Location	Sample #	U-238	Th-230	Ra-226	Th-232	Ra-228	Th-228	Sum Of Ratios
528.31	-950.2	1.5	BH-01	MR940048	0.89	0.14	0.01	0.00	0.63	0.39	0.33
528.31	-950.2	3.5	BH-01	MR940051	2.99	0.00	0.00	0.00	0.33	0.00	0.66
528.31	-950.2	3.5	BH-01	MR940051D	4.19	0.00	0.00	0.00	0.23	0.00	0.88
528.31	-950.2	5.5	BH-01	MR940052	0.09	0.00	0.00	0.00	0.00	0.00	0.02
551.32	-949.6	1.5	BH-02	MR940056	0.00	0.00	0.00	0.69	0.13	0.00	0.16
551.32	-949.6	3.5	BH-02	MR940057	0.00	0.00	0.00	0.00	0.23	0.00	0.05
551.32	-949.6	5.5	BH-02	MR940058	0.00	0.00	0.00	0.00	0.00	0.00	0.00
551.32	-949.6	17.5	BH-02	MR940061	0.00	0.00	0.00	0.00	0.00	0.00	0.00
528.3	-929.3	1.5	BH-03	MR940085	3.49	2.88	0.21	0.29	0.13	0.00	1.40
528.3	-929.3	5.5	BH-03	MR940091	1.79	1.34	1.31	0.00	0.13	0.00	0.91
528.3	-929.3	16.5	BH-03	MR940103	6.39	1.14	0.00	0.49	0.00	0.00	1.60
528.3	-929.3	18.5	BH-03	MR940105	0.00	0.00	0.00	0.19	0.13	0.00	0.06
551.1	-930	2	BH-04	MR940109	0.00	0.00	0.00	0.00	0.00	0.00	0.00
551.1	-930	3.5	BH-04	MR940113	0.49	0.00	0.31	0.00	0.00	0.00	0.16
551.1	-930	18	BH-04	MR940127	5.39	0.44	1.01	0.00	0.03	0.00	1.37
551.1	-930	19	BH-04	MR940129	0.00	0.00	0.00	0.29	0.23	0.00	0.10
528.5	-909.5	1	BH-05	MR940154	4.89	1.44	1.01	0.00	0.43	0.00	1.55
528.5	-909.5	5	BH-05	MR940156	1.12	0.98	0.71	0.19	0.13	0.00	0.63
528.5	-909.5	5	BH-05	MR940156D	1.32	0.88	1.01	0.00	0.00	0.00	0.64
528.5	-909.5	7	BH-05	MR940159	0.00	0.00	0.00	0.09	0.00	0.00	0.02
551.8	-909.5	1	BH-06	MR940133	0.92	0.00	0.00	0.00	0.03	0.00	0.19
551.8	-909.5	5	BH-06	MR940136	0.00	0.08	0.00	0.00	0.00	0.00	0.02
551.8	-909.5	7	BH-06	MR940140	2.22	0.68	0.10	0.29	0.00	0.00	0.66
536.8	-897.3	1	BH-07	MR940175	0.22	0.00	0.00	0.09	0.23	0.00	0.11
536.8	-897.3	4	BH-07	MR940181	4.32	0.06	0.80	0.39	0.83	0.00	1.25
536.8	-897.3	6	BH-07	MR940184	0.12	0.00	0.00	0.00	0.00	0.00	0.02
536.8	-897.3	12	BH-07	MR940191	1.92	1.28	1.81	0.19	0.53	0.00	1.15
550.9	-885.6	1.5	BH-08	MR940203	1.59	0.68	0.91	0.49	0.13	0.00	0.76
550.9	-885.6	6	BH-08	MR940208	4.02	0.00	1.11	0.00	0.03	0.00	1.03
550.9	-885.6	6	BH-08	MR940209	0.00	0.48	0.71	0.00	0.00	0.00	0.24
550.9	-885.6	15	BH-08	MR940219	5.02	0.00	0.00	0.00	0.00	0.00	1.00
550.9	-885.6	18	BH-08	MR940221	1.52	0.00	0.00	0.39	0.00	0.00	0.38

Data Has Background and Blank Values Subtracted From Actual Values
Sum of Ratios Calculated Using Branch Technical Position 1 with 5 pc/gm value for each of the six isotopes

ATTACHMENT 2

September 27, 1996

Health Physics requirements for the remediation of lot east of building 235

The P.W. Stephens workers will be subjected to the following HP monitoring requirements:

1) Urine samples will be taken prior to and immediately after the completion of the cleanup project for bioassays.
2) TLD's will be worn at all times.
3) The contractors will work inside a negative air tented area while operating the surface removing equipment. The area is 10x10 feet and will have a 2,000 CFM fan supplying the negative air.
4) Personnel air samplers will be operated at all times inside the negative air tents and samples will be taken on a daily basis or more frequently if the filters indicate the presence of large quantities of dust.
5) The P.W. Stephens contractors will work in full tyvek uniforms and will wear full face PAPR(power air purifying respirators) while operating the scabbling equipment.
6) The workers will be monitored using an alpha probe each time prior to leaving the immediate work area. Non detectable will be the release limit for personnel contamination.

A large volume air sampler will be operated outside the negative air tent in the area of the hepa discharge and will take continuous samples.

All of the air samples will be measured after 72 hours of radon decay.

Any sign of dust leaving the tent area will trigger immediate shutdown.

The entire area that requires scabbling east of building 235 will be roped off during the cleanup process. Access to this area is restricted.

During this project previously cleaned sections will be surveyed using a Bicron AB100 probe for detecting beta and gamma radiation. Readings will be taken in both the open and closed positions thus giving a net beta measurement. A one minute count will give a MDA of <500 DPM. Smear samples will be taken within each one square meter grid, where there are visual signs of dust and where there are elevated direct measurement readings.

The cleanup limit for this area is 1500 DPM beta as fixed contamination and 300 DPM removable. The release limit for personnel and equipment is non detectable.

Background levels for various media are available and will be subtracted from survey readings.

Jim Adams will supply the HP monitoring and will keep all necessary records for area and equipment surveys and personnel monitoring. All surveys, personnel monitoring and air samples will be evaluated by the radiation safety officer and/or his assistant during the entire cleanup project.

ATTACHMENT 3

FINAL RADIOACTIVITY STATUS SURVEY PLAN FOR THE EXTERIOR OF THE EAST WALL OF BUILDING 235 AND THE ADJACENT CONCRETE PAD

Mallinckrodt Chemical, Inc.
St. Louis Missouri

Table of Contents

FINAL RADIOACTIVITY STATUS SURVEY PLAN FOR THE EXTERIOR OF THE EAST WALL OF BUILDING 235 AND THE ADJACENT CONCRETE PAD

1.1 Background Information

From 1942 to 1957, Mallinckrodt refined uranium for national defense purposes, first for the Manhattan Engineering District and then for the U.S. Atomic Energy Commission (AEC) at its chemical plant in St. Louis, Missouri. From 1955 to 1960, Mallinckrodt extracted columbium, tantalum, uranium, thorium, and rare earths from euxenite mineral ore under AEC source material license R-226. From 1961 to 1985, under source material license STB-401, Mallinckrodt extracted columbium and tantalum oxides and salts from ore and slag feed materials which contained low concentrations of uranium and thorium. After a two month trial run in 1987, the columbium and tantalum facility (C-T), located in Plant 5, was placed on standby.

Mallinckrodt Chemical, Inc., currently holds NRC source material license STB-401 for possession for decommissioning.

1.2 Site Information

1.2.1 Site Description

The site of interest for this final radioactivity status survey plan is the exterior of the east wall of Building 235 and the adjacent concrete pad, hereafter called the site, in Plant 5.

1.2.2 Identity of Contaminants

Based on the knowledge of site operations and the results of a preliminary assessment, a characterization survey, and other measurements, the significant radiological contaminants have been determined to be natural thorium and natural uranium series.

1.2.3 Site Conditions at Time of Final Survey

The site will have been decontaminated to levels that satisfy current NRC guidelines for release for unrestricted use, and it will be ready for the final survey described herein. The Building 235 East Pad Layout shows the location of the site of interest and other features relevant to decontaminating it.

1.3 Final Radioactivity Survey Overview

1.3.1 Survey Objectives

The purpose of the final radioactivity survey is to demonstrate that the radiological conditions at the site satisfy current NRC guidelines, and that the site can therefore be released for unrestricted future use without controls to assure radiological safety. The objectives of the

survey are to show that contamination by licensed radioactive material activity within each survey unit is within an acceptable level for unrestricted release by existing guidelines. Specific objectives are:

1.3.1.1 Radioactive Contamination on Surface

Surface contamination levels for each survey unit are within the acceptable levels specified in FC 83-23, Table 1, Acceptable Surface Contamination Levels, as represented by measurements on a 2 m grid. Conformance with the average acceptable surface contamination limit will be demonstrated at a 95% confidence level for each survey unit as a whole.

Reasonable effort will be made to identify and remove discrete spots that may exceed the average guideline level by greater than a factor of $(100/A)^{1/2}$, where A is the area (in m^2) of the discrete spot.

In the event residual radioactive contamination on a surface were to exceed the maximum acceptable value, *i.e.*, >3 times the average acceptable level at any location, **or** were to exceed the average acceptable level in any contiguous 2 m^2 area, the area will be remediated until release conditions are satisfied.

1.3.1.2 Gamma Exposure Rate

The gamma exposure rate averaged over a 100 m^2 grid area does not exceed 10 µR/hr above background at 1 m above the horizontal surface and at ≥1 m from an adjacent wall.

Maximum exposure rate over any discrete area ≤100 m^2 does not exceed 20 µR/hr above background. In the event gamma exposure rate were to be more than 20 µR/hr above background at any location measured, the area will be remediated until release conditions are satisfied.

1.3.1.3 Radioactivity Concentration in Soil

Average radionuclide concentration in soil represented by measurements in the survey unit are within the acceptable levels specified in NRC BTP Option 1 Radioactivity Concentration Levels.

Reasonable efforts have been made to identify and remove discrete spots that may exceed the average guideline level by greater than a factor of $(100/A)^{1/2}$, where A is the area (in m^2) over the discrete volume.

The maximum radionuclide concentration above background in soil at any location is ≤ 3 times the average acceptable concentration for unrestricted release. In the event residual radioactive contamination in soil beneath the pad were to exceed the maximum acceptable radioactivity concentration, *i.e.*, >3 times the at any location, the soil will be remediated until

release conditions are satisfied.

1.4 ORGANIZATION AND ADMINISTRATION

1.4.1 Organization and Responsibilities

The Senior Environmental Specialist (Radiation Safety Officer, or **RSO**) responsible for radiation safety is responsible for implementing regulatory requirements concerning radiation surveys.

Field measurements of radiological parameters and sample collection are under the direction of the Radiation Safety Officer. He will also oversee the activities of field contractor assistance. RSO, or his delegate, is responsible for retaining records designated by the RSO for the duration of time specified by the RSO.

Quality assurance (QA) responsibilities will be assigned to a Mallinckrodt engineer or QA specialist. As QA officer, he will coordinate quality interface requirements during the survey process. Radiation and radioactive material measurements are subject to the measurement contractor's QA program for radiation and radioactive materials measurements.

1.4.2 Training

Training will be provided on survey activities for those people who will perform radiation measurements, take radioactive samples, and perform laboratory analyses. The training of survey participants will be done in accordance with the survey contractor's training program. Each surveyor attends an in-house training session at which radiation protection, survey procedures, and quality assurance activities are reviewed.

1.5 SURVEY PLAN METHODS

1.5.1 Instrumentation

Table 1, Instrumentation for Final Radioactivity Survey, lists the instrumentation planned for use in the final radioactivity survey, along with applications, typical parameters, and typical detection sensitivities for the instrumentation.

Sensitivities for field scanning applications are based on movement of the detector over the surface at 1 detector width per second or less and optional use of audible indicators to sense changes in instrument count rates. Calibration of field instruments will be maintained in accordance with established contractor procedures. Calibration will be for the specific uranium and/or thorium radiation energies expected to be present at the site or as close as practical. Operational and background checks will be performed as specified by contractor procedures.

MDA. The minimum detectable radioactivity (MDA) of an instrument is an *a priori* estimate of detection sensitivity. The general form of the equation for estimating instrument

MDA is:

$$MDA = \frac{2.71 + 3.29\sqrt{B(1/t_b + 1/t_s)}}{E \cdot A}$$

where MDA = minimum detectable radioactivity
B = background or blank count rate (ct/min)
t_b = background count time (min)
t_s = sample or source count time (min)
E = overall detection efficiency
A = volume, mass, or area of sample measured

When $t_b = t_s$, this equation is equivalent to applications of this relationship to several practical radioactivity survey modes presented in NUREG/CR-5849, §5.2.

The objective MDA for laboratory counting applications is to achieve 50% or less of the unrestricted release limits.

1.5.2. Survey Unit

The exterior of the east wall of Building 235 and the adjacent concrete pad will be divided into survey units having common history or contamination potential or that are naturally distinguishable from other site areas. Mallinckrodt anticipates that two survey units will be identified on the site; they are 1) the exterior east wall of Building 235; and 2) the adjacent east concrete pad.

1.5.2.1 Area Classification

For purposes of establishing the sampling and measurement frequency and pattern, the Building 235 east wall and the adjacent pad have been classified as potentially affected.

If a single, discrete spot in a survey unit were found to exceed an unrestricted release criterion, an affected area of at least 10 m^2 surrounding the spot may be identified as a survey unit and resurveyed accordingly.

1.5.2.2 Reference Grids

Grids will be established for the purpose of referencing locations for measurements and sampling.

All affected building east external wall and adjacent pad surfaces will be gridded at a minimum of 2 m intervals.

1.5.2.3 Surface Contamination Measurements

Surface Scans. Scanning is done to identify locations having elevated radioactivity.

The east wall exterior surface of Building 235 and adjacent concrete pad surfaces will be scanned for beta radiation according to the following guideline:

- Affected Area Surfaces:
  - scan 100% of the concrete pad and lower 2 m of wall surface
  - scan immediate vicinity of each stationary measurement >2 m above the pad to cover at least 10% of the wall surfaces>2 m above the pad.

Instrumentation for scanning is listed in Table 1. The instruments having the greatest detection sensitivity will be used for scanning as physical surface conditions and measurement locations permit. Scanning speeds will be approximately 1 detector width per second or less for beta detection instruments, and 0.5 m per second for gamma detection instruments. Audible indicators (headphones or speakers) may be used. All scanning results will be noted on standard field record forms; locations exhibiting radiation above the ambient level will be identified for subsequent review.

Stationary Measurements. The survey units will be sized to assure a minimum of 30 net beta measurement locations each for the pad and wall.

Direct beta measurements of surface contamination may be performed at biased locations identified during scanning using instrumentation described in Table 1.

For instruments so equipped and calibrated, measurements will be conducted by integrating counts long enough to achieve minimum detectable radioactivity ≤50% of the release limit. Because scanning is capable of detecting uranium and thorium contamination at <50% of the release limit, direct surface contamination measurements will be systematically performed only at 2 m intervals on the east pad and wall in affected areas.

Removable Contamination Measurements. Smears to detect removable surface contamination will be collected and counted at locations where direct measurements of surface contamination are performed.

1.5.2.4 Exposure Rate Measurements

Gamma radiation exposure rates will be measured at 1 m above decontaminated pad surfaces and ≥ 1 m from the wall, using a pressurized ion chamber instrument, or a gamma scintillation instrument or micro-R meter calibrated against the pressurized ion chamber instrument. Measurements will be spaced ≤5 m apart on a square grid.

1.5.2.5 Soil Sampling

Soil sampling has been performed by coring through the pad at 8 locations in the pad area of interest identified on the Building 235 East Pad Layout sketch. The concentration of U238, Th230, Ra226, Th232, Ra228, and Th228 in each of 31 samples collected has been measured. These samples will be the basis of demonstrating that soil beneath the pad area of

interest satisfies NRC BTP Option 1 criteria for unrestricted release.

1.5.3 Background Level Determinations

Background gamma radiation exposure rates and concentrations of uranium and thorium in soil have been determined for outdoor areas during phase 1 characterization by taking measurements and samples at appropriate locations on-site or within a 0.5 to 10 km radius of the site. Results of background radiation exposure rates and concentrations of uranium and thorium in soil will be evaluated to assure that the averages determined are representative of the true averages.

1.5.4 Sample Analysis

Smear samples collected for removable contamination will be analyzed for gross beta activity at the Thermo Nutech Oak Ridge tn laboratory. Soil or other volumetric samples will be analyzed for U^{238}, Th^{230}, Ra^{226}, Th^{232}, Ra^{228}, and Th^{228}.

Laboratory chain-of-custody procedures will be observed for all samples analyzed.

1.6 Data Interpretation

Measurement data will be converted to units of dpm/100 cm^2 (surface contamination), µR/hr (radiation exposure rates), and pCi/g (soil concentrations) for comparison with guidelines. Net measurements, i.e., after subtraction of background, will be used for the comparisons. Individual measurements and soil concentrations will be compared with discrete-spot criteria.

The averages of surface radioactivity measurements will be tested to determine whether the data for each survey unit provide a 95% confidence that the true mean levels meet the guidelines.

In the event additional remediation and/or further sampling and measurement is performed where guidelines are not met or cannot be demonstrated to the specified level of confidence, computations and comparisons will be repeated as necessary.

1.7 Report

A report describing the findings of the final radioactivity survey will be prepared and submitted to the NRC. Data will be summarized in tables and figures. Measurement and sampling locations will be tabulated with spatial coordinates or shown on scale drawings

All field and analytical data, including procedures and instrument calibration certificates used in the survey, will be archived by Mallinckrodt Chemical, Inc. until such time as the NRC agrees that they may be disposed.

TABLE 1

FIELD INSTRUMENTATION SUMMARY

BE[illegible]MA SCAN SURVEY

Model AB-100 alpha/beta/gamma scintillation detector, 125 square centimeter square surface area, 25-34% efficient depending upon detector calibration to specific material of construction, calibration every 12 months.

DIRECT BETA MEASUREMENTS

Bicron Model AB-100 alpha/beta/gamma scintillation detector, 125 square cm active surface area, 25-34% efficient depending upon the detector calibration to specific material of construction, calibration every 12 months. Closed window measurements incorporated a 1/8" aluminum beta shield. Open window composition was 3.5 mg/ cm^2 mylar, chosen to admit beta radiation and to attenuate most alpha radiation.

TRANSFERABLE MEASUREMENTS

TENNELEC Model 5100 gas proportional alpha/beta detector with an efficiency of approximately 45% and daily laboratory calibrations.

GAMMA EXPOSURE RATE MEASUREMENTS

Reuter-Stokes pressurized ionization chamber, Model RSS-111, gamma exposure, 0-100 microR/hour, factory calibration every year.

Eberline Model SPA-3 with a 2" X 2" NaI gamma scintillation detector cross-calibrated to the Reuter-Stokes ionization chamber.