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**INDEPENDENT VERIFICATION OF
PLUTONIUM DECONTAMINATION
ON JOHNSTON ATOLL (1992 - 1996)**

M. J. Wilson-Nichols

J. E. Wilson

L. M. McDowell-Boyer

J. R. Davidson

P. V. Egidi

R. L. Coleman

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**Independent Verification of Plutonium Decontamination
on Johnston Atoll (1992 - 1996)
Interim Report**

**M. J. Wilson-Nichols
J. E. Wilson
L. M. McDowell-Boyer
J. R. Davidson
P. V. Egidi
R. L. Coleman**

May 1998

Prepared by the
Oak Ridge National Laboratory
Life Sciences Division
Environmental Technology Section
2597 B $\frac{3}{4}$ Road, Grand Junction, CO 81503

for the
Defense Special Weapons Agency Field Command
Kirtland Air Force Base
Albuquerque, N.M.

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for the
U.S. DEPARTMENT OF ENERGY
Under Contract #DE-AC05-76OR00001

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ACRONYMS, ABBREVIATIONS, AND INITIALISMS

AEC	U.S. Atomic Energy Commission
ALARA	as low as reasonably achievable
AMAD	activity mean aerodynamic diameter
ANL	Argonne National Laboratory
ANSI	American National Standards Institute, Inc.
ARARs	applicable or relevant and appropriate regulations
ASME	American Society of Mechanical Engineers
Bq	Becquerel
BTEX	benzene, toluene, ethylbenzene, xylene
CDH	Colorado Department of Health
cm	centimeters
cpm	counts per minute
DNA	Defense Nuclear Agency
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOE/NV	U.S. Department of Energy Nevada
DOT	U.S. Department of Transportation
dpm	disintegrations per minute
DSWA	Defense Special Weapons Agency (formerly DNA)
EDE	estimated dose equivalent
EIC	Eberline Instrument Corporation
EPA	U.S. Environmental Protection Agency
ETS	Environmental Technology Section
FCDNA	Field Command, Defense Nuclear Agency
FCDSWA	Field Command, Defense Special Weapons Agency (formerly FCDNA)
FIDLER	field instruments for the detection of low energy radiation
ft	feet
g	grams
gal	gallon
ha	hectare
ICRP	International Commission on Radiation Protection
IV	independent verification
JA	Johnston Atoll
JAPRP	Johnston Atoll Plutonium Remediation Project
JTF-7	Joint Task Force Seven
JTF-8	Joint Task Force Eight
kBq	kiloBecquerel
kcpm	kilocounts per minute
kg	kilograms
in.	inches
IVC	independent verification contractor
lb	pound
LE-1	Launch Emplacement 1
LE-2	Launch Emplacement 2

LLNL	Lawrence Livermore National Laboratory
μ	micro
μCi	micro curie
μm	micron
m	meters
mGy	milligray
min	minutes
mrad	millirad
mSv	millisievert
nCi	nanocurie
NCRP	National Council on Radiation Protection and Measurements
NNTRP	National Nuclear Test Readiness Program
NTS	Nevada Test Site
NV	Nevada
ORNL	Oak Ridge National Laboratory
PASO	Pacific Area Support Offices
pCi	picocuries
QA	quality assurance
QAP	quality assurance plan
QC	quality control
RCA	radiological control area
RCRA	Resource Conservation and Recovery Act
REECO	Reynolds Electric and Engineering Company
RESRAD	U.S. DOE Residual Radioactivity Computer Code
RFETS	Rocky Flats Environmental Technology Site
RFI	RCRA Facility Investigation
RSN	Raytheon Services Nevada
s	second
SOPs	standard operating procedures
SSL	soil screening level
Sv	sievert
TMA	Thermo Analytical, Inc.
TPH	total petroleum hydrocarbons
TRU	transuranic
USAF	United States Air Force
USDA	U. S. Department of Agriculture
V-1	Verification Area 1
vs	versus
WAC	waste acceptance criteria

ACKNOWLEDGMENTS

The editor wishes to acknowledge the Grand Junction, Colorado, Environmental Technology Section team for their input into the independent verification (IV) at Johnston Atoll. John Wilson and Jim Davidson conducted the majority of IV on the Soil Sorter software, hardware, and quality control. Laura McDowell-Boyer, Marcy Espegren, and Doug Halford evaluated the Soil Screening Limit and provided valuable insight into the project. Bobby Coleman and Vaughn Patania of the Measurements, Applications, and Development Group in Oak Ridge, Tennessee, lead and reported on the initial verification surveys.

The surveys and reporting were supported by technical team members Phil Egidi, Robert Schlosser, and Kirk Roemer. Also, many thanks to Penny Roundtree for word processing this report, and Timi Meyer and Debbie Barslund for administrative and financial assistance. As always, the leadership of C. A. Little was greatly appreciated. Finally, thanks is extended to Dr. Edward Bramlitt for providing the history of the project and sharing his experience on both Enewetak and Johnston Atoll.

EXECUTIVE SUMMARY

The Field Command, Defense Special Weapons Agency (FCDSWA) (formerly FCDNA) contracted Oak Ridge National Laboratory (ORNL) Environmental Technology Section (ETS) to conduct an independent verification (IV) of the Johnston Atoll (JA) Plutonium Decontamination Project by an interagency agreement with the U.S. Department of Energy in 1992. JA is an unincorporated territory of the United States consisting of four primarily man-made islands located approximately 800 miles west-southwest of Hawaii. The main island is contaminated with the transuranic elements plutonium and americium, and soil decontamination activities have been ongoing since 1984. FCDSWA has selected a remedy that employs a system of sorting contaminated particles from the coral/soil matrix, allowing uncontaminated soil to be reused.

The objective of IV is to evaluate the effectiveness of remedial action. The IV contractor's task is to determine whether the remedial action contractor has effectively reduced contamination to levels within established criteria and whether the supporting documentation describing the remedial action is adequate. ORNL conducted four interrelated tasks from 1992 through 1996 to accomplish the IV mission. This document is a compilation and summary of those activities, in addition to a comprehensive review of the history of the project.

The IV tasks consisted of 1) evaluation and testing of the soil sorting system; 2) evaluation of the quality control program; 3) evaluation of the soil screening limit; and 4) radiological survey of post-remediation. The purpose of performing these tasks is to ensure that no discrepancies exist that might cast doubt on the quality of soil recycled for use throughout the island, or on the radiological condition of soil beneath the excavated areas.

This IV report was meant to document the interim period from 1992 through 1996. A final report will be prepared at project closure.

The IV found that the soil sorting system significantly reduces plutonium contamination at the site. Issues and concerns raised by the IV tasks are the focus of future planning and activities. The two primary issues for future work involve the preparation of a verification survey plan and further verification of clean soil produced by the sorter.

1.0 INTRODUCTION

In 1992, the Defense Special Weapons Agency (DSWA), formerly the Defense Nuclear Agency (DNA), contracted the Oak Ridge National Laboratory (ORNL) Environmental Technology Section (ETS) to provide Independent Verification (IV) support at the Johnston Atoll Plutonium Remediation Project (JAPRP).

Johnston Atoll (JA), an unincorporated area of the United States Pacific Islands Trust Territory, consists of four primarily man-made islands approximately 800 miles west-southwest of Hawaii (Fig. 1-1). On-site contamination from plutonium and americium is a result of THOR missile aborts during a 1962 testing series. Contaminated soil has been isolated from the general population at JA in a radiological control area (RCA) located on the northern side of the island (Fig. 1-2). Clean-up is currently in progress and employs mining techniques to remediate contaminated soil (DNA 1992). The techniques involve a soil clean-up plant (soil sorter) that sorts out contamination to allow recycling of uncontaminated soil.

The objective of IV is to assure that the clean-up criteria, standards, and/or guidelines specific to JA contamination are appropriately applied and met. The purpose of IV is to validate the accuracy and completeness of field measurements, and the credibility of procedures followed, resulting in an independent assessment of site conditions. This independent assessment will ultimately document that radiological contamination on the island has been reduced to acceptable levels.

Three primary IV tasks at JA that were accomplished from 1992 through 1996 consisted of: 1) IV of the soil sorter plant; 2) IV of the soil screening limit; and 3) IV of the quality control (QC) program. Draft reports were issued for all IV tasks at their completion, and are finalized in this document.

Remedial Action is on-going at the time of this writing, and project scope and plans are currently being modified. Therefore, further verification tasks will follow this document in order to adequately meet requirements for site closure. This document is considered an "interim" report, and will be amended as the project progresses.

The following sections consist of site information (Sect. 2), site history (Sect. 3), characterization history (Sect. 4), remedial action description (Sect. 5), summaries of IV tasks (Sects. 6-8), radiological surveys (Sect. 9), and issues and concerns (Sect. 10).

Fig. 1-1. Location of Johnston Atoll.

2.0 SITE DESCRIPTION

At Latitude 16° 44' north, longitude 169° 31' west, JA is the only land area in approximately 800,000 square miles of ocean (Fig. 1-1 and Fig. 2-1). JA is the near-surface portion of a submarine mountain peak located on the northern extension of the Christmas Ridge (Raytheon 1994). The atoll originally consisted of two islands, Johnston and Sand. Extensive dredge and fill operations created two more islands, Akau Island and Hikina Island, and have considerably enlarged the original two.

The selections below briefly summarize the environmental setting at JA. A complete description of site conditions can be found in the Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) (Raytheon 1994).

2.1 Climate

The weather is temperate, with the annual mean temperature ranging from 75 to 72.7°F (Holmes and Narver 1974). Winds blow consistently, usually between 17 to 23 mph (15 to 20 knots). The tide is normally 2 ft, and the current is westerly at approximately one-half knot. Annual rainfall averages approximately 26.5 in., with precipitation occurring most frequently in November and December (approximately 7 in./month).

2.2 Land Use

The atoll is an unincorporated area of the United States Pacific Islands Trust Territory. It is maintained as a military storage site for chemical munitions, and in the past, as a standby test site should the U. S. ever decide to resume atmospheric testing of nuclear weapons. There is no indigenous human population on JA. The population on JA currently consists of approximately 1,100 servicemen and civilians, employed temporarily for various periods of time.

2.3 Geology and Hydrology

JA, like other atolls, is an eroded volcanic cone surrounded by a coral reef. Unlike other atolls, only the reef on the northwest rim is emergent. This is due to the tilting action caused by the natural subsidence of the ocean floor in the area (DNA 1994). Approximately 5000 ft of coral caps the flatly eroded volcanic cone that supports the island. This is overlain by white lagoon sediments composed of angular coral fragments in a silty matrix (DNA 1994). A hard sandstone layer, 2 to 14 ft thick, formed by the in-place cementation of old beach-sand deposits, extends beneath most of Johnston Island (DNA 1994).

A thin lens of brackish water underlying the original part of JA is encountered at depths of 4 to 9 ft. Because of the high permeability of the soil, and relatively low precipitation, there are no natural bodies of freshwater in the area (DNA 1994).

Fig. 2-1. Johnston Atoll detail.

The RCRA RFI report (Raytheon 1994) contains a thorough examination of the hydrogeology on JA. Since the JAPRP focuses solely on contamination in soil, groundwater has never been investigated at the RCA. Groundwater has been indirectly investigated during the RFI of the site to the south of the RCA (Raytheon 1994). Furthermore, several parameters used in the U.S. DOE Residual Radioactivity Computer Code (RESRAD) model discussed in Sect. 7 were obtained from this RFI (hydraulic conductivity, hydraulic gradient, etc.).

2.4 Soil Characteristics

JA was enlarged by various dredge and fill projects from 1960 to 1965. The size of Johnston Island (625 acres) has been increased over the years by dredge and fill operations. The 557 acres added to the island consists primarily of calcareous sand and coral rubble. In 1965, North and East Island were constructed entirely of dredged lagoon material (Raytheon 1994).

The soil on JA consists primarily of whole or partial shells and skeletons of marine organisms, mainly coral. The soil within the RCA is partially non-native aggregate rock, asphalt, concrete, oxidized metal fragments from the missile incidents, and larger metal fragments (rebar, wire, cable and piping) of anthropogenic origin. Most of the soil is the result of lagoon dredging or soil moving from other areas. The soils at Johnston Island have been so reworked by construction and grading that it is difficult to distinguish fill material from natural soil (DNA 1994). Coral soil density ranges from 1.28 to 1.32 g/cm³, averaging 1.3 g/cm³ (TMA/Eberline 1992a).

2.5 Wildlife

The initial U. S. Department of Agriculture (USDA) survey in 1923 disclosed only three kinds of plants native to the atoll. However, sea life was reported to be abundant: a mixture of Hawaiian and tropical varieties (Holmes and Narver 1974). Lizards and insects had been imported in years past by visiting vessels, and the large flocks of sea birds are still present. There are over 50 species of birds present on JA, including rare species such as the black-footed albatross, laysan albatross, Townsend's shearwater, red-billed tropicbird, masked booby and blue-gray noddy (U.S. DOI 1991).

3.0 SITE HISTORY

The history of JA, chronologically documented in the Johnston Atoll Master Plan (DNA 1994), is briefly summarized here.

JA was discovered by Captain Charles James Johnston of HMS Cornwallis in 1807. Early visitors noticed and documented the extraordinary number of birds existing in the area. In 1856, when the U.S. Guano Act was passed, guano was mined on the atoll until the best was depleted, and then the islands were again abandoned. There was little activity until 1923 when a biological survey of the Hawaiian Bird Reservation was conducted. Subsequently, JA was placed under the control and jurisdiction of the United States Department of Agriculture (USDA) in 1926 as a breeding ground and refuge for the native birds that flock there.

In 1934, JA was placed under the Navy Department at the onset of World War II. A small naval air station was constructed on JA in 1939, when war was imminent. Thus, the site served as one of the outposts in the Pacific throughout the war. As its location grew in importance as a mid-way point in the Pacific, land area increased in size to accommodate air traffic. In 1948, JA was transferred from the U.S. Navy to the United States Air Force (USAF). In 1958, the atoll was used for the first of several atomic tests, Operation Hardtack. The events that led to the radiological contamination of JA are discussed in Sect. 4.

Operational control of the site changed hands with each testing program. It was transferred to Joint Task Force Eight (JTF-8) and the U.S. Atomic Energy Commission (AEC) in 1962. JTF-8 was inactivated in 1969, its responsibilities assumed by the DSWA. Operational control was then returned to the USAF. In 1971, an inter-service support agreement was developed by the U.S. Army and USAF to provide 41 acres of land on the southwest shore of the atoll for use by the Army as a chemical agent and munitions storage area. Hence, the development of the Red Hat area, operating currently to incinerate chemical munitions.

In 1977, a memorandum of understanding between the U. S. Department of Defense (DOD) and U. S. Department of Energy (DOE) documented DOD responsibility to maintain JA and DOE responsibility for retention of other test facilities in the Pacific. JA continues to be of vital importance as a post-war base for military and commercial air travel to the South Pacific and Far East (DNA 1994). The atoll also remains a fish and wildlife refuge, as it has been since 1926.

3.1 Agency Roles and Regulatory Authority

The agencies participating in the clean-up of JA are the Field Command, Defense Special Weapons Agency (FCDSWA) (formerly FCDNA); DOE Nevada (DOE/NV) Operations and DOE Pacific Area Support Offices (DOE/PASO); Raytheon Services Nevada (RSN), a prime contractor to DOE/NV; and the current prime contractor for the clean-up Thermo NUtech [formerly Thermo Analytical, Inc. (TMA)/Eberline]. ORNL is the independent verification contractor (IVC) for the JA project. Argonne National Laboratory (ANL) has conducted on-going research on the contaminant characteristics at the site, and Lawrence Livermore National Laboratory (LLNL) has performed environmental monitoring at the site on a continuing basis.

FCDSWA, operating out of Kirtland Air Force Base in Albuquerque, New Mexico, has the over-all responsibility for the JA clean-up project. Regulatory data were reviewed, and applicable or relevant and appropriate regulations (ARARs) were identified, and listed in Table 3-1. The most problematic of these is the soil screening level (SSL) selected as the clean-up guideline described in Sect. 7. The U.S. Environmental Protection Agency (EPA) *Proposed Guidance on Dose Limits for Persons Exposed to Transuranium Elements in the General Environment* is the basis for the JA SSL (U.S. EPA 1977). The determination of an appropriate clean-up level is difficult because there are no applicable clean-up standards for plutonium in soil.

Therefore, DSWA made the decision to develop a site-specific standard or SSL. EPA provided guidance on developing SSLs to federal agencies, which was first cited in 1977. The 1977 guidance evolved into the two volumes that currently serve as the technical basis for addressing plutonium contamination (U.S. EPA 1990a, 1990b). This is further addressed in Sect. 7.

Table. 3-1. Applicable relevant and appropriate regulations

Regulation	Title of Regulation	Application and Comments
EPA 520/4-77/016	EPA Proposed Guidance on Dose Limits for Persons Exposed to Transuranium Elements	Used to derive the soil and screening limits. The soil limit is used as the clean-up guideline.
U.S. Code of Federal Regulations Title 49, Part 173, DOT	Shippers: General Requirements for Shipments and Packaging	Waste shipped from JA to NTS must comply with DOT regulations.
DOE Order 5820.2A	Radioactive Waste Management	
DOE Order 5700.6B	Quality Assurance	As invoked by DOE 5820.2A.
FCJ Instruction 5000.4	Wildlife Refuge Regulations	The commanding officer at JA prescribed regulations and support federal laws.

DOE = U.S. Department of Energy
DOT = U.S. Department of Transportation
EPA = U.S. Environmental Protection Agency
FCJ = Field Command Johnston
JA = Johnson Atoll
NTS = Nevada Test Site

4.0 CHARACTERIZATION SUMMARY

As part of the IV, ORNL acquired and researched all available previous site investigations. These documents were reviewed and are summarized below. ORNL maintains an archive of all pertinent documentation for use during site closure activities. Table 4-1 presents a chronological listing of activities pertinent to the JA Plutonium Decontamination Project.

4.1 Atomic Testing at JA

Atomic testing began on JA in 1958 with Operation Hardtack, conducted by the Joint Task Force Seven (JTF-7). In 1962, another series of tests began on JA, as part of Operation Dominic, conducted by JTF-8. It was during complications of the Starfish (June 1962) and Bluegill Prime (July 1962) missile launches that the area was contaminated during the destruction of missiles and warheads (Douglas 1962). The missiles were launched from Launch Emplacement 1 (LE-1)(Fig. 4-1). Starfish aborted at an altitude of 30,000 ft on June 19, 1962, Bluegill Prime aborted on the LE-1 pad on July 25, 1962, and Bluegill Double Prime aborted at 109,000 ft on October 15, 1962 (EG&G 1980).

The Limited Test Ban Treaty, approved by Congress in 1962 reduced the testing of nuclear weapons. However, the Joint Chiefs of Staff recommended safeguards to keep the U.S. from falling behind in nuclear technology development. Safeguard C required the development of a capability to resume testing promptly in environments prohibited by the treaty. As part of the National Nuclear Test Readiness Program (NNTRP), JA was established as the principal overseas test base. Construction, planning, and extensive land additions (two additional islets) took place in the following years to accommodate the requirements of the NNTRP. Further testing occurred in 1970 when an AEC high altitude development test was conducted. A THOR missile was mated with an AEC-developed, non-nuclear high altitude test vehicle and was successfully launched. The last of the testing was in 1965 when two THOR missile launches to support an Army requirement were completed. In 1976, Safeguard C was redefined to remove the requirement for capability of promptly returning to atmospheric testing (DNA 1994).

4.2 Description of Contaminants

Contamination from the missile launches is insoluble plutonium oxide (PuO_2^{++}) present as dispersed activity (volume) and hot particles (point sources) (DNA 1991a). The dispersed activity, particles approximately 10 μm in diameter with approximately 10 Bq of transuranic (TRU) activity, is mobile in soil and could migrate due to precipitation runoff, tidal action, or in groundwater. The discrete hot particles, < 45 μm in diameter and with activity >1 kBq, are relatively immobile unless effected by erosion, excavation or physical means of disturbance (DNA 1991a).

As mentioned above, the contamination at JA is from transuranics [elements of the actinide series including Pu isotopes and americium-241 (^{241}Am)]. Americium-241 is the daughter product of ^{241}Pu , which has a 14.35 year half-life. The primary types of radiation associated with transuranics are alpha radiation, characteristic X-rays from ^{239}Pu , and 60-KeV gamma from ^{241}Am .

Table 4-1. Time line of JAPRP activities

Date	Event	Description
1962	Atmospheric nuclear testing series	Three THOR missiles aborted during testing series resulting in Pu/Am contamination on JA. Starfish aborted on June 19, 1962 at 30,000 ft, Bluegill aborted on the launch emplacement pad, and Bluegill Double Prime aborted at 109,000 ft. Documented in <i>Douglass Missile & Space System Division Report on Operation Fishbowl</i> .
1963	Report of radiological safety for Operation Dominic	JTF-8-Q-1 Report by A. L. Knipp
1964	U.S. Public Health Service survey	This survey was conducted with portable alpha meters and resulted in the disposition of 400 drums of contaminated debris.
1965	USAF	X-ray meter survey resulted in the disposition of an additional 50 drums of material.
1973	AEC/NV cursory radiological survey	Conducted August 7-10, 1973.
1974	USAF hospital FIDLER survey	Hand-carried or vehicle-mounted FIDLERs confirmed 1973 findings.
1974	On-going surveys by USAF	Detection and removal of over 500 hot spots. Documented in correspondence from Major Earl Kinsley, ret., and Cliff Lund or Robert Reynolds.
1975	USAF panel investigation	The panel recommended comprehensive radiological remediation of the site and further characterization.
1975	Survey of 30,000 items	A detailed survey protocol was used to survey, record, and move items to Enewetak.
1976 - 1980	Enewetak D & D Effort	Remedial action resources were directed to the D & D of Enewetak Atoll. Dr. Bramlitt's memo that justifies the delay of the JA clean-up based on environmental monitoring below regulatory concern, and the associated measurements or report summaries.
1977	Holmes and Narver Study	Five remedial action options presented to DNA.
1980	EG&G Radiological Study	April through August, 1980. Comprehensive characterization survey of JA using the IMP.
1980	Eberline Instrument Soil Survey	July 9 through 28, 1980. Eberline Instrument Corporation, on contract to DOE/NV conducted intensive soil sampling.
1984	Clean-up of Missile Launch Facility	LE-1 complex, shelter assembly, and concrete pad dismantled and shipped to NTS in 27 containers.

Table 4-1. (continued)

Date	Event	Description
1984	Excavation of material from runway	Material from runway was surveyed, excavated, and stored in the RCA. Survey employed IMP system using golf-cart vehicle. Documented in loose leaf binder. Contains measurements from Sand Island and Dr. Bramlitt's evaluation.
1985	Follow-up EG&G Surveys	Uncompiled survey data by EG&G - report never issued.
1985	Contaminant Characterization Study	A report by Garvin, P.L. referenced in AWC, Inc. report (Sunderland et al. 1985), in support of TRU-Clean.
1985	AWC Pilot Plant Construction	Original pilot plant tested for the TRU-clean Process (fractional classification).
1987	TMA/Eberline Feasibility Study	TMA/Eberline feasibility study of automating soil sorting for clean-up of contamination.
1988	Project Management Plan for JA TRU soil clean-up	DNA documented intent and plan (1989) to use a soil sorting technology to decontaminate soil using a mining method. In 1988, AWC, Inc. was contracted to design, procure, and deliver a plant capable of processing the soil.
1989	Soil Clean-Up Plant Tested	TMA/Eberline Report
1990	TMA/Eberline Modifications	Documented in 1992 TMA/Eberline Annual Report (TMA/Eberline 1992b)
1991	DNA definition of plutonium-clean soil	March 1, 1991. Documented rationale, detail, and definition of clean-up guideline.
1991	Environmental Assessment	May 3, 1991. Issue of Environmental Assessment for JA Cleanup concluding that the proposed action will have no significant adverse effects.
1993	Soil Processing Operations begin	19,314 metric tons of soil were processed by November 1993.
1994	Contaminant Characterization Studies	ANL reports that Pu and Am are highly dispersed throughout contaminated soil and sludge at the site.
1994	Plutonium Aerosol Monitoring	LLNL reports that Pu-aerosol concentrations at the JA site are below regulatory concern based on 1992 measurements.
1994	Independent Verification	ORNL begins Independent Verification to support site D & D and certification.

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Fig. 4-1. Location of Launch Emplacement 1.

Recent studies by ANL indicate that the Pu and Am contamination of JA coral soil and sludge is primarily dispersed (ANL 1994). The activity was demonstrated to be associated with particles as small as 0.4 μm in diameter. The study suggests that a possible mechanism for the dispersal is complexation with calcium carbonate, followed by adsorption onto the coral soil. This would lead to a greater dispersal of Pu and Am than would be expected by physical transport of discrete particles alone (Wolf et al. 1995).

4.3 JTF-8-Q Report by A. L. Knipp, and Other Early Investigations

The clean-up of JA started immediately after the missile-launching incidents and before any official remedial action or characterization program was initiated. This effort is documented in a 1963 report by A. L. Knipp regarding the radiological safety for Operation Dominic and, using manual methods, focused on the area immediately surrounding the launch pads (AEC 1974). This effort was sponsored by Joint Task Force A, the AEC-DOD group organized to conduct the atmospheric testing. Further efforts occurred after the Starfish incident, where debris was searched out and recovered. Thus, after every missile launch and abort, there was clean-up of the resulting contamination (Bramlitt 1994). This continued until approximately 1977, when the last missile launch was conducted. The A. L. Knipp report was unavailable at the time of this writing.

Following this effort, there was another survey conducted by the U.S. Public Health Department. This document was also unavailable at the time of this writing. In approximately 1965, the USAF located and disposed of an additional 50 drums of debris from the missile-launching incidents (Bramlitt 1994).

4.4 AEC/NV Cursory Radiological Survey, August 7 through 10, 1973

At the request of FCDNA (now FCDSWA), AEC/NV (now DOE/NV), conducted a cursory radiological survey of JA. The survey was a four day effort using portable instruments. Alpha and gamma radiation was measured, and soil and swipe samples collected. It was estimated that approximately 1/8 of the JA land surface was investigated during the three day survey (AEC 1974). The instruments used were the FIDLER, standard Geiger counters, air proportional alpha survey meters, and an Eberline Instrument Corporation (EIC) PG-1 survey meter. Roadways were covered by FIDLER probes mounted on a slow-moving Jeep at approximately one foot above the ground. Technicians monitored the instruments by the audible signals. Other areas, such as facilities and barracks, main dining hall, old pod storage location, launch facilities, etc., were covered by walking surveys. Swipe samples were collected from buildings and structures and soil samples collected at all locations. Contamination was removed as it was encountered.

The AEC cursory survey (Table 4.1) showed that contamination in the LE-1 Area was accessible and transferable due to the deterioration of the paint. Gamma readings ranged from background to > 500 kcpm and soil samples ranged from 1.52 nCi/m² (background on North Island) to 2.92 $\mu\text{Ci}/\text{m}^2$ (AEC 1974). The report resulted in the establishment of the RCA, a more stringent radiological safety program, and more extensive environmental monitoring (AEC 1974). Also, the survey report recommended that a comprehensive survey and decontamination be performed on all areas outside LE-1 (AEC 1974). One problem with this survey was that it used an activity per unit area formula.

This is erroneous as it assumes source geometry as a planar surface, which does not characterize plutonium per area (Bramlitt 1994). Based on the findings of the cursory survey, recommendations for radiological controls, exposure evaluation, and further surveys were made by FCDNA.

4.5 USAF Surveys

Beginning with the 1974 AEC survey, USAF radiation technicians stationed on JA had the responsibility of scanning the island for radioactive particles, removing them, and disposing of them in waste barrels. Over 500 hot spots were located and excised from June 1975 to March 1980 (EG&G 1980). This effort continued until 1987 (Table 4.1) (Bramlitt 1994). The USAF surveys employed hand-held FIDLER detectors approximately 2 in. to 1 ft above the ground surface (Bramlitt 1994). The technicians were also responsible for scraping up the larger debris from the missiles. Floors and surfaces were painted to fix contamination. The chips of this paint, along with the other particles and debris collected comprised thirteen drums, and were shipped to NTS for permanent disposal. This effort located and disposed of the majority of the highly-contaminated surface debris (Vesper et al. 1988).

In 1975, a USAF panel was formed to investigate radiological controls and health and safety protocol at the JA site. The committee recommended comprehensive radiological remediation of the site that required further characterization. Another result of the committee findings was the institution of an environmental monitoring program and a radiation safety program under AEC, later to become ERDA. Continuing presently, air and water samples are collected and analyzed from the JA site.

4.6 Release of Material to Enewetak

In 1975, 30,000 items from the missile site were surveyed, recorded and moved to Enewetak. A detailed survey protocol was developed using an American National Standards Institute, Inc., (ANSI) standard as a release criteria, and the records reside at the FCDWSA office in Albuquerque (Bramlitt 1994).

4.7 Remedial Options

In 1977, Holmes and Narver, a private subcontractor, presented five remedial action options and presented estimated costs to the DNA (now DSWA). Because of limited resources, and the fact that the on-going environmental monitoring had revealed that radiation hazards were below concern, the remedial action effort at JA was delayed. At this time, there were only approximately 300 residents on JA (Bramlitt 1994). Resources were therefore directed to the DNA efforts of remedial action at Enewetak Atoll.

4.8 Enewetak Radiological Clean-up

The clean-up of Enewetak commenced and became the predecessor of the policy and methods used at the JA site. The key issue at Enewetak initially was the selection of clean-up criteria. It was AEC's (DOE) responsibility to set the standards for clean-up and determine when those standards

were met. AEC formed a task group to research and recommend clean-up levels. The issue of selecting the most appropriate standard to use continued to be perplexing throughout the Enewetak project. At last, standards were agreed upon and remedial action efforts brought levels to meet those accepted criteria. The clean-up action levels of 40, 80, and 160 pCi/g were applied to the Enewetak Islands based on land uses of either residential, agricultural, or short-term visits, respectively (DNA 1981). The 40 pCi/g limit for residential was considered the SSL for unrestricted use. At Enewetak DOE was responsible for determining the resulting radiological condition after the clean-up and it ultimately certified the clean-up of the Enewetak Atoll (DNA 1980). The final remedial action criteria agreed upon by DOE was directed toward the intended use of the various Enewetak sites. In 1980, the Enewetak project was nearly complete and DNA attention was directed toward the clean-up of JA.

The Enewetak clean-up ended in 1980 with a final cost in excess of \$100 million (Bramlitt 1994). It had been accomplished by soil scraping and removal when measurements indicated the soil was above radiological screening limits. The process resulted in the removal of approximately 100,000 yd³ of contaminated soil. The soil was made into a concrete slurry, and placed into a crater at the atoll.

This costly clean-up encouraged FCDNA to investigate more efficient means to clean-up the remaining JA site. FCDNA sponsored laboratory and pilot plant studies of methods using radiation detection and mining technologies to make the JA clean-up economically viable (TMA/Eberline 1992a). This is discussed further in Sect. 5.

4.9 EIC Soil Sampling for DOE/NV

An intensive soil sampling program was conducted in July 1980 by EIC at the request of DOE/NV. Samples were collected for Pu/Am ratio analysis and elemental composition analysis. Determination of soil density and vertical particle distribution were also made (Eberline 1981).

The survey found hot particles throughout the Atoll, except on Hikina and Akau Islands, and where deep sand and bird tunnels were present on Sand Island. The hot particles were determined to be primarily metal fragments.

Approximately 70 samples were collected for Pu/Am ratio analysis. The range for ²³⁹Pu/²⁴¹Am was 3.2 ± 13.9 , averaging 6.4 in hot particle samples. In continuum samples the ratio range was 0.4 ± 21.0 , averaging 8.2.

The study focused on the vicinity of the present RCA. The surface soil was described as a 0 to 4 cm, fine, gray soil. A hard pack coral base underlies the 4 cm surface. It was found that detectable FIDLER readings dropped upon encountering the hard pack coral.

Concurrently, DNA conducted its own surveys and analyzed samples for chemical hazardous waste components as well as radiological (Bramlitt 1994). The radiological analysis addressed both particles and distributed activity. Data from these investigations was not available at the time of this writing.

4.10 EG&G Energy Measurements Group Survey - April through August 1980

In 1980, EG&G conducted a survey on JA using an in situ radiation measurement method that had been the primary means for evaluating contamination at Enewetak. This system has been referred to in earlier reports (EG&G 1980) as the "IMP" system. IMP is derived from a Delorean Manufacturing Company Trademark. The method elevated a radiation detector several meters above ground, allowing a large field of view for a time sufficient to obtain valid data. Measurements were taken and soil samples collected throughout the island (EG&G 1980). This survey effort resulted in further radiological controls extending to the main island (Johnston Island) where areas exceeded the SSL. The survey indicated that approximately 97% of JA could be used without restriction (FCDNA 1979). The portions of JA that exceeded the SSL were either within the RCA, or had undergone air sampling and were determined to not to produce doses in excess of the EPA guidance (U.S. EPA 1977; FCDNA 1979).

This survey was conducted over the entire atoll and represents the most comprehensive characterization effort. All land areas that were in existence during the testing of the 1960s were surveyed on 100 ft² grids, and land constructed after the events was surveyed on 200 ft² grids. Further measurements were made where Am contamination was found on 50 ft² grids. Soil samples were collected to determine Pu/Am ratios. Hot spots identified while searching for sampling sites were removed and submitted for analysis, or placed in the RCA (EG&G 1980).

Locations with elevated ²⁴¹Am were identified on Johnston Island and Sand Island. No detectable ²⁴¹Am was observed on either East or North Island with the IMP system. Results were expressed in terms of equivalent surface distribution (nCi/m²).

The IMP system is well described in EG&G (1980). The system proved to be more effective than the hand-held FIDLER surveys. An experiment was conducted that proved the IMP would measure ²⁴¹Am at levels below the detection sensitivity of a FIDLER (EG&G 1980).

Sand Island was surveyed, where the Coast Guard resided at the time. Because of the Loran transmitter that was in existence on Sand Island at the time of the survey, the IMP system could not be used. Therefore, the DNA surveyed that portion with hand-held FIDLERs and compiled the raw data, but never finalized the reporting. This was deemed adequate by DNA (FCDNA 1979).

4.11 Clean-up of Johnston Atoll Missile Launch Facility

Vesper et al. (1988) describes the initial "clean-up" of the missile launch facility in detail. Although the site was decommissioned in 1977, it was not until 1984 that funds became available to transport plutonium-contaminated material to the NTS. This phase of the project involved dismantling structures, decontaminating concrete, and preparing waste for transport. This was accomplished by a series of events including painting areas to fix contamination, disassembly of large structures, scabbing of concrete and detailed radiological survey, analysis of samples, and assessment of waste to comply with DOT shipping regulations.

In 1984, the missile launch complex (LE-1), shelter assembly and the entire concrete pad was dismantled and shipped to NTS in 27 steel dry cargo containers (Vesper et al. 1988). In compliance

with the U.S. Department of Transportation (DOT) transportation regulations, the concrete pads were decontaminated to 100 dpm/100 cm² (the former ANSI standard). All other remnants were dismantled and used as shoreline protection. The only remaining structures from the test site are the launch pads and the theodolite tower.

Also, in 1984, material from the runway was surveyed, excavated, and taken to the RCA. At this time the RCA was fully developed as the storage area for contaminated materials for the site (EG&G 1980, 21 April 1986 letter from John Tipton). This survey effort used a similar method to the IMP system employed in the earlier EG&G survey and at Enewetak. A golf cart was used as the mobile vehicle vs the larger Thiokol crane. The measurements and survey locations are documented, but a survey report was never completed. The measurements were reported as activity/area and did not meet the EPA criterion under those assumptions (DNA 1986). The excavation was discontinued at 1 ft, where readings above background were no longer encountered. After this effort, in 1988, formal remedial action was initiated. This is described further in Sect. 5.

4.12 EG&G Surveys, undocumented (1985-1986)

These surveys represent follow-up work to the comprehensive survey that EG&G conducted in 1980. The effort was never compiled or published.

4.13 On-going Environmental Monitoring - LLNL

The 1994 annual report from plutonium aerosol monitoring near the remedial action activities showed the median level of Pu-aerosol concentration was 100 times lower than the federal derived concentration for the public and environment, and 15,000 times lower than the derived air concentration to protect workers (LLNL 1994).

4.14 RCRA RFI

A RCRA RFI was conducted between May 1992 through August 1994. The RFI included 19 sites and Solid Waste Management Units (SWMUs) (Raytheon 1994). The closest SWMU to the plutonium clean-up area is the Swimming Pool-Taxiway SWMU, where aboveground storage tanks were once located. As part of the RCRA RFI, soil and groundwater were investigated within the RCA. Groundwater and soil samples were analyzed for total petroleum hydrocarbons (TPH) and benzene, toluene, ethylbenzene, xylene (BTEX). No soil or groundwater remediation was recommended at the site, including the RCA. The concentrations of BTEX in soil were significantly below EPA Region IX goals (Raytheon 1994). The low levels of BTEX in groundwater were determined not to be a threat to human health or the environment. Furthermore, there was no detection of RCRA hazardous constituents above the RCRA maximum concentration limits for toxicity.

The RCRA RFI provided the following information that may be useful during the course of the plutonium clean-up. Site-specific geological and hydrological information are available from the placement of monitoring wells surrounding and within the RCA. Also, complete characterization of any chemical releases have been investigated that might apply to the plutonium clean-up areas

as part of the RFI at the Swimming Pool SWMU. No soil or groundwater remediation was recommended at this SWMU as concentrations of benzene, toluene, ethylbenzene, and xylene were below the proposed action levels for the project.

4.15 Conclusion

The above paragraphs summarize the characterization efforts at JA. It is important to realize that further characterization outside of the RCA would probably be unsuccessful for several reasons. First, erosion has covered any potential residual radioactivity for almost three decades since the time of the incidents discussed in Sect. 4.2. Erosion has occurred in the form of wind dispersing new material, vegetative coverings, construction efforts throughout the island, and the guano that covers the islands from the resident birds. Therefore, further characterization may not be successful at JA outside of the RCA.

5.0 REMEDIAL ACTION

The selection of remedial action was based upon site specific conditions and needs. The remote location, coupled with the need for fill material for construction throughout the island prompted DSWA to investigate and develop technologies that would decrease the quantity of waste to be shipped to NTS, and also recycle uncontaminated soil for re-use.

In 1988, AWC, Inc., was awarded a contract to test a soil clean-up plant. This contract consisted of erecting the soil clean-up plant in the RCA and conducting a demonstration clean-up of 1,500 yd³ of soil to determine plant performance characteristics (TMA/Eberline 1992a). This effort was the first phase (Phase I) of the clean-up process. The effort successfully constructed the facility, however, the demonstration revealed that the initial design of the plant would not adequately clean soil or reduce the volume of waste to suitable levels (TMA/Eberline 1992a). Therefore, a second phase was initiated.

In August, 1990, TMA/Eberline was awarded a prime contract with DNA to make extensive modifications and improvements to the prior soil clean-up technology demonstration project on JA (TMA/Eberline 1992a). TMA/Eberline modified the plant utilizing a unique segmented gate methodology to separate contaminated soil from clean material. This effort is Phase II of the clean-up process and is described in TMA/Eberline 1992 Annual Report of JA Cleanup. The soil sorting plant was designed, installed, and operated in 1992-1994. The clean soil was intended as an on-island resource to the tenants of JA. This would be extremely beneficial, as fill and construction material must otherwise be conveyed to JA by barges. Soil material is not available locally due to halting of dredging operations because of wildlife habitat concerns.

Again, remedial action measures have been on-going as part of characterization surveys since the first missile abort. The first substantial remedial action occurred in 1986, where soil was removed from 0.025 ha in layers 0.05 to 0.10 m thick (depths approximately 0.2 to 0.5 m). The material was consolidated in the RCA (DNA 1991a). Clean-up is currently in progress and continues to use the soil sorter to remediate the remaining contaminated soil (DNA 1992).

The soil-sorting process (Figs. 5-1 through 5-5) starts with a front-end loader adding soil to a hopper (Fig. 5-2). A screen on the hopper (the "grizzly") removes boulders from processing. The material is then conveyed beneath magnets to remove any steel rubble and on to a vibrating screen to remove large gravel. Gravel, usually uncontaminated, is processed separately from the sands to prevent clean-up by dilution (DNA 1992).

Soil is then conveyed in a thin layer on a 3-ft-wide flat belt beneath radiation detectors. A computer processes radiation signals and controls the positions of eight gates across the conveyor end (Fig. 5-3). In one position, a gate allows soil to fall to a conveyor for removal to a clean soil pile. In the other positions, a gate diverts soil to a "hot soil" conveyor for further processing. Each gate can remain in either position for as little as two seconds. The amount of soil moved through a gate is about one pint (DNA 1992).

The hot soil conveyor has a single gate at its end. In the beginning of the technology process, soil with hot particles was sent to a waste container and soil with dispersed contamination to a spiral classifier. The classifier mixes water and soil and decants suspended fine particles while simultaneously draining and conveying coarse particles out of the classifier. The fine particles, rich

Fig. 5-1a. Soil-sorting process.

- 1 Front-End loader
- 2 Hopper
- 3 Oversize pile +3.5"
- 4 Feeder
- 5 Feed conveyor
- 6 Screens
- 7 Oversize conveyor
- 8 Crusher feed hopper (new)
- 9 Reverse crusher jaw (new)
- 10 Screw conveyor (new)
- 11 Bucket elevator (new)
- 12 Sorter feed conveyor (new)
- 13 Sorter conveyor surge bins (new)
- 14 Sorter conveyor (activated)
- 15 Sorter conveyor
- 16 Sorter system (new)
- 17 Sorter system
- 18 Clean conveyor
- 19 TRU conveyor
- 20 Hot particle chute
- 21 Hot particle drum
- 22 Roll conveyor (new)
- 23 TRU conveyor to dry bin
- 24 Dry bin
- 25 Classifier feed conveyor
- 26 Slurry box
- 27 Classifier
- 28 Coarse pile to dry (new)
- 29 Screens feed hopper
- 30 Screens (new)
- 31 Oversize pile (new)
- 32 Screw conveyor (new)
- 33 Sorter feed hopper (new)
- 34 Sorter conveyor (relocated)

- 35 Sorter system relocated
- 36 Hot particle drum
- 37 Clean conveyor (relocated)
- 38 Stacker conveyor (relocated)
- 39 Clean pile
- 40 Stacker conveyor
- 41 Clean pile

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Fig. 5-1b. Soil-sorting hardware.

Conveyor belt

Fig. 5-2 Contaminated material loaded into Grizzly.

Fig. 5-3 Soil-sorter diversion gates.

5-5

Fig. 5-4 Clean soil on the conveyor belt.

Fig. 5-5 Waste barrels for contaminated material.

with dispersed contamination, were pumped to a settling pond. Pond sediment can be removed (like cleaning a swimming pool) and packaged as waste. The coarse and clean soil from the classifier was sent to a sorting conveyer and will be either released as clean soil or recycled (Fig. 5-4) (DNA 1992).

Currently, the sorting system consists of four sorters. Sorters 1 and 2 have a different gate design than sorters 3 and 4. Sorters 1 and 2 extend when a hot particle is detected, while sorters 3 and 4 retract. The system that conveys the soil uses arrays of thin NaI radiation detectors linked with microprocessors and computer software designed by EIC (Moroney et al. 1992). The software controls the segmented gate methodology for removing the contaminated soil from the moving feed supply on conveyor belts (Fig. 5-4). Contaminated soil is diverted either to metal drums (Fig. 5-5) for collecting "hot" particles or to the distributed activity pile. Low to intermediate levels of contamination are removed from the soil to meet the DSWA's criteria for release for unrestricted use based on proposed EPA guidelines (U.S. EPA 1988).

6.0 INDEPENDENT VERIFICATION OF THE SOIL SORTER PLANT

FCDSWA tasked ORNL/ETS with conducting IV of the soil-sorter process, as one measure to ensure that no deficiencies or discrepancies exist that might cast doubt on the quality of the soil the plant delivers for unrestricted use throughout the island. Independent verification of the soil-sorting system was one of a series of interrelated tasks to provide DSWA with a third party, independent assessment of the project. The other tasks performed were IV of the SSL (Sect. 7), IV of the soil-sorter QC program (Sect. 8), and radiological surveys (Sect. 9).

The IV of the soil-sorter source code and software was conducted in late 1992 (ORNL 1993). The source code and software were developed for DSWA by EIC under a subcontract with TMA/Eberline, the DSWA prime contractor for improving and operating the JA soil clean-up plant. A proprietary information agreement was signed between EIC and ORNL. This allowed ORNL to verify confidential information and protect EIC against unnecessary product disclosure. The sorter code was checked for internal consistency and adequate documentation. The assumptions were examined, mathematical formulas reviewed, and suggestions for improvements made.

The verification confirmed that there were no obvious deficiencies in the underlying technique of determining distributed contamination or hot particles. However, there were deficiencies in the implementation of these techniques (ORNL 1993). The two most important findings were discrepancies with the algorithm that searches for hot particles to divert and discrepancies with the timing of the diversion gates.

Statistically, the normal score algorithm was validated, and the consistently low initial background readings were shown to be suspect. In the statistical evaluation, the examination of the TRU to ²⁴¹Am ratio indicated contradictions between the C source code and the annual report issued by the remedial action contractor.

Based on the magnitude of the IVC findings during the review of the soil-sorter code and software, independent tests on the source code and software were performed on site and are discussed below.

6.1 Soil-Sorter Tests

Four separate field tests were conducted on site at the Johnston Atoll Plutonium Cleanup plant in June 1994. The tests were a continuation of the verification of the sorter source code and software. The tests addressed the field operation of the sorter process and are described below.

6.1.1 Test 1: Reprocessing of "Clean" Material

Test 1 included observation of the procedure to calibrate and start up the system and the sorting of soil. Verification samples of the processed material were collected, and the electronic data from the process were acquired from the contractor. The purpose of this test was to verify whether new contaminated particles were discovered when reprocessing "clean" material. In other words, had the sorter system missed any particles in the previous process? This type of test had been conducted previously and is described in the annual project progress report (TMA/Eberline 1992b).

6.1.1.1 Description of Test 1

On June 16, 1994, TMA Eberline was requested to process approximately 10 tons of contaminated material from the LE-1 area. TMA moved the clean stacker to a new position in order to segregate the test material. The startup and calibration procedures were observed. The test material was processed through sorters 1 and 2 (Fig. 5-1), and grab samples were collected from the clean pile every five minutes. Twelve samples were collected from the first sorting process (cycle 1). After the material had been processed through sorters 1 and 2, the test material was loaded into a dump truck (Fig. 5-4) and hauled to sorters 3 and 4 for the second sorting. Because the area where material is loaded into hoppers to be sorted is likely contaminated with "new" unprocessed material, measures were taken to keep the test material away from potentially contaminated material. The loaders scraped the pavement before dumping the test material. The second sorting process (cycle 2) was initiated on the test material, and grab samples were again collected every five minutes (nine samples total). After the second sorting process was complete, the test material was processed a third and fourth time in the same manner (cycles 3 and 4). After the fourth sorting process, the electronic data were acquired from the contractor for review and evaluation.

The test was conducted a second time (referred to as Run 2) the following day (June 17, 1994) for additional data. Again, the calibration and start-up procedures were observed. Measurements were taken on the ground surface before the test material was processed to ensure that no contamination existed on the area where the processed material was to fall. Approximately 10 tons of contaminated material from the LE-1 area were loaded into sorters 1 and 2. The loader and truck were thoroughly decontaminated afterward. Furthermore, sorters 3 and 4 were decontaminated. The stacker delivered clean material directly to the truck to avoid contact with the ground (Fig. 5-4). These extra measures were an attempt to eliminate all factors that might introduce contamination into the second processing of the test material. During the sorting of the test material, the belt speed was measured and verified. Also, adjustment to the diversion gates, a weekly procedure, was observed. Again, the electronic file of the sorter data was obtained from the contractor.

6.1.1.2 Observations and Results

The hot particle data from the first run (June 16, 1994) are summarized in Table 6-1. The complete data set was presented in Appendix A of the *Independent Verification of the Johnston Atoll Soil-Sorter Plant* report (ORNL 1994).

Table 6-1. Results for Test 1, Run 1

Cycle Number	Total Number of Hot Particles	Total Hot Particle Activity, Bq	Number of Hot Particles w/ Max Activity >5K Bq	Activity of Particles w/ Max Activity >5K Bq, Bq
1	684	11,481,882	499	10,728,410
2	81	517,354	47	377,814
3	46	456,077	26	376,696
4	7	34,490	2	14,058

The first column shows the cycle number. The first cycle was contaminated soil from LE-1 processed through sorters 1 and 2. The second cycle is the "clean" soil processed from the first cycle through sorters 3 and 4. The third cycle is the "clean" soil from the second cycle processed through sorters 3 and 4 again. The fourth cycle is the "clean" soil from the third cycle processed through sorters 3 and 4.

A single hot particle may be reported one to five times (once by each detector that "saw" the particle). The hot particle "reports" from the detectors were grouped together to represent actual particles. The second column shows the number of actual particles. The third column shows the total activity from all the hot particle records. Each grouping of hot particle records is ordered by the amount of radioactivity. The fourth column shows the number of actual particles whose highest report is greater than 5,000 Bq.

The soil diversion data from the first run (June 16, 1994) are summarized in Table 6-2. The complete data set is presented in Appendix A of ORNL 1994. Each segment of soil represents the width of one diversion chute (10 cm), the distance (30.5 cm) the belt travels in 2 s at 30 ft/min, and the thickness of the soil on the conveyor belt (1.9 cm). Each segment contains 0.70 kg of soil.

Table 6-2. Soil diversion data from Test 1, Run 1

Cycle Number	Total Number of Elements Processed	Number of Elements Diverted for Hot Particles	Number of Elements Diverted for Multiple Particles	Number of Elements Diverted for Distributed Activity	Number of Elements Not Diverted
1	32,960	1,303	627	11,011	20,019
2	20,240	133	63	399	19,645
3	18,160	80	27	80	17,973
4	13,520	10	15	240	13,255

The hot particle data from the second run (June 17, 1994) are summarized in Table 6-3. The soil diversion data from the second run (June 17, 1994) are summarized in Table 6-4. Again, the complete data set is presented in Appendix A of ORNL 1994. The third cycle of the second run was cut short because there was no more room for barrels to collect diverted soil. Approximately 26% of the available material was processed in the third cycle.

Table 6-3. Results from Test 1, Run 2

Cycle Number	Total Number of Hot Particles	Total Hot Particle Activity, Bq	Number of Hot Particles w/Max Activity > 5K Bq	Activity of Particles w/Max Activity > 5K Bq, Bq
1	635	9,018,772	442	8,236,282
2	49	279,121	21	163,302
3	8	39,461	5	26,754

Table 6-4. Soil diversion data from Test 1, Run 2

Cycle Number	Total Number of Elements Processed	Number of Elements Diverted for Hot Particles	Number of Elements Diverted for Multiple Particles	Number of Elements Diverted for Distributed Activity	Number of Elements Not Diverted
1	28,160	1,175	570	10,059	16,356
2	16,960	76	39	1,905	14,940
3	3,840	8	7	557	3,268

These tests show that hot particles were being passed through to the clean path. It can be argued that some of the hot particles in the first run were picked up from the ground where the clean soil was piled, from the equipment moving the soil, or from the conveyors and hoppers of sorters 3 and 4. It was for these reasons that a second run was conducted. During Run 2, the soil was not allowed to touch the ground. All the equipment that handled the soil was decontaminated. It is highly unlikely that all the particles found in the second run came from the conveyors and hoppers because at the end of the fourth cycle of the first run, there were only seven hot particles (Table 6-1). However, during the second run, the number of particles again increased (49) when the first batch of "clean" soil from the second run was reprocessed (Table 6-3).

Results from sample analysis are presented in Table 6-5. Again, the samples were collected from the clean pile every five minutes during the first two cycles of the first run (Run 1, cycles 1 and 2). Samples of approximately 50 g were collected from the top of the clean pile during the process. These samples were collected to represent the condition of the material as it was reprocessed. The samples were shipped to ORNL in Oak Ridge, Tennessee, and analyzed for ^{241}Am according to the procedure in Appendix B. Total TRU alpha activity ranged from 2.54 to 9.11 pCi/g. No samples exceeded the criteria for distributed activity of 13.5 pCi/g (500 kg). These samples will remain as part of the IVC sample archives.

This test was conducted again by the on-site DSWA representative in February 1995. Contaminated soil was cycled twice. Samples were collected from material diverted to the contaminated area. The results ranged from 1.62 to 5.52 pCi/g total TRU-alpha activity.

6.1.2 Test 2: Single Source at Incremental Distances on Conveyor

Test 2 was conducted by passing an ^{241}Am source beneath the detectors at incremental horizontal distances across the conveyor belt. The test was conducted on sorters 1 and 3. Its purpose was to verify that there are no "weak" spots across the conveyor belt (portions of the belt where particle activity is under-reported by the system) and that no positions are being misdiverted. Misdiverted is defined as contaminated material that is processed to the "clean pile". Another purpose of the test was to gather statistics on the sorter's response to a known source.

6.1.2.1 Description of Test 2

A 135,000 dpm ^{241}Am check source used to derive the system efficiencies was obtained from the contractor. First, the source was passed beneath the detectors of sorter 3 on the empty belt

Table 6-5. Results from samples collected during Test 1

Sample Number	²⁴¹ Am, pCi/g	+/- 2 sigma	Total TRU Elements ^a , pCi/g	+/- 2 sigma
S001	1.30	0.11	8.46	0.72
S002	1.30	0.11	8.46	0.72
S003	0.90	0.08	5.86	0.52
S004	1.20	0.05	7.81	0.33
S005	0.86	0.04	5.60	0.26
S006	0.64	0.08	4.17	0.52
S007	1.30	0.10	8.46	0.65
S008	0.49	0.07	3.19	0.46
S009	0.62	0.10	4.04	0.65
S010	1.10	0.08	7.16	0.52
S011	0.79	0.08	5.14	0.52
S012	0.73	0.07	4.75	0.46
S013	0.39	0.07	2.54	0.46
S014	0.64	0.11	4.17	0.72
S015	1.20	0.09	7.81	0.59
S016	0.74	0.08	4.82	0.52
S017	0.48	0.11	3.12	0.72
S018	0.84	0.08	5.47	0.52
S019	0.87	0.08	5.66	0.52
S020	0.68	0.08	4.43	0.52
S021	1.40	0.10	9.11	0.65

^a TRU-alpha activity was inferred from the ²⁴¹Am activity results by direct ratio (6.51).

(Test 2a)(Fig. 6-1). The source was placed on 0.5-in. increments along the conveyor from 1.5 to 30 in. (Fig. 6-2). After the source passed beneath the detectors, it was retrieved, and a marker was placed in exactly the same position. The markers consisted of painted coral pebbles. The diversion (or misdiversion) was then noted at the diversion gate housing. This process was repeated 66 times. The raw data results are provided in Appendix C, Table C.1 of ORNL 1994. The electronic files were obtained from the contractor upon completion of the test.

Test 2b was conducted in the same manner as above, except that the ²⁴¹Am source was placed in the center of the base of a 3.5-in.-diameter petri dish and covered with approximately ¾ in. of crushed coral to simulate the contaminated material at the site (ORNL 1994, Appendix C, Table C.2). Again, the source was run at 0.5-in. increments across the belt, and the diversions were observed. The use of painted coral markers was discontinued, and flat washers were used instead. This helped to reduce slipping and rolling of markers. The electronic data were obtained from the contractor.

Fig. 6-1. Placing source on conveyor belt for Test 2.

Fig. 6-2. Incremental distances along conveyor during Test 2.

Tests 2c and 2d (ORNL 1994, Appendix C, Tables C.3 and C.4) were conducted on sorter 1, just as the previous paragraph describes. A slight improvement was made to the markers used to replace the source: the flat washers were numbered. When the markers appeared in the clean pile they could be easily identified.

6.1.2.2 Observations and Results

The visual observations made during Tests 2a-d are presented in Appendix C of ORNL 1994. Tables C.1, C.2, C.3, and C.4. The data sets are presented in Appendix D of ORNL 1994.

The first purpose of the test was to verify that there were no weak spots across the array of detectors where particle activity was being under-reported and that no positions were being misdiverted. Figures C.1 through C.4 in Appendix C are bargraphs that show the response across the detectors with and without soil covering. These figures show that, indeed, there are weak spots across the two conveyors tested. Variations appear as hills and valleys, which may correspond to individual detectors. On sorter 1 with soil covering, one response was as low as 5,893 Bq, which is 40% of actual. On sorter 3, response was 6,582 Bq (44% of actual). Markers did not appear to be misdiverted because of their position across the belt. Only one marker was misdiverted by falling left or right out of a diversion gate (Test 2b, Run 38). However, 14 markers out of 72 were misdiverted because of their positions lengthwise between two segments. The misdiverted markers were later observed in the clean pile. Their positions between the segments can be determined by observing that all the misdiverts happened just as the gates were either extending or retracting, just missing the marker.

The retraction and extension occurs only at the edge of segments (every 2 s). This demonstrates what had been previously theorized by ORNL from studying the software. This issue has been addressed in the following: 1) *Independent Verification of the Johnston Atoll Soil Sorter Plant Source Code and Software* (ORNL 1993), page 9, log_hot_particle point #1; 2) letter from John Wilson, ORNL, to Ed Bramlitt, DNA, May 6, 1993; 3) Letter from Ed Bramlitt, DNA, to Steve Willhoite, TMA, May 7, 1993; 4) Letter from Steve Willhoite, TMA, to Ed Bramlitt, DNA, May 11, 1993; and 5) Letter from John Wilson, ORNL, to Ed Bramlitt, DNA, November 2, 1993.

The second purpose of the test was to gather statistics on the sorter's response to a known source. The 135,000 dpm ^{241}Am source is equivalent to 14,850 Bq of total TRU alpha activity (135,000/60 s/min $\times$ 6.6 total to ^{241}Am ratio). Figures C.5 through C.12 in Appendix C are histograms showing the response in Bq from each of the tests. With soil covering the source, the readings were consistently lower than the known 14,850 Bq. This consistent error would be more acceptable if activity were being overestimated rather than underestimated. The sorters should provide accurate readings on this particular source because it was the one used for calibration.

6.1.2.3 Limitations of the Test

Obvious limitations and pitfalls to this test are as follows:

1. Human error may have occurred when replacing the source with a marker. However, there was no observed misplacement, rolling, or slippage for at least 14 misdiversions.
2. The markers used to replace the actual source may have moved on the belt. This was much more likely when pieces of coral were used since the rounded edges allowed them to roll. The

flat washers had pitfalls also in that they sometimes tended to stick to the belt slightly more than coral might. However, this action could simulate how slightly damp coral might stick to the belt.

3. Human error in consistently placing the source at 0.5-in. intervals across the belt may have occurred.
4. The ^{241}Am source, a 1-in.-diameter round disk, is dissimilar to contaminant particles, which may be as small as 5 microns (TMA/Eberline 1992a).

6.1.3 Test 3: Examination of System Limitations

This test involved passing several sources in various configurations beneath the detectors. Its purpose was to examine the limitations of the system and to ensure that it properly diverted all of the sources.

6.1.3.1 Description of Test 3

Three ^{241}Am sources were used to conduct this test. The total disintegration rates of the sources were 550,000 dpm, 372,000 dpm, and 212,000 dpm. Certificates of Calibration accompanied the sources, which were provided by TMA/Eberline Albuquerque Laboratory. The test was conducted on sorter 1, where the sources were placed in different configurations, passed under the detectors, and replaced with markers. The diversion of the markers was observed and recorded.

6.1.3.2 Observations and Results

No misdiversions occurred. The results of Test 3 are presented in Appendix E of ORNL 1994, labeled as the ungrouped particle data set.

6.1.3.3 Limitations of the Test

1. The ^{241}Am source is dissimilar to contaminant particles, which may be as small as 5 microns.
2. Human error in replacing the sources with markers may have occurred.
3. The sources were of such high activity that they were unlikely to be misdiverted. Results of Test 2 show that the less activity detected by the sorter (because of soil covering, etc.), the greater the likelihood of misdiversion.

6.1.4 Test 4: Examination of Counting Accuracy

This test involved passing three certified sources beneath the detectors of sorters 1 and 3 in the same position. The purpose of this test was to obtain data for a statistical analysis correlating reading to a known source.

6.1.4.1 Description of Test 4

Certified ^{241}Am sources of 550,000 dpm, 372,000 dpm, and 212,000 dpm were used to conduct this final test on sorters 1 and 3. The sources were placed in the center of a petri dish and covered with approximately $\frac{3}{4}$ in. of coral to simulate the contaminated material at the site. The sources were passed beneath the detectors 30 times each, approximately every 15 s (Table 6-6). Visual observation of the diversion gates was not used in this test. The electronic data were obtained from the contractor for statistical analysis.

Table 6-6. Results of Test 4, passing sources under detectors

Time	Source		Sorter	Comments
	kdpm	Activity, Bq		
1505	212	23,320	1	passed source 30 times
1505	372	40,920	3	passed source 30 times
1519	372	40,920	1	passed source 30 times
1519	212	23,320	3	passed source 30 times
1530	550	60,500	1	passed source 30 times
1535	550	60,500	3	passed source 33 times passes 17, 18, and 32 may have placement errors

6.1.4.2 Results and Observations

The sources of 550,000 dpm, 372,000 dpm, and 212,000 dpm correspond to total TRU-alpha activity of 60,500 Bq, 40,920 Bq, and 23,320 Bq, respectively. These sources are referred to as High, Medium, and Low for simplicity. Figures 6-3 through 6-5 are histograms that show the responses of the sorters. The sets of grouped particle data are presented in Appendix F. This test shows, as does Test 2, that the detectors consistently read lower than the known source. The results are summarized in Table 6-7. The average response of sorter 1 detectors was 75% of the actual. The average response of sorter 3 detectors was 77% of the actual.

Table 6-7. Results of Test 4

Sorter #	High Source Response, Bq (% of actual activity)	Medium Source Response, Bq (% of actual activity)	Low Source Response, Bq (% of actual activity)
Sorter 1	44,798 (74.0%)	34,745 (84.9%)	15,737 (67.5%)
Sorter 3	48,237 (79.7%)	32,709 (79.9%)	17,069 (73.2%)

Fig. 6-3. Sorter 1 and Sorter 3, high source.

Fig. 6-4. Sorter 1 and Sorter 3, middle source.

Fig. 6-5. Sorter 1 and Sorter 3, low source.

6.1.4.3 Limitations of the Test

1. The ^{241}Am source is dissimilar to contaminant particles, which may be as small as 5 microns. The ^{241}Am source was a 1.75-in.-diameter round disk, compared to the actual contaminate.
2. The three certified sources available for use were relatively high in activity; therefore, low-activity contamination was not simulated.
3. Human error in placing the source consistently on the belt may have occurred.

6.2 Other Observations

The speed at which the conveyor belt travels is critical to the correct operation of the sorters. Eberline uses the following procedure to check the belt speed twice per day, once in the morning and once in the afternoon. A mark on the edge of the belt is timed with a stop watch as it passes a wire suspended near the belt. The belt is timed for one complete revolution. The time must be within 0.2 s of the predetermined time of 75.65 s. If the time falls outside the range, it is rechecked several more times. If the timing is off consistently, a 5-min average is taken to determine the amount to adjust the belt speed.

ORNL was not able to obtain the source of the predetermined time at the site. A search of the documentation shows that the belt is 37.666 ft long (Bramlitt 1991a). This length would correspond to a revolution time of 75.333 s at a speed of 30 ft/min. Belt revolution time of sorter 1 was measured 16 times by ORNL on June 16, 1994; the results are shown in Table 6-8. The average revolution time was 75.62 s. If 75.333 s is the target time, the observed time might explain some of the misdiversions on Test 2.

The referenced letter defines the distance from the detectors to the point where the contaminated material drops as 11.1 ft. It should be ascertained that this is the value being used for the "belt_length" parameter in the controlling program. These two factors are of utmost importance to the timing of the diversion gates.

The daily plant start-up procedures were observed on June 16, 1994. Background counts are collected for 20 min from each of the 16 detectors (15 detectors plus the background detector). The counts from each of the first 15 detectors are divided by the counts in the 16th detector. This number is called the "background factor" and is used in the program to determine background for each detector during the day. One of the two sorters is checked for background each morning. Each sorter is checked every other day to eliminate 40 min of down time required to perform the check. On off days, the sorter is checked for 5 min of count time to ensure that no hot particles are lodged in the vicinity of the detectors. A board with 15 sources is placed beneath the detector array. The sources are counted for 15 s to ensure all the detectors are responding properly. If one of the detectors is low, the operator ensures that the board is properly aligned before looking for malfunctions. If the board was misaligned, another 15-s count is performed to confirm the problem. Next, the gate response is checked by turning on the sorter (with no soil) and placing a source on the belt. After passing under the belt, the source is replaced by a piece of painted coral as a marker.

Table 6-8. Belt speed check

Check Number	Time	Belt Revolution Time, s
1	08:05	75.59
2		75.58
3		75.50
4	08:22	75.51
5		75.60
6		75.70
7		75.67
8		75.69
9		75.71
10		75.66
11		75.66
12		75.59
13		75.55
14		75.65
15		75.56
16		75.68

The coral is observed to make sure it is diverted properly. This is repeated 3 or 4 times at different places on the belt. After soil is started onto the belt, the same procedure is repeated on top of the soil. This check is not deemed worthwhile if the soil is "hot" because soil is diverted anyway. It should be noted that there was no documentation for the calibration procedure available for on-site examination.

Mechanical checks and adjustments are performed on the diversion gates weekly. These checks were observed June 17, 1994, on sorter 3. Each gate was individually extended and retracted several times. A timer on the control panel showed how quickly the gates responded. The gates must respond in 0.25 ± 0.05 s. Adjustments can be made if the gates respond too fast or slow. At the time of the observation, two gates were responding slowly (> 0.30 s), but the operator made no adjustments. When all of the gates were retracted together, one gate on sorter 3 was visibly slower than the others. Gate response is also critical to the proper diversion of particles. It was observed and also noted by the plant operators that there are more distributed diversions (distributed contamination) when the plant first starts up than later in the day.

This is a result of the moving average background. When the sorter is first started, the background has been collected using an empty belt, so the background is artificially low. Because the sorter is operating very close to the lower limit of detection at the belt speed of 30 ft/min, this artificially low background causes clean soil to appear contaminated. Changes have been made to the software to allow operators to clear out the accumulated background. This is not a perfect solution because it takes several minutes to accumulate a reliable background count.

6.3 Issues, Concerns, and Recommendations

Independent verification of the effectiveness of the JA soil-sorter plant yielded the following issues, concerns, and recommendations at the time of the tests:

1. The diversion of hot particles to the clean path as demonstrated in Test 1 is a major concern. Are these diversions the result of counting efficiency only?
2. Misdiversion of particles as demonstrated in Test 2 is a concern. This is a problem inherent in the controlling software. If the hardware is adjusted perfectly to specifications, particles on the border between two 2-s segments will continue to be misdiverted. A modification to the software is needed to make sure that material is diverted before and after a particle. One solution would be to divert both segments if the particle is within 0.25 s of the border. Another solution would be to divide the soil into 1-s segments and divert two segments, but counting statistics may not allow this.
3. Confirmation of belt length and belt speed is needed.
4. At current belt speed, distributed contamination is so close to the lower limit of detection that soil may be diverted simply because of error in counting statistics. Consider decreasing the speed of the belt.
5. Consider changing the hot particle activity calibration procedure, actually burying the source under $\frac{3}{4}$ in. of soil rather than relying on an attenuation factor. Make sure the calibration accounts for the weak spots uncovered in Test 2.
6. Keep heavy equipment from contaminating the clean area after being used in the contaminated area. Delineate the two areas clearly.
7. Develop a detailed set of calibration procedures that are followed consistently throughout changes in personnel. The findings of the IV of the QC program (in preparation) indicate that better documentation is needed for system procedures.

The above issues and concerns were addressed by the contractor subsequent to the submittal of the draft report in 1995. Furthermore, the FCDSWA repeated test #1 and sampled the diverted material to find that all samples were far below the clean-up guideline (Major Joseph Kimbrell, FCDNA, memorandum from Mary Wilson-Nichols, ORNL, May 2, 1995).

6.4 Conclusion

The tests described in this document indicate that the sorter system significantly reduces soil contamination (see Tables 6-1 to 6-3). However, the tests also indicated the possibility that the system may not remove all the Pu from the soil. Since this ideal state is not a realistic goal, the following paragraph suggests some solutions.

One solution to this problem would be to re-sort limited amounts of soil from the less-contaminated Launch Emplacement 2 (LE-2) area. The re-sorted soil could then possibly be released for unconditional use. A second option would be for DSWA (formerly DNA) to establish a policy on use of processed soil that would include a discussion regarding confidence bounds for the acceptance criteria. This is further discussed in Sects. 8 and 10.

7.0 INDEPENDENT VERIFICATION OF THE SOIL SCREENING LIMIT

ORNL/ETS conducted a thorough evaluation of the SSL as part of the initial IV tasks. The established criteria are SSLs expressed as a soil concentration of 500 Bq of TRU elements per kilogram of soil or 5,000 Bq for a single particle. These levels are equivalent to the EPA value (U.S. EPA 1978) below which the risk of harm to people is trivial and corrective actions are not required (DNA 1989). The purpose of the verification was to ensure that no deficiencies or discrepancies exist within the derivation of the DSWA's selected SSL that might cast doubt on the quality of the soil the clean-up plant delivers for unrestricted use throughout the island.

This IV was accomplished by review of the rationale and calculations used to derive the SSL at JA. DSWA's rationale and a detailed explanation of the development of the SSL are presented in a letter from Edward T. Bramlitt, FCDSWA to John Eddy, DNA, on March 1, 1991, and is included as a reference to Appendix A. In addition, a literature search performed to gain access to recent developments in plutonium migration, uptake, and dose assessment provided information on several sites that have undergone similar experiences in the development of an SSL for plutonium. Clean-up levels from these sites were reviewed and compared to the JA SSL. The following paragraphs describe the evaluation of the SSL and the review of SSLs at other sites.

7.1 Evaluation of the SSL

The EPA's *Proposed Guidance on Dose Limits for Persons Exposed to Transuranium Elements in the General Environment* is the basis for the JA SSL (U.S. EPA 1978, 1988). This proposed guidance to federal agencies, which appeared in the *Federal Register*, Volume 42, 1977, recommends an SSL below which corrective actions are not required. Therefore, soil contaminated to levels below the SSL may be considered clean (DNA 1991b). The EPA's two-volume publication on TRU elements (U.S. EPA 1990a, 1990b) provides an updated technical basis for the SSL, but does not serve as formal guidance and does not indicate an SSL different from the 1988 guidance.

The model basis for the EPA-based SSL is a mass-loading approach to relating concentration of a TRU element in soil to its concentration in air. Although more sophisticated models are available that incorporate more site-specific data on atmospheric and soil conditions, the uncertainty in, and time-dependence of, some of these data suggest a more simplified approach for the purposes of screening.

The mass-loading formulation can be represented by

$$\text{Air Concentration} = \text{Air Mass Loading} \times \text{Soil Concentration} \times \sum f_i \eta_i \quad (1)$$

where

Air Concentration = the activity concentration of the transuranium elements in air, Bq/m³,
Air Mass Loading = mass of soil present in the air in the form of resuspended soil dust, kg/m³,

Soil Concentration = activity concentration of the transuranium elements in soil, Bq/kg,
 $\sum f_i \eta_i$ = the contribution of the TRU elements from each particle-size fraction to the total resuspended material (also called the "enrichment factor").

In order to develop an SSL, Eq. (1) is rearranged to calculate a soil concentration based on a maximum acceptable air concentration at or below which clean-up would not be required. The rearranged form of Eq. (1) becomes

$$SSL = \frac{\text{Acceptable Air Concentration}}{\text{Air Mass Loading} \times \sum f_i \eta_i} \quad (2)$$

In applying Eq. (2), conservative values were selected by EPA for the air mass-loading factor and the values for the enrichment factor, $\sum f_i \eta_i$ (U.S. EPA 1988). Selection of conservative values provides assurance that any area of soil contamination characterized by a TRU concentration less than or equal to the resulting SSL is highly unlikely to provide an exposure to airborne TRU elements that exceeds the acceptable exposure level.

An air mass-loading factor of 10^{-7} kg/m^3 ($100 \text{ } \mu\text{g/m}^3$) was selected for the EPA development of an SSL; this value is higher than annual averages for any non-urban site in the U.S., according to 1965 National Air Sampling Network data (U.S. EPA 1988). Shinn et al. (1994) monitored mass loading at three work locations at JA, during a period of soil clean-up operations, and upwind of these locations, in an area of no measurable Pu contamination. During soil clean-up operations, when the soil was disturbed by the "mining" and "sorting" equipment, the median mass loading at the three work locations was $109 \text{ } \mu\text{g/m}^3$, and the average at the three sites were $1.78 \times 10^{-7} \text{ kg/m}^3$ ($178 \text{ } \mu\text{g/m}^3$), $9.3 \times 10^{-8} \text{ kg/m}^3$ ($93 \text{ } \mu\text{g/m}^3$), and $7.9 \times 10^{-8} \text{ kg/m}^3$ ($79 \text{ } \mu\text{g/m}^3$). However, the upwind "background" mass loading was measured at $4.1 \times 10^{-8} \text{ kg/m}^3$ ($41 \text{ } \mu\text{g/m}^3$), a value which likely overestimates the mass loading of soil because the contribution of sea salt to the sampled particulates was not evaluated. Therefore, the assumed mass-loading factor of 10^{-7} kg/m^3 is a conservatively high value for JA. From Eq. (2), the SSL is inversely proportional to the air mass-loading factor and, thus, selection of a high mass-loading factor leads to a conservatively low estimate of an SSL.

The term $\sum f_i \eta_i$ addresses how the activity concentration in the respirable-size range of soil particles might be enriched with respect to the activity concentration in the soil as a whole. A value of unity would indicate that the activity concentration in the respirable-size range is equivalent to that averaged over all sizes of soil particles. The parameter f_i represents the distribution of airborne soil mass as a function of particle size, and η_i accounts for the variability of soil activity and mass as a function of particle size. Data for f_i and η_i are available for five sites with plutonium contamination in the United States (U.S. EPA 1988). These sites include Mound in Ohio, NTS in Nevada, ORNL in Tennessee, the Rocky Flats Environmental Technology Site (RFETS) (formerly the Rocky Flats Plant) in Colorado, and the Trinity Site in New Mexico. According to EPA, the largest enrichment of activity within the fine particle-size range, which is more respirable, is documented for samples from the RFETS area. Therefore, in keeping with the objective of remaining conservative in the development of a SSL, an average enrichment factor of 1.5, derived from RFETS data, was selected.

Area size was not considered by EPA in development of the SSL. Area becomes a factor if the contaminated soil area is small enough that potential inhalation exposure is reduced by dilution of radioactive dust with uncontaminated dust from an upwind area. The amount of dilution is inversely proportional to the area of the contaminated zone. It is conservative to ignore this potential dilution, and thus, no correction for area size was made in development of the SSL.

Finally, the maximum activity concentration in air that corresponds to some maximum acceptable exposure level is specified to derive an SSL. The EPA guidance recommends a maximum absorbed dose rate to the lung of 0.01 mGy/year (1 mrad/year), and to bone of 0.03 mGy/year (3 mrad/year) after 70 years of chronic ingestion exposure. Dose to the bone and lung is a function of the lung clearance class. Dose to the lung is also a function of the size of inhaled particulate TRU elements. Clearance class refers to the pulmonary residence time and is a function of solubility. For insoluble compounds of TRU elements, a clearance Class Y corresponds to retention on the order of years. Although in the updated technical basis document (U.S. EPA 1990b) it is indicated that some plutonium oxides or other TRU elements may be cleared faster and, thus, result in doses to other organs that exceed the lung doses, the assumption of Class Y leads to lower allowable air concentrations based on dosimetric calculations and, thus, is conservative. Size of inhaled particulates with associated TRU activity is inversely proportional to dose received, although this is a rather weak relationship given that the dose decreases by only about a factor of five over the size range of 0.05 to 5.0 μm activity mean aerodynamic diameter (AMAD) (U.S. EPA 1990b). An AMAD of 1.0 μm was selected upon which to base the dosimetric relationship between suspended TRU activity and lung dose received. For a Class Y, alpha-emitting plutonium or americium compound of AMAD 1.0 μm , the atmospheric concentration corresponding to a 0.01 mGy/year (1 mrad/year) absorbed dose rate is approximately $9.6 \times 10^{-5} \text{ Bq/m}^3$ ($2.6 \times 10^{-15} \text{ Ci/m}^3$) (U.S. EPA 1988, 1990b). Given a quality factor of 20 for alpha radiation, a concentration of $9.6 \times 10^{-5} \text{ Bq/m}^3$ corresponds to an annual committed dose equivalent of 0.2 mSv/year (20 mrem/year) to the pulmonary region.

Assuming the 0.01 mGy/year (1 mrad/year) pulmonary absorbed dose-rate limit, the SSL can be calculated from Eq. (2) as

$$SSL = \frac{9.6 \times 10^{-5} \text{ Bq/m}^3}{100 \mu\text{g/m}^3 \times 1.5 \times 10^{-9} \text{ kg}/\mu\text{g}} \quad (3)$$

resulting in an SSL of 640 Bq/kg (17 pCi/g) of soil. The SSL actually adopted for use at JA is 500 Bq/kg (approximately 13 pCi/g), based on the recommended SSL in the EPA proposed guidance of 7.4 kBq/m² (0.2 $\mu\text{Ci/m}^2$). Using Eq. (1), the soil concentration of 7.4 kBq/m² corresponds to an activity concentration in air of $7.4 \times 10^{-5} \text{ Bq/m}^3$ ($2.0 \times 10^{-15} \text{ Ci/m}^3$), assuming a bulk soil density of 1.5 g/cm³ and considering only the top 1 cm of soil to convert soil concentration on a unit-mass basis to a unit-area basis. The 500 Bq/kg (13 pCi/g) JA SSL is, therefore, consistent with the 1977 EPA proposed guidance and corresponds to a 0.15 mSv/year (15 mrem/year) committed dose equivalent ($7.5 \times 10^{-3} \text{ mGy/year}$ absorbed dose) to the pulmonary region based on dosimetry from the International Commission on Radiation Protection (ICRP) Report #19 (ICRP 1972).

The EPA proposed guidance indicates that this screening level should not be applied if contaminated soils contain americium and curium at activities that constitute more than 20% of the total TRU activity, due to the greater solubility of these radionuclides and, hence, greater possibility of larger doses via the ingestion pathway.

The SSL is based on air concentrations because inhalation of radioactive materials that have deposited on soils, and then are resuspended, is the more direct route of exposure. Ingestion of radionuclides like plutonium, which are poorly absorbed from the gastrointestinal tract before transport to the sensitive organ (i.e., bone), is a less significant hazard, according to EPA (U.S. EPA 1990a). An estimation of absorbed dose rate attributable to ingestion of crops, vegetables, beef, milk, and soil as a result of plutonium and americium soil contamination at RFETS (U.S. EPA 1990b), at levels of $(0.25 \mu\text{Ci}/\text{m}^2)$ and $(0.045 \mu\text{Ci}/\text{m}^2)$, respectively, was 0.65 mrad/ year to bone, based on a 70-year exposure duration. At the same soil contamination level for the top 20 cm of soil (the plow depth assumed in the ingestion dose calculations), the corresponding air concentration according to Eq. (1) would be $4.6 \times 10^{-3} \text{ Bq}/\text{m}^3$ ($1.25 \times 10^{-7} \mu\text{Ci}/\text{m}^3$). This air concentration corresponds to an absorbed dose rate of approximately 48 mrad/year for a Class Y compound. Since the recommended dose limits for bone (the sensitive organ for the ingestion route) and lung are the same order of magnitude, and estimated inhalation doses to lung are significantly higher than ingestion doses to bone, for a given soil concentration, it is reasonable to base the SSL on inhalation doses.

More recent dosimetry (ICRP 1979), upon which DOE bases dose conversion factors, suggests that the 500 Bq/kg SSL (and related $7.4 \times 10^{-5} \text{ Bq}/\text{m}^3$ air activity concentration) corresponds to a 0.01 mGy/year dose rate, a 0.2 mSv/year annual committed dose to the lungs (ICRP 1979). The annual committed estimated dose equivalent (EDE) to the whole body is calculated by using tissue weighting factors, w_T , which represent the ratio of risk arising from each tissue (i.e., red marrow, lung, bone surfaces, and liver) to the total risk when the whole body is irradiated uniformly. Thus,

$$EDE = w_T H_{50,T} \quad (4)$$

where $H_{50,T}$ is the 50-year committed dose equivalent to tissue T , per unit intake of Pu-239. For inhalation of $1.0 \mu\text{m}$ AMAD particles of Class Y Pu-239, the weighted committed dose equivalents for each tissue per unit intake are:

Tissue	$\sum w_T H_{50,T}$
red marrow	$9.1 \times 10^{-6} \text{ Sv/Bq}$
lungs	$3.9 \times 10^{-5} \text{ Sv/Bq}$
bone surfaces	$2.9 \times 10^{-5} \text{ Sv/Bq}$
liver	$1.2 \times 10^{-5} \text{ Sv/Bq}$
Total	$8.9 \times 10^{-5} \text{ Sv/Bq}$

The total of these tissue-specific weighted committed dose equivalents represents a whole body committed EDE of 8.9×10^{-5} Sv/Bq intake of Pu-239. Multiplying the whole body EDE per unit intake by the air concentration of 7.4×10^{-5} Bq/m³ (corresponding to the derived SSL), and an inhalation rate of 8400 m³/year, give a whole body committed EDE of 5.5×10^{-5} mSv/year (5.5 mrem/year).

To compare the calculated committed doses to recommended dose limits other than EPA's, it is useful to consider the National Council on Radiation Protection and Measurements (NCRP) recommended limits on occupational exposure of 50 mSv/year committed EDE, a lifetime exposure to natural background radiation (excluding radon) of 1 mSv/year, and exposure of a maximally exposed individual at a power plant boundary of 0.1 mSv/year (NCRP 1987a, 1987b, 1989). The risk of fatal cancers associated with the above-recommended doses, according to NCRP, are 0.02, 0.001, and 0.0001 respectively. The SSL adopted by DSWA for JA corresponds to a committed EDE (0.055 mSv/year) that falls below the NCRP recommendations. Further evidence that suggests that EPA's SSL is appropriate for screening at JA comes from Garten (1980), who carried out a statistical analysis of the uncertainties in predicting dose to lung from plutonium using EPA's mass-loading model and concluded that the derived SSL is conservative because the likelihood of exceeding the proposed dose limits is small.

The EPA recommends that soil samples be taken to a depth of 1 cm and include all soil particles less than 2 mm in diameter, to obtain samples of soil that represent particles that may be resuspended (U.S. EPA 1990b). At JA, the SSL applies to dispersed activity in unscreened soil in an area not to exceed 0.1 m³. Because "hot" particles are present in JA soils, a requirement also exists that activity of a 0.01 m³ sample must be less than 5,000 Bq. However, conservative elements built into the sampling process include sample sizes of only 0.07 m³, rather than 0.1 m³, for comparison to the 500 Bq/kg limit, and sizes of only 0.0007 m³, instead of 0.01 m³, for comparison to the 5,000 Bq limit. This results in a 30% increase in conservatism and an associated reduction in the dose and risk limit achieved with the SSL.

7.2 SSLs at Other Facilities

Table 7-1 presents plutonium and americium clean-up criteria developed and used at various facilities. The clean-up guidelines at these sites range from 0.9 pCi/g to 200 pCi/g. The SSL of 13.5 pCi/g (500 Bq/kg), selected as the clean-up guideline by DSWA for the JAPRP, is well within this range. Indeed, it is lower than those at several similar sites.

The DOE has recommended using the RESRAD model to calculate risk-based soil clean-up guidelines at DOE sites. For comparison site-specific soil clean-up guidelines were calculated for JA using RESRAD. The resulting values were 40.8 pCi/g for a 30 mrem/year limit, and 136.0 pCi/g for a 100 mrem/year limit. These results are further evidence of the conservatism of the JA soil clean-up criteria.

**Table 7-1. Plutonium and americium clean-up criteria
developed and used at various facilities**

Site	Responsible Agency	Pu/Am clean-up guideline		Comments
Enewetak Atoll	DNA/DOE	residential use:	40 pCi/g	
		agriculture use:	80 pCi/g	
		short-term visit:	160 pCi/g	
Hanford Reservation, Richland, Washington	DOE		30 mrem/year ^a	SSL based on dose rate; clean-up to background if reasonably achievable (ALARA standard)
Los Alamos National Laboratory, Los Alamos, New Mexico	DOE	²³⁸ Pu:	27 pCi/g	Weapons development (high levels in remote canyons)
		²³⁹ Pu:	24 pCi/g ^b	
Mound Facility, Miamisburg, Ohio	DOE	100 pCi/g, 25 pCi/g if reasonably achievable (ALARA standard) ^c		²³⁸ Pu in canal sediments
New Brunswick Laboratory New Jersey Site	DOE		200 pCi/g	²³⁹ Pu, ²⁴¹ Am, and U (ANL 1985)
Boeing Michigan Aeronautical Research Center Missile Accident Site	USAF/EPA		8 pCi/g	Based on risk of 1 in 10,000 excess cancer risk (USAF 1992)
Nevada Test Site	DOE		10 pCi/g	from U.S.DOE 1993a
Rocky Flats Environmental Technology Site	DOE	²⁴¹ Am	209 pCi/g	Office worker exposure area, based on RESRAD modeling (U.S.DOE 1996)
		²³⁹ Pu	1,088 pCi/g	
		²⁴¹ Am	215 pCi/g	Open space exposure area, based on RESRAD modeling (U.S.DOE 1996)
		²³⁹ Pu	1,429 pCi/g	

^a D. Stanton, U.S. Army Corps of Engineers, personal communication with D.S. Foster, ORNL, September 29, 1994.

^b C. Mason, Los Alamos National Laboratory, personal communication with D.S. Foster, ORNL, September 30, 1994.

^c C. Friedman, Mound Facility, personal communication with D.S. Foster, ORNL, September 30, 1994.

ALARA = as low as reasonably achievable
ANL = Argonne National Laboratory
CDH = Colorado Department of Health
DOE = U.S. Department of Energy

dpm = disintegrations per minute
EPA = U.S. Environmental Protection Agency
USAF = United States Air Force

7.3 Conclusion of SSL IV

DSWA developed SSLs for the TRU isotopes plutonium and americium at JA based on EPA SSLs. EPA SSLs result in estimated doses consistent with NCRP dose and risk recommendations. DSWA added additional conservatism by implementing their SSLs on a smaller soil volume. DSWA SSLs are within established regulatory guidelines and provide an adequate level of protection to the worker, the public, and the environment at JA. DSWA (formerly DNA) SSLs were verified through recalculation.

DSWA has opted to use the SSLs as their clean-up criteria. It is our opinion that this is an acceptable clean-up standard, based on comparison to clean-up guidelines used at similar sites. However, it would be valuable to the certification of the site to have written endorsement of this from EPA, as suggested in Number 34 of Appendix A. Other suggestions and concerns are listed in Sect. 10 of this report.

8.0 INDEPENDENT VERIFICATION OF THE QC PROGRAM

Independent verification of the QC soil sampling program was necessary to ensure that no deficiencies or discrepancies exist that might cast doubt on the quality of the soil the clean-up plant delivers for unrestricted use throughout the island. The QA/QC procedures and program described below were as of the date of the IV, which was 1994.

8.1 QC Program

TMA/Eberline, who was the prime contractor to DSWA for the JAPRP, instituted a quality assurance (QA)/QC program to confirm that the contaminated material processed through the sorter plant meets the DSWA release guidelines of 500 Bq/kg or 5000 Bq for single particles.

TMA/Eberline's QC program is described in the 1992 annual report (TMA/Eberline 1992b) and in the quarterly report of March 1994 (TMA/Eberline 1994). The program consists of survey measurements and sample analyses from the piles of processed material referred to as "clean" piles.

TMA/Eberline conducts QC surveys approximately every two hours during plant operations. A calibrated FIDLER probe and an Eberline ESP II rate meter are used to take direct measurements on the clean pile. In addition to the surveys, each day approximately 15 to 20 samples of the clean material are taken for analysis in TMA/Eberline's on-site laboratory. Samples weighing 113.6 g are placed in petri dishes and counted using a BICRON FIDLER detector inside a shielded counting chamber. Five-minute counts are made with an Eberline Model MS-2 Mini-Scaler (TMA/Eberline 1994). Samples are archived on site by TMA/Eberline.

DNA, in the past, had additional QC protocols that further verify the soil-sorting process and has conducted various performance and QC tests throughout the development and initiation of the remedial action (Bramlitt 1994). Some of these efforts are described in Sect. 9.6.1 of the 1992 annual report (TMA/Eberline 1992b). DNA also conducts QC sampling of the processed material. The project management plan for JA describes QA to be conducted by DNA on clean coral from the decontamination process (DNA 1989). QC is to be derived through redundant measurements and independent sample analysis. Redundant measurements use a high-purity germanium gamma detector to monitor samples of soil from the clean piles spread to a thin layer in a well-defined geometry. These are the secondary means for verifying gamma activity measurements made by the sorter plant detector systems (DNA 1989).

8.2 IV of the QC Sampling Program

Because the project has been ongoing for several years and has experienced changes in personnel and contractors, there have been many modifications to the original QA/QC plans. Therefore, the IV review is based primarily on samples and procedures reported by TMA/Eberline in the March 1994 quarterly report (TMA/Eberline 1994). Additionally, observations from on-site visits and discussions with personnel are presented as verification of the ongoing QC program.

It should be noted that QC testing is also performed on the sorter process itself. This consists of passing a calibrated source of known activity under the sorter detectors. This procedure is addressed in the verification of the sorter process (see Sect. 6).

TMA/Eberline's QC protocol was observed during an IVC site visit in October 1993. A TMA/Eberline radiation technician was observed taking QC measurements every two hours. Initially, FIDLER/ESPII measurements are taken on the surface of the pile containing the most recent soil from the sorter process. The pile is visually divided into four quadrants where direct measurements are collected. The ESPII records and electronically stores five readings per 15 s. After the survey is complete, a sample of the most recent soil from the process is collected in a 5-gal bucket. Small samples of coral are collected from different depths in the bucket and placed into a petri dish for analysis. The technician attempts to collect the most representative sample possible; however, gravity allows larger coral pebbles to roll down and spread around the pile faster than the finer material. The remaining sample in the 5-gal bucket is saved and used as DSWA's QC sample. A logbook entry identifies the assigned sample number, date taken, and time taken. Samples are counted using a Bicron FIDLER detector inside a shielded counting chamber. The results were recorded in a logbook and later compiled and presented in the March 1994 quarterly report (TMA/Eberline 1994). A copy of the logbook was provided to ORNL for verification. The raw data in the logbook and the data presented in the quarterly report were compared for accuracy.

The IVC review found the logbook and the March 1994 quarterly report to be in agreement. It was noted that approximately one out of ten samples was counted twice, apparently as a QC check on the counting equipment. This check was not mentioned in the quarterly report, and there was no indication of how it is used.

The duplicate count data were entered into Minitab, a statistics software program, and hand-checked for accuracy (Table 8-1). The differences between count 1 and count 2 were calculated and stored in Minitab's column 4 (see C4 in Table 8-1). A W-test indicated that the count differences were not from a normal distribution (Fig. 8-1), therefore, a non-parametric Wilcoxon signed-rank test was used and found no statistical evidence of a difference in the two sets of counts (Gilbert 1987). However, whether TMA's method has validity as an instrument of the QC process is questionable, based on the fact that it appears to have no built-in accept-reject criteria. Two methods for accepting or rejecting values are:

- (1) The 3-sigma range test that uses a known source to establish an acceptance range when the instrument has just been repaired or calibrated.
- (2) A control chart that defines unacceptable variation or trending in the instrument measurements.

TMA/Eberline's March 4, 1994, quarterly report states that QC measurements of clean soil indicated no radioactivity greater than the DSWA release criteria of 500 Bq/kg or 5000 Bq for a single particle. No petri dish samples were reported to exceed these release criteria. Results from the analysis of 417 petri-dish QC samples were provided in the quarterly report. The IVC obtained 14 of the QC samples and submitted them for confirmatory analysis according to the procedure provided in Appendix B. The samples will remain as part of the verification sample archival for the project. The confirmatory analysis revealed that the 14 samples do not exceed DSWA's release

Table 8-1. JA QC sample analysis, August 1 to October 21, 1993

	C1 Sample ID	C2 Count 1	C3 Count 2	C4 Count 1 minus Count 2
1	1370	366	378	-12
2	1372	246	250	-4
3	1381	232	232	0
4	1389	257	266	-9
5	1401	239	250	-11
6	1409	244	247	-3
7	1416	264	263	1
8	1419	479	433	46
9	1462	255	273	-18
10	1464	265	255	10
11	1482	256	250	6
12	1492	255	244	11
13	1502	277	287	-10
14	1510	275	306	-31
15	1524	267	288	-21
16	1534	253	259	-6
17	1544	239	261	-22
18	1554	222	264	-42
19	1560	259	259	0
20	1563	441	412	29
21	1566	257	270	-13
22	1576	251	239	12
23	1586	243	222	21
24	1594	242	234	8
25	1638	386	352	34
26	1656	377	370	7
27	1657	380	284	96
28	1704	371	402	-31
29	1707	380	444	-64

Fig. 8-1. Normal probability plot, JA QC sample analysis, August 1 to October 21, 1993.

criteria. TMA/Eberline's results were consistently higher than the IVC's, probably due to differences in counting systems and procedures. Because TMA/Eberline's results lend conservatism to the process, there is no reason to take issue with the differences.

The sample collected by TMA/Eberline in the 5-gal bucket is acquired by DSWA for its own QC check on the quality of processed soil. At the end of the processing day, the sample weighs about 40 lb and represents approximately 10 h of the sorting process. DSWA's counting system employs a large, suspended, metal pan. The sample is spread out evenly (to approximately ½ in. thick) in the pan, creating a volume of 0.01 m³ to provide a known density. DSWA uses a high-purity germanium gamma detector for sample analysis. Background counts are taken daily when the pan is empty and recorded in a separate logbook.

8.3 Discussion

QC techniques include all practices and procedures that lead to statistical control and to the achievement of the accuracy requirements of the measurement process (Taylor 1987). The basic elements of QC include: 1) technical competence of staff, 2) suitable facilities and equipment, 3) good laboratory practices, 4) good measurement practices, 5) standard operating procedures (SOPs), 6) protocols for specific purposes, 7) inspection, 8) documentation, and 9) training (Taylor 1987). The IVC has observed the presence of these elements in the QC program for the JAPRP. Because the primary concern is the quality of decontaminated soil to be released for use on JA, there was no in-depth auditing of personnel records, training, or inspection reports. We understand that TMA/Eberline performed these audits on an annual basis. TMA/Eberline's analytical techniques were not audited but only verified by confirmatory analysis and independent sampling.

The IVC's primary observation is the difficulty in designing a QC program at JA that has a valid statistical basis. The following discussion demonstrates this.

8.3.1 Probability of Detecting Hot Particles

A statistical analysis of the QC sampling program indicates that current sampling practices yield low probabilities of detecting hot particles in the clean pile from which the QC samples are collected. A complete discussion of the statistical methodology is presented in Sect. 8.3.2.

The following assumptions were used to calculate the probabilities:

Activity of a hot particle ≥ 5000 Bq

Average density of crushed coral = 1.3 g/cm³

Volume of soil per day = 91 yd³ = 69.58 m³

Mass of one sample = 113 g

Volume of one sample = 86.923 cm³ = 8.692×10^{-5} m³

Sampling frequency = 8 times per day, random samples from successive portions of the growing clean pile.

If any 113-g sample contains a hot particle, there is a 100% probability of detecting the particle.

Using these assumptions, the following conclusions were derived:

- If the clean pile contains one hot particle, the chance of finding this particle on any given day is one in 1×10^5 , or 0.001%. The number of samples necessary to ensure with 90% confidence that the hot particle was detected is at least 360,000 samples per day and, in the worst case, as many as 720,000 samples per day.
- The chance of detecting at least one hot particle on any day if, for example, 64 hot particles are present in the clean pile is one in 6.4×10^4 , or 0.064%. If there are 100, 200, or 500 hot particles uniformly distributed throughout a day's clean pile, the number of samples required to be 90% confident of detecting at least one of them is 18,420, 9,210, and 3,683.

8.3.2 Conclusion

Statistical analysis of the QC shows that extra QC measures are required to provide higher confidence that activities within the clean soil are below established criteria.

Provided below are two alternative methods (1) a one-sided tolerance test and (2) a percentile test.

(1) The One-Sided Tolerance Test

Kenneth J. Eger of Ebasco Environmental suggested (Eger 1992)

"The one-sided tolerance test is a powerful statistical test which can be used for both characterization and release surveys decontamination and decommissioning (D&D)."

The nature of the statistical distribution of the population from which samples are drawn need *not* be known for this test to be used. This is an advantage over parametric tests where a specific probability distribution (e.g., normal, log normal) is assumed. The tolerance test is based on the binomial theorem and provides a confidence level for stating that, for example, 95% of the population is smaller than the highest value sampled. A table of required samples sizes is provided for various confidence levels and percents of population below the highest sample value.

If the highest sample value is less than the screening limit the test is straightforward. However, if the highest value is more than the limit, the test procedure becomes somewhat more complex. This aspect of the test seems confusing and may not be as operationally advantageous as the percentile test to be considered next.

(2) A Percentile- or Quantile-Based Standard

Another method that does not require the assumption of a specific statistical distribution is based on estimates of a given percentile of the population. For example, (Berthouex and Brown 1994, p. 65)

"The use of percentiles in environmental standards and regulations has grown during the past few years. England has water quality consent limits that are based on the 90th and 95th percentiles of monitoring data not exceeding specified levels. The U.S. Environmental Protection Agency (EPA) has specifications for air quality monitoring that are in effect percentile limitations...The U.S. EPA has provided guidance for setting aquatic standards on toxic chemical that require 99th percentiles and using this statistic to make important decisions about monitoring and compliance."

The term quantile is sometimes used instead of percentile. The quantile is just the percentile in fractional form; the 95th percentile is the 0.95 quantile. Gilbert states (1987, p. 134)

"Quantiles of distributions are frequently estimated to determine whether environmental pollution levels exceed specified limits. For example, a regulation may require that the true 0.98 quantile of the population, $x_{0.98}$ must not exceed 1 ppm."

Gilbert later shows how to find nonparametric estimates of quantiles (Gilbert 1987, pp. 141-142)

"Quantiles...can also be estimated when the underlying distribution is either unknown or nonnormal. These methods are called *nonparametric* or *distribution-free* techniques, since their validity does not depend on the data being drawn from any particular distribution."

Briefly, the percentile method consists of ranking the sample measurements and using a formula to estimate, say, the 98th percentile at a 95% confidence level. This test seems more straightforward than the one-sided tolerance test. However, both are operationally feasible.

Confidence Levels

Kenneth J. Eger of Ebasco Environmental suggests (Eger 1992, bold supplied)

"The third prerequisite is a determination of the desired statistical assurance, and the acceptable confidence level. These must usually be chosen with the concurrence or approval of the responsible regulating agency. The EPA, for example, routinely requires advance approval for any statistical technique proposed other than the ones specified in the regulations. The NRC and DOE also require the licensee or operator to submit sampling plans for approval. Draft NUREG/CR 5894 "Manual for Conduction Radiological Surveys in Support of License Termination" **requires a confidence level of at least 95 percent.**"

Extended Table of Sample Sizes for the One-Sided Test

An extended table for the number of samples required for the one-sided tolerance test appears below:

Confidence Level →		90%	95%	96%	97%	98%	99%
Percentage of Population Below Highest Sample	90	22	29	31	34	38	44
	95	45	59	63	69	77	90
	96	57	74	79	86	96	113
	97	76	99	106	116	129	152
	98	114	149	160	174	194	228
	99	230	299	321	349	390	459

If other combinations are desired use the following steps:

- (1) Let CL be the desired confidence level.
- (2) Let p be the percentage of the population below the highest sample.
- (3) Let n be the required sample size.

$$\text{Then } n = \log(1 - CL) \div \log(p).$$

Round n up to the next largest integer, if fractional portion not zero.

Example: Find n when a 92% confidence level is required and 98% of the population is to be smaller than the largest sample value.

$$n = \log(0.08) \div \log(0.98) = 125.02$$

$$n = 126.$$

Note that 126 is about what you would expect from estimating between the table's value for 90%, $n = 114$, and the value for 95%, $n = 149$.

Notes Regarding a Percentile-Based Standard

Suppose the standard states:

The upper 98% confidence limit of the 95th percentile must be less than 500 Bq/kg.

Suppose further that we take 200 samples. How would this standard be demonstrated operationally?

(1) The sample size must be greater than 95. "Percentiles can be estimated using parametric or nonparametric methods. The nonparametric method is simple, but the sample must contain more than p observations to estimate the p th percentile" (Berthouex and Brown 1994, p. 68). With 200 samples we easily meet the $n > 95$ criteria.

(2) Order the samples by size from the smallest to largest, i.e., $x_{[1]} \leq x_{[2]} \leq x_{[3]} \leq \dots \leq x_{[n]}$. "The $x_{[i]}$ are called the order statistics of the data set" (Gilbert 1987, p. 135). Suppose these are the highest four sample values:

Order:	197	198	199	200
Sample value:	456	489	503	517 Bq/kg

(3) Find u , the index of the upper 98% confidence limit for the 95th percentile. Gilbert (1987, p. 142) gives the formula as

$$u = p(n + 1) + Z_{1-\alpha}[np(1 - p)]^{1/2}$$

where

- p is the p th quantile, 0.95 in this case;
- n is the sample size, must be greater than 95 in this case;
- α is 0.02 in this case since we want the 100 (1 - α)% confidence level to be 98%;
- $Z_{1-\alpha}$ is the standard normal deviate that cuts off 100 (α)% of the upper tail of the standard normal distribution, $Z_{0.98}$ for this case is 2.05.

For this example the formula becomes

$$u = 0.95(201) + 2.05[200 \times 0.95 \times 0.05]^{1/2} = 197.27$$

By interpolation of the 197th and 198th order statistics we find the upper 98% confidence limit for the 95th percentile of the population to be $456 \text{ Bq/kg} + 0.27 (489 \text{ Bq/kg} - 456 \text{ Bq/kg}) = 464.9 \text{ Bq/kg}$. Therefore, we have met the standard.

Clearly this method allows some values in the sample to be greater than 500 Bq/kg and still pass the standard. In this sample, 2 out of 200 values or 1% are larger than 500 Bq/kg. Whether this is good or bad depends on the risk resulting from a few samples exceeding 500 Bq/kg. If this risk is considered very high the standard could be rewritten as

The upper 95% confidence limit of the 98th percentile must be less than 500 Bq/kg.

Note that the confidence is lower, 95% instead of 98%, but the percentile is higher, 98th instead of 95th. Solving for μ with this new standard and using the same sample numbers gives

$$\mu = 0.98(201) + 1.645[200 \times 0.98 \times 0.02]^{1/2} = 200.2.$$

By using the 200th order statistic we find the upper 95% confidence limit for the 98th percentile of the population to be 517 Bq/kg. Therefore, the standard has not been met.

In general, if the percentile is raised to around 98 or 99, the order statistic used will be the highest value in the sample (unless n is very large). On the other hand, raising the confidence level to say 98% does not necessarily require the highest value if the percentile is say 95. This is illustrated by the last example.

In conclusion, a standard base on a 98th or 99th percentile will typically require all the samples to be less than 500 Bq/kg. On the other hand, a standard based on say the 95th percentile will allow some sample values greater than 500 Bq/kg.

9. RADIOLOGICAL SURVEYS

The final task described in this report is the independent verification that the coral in the RCA has been excavated to a sufficient depth to remove plutonium particles. As part of this process, ORNL conducted a radiological survey of post-remediation in situ soil conditions at a selected area [Verification Area 1 (V-1)]. V1 (Fig. 9-1) is located within the LE-2 in the RCA on JA.

V-1 (Fig. 9-2) had been previously excavated by the FCDSWA with the intent of removing all TRU contamination greater than the site clean-up guideline. ORNL was requested to independently verify that the top 1 cm of coral in the bottom of the excavation met the clean-up guideline.

9.1 Applicable Guidelines

As mentioned in Sect. 7, specific standards for a clean-up of TRU elements in soil have not been promulgated. EPA recommended that a SSL of 7400 Bq/m^2 ($0.2 \text{ } \mu\text{Ci/m}^2$) be used for land areas contaminated with TRU alpha-emitting isotopes (U.S. EPA 1987) so that any land area that meets this guide can be considered for release for unrestricted use. FCDSWA adopted these values for the soil-sorting operation at JA. ORNL conducted an IV of the SSL to ensure that no deficiencies or discrepancies exist within the derivation of the FCDSWA-selected SSL that might cast doubt on the quality of the soil the sorter plant delivers for unrestricted use throughout the island (Sect. 7). The result of the IV study was that the JA SSL was acceptable and consistent with guidelines used at comparable sites. For consistency, ORNL adopted the sorter plant clean-up criteria for radiological surveys on JA. The sorter plant on JA is designed so that any 0.1-m^3 volume of coral with a contamination level less than 500 Bq/kg (13.5 pCi/g) is considered clean (Bramlitt 1991b). It is also engineered to discard any 0.01 m^3 of coral with a total activity greater than 5000 Bq ($0.135 \text{ } \mu\text{Ci}$). These values are being used to define the state of coral that is to be called clean after remediation. Coral that has not been processed but meets the same criteria as used by the sorter plant is also considered clean.

EPA did not relate the size of contaminated surface areas to the SSL. Investigators evaluating a site need to define the areal size considered significant for comparison to the SSL. Most programs currently in place allow averaging of contamination across 100 m^2 areas, with upper limits set for small areas of elevated activity (U.S. DOE 1990).

The volume of a 10 m^2 area with a depth of 1 cm equals the sorter plant averaging volume of 0.1 m^3 . The following assumption were made

- circular areas of 10 m^2 and 1 cm in depth were the targets for detection for distributed low-level contamination.
- any single particle or highly localized combination of particles that exceeded 5000 Bq ($0.135 \text{ } \mu\text{Ci}$) within an area of 1 m^2 would exceed the clean-up guide. When averaged over a 1-cm depth of coral, this value is approximately 500 Bq/kg (13.5 pCi/g) of total TRU activity.

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Fig. 9-1. Location of V-1 within LE-2.

Fig. 9-2. Normalized FIDLER readings.

ORNL conducted the land area surveys with the intent of detecting TRU contamination contained within approximately the top 1 cm of coral. These surveys were intended to help document that enough soil had been removed for processing through the sorter plant. If no activity is detected from the survey, some assurance is provided that remediation has been effective. If the survey suggests residual activity is still present, further investigations should be considered.

ORNL recognizes that the methods used would have detected ^{241}Am contamination below the top 1 cm; however, the detection efficiency would decrease significantly with increasing depth. For example, a planar source of ^{241}Am beneath 1 cm of coral would give a response of about half what would be obtained if the 1 cm of coral were not present. It then becomes difficult, if not impossible, to determine if the residual activity exceeds the SSL.

9.2 Scope of Work

A team of three ORNL/ETS representatives visited the island during November 1994 to conduct a radiological survey. The area of interest was approximately 0.6 ha (1.5 acres) in size and was at the southeastern end of the LE-2 area (Fig. 9-1). Around 200 radioactive point-source anomalies (hot particles) were found during the survey, of which more than 70% were within a 0.12 ha (0.3 acres) region at the far southeastern end of the area. Based on the in situ measurements, it was estimated that approximately 25% of the hot particles had a TRU alpha activity greater than 5,000 Bq (135 pCi). Following the November survey, FCDSWA reevaluated the methods and equipment being used, removed the hot particles found by ORNL, and subsequently performed another survey of the area.

A second radiological confirmatory survey for the southeastern end of the LE-2 area was performed by ORNL during February 1995 by a team of four representatives. The area of interest was extended to include approximately 1.01 ha (2.5 acres). A total of 53 hot particles were found within the added area, in addition to many hot particles detected at the far southeastern region of the original area.

Based on the results of the walk-over surveys conducted by both ORNL and FCDSWA, a boundary was set where a full evaluation of the radiological status would be performed. The remaining zone was removed from consideration due to the need for further remediation both within the area and along its perimeter. The study area, V-1, is shown in Fig. 9-1 relative to the remainder of the RCA. All data presented in the remainder of this report were collected from within V-1.

9.3 Methods

9.3.1 Document Review

As part of the IV agreement between FCDSWA and ORNL, a review of current issues, documentation, and the final verification report of the remedial action contractor constituted the Type A (document review) task of the IV (U.S. DOE 1993b). FCDSWA performed radiological surveys of V-1 before the arrival of ORNL on JA. ORNL has not reviewed the close-out survey of V-1 because

the data was not available at the time. Two memoranda describing FCDSWA surveys of portions of the LE-2 area were sent to ORNL for review, but did not encompass V-1 (Richter 1993, 1994). Cooperative efforts are underway with FCDSWA to define the responsibilities and requirements for documentation of the close-out surveys for the final completion report and certification.

The environmental assessment (DNA 1991b), the original characterization survey (EG&G 1980), and other background documents (AFFRI 1988; Bramlitt 1991b; U.S. EPA 1987) were reviewed by ORNL for background information. This background was presented in Sect. 4.

9.3.2 Survey Methods

ORNL conducted the land area surveys as described in the Verification Survey Plan for Johnston Atoll LE-2 area (Coleman 1994) with the intent of detecting TRU contamination contained within approximately the top 1 cm of coral. These surveys were intended to help document that enough soil had been removed for processing through the sorter plant. If no activity is detected from the survey, some assurance is provided that remediation has been effective. If the survey suggests residual activity is still present, further investigations should be considered.

ORNL recognizes that the methods used would have detected ^{241}Am contamination below the top 1 cm; however, the detection efficiency would decrease significantly with increasing depth. For example, a planar source of ^{241}Am beneath 1 cm of coral would give a response of about half what would be obtained if the 1 cm of coral were not present. It then becomes difficult, if not impossible, to determine if the residual activity exceeds the SSL.

Background

Typical background count rates on the FIDLER detectors used in these surveys range from 500 to 700 counts per minute (cpm). Background count rates are used here only for comparison to count rates found in the area of interest.

Reference Grid

ORNL established a temporary 3.05-m by 3.05-m (10 × 10-ft) square grid over the survey area using a transit. The zero point for the grid was set relative to an existing fence at the south edge of the RCA (Figs. 9-1 and 9-2). Elevations were obtained to document the contour and depth of the excavation as it was surveyed.

Particles

ORNL conducted a 100% walk-over survey of V-1 using FIDLER detectors coupled to Ludlum 2221 instruments set in ratemeter mode. The primary intent of this phase was to find hot particles and highly localized areas of contamination. The detectors were swung in a serpentine manner from side to side and kept within 15 cm (6 in.) of the coral surface. The scan rate did not exceed 15.25 m² (50 ft²) per minute per person. When an anomaly (a measurement significantly above background) was found, it was flagged and later located and recorded by grid coordinates.

Distributed Contamination

Static measurements were acquired with the FIDLER detectors coupled to Ludlum 2221 instruments set in scaler mode. The readings were taken at each 3.05 m (10 ft) grid point to help guide sampling. The detectors were placed in contact with the coral surface, and 1-min integrated counts were obtained. The resulting data were normalized and plotted across a map of V-1. The normalization algorithm accounts for the difference in the response of each detector to both background radiation and to the radiation emitted by the contaminant. Therefore, the normalized data appear as if only one detector was used. Figure 9-2 shows the normalized FIDLER readings superimposed across Area 1.

ORNL evaluated the map of normalized FIDLER measurements for elevated areas and for patterns in the readings. Samples representing an areal size of approximately 80 cm² were collected at a depth of 0 to 1 cm from selected locations based on the fixed-point measurement data. At least one sample was taken from each area showing a pattern of elevated readings, and several samples were randomly taken from areas with background readings. Sample locations with corresponding sample numbers are shown on Fig. 9-3. A total of 41 samples were collected within V-1.

9.4 Results

9.4.1 Document Review

Although a printout of the surveys performed by FCDSWA for V-1 are not presented herein, reviews of the data that have been submitted indicate that the areas surveyed are clean. However, ORNL surveys indicated residual activity in these area. This discrepancy was investigated by examining FCDSWA instruments and finding fundamental differences in the quality of instrumentation. Discussions of clean-up and verification policy are in progress, and presented in Sect. 10. A plan for final status surveys is in preparation by the contractor and/or FCDSWA.

9.4.2 Field Survey

ORNL found approximately 90 hot particles within V-1 during the walk-over surveys. Based on field measurements, approximately 25% of the particles had activities greater than or equal to the 5000 Bq (0.135 μ Ci) SSL. All hot particles identified within V-1 were remediated by FCDSWA, regardless of the estimated activity, and independently confirmed by ORNL. These hot particles may be due to a combination of cross-contamination from vehicles, erosion of the steep slope adjacent to the excavation, and the equipment and methods used during the FCD-SWA cursory survey. Historical data indicates that a rather complex set of strata of contaminated soil exists within the LE-2 pad area (EG&G 1979).

ORNL compared the 1-min FIDLER measurements taken at the surface to surface radionuclide sample analysis results for corresponding locations. The distribution of FIDLER count rates could not be accounted for by the radionuclide concentrations observed within the top 1 cm of coral.

Table 9-1 shows the total TRU alpha activity and ²³⁸U concentrations for all 41 samples taken within V-1. Analytical instrumentation and methods are described in Appendix B. The uranium data are presented to show that radionuclide activity is not attributable to uranium, which was also used in the fabrication of weapons. The highest concentration observed for a sample was 148 ± 19 Bq/kg (4 ± 0.5 pCi/g) total TRU alpha activity. Although the samples were analyzed for the

Fig. 9-3. Sample locations.

JA011

Table 9-1. Sample analysis results

Sample number ^a	X, Y grid coordinate, ft	Total TRU activity, ^b pCi/g	²³⁸ U, ^b pCi/g
VS65	5,0	<0.10 ^c	1.9 ± 0.5
VS66	20, 70	<0.52 ^c	1.8 ± 0.4
VS67	110, 110	0.32 ± 0.26	0.50 ± 0.25
VS68	130, 100	0.39 ± 0.19	1.1 ± 0.4
VS69	190, 30	1.0 ± 0.32	1.2 ± 0.3
VS70	250, 20	4.0 ± 0.52	1.5 ± 0.4
VS75	30, 80	<0.98 ^c	1.9 ± 0.7
VS76	10, 50	<0.39 ^c	1.2 ± 0.3
VS77	50, 50	<0.72 ^c	2.1 ± 0.5
VS78	20, 70	<0.72 ^c	1.7 ± 0.5
VS79	100, 70	<0.59 ^c	2.2 ± 0.8
VS80	70, 100	<1.0 ^c	2.2 ± 0.7
VS81	90, 120	<0.2 ^c	1.3 ± 0.2
VS82	80, 140	<0.52 ^c	1.8 ± 0.6
VS83	30, 140	0.58 ± 0.26	1.7 ± 0.3
VS84	70, 180	<0.65 ^c	2.3 ± 0.7
VS85	30, 220	0.78 ± 0.45	2.0 ± 0.7
VS86	80, 220	0.65 ± 0.19	1.2 ± 0.3
VS87	60, 230	1.95 ± 0.91	2.7 ± 0.8
VS88	130, 220	0.91 ± 0.45	2.0 ± 0.7
VS89	170, 220	2.8 ± 1.0	2.0 ± 0.5
VS90	200, 220	0.91 ± 0.71	2.0 ± 0.6
VS91	230, 230	3.3 ± 0.6	1.8 ± 0.5
VS92	220, 190	0.91 ± 0.71	2.5 ± 0.7
VS93	250, 170	<0.65 ^c	0.84 ± 0.84
VS94	210, 160	0.45 ± 0.45	1.6 ± 0.4
VS95	240, 130	1.0 ± 0.5	2.1 ± 0.7
VS96	220, 120	0.71 ± 0.26	1.4 ± 0.3
VS97	240, 80	2.8 ± 0.8	2.2 ± 1.0
VS98	250, 40	2.0 ± 0.8	1.8 ± 0.7
VS99	250, 0	2.4 ± 0.9	1.0 ± 0.7
VS100	230, -20	0.97 ± 0.6	1.5 ± 0.5
VS101	150, 40	0.58 ± 0.19	1.4 ± 0.3
VS102	160, 50	<0.52 ^c	1.5 ± 0.4
VS103	130, 70	<1.6 ^c	2.2 ± 1.1
VS104	160, 90	2.8 ± 1.0	1.7 ± 0.6
VS105	140, 100	<1.0 ^c	1.6 ± 0.7
VS106	170, 140	<0.40 ^c	1.3 ± 0.3

Table 9-1. continued

Sample number ^a	X, Y grid coordinate, ft	Total TRU activity, ^b pCi/g	²³⁸ U, ^b pCi/g
VS107	170, 180	<0.91 ^c	2.3 ± 0.6
VS108	130, 160	0.26 ± 0.19	1.2 ± 0.2
VS109	110, 140	<0.39 ^c	1.3 ± 0.3

^a All sample numbers are prefaced by the site code JAT001.

^b Mean concentration ± 1.96 standard deviations (95% confidence interval).

^c The nuclide was not detected. The value is the lower limit of detection for this particular sample.

Note: The samples were analyzed for ²⁴¹Am by gamma spectrometry using high purity Ge detectors. The resulting mean americium values and errors were multiplied by a factor of 6.5 pCi total TRU alpha per pCi of ²⁴¹Am. The resulting total TRU alpha are shown in this table. See Appendix B.

natural nuclides ^{235}U , ^{238}U , ^{226}Ra , and ^{232}Th , only the ^{238}U results are shown in the table. The ^{235}U to ^{238}U activity ratio was consistently about 1 to 22, which is in agreement with the isotopic concentration found in natural uranium. The ^{226}Ra to ^{238}U ratio was approximately 1 to 10 for samples where ^{226}Ra could be detected. Thorium-232 was not detected in any of the samples. The ^{238}U concentrations were consistent with those reported by EG&G (1980) as being present in natural coral on JA and the surrounding islands. The error reported for each analysis represents the 95% confidence bounds for the stated mean activity and only includes error associated with the counting process itself. Errors associated with possible non-uniform particle distributions, sampling methods, or other non-stochastic parameters are not accounted for.

Appendix C provides an evaluation of the homogeneity of TRU distribution within the coral matrix of JA samples. Although not directly applicable to the verification of V-1, this data may be useful during future work involving the issue of homogeneity in JA coral/soil. This issue is crucial to the selection of statistical methods used in the remedial action process at JA.

9.4.3 Sample Archival

ORNL has established a soil sample archival set that resides in Oak Ridge, Tennessee, in order to support the ultimate certification of the site. FCDSWA also archives samples and may choose to establish its own protocol for archival of samples collected for certification.

9.4.4 Conclusions

Several hot particles were found within V-1. All such anomalies were removed by FCDSWA and the area independently verified by ORNL. Sample analysis showed low-level, distributed TRU contamination at some locations across V-1, but no samples had concentrations greater than the SSL of 500 Bq/kg (13.5 pCi/g) total TRU alpha. Based on the information obtained, there is no reason to suspect that TRU contamination greater than the site clean-up guide existed within the top 1 cm of coral in V-1 at the conclusion of the survey work.

The fixed-point FIDLER measurements taken at the surface showed elevated gamma flux rates within discrete areas that could not be explained by either TRU nuclide levels or variations in background nuclide concentrations. It is possible that variation in the measurements within these areas was due to TRU contamination at a depth greater than 1 cm. Further sampling and measurements at greater depths would be required to evaluate fully the cause of the elevated measurements in these areas. ORNL suggests further investigation of anomalies at depth during future surveys (Sect. 10).

It should be noted that in late 1995 the on-site FCDSWA representative recontoured the V-1 area, including V-1, using material from the clean soil pile (Russell 1995). This recontouring included the remnant of the LE-2 pad. ORNL's preliminary measurements found contamination to still exist in the vicinity of the LE-2 pad. Future surveys are suggested to verify the surface radiological condition of the site, when excavation and recontouring activities are complete.

Protocol and verification plans for final surveys were in preparation by FCDSWA at the time of this writing (November 1997).

10.0 CONCLUSION

The JADPP experienced several delays due to funding, equipment and changes in personnel. The project has been extended for an adequate length of time for the IVC, RAC and FCDSWA to resolve several issues and concerns in a joint task team. The focus of future planning and discussions primarily involve these two issues:

1. A survey plan that describes the remediation and verification of land, equipment, and buildings will be formulated. The plan will describe FCDSWA's policy that sets forth the criteria and protocol to be used for verification of land in the RCA. Methods of evaluating potential contamination at depth will be researched and discussed.
2. The verification of the clean soil produced by the sorter will be addressed. A statistical element will be applied to the contractor's QC sampling to provide better verification, and perhaps enable release of clean soil to needs that occur on JA. A 95% confidence level will be applied to the clean-soil criteria used both for the processed soil and clean-up of land, equipment and buildings. The IVC recommends that the project team consider using this statement:

"The definition of clean soil for the Johnston Atoll Plutonium Decontamination Project is based on U.S. Environmental Protection Agency Soil Screening Levels, which were, in turn, based on dose and risk recommendations established by the National Council on Radiation Protection. The established criteria is expressed as specific activity of 500 Bq of transuranic (TRU) elements per kilogram of soil. Hot particles in excess of 5,000 Bq are identified and diverted by the soil-sorting plant to assist in achieving the overall goal of 500 Bq/kg. This standard requires that 98% of the processed soil be less than or equal to 500 Bq/kg at a 95% confidence level. "

The following is a list of issues that have been resolved by the project team, and are presented herein for the record:

1. The IVC was concerned after the examination of the sorter plant QA/QC that when a QC sample exceeded the criteria, there would be difficulty in applying the One-Sided Tolerance Test to the soil sample population within the clean pile and requested that the procedure of reprocessing soil was adequately documented in TMA's protocol. Thermo NUtech issued a revision to their protocol stating that if multiple samples from the same pile exceeded 500 Bq/kg, the pile would be resorted (Thermo NUtech 1996). Sect. 8.3.1 of this document explains that there is a 0.065% chance that a hot particle would be detected during one day of QC sampling. Therefore, the event that a QC sample exceeds the criteria is expected to be very unlikely.
2. The IVC was concerned after the evaluation of the soil clean-up criteria that FCDSWA needed to decide upon a policy that sets forth the clean-up of land, in addition to the clean soil definition for the sorter. At the time of the study, there was no established protocol or adopted guidelines such as NRC release criteria, or DOE clean-up guidelines that were applicable to the project. The FCDSWA is considering adopted the protocol suggested within the Draft Multi-Agency Radiation Survey and Site Investigation Manual, which is currently undergoing public comment. A final decision will be made when this document is cleared by all agencies for use.

3. The IVC also expressed concern to the FCDSWA to consider item #34 in the 1 March 1991 letter from Dr. Bramlitt to John Eddy. EPA endorsement of the criteria would be beneficial to the project. This issue will be addressed at a later stage of the project, when the status of regulatory oversight at JA is better known.
4. The IVC recommended that TMA revise their QC procedure to implement a statistical element in their QC sampling (Sect. 8.3.2). A letter was issued that detailed these concerns (ORNL to Kimbrell, January 18, 1995). TMA (currently Thermo NUtech) revised Procedure 3.0 during 1997 (Thermo NUtech 1996).
5. The IVC recommended that TMA revise their QC procedures to describe what actions are taken when their calibration tests, and other tests, fail. Specifically:
 - a. Procedure 2, 3.5.0. (Describe what action is taken when the background count does not fall within $\pm$ sigma).
 - b. If the "instrument checks" fall outside of the "acceptable range" what action is taken? Tag instruments, etc?
 - c. Procedure 2.0. 3.8.0. Sample evaluation. Re-sort of the pile should be the action taken when a QC sample fails to fall within the criteria.

These items were addressed by Thermo NUtech in a 1997 revision to the procedures.

6. The IVC requested to review the TMA and FCDSWA QC sample results from FY1994 and FY1995. These results will be reviewed by the IVC before site closure.
7. The IVC expressed concern to FCDSWA regarding the remediation of the RCA (land and buildings) be conducted, and suggested a plan that describes the schedule and phases be prepared. This process was initiated in 1997.
8. As part of the verification plan, the IVC will continue to collect verification samples and survey data before clean soil is backfilled into excavations. The RAC, Thermo-NUTECH will also archive post-remedial action samples. This data will subsequently be reviewed by the IVC prior to project close-out. Archival samples are essential to final verification.
9. The IVC questioned the limitation of surface surveys to the top centimeter. The FCDSWA responded that the issue of potential contamination at depth will be addressed within future plans. The IVC intends to investigate at depths below 1 cm during its surveys.
10. The primary concern that arose from the IVC's SSL evaluation was the use of the SSL as a clean-up criterion. EPA clearly indicates that the SSL is "not intended to be interpreted as a derived intervention level or as a soil clean-up standard to which all sites of transuranium contamination must be decontaminated" (U.S.EPA 1990b). As low as reasonably achievable (ALARA) is defined as: "making every reasonable effort to maintain exposures to *radiation* as far below the dose limits as is practical consistent with the

purpose for which the licensed activity is undertaken, taking into account the state of technology, the economics of improvements in relation to state of technology, the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to utilization of nuclear energy and licensed materials in the public interest" (Shleien 1992). It appears from our evaluation, and this definition, that ALARA has been applied in the use of the SSL as the clean-up guideline for TRU contamination at JA.

11. The enrichment factor used in EPA's equation to calculate the SSL is based on samples sieved to 2 mm. The samples collected for QC of the sorting process are not sieved to this size and include larger particles. Since contaminants are associated with smaller particles, the samples may be diluted in terms of potential TRU activity. The IVC suggested that samples be sieved to provide even more conservatism to the process. Number 29 in the Appendix A addresses this issue, but only in reference to large, in situ measurements. This issue will be resolved during future discussions.
12. As an additional verification measure, the effective resuspension factor from EPA's 1988 guidance could be compared to the measured value at JA. If measured resuspension factors are available, we will evaluate this comparison. Also, if activity distribution/size distribution information is available, the IVC can calculate a site-specific enrichment factor. This issue will be discussed as part of the IVC's future scope of work.
13. Appendix C of the March 1994 quarterly report contained the TMA/Eberline QA plan (QAP) for the JA project at the time the QA/QC verification was conducted. It was based on ANSI-ASME NQA-1-1989 guidelines and addressed the 18 criteria prescribed in NQA-1 (ASME 1989). The QAP reiterated the requirements in NQA-1, followed by general and somewhat brief descriptions of what was going to be done, from a QA standpoint, but not necessarily how it is going to be done. At the time, the IVC suggested that the QAP be followed up by a detailed set of SOPs containing step-by-step instructions, descriptions of the work processes, and the steps necessary to complete each task. Because of the remote location of JA, there is constant change in technical staff. SOPs are essential to ensure that the QC procedures are followed consistently. This item was addressed by Thermo NUtech in 1996 when they issued a detailed procedures manual.

The resolution of the above issues has provided the IVC with a basis for the continued independent oversight of the JAPDP. The scope of future IVC tasks will be directed at obtaining independent proof that the site has been decontaminated to levels that are as low as reasonable achievable, by methods well documented in the project record.

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APPENDIX A

**Letter from Edward T. Bramlitt, FCDSWA (formerly FCDNA),
to John Eddy, DSWA (formerly DNA)**

DEFENSE NUCLEAR AGENCY
FIELD COMMAND
KIRTLAND AIR FORCE BASE, NEW MEXICO 87115-5000

FCLH

1 March 1991

SUBJECT: Plutonium Clean Soil at Johnston Atoll

Defense Nuclear Agency
6801 Telegraph Road
ATTN: CSLE/John Eddy
Alexandria, VA 22310-3398

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d. EG&G Survey Report, "An In Situ Determination of ²⁴¹Am on Enewetak Atoll, Date of Survey: July 1977 to December 1979," USDOE Report EGG-1183-1778, UC-41, November 1981.

e. DNA Book, The Radiological Cleanup of Enewetak Atoll, Defense Nuclear Agency, Washington, DC, 1981.

f. EG&G Survey Report, "A Radiological Survey of Johnston Atoll, Date of Survey: April-August, 1980," DNA-8114, Revised April 1982.

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h. Bramlitt, E. T., "Plutonium Mining for Cleanup," Health Physics, 55, 451-453 (1988).

i. FCDNA Report, "Johnston Atoll TRU Soil Clean-Up Project, Assembly & Demonstration of the "TRUClean" Soil Clean-Up Plant," (DRAFT), AWC Incorporated, Las Vegas, NV, 18 August 1989.

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j. DNA Contract DNA001-90-C-0119, Johnston Atoll (JA) Plutonium Contaminated Soil Cleanup, 6 Aug 90.

k. DNA Environmental Impact Assessment for Cleanup of Johnston Atoll Plutonium Contaminated Soil, Revised 13 July 1990.

l. EPA Report, "Workshop on Radioactively Contaminated Sites, May 3-5, 1989," 520/1-90-009, March 1990.

2. This responds to your request, 14 February 1991, for background and details on the definition of plutonium clean soil at Johnston Atoll (JA) for use by headquarters, Defense Nuclear Agency (DNA), to develop a policy statement and to obtain further concurrence and support for our cleanup from the Environmental Protection Agency (EPA) if appropriate.

3. Our definition for JA plutonium clean soil derives from recommendations by the EPA to Federal Agencies for limiting dose from plutonium in the general environment, precedences set by the Department of Energy (DOE) for measuring plutonium in soil to guide plutonium cleanup, and best available technology for plutonium cleanup which DNA is developing.

4. The JA plutonium contaminated soil was created during nuclear weapon tests in 1962. Initially it was a mixture of plutonium isotopes (mass numbers 238, 239, 240, and 241), but it now includes some americium (about 15 percent of long-lived alpha activity is mass number 241) as a result of plutonium radioactive decay. (JA plutonium is free of fission products.) Plutonium and americium are transuranium elements, and the JA cleanup may be called either a plutonium soil cleanup or a transuranium element soil cleanup.

5. The soil contamination is insoluble plutonium oxide present as dispersed activity (volume sources) and "hot particles" (isolated point sources). The dispersed activity is particles less than a few nanograms, say, ten Becquerels (Bq) activity and ten microns (μm) diameter, which may be moved through soil by rain or ground water and tidal action. The hot particles are too big to move unless by soil erosion, excavation, or other physical means. (The weather may break them down to become a source of dispersed activity.) Hot particles more than a kBq ($>45 \mu\text{m}$) in the proximate ground surface are detectable with radiation survey instruments and practical survey procedures. Many hot particles have been detected and removed from JA surface soil over the last two decades.

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6. EPA drafted guidance in the middle 1970s for limiting dose to people from plutonium and other transuranium elements in the environment. The public and Federal agencies concerned with environmental plutonium provided extensive comment. EPA refined the guidance through a series of drafts until it reached the status of Draft Interim Final Guidance. EPA deferred promulgation of final guidance in favor of more general guidance covering all radiological contaminants. The general guidance is still under development.

7. EPA asserts its original guidance would limit the effective whole body dose equivalent from environmental plutonium to 10 millirems per year (mrem/y) and contaminated sites may be used without restriction if this limit is not exceeded. The revised guidance allows higher doses in ranges from 10 to 100 mrem/y and from 100 to 500 mrem/y, but it requires controls which are more stringent with increasing dose range. This change added a flexibility which some Agencies thought was absent in the initial draft. The revisions also made some word changes to enhance understanding and interpretation of the EPA policy and direction.

8. All versions of the EPA guidance retain operational guides of the initial draft called the air screening level (ASL) and the soil screening level (SSL). The screening levels are measurable values related to dose below which cleanup is not required and above which cleanup or controls may be necessary. They are needed because dose at the unrestricted-use dose limit is too low to measure by any dosimetric method, and doses can only be inferred from other measurements or theory.

9. The ASL is 1 femtoCurie per cubic meter of air (fCi/m³). The SSL is 0.2 microCuries per square meter of ground (μ Ci/m²) or 7.4 kBq/m². Compliance with the SSL may be demonstrated with samples taken from the top 1 centimeter (cm) of ground and screened to particles less than 2 millimeters (mm).

10. EPA derived the screening levels from a comprehensive model relating (internal) dose to people from plutonium long-lived alpha emitters in soil. It used the original guidance dose limits with worst-case assumptions for each model input parameter. Since everything bad is unlikely to happen in reality, compliance with the screening levels provides high assurance that the stringent dose limits will not be exceeded.

11. When the SSL is met, the soil is "clean soil." Compliance with the SSL means soil is sufficiently free of plutonium that radiological restrictions may be safely lifted. Any effort to

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further reduce the plutonium concentration would be a needless waste of time and resources when soil is clean to the SSL.

12. The largest plutonium soil cleanup ever accomplished was at Enewetak Atoll from 1977-1980. Enewetak Atoll has 40 islands ranging between about 1 and 130 hectares (ha). For cleanup, each island was classified according to an intended use, either residential, agricultural, or short-term visit, with cleanup action levels of 40, 80, and 160 pCi/g per gram of soil (pCi/g), respectively. The 40 pCi/g residential limit, equivalent to surface deposition of $1.8 \mu\text{Ci}/\text{m}^2$ at Enewetak, is a screening level for unrestricted use. DNA was responsible for cleaning Enewetak soil, and DOE was responsible for determining plutonium conditions and certifying that islands were adequately clean for their intended use.

13. DOE adopted an in situ radiation measurement method as the primary means for evaluating plutonium soil at Enewetak. The method elevates a radiation detector several meters above ground so it can have a large field of view for a time long enough to obtain data with good counting statistics. DOE decided the in situ method provides more representative measures of actual contamination conditions than can be obtained from small samples collected and analyzed elsewhere, as in a radiochemical laboratory, or by isolated in situ measurements near the ground.

14. DOE surveyed the Enewetak islands with significant plutonium contamination on uniform 25-m grids. Each measurement represented a sample of ground 25-m diameter and 0.03-m deep (about 15 m^3). The diameter was controlled by detector collimator and height above ground. Sample depth was selected to minimize the effect of variable plutonium depth distributions on the conversion of count rates to specific activities. (For a 0.03-m depth only, the conversion factor was constant for depth distributions ranging between uniform and exponentially decreasing with relaxation lengths down to 0.03 m.) For the average Enewetak soil density, $1.5 \text{ g}/\text{cm}^3$, the in situ sample was 22 metric tons.

15. DOE divided the grids into 0.25-hectare (ha) work areas and assigned a specific activity to each work area from the average of nine in situ measurements. DNA removed soil from the work areas in layers 0.15-m thick when the average specific activity exceeded the appropriate cleanup action level. Survey and cleanup were iterative until plutonium concentrations were substantially reduced. DOE certified each island as suitable for its intended use when specific activity for most of the island work areas were below the action level.

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16. Since the Enewetak cleanup, the in situ method has been widely used for assessment and cleanup of contaminated soil. A comprehensive in situ survey of JA was made in 1980. Radiological restrictions were removed from a residential island (Sand Island) with plutonium contaminated soil when the survey demonstrated all plutonium measurements were below the SSL, and controls were extended on the main island (Johnston Island) to areas where the SSL was exceeded.

17. Soil cleanup usually means digging up contaminated soil and hauling all soil dug up to a disposal site. The removed soil includes clean soil and normally the valuable top soil. Clean soil is collected inadvertently because contamination is spotty with indefinite boundaries, and digging methods do not differentiate clean soil from contaminated soil. Normal soil cleanup degrades the site from its precontamination condition, and it leads to excess consumption of waste disposal space.

18. Contaminated soil has been dug up and moved at JA on several occasions in the past. In 1986, a dig and remove cleanup was performed according to an in situ survey on 13 ha to consolidate the radiological control area. Soil was removed from 579 grid cells (0.025 ha) in layers 0.05- to 0.10-m thick and to depths typically between 0.2 and 0.5 m. All but three cells were cleaned to less than the minimum detectable activity. Cleanup of these cells which were positive for plutonium was discontinued when the SSL was met and continued digging did not significantly change the plutonium concentration.

19. The classic dig-and-remove soil cleanup is now unattractive because concern over very low levels of contamination leads to cleanup and disposal of larger volumes of soil. Further, radioactive waste disposal regulations are more stringent, and they lead to higher disposal costs. A prudent soil cleanup now will strive to minimize the disposal of clean soil and attempt to extract the contaminant from soil to reduce the volume requiring disposal as waste. Soil which is demonstrated to be clean can be returned to the ground rather than disposed as waste.

20. Over the past decade, DNA has investigated mining methods as a means to differentiate clean soil from contaminated soil, and to reduce the volume of soil requiring disposal in plutonium soil cleanup. DNA sponsored laboratory studies, built and tested a pilot plant capable of cleaning 35 m³ of soil per week, and built and tested a full-scale plant with a capacity for processing 750 m³/week. In 1990, DNA awarded a contract to modify the full-scale plant to increase its capacity and effectiveness with the ultimate objective a complete JA plutonium soil cleanup.

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21. JA plutonium soil cleanup proceeds as follows. Potentially contaminated soil is surveyed for plutonium. When plutonium is detected, normal earth moving equipment and methods are used to dig up the soil and haul it to the cleanup plant. The plant uses radiation detection systems and a variety of mining equipment such as conveyors, crushers, wet and dry screens, magnetic and centrifugal separators, gravimetric filters (mineral jig), thickener, scrubber, and so forth. Soil is conveyed in defined geometry beneath radiation detectors which continuously sample the soil for plutonium. Microprocessor-controlled gates automatically sort the soil to clean or contaminated paths depending on the radiation measurements.

22. Soil in the contaminated path is mined to concentrate plutonium and leave tailings clean of plutonium. A conveyor counting system is used to ensure tailings are clean, and a separate counting system measures plutonium in the concentrate for transport and waste disposal purposes. All clean soil is released from radiological control for beneficial use at JA. Expectations are that the upgraded JA soil cleanup plant will allow removing radiological restrictions from over 90 percent of processed soil and require waste disposal for less than 10 percent.

23. Survey to start plutonium soil cleanup at JA is by the in situ method using an elevated detector as with the Enewetak cleanup. However, survey is on a 15-m grid and the circular detector field of view circumscribes the grid cell. The in situ survey presumes plutonium is present as a uniform plane source over the detector field of view. For such a source, the survey method sensitivity is about a factor of two lower than the SSL.

24. Soil removal following survey is on a grid cell (0.025 ha) basis. In general, soil is dug up if the in situ measurement is greater than the minimum detectable activity regardless of the inferred plutonium concentration. This conservative approach (cleanup on any positive indication of plutonium) is taken because of difficulties in quantifying environmental plutonium (the assumed contamination distribution may not approximate the actual distribution) and soil movement is relatively inexpensive when disposal is not required or when soil is moved through the mining plant to reduce waste volume.

25. Soil moved to the cleanup plant is crushed to free up plutonium entrained in consolidated soil and enhance detection of the 60-kiloelectronVolt (keV) gamma rays associated with the JA plutonium. The crushed soil is conveyed in flat layers 0.02-m thick by 1-m wide (the conveyor width) at 0.15 m/sec. An array of gamma scintillation detectors covering an area 0.2 m by 1 m is

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positioned about 0.01 m over the soil. Detector thickness is optimum for sensing 60-keV gamma rays, and the soil thickness maximizes radiation count rates for the given detector area and soil flow rate.

26. The goal for the JA soil cleanup plant is to clean soil to the SSL. The SSL expressed as a surface activity ($0.2 \mu\text{Ci}/\text{m}^2$) is only suitable for fresh plutonium deposits and other examples of plane sources of contamination. The SSL must be converted to a specific activity for evaluating volume sources of contamination. The SSL is equivalent to $20 \text{ pCi}/\text{cm}^3$ ($740 \text{ kBq}/\text{m}^3$) based on EPA concern for soil in the top 1 cm of ground. It is $13.5 \text{ pCi}/\text{g}$ ($500 \text{ Bq}/\text{kg}$) after factoring out the $1.5 \text{ g}/\text{cm}^3$ density used by EPA in deriving the SSL.

27. The cleanup plant specifications require that clean soil have no more than 500 Becquerels long-lived transuranium element alpha activity (plutonium and americium) per kilogram of soil (Bq/kg), based on samples no more than 0.1 m^3 . The plant in situ plutonium measuring system has adequate sensitivity at this level for the type of plutonium at JA and the soil thickness and flow rate used.

28. The plant plutonium measurements take into account soil density, composition, and moisture content. JA soil is calcium carbonate whose theoretical dry density is $2.9 \text{ g}/\text{cm}^3$ or tons/m^3 . The in situ wet soil density ranges between 1.3 and $1.7 \text{ g}/\text{cm}^3$ and averages about $1.6 \text{ g}/\text{cm}^3$. After crushing in the cleanup plant, the density ranges between 1.1 and $1.3 \text{ g}/\text{cm}^3$. Concentrate density averages $1.9 \text{ g}/\text{cm}^3$.

29. The JA clean soil guide is $500 \text{ Bq}/\text{kg}$ of all soil sampled without regard to particle size. This guide is consistent with EPA guidance even though the SSL suggests samples be screened to 2 mm. The basis for 2-mm particles is the "enrichment factor," a unique EPA term developed to account for nonuniform resuspension of particles of various size and activity. EPA derived the enrichment factor from a study of samples which had been screened to 2 mm, so it suggested samples for comparing with the SSL be screened to 2 mm "in order to achieve a degree of uniformity in application." (The study did not evaluate the $>2 \text{ mm}$ fraction, and plutonium is present in $>2 \text{ mm}$ soil at JA.) EPA presumed that sites would be characterized for plutonium by small, grab samples; it did not anticipate the development and acceptance of in situ sampling as a superior method which does not require sizing for uniformity in application.

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30. JA soil sizing studies have been performed even though the results do not affect plutonium measurements. The <2 mm portion averages about 58 percent by weight for the top 0.03 m of ground and 34 percent for the top 0.3 m. The percentage of particles <75 μm tends to be less in open areas and greater where vegetation is present. The cleanup plant crushes soil to 4.8-mm, and the <2-mm fraction in crushed feed soil is 64 percent by weight.

31. The JA soil particle size distribution varies at different stages of the cleanup process since coral erodes from physical action and some stages function based on particle sizes. For example, concentrate from mineral jigs is particles predominantly in the 75-850 μm range, and process water settling pond sludge is particles in the 2-150 μm range. (A 75- μm plutonium oxide particle has about 5-kBq alpha activity.) The cleanup plant upgrade effort is evaluating initial removal of <150 μm particles (5.4 percent) and crushing remaining soil to <12 mm.

32. To provide assurance that clean soil from the plant meets the 500 Bq/kg guide, design specifications also require that no 0.01 m³ sample has a hot particle more than 5 kBq. (If ten 0.01 m³ samples were at this limit, the average specific activity would be under 400 Bq/kg.) Further, the plant as built tests every 0.07 m³ increment of soil rather than 0.1 m³ against the 500 Bq/kg limit, and every 0.007 m³ rather than 0.01 m³ against the 5 kBq limit. The detection system is also calibrated presuming hot particles are at the bottom of conveyed soil and thus shielded by the soil. This conservative assumption with respect to quality of clean soil means a particle with only 0.5 kBq alpha activity on the soil surface would cause soil to reject from the clean path.

33. The definition of plutonium clean soil at JA and the approach to soil cleanup provide high assurance that any doses to JA residents from "clean soil" will be trivial, the environment will be substantially improved by cleanup, and the cost to society for these pluses will be minimized. Best available technology is being used to clean JA soil to levels which are as low as is reasonably achievable. Although the cleanup method at JA yields these benefits, the method may or may not be suitable for plutonium soil cleanup at any other site.

34. JA cleanup has been discussed with EPA representatives over the past decade and presented at technical symposia and workshops where EPA personnel were present. (See for example, reference 1.) The EPA representatives have been supportive of our endeavors and have not voiced objection, although discussions may not have been as specific as described herein. If DNA chooses to request a

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written endorsement from EPA, then Enclosure 1 indicates the request might be directed to the EPA Office of Radiation Programs. In any event, a prompt resolution of policies and concurrences is critical for the JA cleanup.

FOR THE COMMANDER:

EDWARD T. BRAMLITT
JA Cleanup Technical Manager

1 Encl
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APPENDIX B

Equipment and Analysis Methods

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Equipment and Analysis Methods

1) Bicron G5 NaI(Tl) Probes (FIDLER) with Ludlum 2221 scaler/ratemeters

The ratemeters were configured so that only pulses corresponding to an energy band from approximately 10 keV up to 120 keV were counted. Four separate systems were used; the calibrations were performed such that the detection efficiency for each detector was maximized for ^{241}Am . The efficiency of each detector was within 10% of 0.30 cpm per dpm for ^{241}Am at contact with the detector window. Based on this value, a detection efficiency of 0.28 cpm/Bq/kg was calculated for ^{241}Am uniformly distributed within 1 cm of coral. It should be noted that this efficiency value was used only to estimate in situ detection capabilities for the detectors. It was never used to determine in situ nuclide concentrations.

Notes:

- 1) For the FIDLER as configured under ideal conditions, the minimum detectable activity (MDA) of uniform contamination in the top 1 cm of coral for static 1 min counts was estimated to be about 70 Bq/kg ^{241}Am (1.8 pCi/g). Assuming a total TRU alpha to ^{241}Am ratio of 6.5, this equates to less than 500 Bq/kg (13.5 pCi/g) TRU alpha. This value represents a 90% detection capability and assumes a detection efficiency of 0.28 cpm/Bq/kg for ^{241}Am distributed within 1 cm of coral. Noting that these calculations assume that the background response of the detector remains constant is important. This requires that all variations in detector response be due to the sum of (1) statistical fluctuations in the background response, and (2) variations in the concentration of the target nuclide in the top 1 cm.
- 2) A 3.05 m (10 ft) by 3.05 m (10 ft) grid gives a probability of approximately 94% of hitting a circular area of 10 m² (Davidson 1994).

2) Sample Analysis

All coral samples were dried at 100°C for 24 h and analyzed by gamma spectrometry using high purity Ge detectors.

Coral samples were analyzed using a petri dish geometry. Samples were placed directly onto the end caps of four hyperpure Ge detectors calibrated using a reference material provided by the Technical Measurements Center located at the DOE Grand Junction, Colorado, Projects Office. This material is known as the "mixed nuclide set" or NRM-6 and contains the nuclides ^{238}U , ^{226}Ra , ^{210}Pb , and ^{232}Th . The petri dish used for energy and absolute efficiency calibration contains 60 g of NRM-6. It is important to choose a calibration material whose density falls within the range of the samples to be analyzed. (Coral samples received from JA ranged in mass from about 55 to about 85 g each.) This is important at gamma energies below about 0.5 MeV and becomes particularly important

when analyzing samples for gamma radiation emitters with energies below 0.1 MeV because of self-absorption by the sample matrix itself of low-energy gamma radiation. The efficiency of a Ge

detector at energies below 0.1 MeV is low (except for planar and other thin-entrance-window detectors). To optimize geometry, a thin-layer sample was used (1 cm or less), and the sample container was placed directly onto the end cap, except in cases where activities are high enough to cause dead-time counting losses beyond about 5%.

It is important that the calibration material contain radionuclides that cover the gamma energy range of radionuclides for which the sample is to be analyzed. The NRM-6 material contains ^{210}Pb and ^{238}U , which emit gamma radiation at 46.5 and 63.3 keV respectively (daughter of ^{238}U , not ^{238}U itself). This covers the range necessary to analyze for ^{241}Am , which emits gamma radiation at 59.5 keV. One of the Ge detectors used is a planar detector with a thin entrance window of beryllium. This window allows very low energy gamma radiation (and X-rays) to penetrate the end cap, which increases the photopeak efficiency at these low energies. Photopeak efficiencies at 63 keV for all Ge detectors used range from about 2 to almost 8% for petri dish geometry. Since two of the Ge detectors are much less efficient at low energies, they are typically used only for overnight counts for petri dish samples (> 8 h). However, in the interest of throughput, these detectors are utilized for analysis (at longer count times for similar counting statistics). In order to achieve a MDA of less than 1 pCi/g for ^{241}Am , coral samples are counted for at least 4 h each up to a maximum of 15 h (overnight runs only).

Other radionuclides that are routinely included in analysis results are ^{238}U , ^{235}U , ^{226}Ra , and ^{210}Pb . If other gamma emitters are present in the sample, results can be included if desired.

Since no discrete particles could be detected in any of the samples, a uniformly distributed geometry was assumed. The analyses were done for ^{241}Am ; the resulting concentration values were multiplied by a factor of 6.5 pCi total TRU alpha per pCi of ^{241}Am .

APPENDIX C

Evaluation of Homogeneity of Transuranic Nuclide Distribution within the Coral Matrix

APPENDIX C

**Evaluation of Homogeneity of Transuranic Nuclide
Distribution within the Coral Matrix**

Two samples taken from within the Plutonium Cleanup Area on JA were analyzed to determine the homogeneity of TRU contamination within the coral. The first sample was collected from an area that showed slightly elevated readings using a portable FIDLER detection system. The second sample was collected at a location where FIDLER readings were consistent with the expected background response. The purpose of this document is to publish data that may be useful to others during future work.

Each sample was dried for 24 h at 110°C and analyzed on a high purity Ge detection system assuming a uniform contaminant distribution in a 1.5-cm deep by ~50-cm²-area petri dish. Each sample was then broken into nine small aliquots, and each was analyzed on a high purity Ge system in 1-cm-deep petri dishes with areal size of 9 cm².

Sample JAT001VS072

The ²⁴¹Am analysis results for the entire sample was 3.2±0.17 pCi/g. The analysis results for the aliquots from this sample were as follows:

Aliquot #	Mass	²⁴¹ Am (pCi/g)	±95% Count Error
1	7.9	2.5	0.14
2	9.7	0.97	0.21
3	8.5	1.1	0.34
4	6.4	14	0.29
5	9.5	2.8	0.62
6	5.3	3.7	0.78
7	6.4	1.9	0.46
8	10.9	3	0.49
9	8.0	9.3	1.2

Based on the aliquot results:

- The ²⁴¹Am is not uniformly distributed within the sample.
- A weighted-average ²⁴¹Am concentration for the all aliquots from sample VS072 would be 4.0±0.2 pCi/g. Therefore, the analysis results acquired by analyzing the entire sample resulted in a value approximately 0.8 pCi/g less than that determined by analyzing the sample in small volumes at a time.

Fig. C.1. Frequency histogram of ^{241}Am concentrations for aliquots from sample number JAT001VS072.

Sample JAT001VS091

The ^{241}Am analysis results for the entire sample was 0.51 ± 0.09 pCi/g. The analysis results for the aliquots from this sample were as follows:

Aliquot #	Mass	^{241}Am (pCi/g)	$\pm 95\%$ Count Error
1	4.3	0.67	0.15
2	4.8	0.51	0.27
3	5.1	0.38	0.1
4	3.3	0.72	0.37
5	4.5	0.14	0.1
6	3.1	1.1	0.36
7	4.5	0.42	0.28
8	3.9	0.17	0.1
9	2.8	0.46	0.34

Based on the aliquot results:

- The ^{241}Am is not uniformly distributed within the sample.

- A weighted-average ^{241}Am concentration for all aliquots from sample VS091 would be 0.5 ± 0.08 pCi/g. Therefore, the analysis results acquired by analyzing the entire sample resulted in a value approximately 0.01 pCi/g less than that determined by analyzing the sample in small volumes at a time.

Fig. C.2. Frequency histogram of ^{241}Am concentrations for aliquots from sample number JAT001VS091.

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