

**ROCKY FLATS  
DOSE RECONSTRUCTION PROJECT  
Phase II  
Toxicity Assessment And Risk Characterization**

**Task 2: The Rocky Flats Plant  
903 Area Characterization**

**Final Report**

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*"Setting the standard in environmental health"*

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## THE ROCKY FLATS PLANT 903 AREA CHARACTERIZATION

### INTRODUCTION

A new requirement in the late 1950's for increasingly precise machining of plutonium (Pu)<sup>1</sup> weapons material at the Rocky Flats Plant (RFP) led to the creation of large quantities of plutonium-contaminated oils and solvents at a time when no disposal options were available. The waste was eventually stored outdoors in ordinary steel barrels in a large open area east of the main plant. Internal corrosion of the barrels caused leakage of contaminated oil to the underlying soil, and some of this plutonium-contaminated soil was dispersed into the offsite environment by wind, rain runoff and disturbance by machinery. A number of studies have been conducted to investigate the accidental introduction of plutonium into the environment via this exposure mode. The purpose of this report is to collect information from such studies, and from recent interviews and other research performed by *Radiological Assessments Corporation*, to provide the background information necessary to estimate plutonium releases from the 903 drum storage area. These release estimates will then be used to estimate dose to members of the population living in near Rocky Flats during the time of the releases.

Ideally, historical monitoring of air around the RFP would help assess the amount of Rocky Flats-related plutonium in publicly accessible areas. Such measurements were made during the period of interest here (the late 1960's), but, as [discussed in this report](#), they were not adequately sensitive to detect the levels of airborne plutonium expected from past RFP releases. One Public Health Service air monitoring station in Denver was able to accurately measure low levels of plutonium. As discussed in [Rope et al.](#) (1999), the vast majority of plutonium in air at that monitoring station is believed to have come from fallout from the testing of nuclear weapons. Therefore, this report focuses on collecting and interpreting the data needed to estimate plutonium releases from the 903 area. Additional research, also part of this dose reconstruction, will use available models and meteorological data to estimate air concentrations for the time during which the high releases occurred. These "reconstructed" values will then be used to estimate plutonium dose and risk to members of the public living in the Denver area during the period of interest.

The Phase I Rocky Flats Plant Dose Reconstruction Study<sup>2</sup> pointed to the dominance of the inhalation route in the modeling of plutonium dose to individuals living near the facility. Inhalation of materials released from the plant, whether from stacks, vents, fires or wind-driven suspension of soil particles, was found to be responsible for most of the radiation dose estimated to individuals living offsite. Research performed by ChemRisk staff during Phase I is summarized in a series of reports referenced herein (ChemRisk Tasks 3, 4, 5, 6 and 8), and was analyzed by *Radiological Assessments Corporation* early in Phase II of the study. *Radiological Assessments Corporation* was asked to review and, if feasible, enhance the approach used by ChemRisk to estimate releases from the 903 area and elsewhere.

[ChemRisk](#) (1994a) utilized the Fugitive Dust Model "...to simulate atmospheric processes leading to the soil contamination pattern observed in late 1969 and the early 1970s."

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<sup>1</sup> Plutonium-239 is the major isotope of concern at the Rocky Flats Plant. It will also be identified as plutonium or Pu-239 in this report.

<sup>2</sup> Sponsored by the Colorado Department of Public Health and Environment (CDPHE).

ChemRisk averaged releases over a five-year period (1964 through 1969), recognizing that, "Actual releases from the pad were likely to have varied from day to day...". This approach was utilized in part because, "...determining releases and exposures on a finer time-scale is limited by the absence of detailed information regarding the timing of site disturbances and site meteorology." ([ChemRisk 1993](#)). *RAC* has focused on discovering and applying additional meteorological data to this problem, allowing detailed estimation of 903 area wind-driven releases. The use of discovered meteorological data with a resolution as high as a few minutes allows the application of more detailed atmospheric transport and dispersion models during the calculation of offsite dose and risk.

The complex topography and meteorology in the vicinity of the plant suggested careful examination of available wind-driven suspension and atmospheric dispersion modeling methods, most of which were not designed to deal with the complexities in a high-wind, heavily contoured environment such as that of Rocky Flats. This current report presents the results of a *RAC* search for historical data and current models best suited to predict releases from the 903 area during the late 1960's. A separate Phase II research effort has focused on identifying and evaluating the models best suited to estimating the atmospheric dispersion and transport of RFP releases to populations living offsite. *RAC* technical memos will develop the release estimates based on these data and models, and an additional report will estimate dispersion, transport, dose and risk from the 903 area releases.

While estimates of 903 area releases are currently available (see [ChemRisk 1994a](#) and [ChemRisk 1994b](#)), they are subject to considerable and often undefined uncertainties. The primary goal of the current *RAC* study is to develop alternative methods and data sets to estimate 903 area plutonium releases. These values will be compared to previous estimates, and used to reevaluate historical offsite doses.

Wind-driven suspension from the former barrel storage area has been a major contributor to environmental releases from the Rocky Flats Plant, and comprehensive reconstruction of 903 area releases is an important part of the overall estimation of dose and health risk associated with the Rocky Flats Plant. One approach to developing a new estimate of 903 area releases involves modeling the wind-driven suspension of plutonium-contaminated soil dusts, based on a history of contamination and disturbance events at the site, and an understanding of the wind history during the period of significant releases. The modeling of wind-driven soil suspension is quite difficult, and remains the subject of an ongoing study by *Radiological Assessments Corporation*.

This report discusses the problems involved in estimating 903 area releases, and focuses on the development of data and methods allowing more accurate release estimates.

## **RECONSTRUCTING 903 AREA RELEASES**

### **Approaches to the problem**

The reconstruction of plutonium releases from the 903 area might be approached from several different perspectives. For example, records showing plutonium concentrations in soils in the 903 area could be used to drive existing or newly developed models of wind-driven soil suspension. Alternatively, air sampler measurements of airborne radionuclide concentrations could provide independent appraisals of offsite human exposure, via transport modeling. A third approach might analyze offsite soil measurements to estimate the plutonium releases leading to such data, then utilize the results to calculate historical

airborne plutonium exposures to human populations. While considering the bases available to develop such release and risk estimates, Phase II researchers have examined previous research both onsite and off, evaluated RFP historical records and photographs, and interviewed knowledgeable workers and members of the public.

This report considers the data available to support the above options, and concludes that a two-pronged approach to the estimation of the human impact of historical 903 area releases is optimal. This hybrid method will use a wind-speed-sensitive model and soil concentration data to simulate the wind-driven suspension of contaminated 903 area soils during high-release periods in 1968 and 1969. (Litaor [1995] notes that, “Airborne Pu, resulting from wind erosion in the vicinity of the former storage area, has been minimal since 1970”). These calculated concentrations will be compared to independent estimates derived by back-calculating the quantities of soil that must have been suspended to produce air sampler measurements noted during the same period. The two sets of release estimates will be reconciled, and the estimated Pu releases will be used to develop offsite air concentration, dose and risk estimates for the key release periods.

### **Chronology of 903 Area Events**

Because an understanding of the time history of the facility is important to an interpretation of the available information, we begin with a brief, chronological history of Rocky Flats Plant operations leading to the 903 area releases. Details and references are provided later in the narrative.

- **1954** - ~10 barrels of oily liquid wastes from Rocky Flats Plant were sent to the Arco, Idaho waste storage facility.
- **4/54** - further disposal at Arco was refused; the Mound area (near 903 area, but separate) was created onsite at RFP for drum burial. 900 drums containing uranium-contaminated wastes were in place in the Mound area by early 1954.
- **8/55** - the first potentially plutonium-contaminated drums were placed in the Mound area.
- **8/56** - uranium-contaminated oil from 10 drums was burned in RFP Pit 3.
- **4/57** - uranium-contaminated oil from 169 drums was burned in a pit next to the Mound. Additional, intermittent burning took place from 6/61 until 5/65. Perhaps 1093 drums of uranium-contaminated oil were burned during the entire period.
- **1957** - Building 776 began Pu operations; quantities of Pu-contaminated oil and cleaning solvents increased significantly. Most liquids were straight-chain hydrocarbon mineral oils, some hydraulic oils, vacuum pump oil, carbon tetrachloride, trichloroethylene, perchloroethylene, silicone oils, acetone and still bottoms. Centrifuging was initially used to separate the bulk of plutonium from waste oil. Barrel release limits were  $10^{-2}$  to  $10^{-3}$  g plutonium per liter. Fifty-five gallon barrels each contained some 50 gallons of centrifuged oil. Thus, a first estimate of the quantity of Pu contained in each barrel ranges from 0.2 to 2 grams.
- **1958** - first reports of stored drum corrosion.

- **9/58** -1405 drums, including 89 containing perhaps 300 grams of Pu total, were in storage in the Mound area as of this date.
- **7/59** - ethanolamine was added to drums to neutralize acids and reduce internal corrosion.
- **7/59** - certain drums from the Mound were moved across the road to the 903 area; the beginning of 903 area drum accumulation. (The Mound was excavated in 1970 - no detectable plutonium was found; 1400-1600 barrels were removed.)
- **1962** - early waste solidification research budget request submitted; justification was that some 50-60% of the 903 area drums were corroded, and that the contents were spilling onto the ground.
- **6/62** - date of [photograph](#) of a drum turned on its side, showing weeds penetrating the bottom corroded area. Date of another [photo](#) of drum possibly distorted from corrosion gases. Mention of odor of carbon tetrachloride in the area.
- **1964** - per E. Putzier - “first indication” that drums in 903 area were leaking significantly (note: other records (above) indicate that corrosion was noticed as early as 1958, and leakage noted by 1962). Health Physics Department records showed “soil contamination increases” in the 903 area. A rabbit fence was constructed to prevent the spread of contamination via wildlife.
- **7/64** - “first evidence of large-scale deterioration” of drums; drums were packed tightly in the 903 area, and inspection of interior drums was impossible.
- **“Mid-1960’s”** - new filtering devices were added to the plutonium machining lines, capturing smaller Pu particles and “greatly reducing” contamination levels in waste oil.
- **4/65** - date of [photo](#) showing near-maximum number of drums in the 903 area.
- **1967** - “highly plutonium contaminated” rabbits were reported.
- **1/67** - 903 area clearance operations began. The work lasted until mid-1968, hampered by bad weather and other problems. Report that many barrels were rusted and had little liquid left; filtering of oils in place failed. Sludges were left in the drained drums and shipped.
- **4/67** - date of [photo](#) showing 903 area still at near-maximum barrel loading.
- **4/68** - [photo](#) showing most barrels removed.
- **6/68** - last drums were transferred out of 903 area. Some 5237 drums were removed (reports vary), one report notes total of 3572 drums of plutonium-contaminated oil removed. “Difference (*in total number of drums*) attributed to leakage of oil into the soil and some of the drums were not full when first transferred to the field...” Some 265,430 gallons of oil were transferred to Building 774 for processing; 196,460 gallons were plutonium-contaminated.
- **6/68** - Health Physics Department report that “some slight contamination” was spread from 903 area by wind and rain. 903 oil transfers were confirmed completed as of June. Packaging for shipment of the empty (sludge-containing) drums and pallets “should be completed by June 17.”

- **6/11/68** - leaking solvent drum being transported from 903 to 774 area caused “significant contamination of roadway.” A twenty-five-foot grid was staked out over the 903 contaminated area (a 550 x 475 foot rectangle), soil radioactivity was checked at the grid intersections. Levels of contamination from less than 100 cpm to over 1,000,000 cpm were found.
- **7/68** - date of memo from Mr. Owen noting that plutonium contamination within the rabbit fence was “extremely hazardous;” and that wind and water had carried contamination outside the area. A Health Physics Department survey of the area was completed and forwarded to Division Services, Manufacturing and Facilities.
- **10/68** - weeds and vegetation were burned off the 903 area. Dow requests approval to pave the area to contain contamination.
- **11/68** - a second request to pave area was submitted to management, due to spread of contamination by wind and rain. Use of a road grader to scrape and cover some contamination into a relatively small area was allowed.
- **12/68** Health Physics Department report - “...high winds have blown over as many as 150 of the 5000 drums E of the nitrate ponds.” Details concerning the contents or more exact location/identity of these barrels are unknown.
- **1/69** - Health Physics Department report, “The high winds of January 31 blew all the roofing material off Building 889.” Further spread of contamination from the 903 area was shown by area surveys and perimeter air samples east of the area. Notation that, “..29 leaking drums have been detected in the drum storage area east of the nitrate ponds. These leakers have resulted in high level contamination of about 200 square feet of soil.” The soil was removed and shipped to Idaho.
- **1969** - “Late March to early April”. Leveling of the 903 area by grading. The mechanically faulty grader ran at high speed in third gear; dust was visible as far as 1/2 mile past the perimeter security fence, the cloud was 10-15 feet high. Grading continued for two to three days, five to six hours per day. The soil was dry, and not snow-covered. There were light breezes. Putzier noted that the road grader was used outside the fenced area to move slightly contaminated soil to the more contaminated, fenced area.
- **4/69** - “...large rocks and stakes have been removed from the 903 drum storage area preparatory to the filling and leveling scheduled to start soon.” An interview notes that the rock cleanup took a “couple of days.” Oily rocks were visible, alpha counts were as high as 800,000 cpm.
- **5/69** - a total of 33 drums of contaminated rocks was removed from 903 area. The main contamination concern was the “south edge” of the area. “.filling, leveling and capping of the 903 area have not yet started.” Cleanup of the road grader was completed.
- **5/24/69** - date of [photo](#) showing 903 area cleared and ready for placement of cover.
- **7/69** - the first coat of fill was applied to the 903 area on July 23. Six inches of road base were applied.

- **9/69** - "...base fill has been applied to the 903 area and the area has been rolled." (per Health Physics Department report). The asphalt prime coat was reported to be in place.
- **11/69** - the asphalt work was completed; sampling wells at 4 corners of the asphalt pad were finished on Nov. 11. The asphalt-covered area was 380 by 400 feet.
- **2/70** - the remaining 903 area was covered with 4 inches of road base.
- **5/70** - [photo](#) shows pad and gray, road base area.
- **5/25/71** - [photo](#) showing three gray rectangles, evidence of dust suppressant tests (using a material called Coherex).

A more detailed discussion of the above events, and other occurrences contributing to 903 area releases, follows.

## **EARLY PRODUCTION AND HANDLING OF WASTE**

Buildings 44 and 81 were the first production buildings operating at the Rocky Flats Plant. Both were involved in the machining of depleted (very slightly radioactive) uranium, and both produced oils or oil/water wastes that were defined as radioactive. Even in early 1954, it was difficult to find a disposal site for these radioactively contaminated oily liquids, although approximately 10 barrels were shipped for burial in Idaho. Due to potential leakage problems, Arco later refused to accept such organic liquids for burial ([Putzier 1970](#)).

### **Creation of plutonium-contaminated wastes**

During the late 1950's, changes in weapons designs required the use of metal lathes which produced plutonium-contaminated cutting oil. Increasing quantities of carbon tetrachloride were required to clean the plutonium parts thus produced ([Barrick 1994](#)). The quantities of contaminated oil and cleaner became significant after Building 776 was opened in 1957. Most of the contaminated liquid was straight-chain hydrocarbon mineral oil (Shell Vitrea), but hydraulic oils, vacuum pump oil, trichloroethylene, perchloroethylene, silicone oils, acetone, still bottoms<sup>3</sup> and other liquids were also present ([Seed et al. 1970](#)). Records were not kept of the specific contents of each barrel. Centrifuging was initially used to separate the bulk of the plutonium turnings from the waste oil, with release limits to barrel storage set at between 0.01 and 0.001 grams plutonium per liter ([Seed et al. 1970](#)). About 50 gallons of centrifuged oil were placed in each 55-gallon drum. These figures lead to a first estimate of between 0.2 and 2 grams Pu waste per drum.

No long-term waste disposal methods were available, and experiments onsite and elsewhere produced no obvious alternatives to storage in barrels.

### **Burning uranium-contaminated oils**

[Putzier](#) (1970) states that uranium-contaminated oil from 10 drums was burned in a pit onsite in August of 1956. In March and April of 1957, oil from another 169 drums was burned. The oil was burned at night, and a portable sampler was reportedly used by health physics workers to monitor air concentrations. Logs of air concentration data were said to be

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<sup>3</sup> The term "still bottoms" refers to residual solids/liquids from a distillation process.

kept, although these have not been found. No further burning occurred until June 1961, “after which time oils were burned frequently” (Putzier 1970), through May of 1965. Some 1093 drums of U-contaminated oil were disposed of by burning (Putzier 1970); an unknown number of these drums were 30-gallon volume, the remainder were 55-gallon.

### **Creation of early soil-covered RFP storage -- the Mound**

It is probable that the early loss of access to the Arco burial site led to creation of the Mound onsite at Rocky Flats. The Mound contained solid and drummed-liquid uranium wastes buried under several feet of soil (Putzier 1970). Biles reports some 900 drums in place by early 1954 (Biles 1970). Records from the Waste Disposal Coordination Group indicate that the first drums containing Pu-contaminated oil were placed in the Mound area in August of 1955, although these may have been hydraulic oils from machinery in plutonium processing areas, and not significantly contaminated. A total of 1405, 55-gallon drums accumulated in the Mound area and were buried through September 1958 (Biles 1970). Biles also states that twelve, 30-gallon drums containing Pu-contaminated waste were placed in the Mound; Putzier (1970) states that 89 plutonium-contaminated oil drums from Building 776, and 46 from Building 771, were in the Mound as of September 1958. While additional drums were placed at the Mound site after this time, none were buried, and in July 1959 they were moved across the road to begin the accumulation in the 903 area (Putzier 1970).

### **Excavation of the Mound**

The Mound was excavated in 1970, and oil-containing barrels were processed in Building 774. According to the records available, no detectable plutonium contamination was found in these barrels (Biles 1970). Of the 1400-1600 barrels placed in the Mound, up to 1500 contained organics, with 135 of those containing oil from the plutonium facility (Putzier 1970). Eugene Johnson reported in 1958 that many barrels were corroding (Bronesky 1977).

### **DEVELOPMENT OF THE 903 BARREL STORAGE AREA**

As noted, several interim waste-handling methods were used in the early years, but waste barrels began to accumulate “in the SW corner” of the 903 area in mid-1959 (Biles 1970, Putzier 1970). (Note that there are suggestions that drum storage at the 903 area began in the mid-1950’s; photographic evidence from mid-1955 is not conclusive in this regard.) [Photographs on page 20](#) (the second an enlargement) clearly show two parallel sets of barrel rows in the 903 area as of July 9, 1959. (Note that these and other photographs discussed here are presented as a group beginning on page 20.) Most of the drums transferred to the 903 field were 55-gallon capacity; some were 30-gallon drums (Seed et al. 1970). Not all the drums were full, and perhaps 75% were plutonium-contaminated (Seed et al. 1970). In July of 1959, ethanalamine was first added to the barrel oils to reduce internal corrosion (Seed et al. 1970).

A 1962 waste solidification research budget request noted that 50-60% of these drums were corroded, and that the contents were spilling onto the ground (Bronesky 1977). An aerial [photo](#) taken August 11, 1962 shows a large number of waste oil barrels tightly packed in the 903 area ([page 21](#)). The next three photos on [page 21](#) show the area of stored barrels increasing from May of 1963 through March, 1964 to April, 1965.

[Page 22](#) exhibits a June 1962 photo, shows a drum, tipped on its side for viewing, with weeds penetrating a heavily corroded area on its bottom. Delays in developing solidification technology also resulted from the production emphasis stressed by upper management: work on waste product treatment was viewed as nonproductive.

Leakage from the drums was noted as early as July of 1959, although [Putzier](#) (1970) states that “1964 was the first indication that drums were leaking in the field.” Funding to construct a building to store the barrels was requested early on, but not approved in the site budget. Efforts to develop solidification alternatives for the contaminated oil were also hampered by budget problems, as well as technical difficulties including corrosion of stainless steel components ([Dow](#) 1973).

Ken Freiburg, a Health Physics Department technician, stated that the closely spaced, stored barrels were corroding from the inside out, and that they were bulging and popping in the sunlight. [Page 22](#) displays what may be such a distorted drum, in a June 1962 photo. Freiburg noted the odor of carbon tetrachloride in the area ([Bronesky](#) 1977). Even though leakage and contamination movement were occurring, Freiburg noted that the (then-current) standards for radioactivity in air “were not being violated,” so it was difficult for health physics staff to convince Rocky Flats Plant management that a significant problem existed. Atomic Energy Commission (AEC) staff were aware of the contamination, but it does not appear that any serious effort to deal with the problem was initiated at the Agency level.

It proved difficult to deal with leaking drums except on a case by case basis. Ed Putzier reported that once, when a routine site survey showed contamination from leaky drums, noncontaminated soil was brought in to cover that area. One *RAC* interviewee stated that oil from a leaky drum was once used to suppress dust near the 903 site.

Concerning the 903 area in general, [Litaor](#) (1995) noted, “Leakage from these drums contaminated surface soils and plants. Plutonium particles entrapped in the fine fraction of the surface soils were subsequently lifted by winds and deposited on soils in an east and southeast-trending plume.”

### **Evidence concerning barrel storage conditions**

Drum corrosion and leakage proceeded rapidly during the early 1960’s. By 1964, the Health Physics Department’s Site Survey Group was regularly (during weekly surveys) reporting soil contamination increases in the 903 area. In July of 1964, evidence of large-scale deterioration of drums was reported. Many of the drums were packed so tightly that inspection of barrels located toward the interior of the group was not feasible. A retired health physics manager interviewed by *RAC* stated that “they tried to keep an eye out for leakers,” but that they could not see into the tightly packed pile. A photo taken in April of 1965 ([page 23](#)) views the problem from ground level. The following shot provides a [perspective of the Plant](#), taken from the west, on January 6, 1966. The 903 area is just visible above the twin-stack building toward the lower right side of the photo. Great Western Reservoir is visible in the distance, near the photo’s top right corner.

Wildlife contributed to the spread of contamination. One of the health physics monitors, Joe Ferrerese, reported in the early 1960’s the spread of contamination by rabbits. A rabbit fence was constructed during 1964. Measurements of killed rabbits showed “grossly” contaminated fur, confirmed recently during a *RAC* interview with a union representative who worked at the 903 site during the period. Dale Bokowski noted that he and another Rocky Flats worker had live-trapped two or three rabbits from around the barrel storage area

in 1967. They analyzed lungs, long bones and livers, with results that were “screaming” with Pu-239. He believes that the confirming data may have been lost.

### **The influence of wind and rain**

Ferrerese recalled that winds occasionally caused the contaminated soil to become airborne; he halted sampling work in the area on occasion for this reason. He and another monitor noted contaminated dirt from the 903 area at the Rocky Flats site perimeter ([Bronesky 1977](#)). A worker involved in the eventual barrel removal noted that “one evening a dust devil came from the east” and caused measurable contamination on a guard car. [Litaor \(1995\)](#) noted that, “A detailed analysis of wind direction, frequency and average velocity for each direction for a period between 1953 and 1970 suggested that >75% of the winds exhibited a westerly component.” He states that, “The spatial plume of Pu-239+240<sup>4</sup> and Am-241 clearly followed this wind pattern.” Litaor concludes that, “This spatial distribution could only be explained by a wind dispersal mechanism.” Litaor further notes that, “The isopleth configuration (*of Pu and Am isotopes*) was consistent with the hypothesis that the dominant dispersal mechanism of Pu-239+240 was wind dispersion from west to east.” He also notes that, “The actinides (*Pu and Am*) activity in the soils decreased extremely (*rapidly*) in the north and south directions...” [Words in italics added.] Recent evidence ([Litaor 1996](#)) indicates that significant surface movement of soil plutonium may also have been observed as a result of recent high rainfall events. However, the focus of the Dose Reconstruction study is currently on atmospheric transport and potential inhalation dose.

### **Production of contaminated waste was reduced greatly**

In the mid-1960’s, new filters were added to the lathe equipment in Building 776, greatly reducing the contamination levels in the waste oil. Efforts to solidify the oil were also successful at about this time, and in early 1967 clearance operations began on the drums in the 903 area. Problems in procuring funding for the construction of a building to house the filters and pumps needed for this work delayed actual cleanup efforts for some time, however.

### **CLEANUP: ESTIMATING PLUTONIUM RELEASES TO SOIL**

Clearance operations in the 903 area began in January of 1967. The first photo on [page 24](#) presents a mid-April, 1966 view, and was taken prior to cleanup initiation. The second shot, from April 29, 1967, indicates removal of some barrels (in the center and lower right corner of the 903 storage area). The third photo on page 24 was taken April 10, 1968, and shows most drums removed from their previous locations. The overall clearance operation lasted until mid-1968 ([Biles 1970](#)), hampered by bad weather and difficulties in handling the badly corroded barrels and the viscous sludge they contained. The clearance process itself has been addressed in numerous reports, and in *RAC* and ChemRisk interview summaries<sup>5</sup>. One person who worked on the barrel clearance operation stated that “many” barrels were rusted and had little liquid left. Cleanup initially focused on the most recent drums from Building

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<sup>4</sup> Pu239 and Pu240 cannot be distinguished during routine analyses: they are often reported as Pu239+240 for this reason.

<sup>5</sup> Contact the Colorado Department of Public Health and Environment, Rocky Flats Health Studies Archives, for copies of the most recent *RAC* and ChemRisk interview summaries.

776, and delays occurred during attempts to re-filter the oil in these drums. The attempt to filter drum contents was soon stopped, as it was very slow. The revised method involved transfer of the liquids, leaving sludge in the barrels. The last drums (containing uranium) were transferred in June, 1968.

### Volume estimates

During processing, 5237 drums were removed from the 903 area (Biles 1970, Putzier 1970). Putzier notes that the barrel accumulation process, as shown in Table 1, accounts for only 90% of the barrels actually found. These records show only 4729 drums transferred to the 903 area over the years. Putzier also notes that some of the uranium-contaminated oils initially stored in the 903 area had been burned prior to the 903 area cleanup operation. If these barrels were included in the totals shown in Table 1, the discrepancy between recorded transfers and actual number of barrels recovered would be even larger.

**Table 1. 903 Area Drum Storage, According To Transfer Records**

<u>Source Building</u>	<u>Number of Drums</u>
444	405
881	795
883	165
771	119
77	3245
<b>Total</b>	<b>4729</b>

Seed et al. (1970) reported that the 903-area barrels contained uranium, plutonium and trash or tars. Putzier (1970) reported a total of 3572 drums of plutonium-contaminated oil and 1254 drums of uranium-contaminated oil “stored in the oil drum storage field”. Oil from the 903 area drums was transferred into new 55 gallon drums during cleanup, and volumes were recorded. Putzier states that 4,826 drums containing the repackaged oil were transferred to the plutonium waste processing plant during the cleanup operation, with the “difference of 411 drums...attributed to leakage of oil into the soil and some of the drums were not full when first transferred to the field...” Note that Putzier is apparently comparing the number of new drums (4,826) transferred from the 903 area to the number of drums (5,237) he reports were originally delivered to the 903 area. The difference between these two counts is 411, and this difference is assumed to be due to the fact that a number of barrels were not full, either originally or due to leakage. Some 265,430 gallons of oil (4826 drums at 55 gallons per drum) were transferred to Building 774 for processing, 196,460 gallons (3572 drums at 55 gallons each) of which were plutonium-contaminated.

Note that the contents of 411 drums leaked to soil, at 55 gallons each, would be 22,605 gallons. However, Don Anderson recalled (Bronsky 1977) that the barrels exhibiting the most leakage were those with uranium-contaminated oils. This leads to difficulty in estimating the quantity of plutonium-contaminated oil leaked to soil based on the (22,605 gallon) total leakage (U- and Pu-contaminated liquids) inferred from Putzier’s estimates.

### Health Physics Department Reports

The Health Physics Department surveyed the ground contamination in the 903 area vicinity following barrel removal. A series of Health Physics Department monthly reports

note such surveys and other observations. Excerpts from these Health Physics Department reports are included in the discussion that follows.

Health Physics Department staff reported in their June 1968 monthly that "...some slight contamination spread from the contaminated oil drum storage area by the wind and rain is being experienced. The transfer of the contaminated oil from the area has been completed. The packaging for shipment of the empty drums and pallets should be completed by June 17, 1968. On May 20, a second shift was added to expedite the cleanup of this area." ([HPSR 6/68](#)).

On June 11, "...a leaking solvent drum being transported by forklift truck from the 903 area to the 774 area caused significant contamination to the roadway. No personnel or vehicle contamination resulted. The contaminated roadway was reopened to traffic the following day after a seal coat had been applied. A 25 foot grid has been staked out over the 903 contaminated area to facilitate contamination surveys. The area is approximately 550 feet by 475 feet and the levels of contamination vary from less than 1000 counts per minute to greater than 1,000,000 counts per minute." ([HPSR 7/68](#)).

J. Bruce Owen wrote a memo to J. Seastone in July 1968, noting that plutonium contamination within the rabbit fence around the 903 area was "extremely hazardous." The report noted that wind and water had carried contamination outside the area. Also in July, "A survey of the plutonium contamination on the surface of the soil in the 903 area was completed. The results of the survey<sup>6</sup> and the Health Physics Department recommendation for containment of the contamination have been forwarded to Division Services, Manufacturing and Facilities." ([HPSR 8/68](#)).

After processing to varying extents, all of the contaminated materials removed from the 903 area were shipped for burial to Arco, Idaho ([Putzier 1970](#)).

In October of 1968, "Weeds and vegetation were burned off the 903 contaminated oil drum storage area prior to applying an asphalt cap over the area. No contamination problems were encountered." ([HPSR 11/68](#)). Also in October, Dow Engineering requested initial approval to cover the area with asphalt, at a cost of \$185,000. This proposal was not acted upon, and in November, action was again requested, due to the spread of contamination by wind and rain. Dow was allowed to use a road grader to move some of the plutonium-contaminated soil into a smaller area ([HPSR 12/68](#)) and cover it with dirt, to reduce the spread of contamination.

The occurrence of strong winds is noted in the Health Physics Department record at Rocky Flats. The Health Physics Department reports note that in December of 1968, "...high winds have blown over as many as 150 of the 5000 drums E of the nitrate ponds." ([HPSR 1/69](#))<sup>7</sup>.

In early 1969, "The high winds of January 31 blew all the roofing material off Building 889. Also, further spread of contamination from the 903 area is evidenced by area surveys and perimeter air samples east of that area. Approximately 29 leaking drums have been detected in the drum storage area east of the nitrate ponds. These leakers have resulted in high level contamination of about 200 square feet of soil. The contaminated soil is being dug up and shipped as hot waste." ([HPSR 2/69](#)). (These latter drums were not in the 903 area, which had been partially remediated with all drums removed by this time.) Delays in

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<sup>6</sup> This survey report has not been discovered during the dose reconstruction research.

<sup>7</sup> Included to demonstrate the occurrence of high winds during this key period; details concerning the disturbed barrels are unavailable.

approvals for asphalt coverage of the 903 area were resolved by April of 1969, "...large rocks and stakes have been removed from the 903 drum storage area preparatory to the filling and leveling scheduled to start soon." ([HPSR 5/69](#)).

Mel DiLorenzo, interviewed by *RAC* in 1994, worked as a radiation protection technician during the 903 area cleanup, after barrel removal. He stated that a crew of laborers picked up the larger rocks in the barrel storage area, taking "a couple of days." Health Physics Department used a Ludlum proportional counter to monitor for alpha contamination. Oily rocks were visible; some exhibited contamination as high as "800,000 counts per minute." [Putzier](#) (1970) noted that during May of 1969, 33 drums of contaminated rocks were removed and "discarded as hot waste." He recalled that the main contamination was at the south edge of the area. He did not recall whether soil or smear samples were collected in this area.

### **Leveling of the 903 area**

After the rock was removed from the area, a road grader was employed for leveling. This machine could only be operated "in third gear." Mr. Mel DiLorenzo, interviewed by *RAC* in the summer of 1994, described dust rolling from under the grader's tires and being carried by the breeze to the southeast, visible as far as ½ mile past the perimeter security fence. The dust cloud may have been "10 to 15 feet high." The grading operation took 2 to 3 days, at 5 to 6 hours per day. He recalls only "slight" breezes during the time, 12 mph or less. Mr. DiLorenzo recalls that the soil was dry and not snow-covered.

The first photo on [page 25](#), taken in 1995, demonstrates wind suspension of dusts. The shot was taken near Lafayette, Colorado, well north of the Rocky Flats Plant. Note that dust suspension is occurring only in a specific area, recently disturbed by plowing. Tractor disturbance of soil in the area is illustrated in the second photograph on [page 25](#).

In May of 1969, "...the filling, leveling and capping of the 903 area have not yet started." "The road grader used to move contaminated soil and rocks outside of the 903 fenced area was decontaminated and released to surplus." ([HPSR 6/69](#)). A May 24, 1969 view ([page 25](#)) shows the 903 area cleared and ready for application of cover materials.

[Putzier](#) (1970) indicated that the road grader was used outside the hot fenced area to move slightly contaminated soil to the fenced area. He noted that the Health Physics Department wanted the area covered as soon as the drums were removed; but this was not done, and the site was exposed to the high winter winds.

The Health Physics Department group reported in August of 1969, "The first coat of fill was applied to the 903 area on July 23. Building 903 was moved to a location immediately east of Building 666." ([HPSR 8/69](#)).

### **Placement of the cover**

In September of 1969 the Health Physics Department reported, "The base fill has been applied to the 903 area and the area has been rolled." ([HPSR 9/69](#)). "The base course material overlay, soil sterilant and asphalt prime coat for the 903 contamination barrier were completed on 9/24. The asphalt paving, seal coat, drainage ditch and sampling wells should be done soon." ([HPSR 10/69](#)). "...sampling wells and seal coat are all that remain to complete the 903 contamination barrier." ([HPSR 11/69](#)).

The asphalt work was completed in November of 1969 ([Loser](#) 1970). The sampling wells at the four corners were finished on November 11 ([HPSR 12/69](#)). The asphalted area was 380 by

400 feet in size, with the closest corner located some 290 feet west and 40 feet south of the east guard station on the Rocky Flats Central Avenue.

[Putzier](#) (1970) provides a chronology of the structure of the pad and its surroundings. During July 1969, the area was covered with 6 inches of road base. During September, a 3-inch asphalt layer was applied. During February of 1970, the remaining 903 area was covered with 4 inches of road base. An April 1970 photo shows both the asphalt pad and the gray, road base area ([page 26](#)). The second photo on [page 26](#) displays the results of dust suppressant tests as of May 25, 1971.

### **Basis for Dow estimates of leakage to 903 area soil**

[Biles](#) (1970) reports an estimate that some 5000 gallons of oils had leaked onto the ground during the entire period of barrel storage in the 903 area, and that about “five or six curies” of plutonium were contained in the leaked oil. This value is apparently from an estimate made by Morrie Maas some time after the cleanup operation. In 1980 private conversations, Maas reported to C. W. Barrick the method by which he calculated an 85 g plutonium release. The maximum volume of oil stored was estimated, and the measured volume of oil recovered was subtracted. The remainder was multiplied by the plutonium concentration measured in the recovered oil, yielding a maximum estimate of ~85 g Pu. Putzier estimated in 1970 that about 420 drums leaked some of their contents to soil, with about 50 of those drums emptying completely. In 1970, Putzier estimated about 86 grams of plutonium leaked to soil. [Loser](#) (1970) estimated 85 grams of Pu-239 lost from the drums to soil, based on a private communication with the Health Physics Department site survey technician (probably Maas). It appears that the accuracy of the release estimates noted above is not based on specific measurements. Other information points toward a broader estimated range of plutonium releases to soil. This broader range is used in *RAC* estimates of wind-driven releases from the 903 area (see [Appendix C](#)).

After processing in 1968, some 594 grams of plutonium were recovered from drum liquids, 2,471 grams stayed with the processed liquids, and 5,152 grams remained in the emptied drums. These estimates were made using RFP’s drum counting system. Rocky Flats staff published several papers describing the waste drum plutonium counting capability ([Harlan et al.](#) 1972, [Lawless and Chanda](#) 1970).

James Morrison, involved in waste operations onsite for many years, estimated in an interview with ChemRisk ([Morrison](#) 1991) that some “20-25% of the contents of the (903 area) drums leaked out.” Morrison noted that many of the barrels had become extremely fragile, and couldn’t be moved without falling apart. If Morrison’s recollection is correct, it would suggest some 40–50,000 gallons of Pu-contaminated leakage to soil, vs. the accepted 5000 gallon volume. Using plutonium concentrations measured during cleanup, this would imply upwards of 1000 grams of plutonium leaked to soil. While other evidence suggests that perhaps ten percent of this value is the best estimate, *RAC* will employ the Morrison value as an upper limit to the overall range of estimates. Because Morrison’s estimate is based on his recollection of events occurring more than 20 years prior to the interview, it will only be used to help establish the uncertainty range for the 903 area plutonium release estimate, and this upper limit will be used in *RAC* uncertainty calculations with a very low level of probability.

### Disposal of 903 wastes at the Idaho National Engineering Laboratory

The Idaho National Engineering Laboratory (INEL) received the soil, barrels and related wastes from the 903 area cleanup at Rocky Flats. A report written by D. H. [Card](#) (1977) contains a brief history of each of the pits used for waste burial at what is now called the Radioactive Waste Management Complex (RWMC) at INEL. Those pits that could have received 903 area waste are listed in Table 2. The empty drums disposed in INEL Pits 6 and 9 may have been from the RFP 903 area.

During the earliest years when Rocky Flats wastes were shipped to the INEL, descriptions of the contents of waste containers were limited; however, the numbers of containers and disposal volume are known. A recently published report by [EG&G](#) (1994) notes the annual volumes of material disposed (see Table 2). These are plotted for the early years of operation of the RWMC in [Figure 1](#). There was a substantial increase in disposal volume in 1968, about 90% above the mean for 1966-1967 (~4600 m<sup>3</sup>). Disposal volumes for 1969 and 1970 are about 36% and 96% greater, respectively, than the 1966-1967 average. Cleanup following the 1969 fire is no doubt responsible for much of the volume in these two years.

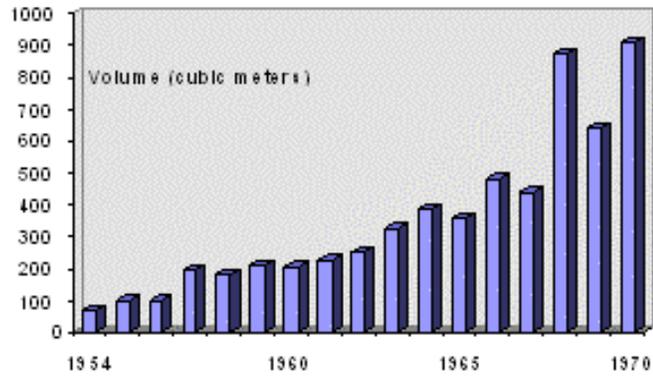
In the report by [Luckett et al.](#) (1982), soil volume removed from the lip area<sup>8</sup> near the 903 pad is stated to be 16,184 ft<sup>3</sup>, or 458 m<sup>3</sup>. This would fill 2,200 fifty-five gallon drums (actual number depending upon packing efficiency and whether they were lined).

**Table 2. Burial of RFP Transuranic (TRU) Waste at the Idaho National Engineering Laboratory\***

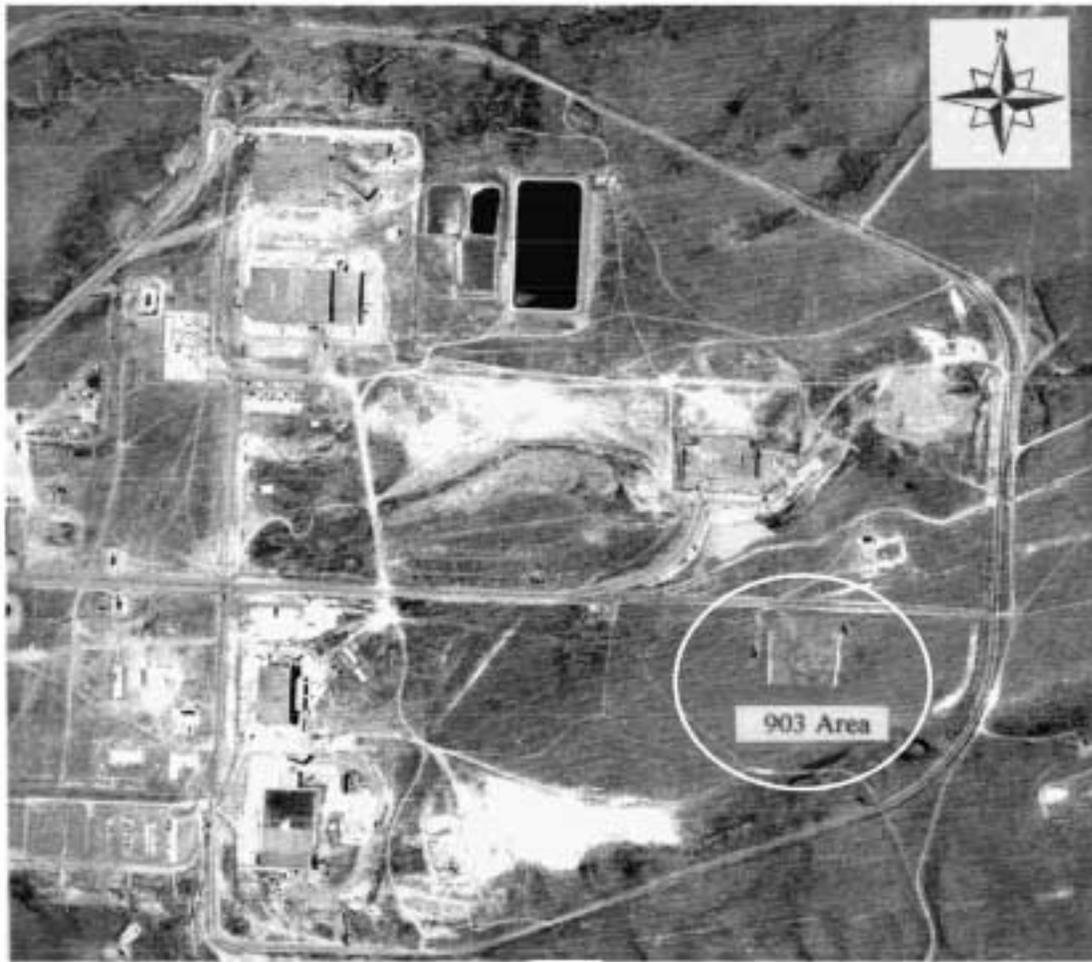
Pit #	Disposal Period	Contents	Comments
5	2/65 - 12/66	18486 drums; 673 boxes; 677 cartons	
6	5/67 - 9/68	14,396 drums; 3,423 boxes	Includes 2,451 boxes of contaminated drums
7, 8			Not used for transuranic waste
9	5/68 - 9/68	3,921 drums; 2,029 boxes	Includes 1,302 boxes of contaminated drums
10	9/68 - 10/70	26,645 drums; 2,849 boxes	Most 1969 fire debris received this period
11	4/70 - 10/70	13,542 drums; 90 boxes	
12	7/70 - 9/72	4,838 drums; 26 boxes	TRU waste burial from July-Nov. 1970 (after which TRU was no longer buried).

\*Table extracted from [EG&G](#) (1994)

<sup>8</sup> The area to the east of the 903 pad where the terrain drops sharply for a short distance.



**Figure 1.** Burial of RFP waste at the Idaho National Engineering Laboratory



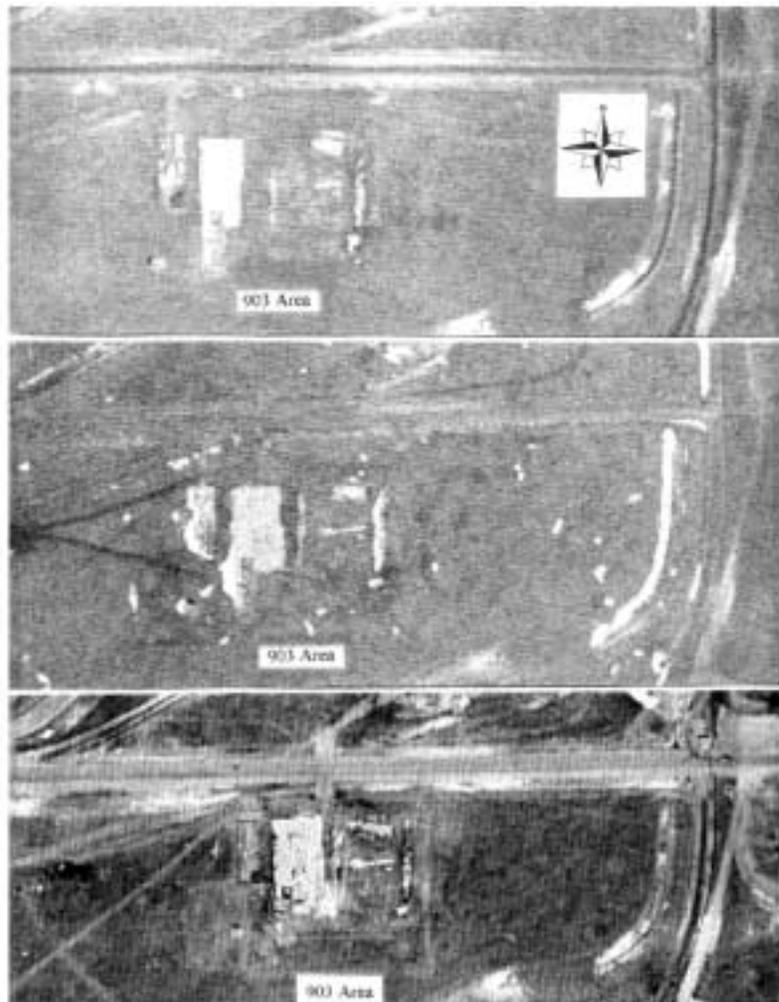
Photograph 1. Two parallel sets of barrel rows in the 903 area as of July 9, 1959.



Photograph 2. Enlargement of Photograph 1.



Photograph 3. August 11, 1962: a large number of waste oil barrels tightly packed in the 903 area.



Photographs 4a, 4b and 4c. Area of stored barrels increasing in size from May of 1963, through March of 1964, to April of 1965.



Photograph 5. June 1962: a waste drum with weeds penetrating a heavily corroded area on its bottom.



Photograph 6. June 1962: distorted waste drum.



Photograph 7. April, 1965 view.



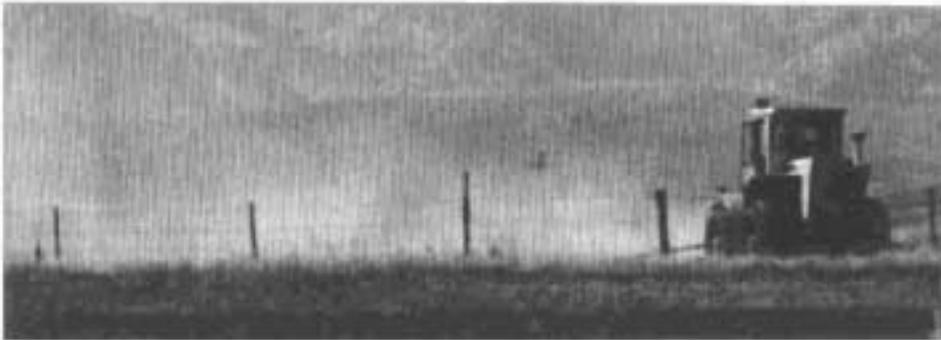
Photograph 8. Perspective of the Plant, taken from the west, on January 6, 1966.



Photographs 9a, 9b and 9c. Photograph 9a presents a mid-April, 1966 view, and was taken prior to cleanup initiation. Photograph 9b, taken April 29, 1967, indicates removal of some barrels (in the center and lower right corner of the 903 storage area). Photograph 9c was taken April 10, 1968, and shows most drums removed from their previous locations.



Photograph 10. 1995 view demonstrating wind suspension of dusts (North of RFP, near Lafayette).



Photograph 11. Recent photo of tractor disturbance of soil in the area. Illustrates mechanical suspension of soil.



Photograph 12. May 24, 1969, view of the 903 area cleared and ready for application of cover materials.



Photograph 13. April 1970 photo: demonstrates both the asphalt pad and the gray, road base area.



Photograph 14. May 25, 1971 view. Results of dust suppressant tests, shown as three gray rectangles just east of the 903 pad (photo lower center).

## **PLUTONIUM RELEASES: AIR SAMPLING, METEOROLOGICAL DATA**

This review of the 903 barrel storage area history points toward a linkage among several causative factors for plutonium releases: Whenever a combination of: (1) recent physical soil disturbance in the contaminated area (barrel or rock removal, grading, etc.) and (2) high wind events occurred, significant contamination events were likely to be observed. Review of the large body of research related to wind-driven soil suspension also causally links the condition of physical disturbance followed by high winds to soil suspension. The suspension of soil by wind is highly wind speed dependent, and is far more likely to occur if the soil has been recently loosened and ridged by physical disturbance. These observations have pointed RAC's research toward the collection of information and techniques needed to quantitatively predict such contamination events.

Portable air samplers were used by Health Physics Department monitors during cleanup operations, to help control worker exposure to airborne contamination, according to a 1994 RAC interview with a Health Physics Department technician present during the work. It does not appear that records of these very important monitoring data still exist; they have not been discovered after extensive research at the Denver Federal Record Center (FRC) and elsewhere. However, continuous onsite air monitoring stations were generally in operation at onsite locations during the entire period of interest. Data from these stations, in handwritten format, were recovered from storage at the FRC and are being used in this research project. A Dow report ([Seed et al.](#) 1970) presented a graph of monthly averages of daily airborne alpha concentrations. The report noted that high airborne levels were detected at the sampler nearest the 903 area, for April, May, November and December, 1968, and January–April 1969. The original data sheets discovered at the Denver Federal Records Center have allowed RAC to reconstruct more detailed information concerning these incidents, as discussed in the following sections.

### **Onsite air monitoring method and reporting**

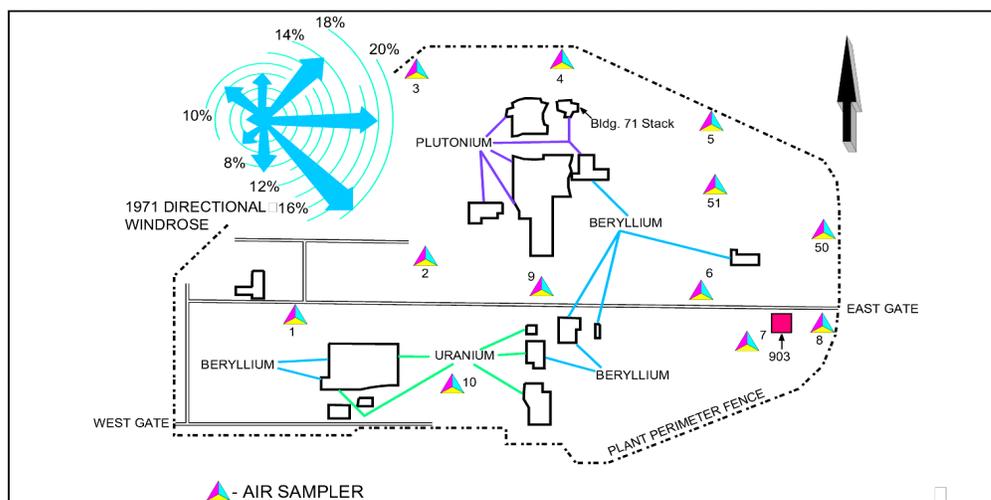
Prior to 1970, air samples collected by the RFP contractor (Dow Chemical Co.) were analyzed for total long-lived alpha (TLL $\alpha$ ) activity, not for plutonium. Gross beta analyses were generally also performed. The RFP contractor began onsite ambient air monitoring at a single station in 1952. By early 1953, ten onsite stations had been established. In 1969, two more stations were added (see [Figure 2](#)).

Copies of handwritten daily results sheets titled, “Health Physics On Site, Site Survey Routine Air Sample Results,” were retrieved from the Denver Federal Record Center. These data bracket the key period of interest for primary releases from the 903 area (1965-1969). The complete set of daily records includes data for air samplers S1–S10, S50 and S51. The S1–S10 data span the time period October 10, 1964 through December 29, 1971 (with the exception of S9 data, which are only available for September 18, 1967 to March 30, 1969). The S50 and S51 data are limited to October 4, 1968 through December 29, 1971. [Subsets of these data are presented in [ChemRisk's](#) Task 6 report (1994), Table M-1 and Appendix O.]

The daily alpha and beta count information were recorded on a standardized form. An example is included here ([Figure 3](#)). Note that the total sampling time (1440 min.) and volume (81.5 cubic meters) were preprinted as standard values for all daily samples; that is, specific times and flow rates were not recorded for each individual sample. This is one source of uncertainty in the measurements. Standard practice in later times was to record the start

and stop clock times and flow rates for each sampler, which would then be used to obtain the volume of air sampled. The flow rate of the onsite samplers at this time was nominally two cubic feet per minute.

The filter from an air sampler was counted in an alpha scintillation detector. In such a detector, energy from an alpha particle emitted during the disintegration of an atom produces a scintillation, or light flash, which is amplified and detected, resulting in a “count” registering on the detector. The sample filters were each counted for a duration of 10 minutes until a change in procedure on August 25, 1969, when the routine count duration was increased to 30 minutes. The total (gross) count during the 10-minute sample count time was recorded on the results sheets.



**Figure 2.** Location of early onsite air samplers (adapted from a figure in the 1971 RFP annual environmental report). The distance from west to east across the Rocky Flats Plant site is roughly one mile. The 903 area is between samplers S8 and S7, to the right of the figure, near the East Gate. Note also indications of significant operations involving plutonium, uranium and beryllium.

A background count rate (counts per minute, or cpm) was recorded on the data sheet, and was subtracted from each gross sample count rate to obtain the net cpm due to alpha activity on the sample filter. On the example sample sheet here, for S-8, the net cpm was 130 counts/10 minutes, or 13 cpm, minus a background of 0.3 cpm, which equals a net count rate of 12.7 cpm. The background count rate refers to the counter (or detector) background, not an estimate of background in the environment. [Putzier](#) (1996) recalled that the background count rate was determined with a blank air filter in the detector. Trace quantities of alpha-emitting radionuclides in the filter, prior sample contamination, and spurious electronic noise contributed to the detector background. The length of time that the background was counted was not given on the data sheets. [Putzier](#) (1996) recalled that a statistical approach was taken to determining how long the background count rate should be, and that it was perhaps about an hour. There were several scintillation counters dedicated to site survey samples.

There are two columns of alpha count data on the results sheet. The first column represents an initial count taken about 4-hours after sample collection. This count is dominated by natural, short-lived alpha emitters, including the decay products of uranium

and thorium. The second count was made one week later, when essentially all of the obscuring, short-lived alpha emitters had decayed to insignificant levels. Thus, the second column of total long-lived alpha (TLL $\alpha$ ) is the value which is correlated with Rocky Flats releases of Pu, americium (Am) and uranium (U). The minimum detectable activity (MDA) stated by the RFP for a 10-minute sample count was 0.21 cpm. From our analysis of the data sheets, this MDA is approximately the median of the detector background. That is, half of the background count rates would have been greater than the stated MDA, and half would have been less. A 90% confidence interval on the detector background for a subset of data from 1969 was 0 to 0.7 cpm (Rope et al. 1999). Gross counts were in the same range as counter background for many locations and times. In Rope et al. (1999), the uncertainty in a daily count due to the statistical nature of radioactive decay (or “counting error”) is examined. Quantitative use of daily counts less than 0.4 cpm is not recommended.

Occasionally the technician would note, in the “remarks” section of the data sheet, the presence of some operational activity or high winds suspected of contributing to airborne contamination. For example, on the data sheet for April 5, 1971, on which a relatively high alpha concentration at S-8 was recorded, the remarks section contains the note “Cutting ditch North of 903 Pad.” On June 26, 1969, the technician noted “High West Winds.” In the event of a sampling problem, e.g. a power outage or pump malfunction, this problem would be noted on the data sheet; in those cases the sample usually was not analyzed.

### Plots of onsite air sample results

An initial look at these air sampler data is provided in Figure 4. These plots illustrate the daily counts per minute for each air sampler. Data are total long-lived alpha activity in daily air samples. Note that the vertical axis for each graph is set to a different scale; very little airborne activity is seen in the plots for most of the air samplers. Very large increases in air concentrations, particularly for the S8 sampler located near and generally downwind of the 903 area, occurred following known disturbances in the 903 area. Almost no excursions of similar magnitude are evident for the remaining samplers, indicating that the air sampling and analysis system was sensitive to plutonium releases from the 903 area.

For some of our purposes, the cpm results from the data sheets must be converted to units of activity per unit volume of air sampled. The “femtocurie” is a convenient unit for concentrations of this magnitude. The femtocurie (fCi) is  $1 \times 10^{-15}$  Ci, or 0.001 picocurie (pCi). For daily onsite air samples analyzed for alpha activity, this conversion from cpm to activity concentration is:

$$\begin{aligned} \text{TLL}\alpha \text{ Activity concentration (fCi m}^{-3}\text{)} &= \\ (\text{TLL}\alpha \text{ cpm}) / [ &((0.21 \text{ cpm dpm}^{-1}) (2.22 \text{ dpm pCi}^{-1}) (10^{-3} \text{ pCi fCi}^{-1}) (81.5 \text{ m}^3))] \\ & \text{or,} \\ \text{TLL}\alpha \text{ Activity concentration (fCi m}^{-3}\text{)} &= \\ (\text{TLL}\alpha \text{ cpm}) / &0.038 \end{aligned}$$

In the conversion equation above, the “total efficiency factor” of 0.21 cpm per dpm, or 21%, is composed of two sub-factors: a 30% detector counting efficiency (determined from counting thinly plated standard alpha-emitting sources) and a 70% correction factor for self-absorption of the alpha particles within the depth of the air filter ( $0.7 \times 0.3 = 0.21$ ). These factors are discussed in more detail in the Phase I Task 5 report, Section 2.2.2.1 (ChemRisk 1994a).

**HEALTH PHYSICS ON SITE  
SITE SURVEY ROUTINE  
AIR SAMPLE RESULTS**

MONITOR: *G. Norman*      DATE ON: *6-26-69*      DATE OFF: *6-27-69*

Sample No	On	Off	Time	Total Time	Total Vol.	Count Duration	Alpha (cpm)		Beta (cpm)	
							Date Time	Rate	Date Time	Rate
S-1	0815	0815	1440	81.5	10 Min.	273	0.6	0.7	0.0	
S-2	0815	0815	1440	81.5	10 Min.	210	0.6	0.4		
S-3	0815	0815	1440	81.5	10 Min.	219	0.5	0.5		
S-4	0815	0815	1440	81.5	10 Min.	122	0.1	0.8	0.6	
S-5	0815	0815	1440	81.5	10 Min.	311	0.1	0.0	0.2	
S-6	0815	0815	1440	81.5	10 Min.	201	0.2	0.3	1.5	
S-7	0815	0815	1440	81.5	10 Min.	358	0.1	0.7	0.2	
S-8	0815	0815	1440	81.5	10 Min.	495	0.5	0.0	0.2	
S-9	0815	0815	1440	81.5	10 Min.	338	0.1	0.7	0.5	
S-10	0815	0815	1440	81.5	10 Min.	189	0.2	0.8	0.2	
S-11	0815	0815	1440	81.5	10 Min.	341	0.2	0.4	0.4	
S-12	0815	0815	1440	81.5	10 Min.	145	0.1	0.4	0.4	
S-13	0815	0815	1440	81.5	10 Min.					

*2.03*  
*6.03*

Remarks: *Alpha West Winds*

*RLV*

**Key to Items on Air Sample Results Sheet**

"DATE ON": Date air samples were started.

"DATE OFF": Date air samples were finished.

"Time": Preprinted clock time (8:15 AM) for filter change.

"Total time": Length of sample, 1440 min. or 24 hours.

"Total Vol.": Volume of air sampled (81.5 cubic meters).

"Count Duration": Length of time that filter was counted (10 min).

"4-hour alpha count": (Note count date is same as date off.)

"Long-lived alpha count": (Note count date is one week after date off.)

"GROSS": Total alpha count in 10 minutes, including counter background.

"BKG": Counter background counts per minute (cpm).

"NET": Net cpm = Gross cpm minus counter background cpm.

Figure 3. Example site survey routine air sample results sheet for onsite air samples: June 26, 1969.

**Figure 4.** RFP onsite air sampler data. Note vertical axis scale changes.  
("Net Count" are counts per minute)

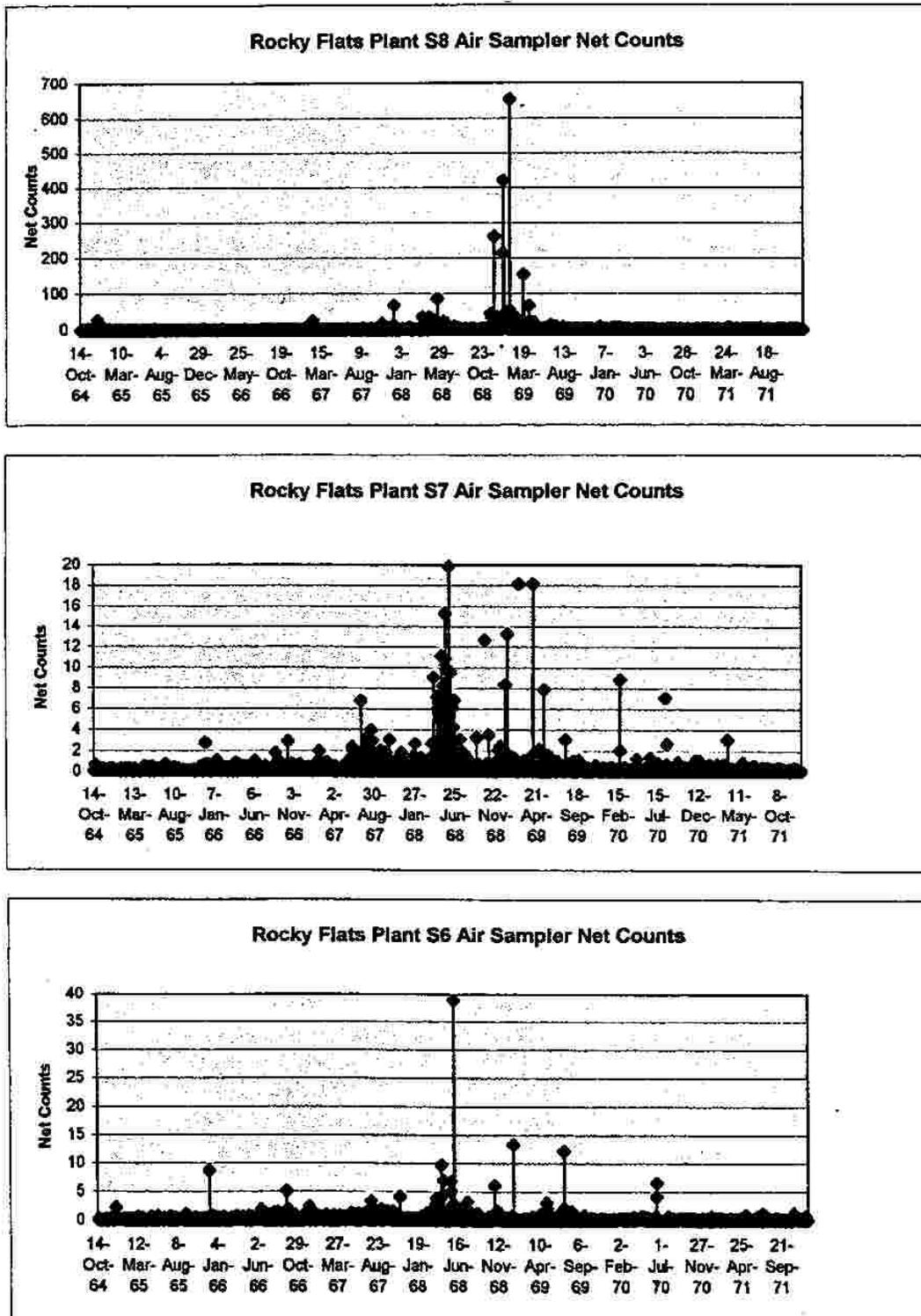


Figure 4 Continued

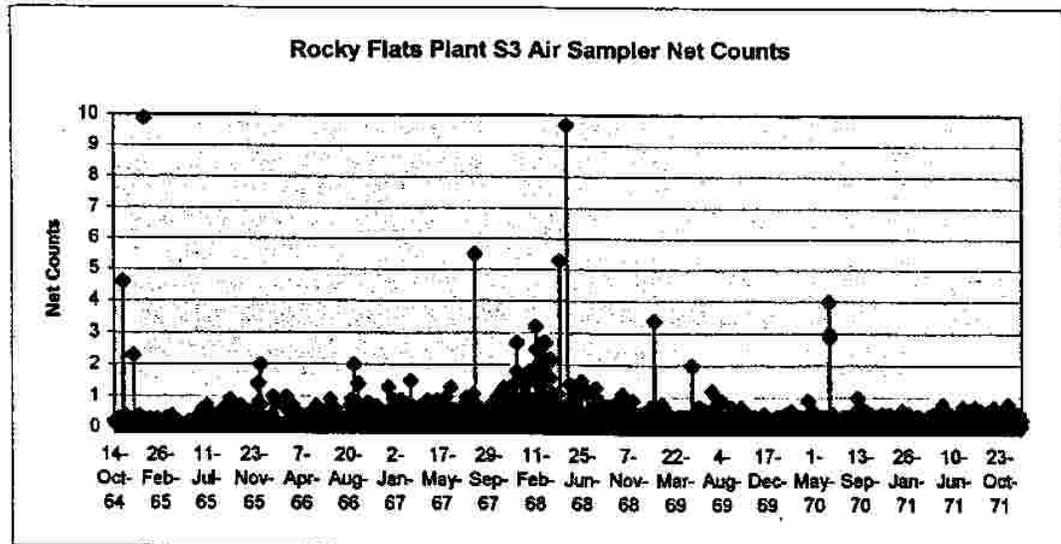
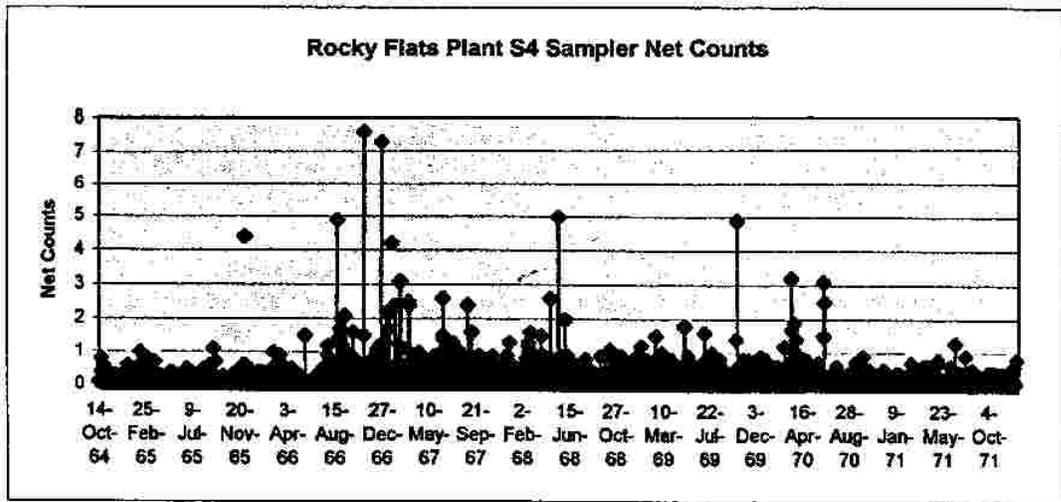
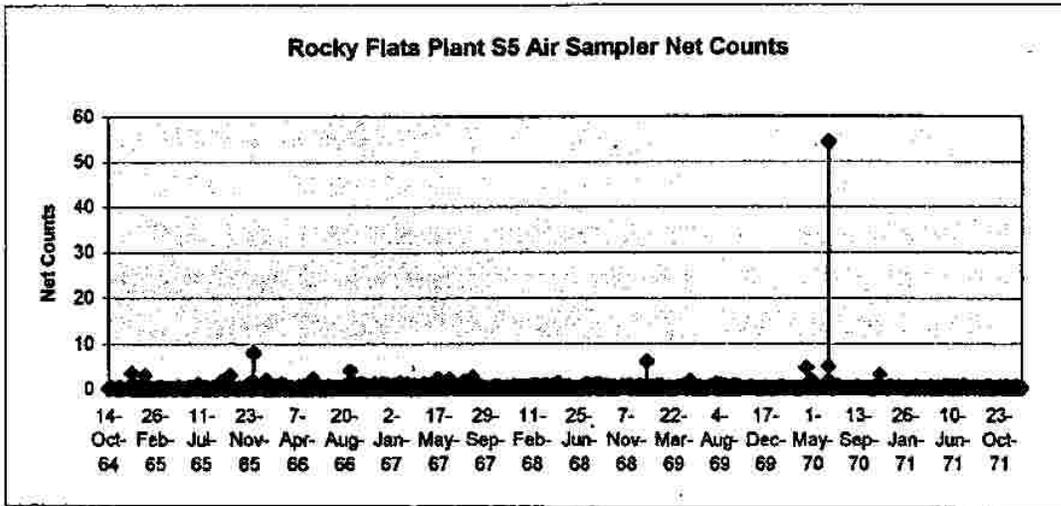


Figure 4 Continued

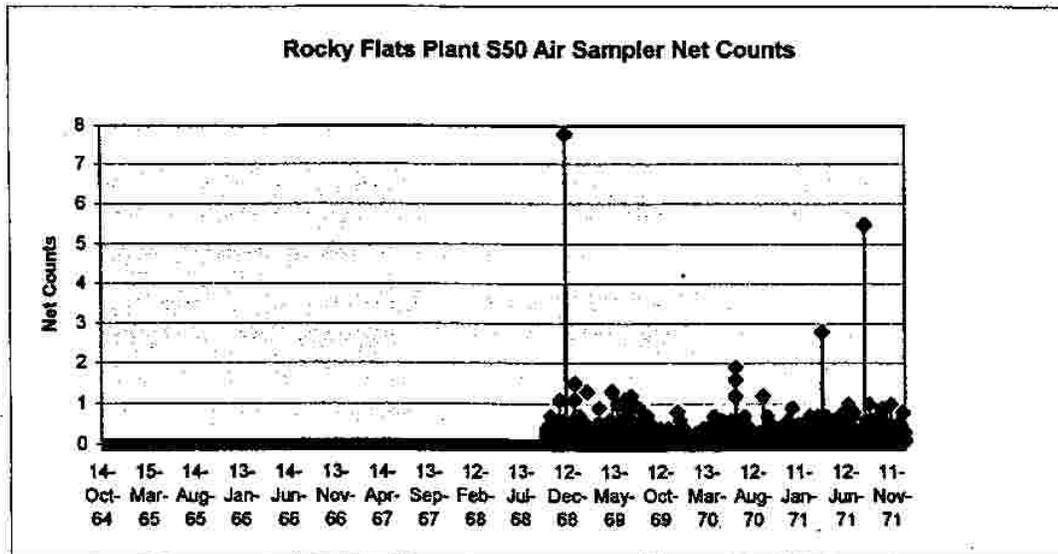
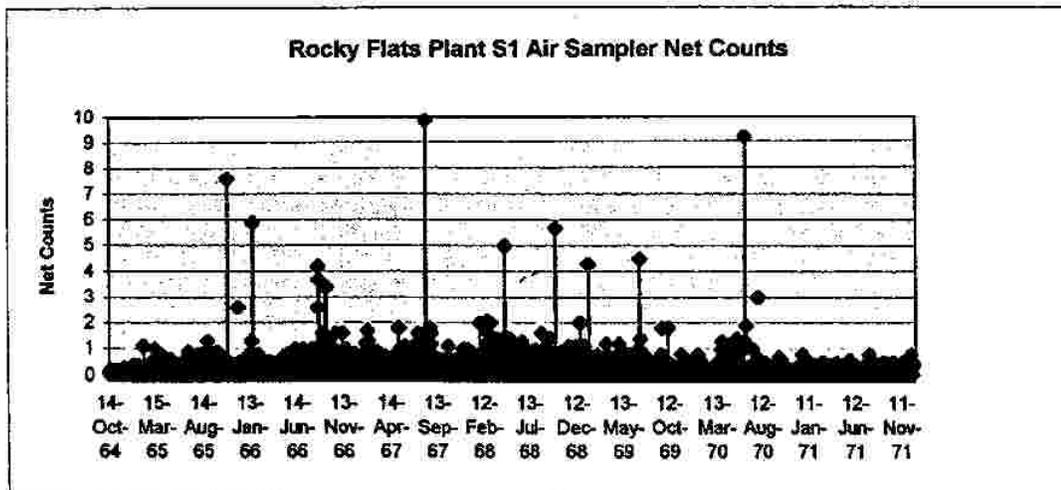
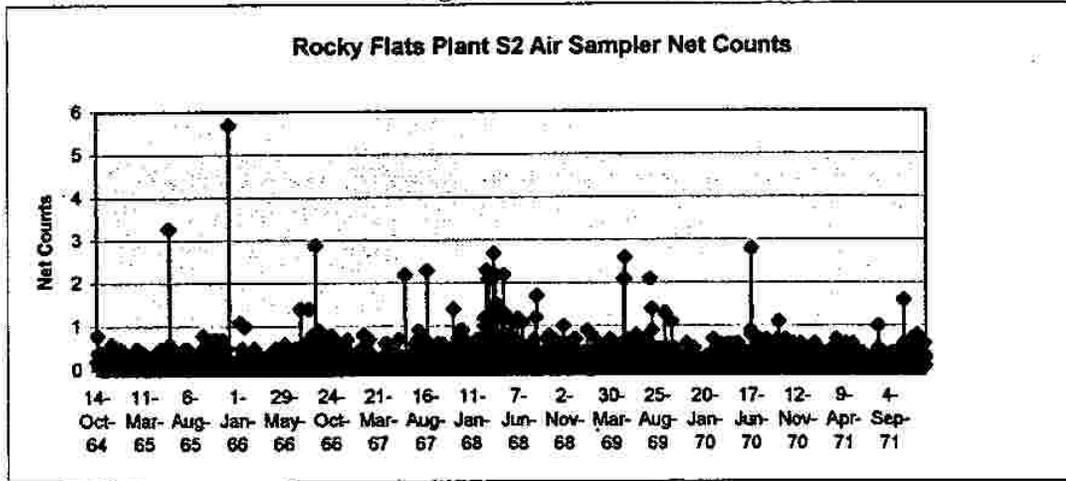
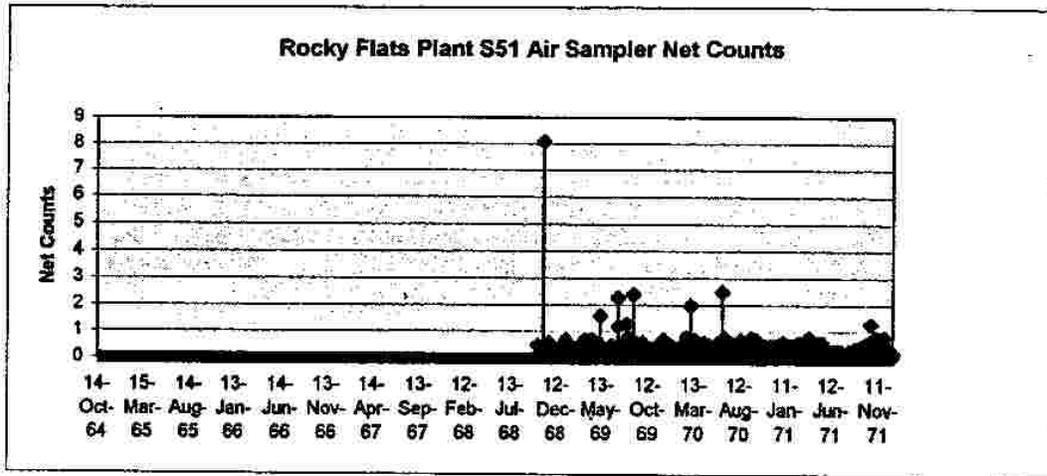


Figure 4 Continued



**Analysis of results of selected daily measurements of TLL $\alpha$  in onsite air**

Rocky Flats total long-lived alpha (TLL $\alpha$ ) air sampler data were transcribed from the handwritten results sheets and analyzed by RAC using Microsoft Excel® software. For samples collected over periods longer than one day (e.g., weekends and holidays), the total cpm value was divided by the number of days of sampling, so that all results in the database are estimates of daily counts.

Table 3 presents some summary statistics for this large data set. The information base is quite complete. There were over 27,700 data points over the 1964-71 time period. Of the 12 onsite samplers, 11 show missing data for less than 2% of the days.

Table 3 also contains summary statistics for the net count results. The alpha counting method was not very sensitive. With the exception of sampler S8, more than 70% of the measurements were lower than the site’s reported minimum detectable activity of 0.21 cpm (5.5 fCi m<sup>-3</sup>), and less than 1% of counts were greater than 5 cpm (net). The mode (most frequently observed value) for all onsite sampler data sets was zero. Table 4 provides some perspective on these levels. The counting method was not adequate to quantitatively measure typical natural background or plutonium fallout concentrations (Rope et al. 1999). However, the method is quite adequate to measure the gross contamination which occurred around the 903 area during high wind events and operational activities.

**Table 3. Summary Descriptive Statistics for Daily Measurements of Total Long-Lived Alpha Activity in Onsite Air, October 1964 through December 1971**

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S50	S51
Number of Data Pts.	2603	2594	2599	2596	2597	2580	2577	2610	2021	2588	1174	1172
Days Missing Data <sup>a</sup>	30	39	34	37	36	53	56	23	612 <sup>c</sup>	45	7	7
% Days Missing	1%	2%	1%	1%	1%	2%	2%	1%	30%	2%	1%	1%
Mean <sup>b</sup> (cpm)	0.25	0.18	0.23	0.23	0.23	0.29	0.39	1.97	0.16	0.19	0.20	0.17
Median (cpm)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.3	0.1	0.1	0.1	0.1
Standard Deviation (cpm)	0.54	0.31	0.45	0.45	1.14	1.02	2.78	17.50	0.25	0.36	0.36	0.33
Minimum (cpm)	0	0	0	0	0	0	0	0	0	0	0	0
Maximum (cpm)	10.6	5.7	9.9	7.6	54.5	39	130.3	654.3	2.7	5.9	7.8	8.1
% < MDA (0.21 cpm)	70%	77%	71%	73%	74%	70%	70%	45%	80%	77%	75%	78%
% > 5 cpm	0.3%	0.1%	0.2%	0.4%	0.2%	0.5%	0.9%	4.9%	0%	0.1%	0.2%	0.1%

<sup>a</sup>Monitoring began at S50 on 10/4/68, and at S51 on 10/7/68. Days missing are computed based on operating interval. See Figure 2 for sampling locations.

<sup>b</sup>The mode (most frequently observed value) for all data sets was zero. All cpm results in this table are net, after subtracting counter background.

<sup>c</sup>There was no monitoring at S9 from 12/22/66 through 1/23/67 and from 9/18/67 through 3/30/69.

The two locations with the highest maximum concentrations (S-8 and S-7) are those which were closest to the 903 barrel storage area. The sampler showing the largest amount of alpha activity is S8, which was downwind of the 903 area. Figure 5 is a plot of the daily TLL $\alpha$  activity concentration in air at S8. The vertical concentration scale is logarithmic, so that the large range in values can be presented. The highest daily value was 654 cpm (17,200 fCi m<sup>-3</sup>) for the sample collected at S8 on January 30, 1969.

Monthly concentrations, computed from the daily data, are tabulated and plotted in [Appendix B](#) at the end of this report. The monthly average concentrations also show a strong correlation to drum storage area activities, although the peak concentrations are not as apparent.

**Table 4. Perspective on Magnitudes of Long-Lived Alpha Concentrations in Air**

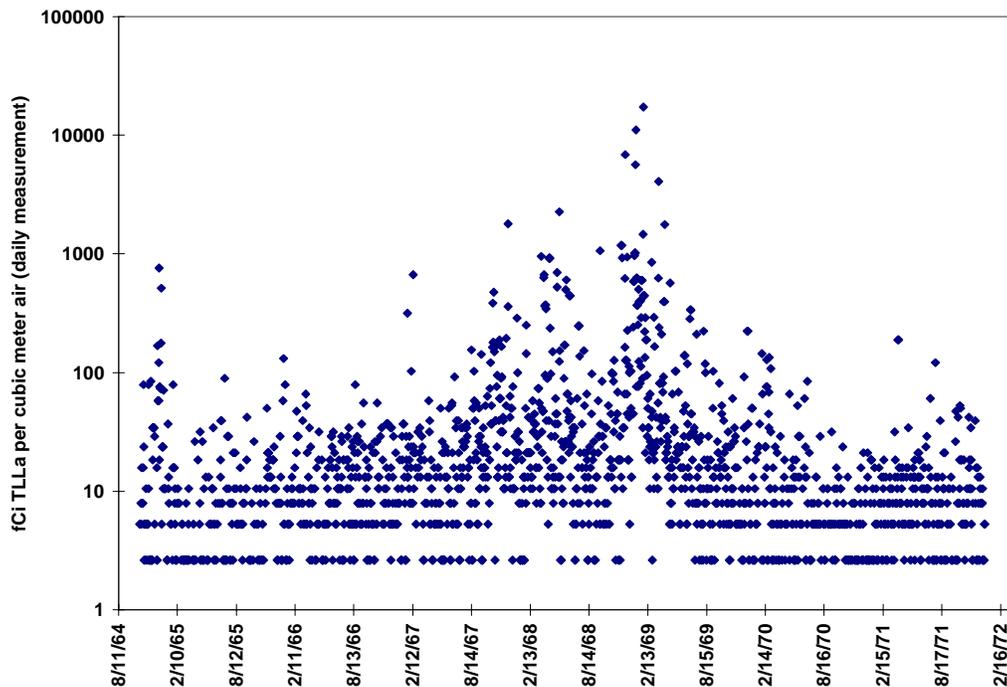
	Net cpm	fCi m <sup>-3a</sup>
Monthly average fallout Pu in Denver air in 1965		<0.3
Background due to naturally-occurring long-lived alpha emitters in air (see <a href="#">later section</a> of this report)	<0.04	<1
Lowest reportable value on daily air sample results sheets	0.1	2.6
Site's quoted minimum detectable activity	0.21	5.5
Long-term average concentrations at onsite stations, except S7 and S8	<0.4	<8
Alpha counter background range	0–1	0–26
Annual average concentration at S7 in 1969	0.76	20
Annual average concentration at S8 in 1969	7.0	185
Maximum monthly average concentration at S8 (Jan 69)	58	1525
Maximum daily concentration at S8 on 1/30/69	654	17,200

<sup>a</sup>For daily onsite air samples, fCi m<sup>-3</sup> = net cpm divided by 0.038 (see [previous section](#), this report).

Note: Quantitative use of RFP daily counts below 0.4 net cpm is not recommended due to large counting error ([Rope et. al](#) 1999).

These detailed air sampling data suggest a number of research possibilities for evaluation of releases from the 903 area; these avenues are being considered during the Phase II research. The actual number of high-concentration events seen in the S1 - S10, S50 and S51 graphs ([Figure 4](#)) is small. Thus, a large fraction of airborne Pu released from the 903 area is probably associated with only a few suspension events, or only a few specific days, in 1968 and 1969. If the bulk of the 903 releases occurred during only a few days, it is important to estimate releases for these specific, brief periods, since transport and dispersion of released plutonium varies drastically when analyzed on a short-term basis. *RAC* plans to calculate releases, transport, dispersion, dose and risk on a short-time-period basis, in contrast to the Phase I preliminary assessment using 5-year averaging.

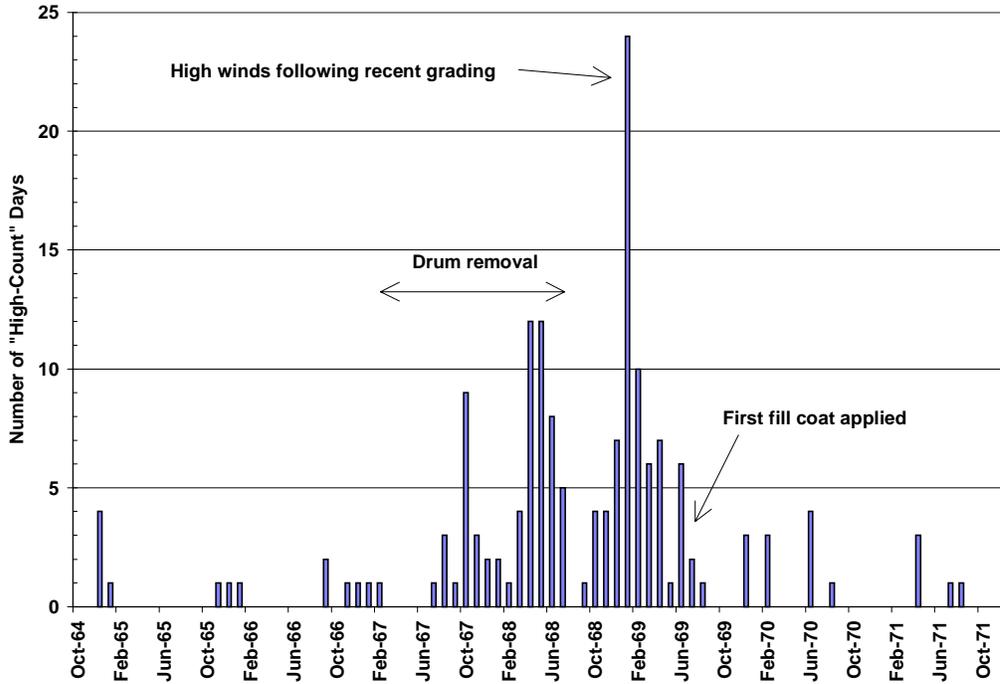
In order to isolate and examine the high airborne contamination days, the entire set of over 27,000 daily counts was sorted, and those with an activity of  $\geq 5$  cpm were selected. There were 166 days out of this 2633-day period in which at least one sampler recorded a TLL $\alpha$  count of 5 cpm or greater. A tabulation of data for these "high-count days," sorted in three ways, by location, by date, and by count rate, is included in [Appendix A](#) at the end of this report. This exercise also pinpointed a few arithmetic errors on the data sheets, which were corrected in the database. In another instance, a high value was due to the fact that the second count of the sample was conducted *two days* after collection, rather than after a week's decay time. Because that count is not comparable to the others, the data were omitted from the database.



**Figure 5.** Daily measurements of total long-lived alpha activity in air at the S8 sampler near the 903 area. Zero values were omitted from this semi-logarithmic plot, although a net cpm of zero was the mode (most frequently observed measurement) in this and all other onsite air data sets. Horizontal-line appearance of plotted points is due to the reporting of data in 0.1 cpm increments. For example, the lowest reportable positive count was 0.1 cpm, which is 2.8 fCi m<sup>-3</sup>, or the lowest line of points on this plot.

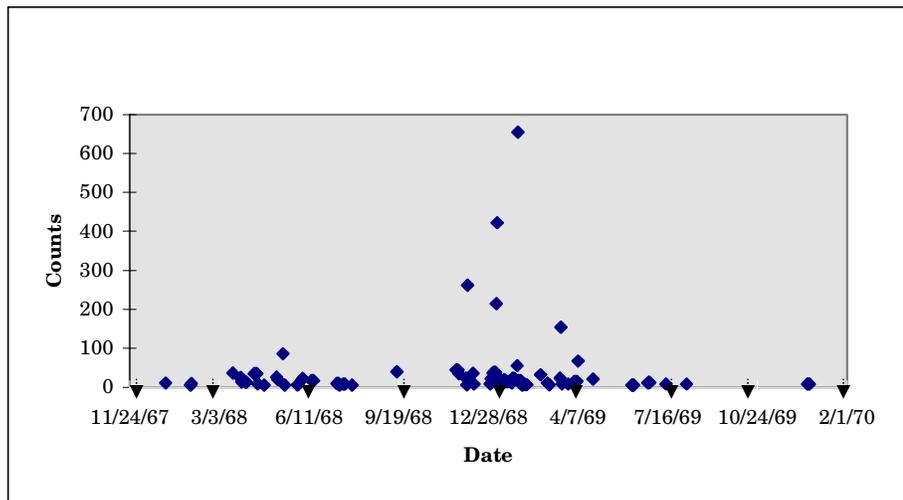
A chart of the number of high-count days per month clearly reflects the dramatic fluctuations in onsite airborne alpha activity ([Figure 6](#)). The month with the most high-count days is January 1969, followed by April and May of 1968. [Table 5](#) summarizes key operational activities and weather which likely affected the timing of releases from the 903 area.

While plutonium contamination of soil began in the late 1950's, suspension by wind was certainly not a simple mathematical function of windspeed, time or any other single factor. The quantity of plutonium moved from the storage area was influenced by periodic high winds. It also was likely to have been influenced by rainfall runoff and soil wetting, snow cover, removal of the drums in 1967, activities including grading and rock removal, and the natural "aging" or "armoring" of soil that occurs after an event such as grading.

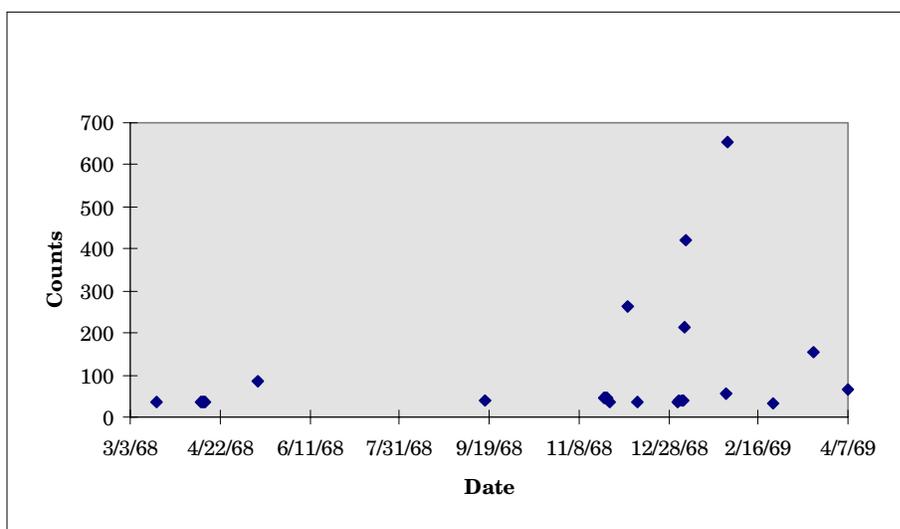


**Figure 6.** Number of days per month between October 1964 and December 1971 in which one or more onsite air samplers recorded a daily net count of at least 5 cpm total long-lived alpha activity (equivalent to 130 femtocuries per cubic meter air). There were 166 “high-count days” out of this 2633-day period. January 1969 was the most active month, with 24 out of 31 days registering high alpha counts. April and May 1968 were the next highest months. The shape of the curve substantiates the timing of releases from the 903 area.

When these same air sampling records are sorted by date to exclude the vast majority of low-count data, Figures 7 and 8 may be developed. These two figures focus attention on those events likely to be responsible for the majority of plutonium release from the 903 area.



**Figure 7.** S8 air sampler results greater than 5 cpm.



**Figure 8.** S8 air sampler results greater than 30 cpm.

Covering the old drum storage area with fill and asphalt in mid-1969 did not completely eliminate airborne contamination, although air concentrations were greatly reduced. Areas of soil outside of the pad were contaminated to a lesser extent than the primary 903 area contamination, but remained subject to wind erosion. This “secondary resuspension” has been a significant relative source of offsite air contamination since 1970, and is discussed in some detail in [Rope et al.](#) 1999. Four sample wells were dug in November of 1969, with moderate increases in air concentrations. A new drainage ditch was completed west of the area in April 1971; higher airborne contamination was observed for a few days.

**Table 5. Highlights of Operational Activities and Weather Which Likely Affected the Timing of 903 Area Releases Before Covering with Asphalt**

Time Interval	Events
Jan 1967–June 1968	Drum Removal
October 1968	Weeds Burned
November 1968	Grading
December 1968–Jan 1969	High Winds
First Quarter 1969	Rock and Rubble Removal
Mar or Apr 1969	Grading
July 23, 1969	First coat of fill (6” road base)
November 1969	Asphalt pad cover work complete

Additional perspectives on the relationship between disturbance activities and air sampler data are presented in [Table 6](#), below.

**Table 6. 1968-69 Air Sampler Major Events Before 903 Area Was Covered**

Date	Sampler	Counts	Rank	Comments
3/18/68	S8	36.3	18	
4/11-4/14/68	S8	34.9	21-24*	4/68 <a href="#">photo</a> shows most barrels removed
5/13/68	S8	86.1	6	
6/4/68	S6	39	13	Last drums transferred out of 903 area in June. Health Physics Department notes "some slight contamination spread from wind and rain". 25' grid staked out over 903 area.
9/17/68	S8	40.3	12	
11/22-11/24/68	S8	44.8	9-11*	10/68: weeds burned off.
11/25/68	S8	35.1	20	
12/5/68	S8	261.5	3	
12/11/68	S8	35.7	19	12/68: high winds blew drums over east of nitrate ponds
1/2/69	S8	36.7	17	
1/3-1/5/69	S8	38.8	14-16*	
1/6/69	S8	215	4	
1/7/69	S8	422.2	2	
1/7/69	S7	130.3		
1/29/69	S8	55.6	8	
1/30/69	S8	654	1	Health Physics Department Rep: high winds of 1/31 blew roofing off Building 889
2/24/69	S8	32.3	25	
3/19/69	S8	154.6	5	Late March, early April: 903 area graded, 2-3 days, 5-6 hr/day, 10-15' height dust cloud.
4/7/69	S8	67.2	7	4/69: large rocks and stakes removed from 903 area, took 2 days; very high surface alpha counts. Main contamination concern noted to be "south edge" of area.
				<i>First coat of fill applied to pad area 7/69. Asphalt completed 11/69. Remainder of area covered with fill 2/70.</i>

\*Note: Three-day groups are weekends - sampled from Fri. a.m. - Mon. a.m. Count rate was divided by 3 when data were tabulated by RAC.

### Summary

As noted, the daily air contamination data suggest a number of research possibilities for evaluation of releases from the 903 area. The magnitude of releases associated with mechanical or wind events known to have occurred on specific days may be evaluated. Development and calibration of more comprehensive models describing both plutonium release and transport may be feasible. The significant airborne plutonium releases from the 903 area appear to be associated with a relatively few events, most likely high winds following mechanical disturbances. Modeling plutonium releases from the 903 area should therefore involve an understanding of incident-related, rather than a time-averaged, release potential.

## **DETAILED WEATHER DATA**

Detailed knowledge of specific atmospheric plutonium-suspension events, both mechanical and wind-induced, allows consideration of models dealing with wind-driven suspension and dispersion of soil dust. To this end, weather data from the Jefferson County (JeffCo) airport for the period 1968 to 1971 have been acquired. The JeffCo airport is located near the Rocky Flats Plant, to the ENE. The wind data are available in a handwritten, hourly format (generally 6 a.m. to 10 p.m.), and date, time, wind speed in knots<sup>9</sup>, direction in tens of degrees from true north, and (when noted) gust data (peak gusts in knots) have been transcribed into spreadsheet format. Additional notes concerning weather observations are also often recorded on the original data sheets. (These latter notes have been extracted by date and are available for review.) [Figure 9](#) presents a summary of all JeffCo data extracted for 1968 only, including some 6400 observations. [Note that Figure 9 horizontal axis wind direction values must be multiplied by ten to correspond to compass directions.] The figure demonstrates that the dominant wind direction (particularly for high-speed events) was from the west-southwest (generally toward the S8 air sampler, located to the east and somewhat north of the 903 area). The JeffCo data are helpful in the evaluation of the relative impact of mechanical disturbances, wind speeds and wind gusts on area releases, and in evaluating air sampling data in the context of wind direction over the 903 area.

### **Analysis of S8 air sampler data and Jefferson County Airport meteorological data**

To use existing wind speed and gust data to estimate plutonium wind-driven suspension releases from the 903 area, it is necessary to establish the applicability of available meteorological data to the Rocky Flats Plant location. As noted above, wind speed, direction and gust data are available for the 1968-1971 period of interest from Jefferson County Airport records.

The JeffCo Airport is located 3.8 miles ENE of the RFP eastern boundary. Great Western Reservoir is located midway between the facilities. The terrain drops 300 feet in elevation from Rocky Flats to the reservoir, then rises 40 feet to the airport. There are no terrain obstacles between the plant and the airport. It is reasonable to expect that late 1969 high wind events recorded at the airport might correlate with events of increased wind-driven suspension at the 903 area. The JeffCo meteorological data would provide appropriate input for environmental transport codes such as Porph and Gifford's [Gaus1 code](#) (discussed later in this report), if it were found that suspension events in the 903 area were sensitive to high winds events as reflected in the JeffCo data.

We evaluate this question in the next series of graphs by performing a direct comparison of JeffCo airport high wind events versus S8 excursions. We select the period January - June 1969 and display the JeffCo wind speed data in [Figure 10](#). In this figure, the horizontal axis is displayed as "observation hours." JeffCo observations were generally made on the hour, from 6 a.m. through 10 p.m.; each day's report thus included 17 sets of data points, or 17 observation hours per day.

Next, the JeffCo wind speed data for the period is combined with reported wind gusts, in [Figure 11](#). Note that the reported wind gusts display approximately 50% higher velocities than the base wind speeds, and that the high velocity events often occur in groups.

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<sup>9</sup>One knot = 1.15 mph.

To analyze the correlation between the JeffCo and air sampler data, we inspect [Figure 12](#), which displays RFP S8 air sampler net long-lived alpha results, emphasizing the early 1969 time period. Then, we extract key data from the graph.

[Figure 13](#) displays S8 data for the period during which the highest air concentrations occurred. [Figure 14](#) presents the JeffCo wind and gust data for the same period. [Figure 15](#) presents the same information with scales and axes tailored to allow comparison of wind and airborne radioactivity events. [Figure 16](#) presents the same data, but with visually coincident events linked between the two plots.

It is evident from this analysis that periods of high air concentrations east of the 903 area coincided with periods of high wind events.

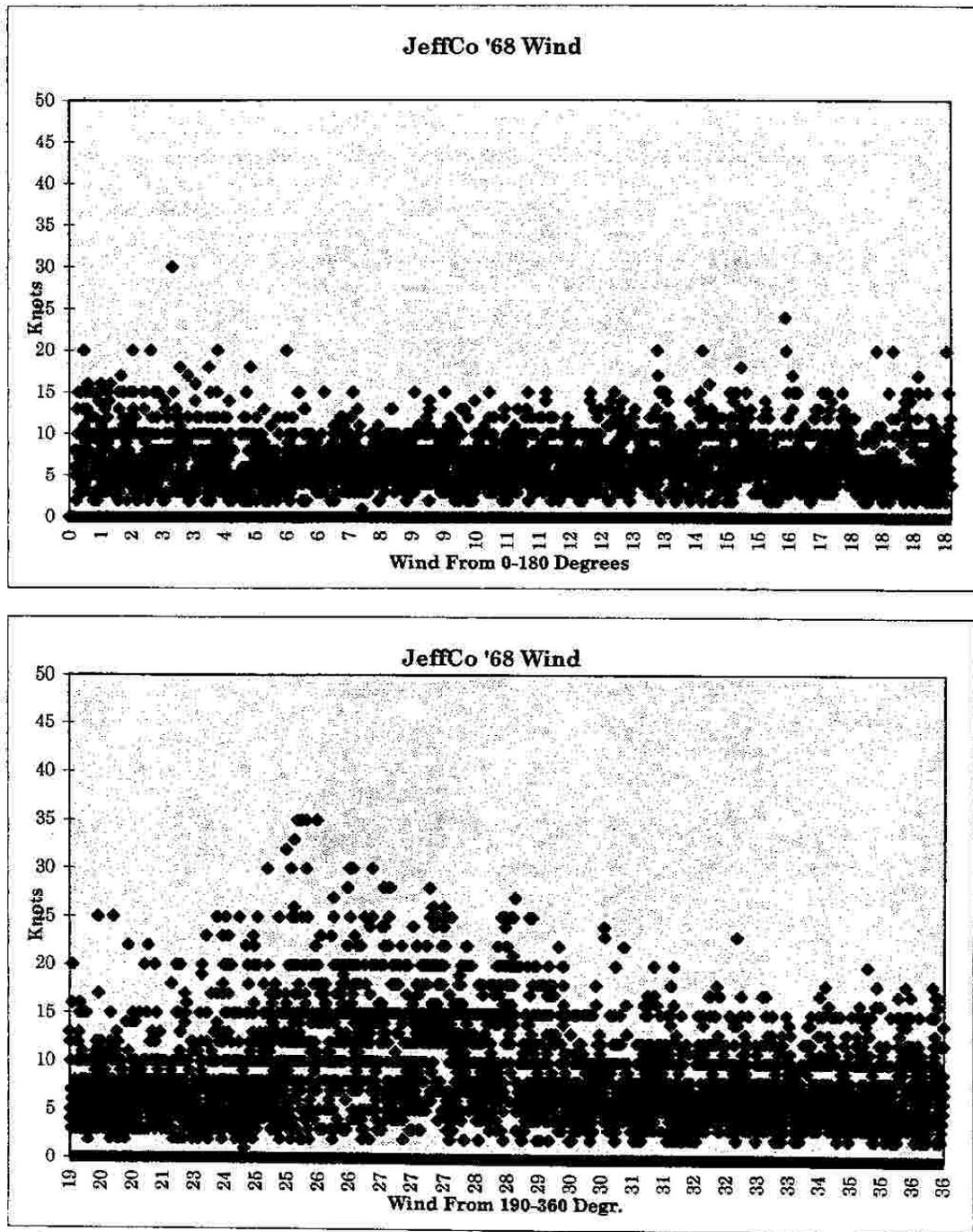
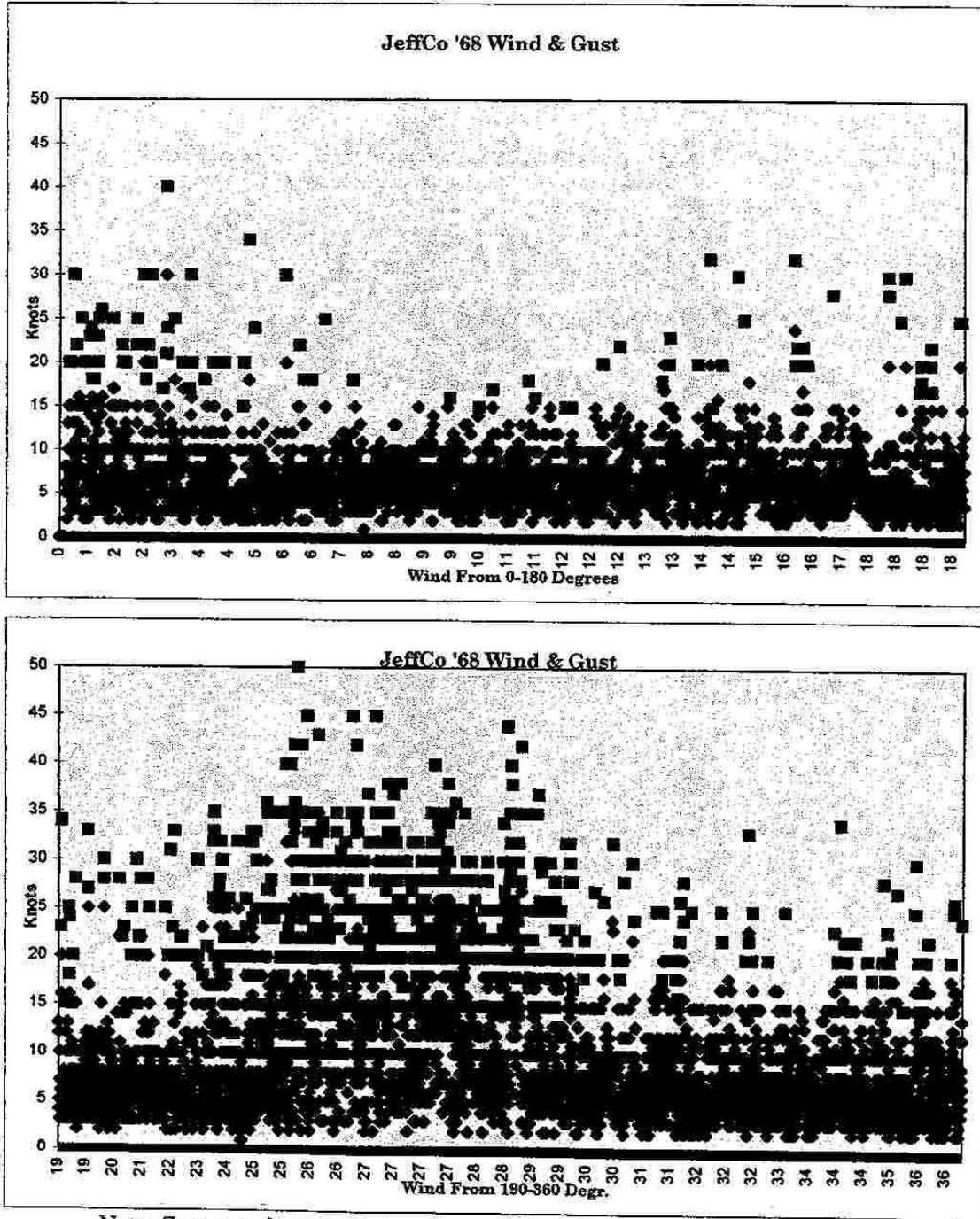
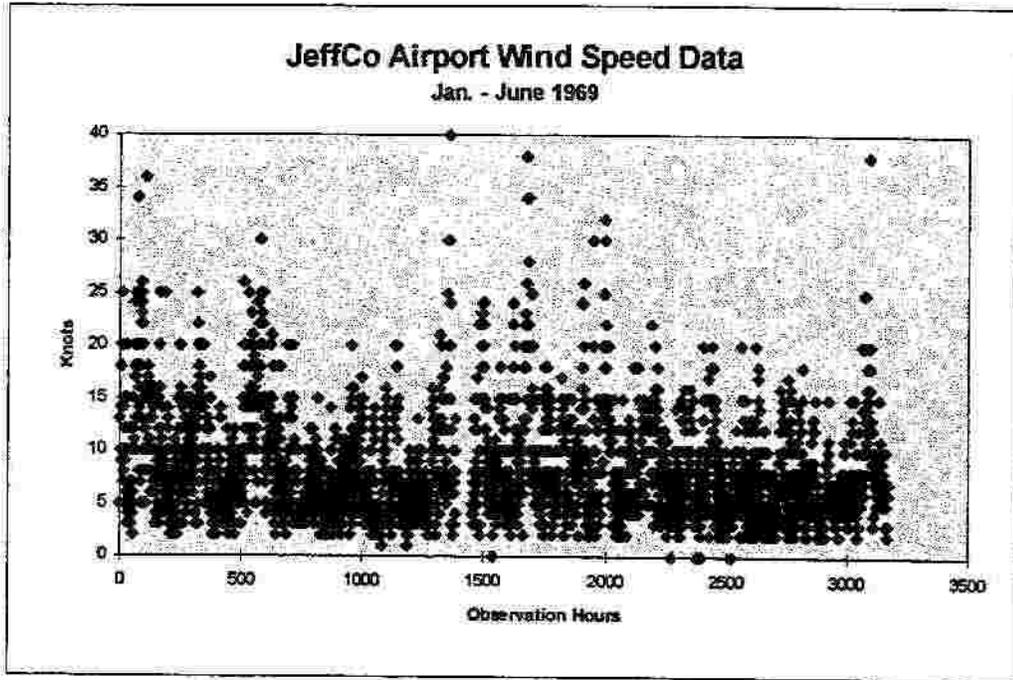


Figure 9. Jefferson County Airport winds for 1968, sorted by wind direction.

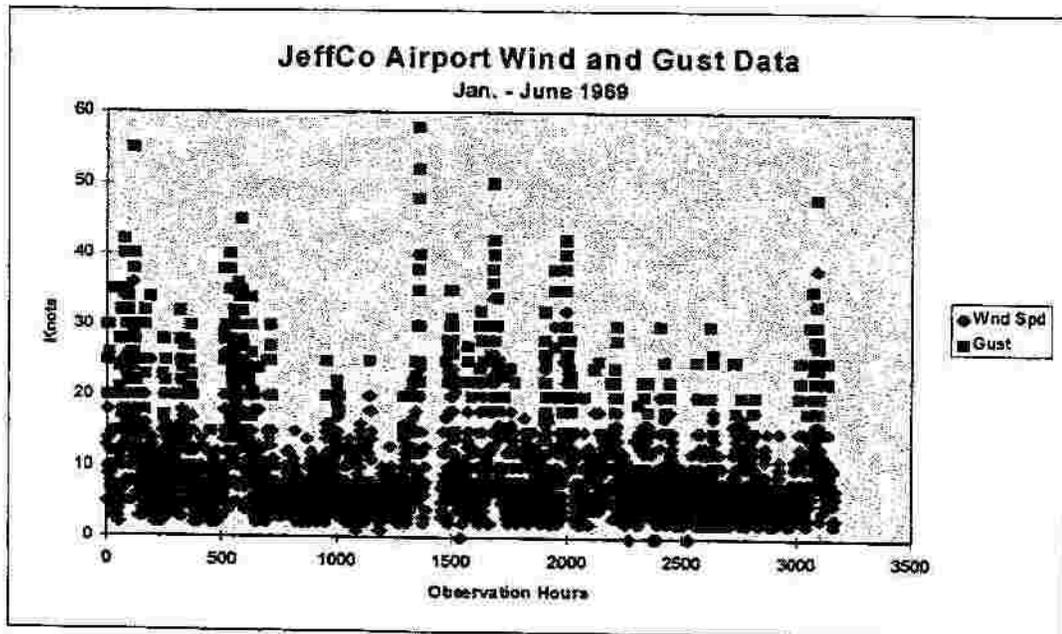


Note: Gust speeds presented as square data points

Figure 9 (Cont.). JeffCo Airport winds plus gusts for 1968, sorted by direction.



**Figure 10.** Jefferson County Airport wind speed, 6AM – 10PM daily, beginning with January 1, 1968 (“0” on horizontal axis).



**Figure 11.** Jefferson County Airport wind speed and gust data, first half 1969.

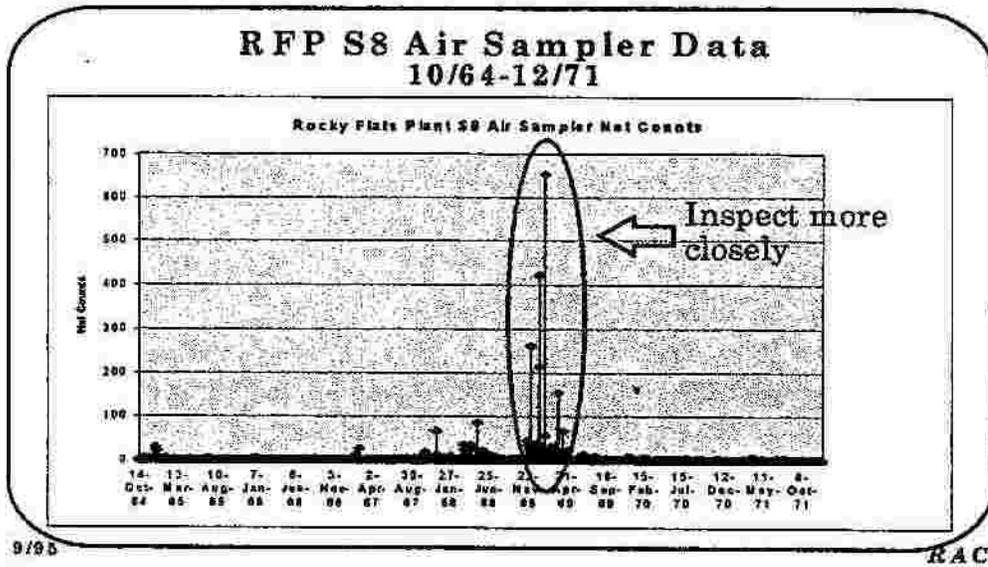


Figure 12. RFP S8 air sampler data, emphasizing the late 1968, early 1969 period of high airborne alpha emitter values.

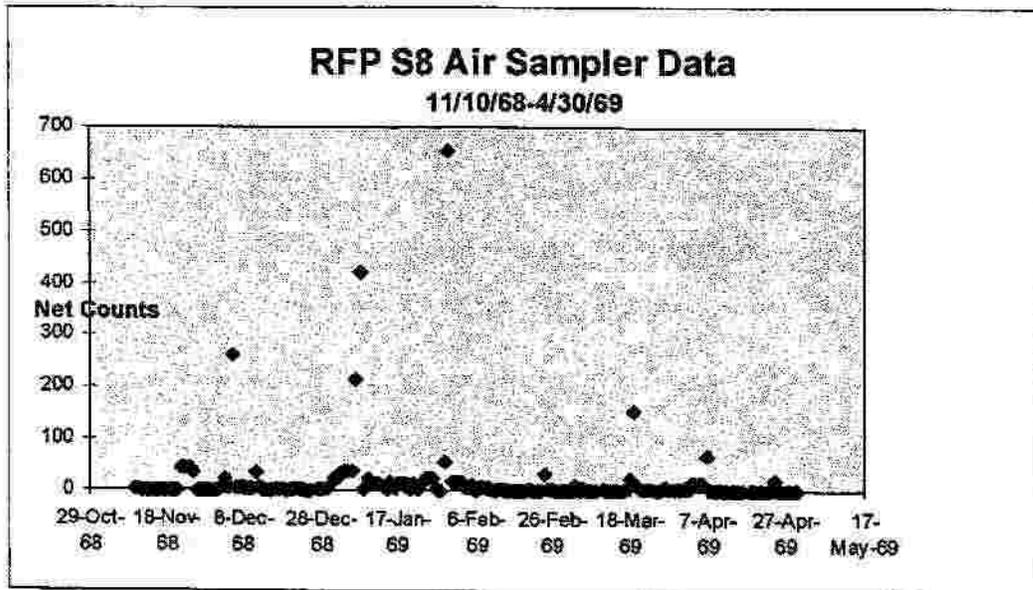


Figure 13. RFP S8 air concentrations for late '68, early '69.

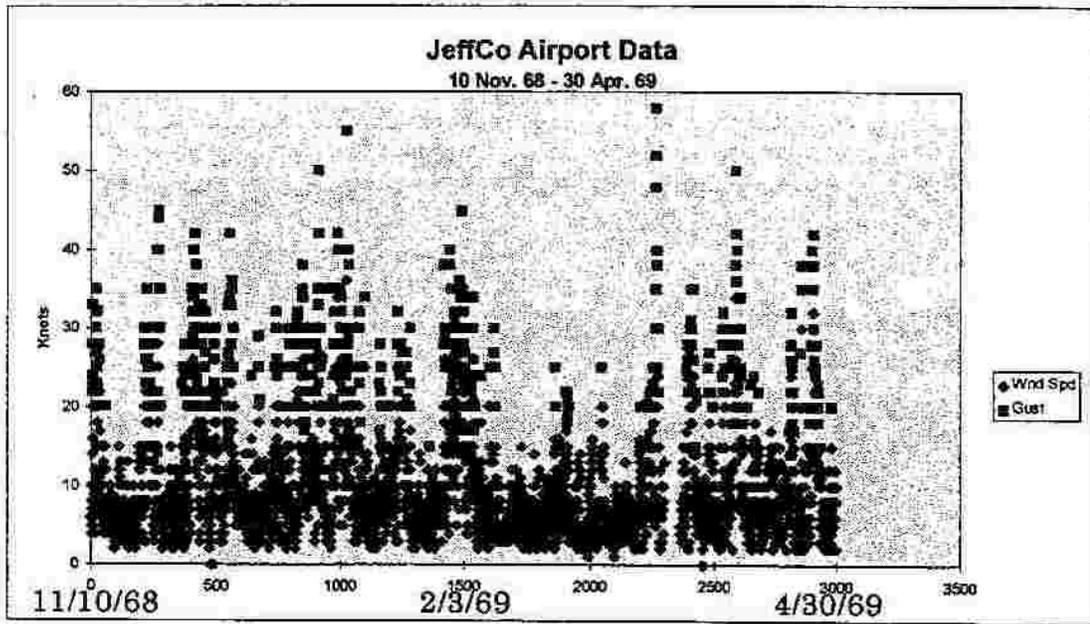


Figure 14. JeffCo wind and gust data, late '68 – early '69.

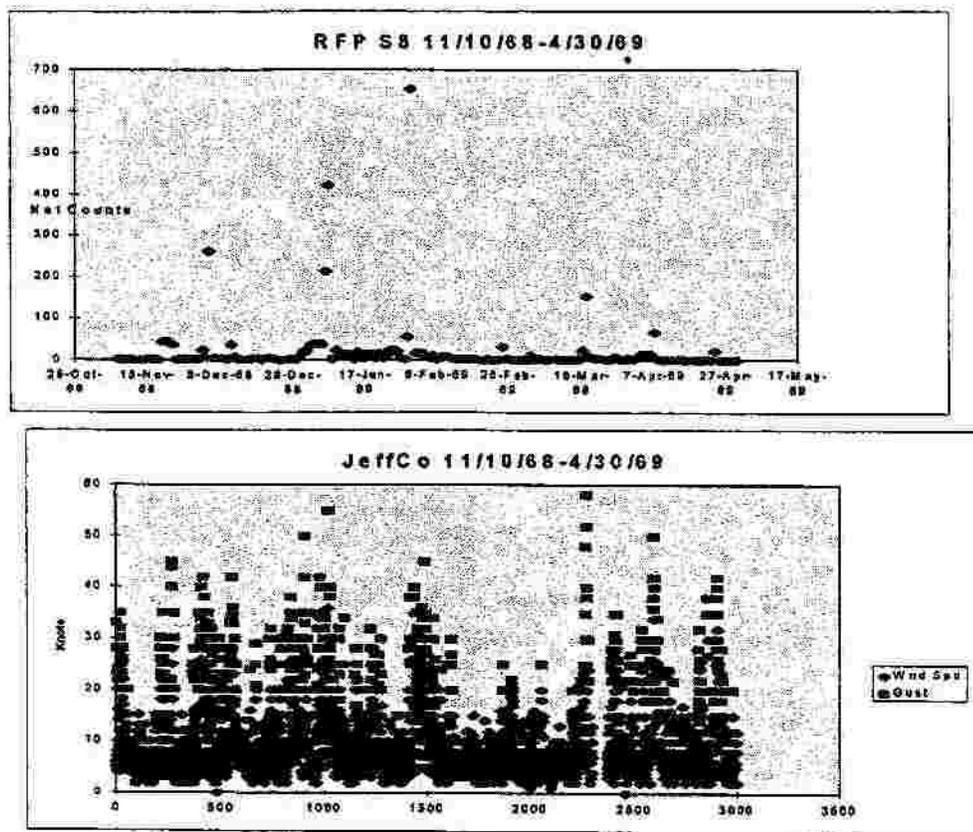
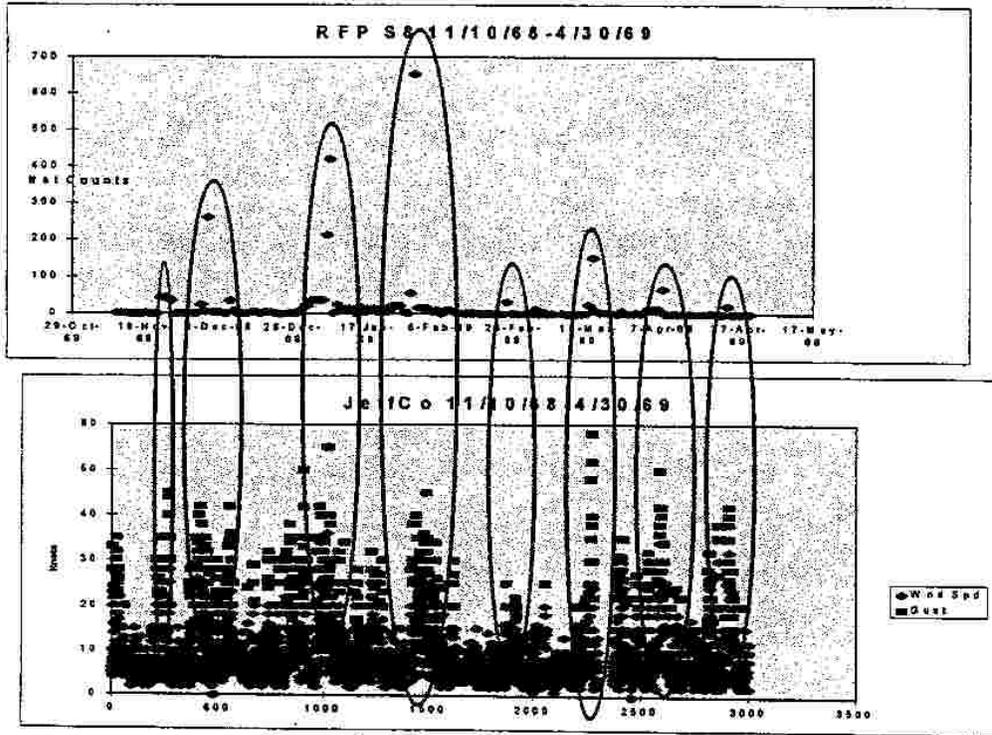
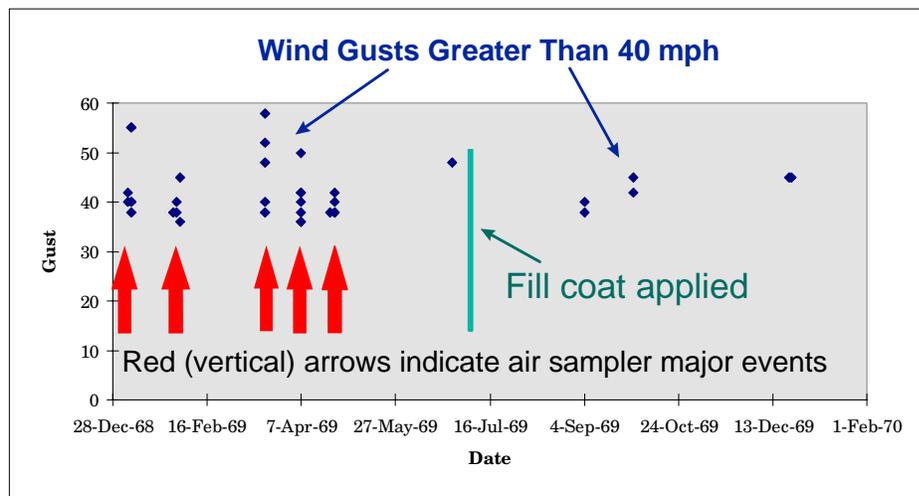
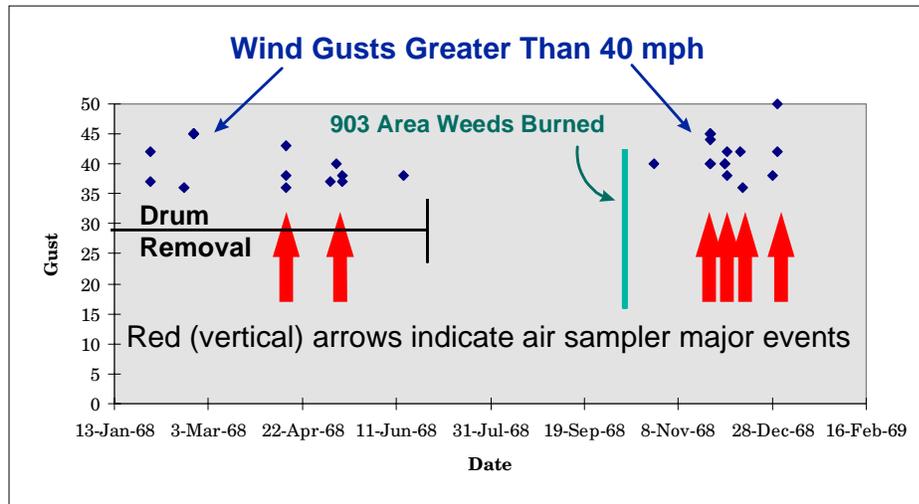


Figure 15. RFP S8 sampler and JeffCo data; horizontal axes (time) synchronized.



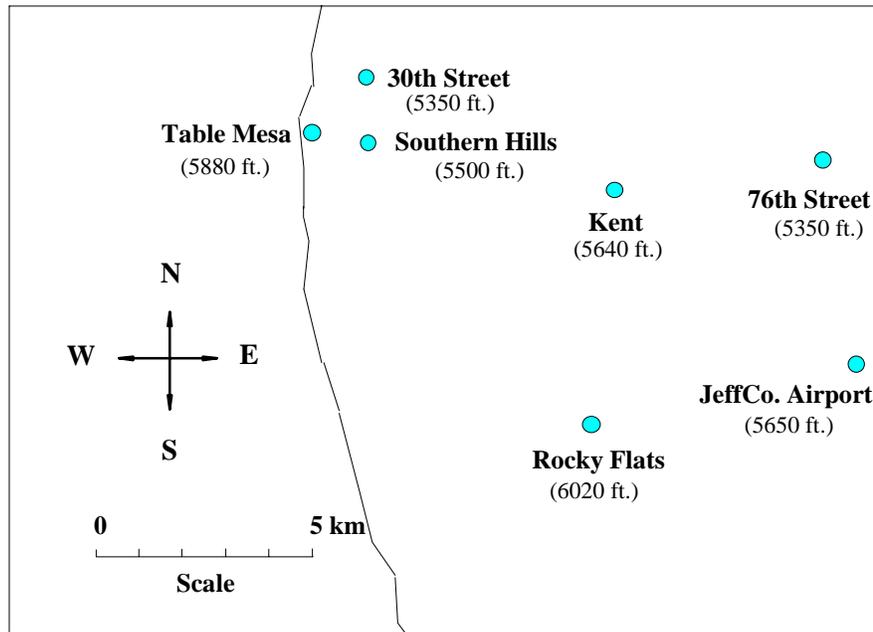
**Figure 16.** With synchronized time axes, S8 and JeffCo data show parallel wind and air concentration events.

When weather, air sample and disturbance information are displayed together, the apparent linkages among the three factors are clear. [Figures 17 and 18](#) present these three sets of information for 1968 and 1969 simultaneously. Jefferson County Airport wind gust data, modified to display only those gusts exceeding 40 mph, are displayed as small diamonds in the Figures below. Periods or events during which the 903 area soil surface was disturbed by, for example, drum removal or the burning of weeds are presented with text inserts as identifiers. Days when onsite air samplers (primarily the S8 sampler) near the 903 area showed high air concentrations are displayed as thick, vertical arrows (red arrows in the presentation version of the Figures below). It is clear that high air contamination periods are associated with high wind events, preceded by soil disturbance activities. Based on these observations, it is reasonable to pursue estimating 903 area releases for those key incidents in which disturbances were followed by high wind events. High resolution wind and weather data are required to carry out such analyses.



**Figures 17 and 18.** Comparing Jefferson County Airport wind gust data, 903 area disturbance activities, and major air sampler events near the 903 area.

RAC has recently discovered high-resolution meteorological 1968-1969 data sets (strip charts) from the National Center for Atmospheric Research (NCAR) in Boulder CO. The diagram below indicates the locations of these meteorological data stations relative to the Rocky Flats Plant. These data will supplement the Jefferson County Airport meteorological data when 903 area source term calculations are made.



**Figure 19.** NCAR Meteorological Stations near the RFP

**EVALUATION OF THE Gaus1 ATMOSPHERIC DISPERSION CODE**

Given an understanding of the 903 area’s history, wind data and air sampler records, we can proceed toward estimation of past releases from the area’s contaminated soil. After reviewing models available to simulate these releases, we focus initially on a model described by [Gifford and Porch](#) in 1993. The Gaus1 code represents one of the computerized models available to estimate wind-driven soil suspension. Other models are also being evaluated for potential use in this regard.

It is important to recognize that a number of variables can influence the rate of wind-driven suspension of soil. Healy, in a review of resuspension models, cites a 1974 report by Chepil in compiling Table 7, which lists factors influencing soil suspension ([Healy](#), 1980).

**Table 7. Key Factors Influencing Soil Suspension by Wind**

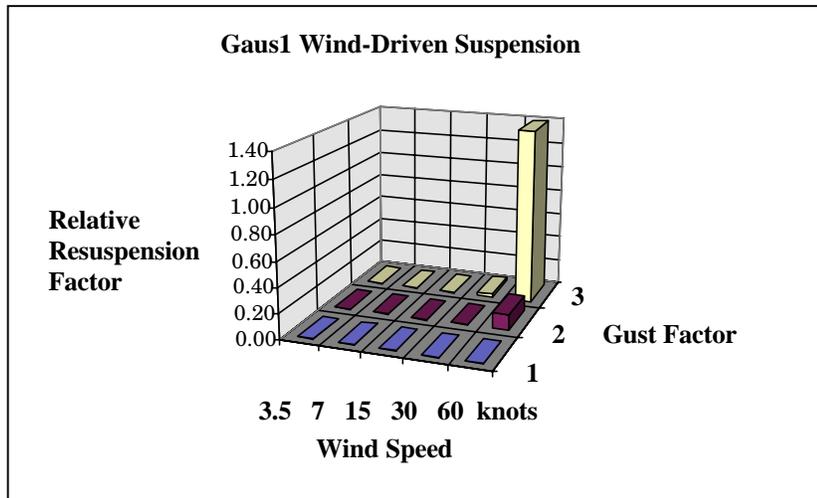
<b>Air</b>	<b>Ground</b>	<b>Soil</b>
velocity	roughness	structure
turbulence	cover	organic matter
density	obstructions	lime content
temperature	temperature	texture
pressure	topographic features	specific gravity
humidity		moisture content
viscosity		

The Gaus1 code is described by [Gifford and Porch](#) (1993) as a general purpose atmospheric dispersion code, running on the HP48GX programmable calculator, designed to evaluate straight-line Gaussian-puff and -plume formulas. The code takes into account many of the factors listed above in Table 7. While a number of other Gaussian dispersion-based computerized models are available, Gaus1 is unusual in that it explicitly provides for the calculation of soil contaminant suspension during gusty wind events. Our research indicates the extreme significance of high-wind events in the movement of 903-area plutonium contamination offsite. The research has also identified sets of meteorological data providing the wind speed and gust input required to implement the wind-driven suspension option within the Gaus1 code. For these reasons, an evaluation of the Gaus1 model algorithms is of interest.

Gaus1 calculates a Resuspension Factor (the air concentration in grams per cubic meter divided by the soil surface contaminant concentration in grams per square meter) as a function of wind speed to the third power or higher. The code’s calculations of wind-driven suspension are very sensitive to wind speed, with relatively small changes in wind speed leading to large changes in the soil suspension rate. The literature reports values for this wind speed dependence ranging from a power of one to as high as ten. This enormous range is based on actual observations by many researchers under a variety of field conditions. However, the differences are largely a function of the nature and physical condition of the surface being wind-suspended. For example, conditions of open, dry desert or disturbed, dusty soils lead to high observed values, while moist, highly-vegetated terrain reflects low values. [Langer](#) (1983) states that, “...gravimetric analysis indicates a power function relation between amount of resuspended dust and the resuspending windspeed with an exponent value of 2.9 +/- 1.1.” Langer’s observations are based on field wind erosion studies on the 903

pad field and adjacent dirt roads, and support use of an exponent value range centering on 3 for Rocky Flats calculations.

Gaus1 also relates soil contamination suspension to a Gust Factor, defined as the “multiple of the average wind speed, when gusts occur.” Incorporation of the gust factor may provide a more realistic reflection of soil contamination releases during the high and variable wind episodes that occur in the Rocky Flats vicinity. The results, evident in Figure 20, are extremely large differences between Gaus1 soil suspension estimates for low wind and gust speeds (3-4 knots, no gusting), versus speeds of 60 knots with significant gusting.



**Figure 20.** Gaus1 sensitivity to wind gust data. The “Gust Factor” is a multiple of the base wind speed when gusting occurs. One knot = 1.15 mph.

The extreme wind speed sensitivity of Gaus1 and similar models implies that the use of average rather than maximum wind speeds underpredicts releases very significantly, when evaluating the short periods during which wind speeds were very high. Contaminant release totals will in fact be dominated by a relatively few, short duration windstorm events. Estimating releases for these few events is the focus of *RAC*'s 903 area Phase II research. Given date-specific plutonium release data, dose and risk estimates may then be calculated for the specific few days when the largest releases occurred, rather than averaging releases over an extended period.

*RAC* has converted the Gaus1 code to a personal computer spreadsheet format, and is using the converted version to estimate 903 area releases for five specific periods when air sampler data indicate that the majority of plutonium releases took place.

## ANALYSIS OF AIR SAMPLING DATA

### Sources of bias in air sampling data

The measurements of total long-lived alpha activity in air at the S8 sampler are critical to at least one approach to estimating releases from the 903 area. [Rope et al.](#) (1999) evaluate sources of uncertainty and bias for these data. Note that [Langer](#) (1986), reporting on a 1983-84 study, considered the problems associated with sampling airborne particles during high-wind events. The study showed that the concentration of respirable particles remained

constant between 1 and 10 m height above ground, but concluded that current sampling devices may not function properly at wind speeds above 50 km hr<sup>-1</sup>. Langer reported that, during a windstorm reaching 80 km hr<sup>-1</sup>, a size-selective sampler seriously underestimated dust (Pu) concentration in air. If the measurement of air concentrations is seriously in error during such events, actual releases could be significantly higher than indicated by the measurements. [ChemRisk](#) (1994a) reached similar conclusions.

A primary source of bias is sampler collection efficiency. The collection efficiency of an air sampler is a measure of how accurately the sampler captures the true airborne concentration of the contaminant of interest. For example, if the true airborne concentration is 100 units, and the air monitoring procedure produces an estimate of 80 units, then the collection efficiency would be 80%. (Analytical bias is not considered here).

The collection efficiency of an air sampler can be viewed as having two components:

1. The *inlet collection efficiency* of the sampling device (how accurately the device draws the ambient aerosol into the filter);
2. The *filter collection efficiency* (the amount of the material drawn into the filter that is retained by the filter, i.e., does not pass through it).

Properties of the air sampler which influence collection efficiency include:

- Inlet face velocity of the incoming air (related to flow rate)
- Placement height and orientation
- Type of sampler shelter or housing
- Filter characteristics

Properties of the environment, such as wind speed and orientation with respect to the sampler inlet, also affect collection efficiency. The particle size (aerodynamic diameter) of the contaminant aerosol being collected is another key property of the environment affecting collection efficiency. It is useful — in conducting a general discussion of this issue — to think in terms of *coarse* and *fine* aerosols. Small particles making up fine aerosols tend to follow the air stream into the sampler; the large particles in coarse aerosols have sufficient inertia that they tend to move in straight lines, not following curved air trajectories. For coarse aerosols, aerodynamic effects in the air outside the sampler are strongly dependent on wind speed, turbulence, orientation effects, etc.; for fine aerosols, such effects are much smaller. Note that [Langer](#) (1987), based on research east of the 903 pad in 1985, states that, “About 70% of the plutonium activity resides on the coarse particles, which represent 60% of the dust. The plutonium activity is approximately proportional to the dust mass. It had been expected that the activity would be proportional to the surface area.” [Little and Whicker](#) (1978) note that, “For all soil depths,...the highest Pu-239+240 activity was associated with submicron size soil particles. Two-thirds of the total Pu was found in the top 5 cm of the soils.” (from [Litaor](#), 1994). The apparent discrepancy between these two contemporary observations has not yet been resolved.

Collection of coarse aerosols is sometimes accomplished by various deposition collectors such as sticky paper and dust deposit gauges. A limited amount of this type of sampling was conducted at Rocky Flats ([Rope et al.](#) 1999). Air samplers are used to collect the finer aerosols. They are generally inefficient collectors of coarse aerosols, due to poor inlet collection efficiency and reproducibility ([Vincent](#) 1989).

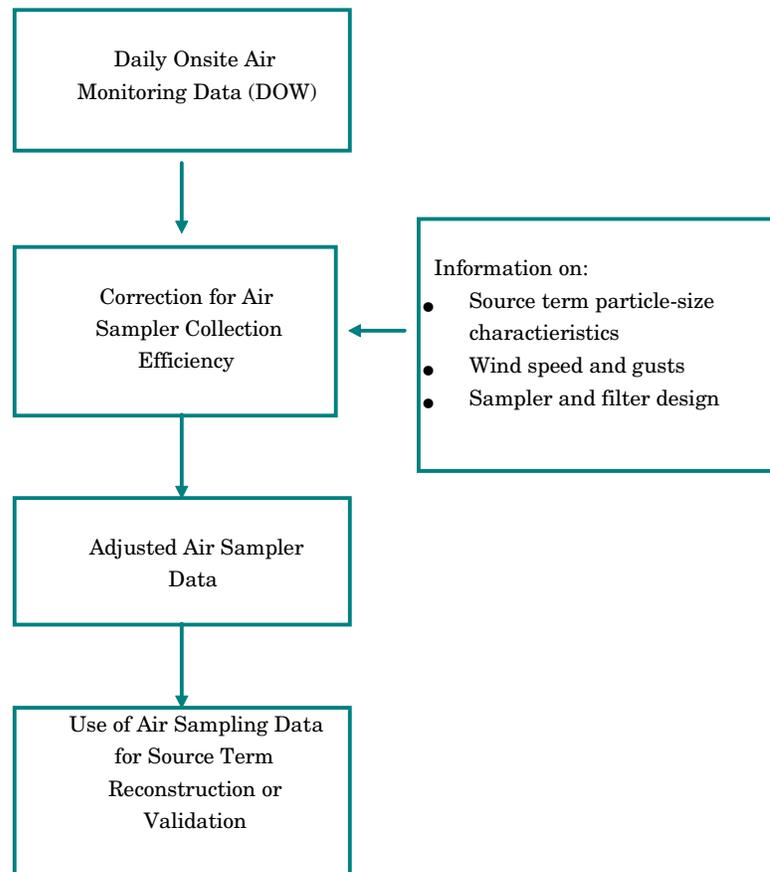
It is widely observed that true isokinetic sampling of air under field conditions is impossible due to changing wind velocities and directions. [Garland and Nicholson](#) (1991) summarize some important features of studies of air sampler performance:

“...all the published tests show some common features: the sampling efficiency declines with (*increasing*) particle size and also with (*increasing*) ambient wind speed. .... Orientation may be important for non-symmetrical inlets. The dependence of efficiency on so many parameters makes it improbable that any correction can be successfully applied to filter samplers operating in field conditions. Few of the filter samplers investigated have had a satisfactory sampling efficiency for particles larger than 30  $\mu\text{m}$ , and it is unlikely that any can sample particles larger than 100  $\mu\text{m}$ .” [Note: words in italics added for clarity.]

Several wind-tunnel and field inter-comparison experiments on the Rocky Flats-designed Surveillance Air Sampler used in the 1970s were used to evaluate the spectrum of particle sizes collected. The collection efficiency of these high-volume samplers as a function of particle size and wind speed is discussed by [Rope et al.](#) (1999). During the time of interest for primary releases from the 903 area, low volume air samplers were used. The collection efficiency of those samplers was assessed by examining the technical literature for other low-volume samplers ([Rope et al.](#) 1999). Other related data quality issues addressed by Rope et al. include filter collection efficiency, dust loading of filters, and counting errors.

Of the Rocky Flats samplers, the onsite samplers and those downwind of the 903 area were probably faced with the largest proportion of coarse aerosols of Pu. Studies have been conducted (mainly in the 1970s and later) of the concentration and particle sizes of suspended Pu at different distances and heights above the ground. Because of the changing nature of the releases from the 903 area, as well as the routine releases from the stacks, the particle size distributions of released Pu (and hence the air sampler collection efficiencies) are time-dependent. During the risk assessment portion of Phase II, we will integrate the air monitoring data with the modeling of dispersion of releases. Depending on how the data are to be used, we may either correct the data for sampler efficiency (see [Figure 21](#) below) or treat the sampler data as a fine-particle fraction.

The collection efficiency is an important consideration in dose reconstruction when the air monitoring data are used for verification of the source term/model validation. However, it should be emphasized that the particle size range that is important for internal dose assessment should have been efficiently collected by the samplers. In fact, the total mass concentration of radioactive particles is a rather poor indication of the inhalation hazard of an aerosol. There is now the widespread view that, if just one aerosol fraction is to be collected relevant to health for a wide range of types of aerosol in the ambient atmosphere, then that fraction should be relevant to the deposition of particles in the lung ([Vincent](#) 1989). Inhalability and deposition of particles in the lungs is a function of particle size, and modern-day samplers are often designed to cut off the largest particle sizes and collect only the respirable fractions, sometimes subdivided into certain size categories. The respirable fraction is generally considered to be that between 1 and 10 micrometers in effective diameter. Depending on the particle sizes of the source term, the total mass concentration and the respirable mass concentration may be quite different.



**Figure 21.** Air monitoring data may be corrected for sources of bias (such as collection efficiency), as shown here. Alternatively, the data may be interpreted as representing only a fine particle fraction (Rope et al. 1999).

### Isotopic composition of long-lived alpha-emitting radionuclides in ambient air

Total long-lived alpha (TLL $\alpha$ ) activity is composed of Rocky Flats-released materials (Pu, Am, U), fallout alpha emitters (mainly Pu), and natural alpha emitters like U, Th, and their decay products including radium. A major issue concerns interpretation of the gross alpha data prior to 1970. In Phase I of this study, ChemRisk concluded, based on review of a number of analyses, that the percentage of total long-lived activity in airborne effluents before 1973 which was associated with  $^{241}\text{Am}$  was 18%, and that associated with  $^{239,240}\text{Pu}$  was 82% (ChemRisk 1994b, p. 108). However, in the ambient environment, alpha activity is also present from natural radioactivity and from weapons fallout. If the onsite air data are to be used in a quantitative way to develop or validate the 903 area source term, the composition of those TLL $\alpha$  measurements must be investigated.

### Contributions from natural alpha-emitting radionuclides

Two approaches were used to estimate the alpha activity in ambient air due to naturally-occurring alpha emitters. The first was examination of data presented in a special study by Illsley (1982), which was conducted to determine the contributions to the TLL $\alpha$  (total long-lived alpha) count made by emitters other than plutonium and americium.

The sampling and analysis protocol used by Illsley is of interest. Over 100 individual filter papers from samplers S-3, S-14, S-23, and S-24 were collected during the months of April, May and June for the years 1978 and 1979. Filters were composited by month to yield a total of 24 samples (1 sample/month-sampler  $\times$  4 samplers  $\times$  3 months/year  $\times$  2 years). The samples were submitted (blind to the analyst) to the Radiological and Environmental Sciences Laboratory (RESL), and to the Los Alamos National Laboratory (LANL). RESL used a sequential radiochemical procedure for the analysis of  $^{226}\text{Ra}$ ,  $^{228}\text{Th}$ ,  $^{232}\text{Th}$ ,  $^{230}\text{Th}$ ,  $^{238}\text{U}$ ,  $^{235}\text{U}$ ,  $^{234}\text{U}$ ,  $^{239,240}\text{Pu}$ ,  $^{238}\text{Pu}$  and  $^{241}\text{Am}$ . Blank samples were analyzed and results subtracted from the sample values. LANL used several different types of procedures for their analyses. Pu and Am were determined by alpha spectrometry following chemical separations. Uranium isotopes were measured by delayed neutron assay after reactor irradiation. The isotopic ratios of uranium isotopes were determined by using the  $^{239}\text{Np}$  from  $^{238}\text{U}$  and the  $^{143}\text{Ce}$  fission product from  $^{235}\text{U}$ . Thorium and radium isotopes were not measured by LANL.

Illsley presented values of pCi per sample for the seven naturally occurring alpha emitters and the three man-made alpha emitters, the total pCi per sample, and the percent of the total pCi due to Pu+Am. The activities were not expressed as a concentration (per unit volume of air). All activities were detectable with the exception of  $^{238}\text{Pu}$  in eight out of the 24 samples. A summary of the contribution of Pu+Am to total activity is shown in [Table 8](#). On average, between 14 and 22% of the total long-lived alpha activity was associated with Pu and Am and the remainder (78–86%) was associated with naturally-occurring alpha emitters. The sample stations did not vary systematically in terms of total activity; all stations contained total Pu+Am in the range of 0.4–3 pCi. Other conclusions made by Illsley include:

- Absolute amounts of Pu and Am appear to be almost the same at all four sampling stations with slightly higher amounts at the N and W samplers.
- Amounts of U and Th were significantly higher W and N of the plant, causing the percentages of Pu and Am to be higher in the E and S samples.
- It is not unexpected that amounts of U and Th are higher in the air samples collected N and W of the Plant, because these soils are known to contain greater amounts of natural radioactivity.

In order to compute the *concentration* of naturally occurring alpha activity, the volume of the air sampled is needed. Illsley indicated that the sampler flow rate was 40 cfm (19 liters per second), which is confirmed in the site annual environmental monitoring report for 1978. The air volume sampled in a month is thus:

$$\text{Volume} = 19 \text{ L s}^{-1} \times 86400 \text{ s day}^{-1} \times 30 \text{ days mo}^{-1} = 4.9 \times 10^7 \text{ L, or } 4.9 \times 10^4 \text{ m}^3$$

The total activities measured by the radiochemical analysis of the air filters were divided by this sample volume to obtain the concentrations shown in [Table 9](#).

**Table 8. Percent of Total Measured Alpha Activity Due to Pu and Am in Air Samples Around Rocky Flats in 1978–1979**

Station	% Activity Due to Pu and Am	
	Range	Average
S-3	6.9-39.2	14.0
S-14	10.4-25.4	15.8
S-23	11.9-35.8	23.3
S-24	14.1-34.4	21.8

Note: Applicable to measurements of long-lived activity collected on filter paper from ambient air monitoring. In the environment, other short-lived decay products of uranium and thorium are also present.

**The dust loading approach to determining natural alpha activity in air**

A method that was used to estimate alpha activity in ambient air from naturally-occurring alpha emitters is a simple dust-loading approach. The two main variables needed to implement this approach are the amount of soil suspended in the air (dust loading) and the concentrations of naturally occurring alpha emitters in soil. This second variable is addressed by [Richmond](#) (1970). The attachments to his memo on naturally occurring radioactivity in soil at Rocky Flats provide radiochemical results for alpha activity in seven soil samples including four within two miles of the Rocky Flats property fence, two from Denver, and one 45 miles east of the RFP. Although the Pu content varies greatly, the total natural alpha activity is relatively constant (ranging from 31.3 to 58.7 and averaging 44 dpm g<sup>-1</sup>). After subtracting the short-lived alpha activity components, the average long-lived alpha concentration in soil is 18 dpm g<sup>-1</sup>. The monthly average total suspended particulates in air around the RFP boundary ranged from 20 to 61 µgrams (µg) per cubic meter air in 1994, with an annual grand average of 34 µg m<sup>-3</sup> ([APCD](#) 1994). This dust loading corresponds to a total long-lived alpha activity of 0.28 fCi m<sup>-3</sup> in air, compared to 0.2 fCi m<sup>-3</sup> determined from the four sampling locations analyzed by Illsley.

**Table 9. Estimated Concentrations of Naturally-Occurring Long-Lived Alpha Emitters in Ambient Air Around Rocky Flats**

	Long-Lived Alpha Activity (fCi m <sup>-3</sup> ) at Sampler			
	S-3 (N security fence)	S-14 (W security fence)	S-23 (S along Woman Creek drainage)	S-24 (NE near holding ponds)
<b>mean<sup>a</sup></b>	0.31	0.20	0.12	0.10
<b>S.D.</b>	0.21	0.12	0.10	0.05
The Grand Average and Std. deviation for all four locations: 0.2 +/- 0.1 fCi m <sup>-3</sup>				
<sup>a</sup> Mean and standard deviation of six monthly composites.				

In conclusion, both methods used to establish the natural long-lived alpha radioactivity concentration in air produce estimated concentrations which are in good agreement, and which are <0.5 fCi m<sup>-3</sup>. A reasonable point estimate might be 0.25 fCi m<sup>-3</sup>.

### **Alpha activity in air from weapons fallout**

The second source of alpha activity in ambient air, which is not related to Rocky Flats emissions, is weapons fallout. The main contributors to alpha activity in fallout are isotopes of plutonium and americium ([UNSCEAR 1982](#)). As discussed in our Task 4 report ([Rope et al. 1999](#)), the monitoring of plutonium in Denver air began in 1965. Monthly or quarterly average concentrations of total plutonium in air ranged from 0.03 to 0.24 fCi m<sup>-3</sup> between November 1965 and 1970. Therefore, the total plutonium fallout concentrations were less than or equal to naturally-occurring alpha activity concentrations of around 0.25 fCi m<sup>-3</sup>. However, it is likely that an individual daily concentration from fallout could have been perhaps 10 times the monthly average, or more, as there were considerable day-to-day variations in fallout activity levels. Americium activity concentrations from fallout were less than one percent of the total plutonium fallout activity ([UNSCEAR 1982](#)).

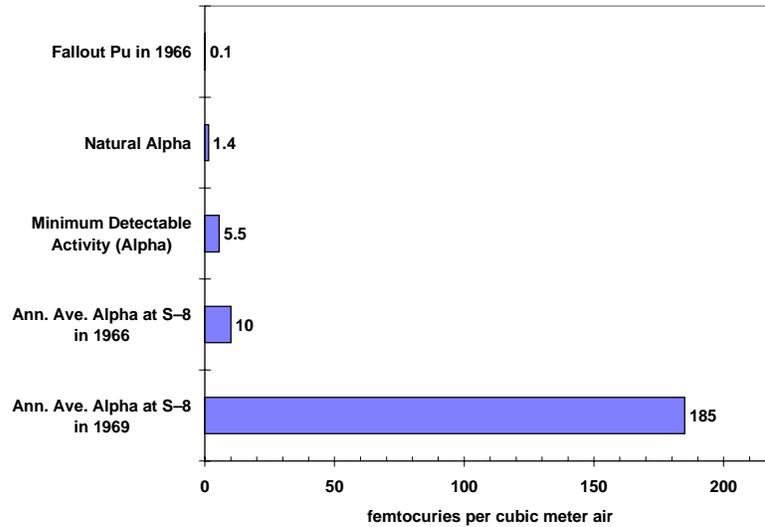
### **Rocky Flats versus background contributions to alpha activity in air**

In summary, this evaluation of non-Rocky Flats sources of alpha activity in ambient air has produced estimated concentrations for natural and fallout activity which theoretically could be subtracted from a gross measurement to obtain the net contribution from Rocky Flats releases. However, fallout and natural LL $\alpha$  activity in air might have together totaled around 0.5 fCi m<sup>-3</sup> in the 1960s. The sampling and analysis method used in the 1960s for monitoring alpha activity in air was not sensitive enough to measure these low levels. The minimum detectable concentration for daily air samples was 5.5 fCi m<sup>-3</sup>, or 10 times our estimated background in the 1960s.

In contrast, concentrations measured in air near the 903 pad in the late 1960s frequently resulted in monthly averages (of daily measurements) exceeding 50 fCi m<sup>-3</sup>, with individual daily concentrations frequently over several hundred fCi m<sup>-3</sup> (see [previous section](#)). These perspectives are illustrated in [Figure 22](#). In the case of the 903 pad assessment, the concentrations in onsite air near the pad in the late 1960s are high enough that the background correction would be slight and quantitative use of the data is warranted. Levels of TLL $\alpha$  above the minimum detectable activity can be attributed to Rocky Flats materials.

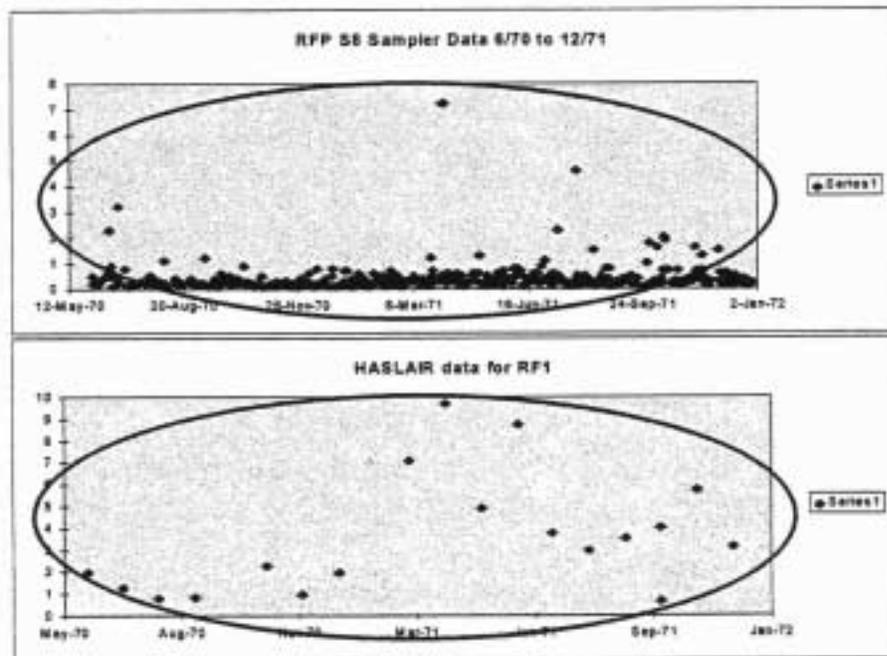
### **Comparing RFP and other air sampler data**

The estimation of health effects associated with airborne releases from the Rocky Flats Plant is sensitive to the proper identification of the radioactive isotope actually present at the time high airborne concentrations were observed. However, airborne monitoring for the 903 area releases is reported as gross alpha activity only (decayed to minimize the influence of naturally-present alpha emitters such as uranium and thorium, and corrected for alpha counter background). There is strong evidence that the S8 air sampler data reflect the presence of airborne plutonium. However, independent analysis of the plutonium contribution to the measured gross alpha activity would be of value. Plutonium-specific data from two years following 903 area remediation were evaluated to determine whether they might be useful in this regard. Plutonium measurements made by the Health and Safety Laboratory in 1970 and 1971 (after the conclusion of major 903 area releases), may be compared to continuing S8 air sampler measurements made by RFP staff during the same period.



**Figure 22.** Perspectives on alpha activity concentrations in air. The air sampling method used by Dow in the 1960s was not adequate to measure natural or fallout long-lived alpha activity. Therefore, levels above the minimum detectable activity can be attributed to Rocky Flats materials. (Based on data from [Table 4.](#))

The Health and Safety Laboratory began air sampling at the S8 sampler location in 1970, and analyzed their filter media specifically for plutonium. Data from the HASL and RFP S8 samplers for an 18 month period of interest are presented below in Figure 23. These data show relatively low airborne plutonium levels, since remediation of the primary 903 contaminated area was complete by mid-1969. While inspection of the two parallel data sets indicates some count rate increases on proximate dates, no clear linkages are present and this line of inquiry has been dropped.



**Figure 23.** Comparison of HASL and RFP S8 data for period of interest.

**Note concerning  $^{241}\text{Am}$  concentrations in air**

The apportioning of the total long-lived alpha concentrations in onsite air into the various isotopes requires further effort. The isotopic ratios (including the ingrowth of  $^{241}\text{Am}$  from  $^{241}\text{Pu}$ ) in the waste oil, which was the source of the contamination, should be examined. The preliminary comparison of HASL air sampling for Pu with TLL $\alpha$  monitoring east of the 903 area in 1970–71 indicates that about 40% of the TLL $\alpha$  at that time might be Pu. Other environmental information, such as alpha spectrometry analyses of vegetation samples conducted in the 1960s, is being examined to possibly add insight into the isotopic composition of onsite contamination.

**CONCLUSIONS**

An examination of the history of the 903 area strongly suggests that offsite plutonium releases were dominated by a few high wind events following mechanical disturbance of the contaminated soils. Several different types of evidence have been collected to allow the date-specific estimation of the 903 area's Pu source term during the 1968-1969 period of greatest releases:

- 1) A combination of photographic, documentary and interview evidence supports development of a range of estimates of total plutonium leaked to soil.
- 2) Meteorological and soils data have been discovered to support models providing soil dust resuspension estimates.
- 3) Air sampling data are available to calibrate such estimates, or to provide independent estimates of 903 area releases.

The next stage of this study (to be reported separately) uses this information to provide uncertainty-bounded plutonium release estimates for the 903 area. This work will support dose and risk calculations. Because the source term estimates being developed are specific to one- to two-day high-wind events, date-specific meteorological data may then be used to estimate atmospheric dispersion, dose and risk to populations located in the downwind directions of interest during the times of the specific suspension events.

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1) Many references listed below are unpublished or not readily available elsewhere, and were discovered during the course of ChemRisk and RAC research on this project. Copies of such documents are archived at the Colorado Department of Public Health and Environment.

2) The complete Radiological Assessments Corporation Topical Bibliography (listing some 1300 documents concerning the 903 area or soil resuspension in general) is available on 3.5" floppy disk from the Colorado Department of Public Health and Environment, Rocky Flats Health Studies Archives.

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**APPENDIX A**  
**HIGH ALPHA COUNTS FROM ONSITE SAMPLERS**

Table A-1 contains all the daily measurements of total long-lived alpha activity which were greater than or equal to 5 cpm (counts per minute). The data were taken from handwritten sheets stored in the Federal Records Center. The data in the table are sorted three ways, by station number, by date, and by the cpm value. The date range encompassed by this data base is October 14, 1964 through December 31, 1971.

**Table A-1. Daily Measurements of Total Long-Lived Alpha Activity  
Greater Than or Equal to 5 cpm**

Sorted by Station			Sorted by Date			Sorted by cpm		
Station	Date	net cpm	Station	Date	net cpm	Station	Date	net cpm
S1	10/7/68	5.7	S8	12/10/64	6.4	S4	5/15/68	5
S1	1/24/66	5.9	S8	12/15/64	29	S5	6/17/70	5.1
S1	11/2/65	7.6	S8	12/21/64	6.7	S6	9/19/66	5.1
S1	6/16/70	9.2	S8	12/22/64	19.6	S6	5/22/68	5.1
S1	8/7/67	9.9	S3	1/13/65	9.9	S8	2/4/69	5.1
S1	9/6/66	10.6	S1	11/2/65	7.6	S8	2/26/70	5.1
S2	12/6/65	5.7	S2	12/6/65	5.7	S8	7/15/68	5.2
S3	4/22/68	5.3	S5	12/6/65	8.1	S3	4/22/68	5.3
S3	8/23/67	5.5	S6	12/6/65	8.7	S8	6/6/69	5.3
S3	5/14/68	9.7	S1	1/24/66	5.9	S8	6/7/69	5.3
S3	1/13/65	9.9	S1	9/6/66	10.6	S8	6/8/69	5.3
S4	5/15/68	5	S6	9/19/66	5.1	S8	9/13/67	5.4
S4	12/27/66	7.3	S4	11/8/66	7.6	S3	8/23/67	5.5
S4	11/8/66	7.6	S4	12/27/66	7.3	S50	8/17/71	5.5
S5	6/17/70	5.1	S8	1/26/67	12	S8	1/31/68	5.5
S5	1/6/69	6.2	S8	2/13/67	25.3	S8	2/3/70	5.5
S5	12/6/65	8.1	S7	7/13/67	6.8	S1	10/7/68	5.7
S5	6/18/70	54.5	S1	8/7/67	9.9	S2	12/6/65	5.7
S6	9/19/66	5.1	S8	8/14/67	5.9	S8	10/24/67	5.7
S6	5/22/68	5.1	S3	8/23/67	5.5	S8	4/22/68	5.7
S6	10/31/68	6.1	S8	9/13/67	5.4	S8	5/15/68	5.8
S6	6/18/70	6.6	S8	10/18/67	6.2	S8	7/29/68	5.8
S6	5/21/68	6.9	S8	10/19/67	14.6	S1	1/24/66	5.9
S6	4/24/68	7	S8	10/20/67	6.8	S8	8/14/67	5.9
S6	12/6/65	8.7	S8	10/21/67	6.8	S7	4/25/68	6
S6	4/16/68	9.7	S8	10/22/67	6.8	S6	10/31/68	6.1
S6	7/15/71	10.4	S8	10/23/67	18.1	S5	1/6/69	6.2
S6	7/10/69	12.2	S8	10/24/67	5.7	S7	6/18/68	6.2
S6	1/7/69	13.4	S8	10/25/67	6.6	S8	10/18/67	6.2
S6	6/4/68	39	S8	10/30/67	6.4	S8	12/4/68	6.2
S7	4/25/68	6	S8	11/9/67	7.2	S8	11/15/67	6.3
S7	6/18/68	6.2	S8	11/15/67	6.3	S8	3/6/69	6.3
S7	7/13/67	6.8	S8	11/30/67	7.4	S8	12/10/64	6.4

Table A-1. (cont.)

Sorted by Station			Sorted by Date			Sorted by cpm		
Station	Date	net cpm	Station	Date	net cpm	Station	Date	net cpm
S7	6/24/68	6.9	S8	12/5/67	13.7	S8	10/30/67	6.4
S7	8/13/70	7.1	S8	12/6/67	67.9	S8	5/29/68	6.5
S7	4/22/68	7.2	S8	1/3/68	10.9	S8	5/30/68	6.5
S7	5/2/68	7.4	S8	1/31/68	5.5	S10	6/8/70	5.9
S7	5/19/69	7.9	S8	2/1/68	9.5	S6	6/18/70	6.6
S7	5/13/68	8.3	S8	3/18/68	36.3	S8	10/25/67	6.6
S7	12/30/68	8.4	S8	3/26/68	23.9	S8	12/21/64	6.7
S7	2/24/70	8.9	S8	3/27/68	25.4	S7	7/13/67	6.8
S7	4/9/68	9.1	S8	3/28/68	13.9	S8	10/20/67	6.8
S7	6/10/68	9.6	S8	4/1/68	14.1	S8	10/21/67	6.8
S7	5/27/68	9.8	S8	4/2/68	13.1	S8	10/22/67	6.8
S7	1/9/69	10.7	S7	4/9/68	9.1	S6	5/21/68	6.9
S7	5/8/68	11.2	S8	4/11/68	34.9	S7	6/24/68	6.9
S7	10/16/68	12.7	S8	4/12/68	34.9	S6	4/24/68	7
S7	5/22/68	15.3	S8	4/13/68	34.9	S7	8/13/70	7.1
S7	2/18/69	18.2	S8	4/14/68	34.9	S7	4/22/68	7.2
S7	4/10/69	18.2	S8	4/15/68	9	S8	11/9/67	7.2
S7	6/4/68	19.9	S6	4/16/68	9.7	S8	2/7/69	7.2
S7	1/7/69	130.3	S3	4/22/68	5.3	S8	2/8/69	7.2
S8	2/4/69	5.1	S7	4/22/68	7.2	S8	2/9/69	7.2
S8	2/26/70	5.1	S8	4/22/68	5.7	S8	4/2/71	7.2
S8	7/15/68	5.2	S6	4/24/68	7	S8	4/3/71	7.2
S8	6/6/69	5.3	S7	4/25/68	6	S8	4/4/71	7.2
S8	6/7/69	5.3	S7	5/2/68	7.4	S4	12/27/66	7.3
S8	6/8/69	5.3	S8	5/6/68	26.5	S7	5/2/68	7.4
S8	9/13/67	5.4	S8	5/7/68	20	S8	11/30/67	7.4
S8	1/31/68	5.5	S7	5/8/68	11.2	S1	11/2/65	7.6
S8	2/3/70	5.5	S7	5/13/68	8.3	S4	11/8/66	7.6
S8	10/24/67	5.7	S8	5/13/68	86.1	S50	12/11/68	7.8
S8	4/22/68	5.7	S3	5/14/68	9.7	S7	5/19/69	7.9
S8	5/15/68	5.8	S4	5/15/68	5	S8	3/27/69	8
S8	7/29/68	5.8	S8	5/15/68	5.8	S8	7/14/69	8
S8	8/14/67	5.9	S6	5/21/68	6.9	S5	12/6/65	8.1
S8	10/18/67	6.2	S6	5/22/68	5.1	S51	10/30/68	8.1
S8	12/4/68	6.2	S7	5/22/68	15.3	S7	5/13/68	8.3
S8	11/15/67	6.3	S7	5/27/68	9.8	S7	12/30/68	8.4
S8	3/6/69	6.3	S8	5/29/68	6.5	S8	2/3/69	8.4
S8	12/10/64	6.4	S8	5/30/68	6.5	S8	8/6/69	8.5
S8	10/30/67	6.4	S8	6/3/68	19	S8	12/19/69	8.5
S8	5/29/68	6.5	S6	6/4/68	39	S8	12/20/69	8.5
S8	5/30/68	6.5	S7	6/4/68	19.9	S8	12/21/69	8.5
S8	10/25/67	6.6	S8	6/4/68	23	S8	12/12/68	8.6
S8	12/21/64	6.7	S7	6/10/68	9.6	S6	12/6/65	8.7
S8	10/20/67	6.8	S8	6/14/68	16.9	S7	2/24/70	8.9
S8	10/21/67	6.8	S8	6/15/68	16.9	S8	4/15/68	9
S8	10/22/67	6.8	S8	6/16/68	16.9	S7	4/9/68	9.1
S8	11/9/67	7.2	S7	6/18/68	6.2	S8	3/20/69	9.1

**Table A-1. (cont.)**

Sorted by Station			Sorted by Date			Sorted by cpm		
Station	Date	net cpm	Station	Date	net cpm	Station	Date	net cpm
S8	2/7/69	7.2	S7	6/24/68	6.9	S1	6/16/70	9.2
S8	2/8/69	7.2	S8	7/12/68	9.4	S8	12/30/68	9.2
S8	2/9/69	7.2	S8	7/13/68	9.4	S8	7/12/68	9.4
S8	4/2/71	7.2	S8	7/14/68	9.4	S8	7/13/68	9.4
S8	4/3/71	7.2	S8	7/15/68	5.2	S8	7/14/68	9.4
S8	4/4/71	7.2	S8	7/29/68	5.8	S8	2/1/68	9.5
S8	11/30/67	7.4	S8	9/17/68	40.3	S7	6/10/68	9.6
S8	3/27/69	8	S1	10/7/68	5.7	S8	1/13/69	9.6
S8	7/14/69	8	S7	10/16/68	12.7	S3	5/14/68	9.7
S8	2/3/69	8.4	S51	10/30/68	8.1	S6	4/16/68	9.7
S8	8/6/69	8.5	S6	10/31/68	6.1	S7	5/27/68	9.8
S8	12/19/69	8.5	S8	11/22/68	44.8	S1	8/7/67	9.9
S8	12/20/69	8.5	S8	11/23/68	44.8	S3	1/13/65	9.9
S8	12/21/69	8.5	S8	11/24/68	44.8	S6	7/15/71	10.4
S8	12/12/68	8.6	S8	11/25/68	35.1	S1	9/6/66	10.6
S8	4/15/68	9	S8	12/3/68	23.6	S7	1/9/69	10.7
S8	3/20/69	9.1	S8	12/4/68	6.2	S8	6/24/69	10.8
S8	12/30/68	9.2	S8	12/5/68	261.5	S8	1/3/68	10.9
S8	7/12/68	9.4	S50	12/11/68	7.8	S8	1/23/69	11
S8	7/13/68	9.4	S8	12/11/68	35.7	S8	2/5/69	11
S8	7/14/68	9.4	S8	12/12/68	8.6	S8	3/4/69	11.1
S8	2/1/68	9.5	S7	12/30/68	8.4	S7	5/8/68	11.2
S8	1/13/69	9.6	S8	12/30/68	9.2	S8	1/26/67	12
S8	6/24/69	10.8	S8	12/31/68	22.2	S6	7/10/69	12.2
S8	1/3/68	10.9	S8	1/1/69	22.2	S7	10/16/68	12.7
S8	1/23/69	11	S8	1/2/69	36.7	S8	6/26/69	12.7
S8	2/5/69	11	S8	1/3/69	38.8	S8	6/25/69	12.9
S8	3/4/69	11.1	S8	1/4/69	38.8	S8	4/2/68	13.1
S8	1/26/67	12	S8	1/5/69	38.8	S6	1/7/69	13.4
S8	6/26/69	12.7	S5	1/6/69	6.2	S8	12/5/67	13.7
S8	6/25/69	12.9	S8	1/6/69	215	S8	3/28/68	13.9
S8	4/2/68	13.1	S6	1/7/69	13.4	S8	1/10/69	14
S8	12/5/67	13.7	S7	1/7/69	130.3	S8	1/11/69	14
S8	3/28/68	13.9	S8	1/7/69	422.2	S8	1/12/69	14
S8	1/10/69	14	S7	1/9/69	10.7	S8	4/1/68	14.1
S8	1/11/69	14	S8	1/9/69	24	S8	10/19/67	14.6
S8	1/12/69	14	S8	1/10/69	14	S8	1/17/69	15
S8	4/1/68	14.1	S8	1/11/69	14	S8	1/18/69	15
S8	10/19/67	14.6	S8	1/12/69	14	S8	1/19/69	15
S8	1/17/69	15	S8	1/13/69	9.6	S8	4/3/69	15
S8	1/18/69	15	S8	1/15/69	19.1	S8	4/4/69	15
S8	1/19/69	15	S8	1/17/69	15	S8	4/5/69	15
S8	4/3/69	15	S8	1/18/69	15	S8	4/6/69	15
S8	4/4/69	15	S8	1/19/69	15	S7	5/22/68	15.3
S8	4/5/69	15	S8	1/21/69	15.3	S8	1/21/69	15.3
S8	4/6/69	15	S8	1/23/69	11	S8	6/14/68	16.9
S8	1/21/69	15.3	S8	1/24/69	22.7	S8	6/15/68	16.9

Table A-1. (cont.)

Sorted by Station			Sorted by Date			Sorted by cpm		
Station	Date	net cpm	Station	Date	net cpm	Station	Date	net cpm
S8	6/14/68	16.9	S8	1/25/69	22.7	S8	6/16/68	16.9
S8	6/15/68	16.9	S8	1/26/69	22.7	S8	1/31/69	16.9
S8	6/16/68	16.9	S8	1/29/69	55.6	S8	2/1/69	16.9
S8	1/31/69	16.9	S8	1/30/69	654.3	S8	2/2/69	16.9
S8	2/1/69	16.9	S8	1/31/69	16.9	S8	10/23/67	18.1
S8	2/2/69	16.9	S8	2/1/69	16.9	S7	2/18/69	18.2
S8	10/23/67	18.1	S8	2/2/69	16.9	S7	4/10/69	18.2
S8	6/3/68	19	S8	2/3/69	8.4	S8	6/3/68	19
S8	1/15/69	19.1	S8	2/4/69	5.1	S8	1/15/69	19.1
S8	12/22/64	19.6	S8	2/5/69	11	S8	12/22/64	19.6
S8	5/7/68	20	S8	2/7/69	7.2	S7	6/4/68	19.9
S8	4/24/69	21.7	S8	2/8/69	7.2	S8	5/7/68	20
S8	12/31/68	22.2	S8	2/9/69	7.2	S8	4/24/69	21.7
S8	1/1/69	22.2	S7	2/18/69	18.2	S8	12/31/68	22.2
S8	1/24/69	22.7	S8	2/24/69	32.3	S8	1/1/69	22.2
S8	1/25/69	22.7	S8	3/4/69	11.1	S8	1/24/69	22.7
S8	1/26/69	22.7	S8	3/6/69	6.3	S8	1/25/69	22.7
S8	6/4/68	23	S8	3/18/69	23.7	S8	1/26/69	22.7
S8	12/3/68	23.6	S8	3/19/69	154.6	S8	6/4/68	23
S8	3/18/69	23.7	S8	3/20/69	9.1	S8	12/3/68	23.6
S8	3/26/68	23.9	S8	3/27/69	8	S8	3/18/69	23.7
S8	1/9/69	24	S8	4/3/69	15	S8	3/26/68	23.9
S8	2/13/67	25.3	S8	4/4/69	15	S8	1/9/69	24
S8	3/27/68	25.4	S8	4/5/69	15	S8	2/13/67	25.3
S8	5/6/68	26.5	S8	4/6/69	15	S8	3/27/68	25.4
S8	12/15/64	29	S8	4/7/69	67.2	S8	5/6/68	26.5
S8	2/24/69	32.3	S7	4/10/69	18.2	S8	12/15/64	29
S8	4/11/68	34.9	S8	4/24/69	21.7	S8	2/24/69	32.3
S8	4/12/68	34.9	S7	5/19/69	7.9	S8	4/11/68	34.9
S8	4/13/68	34.9	S8	6/6/69	5.3	S8	4/12/68	34.9
S8	4/14/68	34.9	S8	6/7/69	5.3	S8	4/13/68	34.9
S8	11/25/68	35.1	S8	6/8/69	5.3	S8	4/14/68	34.9
S8	12/11/68	35.7	S8	6/24/69	10.8	S8	11/25/68	35.1
S8	3/18/68	36.3	S8	6/25/69	12.9	S8	12/11/68	35.7
S8	1/2/69	36.7	S8	6/26/69	12.7	S8	3/18/68	36.3
S8	1/3/69	38.8	S6	7/10/69	12.2	S8	1/2/69	36.7
S8	1/4/69	38.8	S8	7/14/69	8	S8	1/3/69	38.8
S8	1/5/69	38.8	S8	8/6/69	8.5	S8	1/4/69	38.8
S8	9/17/68	40.3	S8	12/19/69	8.5	S8	1/5/69	38.8
S8	11/22/68	44.8	S8	12/20/69	8.5	S6	6/4/68	39
S8	11/23/68	44.8	S8	12/21/69	8.5	S8	9/17/68	40.3
S8	11/24/68	44.8	S8	2/3/70	5.5	S8	11/22/68	44.8
S8	1/29/69	55.6	S7	2/24/70	8.9	S8	11/23/68	44.8
S8	4/7/69	67.2	S8	2/26/70	5.1	S8	11/24/68	44.8
S8	12/6/67	67.9	S10	6/8/70	5.9	S5	6/18/70	54.5
S8	5/13/68	86.1	S1	6/16/70	9.2	S8	1/29/69	55.6
S8	3/19/69	154.6	S5	6/17/70	5.1	S8	4/7/69	67.2

**Table A-1. (cont.)**

Sorted by Station			Sorted by Date			Sorted by cpm		
Station	Date	net cpm	Station	Date	net cpm	Station	Date	net cpm
S8	1/6/69	215	S5	6/18/70	54.5	S8	12/6/67	67.9
S8	12/5/68	261.5	S6	6/18/70	6.6	S8	5/13/68	86.1
S8	1/7/69	422.2	S7	8/13/70	7.1	S7	1/7/69	130.3
S8	1/30/69	654.3	S8	4/2/71	7.2	S8	3/19/69	154.6
S10	6/8/70	5.9	S8	4/3/71	7.2	S8	1/6/69	215
S50	8/17/71	5.5	S8	4/4/71	7.2	S8	12/5/68	261.5
S50	12/11/68	7.8	S6	7/15/71	10.4	S8	1/7/69	422.2
S51	10/30/68	8.1	S50	8/17/71	5.5	S8	1/30/69	654.3

**APPENDIX B**  
**MONTHLY AVERAGE CONCENTRATIONS OF**  
**ALPHA ACTIVITY IN ONSITE AIR: 1964-1971**

**NOTE:**

This material was prepared for the draft report of Task 4 of Phase II, "Evaluation of Historical Environmental Data." It is included here so that the Health Advisory Panel and other readers will have the benefit of this information during review of the 903 area characterization report.

**COMPUTATION OF AVERAGE CONCENTRATIONS**

As discussed in the main text of this report, daily handwritten record sheets have been retrieved from storage in the Denver Federal Records Center which contain the results of onsite air sampling between October 1964 and December 1971. This encompasses the time period of highest releases from the 903 area. The daily counts, which have been entered into a computer spreadsheet, are being used to support one approach to quantifying releases of alpha activity from the 903 area.

For some purposes, an average concentration of airborne alpha activity over a period of time is more useful than the daily measurements. For example, it is easier to visually compare one location with another or examine trends over time without the extremely large number of data points. (There are over 2500 data points for each of the onsite samplers S-1 through S-8 for the period October 1964 through December 1971.) It should also be remembered that a cumulative exposure assessment, e.g. determining the intake of a material due to breathing contaminated air, will produce the same result when using time-average concentrations as for the daily concentrations.

Our computer file containing the onsite alpha activity measurements is structured such that the date associated with each daily alpha count is the date the air sampler was started. This date is the one during which the majority of air was collected, since change-out of air filters was done in the morning. The date the sample was stopped is the following day. Averages were produced for all dates falling within a given month

[Table B-1](#) contains the monthly average concentrations, in femtocuries of long-lived alpha activity per cubic meter of air. A femtocurie is  $1 \times 10^{-15}$  curie, which is a unit of the amount of radioactivity. The femtocurie unit was chosen so that the numbers could be tabulated and plotted without the use of scientific notation. The average concentrations for all onsite samplers are plotted in figures following the table.

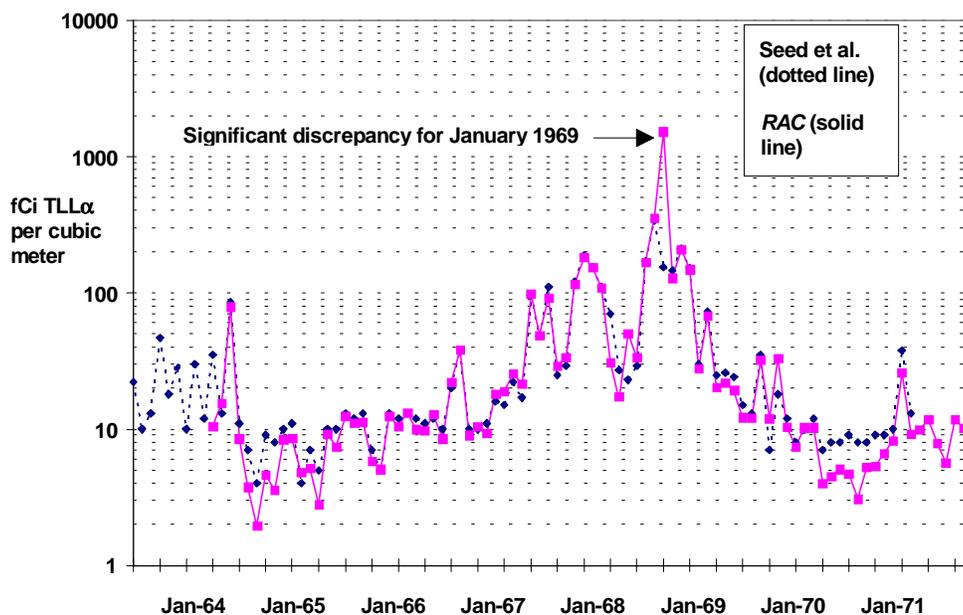
**Table B-1. Monthly Average Concentrations (fCi m<sup>-3</sup>) of Total Long-Lived Alpha Activity in Onsite Air Samples Between October 1964 and December 1971 (Reconstructed from Daily Measurements)**

<b>Sampler:</b>	<b>S1</b>	<b>S2</b>	<b>S3</b>	<b>S4</b>	<b>S5</b>	<b>S6</b>	<b>S7</b>	<b>S8</b>	<b>S9</b>	<b>S10</b>	<b>S50</b>	<b>S51</b>
<b>Oct-64</b>	2	6	2	4	4	3	3	11	6	4		
<b>Nov-64</b>	1	2	6	1	2	2	2	16	3	2		
<b>Dec-64</b>	2	3	4	2	7	4	3	79	4	3		
<b>Jan-65</b>	2	2	11	3	7	2	2	8	3	2		
<b>Feb-65</b>	3	2	2	4	4	4	3	4	2	3		
<b>Mar-65</b>	5	3	3	5	3	5	2	2	3	3		
<b>Apr-65</b>	5	3	2	2	2	3	3	5	2	2		
<b>May-65</b>	3	13	1	3	4	5	3	4	2	3		
<b>Jun-65</b>	4	2	2	2	4	5	2	8	2	2		
<b>Jul-65</b>	4	2	2	2	3	6	2	9	1	3		
<b>Aug-65</b>	4	1	2	3	3	4	2	5	2	3		
<b>Sep-65</b>	5	3	3	3	7	5	0	5	2	4		
<b>Oct-65</b>	3	3	3	1	2	4	2	3	3	2		
<b>Nov-65</b>	10	3	3	2	4	4	2	9	3	4		
<b>Dec-65</b>	4	7	7	6	14	13	5	7	4	9		
<b>Jan-66</b>	11	6	4	2	8	4	3	12	6	14		
<b>Feb-66</b>	3	2	3	5	6	2	1	11	3	4		
<b>Mar-66</b>	4	2	4	3	3	3	2	11	5	3		
<b>Apr-66</b>	3	2	3	4	4	4	2	6	3	2		
<b>May-66</b>	4	4	4	3	6	5	5	5	7	7		
<b>Jun-66</b>	7	5	4	2	3	13	8	12	6	8		
<b>Jul-66</b>	7	6	4	4	6	6	5	11	7	6		
<b>Aug-66</b>	15	7	4	12	7	11	8	13	8	6		
<b>Sep-66</b>	28	8	9	12	18	16	5	10	7	8		
<b>Oct-66</b>	11	4	4	7	8	8	9	10	7	4		
<b>Nov-66</b>	7	2	3	16	8	6	6	13	5	3		
<b>Dec-66</b>	7	4	5	14	10	12	4	8	8	6		
<b>Jan-67</b>	8	4	7	15	13	7	6	22	23	8		
<b>Feb-67</b>	5	6	6	22	8	8	13	38	6	4		
<b>Mar-67</b>	6	1	5	11	7	8	5	9	5	3		
<b>Apr-67</b>	3	3	6	6	10	7	3	11	5	7		
<b>May-67</b>	9	4	7	8	9	12	8	9	6	5		
<b>Jun-67</b>	10	5	8	13	14	11	17	18	5	5		
<b>Jul-67</b>	15	5	7	8	11	14	28	19	9	3		
<b>Aug-67</b>	27	6	15	10	11	17	28	26	10	12		
<b>Sep-67</b>	5	3	3	6	4	14	14	22	4	5		
<b>Oct-67</b>	5	3	7	7	5	15	24	99		7		
<b>Nov-67</b>	6	5	10	6	4	9	8	49		7		
<b>Dec-67</b>	9	7	17	7	3	3	9	92		4		
<b>Jan-68</b>	8	4	12	5	6	3	8	29		5		
<b>Feb-68</b>	15	9	23	12	7	6	10	33		11		
<b>Mar-68</b>	14	18	22	8	9	17	11	116		28		
<b>Apr-68</b>	16	11	13	9	6	27	31	182		10		

<b>Sampler:</b>	<b>S1</b>	<b>S2</b>	<b>S3</b>	<b>S4</b>	<b>S5</b>	<b>S6</b>	<b>S7</b>	<b>S8</b>	<b>S9</b>	<b>S10</b>	<b>S50</b>	<b>S51</b>
<b>May-68</b>	8	9	17	10	7	21	70	155		8		
<b>Jun-68</b>	6	6	8	12	4	51	68	110		18		
<b>Jul-68</b>	5	4	7	4	4	14	14	31		3		
<b>Aug-68</b>	9	6	8	5	7	9	10	17		4		
<b>Sep-68</b>	6	6	7	5	5	4	9	50		3		
<b>Oct-68</b>	12	7	8	6	4	11	19	33		3	7	11
<b>Nov-68</b>	7	4	6	3	7	9	6	168		4	4	2
<b>Dec-68</b>	11	6	4	8	6	6	20	357		3	11	3
<b>Jan-69</b>	10	6	9	7	10	15	127	1525		3	7	5
<b>Feb-69</b>	6	4	8	5	5	4	23	129		3	4	3
<b>Mar-69</b>	7	4	3	5	4	2	4	208		2	5	3
<b>Apr-69</b>	7	3	5	3	6	3	22	148	4	4	5	6
<b>May-69</b>	5	11	9	9	9	17	21	28	10	6	9	6
<b>Jun-69</b>	4	4	7	4	4	7	9	68	4	4	7	3
<b>Jul-69</b>	15	7	7	7	4	20	7	20	4	4	11	6
<b>Aug-69</b>	4	6	5	6	5	7	7	22	5	3	6	9
<b>Sep-69</b>	6	6	5	5	6	5	6	19	4	3	5	5
<b>Oct-69</b>	6	3	5	18	3	5	3	12	2	3	3	3
<b>Nov-69</b>	3	2	4	5	4	3	2	12	2	3	4	4
<b>Dec-69</b>	5	4	5	7	4	2	4	32	7	5	4	4
<b>Jan-70</b>	3	2	4	4	4	3	3	12	3	4	2	3
<b>Feb-70</b>	2	4	5	4	3	4	13	33	3	6	2	7
<b>Mar-70</b>	3	4	4	15	3	5	4	10	4	4	3	5
<b>Apr-70</b>	10	5	5	7	9	7	5	7	2	3	5	3
<b>May-70</b>	9	4	5	3	4	4	2	10	1	4	4	4
<b>Jun-70</b>	14	7	12	9	57	13	7	10	4	13	7	10
<b>Jul-70</b>	7	5	1	3	2	2	2	4	3	3	4	4
<b>Aug-70</b>	3	4	2	3	2	4	10	4	3	4	2	5
<b>Sep-70</b>	2	6	6	3	3	3	3	5	3	4	4	4
<b>Oct-70</b>	5	3	5	4	3	4	2	5	3	4	3	4
<b>Nov-70</b>	2	6	3	3	5	4	1	3	2	2	4	2
<b>Dec-70</b>	3	4	3	3	3	3	6	5	2	3	4	2
<b>Jan-71</b>	4	4	3	2	3	4	7	5	4	4	4	4
<b>Feb-71</b>	3	4	2	4	4	3	6	7	4	5	3	5
<b>Mar-71</b>	5	4	4	5	3	3	8	8	4	5	8	4
<b>Apr-71</b>	4	4	5	7	4	3	3	26	4	5	5	5
<b>May-71</b>	5	4	5	3	4	6	4	9	4	5	5	4
<b>Jun-71</b>	4	3	4	5	5	4	4	10	4	7	7	4
<b>Jul-71</b>	4	3	5	4	4	12	3	12	3	2	4	2
<b>Aug-71</b>	4	4	6	4	3	3	4	8	4	3	9	4
<b>Sep-71</b>	5	3	6	3	3	3	2	6	3	4	6	3
<b>Oct-71</b>	5	4	4	3	6	3	2	12	2	5	7	5
<b>Nov-71</b>	3	4	6	3	5	5	3	10	2	4	5	4
<b>Dec-71</b>	4	5	4	3	3	4	4	6	3	4	5	4

### COMPARING SAMPLER S-8 MONTHLY AVERAGES WITH SEED REPORT PLOT

A Dow committee evaluation of plutonium levels in soil near Rocky Flats (Seed et al. 1971) presented a monthly average plot for sampler S-8, downwind of the 903. This plot has been widely reproduced in various reports, to illustrate the timing of historical releases of radioactivity from the 903 area. After production of our plot of monthly averages for sampler S-8, it was evident that there was a significant discrepancy for the peak month, January 1969 (Figure B-1). There are no numerical data in the Seed report, only the plot. We estimated the concentrations from the Seed plot in order to illustrate the comparison in Figure B-1. Our monthly average for January 1969 is  $1525 \text{ fCi m}^{-3}$ , whereas the Seed report value is about  $150 \text{ fCi m}^{-3}$ .



**Figure B-1.** Comparison of monthly average concentrations of total long-lived alpha (TLLα) activity computed in this study by *Radiological Assessments Corporation (RAC)* and those previously plotted by [Seed et al.](#) (1971), for the RFP S8 air sampler. Note the semi-logarithmic scale. The minimum detectable activity was 5.5 femtocuries per cubic meter.

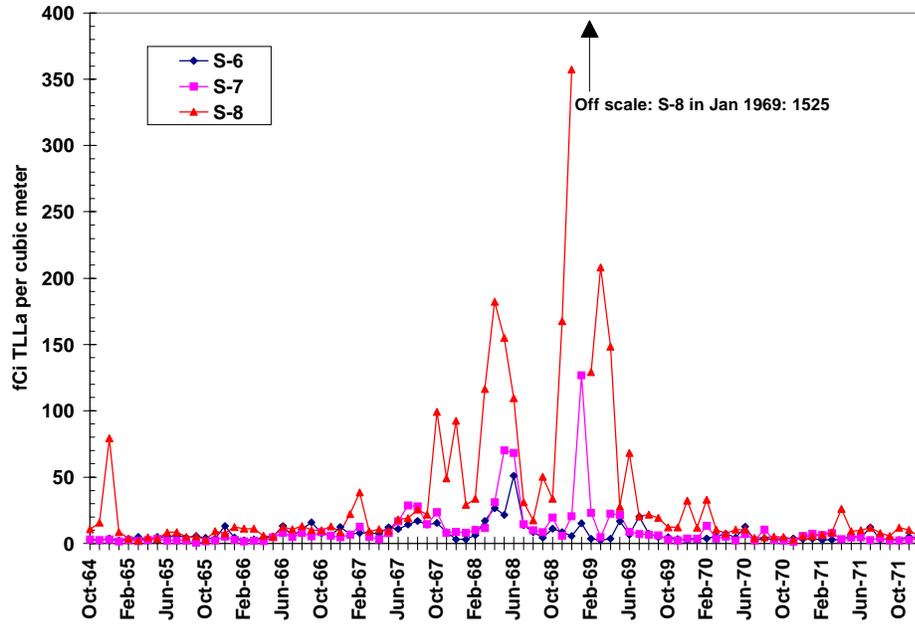
We double-checked our computation from the daily data sheets, and cross-checked several other types of historical Dow records. The peak *daily* concentration of 17,200 fCi per cubic meter, which we computed from the cpm reported on the data sheet, is confirmed in the January 1969 site survey report. This gives an onsite maximum value of  $1720 \times 10^{-14} \mu\text{Ci/cc}$ . This is equivalent to an onsite maximum value of 17,200 fCi per cubic meter. In addition, our total activity (in cpm) collected at S-8 during January 1969 agrees with a monthly computation sheet, on which Dow summarized the daily records for this month. *RAC* concludes that an error was made in the Seed report; *RAC* will utilize the data-sheet-derived values during this research.

Our averages for the other months agree reasonably well with the Seed report. There are several known reasons for slight discrepancies between our reconstructed averages and Dow's. For weekend or holiday samples, we divide the total activity collected (in cpm) by the number of days and assign that amount to each day of the interval. Dow assigns all the activity to the sample change-out day. We assign a measurement to the date the majority of sampling was conducted; Dow often assigned the count to the date of change-out. For example, the maximum recorded long-lived alpha concentration of 654.3 cpm was obtained from a sample which was started on January 30, 1969 and stopped on January 31, 1969. This sample is associated with a date of January 30 in our computer file and with January 31 in the Dow document titled "Result Sheet for Offsite Air Samples," on which the monthly average concentration is computed. Depending on how dates fell with respect to the end of the month, we might include a count (or part of it) in January, e.g., whereas Dow would have included it in February.

Our reconstructed averages are frequently less than Dow's, for low contamination months, due to the site practice of using the minimum detectable activity (MDA) of 0.21 cpm for any sample which had a net sample count less than the MDA. (0.21 cpm translates to 5.5 fCi per cubic meter.) In contrast, we used the actual net cpm, which frequently was zero, in computation of averages. Dow's procedure introduces a known positive bias when concentrations are low, but no significant bias for time periods in which there was a large amount of airborne activity.

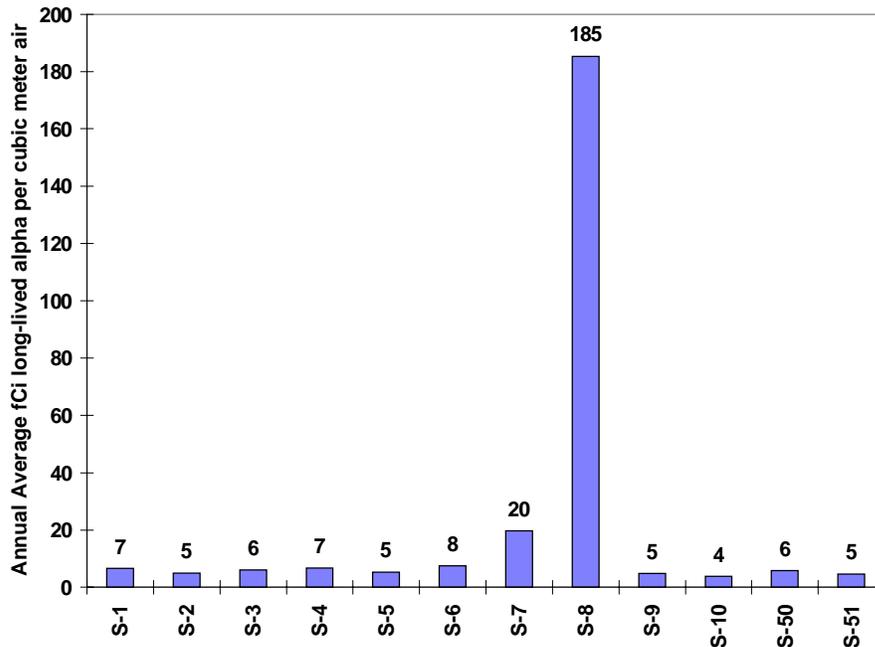
There are two months, September 1968 and January 1970, in which our reconstructed averages are about two times the estimated Seed value. For September 1968, Dow's monthly calculation sheet reported as "missing" the highest daily result for that month. We had no reason to invalidate that datum. We could determine no reason for the January 1970 discrepancy — our values are consistent with Dow's monthly calculation sheet. *RAC* concludes that the Seed value is plotted too low. However, both concentrations are low for that month, and further investigation does not appear warranted.

The monthly average concentrations at the three samplers closest to the 903 area are illustrated in [Figure B-2](#). A map of the sampler locations was presented in the main text of this report. As opposed to [Figure B-1](#), [Figure B-2](#) and subsequent plots in this appendix use a linear scale. These data support the timing of releases from the 903 area, which have been documented earlier in this report. The peak concentrations in 1968 and 1969 coincide with known dust-suspension periods in the 903 area. January 31, 1969 was the date of high winds which "blew all of the roofing material off Building 889" ([Putzier 1969](#)).



**Figure B-2.** Time trend in monthly averages of daily measurements of total long-lived alpha activity in air at the three samplers nearest the 903 area.

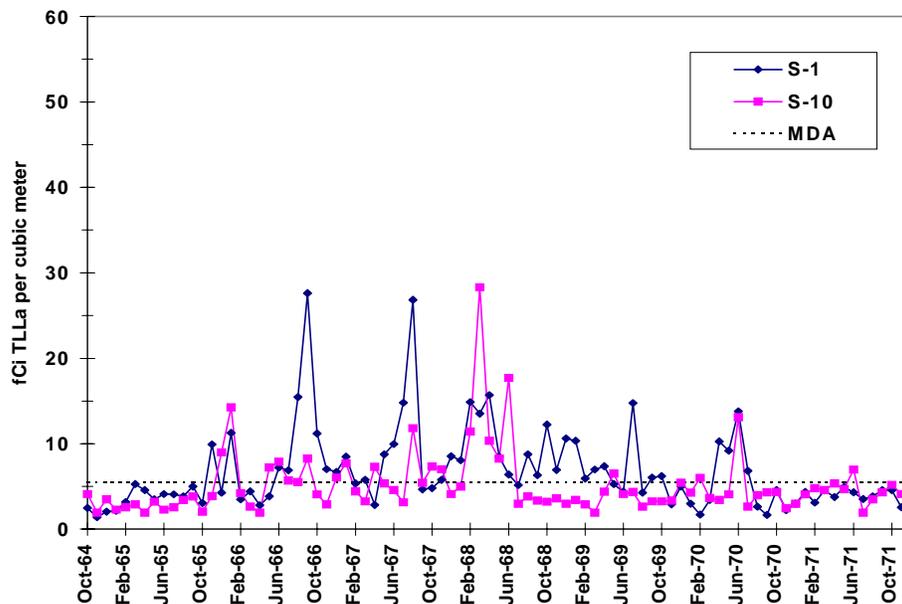
Relative to these three, the other onsite locations did not pick up much contamination from the 903 area events. Figure B-3 illustrates the annual average concentrations at all onsite samplers in 1969, the year of highest airborne activity at S-8. With the exception of S-7, the other samplers are less than 10% of the S-8 level, and are nearly non-detectable (MDC = 5.5).



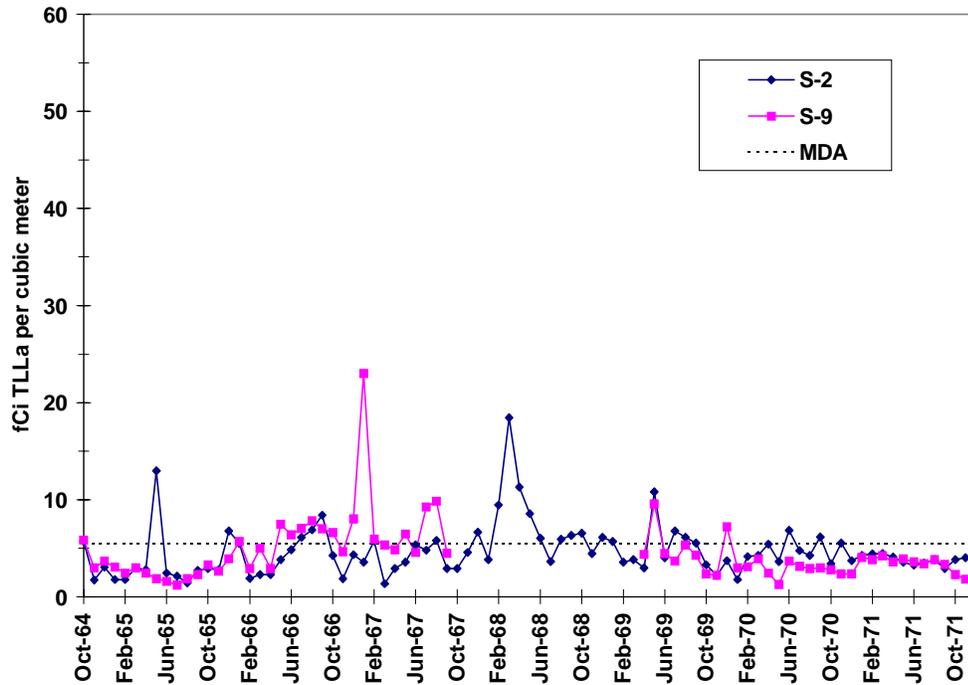
**Figure B-3.** Annual average concentrations of total long-lived alpha activity at onsite air samplers in 1969. Minimum detectable concentration = 5.5.

Figures B-4 through B-7 display the time trends in monthly averages for the other onsite samplers which are not near the 903 pad. The vertical scale of all four figures was purposely set to the same maximum value,  $60 \text{ fCi m}^{-3}$ , to create a comparable visual perspective. It is obvious that the samplers near the 903 area (Figure B-2) show much higher airborne contamination levels than these other samplers. Many of the averages are below the minimum detectable activity, shown by dotted lines on the plots.

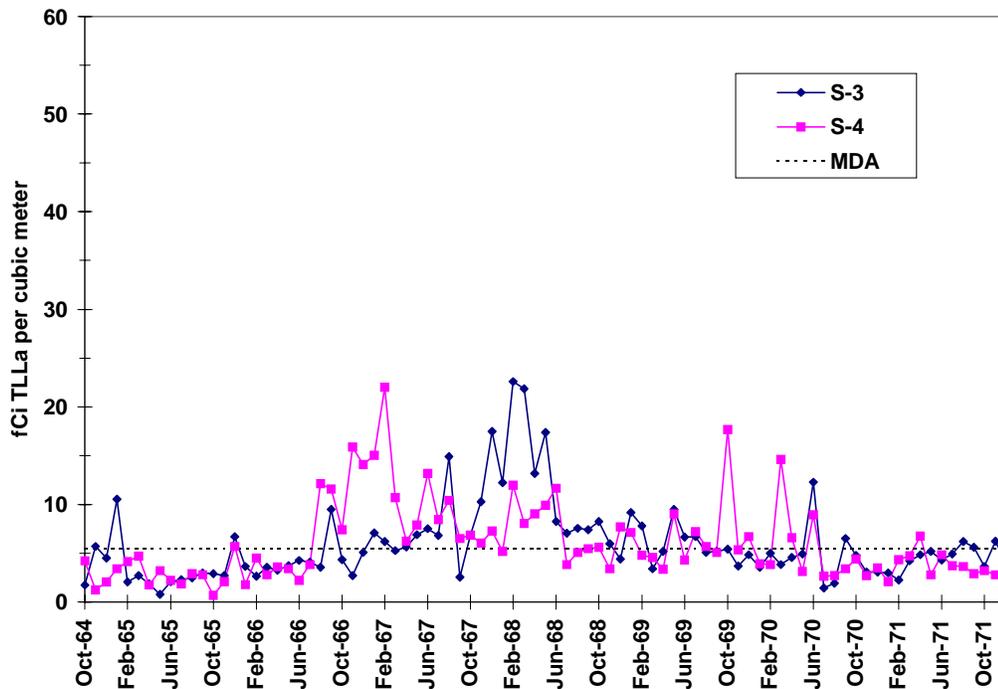
The peaks in the air sampling record continue to be investigated. In addition to the 903 area, stack releases, spills, operational disturbances, and other sources of fugitive emissions (such as the solar ponds) could have contributed to increases in airborne alpha activity. As discussed in the main text, the minimum detectable activity is approximately ten times higher than concentrations which would be expected from naturally occurring or fallout alpha emitters.



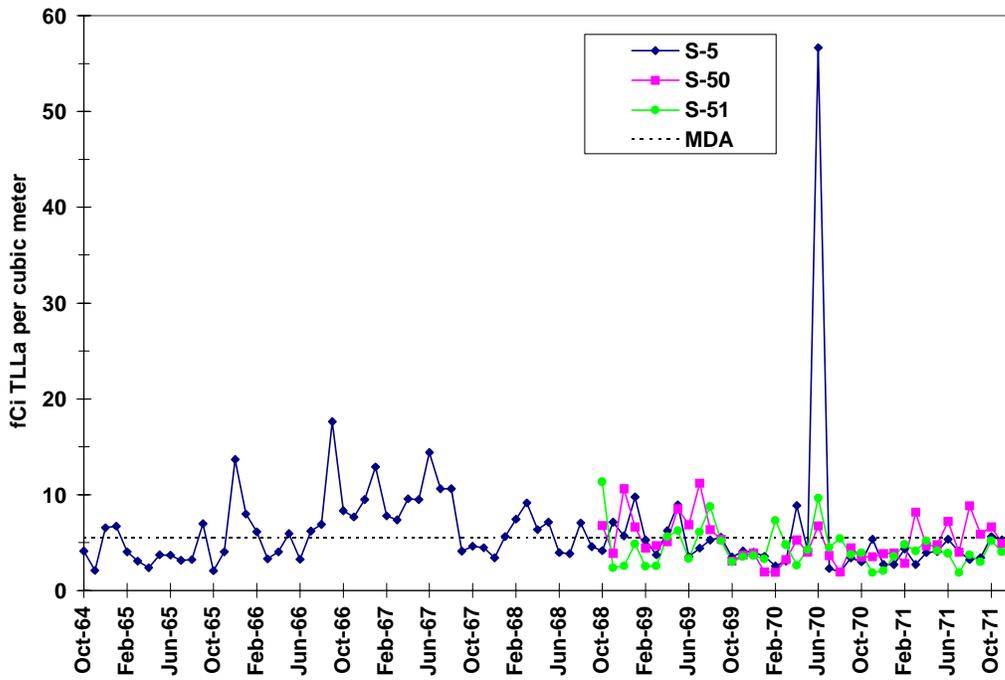
**Figure B-4.** Monthly average concentrations of total long-lived alpha activity in air at onsite samplers S-1 and S-10, in the SW quadrant of the RFP.



**Figure B-5.** Monthly average concentrations of total long-lived alpha activity in air at onsite samplers S-2 and S-9, roughly in the center of the RFP. These samplers show little correlation to 903 area releases, as illustrated in [Figure B-2](#).



**Figure B-6.** Monthly average concentrations of total long-lived alpha activity in air at onsite samplers S-3 and S-4, on the northern part of the RFP.



**Figure B-7.** Monthly average concentrations of total long-lived alpha activity in air at onsite samplers S-5, S-50, and S-51, in the northeastern quadrant of the RFP. The cause of the large peak in June 1970 is being investigated.

### **REFERENCES FOR APPENDIX B**

- ChemRisk. Exposure Pathway Identification & Transport Modeling. Project Task 6 Report. Phase I: Historical Public Exposures, Health Studies on Rocky Flats, Prepared for Colorado Department of Public Health and Environment, 1994.
- Putzier E.A. Health Physics Department Status Report for Buildings 444, 881, 883, 886, 991, Site Survey, Equipment Decontamination and Construction – January, 1969. February 11, 1969, Dow Chemical Company, Golden, Colorado, 1969, Available from the Colorado Department of Public Health and Environment, Rocky Flats Health Studies Archives.
- Seed, J. R., Calkins, K. W., Illsley, C. T., Miner, F. J., Owen, J. B., RFP-INV-10, Committee Evaluation of Plutonium Levels in Soil Within and Surrounding USAEC Installation at Rocky Flats, Colorado, July 9, 1971, Available from the Colorado Department of Public Health and Environment, Rocky Flats Health Studies Archives.

**APPENDIX C****NOTES CONCERNING SOIL STUDIES AT ROCKY FLATS****Major Studies**

A number of studies have been performed to evaluate plutonium concentrations in soil near the Rocky Flats Plant. Dow employee R.W. Loser performed a statistical evaluation of the available data during the fall of 1970 ([Loser](#) 1970) after the 903 paving work was finished. The plutonium soil concentration data used by Loser came from three sources: the Rocky Flats Health Physics Department, the Health and Safety Laboratories, and the Colorado Committee on Environmental Information. He developed a set of mathematical functions to describe portions of the data sets available, and defined concentration lines for plutonium ranging from greater than 2000 mCi/km<sup>2</sup> to less than 15 mCi/km<sup>2</sup>. The concentration map produced by Loser showed the majority of offsite plutonium in soil to the east of the plant, with a small plume to the southeast. The existence of the southeast plume has been questioned by I. Litaor, based on additional data and revised data evaluation techniques ([Litaor](#) [1994](#), [1996](#)).

The [Seed](#) report (1970) estimated that, of the 85 g (6 Ci) of plutonium lost from the barrels to soil, 7.6 g was outside the plant boundary, spread over 1400 acres to the 13 mCi/km<sup>2</sup> contour line. The [HASL](#) 235 report (1971) estimated some 38 to 85 g (2.6 to 5.8 Ci) of plutonium to be outside the 1970 site boundary. [Langer](#) (1991) estimated that nearly 4 Ci were immobilized under the asphalt pad, about 1.2 Ci were onsite east of the 903 pad, and 0.67 Ci were located in a small area on the east side of the security fence, as of late 1991. [Krey](#) (1976) estimated that some 3.4 Ci of plutonium were spread over a wider region, outside the 903 Pad and Field areas. Much of the region evaluated by Krey involves a limited set of samples, with plutonium concentrations near fallout levels. Krey's projections indicated that more than 9 Ci of Pu-239 leaked from the drums, and about 5 Ci were redistributed by various mechanisms from the drum storage area. According to Krey, the contribution from Rocky Flats to plutonium levels east of Indiana Street totaled approximately 0.1 Ci. Krey and others also estimated a Rocky-Flats-related plutonium maximum of 155 g (+/- 20%) in the Denver area ([Krey and Hardy](#) 1970, [Krey and Krajewski](#) 1972, [Krey](#) 1976, [Krey](#) 1979). [Barrick](#) (1981) evaluated [Hammond's](#) (1971) data to conclude that the maximum plutonium release from the 903 area occurred between May and October 1968, continued until July 1969, and concluded with the application of dirt fill to the former barrel storage area.

**Other Soil Monitoring Data**

In late 1970, soils taken from under the pad were analyzed for plutonium. RAC has discovered a marginally useful copy of the 881 laboratories logbook for this period, reporting the analytical methods and results. Barrick (undated draft) presented the data results as plutonium parts per billion of soil. The numbers ranged from 0.003 to 77. No explanation of the location code was provided. We have found no statement of soil collection depth or method.

Other records of plutonium in soil at or near the barrel storage area differ greatly in quality (e.g. no exact location given, no indication of isotopic discrimination). [Joshel](#) (1970) reported plutonium in soil surrounding the drum storage area from 0.4 dpm/g at 25 feet north of the pad to 45,000 dpm/g 25 feet east of the pad. M. R. [Boss](#) reported soil sampling results for the week ending May 28, 1970, including random core collections from west of the

drum storage area. Cores were sectioned so depths could be given, but the results do not specify whether plutonium-239 or gross alpha were reported. This report also provides 1970 soils activity maps for the areas adjacent to the asphalt pad.

### **Particle Size Information**

[Langer](#) (1991) reported that the plutonium particles actually contained in the 903 area drums were less than 3  $\mu\text{m}$  in size, but that the plutonium captured by air samplers was attached to soil particles ranging in size from a few  $\mu\text{m}$  to mm. [Hayden et al.](#) (1975) described a simple system to visualize the number and size of plutonium particles at 30 locations within the buffer zone east of the plant. One square inch cellulose nitrate films, materials sensitive to alpha particles emitted by plutonium and other alpha emitters, were placed directly on the ground surface at each location. Exposure time for the weather-protected material was 23.5 days. The films, three per location, were etched in NaOH, and tracks associated with alpha interactions were counted under a microscope. The experimenters assumed that all particles detected were pure plutonium dioxide, density 11.45 g/cc. Under these conditions and assumptions, minimum particle size was considered to be 0.07  $\mu\text{m}$ , yielding 5 tracks from a point source. Observed track sources were grouped (3-7 tracks, 8-17 tracks, etc.), and judgment factors were introduced to account for observed partial patterns attributed to soil absorption, etc. Analysis indicated minimal errors likely to be introduced by non-point-source natural uranium. Alpha spectroscopy indicated an Americium-241 contribution to star patterns of perhaps 10%. Control films were placed in Arvada, Boulder, Dillon and one mile NW of the plant. No star tracks were observed at these locations. For films placed in the buffer zone, plutonium distribution was found to be quite heterogeneous (0 vs. 29 particles), indicated by two films placed 10 - 20 feet apart, particularly directly east of the plant.

Results of the study by [Hayden et al.](#) indicated two sources of plutonium particles, one, generally distributed across the three square mile surface studied, of a size (0.08  $\mu\text{m}$ ) corresponding to routine, HEPA-filtered stack emissions. The other group of particles was of relatively large size (0.5  $\mu\text{m}$   $\text{PuO}_2$ ) and located directly east of the plant. The memo notes that, according to other studies,  $\text{PuO}_2$  particles as large as 3  $\mu\text{m}$  have been found at the 903 drum storage area, and that a mean particle size of 0.3  $\mu\text{m}$  was measured in one sample excavated from the 903 area. Given the quantity, particle size and location of this second contamination set, the 903 area is identified in Hayden et al. as the likely source. This contamination "...shows signs of tapering off at Indiana Street." The study notes that the cellulose nitrate film approach might profitably be used in locations more distant from the plant.

### **Plutonium Soil Sampling Problems**

One area of concern is the clear definition of ambient levels of plutonium around the Rocky Flats plant. Isotopic studies conducted by [HASL](#) (1971) and others demonstrate that the use of mass spectrometry is a viable way to distinguish between plutonium released from the Rocky Flats Plant and global, weapons-test fallout.

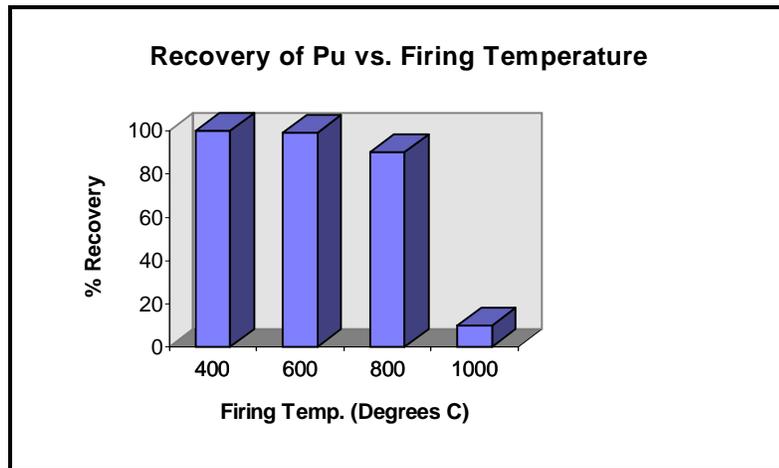
There are several potential difficulties with the data produced by previous soil studies near the Rocky Flats Plant. Besides deficiencies in documentation of quality assurance programs used by researchers, the locations and sampling depths (as well as methods) are

not consistent, thus making comparisons difficult. Also, a set of HASL studies, used heavily in developing 903 area source terms, involved very few samples. As noted previously, [Litaor \(1993\)](#) has observed that the data involved in these studies were insufficient for the application of geostatistical techniques. Moreover, according to Litaor, the techniques used by HASL and [Seed et al. \(1970\)](#) to develop concentration isopleths could have produced some erroneous contours and resulted in an overestimation of the amount of plutonium in soil, particularly in the southeast direction.

### Potential Plutonium Analytical Problems

The [Seed et al.](#) report (1970) included a discussion concerning the problems of plutonium analysis, focusing on difficulties in analyzing plutonium oxidized at high temperatures. Plutonium released as a result of 903 area barrel leakage should not exhibit this problem.

According to an experiment performed by the Rocky Flats Plant 881 Analytical Laboratory, plutonium oxidized at high temperature (high-fired) may not be extracted efficiently from soil samples via conventional acid-leaching techniques (HCl-HNO<sub>3</sub>). The illustration below (Figure C-1) demonstrates the results of the 881 laboratory study:



**Figure C-1.** Dependence of plutonium chemical recovery on original firing temperature.

This information indicates that caution must be used when interpreting the results of analyses involving deposited plutonium that may have been subject to high temperature oxidation. Reported values may be low if nonaggressive acid leaching was used to attempt to extract Pu; non-high-fired plutonium tracer recovery rates would not indicate this problem. While the plutonium released from the 903 area was *not* high-fired, and this analytical difficulty should therefore not be a problem in the context of 903 area releases, analyses involving comparisons to releases from other Rocky Flats Plant sources must consider the potential for reduced recovery of high-fired Pu.

### A comprehensive evaluation of soil studies

Some plutonium-in-soils data, derived from diverse studies at Rocky Flats, have not been capable of straightforward comparison. In part, this was because of differences of sampling or analysis techniques such as sample treatment or sampling depth. Due to such factors, certain

important data could not be normalized, combined or fit to contour maps of plutonium in soil. Such contour maps are of substantial value in estimating the total release of plutonium from Rocky Flats Plant. Soil samples have been taken from various depths and by various techniques and survey designs over a period of 20 years or more.

[Jones and Zhang](#) (1994) of the Department of Preventive Medicine and Biometrics, School of Medicine, University of Colorado Health Sciences Center, under contract to the Colorado Department of Public Health and Environment, have recently published statistical analyses of selected sets of Rocky Flats plutonium-in-soils data. Their results indicate that the concentrations of plutonium in surface soil (dpm/g of dry soil) have not decreased with time. Jones and Zhang concluded that measured concentrations had decreased due to the dilution effect of greater soil sample depths utilized over the years. An independent citizens' sampling and analysis study sponsored by the Colorado Department of Public Health and Environment, to be published in 1997, will provide additional data concerning offsite soil concentrations.

### **Contamination of the field east of the pad**

A roughly 500 by 600 foot soil area east of the 903 pad was contaminated by windblown plutonium, but to lesser concentrations than the former barrel storage area. It was covered with 4 inches of road base in February 1970, as discussed earlier. Dr. Iggy [Litaor](#) (1994) has stated that, during the ensuing years, earthworms have been responsible for returning contaminated soil to the surface. Gerhard [Langer](#) (1989) conducted some soil analyses of this area and found contamination to 2200 pCi Pu-239 per g soil (collection method unspecified). The litter cover (dead, nonrooted plant material) contained 510 pCi Pu-239 per gram. [Langer](#) reported (1991) that a gamma survey for Am-241 associated with plutonium indicated about 1.2 Ci plutonium existing in the area west of the security fence and east of the pad itself. This survey was made after a 1978 removal of soil from the hill crest (the "lip") near the site boundary.

According to a report by [Langer](#) (1991), recent measurements of total resuspension from the area east of the 903 pad indicate perhaps 200  $\mu$ Ci/yr being released. Most of the material being resuspended from this area is associated with soil and grass litter particles, having airborne radioactivity roughly proportional to the mass of particles collected. [Langer](#) (1991) also discusses the studies that have been performed to measure resuspension from this area. Studies, involving both reflection from lasers and capture of saltating particles, failed to demonstrate significant resuspension, even at high winds. He ascribes these observations to the soil becoming crusty over time and to protection of soils by the grass canopy. Langer explains apparent contradictions with earlier work by [Sehmel](#) (1984), showing significant resuspension, by suggesting the influence of disturbances (ditch construction) just prior to Sehmel's pre-1972 measurements. Langer states that it took 9 months for the effects of this disturbance to disappear. He also describes tests demonstrating that, for grass covered areas, resuspension of soil particles attached to fine hairs on grass dominates other sources. However, resuspension from grass may be one to two orders of magnitude less significant than resuspension from open, dry soil. Such factors as recent rainfall, freezing temperatures and snow cover are also potentially important influences on the short-term availability of soil to be suspended by wind.