THE ROCKY FLATS NUCLEAR WEAPONS PLANT DOSE RECONSTRUCTION AND RISK CHARACTERIZATION PROJECT

PHASE II: TOXICITY ASSESSMENT AND RISK CHARACTERIZATION

Preliminary Draft Technical Memorandum: REVIEW OF AERIAL GAMMA RADIATION SURVEYS AROUND THE ROCKY FLATS PLANT

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May 1995

PREFACE

The material in this memorandum is intended for inclusion in the report of Task 4, and will be part of the section on soil data. It is currently being distributed to the Health Advisory Panel via the May 1995 briefing book. This is a preliminary draft, and comments are encouraged.

INTRODUCTION

Gamma radiation surveys can be used to characterize the concentrations of gamma-emitting radionuclides in soils. For the Rocky Flats Plant (RFP), the primary radionuclides of concern have been isotopes of plutonium. However, the primary radiations emitted by plutonium are alpha and beta radiations which are difficult to measure, except with laboratory analyses of samples. Thus, direct field measurements of plutonium in soil, using radiation survey instruments techniques, are not feasible. However, ^{241}Pu is present in the Pu from the RFP, and it decays to form ^{241}Am. The decay of ^{241}Am includes coincident emission of an x-ray of energy about 60 keV, which can be detected by some gamma radiation survey instruments. Concentrations of ^{241}Pu and ^{239}Pu can be calculated from the measured ^{241}Am concentrations and ratios of Pu to ^{241}Am, obtained from other studies. Gamma radiation surveys may also be useful for investigating other radionuclides of potential concern, including ^{137}Cs and ^{238}U.

Aerial gamma radiation surveys are generally performed to study large areas of land and facilities that may be difficult or costly to survey with other techniques. Such aerial surveys have been routinely performed around many of the Department of Energy (DOE) nuclear weapons facilities.

In this technical memorandum we briefly summarize results of aerial gamma radiation surveys that have been performed around the RFP. We focus primarily on measured concentrations of ^{241}Am in soil, as these can be related to Pu concentrations in soil.

RESULTS OF AERIAL SURVEYS AROUND THE ROCKY FLATS PLANT

Aerial gamma radiation surveys of DOE facilities have been routinely performed by EG&G for the DOE and its predecessor agencies. The routine surveys by EG&G were initiated in 1958 to monitor radiation levels around facilities involved in producing or using radioactive materials. EG&G is the only group known (by us) to have performed such aerial radiation surveys of the RFP. We have obtained reports describing three aerial gamma radiation surveys of the area around the RFP, performed in 1972 (EG&G 1974), 1981 (Boyns 1982), and 1989 (Boyns 1990). The first report (EG&G 1974) indicates that the 1972 survey was the first in the RFP area since the plant began operations. As described below, there is reason to believe that another survey was performed in 1973. These four (three known and one potential) are thought to be the only aerial gamma radiation surveys performed around the RFP. However, if additional information is obtained, it will be evaluated.

The three known aerial surveys were performed for large areas around the plant, and results were described for plant areas and areas outside the plant. Because we are interested in releases of radioactivity from the plant, we focus on results for areas outside the plant boundary. The aerial surveys generally attempt to determine radiation contributions from radionuclides in soils and facilities (terrestrial sources), so corrections are made to account for contributions from airborne radioactivity and cosmic radiation.

1972 Aerial Survey

The 1972 survey was performed in two stages, with a detailed survey performed in May for an area of about 2 miles (east-west) by eight miles (north-south), and a larger-area survey performed in October over an area of about 200 square miles (EG&G 1974). Both surveys were performed with radiation detectors mounted in a small airplane, flying at altitude of about 500 ft. The detailed-area survey involved flight lines spaced about 0.2 nautical miles apart, while the larger-area survey used spacing of about 1 nautical mile. The radiation detector system consisted of an array of 14 NaI(Tl) scintillation crystals, each 4 inch by 4 inch (assumed to be diameter by thickness).

Measurements consisted of two types, made simultaneously. The first is gross counts of gamma radiation having energy greater than 50 keV. These gross counts were converted into equivalent radiation exposure rates ($\mu R\ h^{-1}$) at a level three feet above the ground surface, by applying corrections to account for background (nonterrestrial) radiation and to adjust from the flight altitude to the 3-foot level. The second measurement type is gamma spectral data (which show the distribution of gamma energies), recorded for the energy range 0.05 to 3.0 MeV (50 to 3000 keV). The gamma spectra could be used to identify particular radionuclides.

Based on results of the larger-area survey, EG&G concluded that "...both the concentration and relative abundance of radioactive isotopes are consistent with normal terrestrial background radiation." The 3-ft exposure rates were generally between 14 and 22 $\mu R\ h^{-1}$. The detailed survey, however, showed elevated exposure rates, from 20 to 100 $\mu R\ h^{-1}$, near or over plant buildings. These elevated exposure rates were thought to be due to the accumulation of fissionable material (this could include U or Pu) in the buildings. The radioisotopes responsible for the elevated exposure rates could not be absolutely identified, due to constraints of aircraft speed and minimum flying altitude.

Plutonium and associated radionuclides were thought to be at least partially responsible for the elevated exposure rates. The EG&G report (EG&G 1974) indicates that another survey of the RFP was conducted in May 1973, using special instrumentation, carried in a helicopter, to determine ^{241}Am concentrations associated with Pu contamination. The report indicates that the 1973 survey was to be the subject of a separate report. So far, we have been unable to determine the existence of such a report, describing the 1973 survey.

1981 Aerial Survey

The 1981 survey was performed in August, over an area around the RFP of about 93 km^2 (36 square miles) (Boyns 1982). The survey area was roughly 7 miles (east-west) by 5 miles (north-south). The survey used radiation detectors mounted in a helicopter. Flight lines were spaced about 250 ft apart, and were flown at altitude of about 150 ft. The radiation detector system consisted of 20 NaI(Tl) scintillation crystals, each 12.7 cm in diameter by 5.1 cm thick.

The radiation detection capabilities were improved over the 1972 survey, and ^{241}Am could be detected. The minimum detectable activity for ^{241}Am was expressed as the following amounts, any of which would produce essentially the same detector response:

- 5.8 mCi for a point source,
- a surface concentration of 0.8 μCi m^{-2} for surface contamination, or
- a concentration in soil of 28.6 pCi g^{-1}, for a 5-cm thick surface layer of soil, with a particular, assumed exponential distribution with depth.

No specific analyses were reported for ^{137}Cs.

Results of the survey showed ^{241}Am contamination in a "plume" extending eastward from the general area of the 903 Pad Area. This contamination was measureable as far as about 500 m east of the former Pad. Because the exact distribution of contamination with depth was not known, the measurements were not converted into concentrations in soil, but were just given as counts per second. However, the report (Boyns 1982) did provide conversion factors for a variety of possible depth distributions. If we apply these correction factors, maximum concentrations within the plume area would be around 50–140 pCi g^{-1} (where the range reflects the use of a range of factors for the possible depth distributions). This level of maximum concentration corresponds relatively well with the maximum of about 90 pCi g^{-1} seen for the same area in the more recent soil sampling of DOE (1993).

1989 Aerial Survey

The 1989 survey was performed in July 1989, over an area around the RFP of about 124 km^2 (48 square miles) (Boyns 1990). The survey area was roughly 8 miles (east-west) by 6 miles (north-south). The survey used radiation detectors mounted in a helicopter. Flight lines were spaced about 250 ft apart, and were flown at altitude of about 150 ft. The radiation detector system consisted of eight NaI(Tl) scintillation crystals, each 2 inches thick by 4 inches wide by 16 inches long.

The radiation detection capabilities for ^{241}Am were improved again over the 1981 survey. For the aerial survey, the minimum detectable activity for ^{241}Am was expressed as the following amounts, any of which would produce essentially the same detector response:

- 2.9 mCi for a point source,
- a surface concentration of 0.35 μCi m^{-2} for surface contamination, or
- a concentration in soil of 11.2 pCi g^{-1}, for a 5-cm thick surface layer of soil, with a particular, assumed exponential distribution with depth.

For this 1989 survey, results were also reported for ^{137}Cs measurements.

Field measurements were also made at ground level in the general area where elevated ^{241}Am was seen in the 1981 survey (Boyns 1990). These in situ measurements used high purity germanium detectors (HPGe), which allow better discrimination of low-energy gamma radiation than do the NaI(Tl) detectors used in the aerial survey. For the field survey, measurements were made on a grid spacing of 200 feet, with the detector about 3 feet above the ground surface. The minimum detectable surface concentration of ^{241}Am was indicated to be 0.006 μCi m^{-2}.

As for the 1981 survey, results of the 1989 aerial survey were presented as counts per second. Conversion factors were again provided, for converting to concentrations in soil, for various depth distributions. The "plume" of ^{241}Am, extending eastward from the 903 Pad Area, was seen in this 1989 survey, and the activity appeared to be in the same location and to have similar magnitude as seen in the 1981 survey (Boyns 1990). The area showing measureable ^{241}Am was slightly larger than in the 1981 survey, but this was attributed to the improved sensitivity (lower minimum detectable activity) of the 1989 survey.

Results of the aerial measurements for ^{137}Cs indicated that concentrations were similar to worldwide background concentrations (Boyns 1990). In addition, there was no pattern of ^{137}Cs distribution to suggest emissions from the RFP. In fact, ^{137}Cs concentrations were generally lower over the RFP area, as well as for other recently disturbed areas, such as new housing developments. This is expected, and is consistent with recent soil disturbances causing the dilution of the surface contamination (where it was initially deposited) into the generally less contaminated deeper soils.

Results of the in situ survey were converted to surface concentrations, with the assumption of uniform surface contamination (Boyns 1990). Results indicated surface concentrations of 0.006–0.84 μCi m^{-2} outside the perimeter fence. These levels were indicated to be consistent with results of the aerial survey.

POTENTIAL PROBLEMS IN EVALUATING AERIAL SURVEY RESULTS

There are two important considerations for evaluating results of aerial radiation surveys, that are not encountered for soil sampling. First is the very large field of view of the radiation detectors, due to their altitude above the ground. For the 1972 survey, the field of view was about one-quarter mile wide, for a mean gamma energy of naturally occurring isotopes (EG&G 1974). This field of view would be somewhat smaller for the lower energy radiation from ^{241}Am, and would be smaller at lower altitudes (as in the later surveys). Because of the large field of view, it is difficult to use the results to precisely locate the radiation sources. When isoexposure contours (contour lines of constant exposure rate or radiation count rate) are then drawn, the result is some broadening and averaging of the actual soil radionuclide concentrations. As an example, if there was an isolated "hot spot" of activity on the soil (i.e. a point source), the aerial survey would indicate an elevated area larger than it actually was, and would indicate a lower average concentration in soil. If the exact area of the source was known, correction factors, which are provided (Boyns 1990), can be applied to calculate the actual concentration. In the case of a small source, the *total* activity measured should correspond to the actual total, within analytical uncertainties.

A second difficulty in evaluating results of the aerial surveys arises because the actual distribution of contamination with depth in the soil is unknown. We mentioned above that conversion factors are provided, in the aerial survey reports, to convert gross count rates into estimated concentration of radioactivity in soil. These conversion factors are provided for a number of different potential depth distribution of the radioactivity. For perspective on the variability of these conversion factors, we considered a table given in the 1989 survey report (Boyns 1990) for ^{241}Am. In converting gross counts to an average concentration in the top 5 cm of soil, the conversion factors have a range of more than a factor of two. For the soil concentration in the top 10 cm of soil, the conversion factors have a range of a factor of about five. The actual conversion factors vary for different radionuclides (because of gamma energy), different depth distributions in soil, and for different radiation detector systems.

CONCLUSIONS

Based on the three aerial surveys reviewed here, some conclusions can be made. First, it is clear that ^{241}Am contamination in soils extends outside the perimeter fence, in a "plume" extending eastward from the 903 Pad Area. This area of contamination appears qualitatively similar to results of recent soil sampling in the same area (DOE 1993). Maximum concentrations seen in the aerial surveys are also similar to those of the soil sampling study. Though only three aerial surveys have been performed (that we have located), the results of the three are generally consistent. However, detection sensitivities have been improved over time, so the more recent surveys have measured somewhat larger areas of contamination, with the outer limits measuring lower concentrations. There is no information to indicate that the areal distribution of ^{241}Am in soils has changed over time.

The levels of ^{137}Cs measured were generally consistent with worldwide fallout levels, and showed no pattern indicating release from the RFP.

For determining soil concentrations of radionuclides, aerial surveys generally provide a less accurate method than collection and analysis of soil samples. This is due to at least two important factors: (1) the radiation detectors in aerial surveys have a large field of view, which means the locations of contamination cannot be precisely determined, and (2) assumptions must be made about the distribution of contamination with depth, which introduces additional, potentially large uncertainties into the results. However, benefits of aerial and in situ gamma surveys are (1) that a very large area can be monitored, and (2) problems of spatial heterogeneity with soil sampling and analysis are not an issue.

Recently, much soil sampling work has been performed in the area east of the 903 Pad Area. The RFP site contractor has done extensive sampling in this area, with analyses for ^{241}Am, in addition to Pu and uranium (DOE 1993). The Colorado State University has also performed extensive sampling in this area, for Pu and ^{241}Am, with particular emphasis on ^{241}Am to Pu ratios (Schierman 1994 and Webb et al. 1994). It is our preliminary conclusion that the results of these and other soil sampling studies will be more useful for quantitative evaluations of Pu and Am contamination around the RFP. However, the aerial surveys are useful, at least for general corroboration of the soil sampling results. Additional review of the aerial surveys may be appropriate, dependent on evaluations of the other soil studies.

We mentioned above that another report may exist, detailing ^{241}Am survey results for a survey performed in 1973. As of this writing, we have yet to determine if such a report was produced. We continue to search for information about this. If such a survey was performed, it may be useful to provide additional information about the possible redistribution of ^{241}Am in soils around the RFP (and thus Pu also).

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