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RADIOLOGICAL SAFETY EVALUATION REPORT FOR NUWAX-79 EXERCISE

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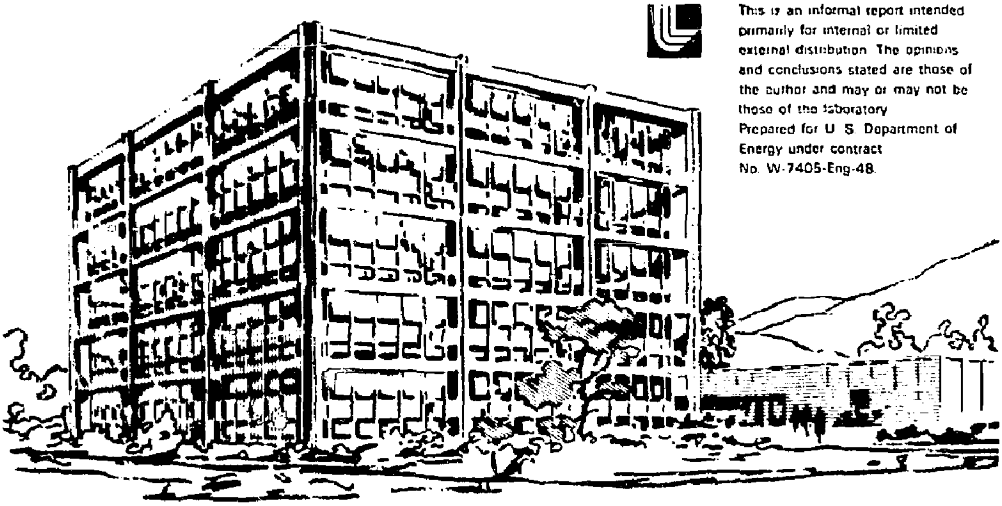

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CONTENTS

Abstract 1

Introduction 1

Exercise Site Location 2

Preparation of ^{223}Ra Source 2

The Health Physics Aspects of ^{223}Ra 3

Radiological Safety Evaluation 8

- External Exposure to the Source Container 8
- Hazards Associated with Dispersal of Radioactive Solutions 10
- Hazards Associated with Working in the Contaminated Area 11
- Contamination Spread Outside the Controlled Area 13

Bioassays 16

Conclusion 18

References 19

Appendices

- A. NTS Wind Data for Tower 4 20
- B. Gamma Radiation From a Point Source of ^{223}Ra and Daughters 23
- C. Dust Loading in Air 25
- D. Urine Excretion of ^{223}Ra 27
- E. Activity Transport by Rainwater Runoff 29

NOTICE

LIST OF ILLUSTRATIONS

1. Decay chain of ^{223}Ra 4
2. AERIN code model 9
3. ^{223}Ra urine counting 17

A-1. Wind direction frequency (%) for 10 degree increments of direction at Tower 4 during April 21

A-2. Average wind speed in miles per hour as a function of time of day at Tower 4 22

C-1. Empirical dependency of dust concentration on the wind frictional velocity at the Nevada Test Site 26

E-1. Precipitation summary for test site locations 30

LIST OF TABLES

1. Maximum permissible concentration in air and water for ^{223}Ra and daughters (radiation workers) 7
2. Radiation level from a disc source of ^{223}Ra and daughters 12

B-1. Gamma radiation from a point source of ^{223}Ra in equilibrium with its daughters 23

RADIOLOGICAL SAFETY EVALUATION REPORT FOR NUWAX-79 EXERCISE

ABSTRACT

This report is an analysis of the radiological safety of the NUWAX-79 exercise to be conducted on the Nevada Test Site in April, 1979.

An evaluation of the radiological safety to the participants is made using depleted uranium (D-38) in mock weapons parts, and ^{223}Ra and its daughters as a radioactive contaminant of equipment and terrain.

The radiological impact to offsite persons is also discussed, particularly for people living at Lathrop Wells, Nevada, which is located 7 miles south of the site proposed for the exercise.

It is the conclusion of this evaluation that the potential radiological risk of this exercise is very low, and that no individual should receive exposures to radioactivity greater than one-tenth of the level permitted under current federal radiation exposure guidelines.

INTRODUCTION

NUWAX-79 is an exercise that simulates an accident that involves several nuclear weapons and in which a spread of ^{239}Pu, ^{240}Pu, and ^{235}U occurs. In place of ^{239}Pu and ^{240}Pu, however, ^{223}Ra will be used as the radioactive contaminant; D-38 will be substituted for the ^{235}U. The ^{223}Ra will be dispersed manually over a number of objects, such as pieces of wrecked aircraft and nuclear weapons parts, and over the terrain for 400 meters downwind of the southeast boundary of the accident site. ^{223}Ra is used because it is an alpha emitter of short half-life (11.43 days) and has no long-lived daughters. D-38 is substituted for ^{235}U for criticality safety purposes. This report evaluates the radiological hazards associated with using ^{223}Ra and D-38 weapons parts in this exercise.

Radiation exposure to personnel participating in NUWAX-79 will be kept as low as reasonably achievable by the use of proven health physics techniques. A detailed operational safety plan is being generated by the Radiological Safety working group.

EXERCISE SITE LOCATION

The location for the NUWAX-79 exercise will be within the boundaries of the Nevada Test Site, approximately 7 miles north-northeast of Lathrop Wells, Nevada. Lathrop Wells is the nearest inhabited community to the simulated accident site, and has a resident population of 55 adults and 10 children (under 10 years of age).

The elevation at the exercise site is about 3000 feet MSL. There is a general downslope of the terrain as it progresses towards Lathrop Wells, which is at an elevation of about 2650 feet MSL. The surface terrain is dry, desert, alluvial sand, covered with the native grass and shrubs that are characteristic of the southern Nevada desert.

The region is very arid with an average annual rainfall of 4.52 inches.[1] The fraction of rainfall that runs off as drainage depends on the rate at which the rain falls. Rainwater runoff from the area drains down Topopah Wash to the Amargosa Desert, and finally drains into a dry lake bed located about 15 miles south-southeast of Lathrop Wells.

Surface winds in April are upslope (southerly winds) during late morning and afternoon hours, and downslope (northerly winds) during the night. Under normal conditions, upslope winds reach about 13 knots (15 mph) and downslope winds reach about 10 knots (12 mph).[1] Appendix A contains wind charts that give the average wind speed and directional frequency at the test site.

PREPARATION OF ^{223}Ra SOURCE

The ^{223}Ra source will be supplied by the nuclear chemistry division of the Lawrence Livermore Laboratory in Livermore, California. ^{223}Ra will be obtained by chemically separating the radium daughter from its parents, ^{227}Th and ^{227}Ac. The purity of the solution will be checked before shipment. If the ^{226}Ra and ^{227}Ac activities are not less than 10^{-6} times the ^{223}Ra activity, the solution will not be used until further purification is accomplished. A total of about 0.5 Ci of ^{223}Ra, contained in a 500 ml solution of barium nitrate and water, will be produced.

The source container will be placed in a shielded DOT/DOE approved shipping container and shipped to Mercury, Nevada by dedicated truck. When the source is inside the shielded DOT/DOE shipping container the radiation level will be $\leq$ 200 mrem/hr at the surface of the container. No hazard should exist when the source solution is in the shipping container.

When the source solution arrives at Mercury, Nevada, it will be transported in its shipping container to the simulated accident site. Transport will be by truck in accordance with NTS regulations on the movement of radioactive materials.

An area will be selected within the roped off accident site where aliquots of the source solution can be transferred into 3-gallon pressure sprayers from which it will be dispersed in the accident area. The source container is designed to allow removal of small aliquots of the solution (containing about 50 mCi of ^{223}Ra) without taking the source container out of its shielded shipping container.

The transfer operation will result in some external exposure to the personnel making the transfer. The highest exposure will occur to the hands; therefore, finger or wrist dosimeters will be worn. The transfer operation will be monitored by a health physics monitor.

There is a small potential that some spread of contamination, with the possibility of internal exposure to operating and monitoring personnel, may occur during the transfer operation. Therefore, personnel involved in this operation will wear full, water-repellent, anti-contamination clothing, including fullface respirators.

THE HEALTH PHYSICS ASPECTS OF ^{223}Ra

^{223}Ra is an alpha and gamma emitter with a half-life of 11.43 days. All of the daughters have short half-lives, and emit α, β and γ radiation. By the time the ^{223}Ra source arrives at the NTS, all daughters will be in transient equilibrium with the parent ^{223}Ra. At any given time, therefore, there is an equal amount of activity for each daughter as there is for the parent. The total activity is the sum of the contributions of each isotope in the decay chain. Figure 1 shows the decay chain of ^{223}Ra with the significant radiation from each isotope in the chain. In Appendix B, we calculate the gamma radiation from a point source of ^{223}Ra in equilibrium

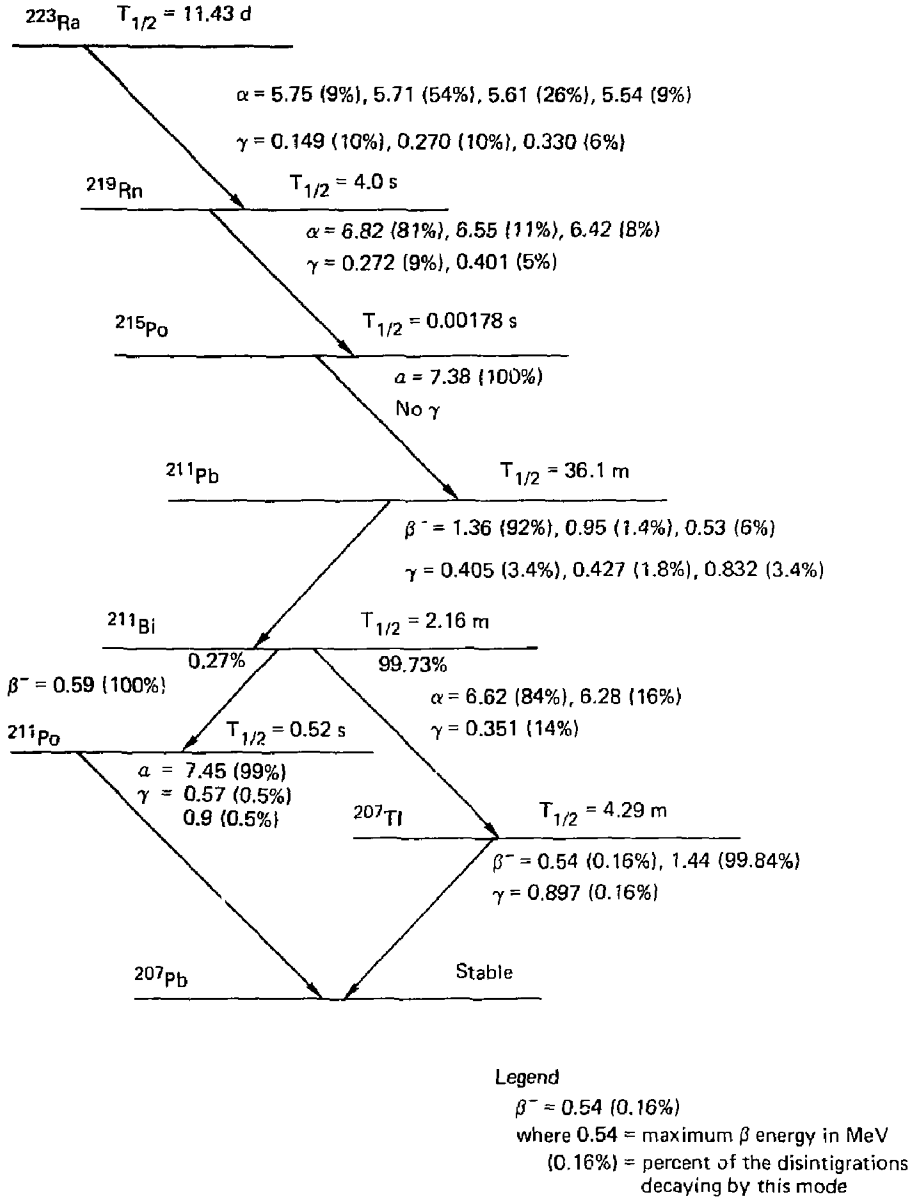

FIG 1. Decay chain of ^{223}Ra.

with its daughters as 0.12 R/hr per Ci at 1 meter. The average energy of the photons is 0.33 MeV, and 2.32×10^{10} photons/s are emitted per Ci.

The potential for exposure to radioactivity during this exercise may occur in the following operations:

- External exposure from the source solution during transfer of aliquots to sprayer.
- External exposure from material in spray tanks during the dispersal operation.
- β and γ external exposure from the contaminated terrain and contaminated parts during dispersal and the training operation.
- Internal exposure by inhalation or through wounds during transfer of aliquots of material to the sprayers.
- Internal exposure from inhalation of material during the dispersal operation.
- Internal exposure by inhalation, ingestion, or wounds during the training operations.
- Internal exposure by inhalation, ingestion, or wounds during the decontamination of critical weapons parts and radiation instruments.

Because the offsite population is about 7 miles south of the accident simulation area, there is a small probability that some exposure may occur in the public domain. Such exposure would be caused by contaminated dust carried to Lathrop Wells by northerly winds. There also may be contaminated rainwater runoff which could be carried downslope towards Lathrop Wells. Minimal exposure could result when the water evaporates and the contaminated dust is resuspended in the air, or if the radioactive material should invade the potable water supply of the community.

Because radium nitrate is soluble in body fluids, any radium taken into the body will be translocated from the initial site of disposition, such as the lungs, gastrointestinal tract or wound site, to the bone. The maximum bone burden for radiation workers permitted under current federal radiation protection guidelines is 30 nCi for a continuous intake of ^{223}Ra and its daughters.* For a single intake, however, as much as 140 nCi is permitted in the bone of a

*This value is less than the maximum dose of 50 nCi given in ICRP Publ. 2. The value given here is based on the amount of ^{223}Ra in equilibrium with its daughters, which will give 7.5 rem/quarter for a bone mass of 5 kg.

radiation worker. If the intake occurred over a 7-day period, the maximum bone burden permitted would be 125 nCi.

Because of the short half-life of ^{223}Ra and its daughters, the dose integrated to infinity for a single 7-day intake is approximately the same as the first quarter-year dose.

Because of the translocation of radium nitrate in the body, detection of an internal exposure can be made by monitoring the urine of a suspected individual. However, because of the short half-life of ^{223}Ra and its daughters, the urine must be collected and analyzed within a few days after the suspected exposure.

Ninety-five percent of the systemic burden* of radium is in the bone.[2] If the radium nitrate should form complexes with the soil, the radium may become less soluble in the body. In such a case, the lung dose will exceed the bone dose for a given intake. The maximum lung burden would be 1.7 nCi for a continuous intake of insoluble ^{223}Ra. For a single intake, 16 nCi could be permitted in the lung. For a 7-day intake, 8.8 nCi could be permitted in the lung.†

Table 1 shows the maximum permissible concentration of ^{223}Ra and its daughters in air and water. These values are calculated from the AERIN[3] code computer runs, using 3.75 rem exposure to the lung and 7.5 rem exposure to the bone for the first quarter-year. For unrestricted areas divide the continuous exposure MPC_a and MPC_w by 30 for ^{223}Ra.

The values for inhalation shown in Table 1 are somewhat different than the values listed in Table 1 of 10 CFR 20 Appendix B because they are based on the new ICRP Lung Model, which is described in ICRP-19.

The maximum permissible amount of ^{223}Ra in a wound is conservatively based on the material being soluble in the body fluids. The assumed model for retention of soluble radium in the wound is given by the equation:

$$A = [0.5\ I_o \exp(-t\ \ln 2/0.01) + 0.5\ I_o \exp(-t\ \ln 2/0.5)][\exp(-t\ \ln 2/11.43)],$$

where A is the amount of activity in the wound at any time (t) in days.

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*Systemic burden is defined as the quantity of a radioactive isotope in the body that has been translocated from the initial deposition site.

†Based on a lung mass of 600 g.

TABLE 1. Maximum permissible concentration in air and water for ^{223}Ra and daughters (radiation workers).

Particle size inhaled	MPC_a (μCi/cc)[a]		
	Continuous	7 days	1 day
1 μm AMAD	1.7E-09 (S)[b]	5.1E-09 (S)	3.5E-08 (S)
	2.1E-10 (I)[c]	9.3E-10 (I)	6.5E-09 (I)
10 μm AMAD	3.1E-09 (S)	4.1E-09 (S)	2.8E-08 (S)
	4.1E-10 (I)	2.8E-09 (I)	1.9E-08 (I)
50 μm AMAD	3.0E-09 (S)	4.2E-09 (S)	3.0E-08 (S)
	1.6E-09 (I)	7.4E-09 (I)	5.2E-08 (I)
	MPC_w (μCi/ml)[d]		
Ingested material	2.0E-05 (S)	5.2E-05 (S)	3.7E-04 (S)

[a] Based on an inhalation of 10 m^3 of air per work day.
[b] (S) = Soluble, "D" class.
[c] (I) = Insoluble, "Y" class.
[d] Based on water intake of 1500 ml per work day and a value of 0.3 for the fraction going from the GI tract to the bloodstream.

The same units are in A as are in I_o, the initial amount deposited in the wound.

From this model we assume that 50 percent of the material deposited in the wound is transferred to the blood with a 0.01 day half-life and 50 percent with a 0.5 day half-life. Ninety-five percent of the material transferred in the blood stream is deposited in the bone.

From a modification of the AERIN code, which represents the wound model, we find that a maximum amount of ^{223}Ra will be deposited in the bone on the third day after the wound was inflicted. It would take an initial deposit of 160 nCi in the wound to give a bone dose equivalent of 7.5 rem the first quarter-year.

RADIOLOGICAL SAFETY EVALUATION

This section discusses the degree of hazard associated with the NUWAX-79 exercise. The AERIN[3] code was used to compute the absorbed dose to the bone and lung following the intake of ^{223}Ra. The code also gives the amount of activity showing in the urine and feces at any time after exposure. Figure 2 is a schematic drawing of the AERIN code model. Code runs were made for "D" and "Y" solubility classes of particulate sizes 1-, 10-, and 50-μm AMAD.*

EXTERNAL EXPOSURE TO THE SOURCE CONTAINER

Approximately 0.5 Ci of ^{223}Ra will be contained in a metal flask of about 500 ml volume. The radium will be in solution so that it can be easily proportioned for use in sprayers. Unshielded, the metal flask should have a radiation level of about 42 rem/hr at the surface, 0.88 rem/hr 1 foot from the edge of the flask, and 0.090 rem/hr at 1 meter.

Because the flask is designed so that aliquots of the solution can be removed from the flask without removing the flask from its shielded shipping container, very little exposure from the flask should occur unless some difficulty arises in making the transfers.

The actual transfer of small aliquots from the metal flask to the sprayers will be done by two LLL employees using a radsafe monitor to monitor the operation. There will be about 10 transfers made during the course of the dispersal operation. Aliquots containing about 50 mCi each of ^{223}Ra will be transferred to 3-gallon sprayers. The sprayers will be filled with a water-glycerine mixture, diluting the source to a concentration of about 4.4 μCi/ml.

Because the personnel engaged in this transfer operation will be completely dressed in anti-contamination clothing including fullface respirators, very few internal exposures should occur. Some external exposure will occur, however, particularly to the hands. Finger dosimeters will be

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* Activity mean aerodynamic diameter.

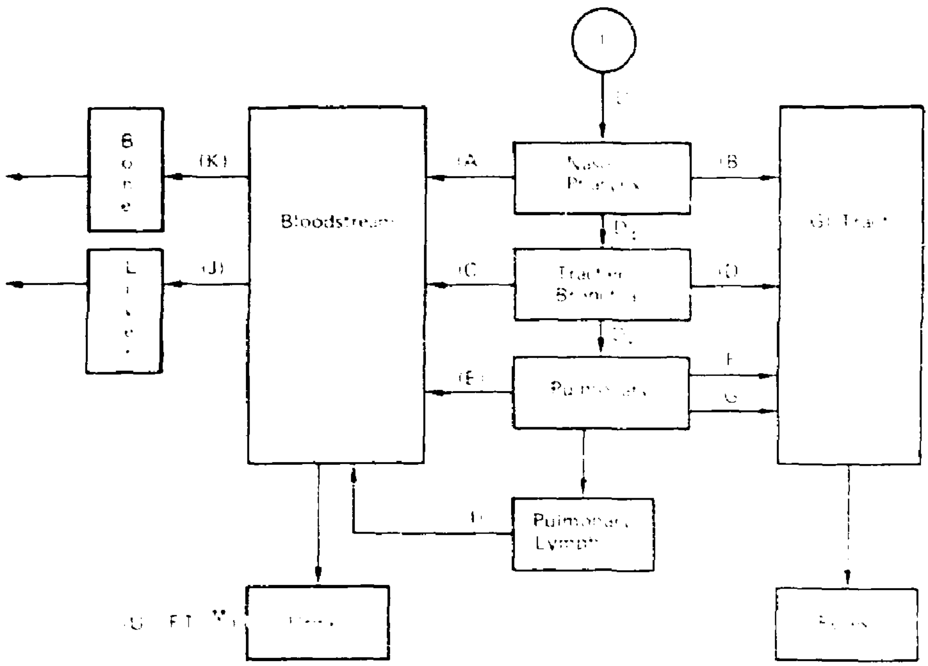

FIG. 2. AERIN dose model.

worn. It is estimated that hand exposures should not exceed 500 mrem and whole-body exposures should not exceed 100 mrem during the transfer of aliquots to the sprayers.

HAZARDS ASSOCIATED WITH DISPERSAL OF RADIOACTIVE SOLUTIONS

The terrain and the parts of the wrecked aircraft will be contaminated by spraying, swabbing, or rolling on the radioactive solutions. The radioactive solution will contain glycerine to retard the evaporation of the liquid, which will minimize the production of airborne radioactivity. In addition, the nozzles on the sprayers have been designed to produce a stream of water rather than to atomize the solution, which will also retard the formation of airborne activity.

Even with these precautions, however, a small part of the activity may become airborne. Estimated release will be 0.1 percent of the activity. Therefore, the workers who are performing the transfer, and others who are within 20 meters downwind, will be dressed out in full anti-contamination clothing including hair covering, and will wear a fitted fullface respirator that will have been smoke-tested to check the mask-to-face seal. Calculations show that with 0.1 percent of the activity becoming airborne during the spraying operation, the air activity concentration may reach 10^{-8} to 10^{-7} µCi/cc in the vicinity nearest to the spray operations.

This task will be performed by personnel who have had experience in working with radioactive materials. Very few exposures should occur during this operation if proper procedures are followed in the use of the anti-contamination clothing and equipment.

The external radiation from the sprayer tank, which contains 50 mCi of ^{223}Ra and daughters, should be about 700 mr/hr at the surface of the container. The level of radiation at 1 foot from the edge of the tank will be 60 mr/hr, and at 1 meter, it will be 9 mr/h. The tanks will be mounted on a pole between two carriers where distance from the tank can be maintained to reduce the external exposure of the operators. It is expected that the external exposure received by personnel carrying out this task will be less than 100 mrem.

HAZARDS ASSOCIATED WITH WORKING IN THE CONTAMINATED AREA

The following paragraphs discuss the hazards associated with working in a contaminated area.

Airborne Radioactivity

Airborne radioactivity may be present downwind from the contaminated terrain. Resuspension of contaminated dust particles can occur from wind and from work activity in the contaminated area. The maximum surface contamination that will be applied during the dispersal operation will be 25 $\mu Ci/m^2$. If we conservatively assume that the top 1 mm of soil will contain all of the ^{223}Ra activity and that the density of the soil is 1.7 g/cm^3, then we calculate that soil will have a specific activity of 15 pCi/mg. To estimate the amount of activity resuspended from the contaminated surface, a reasonable dust loading of 1 mg/m^3 will be used, as described in Appendix C. The ^{223}Ra concentration which will occur in the air as a result of work activity in the area, or because of wind erosion, will be 15 pCi/m^3. This concentration is less than the maximum permissible concentration for continuous exposure to insoluble material as shown in Table 1.

External Exposure

Table 2 shows the external beta and gamma radiation at 1 foot and at 1 meter from the surface of circular disc sources of various diameters when the surface is contaminated at 25 $\mu Ci/m^2$ with ^{223}Ra.

Ninety-eight percent of the beta radiation comes from the 1.33 MeV β, which comes from ^{211}Pb, and the 1.44 MeV β, which comes from ^{207}Tl. Both ^{211}Pb and ^{207}Tl are daughters of ^{223}Ra. It would take about 660 mg/cm^2 of material to absorb all the beta rays. Therefore, the maximum range of the beta rays will be about 6.6 meters in the air at the NTS. Beta radiation exposes the basal layers of the skin, where the maximum permissible dose equivalent is 7.5 rem/quarter, or 30 rem/yr. Beta radiation also exposes the lens of the eye, where the maximum permissible dose equivalent is 1.25 rem/quarter.

TABLE 2. Radiation level from a disc source of ^{223}Ra and daughters.

Diameter of source cm	Radiation at 1 ft[a] μR/hr	Radiation at 1 m μR/hr
10	0.9	0.02
30	2.1	0.9
100	25.6	9.8
1000	40.5	22.3
2000	46.1	27.2
∞	48.6	29.6
	β radiation at 1 ft	β radiation at 1 m
∞	18 mrad/hr	5 mrad/hr

[a]Natural background radiation in the area is about 10-20 μR/hr. The gamma radiation from the ^{223}Ra and daughters will temporarily increase the level to a little over 3 times the natural background.

If personnel are limited to a 12-hour work day in the area of contamination, then the maximum skin dose that could be received for 7 days of work would be

$$D = \int_0^7 (12 \times 5) \exp\left[- t \ln 2/11.43\right] dt$$

or D = 340 mrem. The average skin dose is calculated using the radiation level of 5 mrem/hr at 1 meter above the surface.

Handling contaminated debris and D-38 using bare hands will expose the hands to beta activity in the range of 100 to 200 mrem/hr. The maximum permissible dose equivalent to the hands and feet is 18.75 rem/quarter. Shoes will protect the feet when participants walk on contaminated ground, but the dose to the hands from handling contaminated parts must be evaluated by radsafe monitoring personnel on a case-by-case basis.

Parts made of D-38 metal will be used in the exercise. Surface radiation from D-38 will be 200 mrem/hr. Hands on contact with these parts should be limited to 10 hours over a 7-day operation.

Wounds

In the NUWAX-79 exercise, wounds are a radiological hazard. Because of the high solubility of the contaminant, Ra $(NO_3)_2$, any activity injected through the skin is transported rapidly from the wound site to the bone through the blood. It is recommended that treatment facilities, where minor wounds can be flushed and cleaned out as quickly as possible, should be located close by.

If one assumes that a puncture wound is caused by a piece of metal contaminated to a level of 25 $\mu Ci/m^2$, that 50 percent of the contamination is deposited in the wound, and that the surface area involved is 2 cm^2, then 2.5 nCi of ^{223}Ra will be deposited in the wound. If 100 percent of this amount is transported to the bone, the bone dose equivalent would be 110 mrem for the first quarter-year.

CONTAMINATION SPREAD OUTSIDE THE CONTROLLED AREA

The following paragraphs discuss the hazards of contamination outside the controlled area.

Visitors' Observation Area

As there will be nonparticipating personnel observing the exercise, an observation area will be located outside the demarcation line of control.

Observers may be exposed to the airborne activity created by the work activity and the wind, although they will be 120 meters or more from the nearest contaminated area.

Diffusion of the radioactive material will reduce concentrations by a factor of about 5 within a distance of 120 meters under the meteorological conditions of the NTS. This factor was taken from the continuous point source (CPS) computer code printout for the NTS.[4]

Since the maximum air concentration at the work location, as determined in the calculations above, is 1.5×10^{-11} $\mu Ci/cc$, the maximum air concentrations at the observation area would be about 3×10^{-12} $\mu Ci/cc$. This amount is less than the allowable concentration in unrestricted areas as calculated in using the values in Table 1.

If a person were to breathe air contaminated to a concentration of 3×10^{-12} μCi/cc for 12 hours a day, in 7 days he would receive a maximum internal bone dose of 8 mrems for soluble material and a lung dose of 18 mrem for 1 μm AMAD insoluble material for the first quarter-year. This dose compares with 25 mrem from natural background that the individual would receive during this time. As visitors are not expected to be present for more than 4 hours a day, the dose values above can be reduced by a factor of 3.

The Harvest Eagle Area

The Harvest Eagle area is more than 500 meters from the nearest contaminated terrain in a direction which is least likely to be downwind from the contaminated area. If the site were located directly downwind, however, the maximum concentration of observable air activity would be 38 times less (from CPS code printout) than the concentration in the controlled area, or about 4×10^{-13} μCi/cc. Breathing this concentration continuously 24 hours/day for 7 days would result in a maximum dose to the bone of 1.5 mrem for the first quarter-year. The lung dose equivalent for insoluble material of 1 μm AMAD size would be 3.2 mrem for the first quarter-year.

It is remotely possible that contamination will be carried to the Harvest Eagle area on contaminated clothing or equipment. The contaminated area will be established as a controlled area. Entry will be made only through points on the perimeter where "hot-lines" have been established. All personnel and equipment egressing the area will be checked and certified to be free of radioactive contamination before release.

Lathrop Wells

The community of Lathrop Wells is just outside the boundary of the Nevada Test Site and is located about 7 miles south-southwest of the simulated accident site. There are approximately 65 permanent residents of Lathrop Wells. The concentration of airborne radioactivity blown from the contaminated area will be reduced through atmospheric diffusion by a factor of 6700. Therefore, under dusty conditions at the exercise site (1 mg/m^3), the resulting concentration at Lathrop Wells will be approximately 2×10^{-15} μCi/cc. Based on the calculation in Table 1, this amount is 1100 times less than the concentration of soluble material permitted in unrestricted areas.

Continuous exposure to soluble material with an air concentration of 2×10^{-15} μCi/cc during the life of the ^{223}Ra and daughters results in a total integrated bone dose of 0.002 mrem, while exposure to insoluble material results in a lung dose of 0.038 mrem. This dose compares with the 40 mrem dose that will result from exposure to natural background in 150 days (the time ^{223}Ra and daughters will contribute a dose to the individual).

Heavy Rainfall

Radioactive material may also be carried outside the controlled area by heavy rainfall. If a heavy rainfall should occur during the exercise, some of the radioactive materials may be washed along in the runoff; the remainder will be absorbed into the soil particles or will seep into the soil.

Tests run at the Lawrence Livermore Laboratory, using the ^{223}Ra solution on samples of soil collected at the simulated accident site, show that the ^{223}Ra activity is tightly adsorbed onto the soil particles. We measured the distribution coefficient, K_d, as 0.370 m^3/kg. Using this value in a transport equation shows that a normal amount of rainfall will not transport the activity to the Topopah Wash. It will take a steady rain lasting 5 hours at a rate of 0.5 in./hr to move 10^{-6} of the activity a distance of 1 meter. The nearest edge of the contaminated area is 10 meters from the Topopah Wash. Appendix E contains a detailed report on activity transport due to rainwater runoff.

Ingestion Hazard

The possibility of ingesting radioactive material will occur only among participants in the operation. Other people, including the residents of Lathrop Wells, will not come in contact with the radioactive materials. Because of the short half-life of ^{223}Ra and its daughters, no reasonable scenario can be developed in which the activity gets into the potable water supply of either Lathrop Wells or the Harvest Eagle area.

Workers who handle the radioactive materials may ingest it, but this possibility is remote. If ingestion should occur, about 30 percent* of the

*See Ref. 1, Table 12.

soluble material will pass through the lining of the GI tract into the blood stream; 95 percent will be deposited in the bone. Seventy percent of the ingested material should pass through the GI tract and end up in the feces. If the material is insoluble, however, much less material will be transferred to the blood from the GI tract.

Ingesting 550 nCi of ^{223}Ra in a single dose will result in a maximum permitted bone dose for the first quarter-year. The total intake should not exceed 540 nCi for a 7-day period.

BIOASSAYS

Two bioassay methods could be used to determine the internal dose of exposed personnel: lung counts in a whole body counter or urinalysis. Lung counting has limitations that preclude its use except in special cases when there is knowledge of a significant internal exposure. Urinalysis is a more attractive method of scanning a group of workers.

Because of the short half-life of ^{223}Ra and its daughters, either bioassay method must be done soon after the exposure occurs. The sensitivity of detection is dependent, to a large extent, upon how quickly after the exposure the analysis is performed.

Assume that a specimen of 100 ml of urine was collected 10 days after the internal intake occurred and that the analysis was completed 7 days after that. A reasonable sensitivity for analyzing ^{223}Ra in urine would be 0.5 d/m for the 100 ml sample. Since the average urine excretion volume is about 1400 ml/day, on day 10 this level of activity is represented as:

$$(0.5 \times 1400/100) \times \exp\left[+ 7 \ln 2/11.43\right] = 10.7 \text{ d/m}$$

Based on the AERIN code, an intake of 1 pCi of soluble ^{223}Ra will give a urine activity of 9.65×10^{-5} pCi on day 10. A urine activity of 10.7 d/m (4.8 pCi) on day 10 therefore represents an intake of 5.0×10^{-4} pCi or 50 nCi. Intake of this level results in a dose equivalent of 1.3 rem to the bone. Appendix D contains additional information on urine excretion of ^{223}Ra.

Figure 3 shows the quarter-year dose equivalent to the bone for a single inhalation of soluble ("D" class) ^{223}Ra when 100 ml urine sample indicates

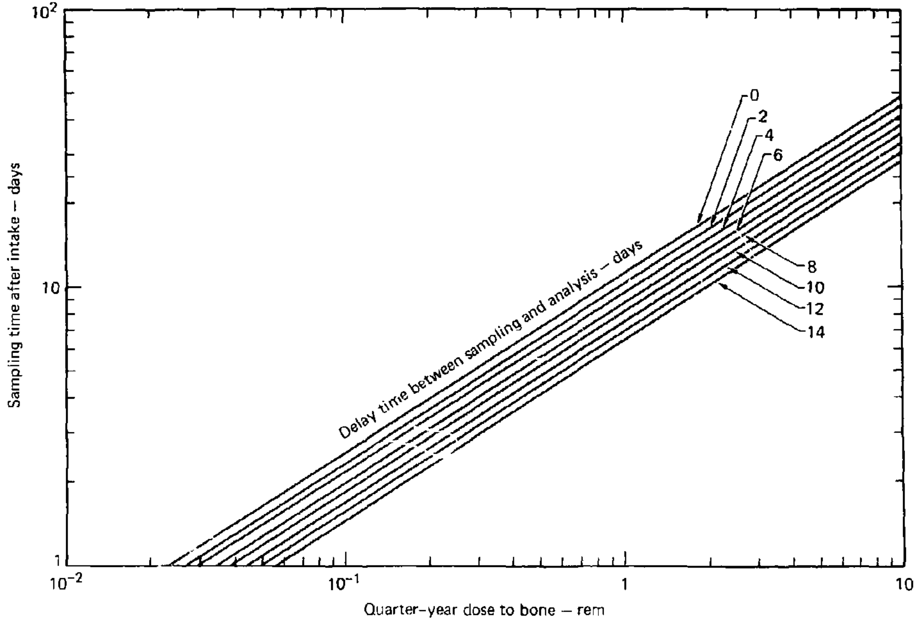

FIG. 3. ^{223}Ra urine counting.

0.5 d/m of ^{223}Ra at the time of counting. The ordinate represents the time between inhalation and sampling. The family of curves represent the delay time between sampling and analysis of the sample. If the internal intake occurred over several days, or if sampling and analysis is accomplished sooner, the minimum detectable dose would be smaller. The maximum permissible dose equivalent permitted to radiation workers under current federal radiation protection guidelines is 30 rem/year.

If the material inhaled is relatively insoluble in the body fluids, then the sensitivity of detecting an internal exposure from urinalysis is greatly decreased. Based on the example above, a 1400 ml urine sample activity of 4.8 pCi on day 10 would represent an intake of 6.5 µCi. This intake would result in a dose equivalent of 375 rem to the lungs the first quarter-year following the intake, which illustrates that urine sampling as a bioassay method is not adequate for insoluble material.

If ^{223}Ra becomes insoluble after mixing with the soil, as empirical evidence now seems to suggest (see Appendix E), in vivo lung counting will be necessary on individuals suspected of inhaling significant quantities of the material.

CONCLUSION

The results of this study show that very little radiological hazard exists from the use of ^{223}Ra and D-38 in the NUWAX-79 exercise.

Individual radiation exposure to the workers and to offsite personnel should not exceed one-tenth the level permitted under current federal radiation protection guidelines.

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4. Peterson, K. R., Crawford, T. U., and Lawson, L.A., *CPS: A Continuous-Point-Source Computer Code for Plume Dispersion and Deposition Calculations*, Lawrence Livermore Laboratory, Livermore, CA, UCRL-52049 (May 1976).

CB/mh

APPENDIX A

NTS WIND DATA FOR TOWER 4

This appendix includes wind charts taken from Ref. 1 which show the average wind speed and directional frequency for April at Tower 4. Tower 4 is located near the center of Jackass Flats at NTS coordinates 752,000 N and 620,000 E. Tower height is 96 feet and surface elevation is 3735 feet MSL.

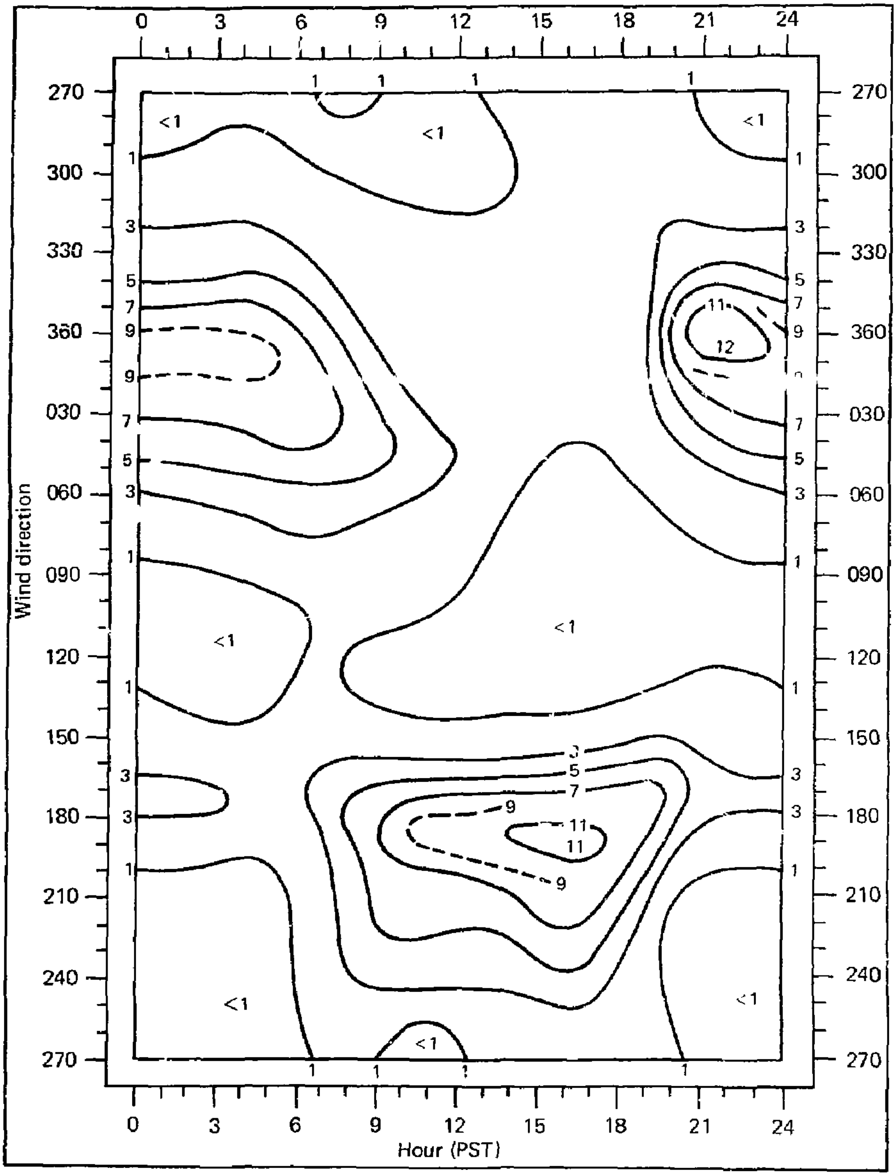

FIG. A-1. Wind direction frequency (%) for 10 degree increments of direction at Tower 4 during April.

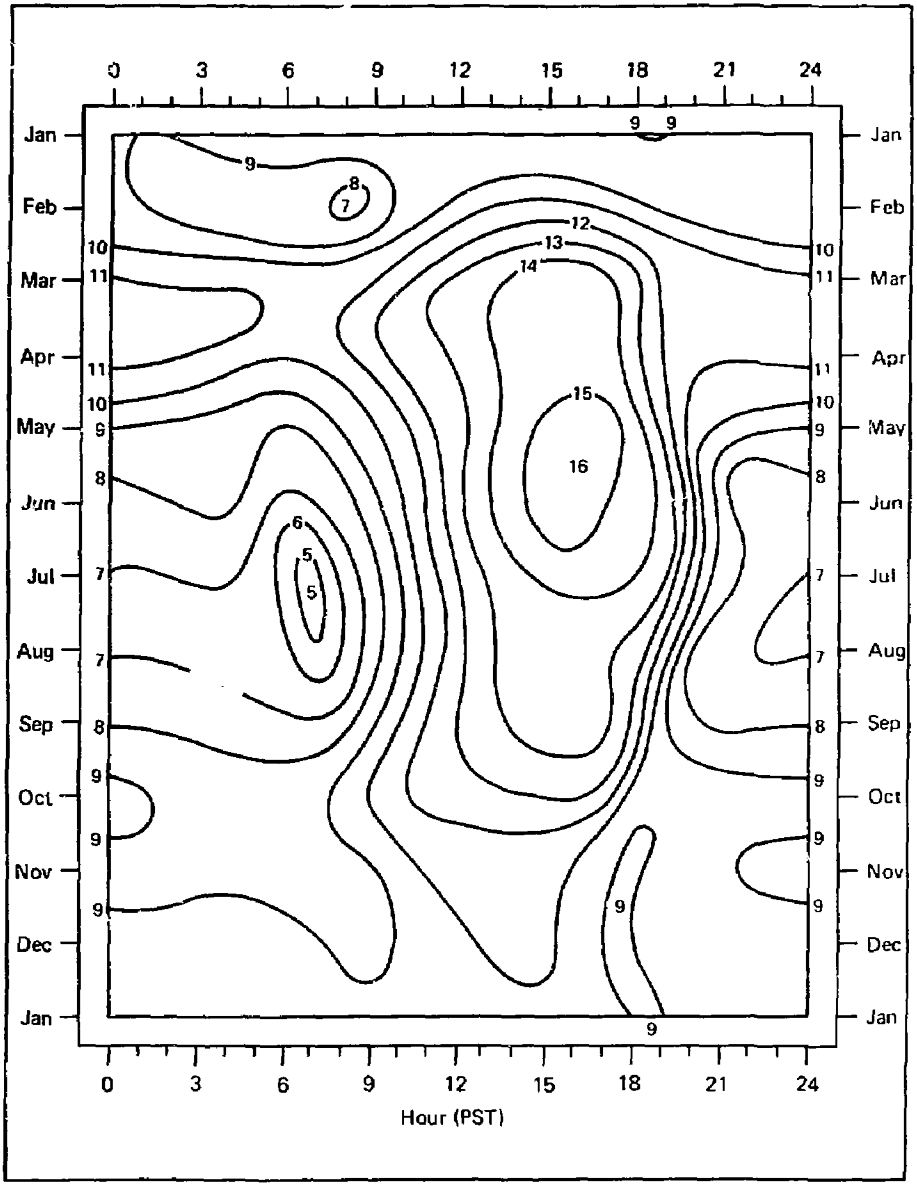

FIG. A-2. Average wind speed in miles per hour as a function of time of day at Tower 4.

ΣfE = 0.207 MeV/dis

$\bar{E}$ = $\Sigma fE/\Sigma f$ = 0.33 MeV/dis

For 1 Ci there are 3.7×10^{10} dis/s

1 Ci $\cdot$ $\Sigma fE = 3.7 \times 10^{10}$ (0.207) = 7.66×10^{9} MeV/s-Ci

For a gamma energy of 0.33 MeV it takes an energy fluence rate of 5.2×10^{5} MeV/cm^2-s to give 1 R/hr.[B1] Therefore at 1 m from a point source

$$RHM = \frac{7.66 \times 10^{9} \text{ MeV/s-Ci}}{4\pi \times (100 \text{ cm})^2 \times 5.2 \times 10^{5} \text{ MeV}/(\text{cm}^2\text{-s})(\text{R/hr})} \qquad \text{(B-1)}$$

$$RHM \approx 0.12 \text{ (R/hr)/Ci}$$

The photons emitted per second for 1 Ci of ^{223}Ra are

$$3.7 \times 10^{10} \text{ (dis/s-Ci)} \times \Sigma f \text{ (photons/dis)} = 2.32 \times 10^{10} \frac{\text{photons}}{\text{s-Ci}} .$$

REFERENCES

B1 Bureau of Radiological Health and the Training Institute Environmental Control Administration (Ed), *Radiological Health Handbook*, Revised Edition, U.S. Dept. of HEW Public Health Service, Rockville, Md. p. 132 (January 1970).

APPENDIX C

DUST LOADING IN AIR

"The Radioecology of Plutonium and Other Transuranics in Desert Environments" (NVO-153), which was published in June 1975 by the ERDA Nevada Operations Office, is a study on the resuspension of contaminated dust at the Nevada Test Site. On page 211 of this report there is a graph showing the empirical dust concentration at a height of 1 meter for given frictional velocities of the wind at NTS. This graph is reproduced here as Fig. C-1.

The friction velocity U_* given in the text is proportional to the wind speed and can be represented by the equation,

$$U_* = C_1 U_1$$

where U_1 is the wind speed at a height of 1 meter and C_1 is a drag coefficient. C_1 for the Nevada Test Site is confined to the range of 0.05 to 0.15. Using the value of 0.08 for C_1 and an average wind speed of 12 mph, we obtain a value of dust loading of 1.1 mg/m^3. This value is used to calculate the air concentration in the work area.

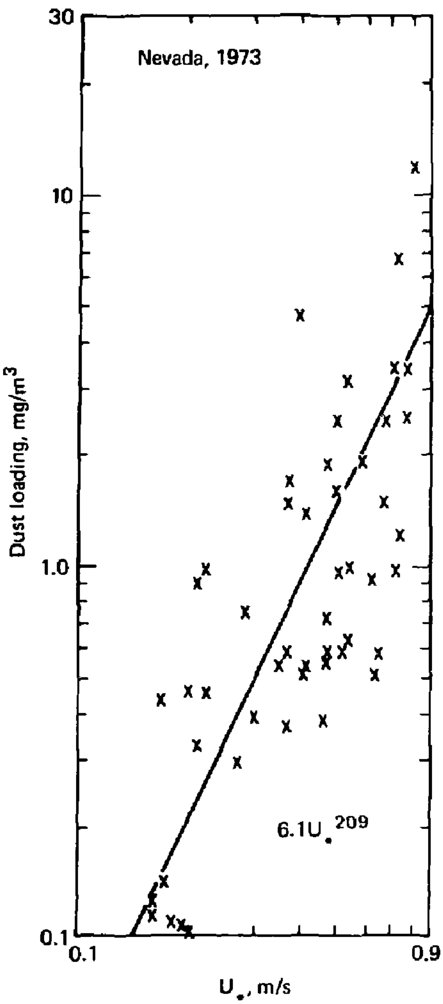

FIG C-1. Empirical dependency of dust concentration on the wind frictional velocity at the Nevada Test Site.

APPENDIX D

URINE EXCRETION OF ^{223}Ra

The excretion of ^{226}Ra in the urine is given by S. Jackson and G. W. Dolphin in *Health Physics 12*: No. 4, page 491 as

$$U(t) = 0.56t^{-1.52} \quad ,$$

where 0.56 represents the percentage of the systemic burden. This value originally came from work done by Norris, et al.,[D1] where the retention of radium was measured in persons who had internal deposits of ^{226}Ra. The retention equation was deduced as

$$R(t) = 54t^{-0.52} \quad ,$$

where the 54 represents the percentage retention of radium. Norris, et al. also found that only about 2 percent of the excreted radium was in the urine, thus

$$E(t) = \frac{dR}{dt} = -28t^{-1.52} \quad ,$$

where E(t) indicated the amount excreted/day. Since

$$U(t) = 0.02 \times E(t)$$
$$U(t) = 0.56t^{-1.52} \quad .$$

The 0.56 represents the percentage value; the fractional value is 0.0056. This value was used in the AERIN code to predict the urine excretion of ^{223}Ra.

The following equation can be used for ^{223}Ra since the body makes no significant physiological distinction between isotopes of the same element.

$$U(t) = 0.0056t^{-1.52} \quad .$$

REFERENCES

D1 *American Journal of Roentgenology*, Vol. 73, p. 785 (1955).

APPENDIX E

ACTIVITY TRANSPORT BY RAINWATER RUNOFF

A report by ESSA Research Laboratories on Climatological Data of the Nevada Test Site (reference cited previously), which is a weather station located at NTS Coordinates 580,300 E, 708,000 N, recorded precipitation data over a period from March, 1963 through September, 1967. The elevation at this station, which is not far from the proposed exercise site, is 2840 feet MSL. Analyses of these data show that for the month of April the average number of days in the month with measurable precipitation is 4.3 days. The average rainfall in April, which is the second wettest month of the year, is 0.65 inches. Station ADA 27 in Fig. E-1 shows the precipitation data for the entire year.

A study of USGS topographic maps reveals that the average slope of the site is about an 11-foot drop in elevation per 1000 feet. Manning's equation for the flow of water in an open channel is given as

$$V = 1.486\ m^{2/3}\ S^{1/2}/n$$

where

V is the velocity of flow in ft/s

m is the hydraulic radius (cross-sectional area/wetted perimeter)

S is the hydraulic slope (dz/l), and

n is the coefficient of roughness of the stream bed.

For ordinary riverbeds free of large rock and weeds, $n = 0.025$. For flow over a wide stream bed, m is approximately equal to d, the depth of the stream. For the simulated accident site, S is equal to 0.011.

In calculating the transport of radioactivity from the accident site, we shall assume that rain falls on the contaminated area at a rate of 0.5 in./hr.

A Average monthly precipitation amount (inches)
B Average number of days with measureable precipitation
C Number of years of record
D Maximum monthly precipitation amount
E Minimum monthly precipitation amount
F Maximum daily precipitation amount
G Maximum number of days with measureable precipitation

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Schultz Ranch													
A	0.30	0.05	0.11	0.46	0.12	0.06	0.51	0.42	0.05	0.02	0.38	0.63	3.11
B	2.3	0.8	1.5	4.5	1.0	1.8	3.0	3.8	0.5	0.3	4.0	2.3	25.8
C	3	4	4	4	4	4	4	4	4	3	3	3	
ADA 27													
A	0.43	0.10	0.09	0.65	0.14	0.14	0.46	0.38	0.15	0.04	1.04	0.90	4.52
B	2.3	1.7	2.3	4.3	2.7	2.3	3.0	3.3	1.0	1.0	4.0	1.7	29.6
C	3	3	3	3	3	3	3	3	3	2	2	3	
Rock Valley													
A	0.53	0.17	0.25	0.80	0.15	0.17	0.34	0.68	0.36	0.08	0.78	0.73	5.04
B	3.0	1.3	2.6	4.0	1.4	2.2	2.2	2.8	2.4	1.8	5.5	2.5	31.7
C	4	4	5	5	5	5	5	5	5	4	4	4	
Desert Rock													
A	0.33	0.25	0.25	0.70	0.15	0.22	0.30	0.68	0.59	0.10	0.64	0.63	4.84
B	2.4	1.4	3.0	4.4	2.8	2.6	3.2	3.6	1.8	1.8	3.2	2.4	32.6
C	5	5	5	5	5	5	5	5	6	5	5	5	

FIG. E-1. Precipitation summary for test site locations.

The total area of contamination is

$$\frac{0.5\ \text{Ci}}{25\text{E-}6\ \text{Ci/m}^2} = 2\text{E} + 4\ \text{m}^2$$

Rain falling at 1/2 in./hr will result in a volume production of

$$\begin{aligned} \text{vol} &= (2\text{E} + 4\ \text{m}^2)\ (0.5\ \text{in./hr})\ (2.54\text{E} - 2\ \text{m/in.}) \\ &= 2.54\text{E} + 2\ \text{m}^3/\text{hr} \end{aligned}$$

of water washing the contaminated area. As the water runs off the surface towards the Topopah Wash which drains the area, some radioactive material will be leached from the soil and be transported to the wash. As the flow of activity proceeds to the wash, some radioactive material will be adsorbed by the soil, some will seep into the soil, and the remainder will be diluted and dispersed. Some of the activity that was adsorbed onto the soil particles will desorb and add to the activity in later flow. We can model the flow of ^{223}Ra from the area of deposit to the Topopah Wash using a transport equation described by A. H. Lu.[E1]

$$D_o \frac{\delta^2 C}{\delta^2 x} - V_o \frac{\delta C}{\delta x} - \left(1 + \frac{\rho K_d}{\theta}\right) \frac{\delta C}{\delta t} - \lambda \left(1 + \frac{\rho K_d}{\theta}\right) C = 0$$

where

- D_o is the effective dispersion coefficient in m^2/hr
- V_o is the average run off water velocity in m/hr
- ρ is the density of the soil in kg/m^3
- θ is the porosity of the soil
- C is the concentration of activity in the runoff water in Ci/m^3
- λ is the radioactive decay constant in hr^{-1}, and
- K_d is the distribution coefficient in m^3/kg.

The solution of this equation has been programmed, and runs have been made to determine the movement of activity from the area of deposit.

The distribution coefficient, K_d, is determined empirically and is defined as follows:

$$K_d = \frac{\text{Quantity of absorbed activity/mass of soil}}{\text{Quantity of dissolved activity/volume of water}} .$$

By contaminating samples of the desert soil collected from the proposed accident site with the actual solution of ^{223}Ra that will be used, we found that the distribution coefficient was 0.370 m^3/kg. The velocity of the runoff water was determined from Manning's equation assuming the depth of the runoff to be 1 cm. V_o was calculated to be 73.5 m/hr. The density of the soil was taken as 1.7E + 3 kg/m^3 and the porosity as 0.34. D_o, the dispersion coefficient, was calculated using the increase in volume of water caused by the rainfall along the transport path and the seepage of 40 percent of the flow into the soil. This seepage factor was obtained from NVO-153.[E2]

The value of D_o was calculated to be 3.67 m^2/hr. From the computations we find that it would take a steady rain of 12 hours at 0.5 in./hr for the concentration of activity to equal the original concentration just 1 meter downstream from the deposit. If we move 2 meters downstream, it will take 30 hours of rain at this rate to equal the concentration of activity originally present. With a 1 in./hr rainfall, it will take 7 hours of steady rain for the concentration of activity originally present to arrive 1 meter downstream; arriving 2 meters downstream will take 16.9 hours.

The original concentration in the rainwater runoff is simply

$$C_o = \frac{C_s \ \text{Ci/kg}}{K_d \ m^3/\text{kg}}$$

C_s equals 25E-06 Ci/m^2 divided by the depth of deposit, which was assumed previously to be 1 mm times the density of the medium, or

$$C_s = \frac{25E-06}{0.001 \times 1700} \ \text{Ci/kg} .$$

Thus, C_o = 3.97E-5 Ci/m^3.

Even if one assumes that average rainfall for the month of April occurs in one rainstorm lasting for 2 hours, no detectable activity will reach the Topopah Wash. The calculations show that the detectable activity will migrate less than a meter from the point of original deposit.

REFERENCES

E1 Lu, A. H., "Modeling of Radionuclide Migration from a Low-Level Radioactive Waste Burial Site," *Health Physics 34* (1) p. 39 (1978).

E2 Nevada Applied Ecology Group, *The Radioecology of Plutonium and Other Transuranics in Desert Environments*, Las Vegas, NV, NVO-153 (June 1975).