SWRHL-92r

# SUMMARY OF HYPOTHETICAL WHOLE-BODY GAMMA EXPOSURES AND INFANT THYROID DOSES RESULTING OFF-SITE FROM PROJECT ROVER NUCLEAR REACTOR/ENGINE TESTS AT THE NUCLEAR ROCKET DEVELOPMENT STATION


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Southwestern Radiological Health Laboratory

U. S. Department of Health, Education, and Welfare
Public Health Service
Environmental Health Service


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This work performed under a Memorandum of Understanding (No. SF 54 373)
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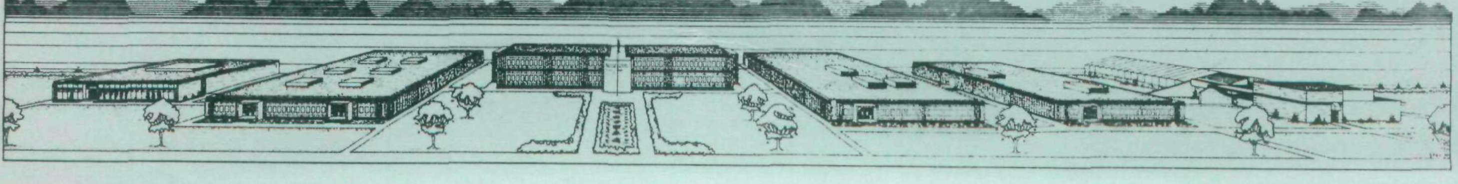

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## ABSTRACT

From 1959 through 1969, thirty-one nuclear reactor engine tests, conducted at the Nuclear Rocket Development Station (NRDS) as part of Project Rover, released airborne radioactivity which was detected in the area surrounding the Test Range Complex (NRDS, Nevada Test Site, Tonopah Test Range, and Nellis Air Force Range). For these tests the Southwestern Radiological Health Laboratory (SWRHL) performed radiological monitoring and sampling. From the radiation exposure information reported by SWRHL, whole-body gamma exposures and infant thyroid doses were postulated for hypothetical receptors and summarized by year and sector from NRDS. A comparison of the Radiation Protection Standards of AEC Manual Chapter 0524 with this summary indicated that for each year of testing, the off-site whole-body exposures and infant thyroid doses were below 12% and 14%, respectively, of the Radiation Protection Standards for a population sample.

# PREFACE

In accordance with Memorandum of Understanding, SF-54-373, the Southwestern Radiological Health Laboratory (SWRHL) provides an off-site radiological safety program for the Atomic Energy Commission in support of nuclear tests conducted at the Nevada Test Site (NTS) and at the Nuclear Rocket Development Station (NRDS) which lies adjacent to NTS. In this capacity SWRHL is responsible for the following during reactor tests:

1. Documenting the radiological situation in off-site areas through comprehensive environmental sampling and radiation monitoring.
2. Assuring continuous protection of public health and safety by determining potential and past exposures to radioactivity, and implementing protective measures as directed by the Test Manager, AEC.
3. Conducting a public contact and information program in the off-site area to assure local residents that all reasonable safeguards are being employed to protect public health and property from radiation hazards.
4. Collecting information regarding incidents which may be attributed to radioactive releases to the off-site area.

Off-site areas are considered those areas outside the boundaries of NTS, NRDS, the Tonopah Test Range, and the Nellis Air Force Range, which together are referred to as the Test Range Complex.

The Southwestern Radiological Health Laboratory also represents the Bureau of Radiological Health (BRH), Environmental Control Administration, Environmental Health Services, Department of Health, Education, and Welfare, and thereby maintains close working relationships with other components of BRH and the surrounding states. When any off-site radiological safety operation is conducted, all appropriate parties are kept advised and all state and BRH surveillance networks are alerted, as appropriate, to assist in documenting levels of radioactivity.

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## Introduction

Thirty-one nuclear reactor/engine tests (Table 1) conducted as part of Project Rover at the Nuclear Rocket Development Station (NRDS) between 1959 and 1969 have produced airborne radioactivity which was detected in the areas surrounding the Test Range Complex (NRDS, Nevada Test Site, Tonopah Test Range, and Nellis Air Force Range). The results of the radiological monitoring and sampling performed by the Southwestern Radiological Health Laboratory (SWRHL) for these tests are contained in reports for each test series (1-18). For the purpose of comparing the radiological effects that these tests had in off-site areas, the radiation exposure information in these reports was summarized by year and sector from NRDS.

## Monitoring Methods

When the first Kiwi reactor was tested in 1959, SWRHL operated a network of 12 air sampling stations and a network of 28 film badge stations in the immediate off-site area. During the reactor tests, mobile monitoring personnel (monitors) were used to supplement information from the networks. Prior to each test, the monitors were positioned at populated locations and on existing highways which crossed the predicted effluent trajectory to measure radiation levels and to collect environmental samples (milk, water, cow feed) should airborne radioactivity be released. They were equipped with Geiger-Mueller (G-M) survey instruments, portable gamma-rate recorders with G-M detectors and supplies for collecting environmental samples. Since the monitors were in two-way radio contact with a control center which followed reactor test operations and meteorological conditions, they could be repositioned, as required.

During the following years, several changes in monitoring techniques and expansions in SWRHL routine monitoring networks were made. Beginning in 1961, self-powered air samplers were included with the monitor's equipment, making the air sampling coverage for tests more adaptable. In the same year, the monitoring of NRDS test effluents by aircraft was begun, aiding in the locating of effluent trajectories and in the positioning of ground monitors.

Table 1. Project Rover Reactor/Engine Tests at NRDS From Which Airborne Radioactivity Was Detected Off-Site

| Reactor/Engine | Experimental Plan | Date |
|---|---|---|
| Kiwi A | XVI | 7/1/59 |
| Kiwi A' | VII-116-B | 7/8/60 |
| Kiwi A-3 | VII-216-B | 10/19/60 |
| Kiwi B-1A | VI/A | 12/7/61 |
| Kiwi B-1B | IV | 9/1/62 |
| Kiwi B-4A | VI | 11/30/62 |
| Kiwi B-4D | IV | 5/13/64 |
| Kiwi B-4E | V | 8/28/64 |
| | VI | 9/10/64 |
| NRX-A2 | IV | 9/24/64 |
| | V | 10/15/64 |
| Kiwi | (TNT) | 1/12/65 |
| NRX-A3 | IV | 4/23/65 |
| | V | 5/20/65 |
| | VI | 5/28/65 |
| Phoebus 1A | IV | 6/25/65 |
| NRX-A4/EST | IIB | 2/3/66 |
| | III | 3/3/66 |
| | IV | 3/16/66 |
| | IVA | 3/25/66 |
| NRX-A5 | III | 6/8/66 |
| | IV | 6/23/66 |
| Phoebus 1B | III | 2/10/67 |
| | IV | 2/23/67 |
| NRX-A6 | IIIA | 12/15/67 |
| Phoebus 2A | III | 6/8/68 |
| | IV | 6/26/68 |
| | V | 7/18/68 |
| Pewee 1 | III | 12/4/68 |
| XE Prime | VC | 6/11/69 |
| | IXA | 8/28/69 |

In 1963, gamma-rate recorders were placed at 16 of the air sampling locations. In 1965, Model TL-12 thermoluminescent dosimeters by Edgerton, Germeshausen & Grier, Inc., were included in the film badge network and used off-site by mobile monitors. However, off-site radiation exposures from reactor tests were never detected by SWRHL with the more sensitive TLD's nor with the film badges. The film badge and air sampling networks were expanded after the latter part of 1961, due to the resumption of nuclear weapons testing. These off-site networks were gradually expanded through the years so that they now include 102 off-site air sampling stations in Nevada and the Western United States, 32 gamma-rate recorders, and 96 fixed stations with thermoluminescent dosimeters. The use of film badges at the fixed dosimetry stations was terminated in April 1970. Film badges were also assigned to a number of off-site residents beginning in 1963; the number varying from 60 to 200 with testing activities.

## Calculations and Assumptions

The modes of radiation exposure or dosage considered for the SWRHL monitoring data were whole-body gamma exposures from cloud passage and deposition, infant thyroid doses calculated from the hypothetical inhalation of airborne radioactivity, and infant thyroid doses calculated from the assumed ingestion of milk contaminated with radioiodine. Radiation exposures or doses less than 1 mR or 1 mrad, respectively, were considered to be negligible. The whole-body exposures and infant thyroid doses are generally for a hypothetical receptor since air samples were often taken at unpopulated locations and infants were not present at any of the locations where air and/or milk samples were collected.

Since film badges and TLD's have never detected releases of airborne radioactivity from reactor/engine tests, whole-body gamma exposures were estimated from G-M survey instrument data. The exposure rate readings from cloud passage and deposition were integrated from cloud arrival time to infinity or from cloud arrival time to end of cloud passage, if no measurable deposition occurred. No exposures were measured by film badges or TLD's for two reasons: 1) The minimum detectable exposure of the film badge and the TLD is 30 mR and 1-5 mR, respectively; 2) film badges and/or TLD's were not always located directly within the paths of the test effluents.

The infant thyroid doses from inhalation were estimated by multiplying the adult thyroid doses by a factor of 3. The adult thyroid doses were determined by the product of the time-integrated concentrations of airborne radioiodine ($\mu Ci \cdot sec/m^3$) and the following conversion factors:

| ISOTOPE | $mrad \cdot m^3/\mu Ci \cdot sec$ ESSA | SWRHL |
|---|---|---|
| $^{131}I$ | 0.341 | 0.34 |
| $^{132}I$ | 0.0124 | 0.051 |
| $^{133}I$ | 0.0922 | 0.093 |
| $^{135}I$ | 0.0284 | 0.029 |

The factor of 3 compensated for differences in thyroid weight and breathing rates ($m^3$/day) between an adult and an infant $\{3 = [20\ g/2\ g][(6\ m^3/day)/(20\ m^3/day)]\}$. The two sets of conversion factors above were used within the referenced SWRHL reports; the first set is that used by the Air Resources Laboratory of Environmental Science Services Administration (ESSA) (19) in their dose predictions for each reactor/engine test, and the other set is one derived by SWRHL (Appendix). Little difference exists between the two sets of factors except for $^{132}I$, which contributes only a small percentage of the total dose. The higher SWRHL factor is based upon the fact that $^{132}Te$, the precursor of $^{132}I$, is also inhaled and contributes an increase in the quantity of $^{132}I$ which reaches the thyroid (20, 21).

The infant thyroid doses from milk ingestion were estimated from a product of the following conversion factors and the time-integrated radioiodine concentrations (pCi·day/l) for those situations when milk samples were collected at regular intervals for as long as radioactivity was detected in the milk:

| ISOTOPE | mrad·l/pCi·day |
|---|---|
| $^{131}I$ | 0.019 |
| $^{133}I$ | 0.0052 |
| $^{135}I$ | 0.0016 |

When only the peak radioiodine concentrations in milk were measured, the equivalence of 16 mrad for a 100 pCi/l peak concentration was used (22).

Once the whole-body gamma exposures and the infant thyroid doses from inhalation and ingestion determined by the above procedures were summarized for each reactor/engine test within a given year, the maximum exposure and dose for each test was selected within each sector in which an exposure occurred. The maximums for each test occurring within each year and a given sector were then summed and entered within the appropriate sector. The blank sectors indicate that no radioactivity was detected, or if it was detected by air samples, the potential infant thyroid dose from inhalation was <1 mrad and no milk samples were considered necessary. Since radiation exposures during the years 1959 through 1962 were negligible and no reactor/engine tests released airborne radioactivity during 1963, these exposures were summarized in one illustration, Figure 1. Figures 2-7 represent the exposure and dose summaries for each calendar year 1964 through 1969.

## Conclusion

Table 2 compares the Radiation Protection Standards of AEC Manual Chapter 0524 with the maximum whole-body gamma exposures and the maximum infant thyroid doses received by hypothetical receptors during the above periods.

Table 2. Comparison of Maximum Hypothetical Whole-Body Gamma Exposures and Infant Thyroid Doses with Radiation Protection Standards

| | Radiation Protection | Maximum Whole-Body Gamma Exposure (mR) and Infant Thyroid Doses (mrad)** | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Type of Exposure/Dose | Standard* | '59-'63 | '64 | '65 | '66 | '67 | '68 | '69 |
| Whole-body gamma exposure | 170 mrem/yr | ND | < 1 | 6 | 20 | 2 | < 1 | < 1 |
| Thyroid dose | 500 mrem/yr | < 3 | 24 | 72 | 36 | 18 | 13 | 2 |

*Standards are for sample of population, AEC Manual Chapter 0524.

**Units in mR and mrad are equivalent to mrem for this comparison.

For any given year the whole-body gamma exposures and infant thyroid doses were below 12% and 14%, respectively, of the radiation protection standards for a sample of the population.

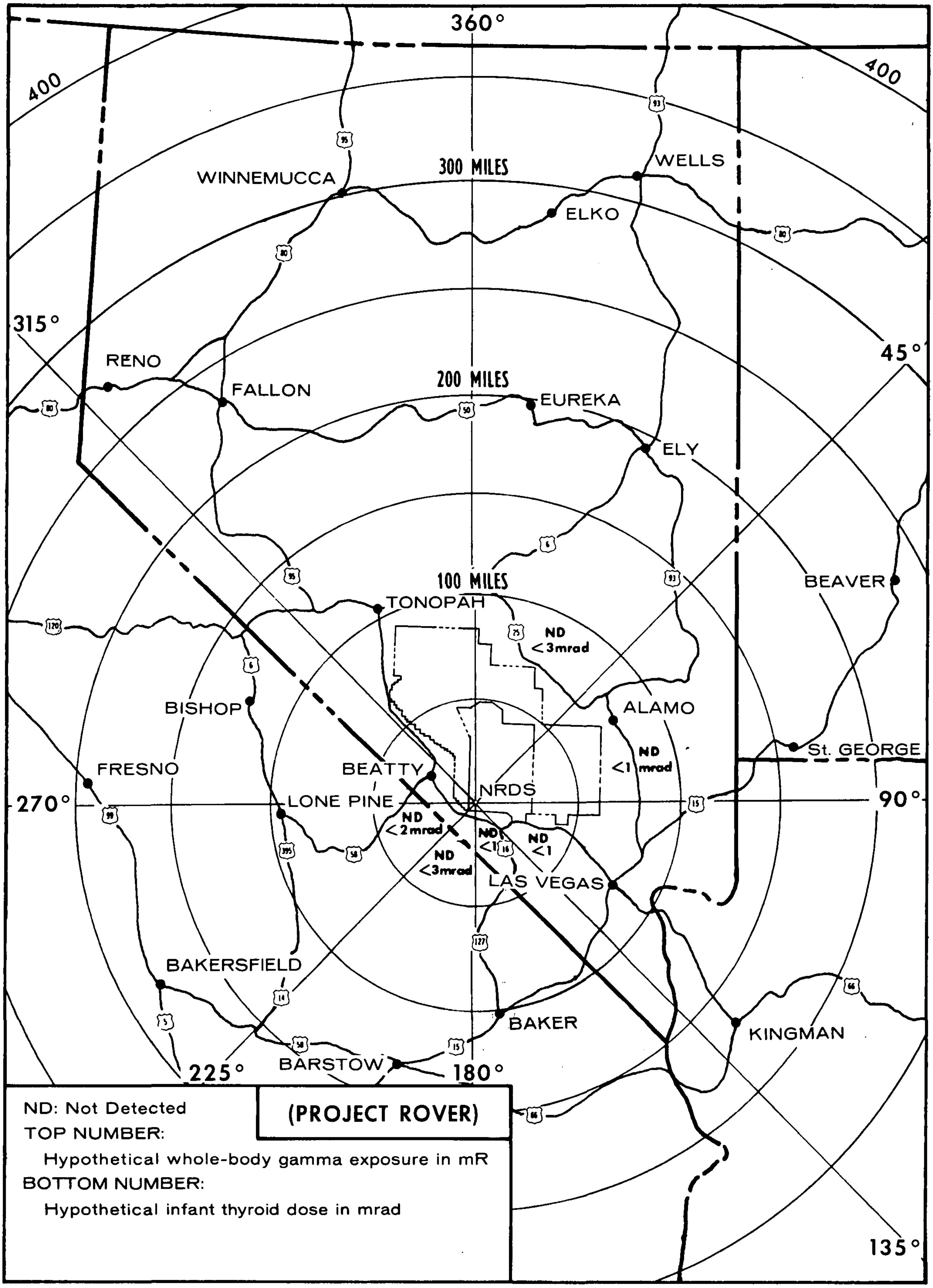


**FIGURE 1**
**OFF-SITE WHOLE-BODY GAMMA EXPOSURES AND INFANT THYROID DOSES RESULTING FROM REACTOR/ENGINE TESTS FROM CY 1959 TO 1963**

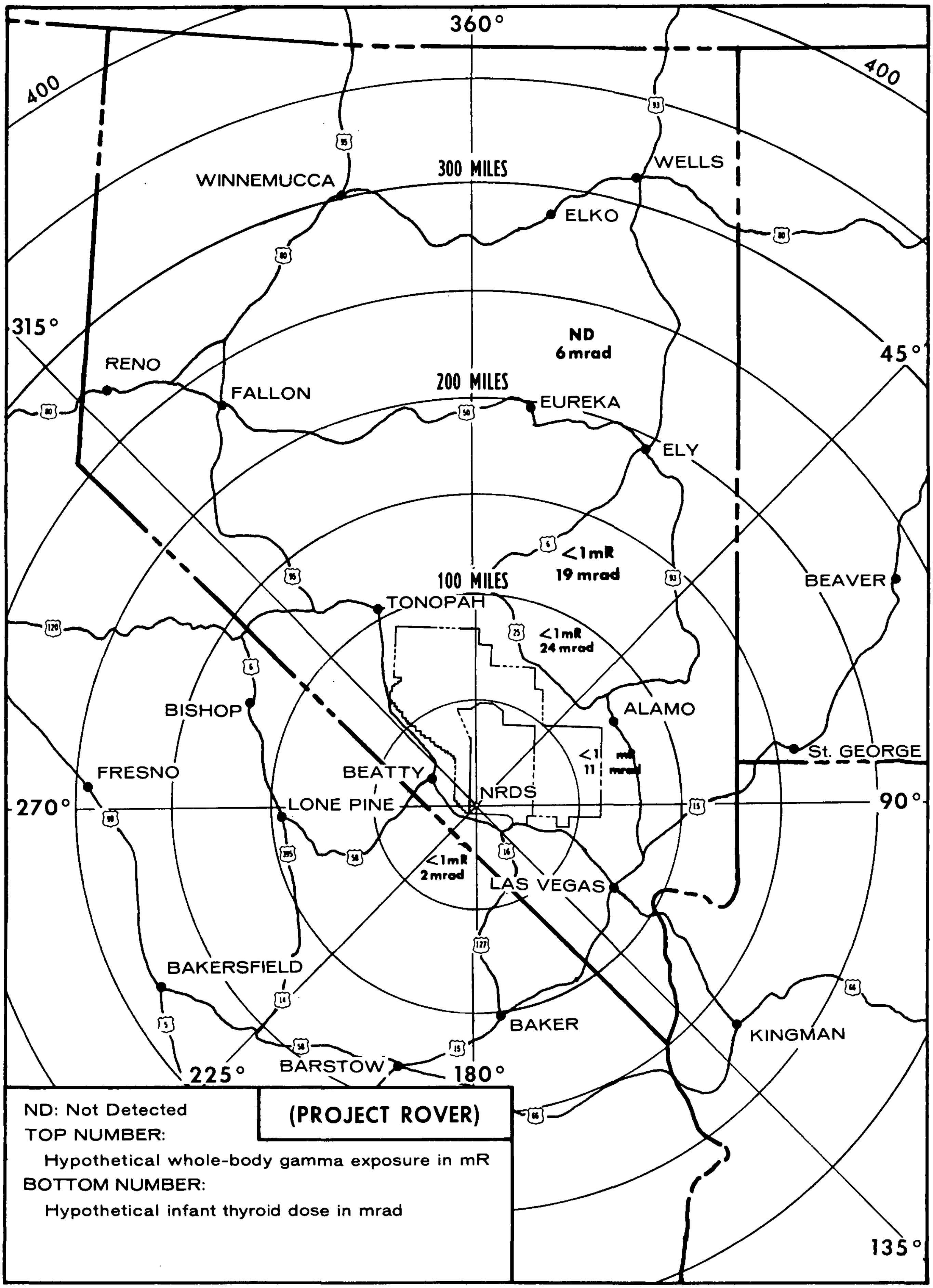


**FIGURE 2**
**OFF-SITE WHOLE-BODY GAMMA EXPOSURES AND INFANT THYROID DOSES RESULTING FROM REACTOR/ENGINE TESTS DURING CY 1964**

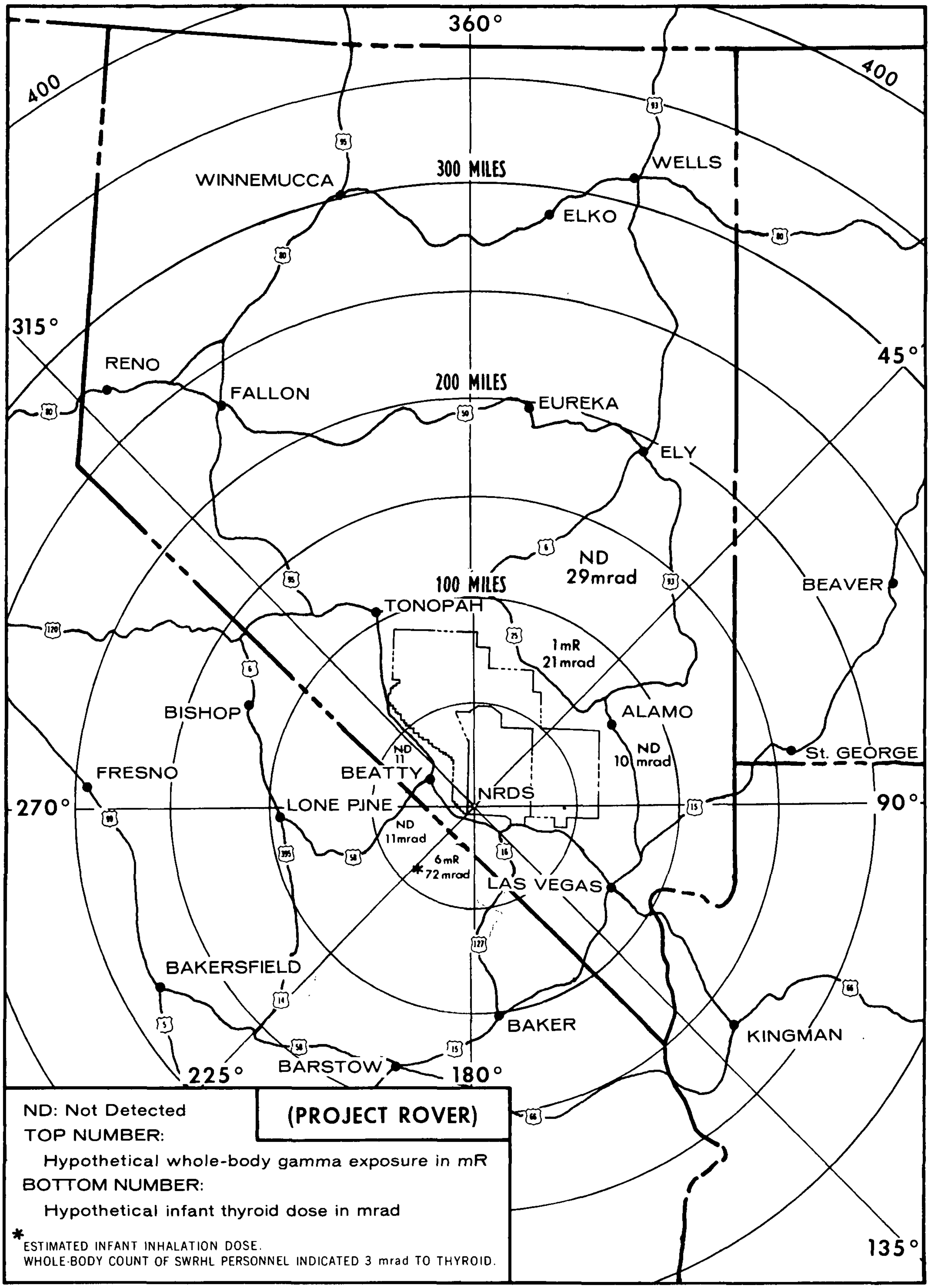


**FIGURE 3**
**OFF-SITE WHOLE-BODY GAMMA EXPOSURES AND INFANT THYROID DOSES RESULTING FROM REACTOR/ENGINE TESTS DURING CY 1965**

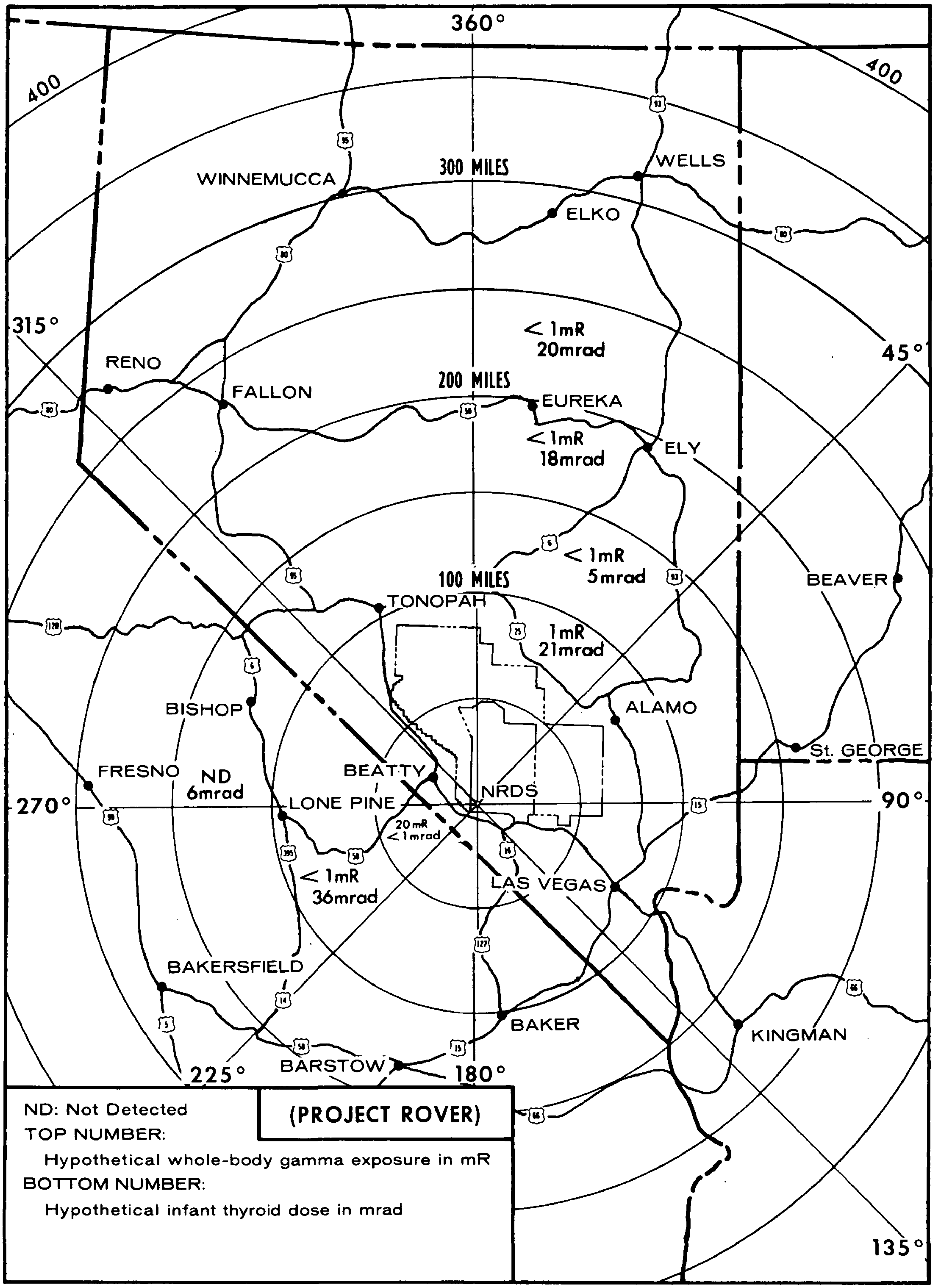


FIGURE 4
OFF-SITE WHOLE-BODY GAMMA EXPOSURES AND INFANT THYROID DOSES RESULTING FROM REACTOR/ENGINE TESTS DURING CY 1966

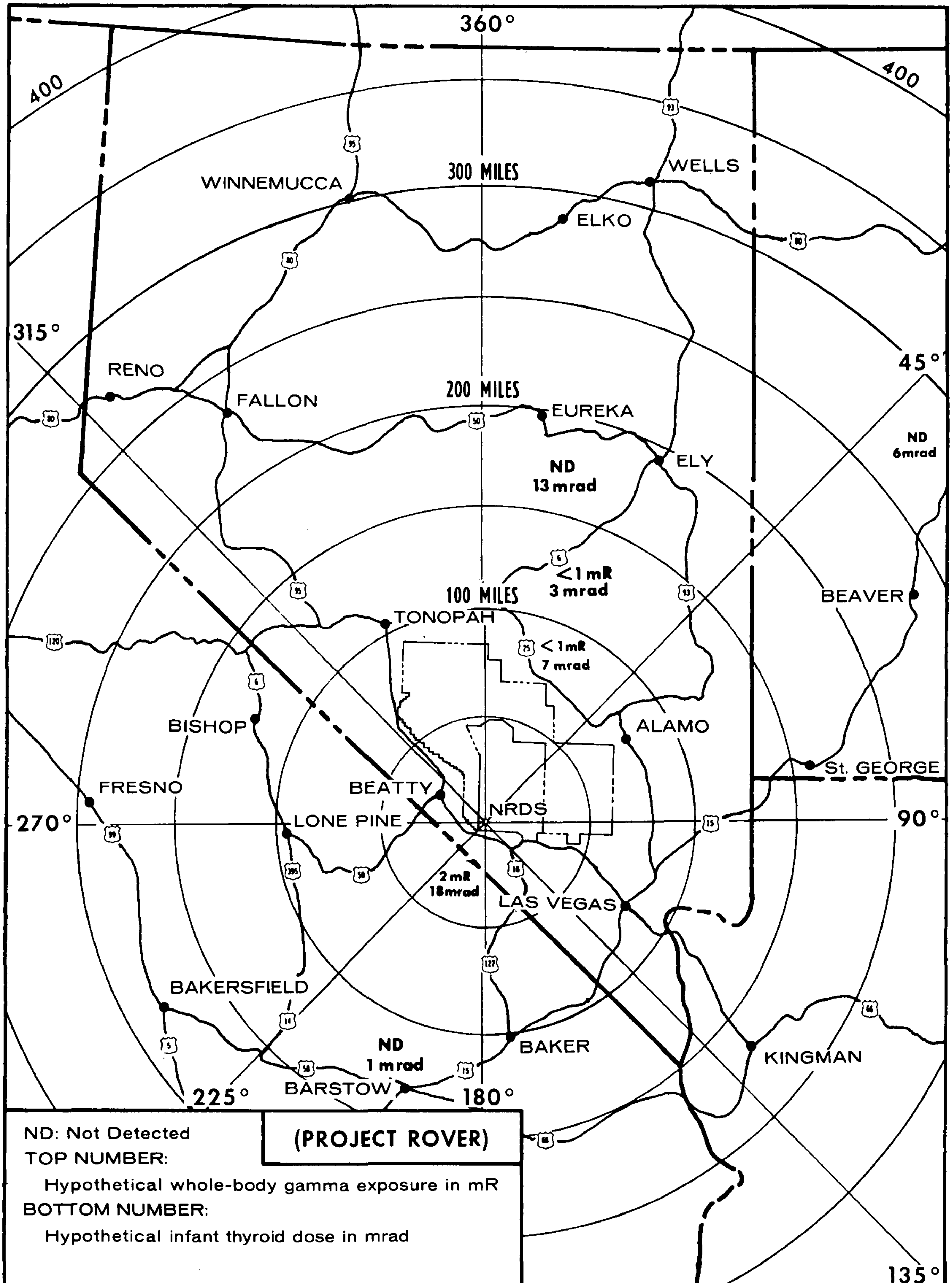


**FIGURE 5**

**OFF-SITE WHOLE-BODY GAMMA EXPOSURES AND INFANT THYROID DOSES RESULTING FROM REACTOR/ENGINE TESTS DURING CY 1967**

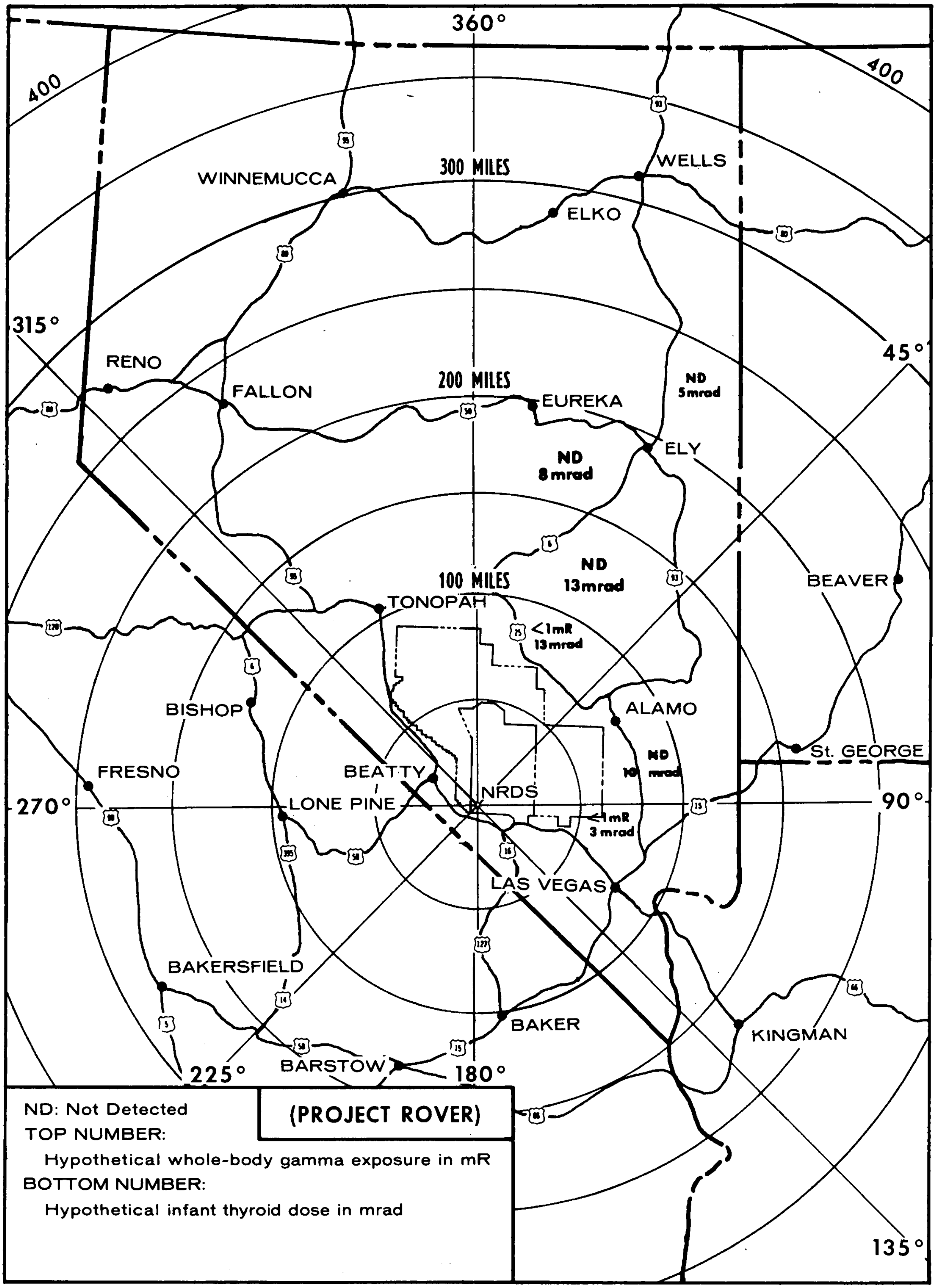


**FIGURE 6**

**OFF-SITE WHOLE-BODY GAMMA EXPOSURES AND INFANT THYROID DOSES RESULTING FROM REACTOR/ENGINE TESTS DURING CY 1968**

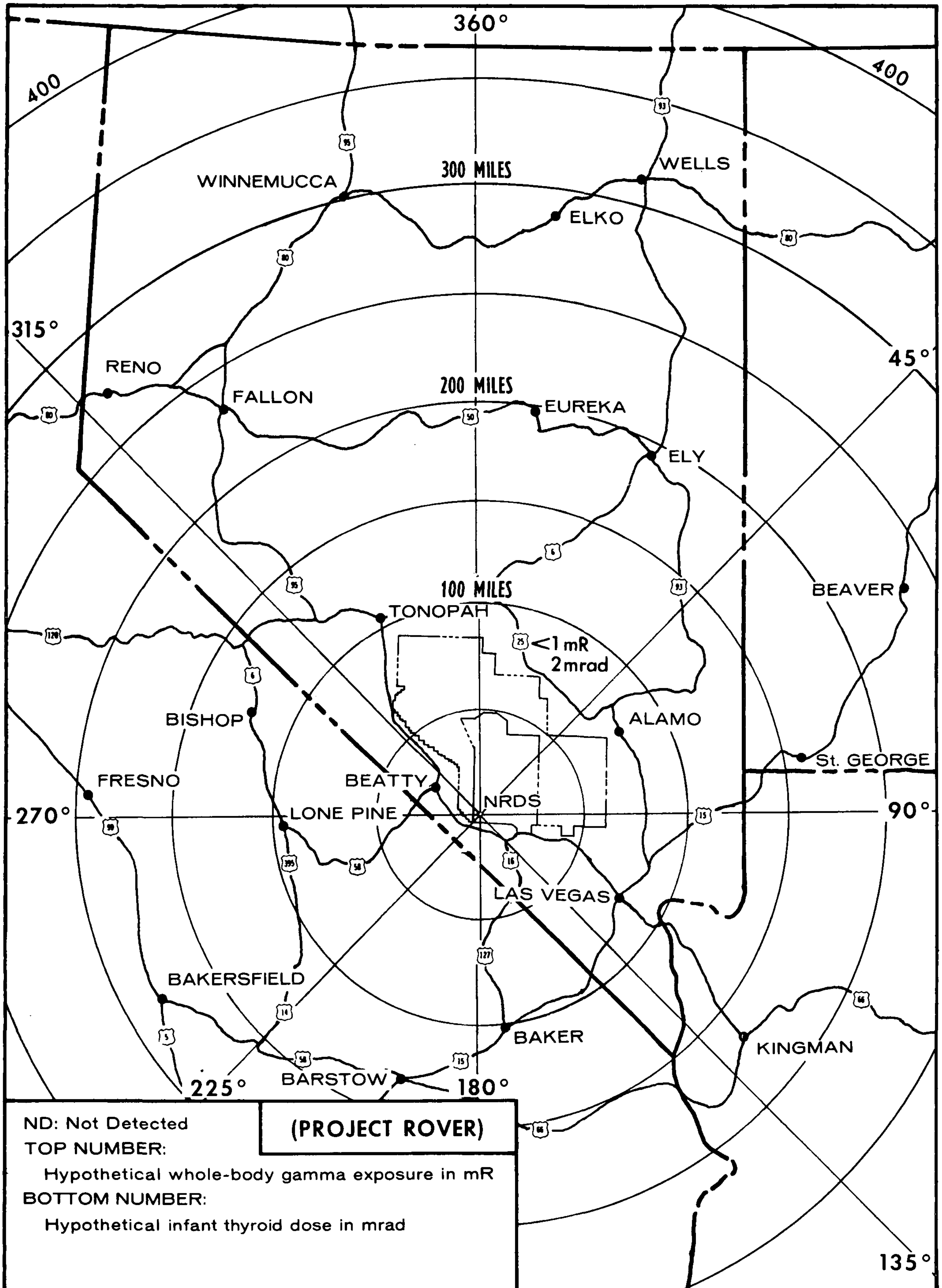


**FIGURE 7**
**OFF-SITE WHOLE-BODY GAMMA EXPOSURES AND INFANT THYROID DOSES RESULTING FROM REACTOR/ENGINE TESTS DURING CY 1969**

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## APPENDIX

### Calculation of Thyroid Dose

The dose rate to the thyroid may be described by the equation

$dD/dt = KEA \exp - (\lambda_{eff} t)$ where:

$dD/dt$ = dose rate per unit time

$K$ = dimensional constant

$E$ = effective energy of beta and gamma radiation, MeV per disintegration

$A$ = concentration of radioiodine in thyroid, μCi/g

$\lambda_{eff}$ = effective decay constant, 1/unit time

$t$ = time after deposition in thyroid

This assumes that the radioiodine is uniformly distributed throughout the thyroid and that the size of the thyroid is large compared to the range of the beta particles.

The total dose is estimated by integrating the above equation from time zero to infinity assuming D = 0 at time zero.

$$D = KEA \int_0^\infty \exp -(\lambda_{eff} t)\, dt$$

$$D = (-1/\lambda_{eff})\ KEA \exp -(\lambda_{eff} t) \Big|_0^\infty$$

$$D = 0 + KEA/\lambda_{eff}$$

Dose from Inhalation of Radioiodines

The actual values for the parameters in the dose equation for $^{131}I$ are as follows:

$$K = \frac{1 \text{ rad}}{100 \text{ erg/g}} \times \frac{\text{erg}}{6.24\times10^5 \text{ MeV}} \times \frac{3.7\times10^4 \text{ dis}}{\mu\text{Ci}\cdot\text{sec}} \times \frac{8.64\times10^4 \text{ sec}}{\text{day}}$$

$$K = \frac{51.2 \text{ rad}\cdot\text{g}\cdot\text{dis}}{\text{MeV}\cdot\mu\text{Ci}\cdot\text{day}}$$

$E = 0.23$ MeV (1)

---

$A = \frac{\chi B f}{m}$, where:

$\chi$ = time-integrated concentration of radioactivity, $\mu Ci \cdot sec/m^3$

$B$ = breathing rate of standard man, $2.32 \times 10^{-4} m^3/sec$ (1) (averaged over 24 hours)

$f$ = fraction of inhaled radioiodine reaching the thyroid, 0.23 (1)

$m$ = thyroid weight of standard man, 20 g

$$A = \frac{(2.32 \times 10^{-4} m^3/sec)(0.23)\chi}{20 \text{ g}}$$

---

$\lambda_{eff}$ = 0.693/(effective half-life for $^{131}I$)

$\lambda_{eff}$ = (0.693)/7.6 days (1)

---

Substituting these parameters, the dose equation becomes:

$$D = \frac{(51.2)(0.23)(2.32 \times 10^{-4})(0.23)(7.6)\chi}{(20)(0.693)}$$

$$D(\text{rads}) = \left(3.44 \times 10^{-4} \frac{\text{rads} \cdot m^3}{\mu Ci \cdot sec}\right)\chi \left(\frac{\mu Ci \cdot sec}{m^3}\right)$$

or $D(\text{mrad}) = \left(0.34 \frac{\text{mrad} \cdot m^3}{\mu Ci \cdot sec}\right)\chi \left(\frac{\mu Ci \cdot sec}{m^3}\right)$ rounded off to two significant figures.

For the dose to a child's thyroid the above equation must be multiplied by a factor of 3 to account for differences in thyroid weight and breathing rates ($m^3$/day) between an adult and a child {$3 = [(20g/2g)][(6m^3/day)/(20m^3/day)]$}.

For other radioiodines the dose equation changes according to differences in effective half-life and effective decay energies. The dose equations for $^{133}I$ and $^{135}I$ are as follows:

$^{133}I$, D(mrad) = $(0.093\ mrad \cdot m^3/\mu Ci \cdot sec)\chi$ for E = 0.54 MeV and $\lambda_{eff} = 0.693/0.87d$

$^{135}I$, D(mrad) = $(0.029\ mrad \cdot m^3/\mu Ci \cdot sec)\chi$ for E = 0.52 MeV and $\lambda_{eff} = 0.693/0.28d$

In addition to differences in effective half-life and effective beta particle energies, the dose equation for $^{132}I$ is effected by the rapid decay of $^{132}I$ in the blood stream before it gets to the thyroid and by the decay rate of $^{132}Te$, the precursor of $^{132}I$ (2, 3). With these effects incorporated, the dose equation for $^{132}I$ becomes

$$D(mrad) = (5.1 \times 10^{-2}\ mrad \cdot m^3/\mu Ci \cdot sec)\chi$$

where $\chi$ is the time-integrated concentration of $^{132}Te$.

Dose from Ingestion of Milk Containing Radioiodine

For ingestion, parameter A, integrated concentration of radioiodine in the thyroid, is defined by $A = \frac{CVf}{m}$ where,

C = the time-integrated concentration of radioiodine in milk, pCi·day/l (time-integrated concentration from time zero to infinity assuming that the effective half-lifes of $^{131}I$, $^{133}I$, and $^{135}I$ in milk are 5 days, 21 hours, and 6.7 hours, respectively)

V = the rate by which milk is consumed by a child one year old or less, 1 liter/day (4)

f = fraction of ingested radioiodine reaching the thyroid, 0.3 (1)

m = thyroid weight of a child one year old or less, 2 g (4)

With the values for V, f, and m substituted,

$$A = \frac{(1\ liter/day)(0.3)}{2\ g} C, \text{ or}$$

$$A = \frac{0.15\ liter}{day \cdot g} C$$

For $^{131}I$ the dose equation $D = KEA/\lambda_{eff}$ becomes applicable to milk ingestion with the above expression for A substituted.

$$D(\text{mrad}) = \left(5.12 \times 10^{-2} \frac{\text{mrad}\cdot\text{g}\cdot\text{dis}}{\text{MeV}\cdot\text{pCi}\cdot\text{day}}\right)\left(\frac{0.23\ \text{MeV}}{\text{dis}}\right)\left(\frac{0.15\ \text{l}}{\text{day}\cdot\text{g}}\right)\left(\frac{7.6\ \text{day}}{0.693}\right)C$$

$$\text{or, } D = \left(\frac{1.9 \times 10^{-2}\ \text{mrad}\cdot\text{l}}{\text{pCi}\cdot\text{day}}\right) C \left(\frac{\text{pCi}\cdot\text{day}}{\text{liter}}\right)$$

For other radioiodines, the above dose equation changes according to differences in effective half-life and effective decay energies to become:

$$D = \frac{(5.12 \times 10^{-2})(0.54)(0.15)(0.87)}{0.693} = (5.2 \times 10^{-3})\ C \text{ for } {}^{133}I \text{ and}$$

$$D = \frac{(5.12 \times 10^{-2})(0.52)(0.15)(0.28)}{0.693} = (1.6 \times 10^{-3})\ C \text{ for } {}^{135}I.$$

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4. "Background Material for the Development of Radiation Protection Standards." Staff Report No. 5 of the Federal Radiation Council. Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. July 1964. pp. 14-16.

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28 M. Klein, SNPO, Washington, D. C.

29 R. Decker, SNPO, Washington, D. C.

30 R. Hartfield, SNPO-C, Cleveland, Ohio

31 J. P. Jewett, SNPO-N, Jackass Flats, Nevada

32 - 41 R. Nelson, SNPO-N, NRDS, Jackass Flats, Nevada

42 Wm. C. King, LRL, Mercury, Nevada

43 Roger Batzel, LRL, Livermore, California

44 J. E. Carothers, LRL, Livermore, California

45 H. T. Knight, LASL, Jackass Flats, Nevada

46 P. Gothels, LASL, Los Alamos, New Mexico

47 H. S. Jordan, LASL, Los Alamos, New Mexico

48 Charles I. Browne, LASL, Los Alamos, New Mexico

49 Wm. E. Ogle, LASL, Los Alamos, New Mexico

50 R. E. Smith, LASL, NRDS, Jackass Flats, Nevada

51 Keith Boyer, LASL, NRDS, Jackass Flats, Nevada

52 - 54 Wm. W. Allaire, AEC/NVOO, Las Vegas, Nevada

55 G. Hoover, AEC/OCC, Mercury, Nevada

Distribution (continued)

56 D. Gray, NRTO, NRDS, Jackass Flats, Nevada

57 J. Powell, NRTO, NRDS, Jackass Flats, Nevada

58 H. G. Simens, NRTO, Aero-jet General Corp., Jackass Flats, Nev.

59 R. A. Smith, NRTO, NRDS, Jackass Flats, Nevada

60 G. Grandy, WANL, NRDS, Jackass Flats, Nevada

61 E. Hemmerle, WANL, Pittsburgh, Pennsylvania

62 H. Mueller, ARL/ESSA, AEC/NVOO, Las Vegas, Nevada

63 J. Doyle, EG&G, Las Vegas, Nevada

64 J. Gallimore, Pan. Am. World Airways, Jackass Flats, Nevada

65 J. Mohrbacher, Pan. Am. World Airways, Jackass Flats, Nevada

66 Martin B. Biles, DOS, USAEC, Washington, D. C.

67 R. S. Davidson, Battelle Memorial Institute, Columbus, Ohio

68 Byron Murphey, Sandia Labs., Albuquerque, New Mexico

69 - 70 Charles L. Weaver, PHS, BRH, Rockville, Maryland

71 John C. Villforth, Director, BRH, Rockville, Maryland

72 John G. Bailey, Office of Information, BRH, Rockville, Maryland

73 Wm. Link, BRH Library, Rockville, Maryland

74 Arden E. Bicker, REECo., Mercury, Nevada

75 Southeastern Rad. Health Lab., Montgomery, Alabama

76 Northeastern Rad. Health Lab., Winchester, Mass.

77 - 78 DTIE, USAEC, Oak Ridge, Tennessee