DOE/EIS-0064

File Copy

Final environmental Impact Statement
(Final Statement to ERDA 1545-D)

Rocky Flats Plant Site

Golden, Jefferson County, Colorado

U.S. DEPARTMENT OF ENERGY

APRIL 1980
Volume 2 of 3
Appendices

Available from:

National Technical Information Service (NTIS)
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

Price:

Printed Copy: $22.50
Microfiche: $22.50

Sold only as 3 volume sets

DOE/EIS-0064
UC-2,11

Final environmental Impact Statement
(Final Statement to ERDA 1545-D)

RockyFlats Plant Site

Golden, Jefferson County, Colorado

Responsible Official

Ruth C. Clusen
Assistant Secretary for Environment

U.S. DEPARTMENT OF ENERGY
Washington, D.C. 20585

APRIL 1980
Volume 2 of 3
Appendices

SUMMARY OF CONTENTS

TABLE OF CONTENTS

VOLUME II--APPENDICES

APPENDIX A

FLORA AND FAUNA

Appendix A consists of two parts. The first, Appendix A-1, is a composite listing of Rocky Flats flora and fauna generated by on-site and off-site researchers.

The second document, Appendix A-2, is a reproduction of a three-year summary report of Colorado State University researchers.

APPENDIX A-1

LIST OF FLORA AND FAUNA AT ROCKY FLATS

Numerous species of animal and plant life have been identified in the Rocky Flats area. None are classified as rare or endangered.

Rocky Flats floras have been identified (Table A-1) through an on-site inventory by Dr. W. A. Weber, et al., (Weber, 1974), from the University of Colorado. The inventory revealed 327 species of vascular plants, 25 lichens, 16 bryophytes, and one macroscopic green algae.

The species listed in Table A-1 are documented by specimens on permanent file in the University of Colorado Museum herbarium. A second set, complete except for species that were in extremely short supply, was deposited with the management of the Rocky Flats Plant. Duplicate collections of the bryophytes and lichens were not prepared for on-site documentation, however, these specimens are on permanent file in the University of Colorado Museum herbarium.

Table A-1 is divided into four sections: vascular plants, bryophytes, lichens, and macroscopic green algae. The list within each section is arranged alphabetically by species, with the family indicated secondarily. In addition, square brackets are used to identify some species reported by Dr. Whicker of CSU, (Whicker, 1973) but which Weber did not find in his inventory.

Abbreviations used in Table A-1 are as follows:

ADV-Adventive	BIEN-Biennial	PER-Perennial
AN-Annual	IND-Indigenous	

Shown in Tables A-2 and A-3 is a listing of fauna at Rocky Flats, which was generated from observations of CSU researchers (Whicker, 1974), and those of a Rocky Flats' biologist (Zillich, 1974). Fish known to occur at Rocky Flats were identified by Zillich (1974) and are listed in Table A-4. Other species of aquatic life within the Plant site were identified by Johnson, et al., (1974), and are also listed in Table A-4.

REFERENCES

Clark, S. J. V. The Vegetation of Rocky Flats, Colorado. Master's Thesis. University of Colorado. Prepared under ERDA Contract No. E(11-1-2371). 1977.

Johnson, J. E., S. Svalberg, and D. Paine. Study of Plutonium in Aquatic Systems of the Rocky Flats Environs. Final Technical Report. Colorado State University, Fort Collins, Colorado. Prepared under The Dow Chemical Company Contract No. 41493-F. June 1974.

Weber, W. A., G. Kunkel, and L. Shultz. A Botanical Inventory of the Rocky Flats AEC Site, Final Report. COO-2371-2. University of Colorado, Boulder, Colorado. Prepared for the U. S. Atomic Energy Commission under Contract No. AT(11-1)-2371, July 31, 1974.

Whicker, F. W. Radiology of Some Natural Organisms and Systems in Colorado. Eleventh Technical Progress Report. Colorado State University, Fort Collins, Colorado. Prepared for the U. S. Atomic Energy Commission under Contract No. AT(11-1)-1156. 1973.

Whicker, F. W. Radiology of Some Natural Organisms and Systems in Colorado. Twelfth technical Progress Report. Colorado State University, Fort Collins, Colorado. Prepared for the U. S. Atomic Energy Commission under Contract No. AT(11-1)-1156. 1974.

Zillich, J. A. Biological Impacts of Rocky Flats Wastes Discharged to Surface Waters. RFP-2210. Dow Chemical U.S.A., Rocky Flats Division, Golden, Colorado. April 9, 1974.

TABLE A-1

PLANTS KNOWN TO OCCUR AT THE ROCKY FLATS SITE

Vascular Plants (327 Species)

ACHILLEA LANULOSA Nutt. "Yarrow" (Compositae). IND PER
AGOSERIS GLAUCA (Pursh) Raf. "False Dandelion" (Compositae). IND PER
AGRIMONIA STRIATA Michx. "Agrimony" (Rosaceae). IND PER
AGROPYRON DESERTORUM (Fisch.) Schult. "Crested Wheatgrass" (Gramineae). ADV PER
AGROPYRON REPENS (L.) P.Beauv. "Quack-Grass" (Gramineae). ADV PER
AGROPYRON SMITHII Rydberg. "Western Wheat-grass" (Gramineae). IND PER
AGROPYRON TRACHYCAULUM (Link) Malte. "Slender Wheat-grass" (Gramineae). IND PER
AGROSTIS GIGANTEA Roth (A.alba of American treatments). "Red-top" (Gramineae). ADV PER
ALISMA PLANTAGO-AQUATICA L. ssp. BREVIPES (Greene) Samuelsson. "Water-plantain" (Alismaceae). IND PER ALLIUM CERNUUM Roth. "Nodding Onion" (Liliaceae). IND PER
ALLIUM TEXTILE Nels. and Macbr. "Plains Wild Onion" (Liliaceae). IND PER
ALYSSUM ALYSSOIDES L. "Sweet Alyssum" (Cruciferae). ADV
ALYSSUM MINUS (L.) Rothmaler. "Alyssum" (Cruciferae). ADV
AMBROSIA ARTEMISIIFOLIA L. "Roman wormwood" (Compositae). ADV AN
AMBROSIA PSILOSTACHYA DC. "Western wormwood" (Compositae). IND PER
AMBROSIA TRIFIDA L. "Giant Ragweed" (Compositae). ADV AN
AMELANCHIER ALNIFOLIA Nutt. "Shadbush" or "Serviceberry" (Rosaceae). IND
AMORPHA FRUTICOSA L. var. OCCIDENTALIS (Abrams) Kearney and Peebles. "Lead-plant" (Leguminosae). IND
[Amorpha nana.] In the absence of a voucher, we suspect that this is a misidentification of Amorpha fruticosa.
ANDROPOGON GERARDII Vitm. "Big Bluestem" (Gramineae). IND PER
[Andropogon hallii.] We suspect this report to be a misidentification of A.gerardii. A.hallii has not yet been found in the Boulder area and is typical of sand dune areas to the east.
ANDROSACE OCCIDENTALIS Pursh. "Western rock-primrose" (Primulaceae). IND AN
ANEMONE CYLINDRICA Gray. "Thimbleweed" (Ranunculaceae). IND PER
ANTENNARIA PARVIFOLIA Nutt. "Pussytoes" (Compositae). IND PER
ARABIS FENDLERI (Wats.) Greene. "Rock Cress" (Cruciferae). IND PER
ARABIS GLABRA (L.) Bernh. "Tower Mustard" (Cruciferae). ADV BIEN
ARABIS HIRSUTA (L.) Scop. "Hairy Rock-cress" (Cruciferae). IND
ARENARIA FENDLERI Gray. "Sandwort" (Caryophyllaceae). IND PER
ARGEMONE POLYANTHEMOS (Fedde) G.B. Ownbey. "Prickly Poppy" (Papaveraceae). IND BIEN
ARISTIDA BASIRAMEA Engelm. "Harvard Three-awn" (Gramineae). IND AN
ARISTIDA LONGISETA Steud. "Red Three-awn" (Gramineae). IND PER
ARNICA FULGENS Pursh. "Orange Arnica" (Compositae). IND PER
ARTEMISIA CAMPESTRIS L. "Field Wormwood" (Compositae). IND PER
ARTEMISIA DRACUNCULUS L. "Linear-leaved Wormwood" (Compositae). IND PER

TABLE A-1 (continued)

ARTEMISIA DRACUNCULUS L. "Linear-leaved Wormwood" (Compositae). IND PER

ARTEMISIA FRIGIDA Willd. "Pasture Sagebrush" (Compositae). IND PER

ARTEMISIA LUDOVICIANA Nutt. ssp. LUDOVICIANA

ASCLEPIAS SPECIOSA Torr. "Showy Milkweed" (Asclepiadaceae). IND PER

[Asclepias stenophylla.] We undoubtedly overlooked this species, which occurs very sporadically and never occurs in large numbers.

ASCLEPIAS VIRIDIFLORA Raf. "Green Milkweed" (Asclepiadaceae). IND PER

ASPARAGUS OFFICINALIS L. "Asparagus" (Liliaceae). ADV PER

[Aster commutatus crassulus.] Aster falcatus Lindley. Very late-flowering species which we may well have missed. However, there is also the possibility of a misidentification of Aster porteri.

[Aster ericoides.] See note under A.commutatus. Both species should occur in the area.

ASTER PORTERI Gray. "White Aster" (Compositae). IND PER

ASTRAGALUS ADSURGENS Pall. var. ROBUSTIOR Hook. "Milk Vetch" (Leguminosae). IND PER

ASTRAGALUS BISULCATUS (Hook.) Gray. "Two-grooved Milk Vetch" (Leguminosae). IND PER

ASTRAGALUS CRASSICARPUS Nutt. "Ground-plum" (Leguminosae). IND PER

ASTRAGALUS DASYGLOTTIS Fisch. ex DC. "Milk Vetch" (Leguminosae). IND PER

ASTRAGALUS DRUMMONDII Dougl. ex Hook. "Milk Vetch" (Leguminosae). IND PER

ASTRAGALUS FLEXUOSUS (Dougl.) Don. "Milk Vetch" (Leguminosae). IND PER

ASTRAGALUS SHORTIANUS Gray. "Milk Vetch" (Leguminosae). IND PER

BARBAREA ORTHOCERAS Ledeb. "Winter Cress" (Cruciferae). IND PER

BIDENS CERNUS L. "Nodding Bur-marigold" (Compositae). IND AN

BOUTELOUA GRACILIS (H.B.K.) Lag. "Blue Grama" (Gramineae). IND PER

BOUTELOUA CURTIPENDULA (Michx.) Torr. "Side-oats Grama" (Gramineae). IND PER

BROMUS BRIZAEFORMIS F. and M. "Rattlesnake Grass" (Gramineae). ADV AN

BROMUS INERMIS Leyss. "Smooth Brome" (Gramineae). ADV PER

BROMUS JAPONICUS Thunb. "Japanese Brome" (Gramineae). ADV AN

BROMUS TECTORUM L. "Cheat-grass" (Gramineae). ADV AN

BUCHLOE DACTYLOIDES (Nutt.) Engelm. "Buffalo Grass" (Gramineae). IND PER

CALLITRICHE PALUSTRIS L. "Water Starwort" (Callitrichaceae). IND AN

CALOCHORTUS GUNNISONII Wats. "Mariposa or Sego Lily" (Liliaceae). IND PER

CALYLOPHUS SERRULATA (Nutt.) Raven. "Bushy Evening-Primrose" (Onagraceae). IND PER

CALYSTEGIA SEPIUM (L.) R.Br. ssp. AMERICANUM (Sims) Brummitt. "Hedge Bindweed" (Congolvulaceae). IND PER

CAMELINA MICROCARPA Andrz. "False Flax" (Cruciferae). ADV AN

CAMPANULA ROTUNDIFOLIA L. "Common Harebell" (Campanulaceae). IND PER

CARDARIA DRABA (L.) Desv. "Whiteweed" (Cruciferae). ADV PER

CARDUUS NUTANS L. ssp. MACROLEPIS (Peterm.) Kazmi. "Nodding Thistle" (Compositae). ADV BIEN

CAREX ATHROSTACHYA Olney. "Sedge" (Cyperaceae). IND PER

CAREX AUREA Nutt. "Sedge" (Cyperaceae). IND PER

CAREX BREVIOR (Dewey) Mack. "Sedge" (Cyperaceae). IND PER

TABLE A-1 (continued)

CAREX DOUGLASII Boott in Hook. "Sedge" (Cyperaceae). IND PER
[Carex filifolia.] We suspect that this report refers to Carex oreocharis.
CAREX HELIOPHILA Mack. "Sedge" (Cyperaceae). IND PER
CAREX HYSTRICINA Muehl. "Bottle-brush Sedge" (Chperaceae). IND(?)PER
CAREX INTERIOR L.H. Bailey. "Sedge" (Cyperaceae). IND PER
CAREX LANUGINOSA Michx. "Sedge" (Cyperaceae). IND PER
CAREX NEBRASKENSIS Dewey. "Sedge" (Cyperaceae). IND PER
CAREX OREOCHARIS Holm. "Sedge" (Cyperaceae). IND PER
CAREX PRAEGRACILIS Boott. "Sedge" (Cyperaceae). IND PER
CAREX SCOPARIA Schkuhr. "Sedge" (Cyperaceae). IND PER
CAREX SIMULATA Mack. "Sedge" (Cyperaceae). IND PER
CAREX STENOPHYLLA Wahlenb. ssp. ELEOCHARIS (L.H. Bailey) Hulten. "Sedge" (Cyperaceae). IND PER
CAREX STIPATA Muehl. "Sedge" (Cyperaceae). IND PER
CAREX UTRICULATA Boott. "Sedge" (Cyperaceae). IND PER
CASTILLEJA INTEGRA Gray. "Orange Paintbrush" (Scrophulariaceae). IND PER
CASTILLEJA SESSILIFLORA Pursh. "Plains Paintbrush" (Scrophulariaceae). IND PER
CENCHRUS LONGISPINUS (Hack. in Kneuck.) Fern. "Sand Bur" (Gramineae). IND PER
CERASTIUM ARVENSE L. "Field Mouse-ear" (Caryophyllaceae). IND PER
CERASTIUM FONTANUM Baumg. "Mouse-ear" (Caryophyllaceae). ADV PER
CERASTIUM NUTANS Raf. var. BRACHYPODUM Engelm. "Mouse-ear" (Caryophyllaceae). IND AN
[Cercocarpus montanus.] We did not find this conspicuous shrub and feel obliged to doubt the report.
CHAMAESYCE GLYPTOSPERMA (Engelm.) Small. "Thyme-leaved Spurge" (Euphorbiaceae). IND AN
CHENOPODIUM ALBUM L. "Common Pigweed" (Chenopodiaceae). ADV AN
CHENOPODIUM BOTRYS L. "Jerusalem-oak" (Chenopodiaceae). ADV AN
CHENOPODIUM LEPTOPHYLLUM (Moq.) Wats. "Narrow-leaved Goose-foot" (Chenopodiaceae). IND AN
[Chrysopsis villosa.] This is the same as Heterotheca villosa.
[Chrysothamnus nauseosus pinifolius.] We do not believe that we could have overlooked this conspicuous shrub, and we suggest that this was possibly based on a misidentification of Gutierrezia sarothrae.
CICHORIUM INTYBUS L. "Chicory" (Compositae). ADV PER
CIRSIUM ARVENSE (L.) Scop. "Canada Thistle" (Compositae). ADV PER
CIRSIUM OCHROCENTRUM Gray. "Thistle." IND BIEN
CIRSIUM UNDULATUM (Nutt.) Spreng. "Wavy-leaved Thistle" (Compositae). IND BIEN
CLEMATIS LIGUSTICIFOLIA Nutt. "Western Virgin's-bower" (Ranunculaceae). IND
COLLINSIA PARVIFLORA Lindl. "Baby-blue-eyes" (Scrophulariaceac. IND AN
COLLOMIA LINEARIS Nutt. "Collomia" (Polemoniaceae). IND AN
COMANDRA UMBELLATA (L.) Nutt. "Bastard Toadflax" (Santalaceae). IND PER
CONVOLVULUS ARVENSIS L. "Bindweed; Creeping-Jenny" (Convolvulaceae). ADV PER
CORYPHANTHA MISSOURIENSIS (Sweet) Britt. and Rose. "Nipple Cactus" (Cactaceae). IND PER
CRATAEGUS ERYTHROPODA Ashe. "Hawthorn" (Rosaceae). IND

TABLE A-1 (continued)

CREPIS OCCIDENTALIS Nutt. "Hawksbeard" (Compositae). IND PER

CREPIS RUNCINATA T. and G. "Hawksbeard" (Compositae). IND PER

CUSCUTA APPROXIMATA Bab. "Dodder" (Convolvulaceae). IND AN

CYNOGLOSSUM OFFICINALE L. "Hound's-tongue" (Borginaceae). ADV BIEN

[Cyperus filiculmis.] We doubt that this species occurs in the area, but in the absence of a voucher specimen, we cannot guess what other species might have been mistaken for it.

DACTYLIS GLOMERATA L. "Orchard Grass" (Gramineae). ADV PER

DALEA CANDIDA Willd. "Prairie-clover" (Leguminosae). IND PER

DALEA PURPUREA Vent. "Prairie-clover" (Leguminosae). IND PER

DELPHINIUM NELSONII Greene. "Larkspur" (Ranunculaceae). IND PER

DELPHINUM VIRESCENS Nutt. "Plains Larkspur" (Ranunculaceae). IND PER

DESCURAINIA PINNATA (Walt.) Britt. "Tansy Mustard" (Cruciferae). IND AN

DESCURAINIA SOPHIA (L.) Webb. "Tansy Mustard" (Cruciferae). ADV AN

DODECATHEON PULCHELLUM (Raf.) Merrill. "Shooting-star" (Primulaceae). IND PER

DYSSODIA PAPPOSA (Vent.) Hitchc. "Fetid Marigold" (Compositae). IND AN

ECHINOCEREUS VIRIDIFLORUS Engelm. "Hen-and-chickens" (Cactaceae). IND PER

ECHINOCHLOA CRUS-GALLI (L.) P. Beauv. "Barnyard Grass" (Gramineae). ADV AN

ELEOCHARIS COLORADOENSIS (Britt.) Gilly. "Spike-rush" (Cyperaceae). IND PER

ELEOCHARIS ELLIPTICA Kunth var. COMPRESSA (Sull.) Drap. and Mohl. "Spike-rush" (Cyperaceae). IND PER

ELEOCHARIS MACROSTACHYA Britt. "Spike-rush" (Cyperaceae). IND PER

ELYMUS CANADENSIS L. "Canada Wild-rye" (Gramineae). IND PER

EPILOBIUM ADENOCAULON Hausskn. "Northern Willow-herb" (Onagraceae). IND PER

EPILOBIUM PANICULATUM Nutt. "Panicled Willow-herb" (Onagraceae). IND AN

EQUISETUM LAEVIGATUM A. Br. "Scouring-rush" (Equisetaceae). IND PER

ERIGERON CANUS Gray. "Fleabane" (Compositae). IND PER

ERIGERON DIVERGENS T. and G. "Spreading Fleabane" (Compositae). IND AN BIEN

ERIGERON FLAGELLARIS Gray. "Trailing Fleabane" (Compositae). IND PER

ERIGERON PUMILUS Nutt. "Low Daisy" (Compositae). IND PER

[Erigeron speciosus.] This report must represent a misidentification, most likely of Erigeron strigosus.

ERIGERON STRIGOSUS Muehl. "Daisy Fleabane" (Compositae). ADV AN BAINE PER

ERIOGONUM ALATUM Torr. "Winged Eriogonum" (Polygonaceae). IND PER BIEN

ERIOGONUM UMBELLATUM Torr. "Sulphur-flower" (Polygonaceae). IND PER

ERODIUM CICUTARIUM (L.) L'Her. "Filaree" (Geraniaceae). ADV PER

ERYSIMUM ASPERUM (Nutt.) DC. "Western Wallflower" (Cruciferae). IND BIEN PER

[Euphorbia dictyosperma.] We have only found this species outside the site boundary.

EUPHORBIA MARGINATA Pursh. "Snow-on-the-Mountain" (Euphorbiaceae). IND AN

EUPHORBIA ROBUSTA (Engelm.) Small. "Rocky Mountain Spurge" (Euphorbiaceae). IND PER

FESTUCA PRATENSIS Huds. "Meadow Fescue" (Gramineae). ADV PER

FRASERA SPECIOSA Dougl. "Monument Plant" (Gentianaceae). IND PER

TABLE A-1 (continued)

GAILLARDIA ARISTATA Pursh. "Blanket-flower" (Compositae). IND PER

GALIUM APARINE L. "Cleavers" (Rubiaceae). IND AN

GALIUM BOREALE L. "Northern Bedstraw" (Rubiaceae). IND PER

GAURA COCCINEA Nutt. "Scarlet Gaura" (Onagraceae). IND PER

GENTIANA AFFINIS GRISEB. IND PER

GERANIUM CAESPITOSUM James (G. fremontii of Colorado literature). "Wild Geranium" (Geraniaceae). IND PER

GILIA OPHTHALMOIDES brand ssp. CLOKEYI (MASON) A. and V. Grant. "Gilia" (Polemoniaceae). IND AN

GLYCERIA MAXIMA (Hartm.) Holmboe ssp. GRANDIS (Wats.) Hulten. "American Manna-grass" (Gramineae). IND PER

GLYCERIA STRIATA (Lam.) Hitchc. "Fowl Manna-grass" (Gramineae). IND PER

GLYCYRRHIZA LEPIDOTA (Nutt.) Pursh. "Wild Liquorice" (Leguminosae). IND PER

GRINDELIA SQUARROSA (Pursh.) Dunal. "Gumweed" (Compositae). IND BIEN

GUTIERREZIA SAROTHRA E (Pursh.) Britt. and Rusby. "Snakeweed" (Compositae). IND PER

HARBOURIA TRACHYPLEURA (Gray) C. and R. "Whiskbroom Parsley" (Umbelliferae). IND PER

HEDEOMA HISPIDUM Pursh. "Pennyroyal" (Labiatae). IND AN

HELIANTHUS ANNUUS L. "Common Sunflower" (Compositae). IND AN

[Helianthus petiolaris.] We may have overlooked this species, which is very similar to H. annuus. Both species and hybrids between them occur commonly in the Boulder area.

HELIANTHUS PUMILUS Nutt. "Sunflower" (Compositae). IND PER

HERACLEUM LANATUM Michx. "Cow Parsnip" (Umbelliferae). IND BIEN PER

HETEROTHECA VILLOSA (Pursh.) Shinners. "Golden Aster" (Compositae). IND PER

HEUCHERA PARVIFOLIA Nutt. "Alum-root" (Saxifragaceae). IND PER

HORDEUM JUBATUM L "Foxtail Barley" (Gramineae). IND PER

HYDROPHYLLUM FENDLERI (Gray) Heller. "Waterlead" (Hydrophyllaceae). IND PER

HYMENOPAPPUS FILIFOLIUS Nutt. (Compositae). IND PER

HYPERICUM PERFORATUM L. "Klamath Weed"(Hypericaceae). ADV PER

IPOMOPSIS SPICATA (Nutt.) V. Grant. "Spike Bilia" (Polemoniaceae). IND BIEN

IRIS MISSOURIENSIS Nutt. "Wild Iris" (Iridaceae). IND PER

JUNCUS ARCTICUS Willd. ssp. ATER (Rydb.) Hulten. "Baltic Rush" (Juncaceae). IND PER

[Juncus balticus.] Juncus arcticus ssp. ater.

JUNCUS BUFONIUS L. "Toad Rush" (Juncaceae). IND AN

JUNCUS DUDLEYI Wieg. "Rush" (Juncaceae). IND PER

JUNCUS NODOSUS L. "Rush" (Juncaceae). IND PER

JUNCUS SACIMONTANUS A. Nels. "Rush" (Juncaceae). IND PER

JUNCUS SPHAEROCARPUS Nees. "Toad Rush" (Juncaceae). ADV AN

JUNCUS TORREYI Cov. "Rush" (Juncaceae). IND PER

JUNCUS TRACYI Rydb. "Rush" (Juncaceae). IND PER

[Kochia iranica.] This is the most abundant ruderal weed in the Boulder area. We did not see it in our inventory, but it probably occurs, most likely in the vicinity of buildings within the security fence.

TABLE A-1 (continued)

KOELERIA GRACILIS Pers. "June Grass" (Gramineae). IND PER

LACTUCA SERRIOLA L. "Prickly Lettuce" (Compositae). ADV AN

LAPPULA REDOWSKII (Hornem.) GREENE. "Beggar's Tick" (Boraginaceae). IND AN

LATHYRUS EUCOSMUS Butters and St. Joh. "Pea-vine" (Leguminosae). IND PER

LEMNA MINOR L. "Duckweed: (Lemnaceae). IND AN PER

LEPIDIUM CAMPESTRE (L.) R. Br. "Field Cress" (Cruciferae). ADV AN

[Lepidium densiflorum.] This undoubtedly occurs as a weed in the area, possibly within the plant enclosure. We did not see it in the area which we covered.

LESQUERELLA MONTANA (Gray) Wats. "Mountain Bladder-Pod" (Cruciferae). IND PER

LEUCANTHEMUM VULGARE Lam. "Ox-eye Daisy" (Compositae). ADV PER

LEUCOCRINUM MONTANUM Nutt. "Sand Lily" (Liliaceae). IND PER

LIATRIS PUNCTATA Hook. "Blazing Star" (Compositae). IND PER

LINARIA DALMATICA (L.) Mill. "Butter-and-eggs" (Scrophulariaceae). ADV PER

LINUM LEWISH Pursh. "Wild Blue Flax" (Linaceae). IND PER

LITHOSPERMUM INCISUM Lehm. "Narrow-leaved Puccoon" (Boraginaceae). IND PER

LOMATIUM ORIENTALE C. and R. "Salt-and-pepper" (Umbelliferae). IND PER

LUPINUS ARGENTEUS Pursh. "Lupine" (Leguminosae). IND PER

LYSIMACHIA CILIATA L. "Fringed Loosestrife" (Primulaceae). IND PER

LYTHRUM ALATUM Pursh. "Winged Loosestrife" (Lythraceae). IND PER

MAHONIA REPENS (Lindl.) G. Don. "Oregon-grape" (Berberidaceae). IND

MEDICAGO LUPULINA L. "Black Medic" (Leguminosae). ADV PER

MELANDRIUM DIOICUM (L.) Coss. and Germ. "White Campion" (Caryophyllaceae). ADV PER

MELANDRIUM DRUMMONDII (Hook.) Hulten. "Campion" (Caryophyllaceae). IND PER

MELILOTUS ALBA Desr. White Sweet-clover" (Leguminosae). ADV AN BIEN

MELILOTUS OFFICINALIS (L.) Lam. "Yellow Sweet-clover" (Leguinosae). ADV AN BIEN

MENTHA ARVENSIS L. "Field Mint" (Labiatae). IND PER

MERTENSIA LANCEOLATA (Pursh.) A. DC. "Narrow-leaved Mertensia" (Boraginaceae). IND PER

MIMULUS FLORIBUNDUS Doubl. "Monkey-flower" (Scrophulariaceae). IND AN

MIMULUS GLABRATUS H.B.K. "Smooth Monkey-flower" (Scrophulariaceae). IND PER

MONARADA FISTULOSA L. "Pink Bergamot" (Labiatae). IND PER

MUHLENBERGIA MONTANA (Nutt.) Hitche. "Mountain Muhly" (Gramineae). IND PER

MUSINEON DIVARICATUM (Pursh.) Raf. "Musineon" (Umbelliferae). IND PER

MYOSURUS MINIMUS L. "Mousetail" (Ranunculaceae). IND AN

NASTURTIUM OFFICINAL R. Br. (formerly called Rorippa nasturtium-aquaticum [L.] Schinz and Thell.) "Water Cress" (Cruciferae). IND PER

NAVARRETIA MINIMA Nutt. "Navarretia" (Polemoniaceae). ADV (in our area at least) AN

NEPETA CATARIA L. "Catnip" (Labiatae). ADV PER

NOTHOCALAIS CUSPIDATA (Pursh.) Greene. "False Dandelion" (Compositae). IND PER

OENOTHERA BRACHYCARPA Gray. "Yellow Stemless Evening-primrose" (Onagraceae). IND PER

OENOTHERA FLAVA (A. Nels.) Munz. "Evening-primrose" (Onagraceae). IND PER

TABLE A-1 (continued)

OENOTHERA STRIGOSA (Rydb.) Mack. and Bush. "Tall Evening-primrose" (Onagraceae). IND BIEN

ONOSMODIUM MOLLE Michx. var. OCCIDENTALIS (Mack.) Johnston. "False Gromwell" (Boraginaceae). IND PER

OPUNTIA COMPRESSA (Salisb.) Macbr. "Prickly-pear Cactus" (Cactaceae). IND PER

OPUNTIA FRAGILIS (Nutt.) Haw. "Brittle Cactus" (Cactaceae). IND PER

OPUNTIA POLYACANTHA Haw. "Starvation Cactus" (Cactaceae). IND PER

[Opuntia rafinesquei.] = O. compressa.

OROBANCHE FASCICULATA Nutt. "Clustered Cancer-root" (Orobanchaceae). IND AN

OXALIS DILLENII Jacq. "Wood-sorrel" (Oxalidaceae). IND PER

OXYBAPHUS LINEARIS (Pursh.) Robinson. "Narrow-leaved Umbrella-wort" (Nyctaginaceae). IND PER

OXYBAPHUS NYCTAGINEUS (Michx.) Porter and Coulter. "Heart-leaved Umbrella-wort" (Nyctaginaceae). IND PER

OXYTROPIS LAMBERTII Pursh. "Colorado Loco" (Leguminosae). IND PER

PANICUM CAPILLARE L. "Witchgrass" (Gramineae). IND PER

PANICUM OLIGOSANTHES Schult. "Panic-grass" (Gramineae). IND PER

PANICUM VIRGATUM L. "Switchgrass" (Gramineae). IND PER

PARONYCHIA JAMESII T. and G. "Nailwort" (Caryophyllaceae). IND PER

PEDIOCACTUS SIMPSONII (Engelm.) Britt, and Rose. "Mountain Ball Cactus" (Cactaceae). IND PER

[Penstemon angustifolinus.] We suspect this report to be a misidentification of Penstemon virgatus ssp. asagrayi.

PENSTEMON VIRENS Pennell. "Penstemon" (Scrophulariaceae). IND PER

PENSTEMON VIRGATUS Gray ssp. ASA-GRAYI Crosswhite. "One-sided Penstemon" (Scrophulariaceae). IND PER

PERSICARIA LAPATHIFOLIA (L.) S.F. GRAY. "Smartweed" (Polygonaceae). ADV AN

PERISCIARIA MACULATA (Raf.) S.F. Gray. "Lady's Thumb" (Polygonaceae). ADV PER

[Petalostemon purpureus.] = Dalea purpurea.

PHACELIA HETEROPHYLLA Pursh. "Scorpion Weed" (Hydrophyllaceae). IND PER

PHLEUM PRATENSE L. "Timothy" (Gramineae). ADV PER

PHYLA CUNEIFOLIA (Torr.) Greene "Fog-fruit" (Verbenaceae). IND PER

PHYSALIS LOBATA Torr. "Purple-flowered Ground-cherry" (Solanaceae). IND PER

PHYSALIS VIRGINIANA Mill. "Ground-cherry (Solanaceae). IND PER

PHYSOCARPUS MONOGYNUS (Torr.) Coult. "Ninebark" (Rosaceae). IND

PINUS PONDEROSA Laws. var. SCOPULORUM Engelm. "Ponderosa Pine" (Pinaceae). IND

PLANTAGO LANCEOLATA L. "English Plantain" (Plantaginaceae). ADV BIEN PER

PLANTAGO PATAGONICA Jacq. "Woolly Plantain" (Plantaginaceae). IND AN

POA CANBYI (Scribn.) Piper. "Blue-grass" (Gramineae). IND PER

POA COMPRESSA L. "Canada Blue-grass" (Gramineae). IND PER

PODOSPERMUM LACINIATUM (L.) DC. (Compositae). ADV BIEN PER

POLYGONUM DOUGLASII Greene. "Knotweed" (Polygonaceae). IND AN

POLYPOGON MONSPELIENSIS (L.) Desf. "Rabbitfoot Grass" (Gramineae). ADV AN

POPULUS SARGENTII Dode. "Plains Cottonwood" (Salicaceae). IND

POTAMOGETON NATANS L. "Pondweed" (Potamogenonaceae). IND PER

POTENTILLA FISSA Nutt. "Sticky Cinquefoil" (Rosaceae). IND PER

POTENTILLA GRACILIS Dougl. ex Hook. "Cinquefoil" (Rosaceae). IND PER

POTENTILLA HIPPIANA Lehm. "Woolly Cinquefoil" (Rosaceae). IND PER

PRUNELLA VULGARIS L. "Self-heal; Heal-all" (Labiatae). IND PER

PRUNUS AMERICANA MARSH. "Wild Plum" (Rosaceae). IND

PRUNUS VIRGINIANA L. var. MELANOCARPA (A. Nels.) Sarg. "Choke-cherry" (Rosaceae). IND

PSORALEA TENUIFLORA Pursh. (Leguminosae). IND PER

PYRUS MALUS L. "Apple" (Rosaceae). ADV

RANUNCULUS AQUATILIS L. "Water Crowfoot" (Ranunculaceae). IND PER

[Ranunculus glaberrimus.] We do not believe this occurs on the site, but have no idea what other species might be meant.

RANUNCULUS MACOUNII Britt. "Buttercup" (Ranunculaceae). IND PER

RATIBIDA COLUMNIFERA (Nutt.) Woot. and Standl. "Prairie Cone-flower" (Compositae). IND PER

RHUS TRILOBATA Nutt. "Skunkbrush" (Anacardiaceae). IND

RIBES AUREUM Pursh. "Golden Currant" (Grossulariaceae). IND

[Rorippa islandica.] The report undoubtedly refers to Rorippa palustris ssp. hispida.

RORIPPA PALUSTRIS (L.) Besser ssp. HISPIDA (Desv.) Jonsell. "Yellow-cress" (Cruciferae). IND AN BIEN

ROSA ARKANSANA Porter. "Wild Prairie Rose" (Rosaceae). IND

RUBUS IDAEUS L var. STRIGOSUS (Michx.) Maxim. "Wild Raspberry" (Rosaceae). IND

RUDBECKIA HIRTA L. "Black-eyed Susan" (Compositae). IND PER

RUDBECKIA LACINIATA L. var. AMPLA (A. Nels) Cronquist. "Tall Cone-flower" (Compositae). IND PER

RUMEX ACETOSELLA L. "Sheep Sorrel" (Polygonaceae). ADV PER

RUMEX CRISPUS L. "Curly Dock" (Polygonaceae). ADV PER

RUMEX SALICIFOLIUS Weinm. ssp. TRIANGULIVALVIS Danser. "Willow Dock" (Polygonaceae). IND PER

[Sagittaria cuneata.] We found only S.latifolia, but it is entirely possible that s.cuneata occurs on the site, since they frequently inhabit the same area; they are only distinguishable on examination of mature fruit.

SAGITTARIA LATIFOLIA Willd. "Arrowhead" (Alismaceae). IND PER

SALIX AMYGDALOIDES Anderss. "Peach-leaved Willow" (Salicaceae). IND

SALIX ECIGUA Nutt. "Sand-bar Willow" (Salicaceae). IND

SALIX INTERIOR Rowlee. "Sand-bar Willow" (Salicaceae). IND

SALIX LIGULIFOLIA (Ball) Ball. "Willow" (Salicaceae). IND

[Salsola kali tenuiflora .] This is the common "Russian Thistle," Salsola iberica sennen and Pau. It must be present on the area and we are at a loss to know why we overlooked it.

SALVIA REFLEXA Hornem. "Lance-leaved Sage" (Labiatae). IND AN

SCHEDONNARDUS PANICULATUS (Nutt.) Trel. "Tumble-grass" (Gramineae). IND AN

SCHIZACHYRIUM SCOPARIUM (Michx.) Nash (Andropogon scoparius of older treatments). "Little Blue-stem" (Gramineae). IND PER

SCIRPUS ACUTUS Muehl. "Bulrush; Tule" (Cyperaceae). IND PER

SCIRPUS AMERICANUS Pers. "Three-square" (Cyperaceae). IND PER

SCIRPUS LACUSTRIS L. ssp. VALIDUS (Vahl) Koyama. "Bulrush; Tule" (Cyperaceae). IND PER

[Scirpus microcarpus.] = Scirpus pallidus.

SCIRPUS PALLIDUS (Britt.) Fern. (Cyperaceae). IND PER

SCROPHULARIA LANCEOLATA Pursh. "Figwort" (Scrophulariaceae). IND PER

SCUTELLARIA BRITTONII Porter. "Skullcap" (Labiatae). IND PER

SECALE CEREALE L. "Rye" (Granimeae). ADV AN

SEDUM LANCEOLATUM Torr. "Stonecrop" (Crassulaceae). IND PER

[Senecio atratrus.] This is a species of scree slopes in the subalpine sone and hardly would be expected to occur on the site. Very likely this was a misidentification of Senecio intergerrimus.

SENECIO INTEGERRIMUS Nutt. "Butterweed" (Compositae). IND PER

SENECIO PLATTENSIS Nutt. "Butterweed" (Compositae). IND PER

SENECIO SPARTIOIDES T. and G. "Broom Ragwort" (Compositae). IND PER

SETARIA VIRIDIS (L.) P. Beauv. "Green Bristle-grass" (Gramineae). ADV AN

SILENE ANTIRRHINA L. "Sleepy Catchfly" (Caryophyllaceae). ADV AN

SISYMBRIUM ALTISSIMUM L. "Jim Hill Mustard" (Cruciferae). ADV AN

SISYRINCHIUM MONTANUM Greene. "Blue-eyed-grass" (Iridaceae). IND PER

[Sitanion hystrix.] = Sitanion longifolium.

SITANION LONGIFOLIUM J.G. Smith. "Squirrel-tail" (Gramineae). IND PER

SMILACINA STELLATA (L.) Desf. "False Solomon's Seal" (Liliaceae). IND PER

[Solanum eleagnifolium.] We do not doubt this report. The plant could occur very sporadically in waste ground, but we did not see it.

SOLANUM ROSTRATUM Duanl. "Buffalo Bur" (Solanaceae). ADV (here at least) AN

[Solidago ciliosa.] Highly unlikely for Rocky Flats and probably based on a misidentification of Solidago missouriensis.

SOLIDAGO MISSOURIENSIS Nutt. "Smooth Goldenrod" (Compositae). IND PER

SOLIDAGO MOLLIS Bartl. "Goldenrod" (Compositae). IND PER

SPARTINA PECTINATA Link. "Prairie Cordgrass" (Gramineae). IND PER

SPHAERALCEA COCCINEA (Pursh.) Rydb. "Copper Mallow" (Malvaceae). IND PER

SPOROBOLUS CRYPTANDRUS (Torr.) Gray. "Sand Dropseed" (Gramineae). IND PER

SPOROBOLUS HETEROLEPIS Gray. "Prairie Dropseed" (Gramineae). IND PER

STELLARIA LONGIFOLIA Muehl. "Long-leaved Stitchwort" (Caryophyllaceae). IND PER

STEPHANOMERIA PAUCIFLORA (Torr.) Nees. "Wire-lettuce" (Compositae). IND PER

[Stipa comata Trin.] This species should be in the area, but we did not find it in our survey. We see no reason to doubt the report.

[Stipa neomexicana.] This species should be in the area, and it is very distinctive, but we did not find it in our survey. We see no reason to doubt the report.

STIPA VIRIDULA Trin. "Green Needle-grass" (Gramineae). IND PER

SYMPHORICARPOS OCCIDENTALIS Hook. "Snowberry; Buckbrush" (Caprifoliaceae). IND

SYMPHORICARPOS OREOPHILUS Gray. "Snowberry; Buckbrush" (Caprifoliaceae). IND

TALINUM PARVIFLORUM Nutt. "Fame-flower" (Portulacaceae). IND PER

TARAXACUM OFFICINALE Web. in Wiggers. "Common Dandelion" (Compositae). ADV PER

THELESPERMA MEGAPOTAMICUM (Spreng.) Kuntze. "Green-thread" (Compositae). IND PER

THERMOPSIS DIVARICARPA A. Nels. "Golden Banner" (Leguminosae). IND PER

[Thlaspi alpestre.] Thlaspi montanum L. "Candytuft" (Cruciferae). T.alpestre is restricted to Eurasia, although the name has been used until recently for the latter. We do not doubt the report, but we did not find this in our survey.

THLASPI ARVENSE L. "Penny Cress" (Cruciferae). ADV AN

TINIARIA CONVOLVULUS (L.) Webb and Moq. (Bilderdykia convolvulus [L.] Dum.) "Black Bindweed" (Polygonaceae). ADV AN

TOWNSENDIA GRANDIFLORA Nutt. "Easter Daisy" (Compositae). IND BIEN

TOWNSENDIA HOOKERI Beaman. "Easter Daisy" (Compositae). IND PER

TOXICODENDRON RYDBERGII (Small ex Rydb.) Greene. "Poison Ivy" (Anacardiaceae). IND PER

TRADESCANTIA OCCIDENTALIS (Britt.) Smyth. "Spiderwort" (Compositae). IND PER

TRAGOPOGON DUBIUS Scop. "Salsify" (Compositae). ADV BIEN PER

TRAGOPOGON PORRIFOLIUS L. "Purple Salsify" (Compositae). ADV BIEN PER

TRIFOLIUM HYBRIDUM L. "Alsike Clover" (Leguminosae). ADV PER

TRIFOLIUM PRATENSE L. "Red Clover" (Leguminosae). ADV PER

TYPHA LATIFOLIA L. "Broad-leaved Cat-tail" (Typhaceae). IND

VACCARIA PYRAMIDATA Medic. "Cow Cockle" (Caryophyllaceae). ADV AN

VERBASCUM BLATTARIA L. "Moth Mullein" (Scrophulariaceae). ADV BIEN

VERBASCUM THAPSUS L. "Great Mullein" (Scrophulariaceae). ADV BIEN

VERBENA BRACTEATA Lag. and Rodr. "Prostrate Vervain" (Verbenaceae). ADV AN

VERBENA HASTATA L. "Blue Vervain" (Verbenaceae). IND PER

[Veronica americana.] Probably a misidentification of V.anagallis-aquatica, although there is no reason why it could not occur here.

VERONICA ANAGALLIS-AQUATICA L. "Water Speedwell" (Scrophulariaceae). ADV PER

VERONICA PEREGRINA L. "Purslane Speedwell" (Scrophulariaceae). ADV AN

VICIA AMERICANA Muehl. "Common Vetch" (Leguminosae). IND PER

VIOLA CANADENSIS L. "White Violet" (Violaceae). IND PER

VIOLA NUTTALLII Pursh. "Yellow Violet" (Violaceae). IND PER

VULPIA OCTOFLORA (Walt.) Rydb. "Six-weeks Fescue" (Gramineae). IND AN

XANTHIUM STRUMARIUM L. "Cocklebur" (Compositae). ADV AN

YUCCA GLAUCA Nutt. "Spanish Bayonet" (Liliaceae). IND

ZYGADENUS VENENOSUS Wats. var. GRAMINEUS (Rydb.) Walsh ex Peck. "Death Camas" (Liliaceae). IND PER

Lichens (25 Species)

ACAROSPORA FUSCATA (Schrad.) Arn.

ASPICILIA CAESIOCINEREA (Nyl.) Arn.

CALOPLACA LAMPROCHEILA (DC.) Flag.

CANDELARIELLA ROSULANS Muell.-Arg.

CLADONIA PYXIDATA (L.) Fr.

DERMATOCARPON LACHENUM (Ach.) A.L. Sm.

TABLE A-1 (continued)

DIMELAENA OREINA Norm.
DIPLOSCHISTES SCRUPOSUS (Schreb.) Norm.
LECANORA CHRYSOLEUCA (Sm.) Ach.
LECANORA MURALIS (Schreb.) Rabenh.
LECIDEA AURICULATA Th. Fr.
PARMELIA EXASPERATULA (Ach.) Nyl.
PARMELIA SUBDECIPIENS Vain. ex Lynge.
PARMELIA SUBRAMIGERA Gyel.
PARMELIA ULOPHYLLODES (Vain) Savicz.
PARMELIA (XANTHROPARMELIA) indet.
PELTIGERA CANINA (L.) Willd. var.RUFESCENS (Weiss) Mudd.
PHYSCIA ORBICULARIS (Neck.) POETSCH.
PHYSCIA CAESIA (Hoffm.)Hampe.
PHYSCIA DUBIA (Hoffm.) Lett.
PHYSCIA STELLARIS (L.) Nyl.
PHYSCONIA GRISEA (Lam.) Poelt.
RINODINA sp. indet.
SARCOGYNE CLAVUS (Ram. ex Lam. and DC.) Kremp.
XANTHORIA FALLAX (Hepp in arn.) Arn.

Bryophytes (16 Species)

AMBLYSTEGIUM SERPENS (Hedw.) B.S.G. var. JURATZKANUM (Schimp.) Rau et Herv.
BRACHYTHECIUM FENDLERI (Sull.) Jaeg. et Sauerb.
BRYUM ARGENTEUM Hedw.
BRYUM CAESPITICIUM Hedw.
BRYUM CAPILLARE Hedw.
CAMPYLIUM CHRYSOPHYLLUM (Brid.) J. Lange.
CERATODON PURPUREUS (Hedw.) Brid.
DREPANOCLADUS ADUNCUS (Hedw.) Warnst.
GRIMMIA MONTANA B.S.G.
MARCHANTIA POLYMORPHA L.
ORTHOTRICHUM PALLENS Bruch ex Brid.
ORTHOTRICHUM PUMILUM Sw.
PHYSCOMITRIUM PYRIFORME (Hedw.) Hampe.
POHLIA NUTANS (Hedw.) Lindb.
POLYTRICHUM PILIFERUM Hedw.
TORTULA RURALIS (Hedw.) Gaertn.

Macroscopic Green Algae

CHARA species (Characeae).

TABLE A-2

ANIMALS KNOWN TO OCCUR AT THE ROCKY FLATS SITE

Mammals

LEPUS TOWNSENDII - White-tailed Jack Rabbit
SYLVILAGUS spp - Cottontail
SPERMOPHILUS TRIDECEMLINEATUS - Thirteen-lined Ground Squirrel
THOMOMYS TALPOIDES - Northern Pocket Gopher
PEROGNATHUS HISPIDUS - Hispid Pocket Mouse
PEROGNATHUS FLAVUS - Silky Pocket Mouse
PEROMYSCUS MANICULATUS - Deer Mouse
PEROMYSCUS DIFFICILIS - Rock Mouse
MICROTUS PENNSYLVANICUS - Meadow Vole
ONDATRA ZIBETHICUS - Muskrat
MUS MUSCULUS - House Mouse
VULPES FULVA - Red Fox
CANIS LATRANS - Coyote
PROCYON LOTOR - Raccoon
MUSTELA FRENATA - Long-tailed Weasel*
TAXIDEA TAXUS - American Badger
MEPHITIS MEPHITIS - Striped Skunk
ODOCOILEUS HEMIONUS - Mule Deer

BIRDS

ARDEA HERODIAS - Great Blue Heron
ANAS PLATYRHYNOCHOS - Mallard
ANAS STREPERA - Gadwall*
ANAS CYANOPTERA - Cinnamon Teal*
MARECA AMERICANA - Baldpate*
ANAS CAROLINENSIS - Green-winged Teal*
ANAS DISCORS - Blue-winged Teal*
AYTHYA AMERICANA - Redhead*
BUTEO JAMAICENSIS - Red-tailed Hawk
BUTEO LAGOPUS - American Rough legged Hawk*
CIRCUS CYANEUS - Marsh Hawk*
FALCO SPARVERIUS - American Kestrel*
BUTEO REGALIS - Ferruginous Hawk*
CHARADRIUS VOCIFERUS - Killdeer*
COLUMBA LIVIA - Rock Dove*

*Species shown with an asterisk have been seen within the site by a Rocky Flats biologist. All other species were previously identified by Whicker (1974).

TABLE A-2 (continued)

ZENAIDURA MACROURA - Mourning Dove
BUBO VIRGINIANUS - Horned Owl
CHORDEILES MINOR - Common Nighthawk
MEGACERYLE ALCYON - Belted Kingfisher*
SAYORNIS SAYA - Say's Phoebe
AGELAIUS PHOENICEUS - Red-winged Blackbird
EREMOPHILA ALPESTRIS - Horned Lark*
HIRUNDO RUSTICA - Barn Swallow*
PICA PICA - American Magpie
CORVUS CORAX - Raven*
TURDUS MIGRATORIUS - Robin*
STURNUS VULGARIS - Starling*
STURNELLA NEGLECTA - Western Meadowlark
QUISCALUS QUISCULA - Common Grackle*
MOLOTHRUS ATER - Brown-headed Cowbird*
PASSERINA AMOENA - Lazuli Bunting
PIPILO ERYTHROPTHALMUS - Rufous-sided Towhee
POOECETES GRAMINEUS - Vesper Sparrow
MELOSPIZA MELODIA - Song Sparrow*
SIALIA CURRUCOIDES - Mountain Bluebird*
JUNCO HYEMALIS - Slate-colored Junco*
SPEOTYTO CUNICULARIA - Burrowing Owl
CALAMOSPIZA MELANOCORYS - Lark Bunting

---

*Species shown with an asterisk have been seen within the site by a Rocky Flats biologist. All other species were previously identified by Whicker (1974).

TABLE A-3

REPTILES AND AMPHIBIANS KNOWN TO OCCUR AT THE ROCKY FLATS SITE*

RANA PIPIENS BRACHYCEPHALA - Western Leopard Frog*
CHRYSEMYS PICTA - Painted Box Turtle
PHRYNOSOMA DOUGLASSI BREVIROSTRE - Eastern Short-horned Lizard*
THAMNOPHIS RADIX - Plains Garter Snake
COLUBER CONSTRICTOR - Racer
PITUOPHIS MELANOLEUCUS - Common Bullsnake
CROTALUS VIRIDIS - Prairie Rattlesnake

---

*All of these species were identified by Whicker (1974).

TABLE A-4

AQUATIC SPECIES KNOWN TO OCCUR AT THE ROCKY FLATS SITE

Algae

Cyanophyta (Blue-Green Algae)	Chlorophyta (Green Algae)	Chrysophyta
GLEOTRICHA	HYDRODICTYON	DINOBRYON
GLEOCAPSA	CHLOROCOCCUM	CYMBELLA
OSCILLATORIA LIMNOSA	CHLORELLA	HYLOTHECA
NOSTOC PRUNIFORME	OEDOGONIUM	NAVICULA
ANABAENA	CLADOPHORA	
SCYTONEMA	ZYGNEMA	
STIGONEMA	ULOTHRIX ZONOTA	
TOLYPOTHRIX	CHAETOPHORA	
APHANIZOMENON	PEDIASTRUM	
APPHITHRIN	SPIROGYRA CRASSI	
CALOTHRIX	SPIROGYRA	
	SCENEDESMUS	
	MOUGEOTIA	
	CLOSTERIUM	
	EUGLINOIDS	

Crustaceans*	Insect Orders*	Fish**
DAPHNIA PULEX	PLECOPTERA	PIMEPHALES PROMELAS - Fathead Minnow
DIATPOMUS	EPHEMEROPTERA	LEPOMIS CYANELLUS - Green Sunfish
GAMMARUS	ODONATA	CATOSTOMUS COMMERSONI - Western White Sucker
CAMBARUS	DIPTERA	MICROPTERUS SALMOIDES - Largemouth Bass
	COLEOPTERA	SALMO GAIRDNERII - Rainbow Trout
	TRICHOPTERA	

* Identified by Johnson, et al (1974)
** Identified by Zillich (1974)

APPENDIX A-2

THREE-YEAR SUMMARY REPORT

to

U. S. Energy Research and Development Administration

on

Contract EY-76-S-02-1156

RADIOECOLOGY OF NATURAL SYSTEMS

For the period

May 1, 1974 - July 31, 1977

F. W. Whicker, Principal Investigator
Department of Radiology and Radiation Biology
Colorado State University
Fort Collins, Colorado

August 1, 1977

INTRODUCTION

This report is intended to provide a general summary of the progress and findings of work sponsored by ERDA under contract EY-76-S-02-1156 over the period May 1, 1974 through July 31, 1977. During this period, the overwhelming majority of effort was devoted to studies on the distribution, transport, characterization and ecological consequences of plutonium in the terrestrial environs of the Rocky Flats nuclear weapons plant near Denver, Colorado. During the period, however, additional studies were carried out on the geochemistry of stable lead in an alpine lake and its watershed, cesium kinetics in a montane lake, long-term patterns of fallout ^{137}Cs in trout and mule deer populations, and effects of chronic gamma irradiation on a shortgrass plains ecosystem. Since the studies on lead and cesium have been of comparatively low intensity and because the data generated have not been analyzed sufficiently for a substantive summary, they are not reported on here. Those interested in the lead and cesium studies should consult the recent annual progress reports. In 1975, the investigation of the effects of chronic irradiation on a shortgrass plains ecosystem was transferred to ERDA Contract EY-76-S-02-2743; therefore, it is not reported here either. This report provides a brief synthesis of progress on the plutonium studies.

Public and scientific interest in plutonium contamination of the environment has been keen in recent years. One focal point of concern is the grassland near the Rocky Flats installation of the U. S. Energy Research and Development Administration northwest of Denver, Colorado. Now operated for ERDA by Rockwell International, the Rocky Flats Plant handles large amounts of plutonium metal for defense purposes. The plant, approximately 12 km northwest of the Denver, Colorado, metropolitan area, utilizes nearly 30 km^2 as a buffer zone which separates the public from production operations. The climate of Rocky Flats is typified by occasional strong W-NW winds exceeding 40 m/s and moderate precipitation (40 cm/y average). The physiognomy of Rocky Flats is described as modified grassland which includes species typical of shortgrass plains (Bouteloua gracilis, Buchloe dactyloides, etc.) as well as tall-grass prairie (Agropyron spp., Andropogon spp.), and ponderosa pine woodland. Mule deer (Odocoileus

hemionus hemionus) reside alongside typically grassland species of arthropods, reptiles, rodents, and birds.

Drums containing plutonium-contaminated oil which leaked during 1959-1964 on the barrel storage area were the major source of plutonium contamination. Investigations by ERDA's Health and Safety Laboratory, Rocky Flats personnel, and others indicated that plutonium contamination patterns in soil were consistent with predominant wind directions (i.e., plutonium concentration isopleths in soil extended primarily east and southeast from the barrel storage area). Evidence supports the concept that soil particles near the base of leaking drums became heavily contaminated with plutonium and were subsequently resuspended by strong winds. Contaminated soil particles were deposited downwind at levels which decreased with distance. The plutonium has largely remained in soil, near the surface. However, measureable amounts have been found to depths of 30 cm in soil and in the biota. Public concern, lack of knowledge on the environmental behavior of plutonium, and the high radiotoxicity of the element all provided justification for the research program described in this document.

The findings described in this report were obtained by (alphabetically): staff members A. W. Alldredge, J. A. Bly, L. Fraley, Jr., and T. F. Winsor; and graduate students L. E. Alexander, W. J. Arthur, S. J. Baker, M. P. Carson, R. A. Geiger, G. S. Hiatt, C. A. Little, L. M. McDowell, S. L. Mecker, and M. L. Miller.

SUMMARY OF FINDINGS

Distribution of Plutonium in the Terrestrial Ecosystem

We established three sampling areas southeast (downwind) of the former oil barrel storage area: a 0.25 ha plot 50 m away, a 0.75 ha study macroplot about 200 m away, and a 500 m-long sampling transect running from 270 to 770 m downwind. Two other study plots were established, one 1400 m south of the former oil barrel storage area, and one in the northwest corner and upwind of the plant. During 1972-1976, we collected samples of soil, litter, vegetation, arthropods (orders Arachnida, Thysanura, Orthoptera, and Coleoptera), small mammals (Peromyscus maniculatus, Thomomys talpoides, and Spermophilus tridecemlineatus), mule deer, snakes (Coluber constrictor flaviventris, Pituophis melanoleucus sayi, and Crotalus viridis viridis), and mourning doves (Zenaidura macroura) from the study areas for plutonium analysis and biomass estimations. Samples were analyzed by liquid scintillation counting in our laboratory or alpha spectrometry by commercial laboratories.

Data from or representative of macroplot 1, the principal study plot 200 m downwind of the former barrel storage area, are given in Table 1. Mean concentrations, compartmental inventories, and concentration ratios are summarized. The data indicate that the top 21 cm of soil contained more than 99% of the total plutonium inventory of the ecosystem; the 0-3 cm and 3-21 cm layers had about equal fractions. The fractions of total plutonium in the non-soil compartments were orders of magnitude lower than the soil. Litter had a higher fraction of the total plutonium inventory than vegetation which in turn had a substantially larger fraction than the animal compartments. These data imply that because most of the plutonium is in soil, land management practices are very important on contaminated areas and also that plutonium transport by biota appears relatively insignificant, at least in the short term.

The values given in Table 1 for vegetation and small mammals need to be qualified in the light of recent findings. For example, vegetation from macroplot 1, when cleansed of surface dust using an ultrasonic bath, contains of the order of 1 to 2 dpm/g of ^{239}Pu. This is strong evidence

Table 1. Distribution of ^{239}Pu in samples from Rocky Flats study macroplot no. 1. Compartmental ^{239}Pu inventory (dpm/m^2) = mean biomass (g/m^2) x mean concentration (dpm/g). Fraction of total = mean compartmental inventory (dpm/m^2) ÷ total inventory (dpm/m^2). Concentration ratio = mean concentration of compartment (dpm/g) ÷ mean concentration of 0-3 cm soil (dpm/g).

Compartment	Mean	n*	95% confidence interval
	Plutonium concentrations (dpm/g)		
soil, 0-3 cm	1850	72	1230 - 2480
soil, 3-21 cm	233	309	154 - 312
litter	914	29	698 - 1130
vegetation	63.4	76	34.8 - 92.0
arthropods	12.6	23	7.19 - 18.0
small mammals	14.4	304	5.29 - 23.5
	Fraction of total Pu		
soil, 0-3 cm	5.0×10^{-1}		2.5×10^{-1} - 7.4×10^{-1}
soil, 3-21 cm	5.0×10^{-1}		2.5×10^{-1} - 7.5×10^{-1}
litter	2.9×10^{-3}		1.6×10^{-3} - 4.2×10^{-3}
vegetation	1.0×10^{-4}		4.1×10^{-5} - 1.6×10^{-4}
arthropods	1.2×10^{-8}		4.6×10^{-9} - 2.0×10^{-8}
small mammals	3.3×10^{-9}		6.6×10^{-10} - 6.0×10^{-9}
	Concentration ratio		
soil, 0-3 cm	1.0×10^{0}		---
soil, 3-21 cm	1.3×10^{-1}		6.6×10^{-2} - 1.9×10^{-1}
litter	4.9×10^{-1}		2.9×10^{-1} - 7.0×10^{-1}
vegetation	3.4×10^{-2}		1.5×10^{-2} - 5.4×10^{-2}
arthropods	6.8×10^{-3}		3.1×10^{-3} - 1.1×10^{-2}
small mammals	7.8×10^{-3}		2.2×10^{-3} - 1.3×10^{-2}

*n = no. of samples for which the mean is calculated: for arthropods and vegetation, n is the number of groups of individuals analyzed; for small mammals, the number of tissue samples, not individual animals.

that the mean value of 63 dpm/g in Table 1 mainly reflects plutonium in the surficial dust. In addition, more recent data on small mammal samples which were pooled to obtain more activity per sample, gave lower mean values, on the order of 0.4 dpm/g.

Levels of ^{239}Pu in the tissues of mule deer, snakes, and mourning doves in most cases have been below the analytical detection limit. In no case has a sample of internal tissue from these species contained more than 1 dpm/g. These data collectively indicate that the plutonium in the environs of Rocky Flats is highly insoluble and is not moving into the biota to an unexpected extent. Of the animals sampled, arthropods clearly contain the highest concentrations of ^{239}Pu and also the largest fraction of the inventory associated with animals. As with vegetation however, arthropods were not cleansed of surficial activity prior to assay and the ^{239}Pu concentrations of internal body parts is not known.

Plutonium concentrations in Rocky Flats soil varied inversely with distance from the original plutonium source, depth of the sample, and particle size of sieved soil samples. Coefficients of variation of plutonium in soil ranged to more than 300%, and frequency distributions were highly skewed with most samples lying below the mean and a few being much larger than the mean. The plutonium distribution patterns and known characteristics of the plutonium source indicated that the mechanisms of environmental dispersion may have involved: the attachment of plutonium oxide to soil particles; primary dissemination of the contaminant from the source by wind; and weathering, microdispersal, and penetration into soil of deposited particles. The high degree of spatial variability, in particular, suggested that the most common functional form of the contaminated soil during dissemination was probably an agglomerated particle containing many plutonium oxide and soil particles bound together.

In an effort to more fully understand the problem of sampling heterogeniety, soil samples from macroplot 1 were examined microscopically so that plutonium particle sizes and micro-distribution could be investigated. We wanted to explore the idea that occasional high-activity samples were possibly caused by "hot particles" of plutonium. An autoradiographic technique, utilizing nuclear emulsion plates, was used to obtain abundance of, and equivalent size distributions for, plutonium particles in Rocky

Flats surface soil. A total of 1700 particles were sized, for which mean $^{239}PuO_2$ equivalent diameters of 0.29 μm, 0.25 μm, and 0.20 μm were found for 7-, 14-, and 37-day exposures of soil to emulsion plates. A method to scan for particles greater than 1.50 μm equivalent diameter, utilizing Kodak AA Industrial X-Ray film, was also used. The largest particle sized with this procedure was 6.86 μm $^{239}PuO_2$ equivalent diameter. None of the particles sized was of sufficient magnitude alone to account for elevated plutonium activity observed previously in Rocky Flats surface soil samples. Variability in particle concentrations was observed, however, which suggested that heterogeneity in the spatial distribution of plutonium particles in the soil may partially explain observed variability in soil plutonium concentrations. While no "hot particles" (> 1000 dpm) were found, their presence cannot be ruled out because of the limited quantity of soil that can be feasibly examined by the autoradiographic technique.

Based upon data from samples taken across gradients of plutonium contamination, levels of plutonium in litter, vegetation and arthropods were significantly correlated to concentrations in soil. These correlations provided additional evidence that most of the plutonium associated with these samples was actually attached to surficial dust. This study corroborates the idea expressed by other investigators that plutonium moves in the environment principally by physical rather than physiological mechanisms.

Data on ^{239}Pu concentrations in vegetation, small mammals and arthropods were too variable to show statistically significant differences between species or taxonomic groups. We also have not been able to show significant differences between collection dates nor types of small mammal tissues. Statistical analyses have been exhaustive, in that data were log-transformed to reduce heterogenous variance and skewness of distributions, and normal as well as non-parametric procedures have been used.

Plutonium Transport Processes

In an effort to understand and possibly predict the behavior of plutonium in the environment, several studies dealing with transport processes have been undertaken. These include measurements of aerial

deposition rates, soil erosion, plutonium export resulting from biological processes, and plant uptake. Data from these studies have not been fully analyzed, but several noteworthy points have emerged.

Aerial deposition rates over the past two years have averaged about 20 dpm/m^2-day in macroplot 1, based upon data from 21 wet pot collectors. This value is in good agreement with mean air concentrations over the area of about 10^{-15} μCi/cm^3 and a reasonable deposition velocity figure of 5 cm/sec. This deposition rate would provide an increment to the soil inventory of only 0.006% per year. A deposition rate of 20 dpm/m^2-day would theoretically lead to a ^{239}Pu concentration in vegetation of about 2 dpm/g, assuming a mean biomass of 220 g/m^2 and an effective half-time of 14 days.

Since over 99% of the plutonium in the ecosystem is associated with the soil, erosional processes offer the potential of dispersing significant plutonium contamination. Such processes include water erosion, both gully and sheet forms, and resuspension by winds. These processes may be enhanced by soil disturbance from natural phenomena such as animal activity and needle ice formation. We attempted to measure soil erosion by tracing through time the location of soil particles tagged with ^{59}Fe and by recording beta counts from ^{90}Sr sources buried at fixed positions beneath the soil surface. These data gave no indication of measureable soil erosion over the duration of the study in undisturbed, well-vegetated areas. If surficial erosion were to occur, the fact that most of the soil plutonium is greater than a few mm deep lends assurance that significant quantities of the element would not move. Severe gully erosion could move substantial quantities of plutonium, but this has not been observed except in steep, disturbed areas.

The potential of mammals for dispersing plutonium has been investigated in considerable detail by quantifying certain activities of pocket gophers and mule deer. Burrowing and mound building by small mammals exposes contaminated soil to erosional forces. Pocket gophers at Rocky Flats form mounds and dig tunnels and burrows, and move large quantities of soil in the process. In a plutonium-contaminated area of 2.6 ha, gophers constructed about 4.5 mounds/day, representing about 5,000 kg of soil per year which contained about 85 μCi of ^{239}Pu. Most of the

mound soil originated from the 10-15 cm horizon. The fate of plutonium in exposed mounds has not been studied, but observations suggest that most remains in the immediate area of the mound. Mule deer ingest plutonium associated with vegetation and soil and transport the material to the surrounding area, where most is excreted with fecal material. Measured soil ingestion rates of up to 30 g/day and ingestion of contaminated vegetation (1100-1400 g/day) lead to an estimated probable annual intake of 0.07 μCi per deer feeding around the contaminated areas at Rocky Flats. An estimated maximum possible annual intake per deer is 13 μCi if the animal were confined entirely to macroplot 1. Around 100 deer utilize the Rocky Flats buffer zone, but their activity is seldom concentrated in the more highly contaminated areas. An upper limit estimate of the proportion of total plutonium dispersed from macroplot 1 by mammalian activities is of the order of 0.1 to 1% per decade. A more probable estimate is 0.001 to 0.01% per decade.

We have attempted to measure the degree of plutonium uptake from soil to plants through root assimilation, and the comparative importance of root uptake and aerial deposition. Intact, contaminated soil blocks and columns from macroplot 1 were transplanted either to an uncontaminated area northwest of the Rocky Flats Plant or to a greenhouse at Colorado State University. Vegetation growing on these blocks and columns has been clipped at various time intervals and assayed for plutonium to get an estimate of root uptake. The values have run of the order of 0-4 dpm/g dry vegetation, which is similar to the values for ultrasonicated vegetation from macroplot 1, but substantially less than unwashed vegetation from macroplot 1 which averaged about 60 dpm/g. These facts strongly implicate aerial deposition as the major transport mechanism. However, other data do not support this concept. For example, uncontaminated soil blocks placed in contaminated macroplot 1 generated vegetation that was also of the order of 0-4 dpm/g. Also, aerial deposition rates as measured by wet pot collectors in macroplot 1 would only account for about 2 dpm/g, assuming a retention half-time of 14 days for plutonium on vegetation surfaces. Because of this discrepancy and our inability to explain it, we cannot yet draw a definite conclusion as to the relative importance of root uptake and aerial deposition.

Comparative Behavior of ^{238}Pu and ^{239}Pu

It has been consistently observed that the isotopic activity ratio (dpm ^{239}Pu/g ÷ dpm ^{238}Pu/g) is of the order of 65 in surface soil samples. However, the isotopic ratio (IR) has been observed to decrease with soil depth. Also, IRs for animal tissues have been substantially lower than for surface soil, running of the order 5-30. Our initial interpretation of this observation was that ^{238}Pu is more mobile than ^{239}Pu and penetrates more rapidly into the soil and through biological membranes more efficiently. Such isotopic discrimination has some theoretical basis because it has been demonstrated that particles of ^{238}Pu break down in aqueous systems much more rapidly than ^{239}Pu particles because of the higher specific activity of ^{238}Pu. The more rapid breakdown is consistent with the process of "radiolytic weathering."

An argument against the concept of differential rates of particle breakdown from radiolysis is the fact that we have no reason to suspect that ^{238}Pu particles occur distinct from ^{239}Pu particles. Plutonium particles in the environs of Rocky Flats likely contain both isotopes intimately mixed in a reasonably predictable ratio. Thus, the radiolytic effect of ^{238}Pu decay, manifested in recoil energy of the ^{234}U nucleus, should dislodge fragments containing ^{239}Pu as well as ^{238}Pu. Another argument is that much of the plutonium in soil at Rocky Flats appears monomeric and there is little if any reason to suspect isotopic discrimination for monomeric plutonium.

Recently, we have examined several data sets by plotting the IR as a function of total plutonium in the sample. Each data set has shown a similar pattern, with IR values below 50 nearly always associated with samples containing less than 10 dpm of plutonium. Above 10 dpm, the IR appears independent of the total plutonium in the sample. Therefore, it seems clear that the IR is biased by sample activity, the bias becoming more severe as the total Pu content decreases below 10 dpm. Unaccounted-for interference under the ^{238}Pu peak of the alpha spectrum could explain the bias observed, but this possibility has not been explored fully. Formulation of conclusions regarding the isotopic ratio variations therefore awaits further data analysis.

Ecological Consequences of Plutonium Contamination at Rocky Flats

The contamination of a portion of the terrestrial environs of Rocky Flats with substantial quantities of plutonium provided the opportunity to search for possible ecological effects resulting from the presence of the element. Gross population effects from the levels of plutonium present in the environment were not expected on the basis of predictions and extrapolations from laboratory studies. However, prior to our studies, a lack of population effects had not been demonstrated and furthermore, extrapolation from the laboratory to the natural environment is frequently not a valid practice, owing to complexities and interactions which occur in nature but not in the laboratory.

We conducted studies which permitted comparisons of various biological measurements and pathological data between ecologically similar study areas at Rocky Flats of widely varying plutonium levels. Soil in the principal study areas ranged from 100 to over 20,000 dpm ^{239}Pu/g in the upper 3 cm (2-400 $\mu Ci/m^2$). In addition, comparative data were obtained from control areas, containing only world-wide fallout plutonium of the order of 0.1 dpm/g (0.002 $\mu Ci/m^2$). Biological measurements such as vegetation community structure and biomass; litter mass; arthropod community structure and biomass; and small mammal species occurrence, population density, biomass, reproduction, and physical size of whole carcass and organs were made. In addition, pathological examinations of small mammals, including x-ray for skeletal sarcomas, microscopy for lung tumors, and necropsy for general pathology and parasite occurrence were carried out.

While minor differences in certain biological attributes between study areas were observed, none could be related to plutonium levels. Pathological conditions and parasites were found in some rodents, but occurrence frequencies between control and contaminated areas were similar. No evidence of cancers or other radiogenic diseases was found. These observations and measurements, combined with intensive field observations over a period of five years, leads us to conclude that plutonium contamination at Rocky Flats has not produced demonstrable ecological changes. Furthermore, the levels of plutonium observed in tissues of plants and animals in contaminated areas were insufficient to produce

the doses that would be required to produce obvious biological changes. Subtle biological changes, such as chromosome aberrations, cannot be ruled out at Rocky Flats. However, even if chromosome aberration frequencies were increased in the more highly contaminated areas, population-level changes would likely not persist because of the surrounding reservoir of normal genetic information.

APPENDIX B
METEOROLOGY

Appendix B consists of two documents that present detailed information relating to climatic characteristics and diffusion meteorology of the Rocky Flats Plant. The first of these documents, Appendix B-1, is a complete copy of a report entitled "Characteristic Airflow Patterns Near Rocky Flats Plant and Their Relationship to Metropolitan Denver." This report was prepared for the Plant's operating contractor by Loren W. Crow, a consulting meteorologist. Dated December 16, 1974, the report was based on a three-year study of the site meteorology.

The second document, Appendix B-2, presents information detailing diffusion estimates made for the Plant site. These estimates were used to estimate accidental and normal emission doses for various sectors and distances from the site.

CHARACTERISTIC AIRFLOW PATTERNS NEAR ROCKY FLATS PLANT AND THEIR RELATIONSHIP TO METROPOLITAN DENVER

Prepared for

DOW CHEMICAL USA

ROCKY FLATS DIVISION

By

LOREN W. CROW
Certified Consulting Meteorologist

December 16, 1974 LWC #143

TABLE OF CONTENTS

SUMMARY

Neutral stability conditions with corresponding well-mixed airflow prevails slightly over 50 percent of the hours per year at both Rocky Flats and Denver Airport (Stapleton International Airport). Under such conditions there is a wide range of directions of flow with a slightly higher frequency in the direction range from west-northwest through northeast.

During stable conditions there is a marked difference in the patterns of airflow emanating from the Denver metropolitan area and the airflow emanating from Rocky Flats. The confluence of drainage air from both areas generally occurs above the lower part of the Platte River Valley to the west and north of Brighton, Colorado. There is very little vertical mixing during stable air periods. Stable conditions prevail for 35 and 40 percent of all hours.

The least frequent stability class is unstable conditions. Most of the unstable hours occur in the summer time when there is strong vertical mixing produced by high surface temperatures during daylight hours. The unstable hours constitute less than 15 percent of the total hours per year. Unstable conditions generally occur when air is moving toward the mountains and with corresponding rapid vertical mixing.

Repeatable patterns of airflow can be identified in five separately defined categories. Days which are primarily controlled by "synoptic" airflow and "turn-around" days are the most frequent types. Almost all dense pollution occurs on "turn-around" type days in the Denver metropolitan area. The effluents which moved away from either Rocky Flats or

the Denver metropolitan area under downslope stable conditions seldom move back over the same source point with more than a small fraction of the initial density. This is particularly true at Rocky Flats where effluents emanate from essentially a point source.

High wind speeds $\geq$20 mph occur between 500 and 600 hours per year at Rocky Flats. The dominant direction of airflow for such winds is from the west or northwest. Such strong winds are capable of picking up and re-transporting dust particles which have previously obtained some collected burden of pollutant material from a localized source. Densities of gaseous pollutant material or the very small and slowly falling particles containing toxic pollutants would be very low under such strong wind conditions at distances of more than a few hundred yards.

The estimates of wind frequencies by stability categories in this report will be replaceable by improved data when more reliable stability measurements can be made using the planned 200-foot meteorological tower at Rocky Flats.

INTRODUCTION

This report summarizes airflow patterns within estimated stability categories. These estimates have been made in the absence of vertical temperature profile measurements in the immediate vicinity of the Rocky Flats Plant. Hourly wind data from January 1, 1972, through August, 1974, furnished the major source of information in the plant area. Determination of annual frequencies was based on the two-year period 1972 and 1973.

The wind measuring unit at Rocky Flats is located on the roof of the Health Physics Building which is located near the west end of the entire complex. That building has been circled on the plant site map shown as Fig. 1.

Only eight direction ranges (45 degrees each) were used in determining hourly wind directions at the Rocky Flats Plant. This prevents a direct relationship with the 36 directional values, one for each 10 degrees, reported by the National Weather Service at Denver Airport. When direct comparisons were used the Denver Airport data were grouped into 50 degree ranges for each of the four major coordinates - north, east, south and west. For each of the other four directions - northeast, southeast, southwest, and northwest - a 40 degree range was used.

Future use of meteorological tower data, particularly temperature differences with height, will be very useful in determining the hourly frequency of observations which fall within the major stability categories.

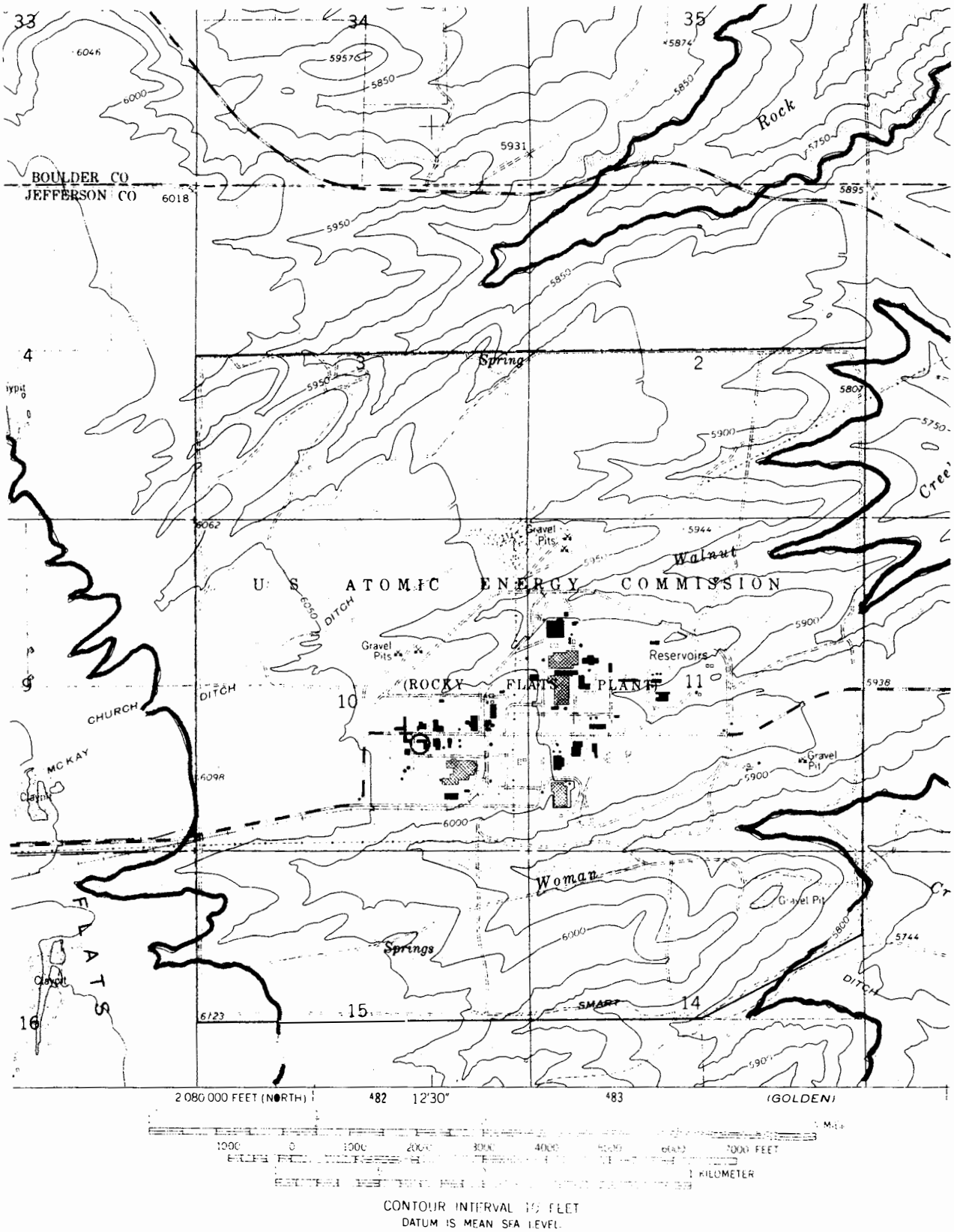


Figure 1. Local physical contour pattern in the immediate area of the Rocky Flats Plant.

LOCAL TOPOGRAPHIC INFLUENCES

Most of the building complex at the Rocky Flats Plant is located on a shelf of gradually sloping terrain. This location is shown in the physical contour map, Fig. 1. The entire plant area covers a nearly square area, two miles on each side. There are three important drainage ditches in this area - Woman Creek, Walnut Creek, and Rock Creek. The deepest and most extensive drainage ditch, Woman Creek, is near the southern portion of the plant site area. The general downward slope from west to east covers a 300-foot decline from near 6100 feet MSL near the western plant boundary to approximately 5800 feet near the eastern edge.

The relatively sharp slope downward to the bottom of Woman Creek from the plant complex can help account for some downslope drainage of cooler air near the ground from northwest toward southeast in the immediate area of the wind measuring unit on the roof of the Health Physics Building. In other light wind situations of downslope drainage, airflow seems to seek an alternate path from southwest toward northeast with a net downward flow into Walnut Creek. The collection of supplemental wind data near the surface along both Woman Creek and Walnut Creek will produce good comparative data after the meteorological tower has been installed near the Health Physics Building.

An examination of over 23,000 hours of wind data shows that light airflow from north to south during night or forenoon hours is most often related to drainage flow. Light airflow from south to north is generally part of the upslope motion during daylight hours.

The annual climatic range of temperatures and the extreme wind speeds recorded at the measuring point of the Health Physics Building are carried in the Annual Environmental Monitoring Reports.[1] Variations in temperature are less than 2°F. under most airflow conditions throughout the entire Rocky Flats Plant Complex. However, temperature differences between parking lot areas and grassland areas could be much greater than 2°F. during the warmest part of the day under light wind speed conditions.

REGIONAL TOPOGRAPHIC INFLUENCES

The Rocky Flats Plant is only a few miles to the east of rapidly increasing elevations of the front range of the Rocky Mountains. Terrain heights increase from near 6000 feet above sea level in the immediate vicinity of the Rocky Flats Plant to above 10,000 feet MSL within a distance of less than 20 miles to the west. The relative location of the Rocky Flats Plant to the metropolitan area of Denver to the southeast of the plant and the city of Boulder to the northwest is identified in both Figs. 2 and 3.

The height contours are at 500-foot intervals in the geographic map, Fig. 2. However, more detailed maps identify a ridge of higher ground between the drainage toward the east and northeast from Rocky Flats and the next drainage basin to the south which feeds into Clear Creek and joins the Platte River at the north edge of metropolitan Denver. That ridge of higher ground is identified on both the geographic contour map, Fig. 2, and the shaded relief map, Fig. 3. The drainage basin of Big Dry Creek joins the Platte River near Fort Lupton which is approximately 18 miles farther north from the mouth of Clear Creek.

The net drainage of the several tributaries to the Platte River is toward the north-northeast from Denver toward Greeley. However, there is well documented evidence of downslope flow toward the center of the valley in the Denver metropolitan area during most hours of stable air conditions. The drainage is downslope from the 5500 foot contour toward the 5200 foot elevation of the Platte River as it moves through downtown Denver. A dashed red line is used to emphasize the 5500 contour line which approximates most of the Denver metropolitan area in Fig. 2. Elevations in the

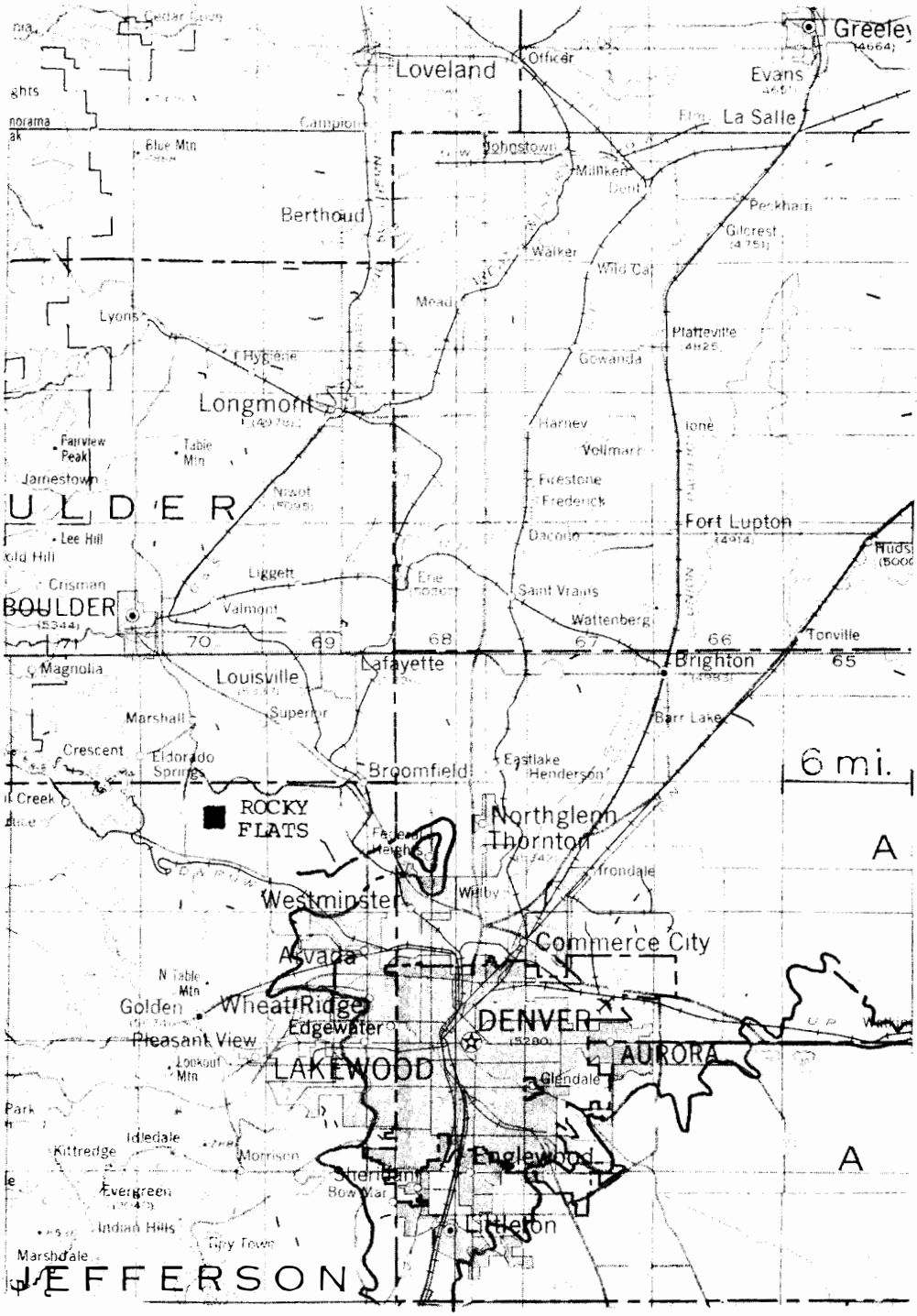


Figure 2. Geographic contour map.

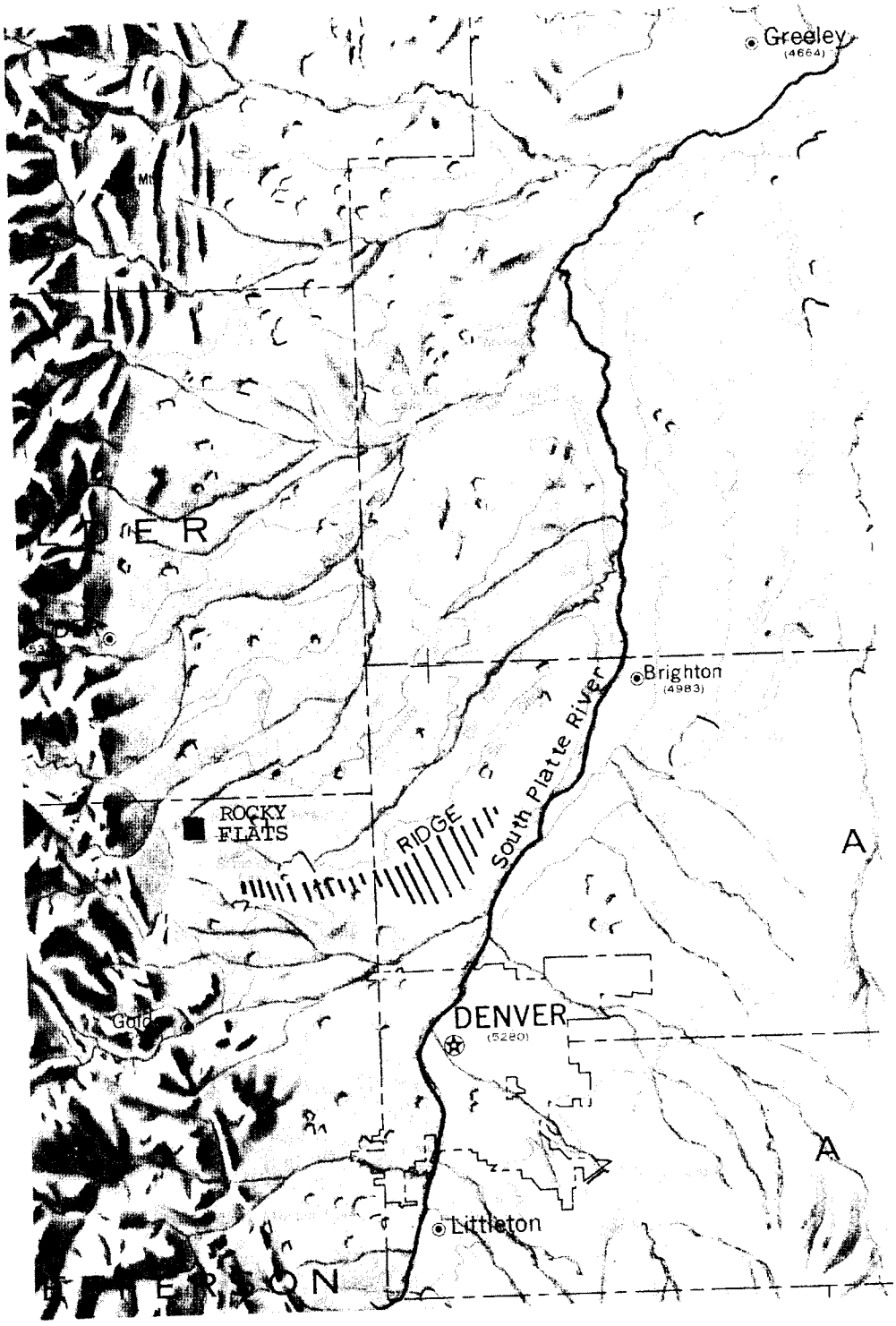


Figure 3. Shaded relief map.

Federal Heights area near the north end of the metropolitan area rise above 5600 feet at the highest point. These differences are most important as they relate to any air pollutants which are emitted near the ground during stable hours when the net flow is almost always downslope.

The sharply higher terrain to the west of the Rocky Flats area is graphically portrayed in the shaded relief map, Fig. 3. This higher terrain receives a comparatively large amount of surface heating from the sun under clear or partly cloudy conditions in the early forenoon hours. A reversal of airflow from downslope to upslope takes place generally one to two hours earlier in the vicinity of Rocky Flats than at the Denver Airport which is located in the northeast part of the Denver metropolitan area.

SYNOPTIC VS. NON-SYNOPTIC AIRFLOW

In meteorology the term "synoptic" has developed a special meaning which relates to the various "same time" maps which are prepared to give a nearly instantaneous over-all view of airflow patterns. The map most commonly understood is the pressure pattern map. Such a map indicates the general airflow pattern around high and low pressure centers over broad areas and above the so-called "surface friction layer". This pattern can be determined even though surface observation points are separated by many miles. For purposes of this summary, "synoptic" flow at the surface near the Rocky Flats Plant is indicated whenever the surface wind velocity and directions are both very similar to the synoptic flow pattern at approximately 1500 feet above the ground.

The linkage of the surface wind direction and velocity with the flow at 1500 feet takes place primarily during daytime hours but can occur any time during the day or night when the large-scale weather map pattern is sufficiently strong to control airflow throughout a well-mixed layer from the surface of the earth upward.

Non-synoptic flow regimes are those in which the surface wind direction and velocity may carry little or no direct relationship to the general flow pattern as indicated on the weather map at approximately 1500 feet above the ground. When nighttime radiation takes place and a layer of cooler stable air develops near the earth's surface, the airflow pattern within that layer generally has a much lighter velocity and the direction can vary considerably from the flow above the stable air. The stable layers of air near the surface generally occur in the time period between

8 p.m. and 9 a.m. but can occur for several additional hours per event. Overcast cloud cover conditions and/or precipitation would decrease the chance that a separate stable layer can develop near the surface. Data from a 200-foot tower will permit the determination of stability classes and linkage with synoptic flow on almost an hourly basis.

CHARACTERISTIC AIRFLOW PATTERNS

Several repeatable patterns of airflow at both Rocky Flats and Denver Airport can be identified from a review of the hourly sequences of wind observations. In Figs. 4 through 11 examples of these repeatable airflow patterns are illustrated. In these figures the hourly observations of wind speeds at Rocky Flats are presented in miles per hour and at the Denver Airport they are listed in knots. The appropriate conversion factor to change knots to mph is to multiply by 1.15.

In these several figures containing hourly wind direction and speed observations, the direction indicator ends at a center point for each hourly plotted value. The number at the outer end of the direction indicator shows the wind speed. For instance, a wind from the east at 10 mph is shown as ⟵10. A wind from the northwest at 15 mph is shown as 15↖. "C" stands for calm. Gusts are indicated by the letter "G", followed by the number of the peak velocity for the Denver Airport data. Precipitation is also shown only as reported at Denver Airport.

1. Synoptic Flow with Precipitation

Examples of closely related airflow at both locations are illustrated when active precipitation is taking place in the entire region. In Fig. 4, six days of airflow which had extended periods of active precipitation are presented. Precipitation is listed only in the hourly observations at Denver Airport but it can be assumed that the same type of precipitation was occurring at Rocky Flats. The code letter indicators are S = snow, R = rain, L = drizzle, SW and RW indicate shower-type precipitation, and ZL = freezing drizzle.

In each instance the hourly winds at Rocky Flats are shown at the left of the two columns with hourly data from Denver Airport in the right column. With only eight separate direction classes used at Rocky Flats, there appears to be longer periods of continuous flow within a single 45 degree bracket than occurs ocrrespondingly at Denver Airport where wind directions are observed to 36 points of the compass. Generally speaking, airflow coincident with precipitation occurs when winds are in the quadrant north through east. The hourly wind direction records from the two stations are matched very well on November 12, 1972, and on April 30 and May 6, 1973.

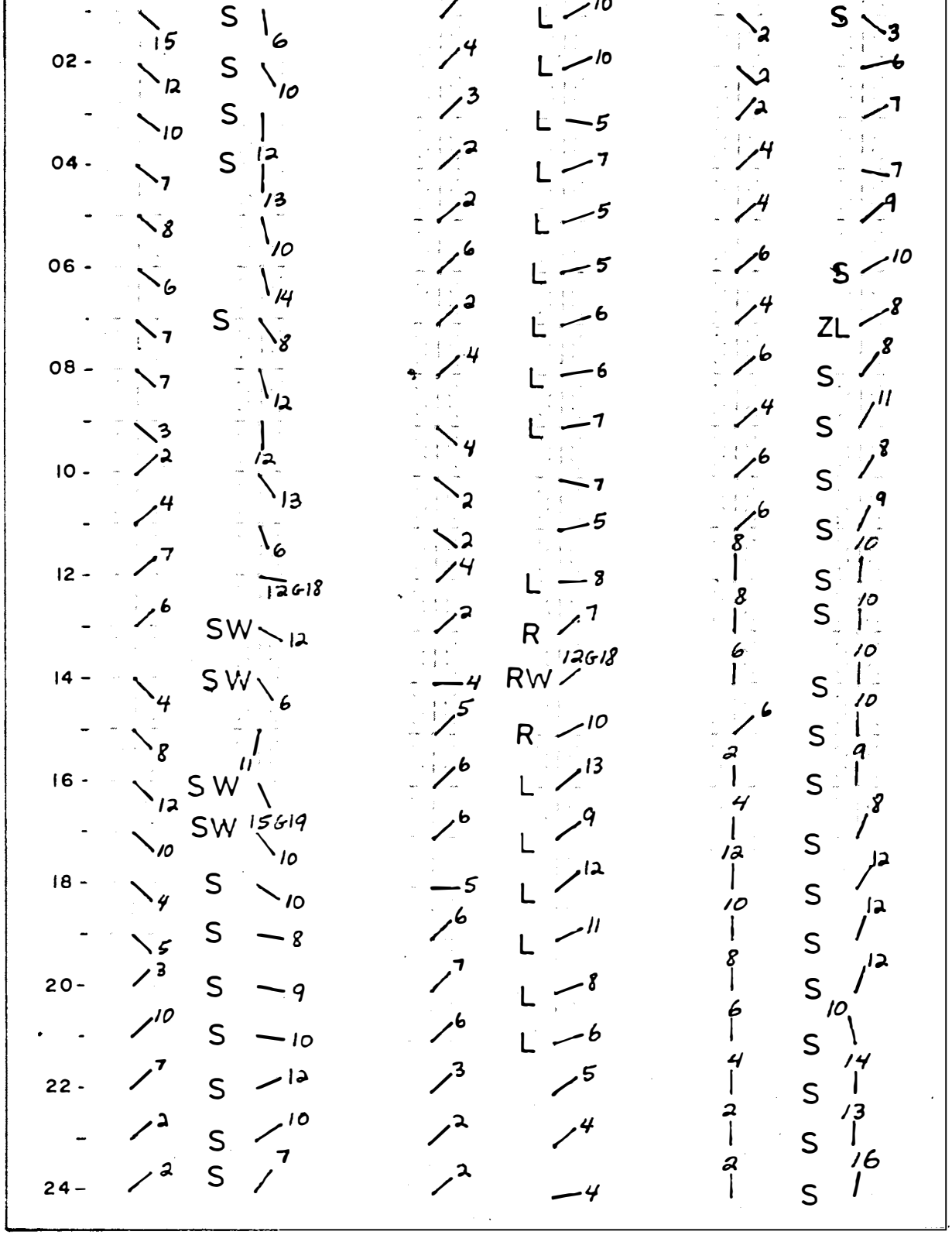


Figure 4. Sets of 24-hour periods of synoptic airflow dominated by active precipitation during 1972 and 1973.

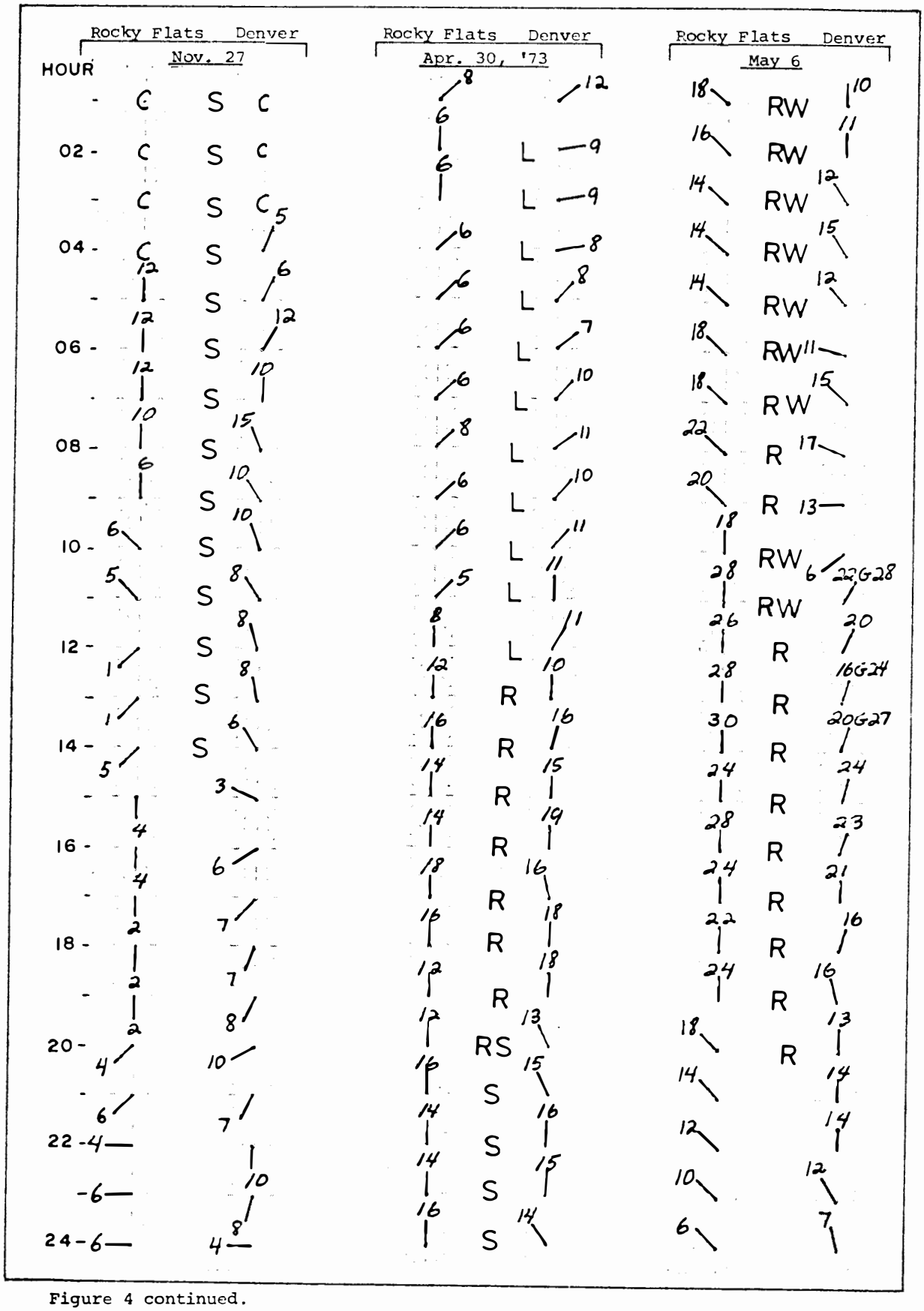


Figure 4 continued.

2. Additional Synoptic Flow Examples

Sets of seven separate days with six of them having no precipitation are shown in Fig. 5. In this instance all Rocky Flats hourly winds are shown for individual days on page 18. Corresponding hourly winds at the Denver Airport for the same seven days are shown on page 19. In many instances there are notably lower wind speeds at Denver than at Rocky Flats. Even the peak gusts at Denver Airport on December 12 do not equal the steady winds for most hours at Rocky Flats. Essentially all hours on these days could be listed as synoptic airflow. However, the light winds at Denver which occur primarily during nighttime hours may be disassociated from the general synoptic flow and may represent what can be called "dropout" hours when the colder air near the ground permits disassociation from the stronger flow aloft. Data for the early morning hours of November 27 show four or more hours at both Rocky Flats and Denver when there was probably a "dropout" of airflow near the surface from the general synoptic flow.

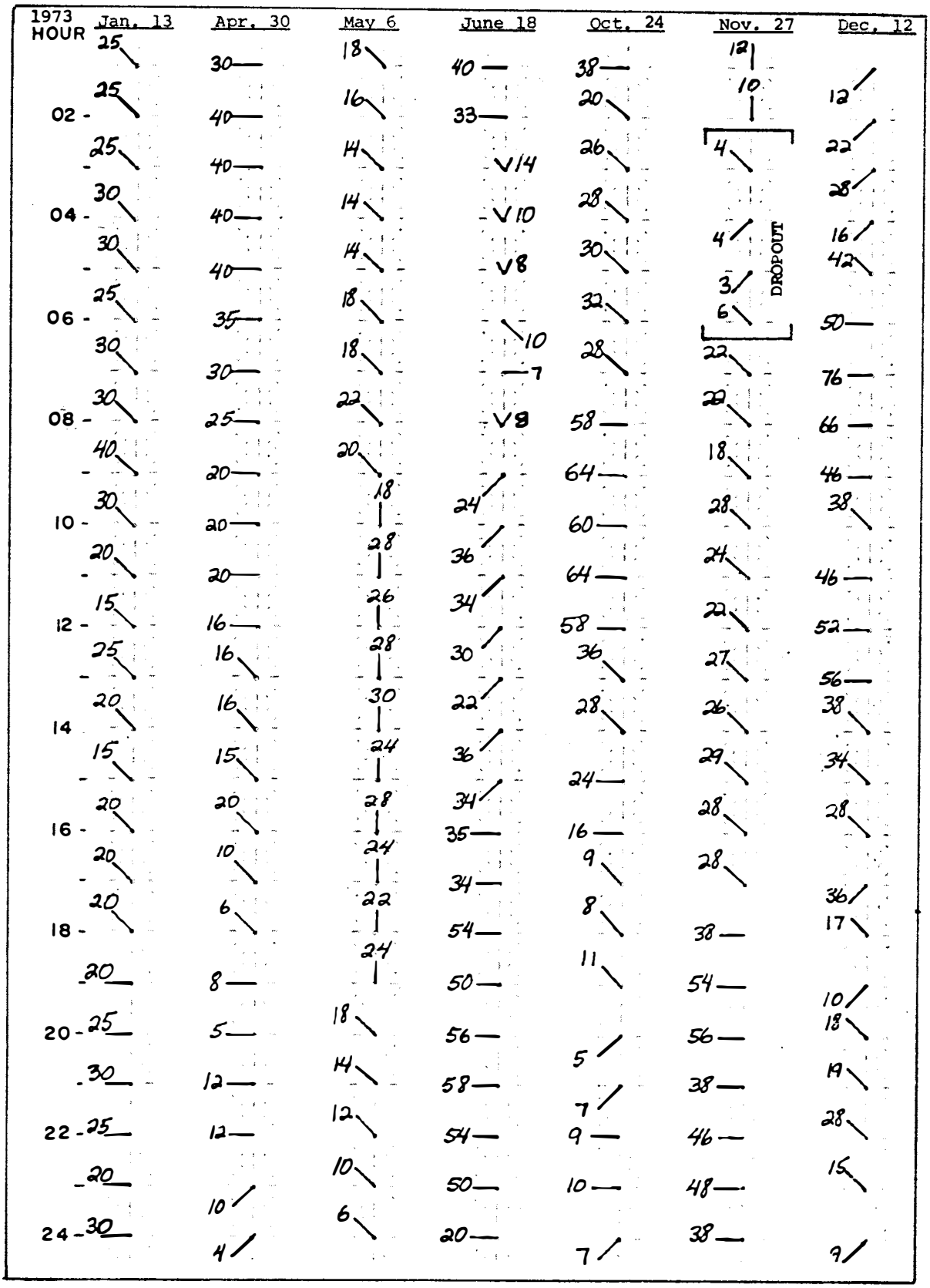


Figure 5a. Set of seven 24-hour periods of synoptic airflow at Rocky Flats.

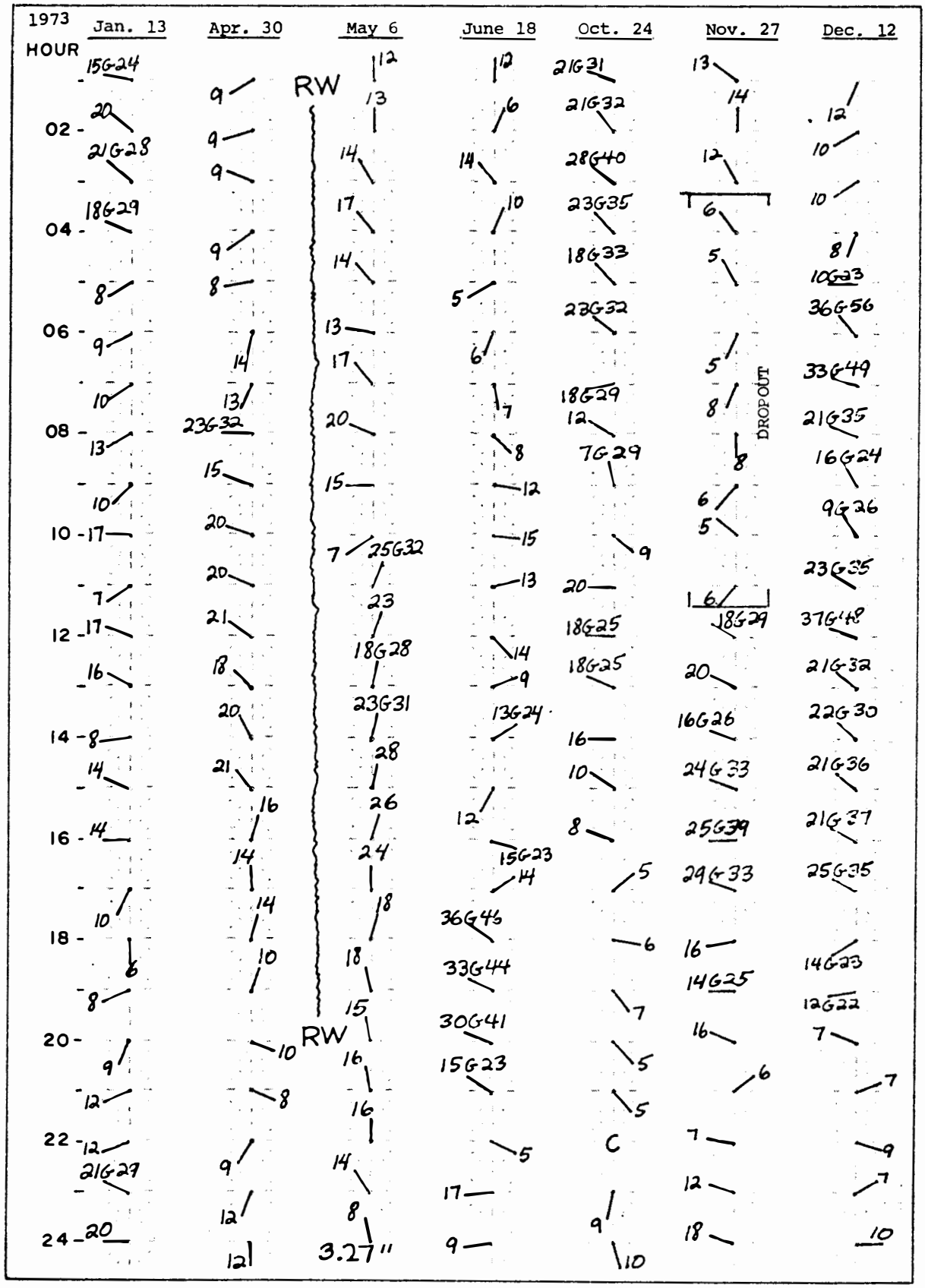


Figure 5b. Coincident hourly winds for same seven days as those shown in Figure 5a recorded at Denver Airport.

3. Additional Synoptic Flow Days with "Dropout" Hou

Some additional illustrations of predominately synoptic flow type days with some hours when there was a dropout at both locations similar to that mentioned for November 27 above are presented in Fig. 6. The hours which appear to be totally independent of general synoptic flow are bracketed. These "dropout" hours when colder stable air is present near the ground generally begin by midnight and end before noon. Many times they end by 8 a.m.

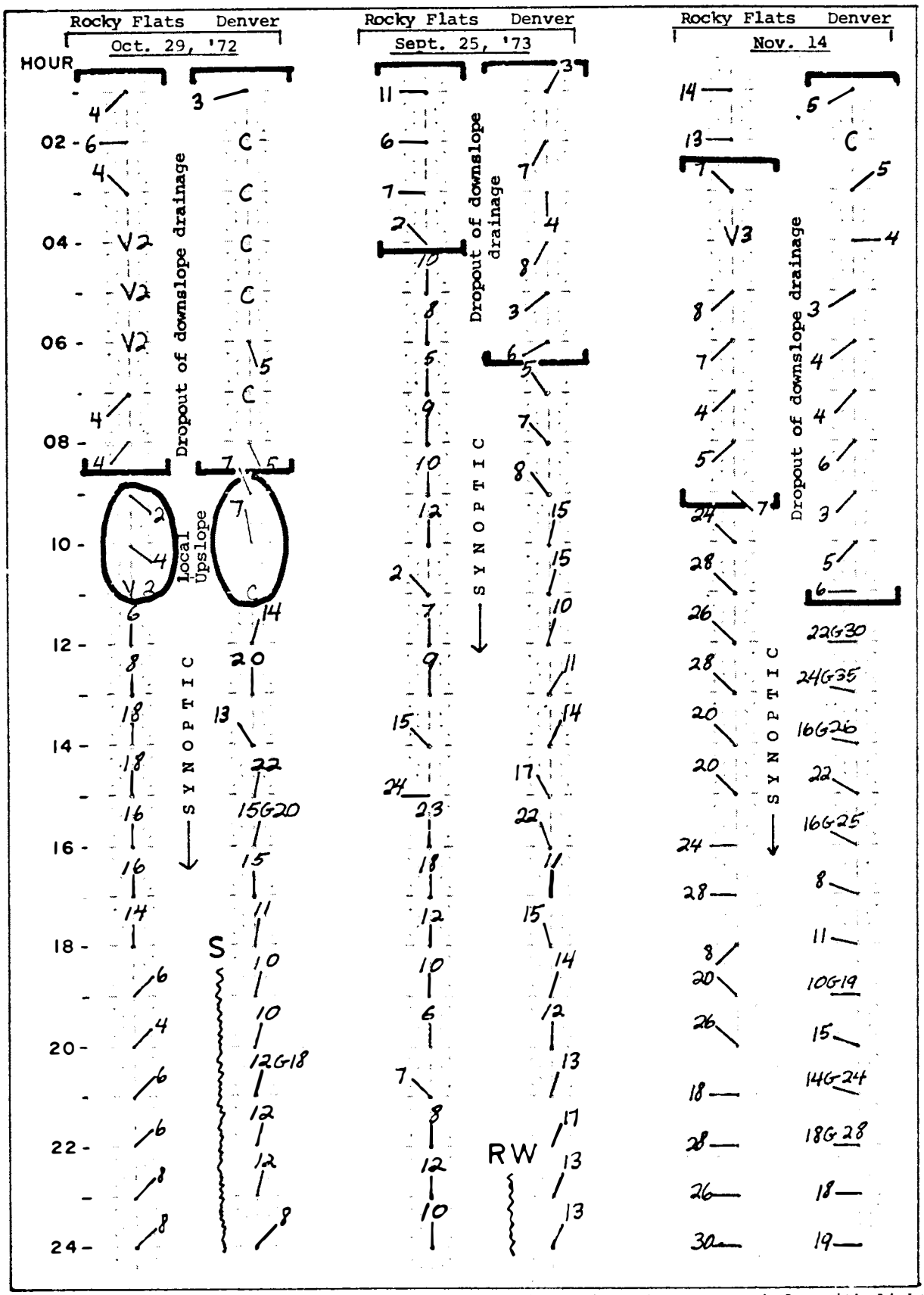


Figure 6. Three sets of 24-hour wind records during which "dropout periods" with light and variable winds and local upslope can be identified as separate from general synoptic airflow.

4. Afternoon Linkage with Synoptic Flow at Denver Airport

A frequent repeatable pattern of airflow is one in which synoptic flow from some westerly direction persists throughout the entire 24 hours at Rocky Flats but only is linked with the surface flow at Denver during the warmer hours of the day after the stable layer of air near the ground has been eliminated due to surface heating. Three sequential days that illustrate this repeatable pattern are shown in Fig. 7. In this case the hourly winds on three days, January 28, 29, and 30, at Rocky Flats are shown at the left. The hours when synoptic linkage prevails at Denver Airport are identified with a long vertical bracket.

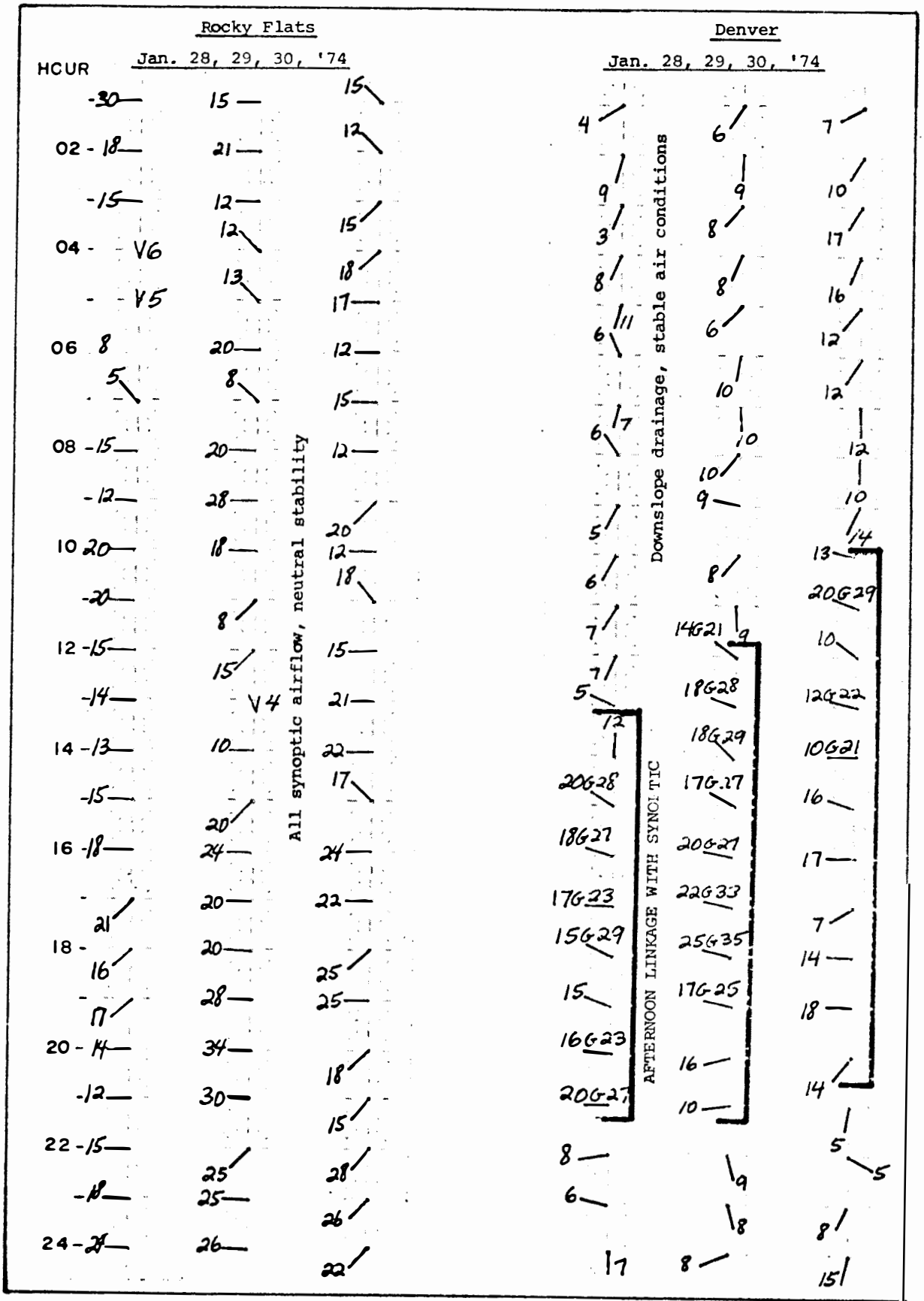


Figure 7. Three-day comparison of almost continuous synoptic airflow at Rocky Flats but at Denver Airport only the afternoon hours are linked with synoptic airflow.

5. Western Synoptic Flow at Rocky Flats Matched with Easterly Flow in Afternoon at Denver

In some instances airflow continues at Rocky Flats from a westerly component with occasional wind speeds greater than 20 mph while at the same time airflow at Denver Airport is from some easterly component. It is not completely clear whether or not this east to west flow at the Denver Airport constitutes a replacement eddy. The airflow at Denver may move toward the mountains at some point south of Rocky Flats where it then rises and joins into a flow from west to east at some upper level. Three sets of such days are shown in Fig. 8.

It is certainly true that data from the Denver Airport would not be representative of airflow at Rocky Flats on these days. The hours during which the airflow is predominantly east to west at Denver Airport are circled in black.

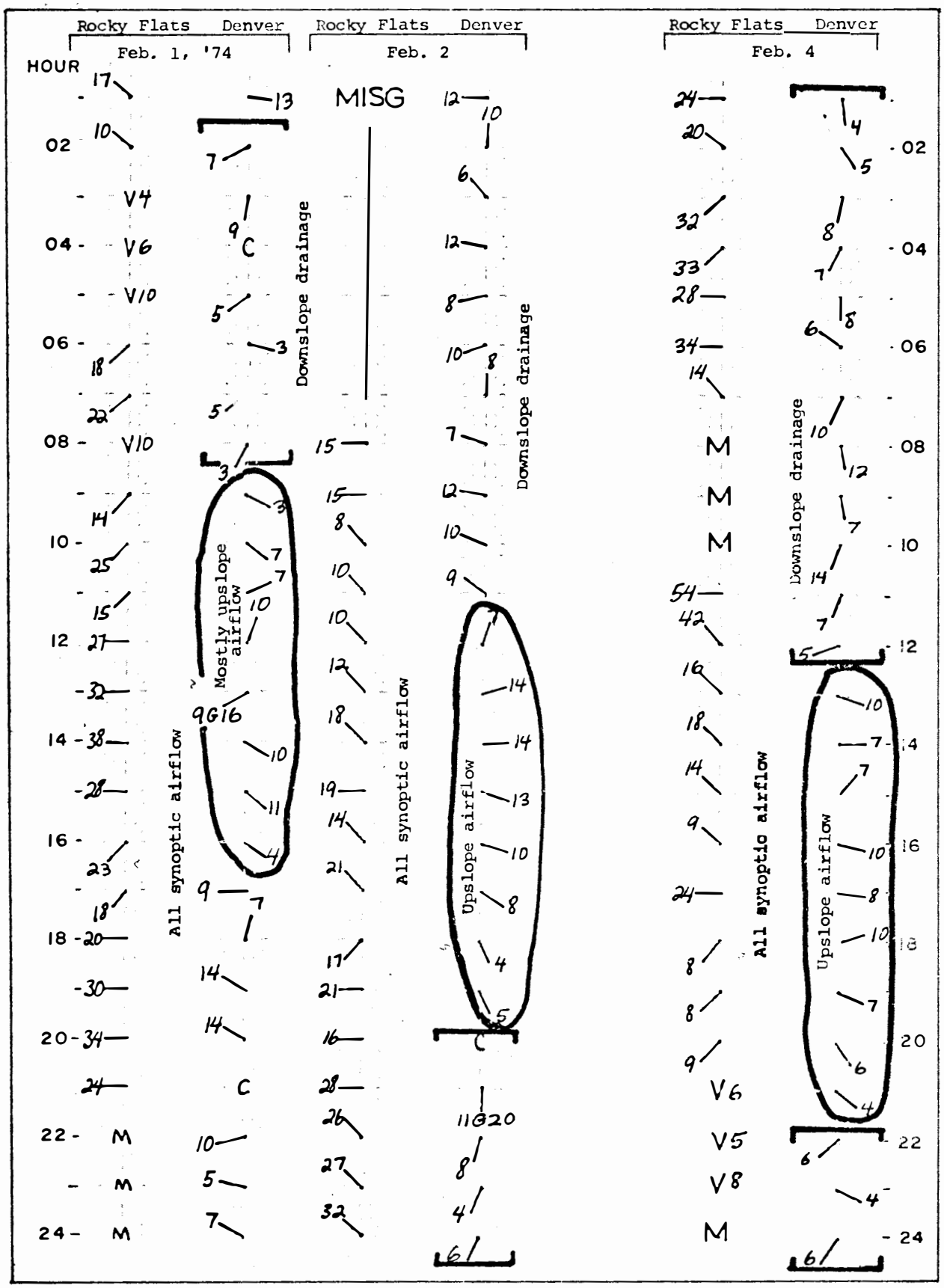


Figure 8. Three sets of days when westerly synoptic airflow prevails at Rocky Flats while there are periods of "upslope" or "turn-around" airflow at Denver.

6. Downslope Drainage at Rocky Flats and "Turn-Around" Days at Denver Airport

During winter months it is often possible for downslope drainage flow to continue at Rocky Flats for almost all hours while on these same days there is a downslope drainage flow for 14 or more hours and a reversal to upslope flow for three or more hours at Denver Airport. Five sets of this combination of airflow are presented in Fig. 9. The period of downslope drainage flow at Denver is identified with a bracket. The upslope or up-valley flow hours are circled for identification. These days at Denver Airport fit the description of "turn-around" days while drainage flow continues at Rocky Flats.

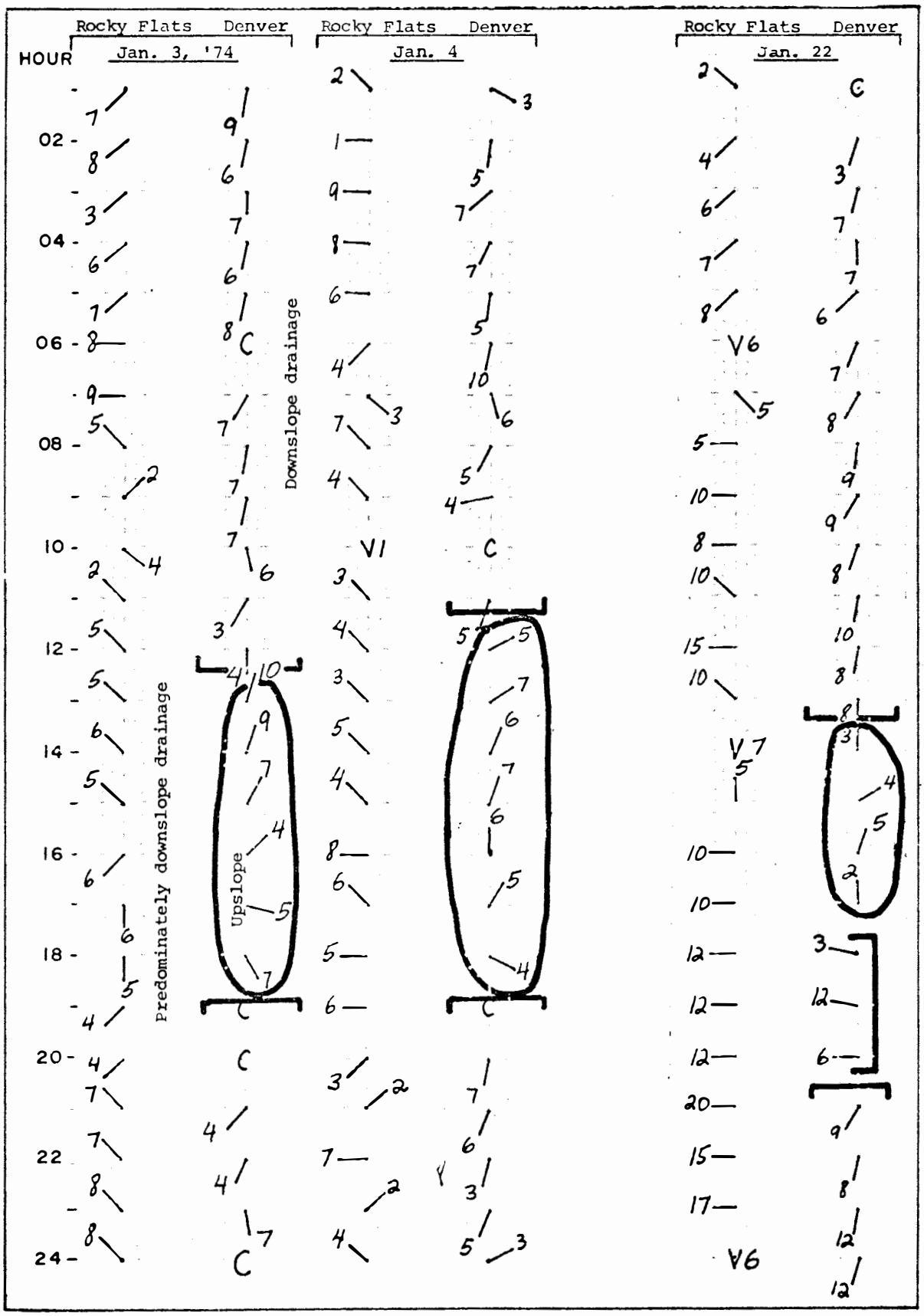


Figure 9. Five sets of days when downslope drainage dominates the airflow at Rocky Flats while "turn-around" type airflow occurs at Denver.

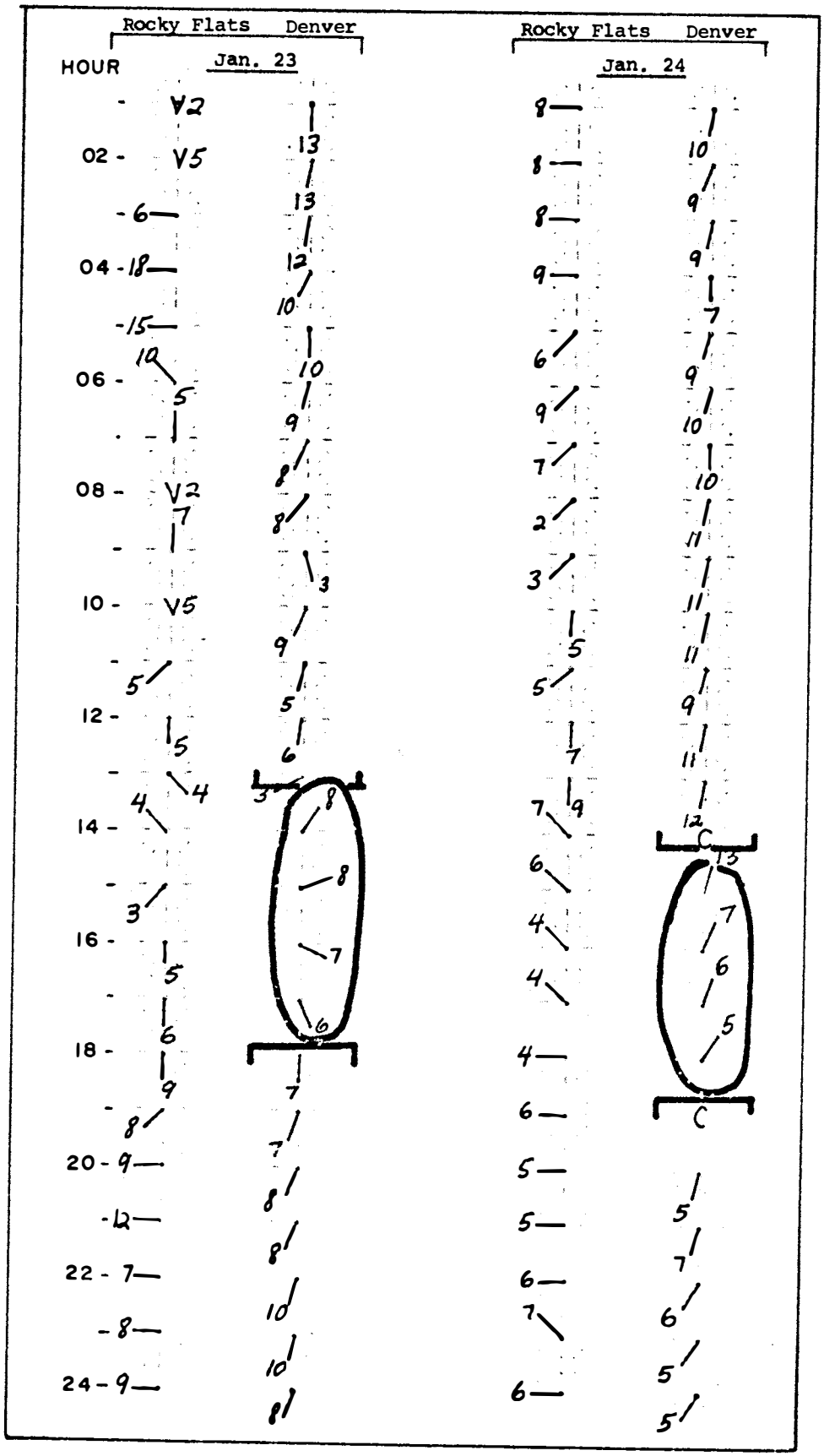


Figure 9 continued.

7. "Turn-Around" Days and Comparisons of Timing

Along the eastern slope of the Rocky Mountains a high fraction of the days experience a "turn-around" of airflow. Under these conditions downslope drainage flow begins in the evening hours after solar heating can no longer prevent formation of a colder layer of air near the ground. This colder more dense air moves down-valley with extremely local influences of terrain features. In the southeast portion of the Denver metropolitan area drainage flow is from southeast toward northwest. In the southwest portions of Denver the flow is from the southwest. The net flow of all drainage winds moves air down-valley along the lower regions of the Platte River and all tributaries thereto.

The Rocky Flats downslope motion is represented by winds from northwest through southwest. Upslope motion at Rocky Flats is represented mostly by winds from northeast through southeast. The immediate terrain features surrounding the wind unit at Rocky Flats tend to show that light winds from the north are still part of downslope flow toward Woman Creek, whereas light winds from the south are generally a part of very localized upslope flow.

At Denver the downslope flow is from a southerly direction, generally from 180 degrees through 220 degrees. However, the local drainage along Sand Creek near the wind measuring unit at the Denver Airport often reflects a drainage flow from the southeast. Upslope flow includes the north to south flow along the lower regions of the Platte River Valley in the Denver metropolitan area. It also includes all of the winds from an easterly component during the warmer hours of

the day. Four sets of turn-around type days at both stations are shown in Fig. 10. The identification of hourly periods of drainage flow and the reverse type upslope flow is the same as that described above. It is quite typical that a period of near calm conditions occurs at or near the turn-around times, whether from downslope to upslope or from upslope to downslope.

The reversal of airflow on turn-around days generally takes place somewhat earlier at Rocky Flats than at Denver. An analysis of comparative minimum temperatures at the two stations showed that Denver Airport had colder minimum temperatures on 255 mornings out of the 366 days in 1972. Thus, there is a higher surface temperature to start with on most mornings at Rocky Flats than at Denver Airport. There would be a thinner layer of cooler stable air to be heated before the reversal to upslope flow could take place at Rocky Flats. The earlier time of turn-around is confirmed by the 24 sets of turn-around periods covered in Fig. 11. Most turn-arounds occur before 9 a.m. at Rocky Flats, whereas nearly one-half of all the turn-arounds occur after 10 a.m. at the Denver Airport. Examples can be found of an earlier turn-around at Denver but they are relatively rare. A one hour earlier turn-around is shown for April 10 which appears in the upper part of Fig. 11.

Calm and/or light and variable winds are generally included within the hours of stable downslope flow but it could be argued that they also are a part of the changing air motion produced by surface heating eliminating the colder layer near the ground. Longer delays for timing

of turn-arounds tend to occur during winter months. However, these are also the months when synoptic flow has a higher frequency at Rocky Flats than at Denver.

Maximum temperatures are typically higher at Denver Airport than at Rocky Flats. During 1972 there were 287 days with higher maxima at Denver Airport.

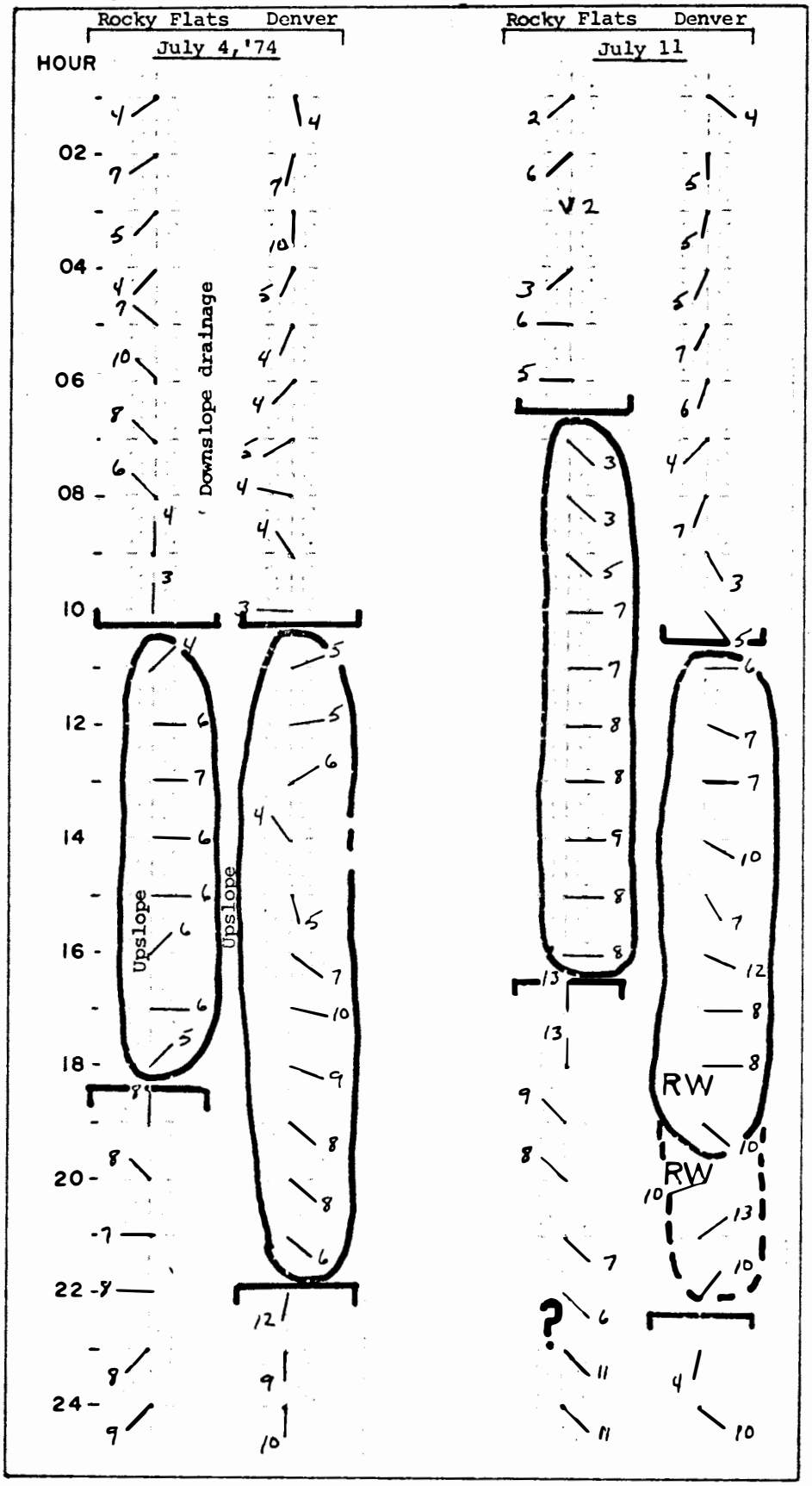


Figure 10. Four sets of "turn-around" type days at both Rocky Flats and the Denver Airport.

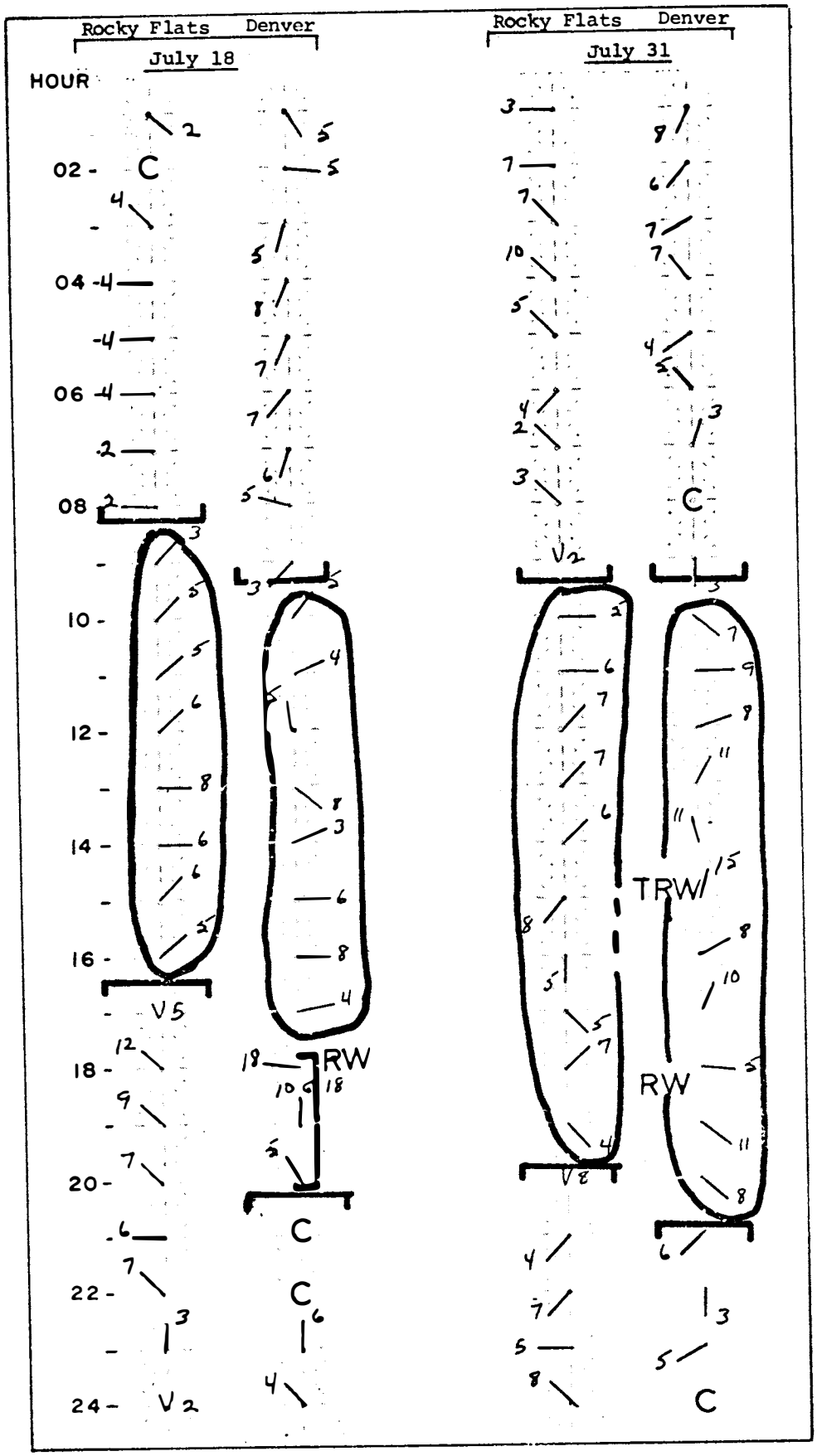


Figure 10 continued.

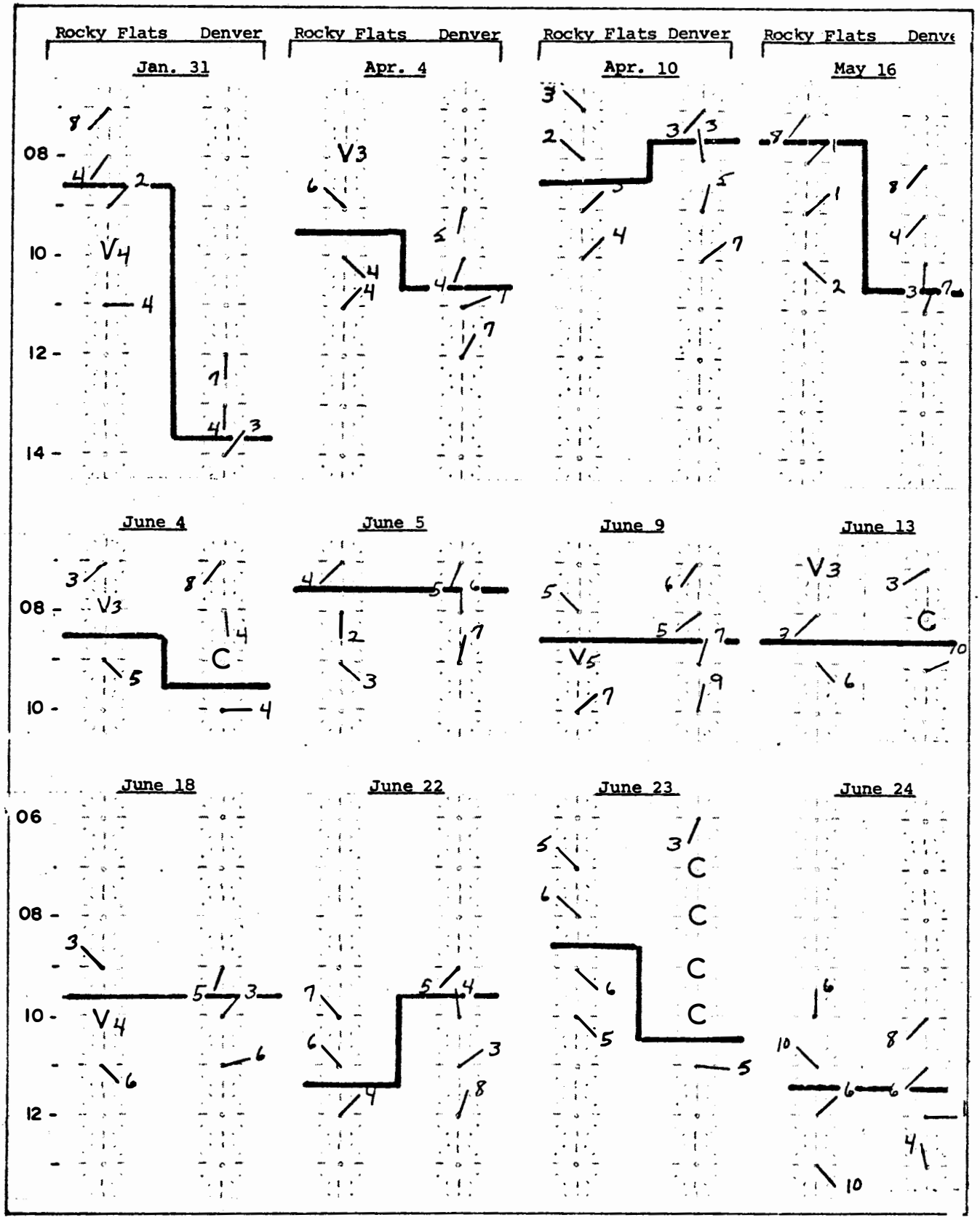


Figure 11. Sets of hourly wind measurements surrounding the near reversals of airflow on "turn-around" days.

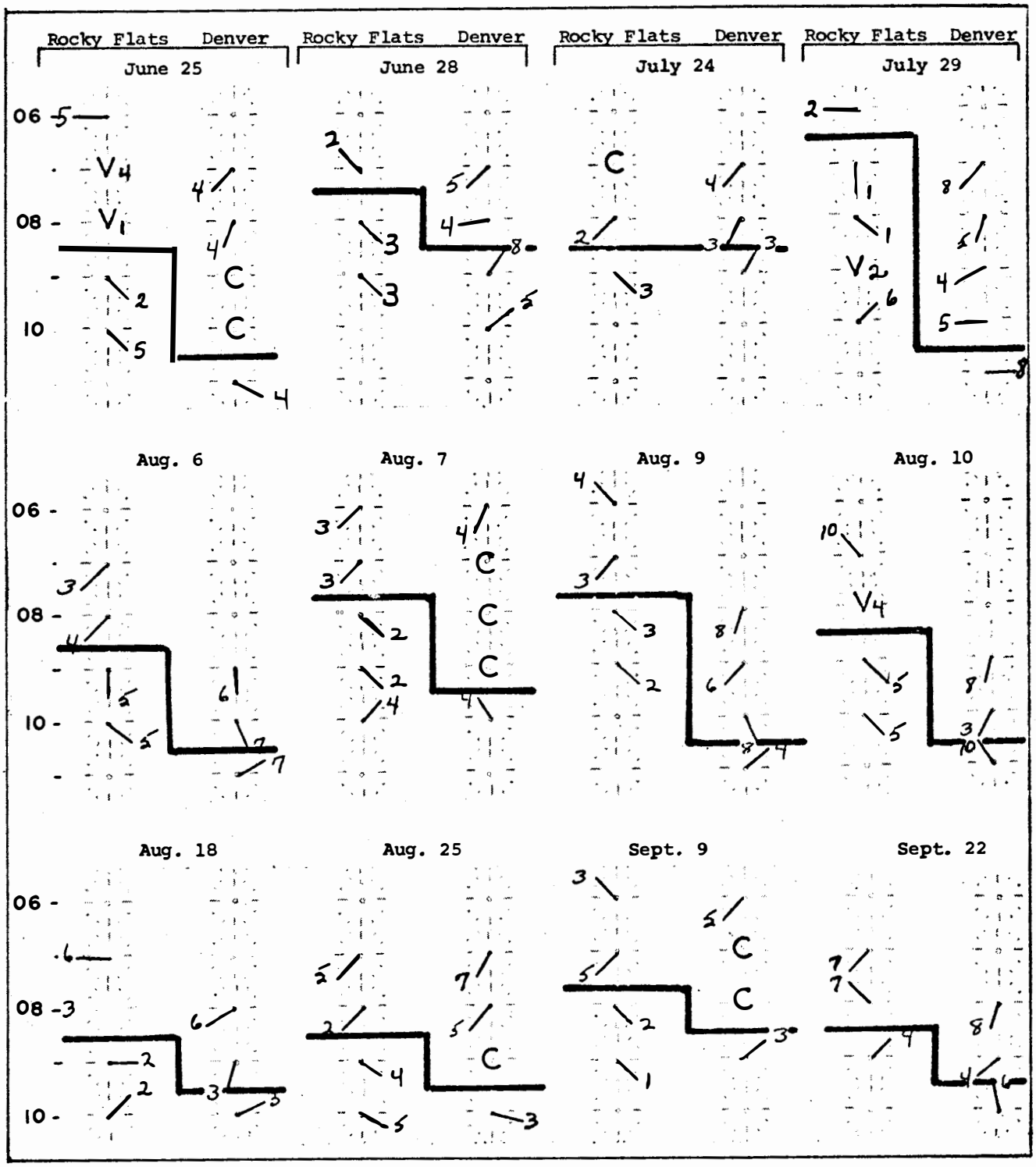


Figure 11 continued.

The relative frequency of different types of airflow patterns can be indicated by assigning the dominant airflow pattern which prevails for each day in the year. A summary of this type documentation for the 731 days during the two-year period 1972-73 is shown in Table I. If more than one-half of the hours in a given day could be classified into one of the five repeatable-type categories, that day was given an appropriate "type" assignment. The two highest frequencies were "synoptic" and "turn-around" type days at both locations. There were slightly higher frequencies for both "synoptic" and "turn-around" days at Rocky Flats than at Denver Airport. However, there was a notably higher number of instances when the afternoon hours were linked with synoptic flow at Denver as compared with Rocky Flats. Each of these characteristic type airflow patterns has been described above. The special type days of synoptic with some dropout hours and drainage-type days have a higher frequency in the months October through May than in the warmer summer months.

TABLE I. DISTRIBUTION OF PREDOMINANT AIRFLOW PATTERNS FOR ROCKY FLATS AND DENVER FOR THE YEARS 1972 and 1973 (731 days)

Type Day	Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Synoptic	Rocky Flats	37	19	26	25	22	15	20	19	23	17	23	31	277
	Denver	22	15	28	31	27	14	22	17	21	20	23	24	264
Synoptic Drop-out Hours	Rocky Flats	2	2	1	7	5	1			4	8	6	6	42
	Denver	3		2	7	7	3	4	5	2	3	3	1	40
Afternoon Linkage with Synoptic	Rocky Flats	1	6	9	2	6	5	12	12	3	2	2	7	68
	Denver	9	9	10	8	8	22	22	19	6	6	3	6	128
Turn-around Days	Rocky Flats	12	20	20	18	25	34	29	30	30	34	21	9	282
	Denver	21	24	21	14	20	19	14	20	30	32	25	19	259
Drainage	Rocky Flats	9	4	5	4	1	1		1			6	9	40
	Denver	7	9	1			2		1	1	1	6	12	40
Missing	Rocky Flats	1	6	1	4	3	3	1			1	2		22

CONFLUENCE OF DOWNSLOPE AIRFLOW AND DIVERGANCE OF UPSLOPE AIRFLOW

Examination of terrain features and the directions of air motion during the hours when cooler air prevails near the ground indicates a confluence of air from the Denver metropolitan area with air from the Rocky Flats area in a broad zone above the Platte River Valley to the west and north of Brighton, Colorado. This is illustrated in Fig. 12. There would be considerable dilution of pollutant material from both sources before reaching the confluence area.

After surface heating has eliminated the cooler layer of air near the ground the downslope drainage flow of this more dense air ceases. This is followed by a relatively brief period of near calm, or light and variable wind conditions, which in turn is followed by upslope motion. Fig. 13 shows upslope airflow patterns which are typical immediately following the time of airflow reversal. Note that all "clouds" or layers of pollutants which have previously moved downslope during prior hours would move upslope from their current position at the time of turn-around. The upslope path will not be a direct reversal of the downslope path. This is specially true of any point source. Upslope paths are also generally divergent.

In the warmer part of the afternoon hours on all turn-around days some easterly wind component prevails along a belt at least 40 miles eastward from the mountainous terrain which rises above 7000 feet.

The documentation of the airflow patterns related to air pollution in the Denver metropolitan area is supported by multiple prior studies. In the winter of 1961-62 Riehl and Crow[2] used data from a network of 11 wind

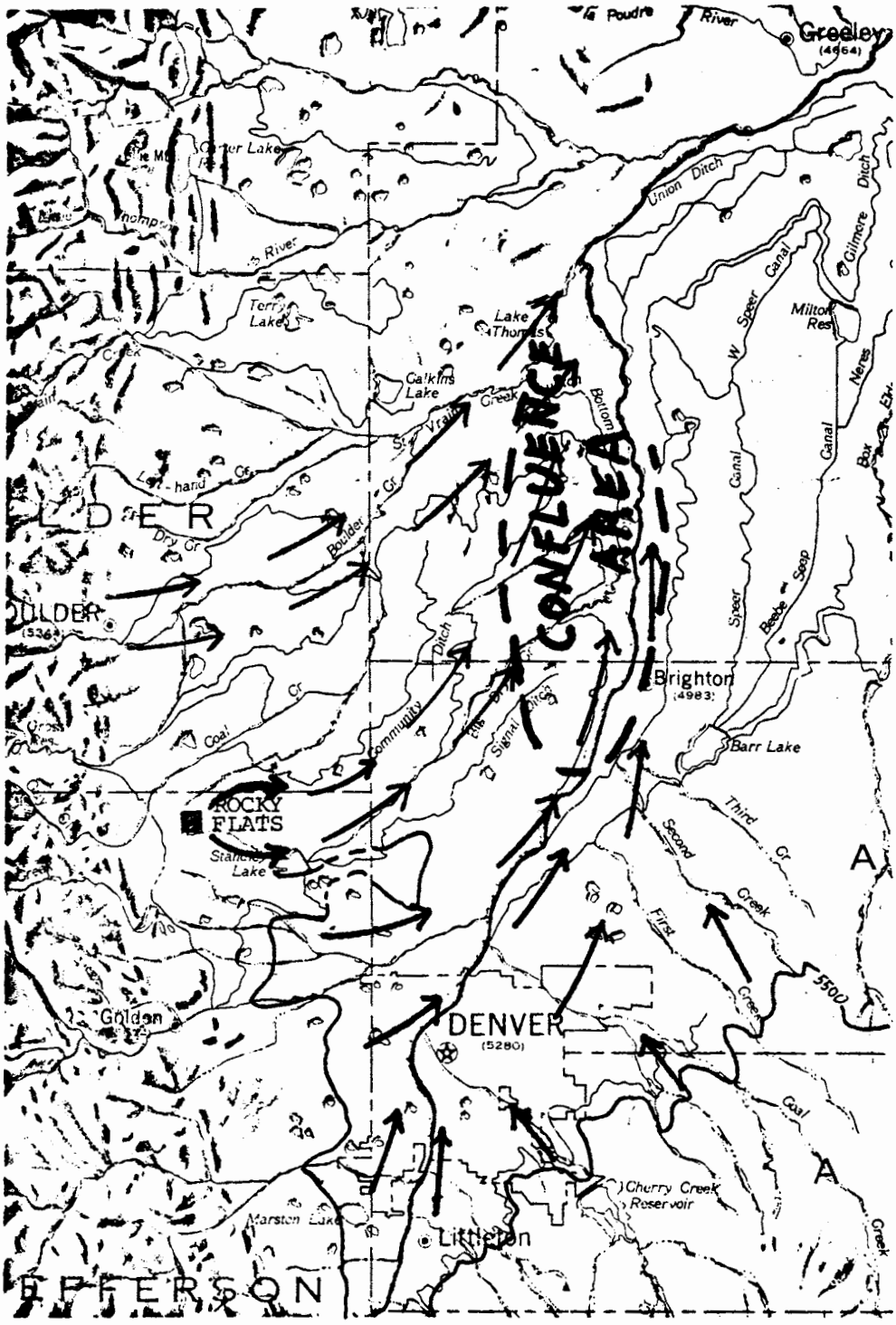


Figure 12. Characteristic downslope airflow during STABLE conditions in the geographic region from the south edge of the Denver metropolitan area northward.

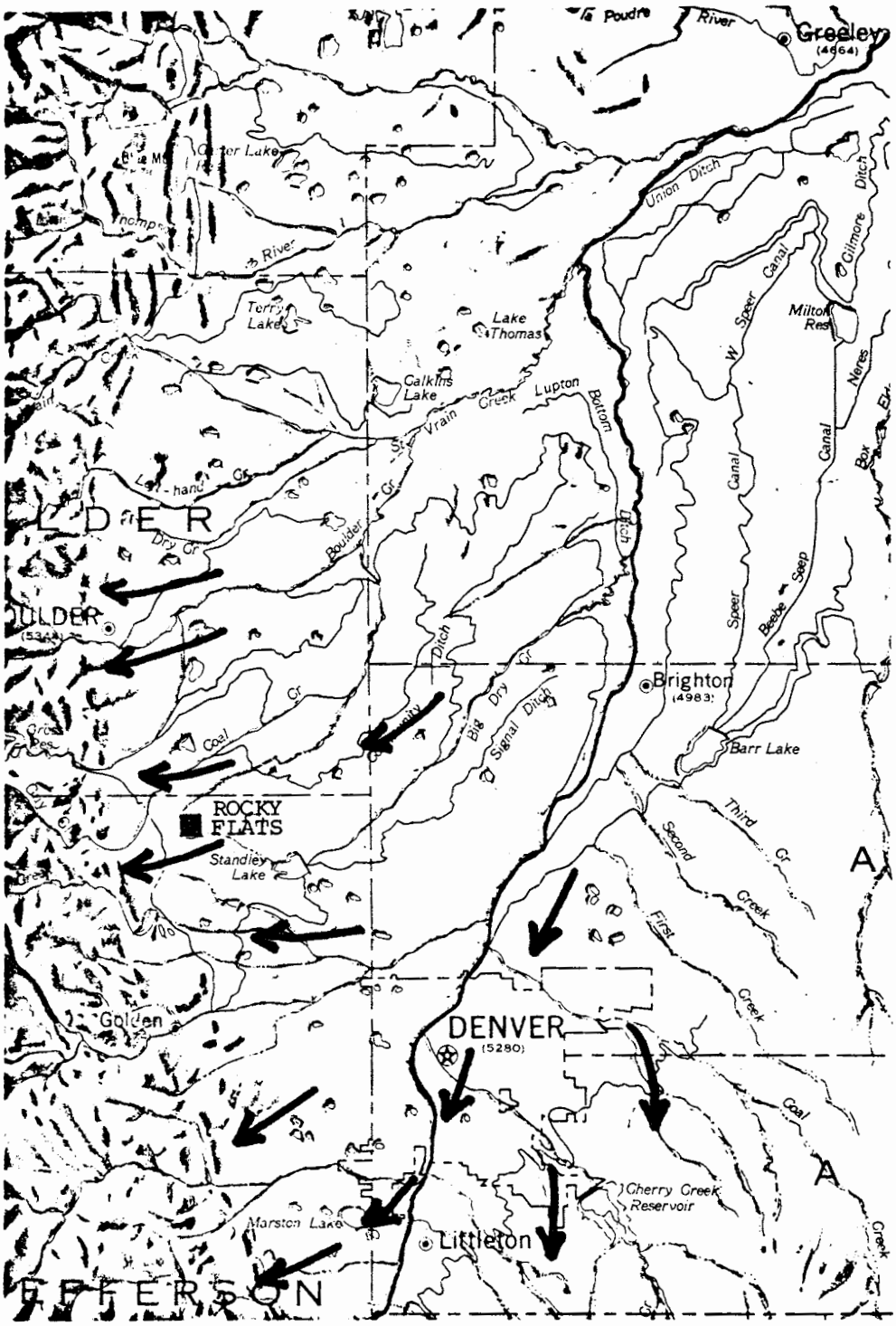


Figure 13. Characteristic upslope flow patterns which occur immediately following the reversal of airflow on "turn-around" type days.

measuring units covering 10 detailed episodes of relatively dense air pollution. A second study expanded by the Atmospheric Sciences Department of Colorado State University[3] used continuous wind records from 17 wind measuring units distributed in a pattern throughout the Denver metropolitan area.

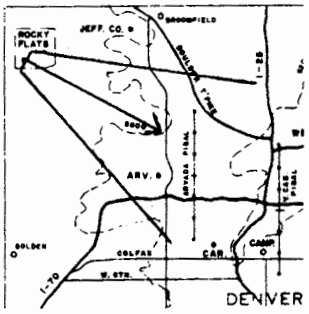
A description of the "heat island" and cross-sectional dimension of pollution for the Denver area was reported by Crow in a special study prepared for the Colorado Department of Public Health in 1964[4]. (Not published.)

Typical daily airflow patterns related to air pollution are also described in "Air Pollution in the Denver Area" published by Public Service Company of Colorado, 1967[5]. Excerpts of that report are presented in Appendix A. The depths of the polluted layer as shown therein for 8 and 11 a.m. have subsequently been found to be from 200 to 400 feet deeper.

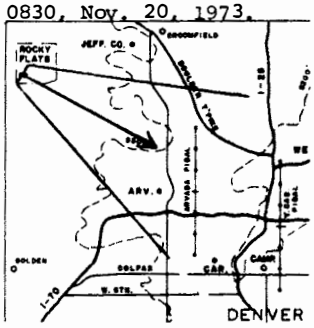
The most recent documentation of detailed airflow over Denver related to air pollution was part of the Environmental Protection Agency's "Brown Cloud" study in November, 1973[6]. During that study period many photographs were taken from Rocky Flats to show typical dimensions of the main body of the visible pollution layer in the Denver metropolitan area. Most of those photographs showed the polluted layer to be several miles to the southeast of Rocky Flats. Two sets of such photographs are shown in Figs. 14 and 15. The principal time period when some of the pollution from the Denver metropolitan area moves over Rocky Flats is during afternoon hours. Material which initially moved to the north-northeast from Denver moves back westward toward the mountains. These diluted effluents from Denver may join

with the upslope motion of the effluents emanating from the Rocky Flats area.

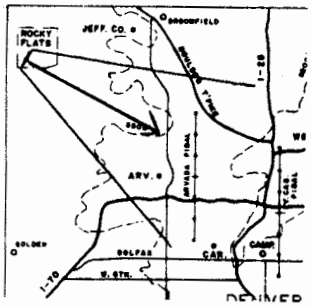
It would also be possible under rare circumstances for air moving generally in the downslope mode to have confluence with pollution from the Denver metropolitan area over the Platte River Valley several miles north-northeast of Denver with subsequent return of that air moving back over Denver from the north-northeast.



Cloud cover and high plume rise from both cooling towers and stacks at Cherokee Power Plant as seen from Rocky Flats three hours after end of snowstorm; 0830, Nov. 20, 1973.

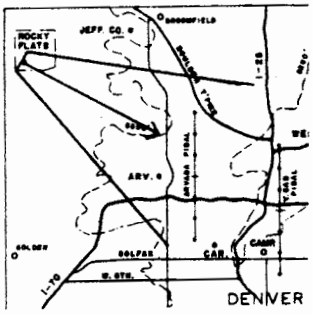


Four-hour buildup of air pollution over Denver as seen from Rocky Flats; 1230, Nov. 20

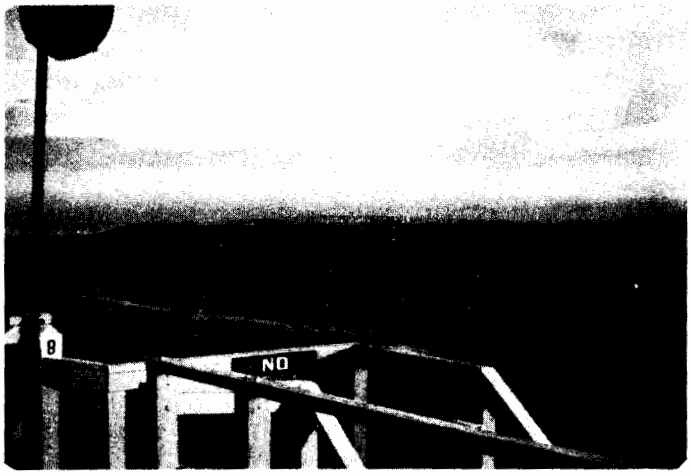


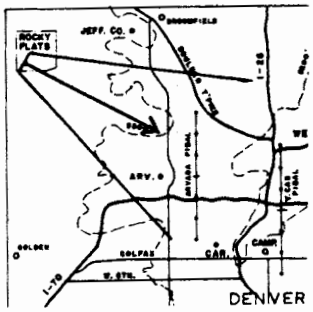
Seven-hour buildup of air pollution over Denver as seen from Rocky Flats; 1530, Nov. 20

Figure 14. Progressive development with changes in depth, dimension, and location of pollution layer, Nov. 20, 1973.

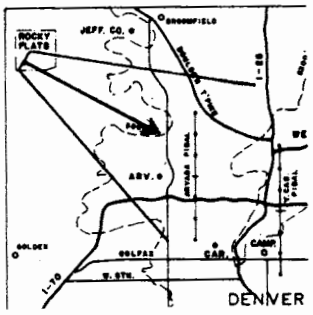


Air pollution layer over Denver as seen from Rocky Flats
1400, Nov. 29, 1973.





Same scene:
1600, Nov. 29



Same scene, following day:
1530, Nov. 30.

Figure 15. Two photographs showing progressive development and changes in depth and dimension of pollution layer during afternoon hours of Nov. 29, plus one view of the pollution layer in mid-afternoon on Nov. 30, 1973.

AIR POLLUTION CYCLE OVER DENVER METROPOLITAN AREA

Notations in the Remarks Column of the hourly observations made at the Denver Airport include reference to the location of where smoke is observed. An analysis of the entire 8760 hours of 1972 resulted in the summary prepared in Table II. The highest frequency of smoke observations occurs between 8 a.m. and noon with the quadrant of direction west through north being the most frequent. The remark of "smoke over the city" has nearly an equal frequency in the early forenoon hours and late afternoon. The appropriate direction for a "smoke over the city" observation would be to the west of the observer.

When smoke is reported for all quadrants it would mean there is some pollution to the east and south of the Denver Airport. Such observations would directly relate to those instances when the air motion has reversed and is moving polluted air back from the north over the northeastern part of the city. The total frequency of remarks regarding smoke accounted for 16 percent of all observations during 1972. There is no exact requirement for observers to list smoke in the Remarks Column. Therefore, this statistic is very far from exact or totally inclusive. It does, however, prove that Denver Airport has more hours when the airport is to the south or east of smoke or a layer of visible pollution than any other direction.

Fig. 16 presents a cross-section prepared as a part of the special study of November, 1973. Multiple pollution episodes were used to develop the height and dimension of the polluted layer.

The nearly repeatable pattern of pollution over Denver on episode days of November, 1973, is illustrated in the cross-section diagram of Fig. 16.

TABLE II. FREQUENCY OF HOURS WHEN WEATHER OBSERVER AT STAPLETON FIELD REPORTED THAT SMOKE WAS NOTABLY VISIBLE IN ONE OR MORE DIRECTIONS FROM THAT POINT OF OBSERVATION DURING 1972.

Hour	Over City (no dir.)	SMOKE VISIBLE TO: S	SW	W	NW	N	NE	E	All Quadrants*	Total Hours Smoke/Year
01	7		1	1	1				1	11/366
02	10		2	1	1				1	15
03	12			2	4				1	19
04	10		1	4	3	1			1	20
05	18			5	6	3			2	34
06	21			6	13	6			2	48
07	23			6	13	7			3	52
08	18		3	14	26	20	1		5	87
09	24		5	22	32	23	6		9	119
10	26	1	5	20	32	27	8		12	131 Peak
11	27	1	5	19	32	26	8	1	12	131 ← Freq.
12	18	1	7	22	27	24	5	1	13	118
13	18	1	6	18	22	18	4		10	97
14	19	1	5	11	15	11	2		11	75
15	15	1	5	15	16	13	3		9	77
16	21		5	11	10	5			6	58
17	24	2	8	11	11	5			4	65
18	24	1	5	8	8	4				50
19	19	1	6	12	10	5				53
20	10	1	5	9	7	4	2	1	1	40
21	5	1	4	7	7	4			5	33
22	3		4	6	7	5			3	28
23	3		3	5	6	1			4	22
24	4		2	2	3				3	14
										1397/8784
										16%

*During 49 hours smoke was listed as reason for visibility being limited to six miles or less at Stapleton Field.

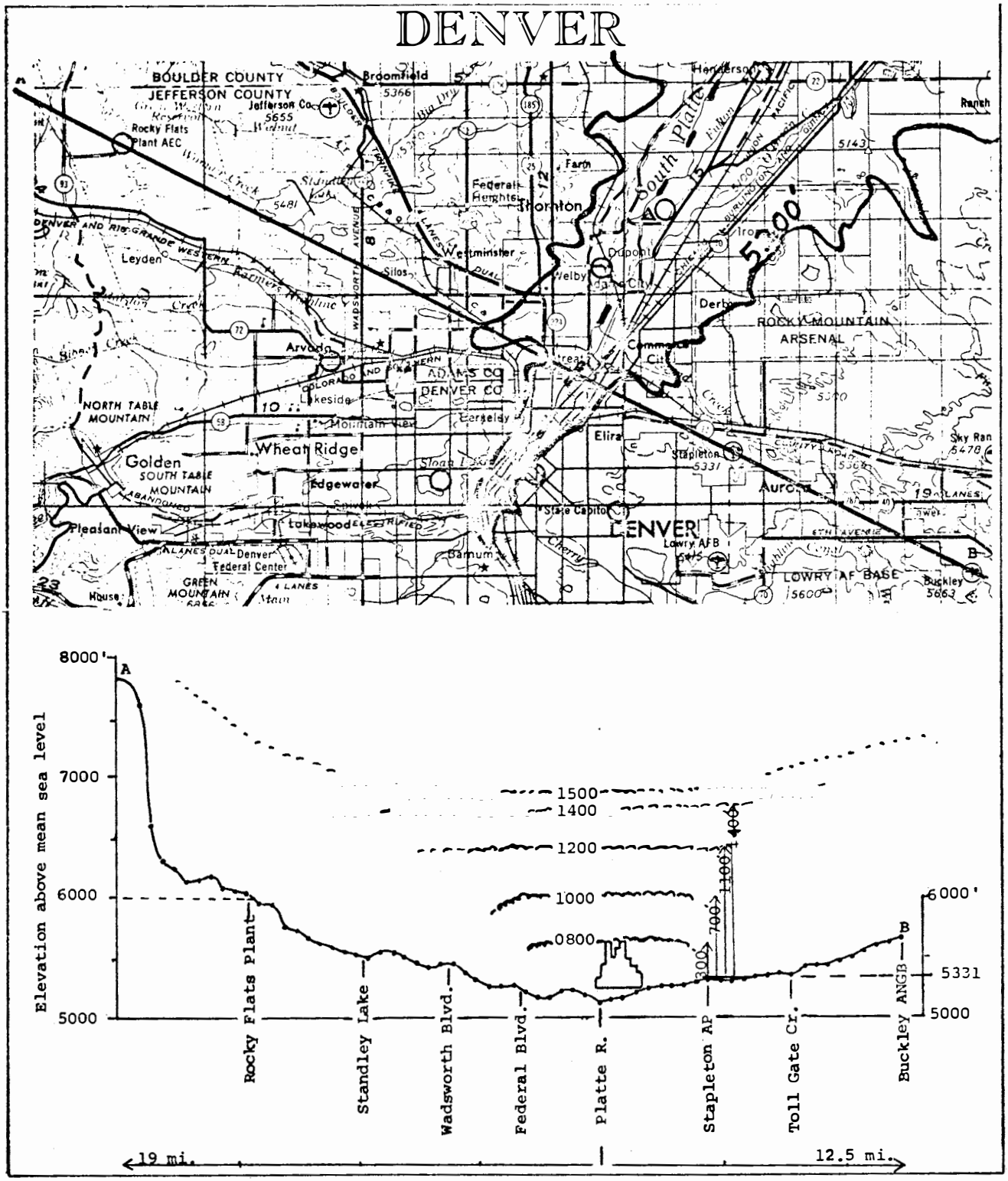


Figure 16. Typical WNW-ESE profile of pollution layer depths over metropolitan Denver between 0800 and 1500 on days when temperature inversions are not eliminated and when the polluted layer which forms near the downtown area spreads southward and away from its original location over the north edge of Denver.

This cross-section has been prepared to show the vertical profile of terrain and the pollution layer at various hours of the day as it is typically observed. The profile, which is greatly distorted in the vertical scale, runs from the mountainous area to the west-northwest of the Rocky Flats Plant south-eastward to Buckley ANGB. This profile crosses the Platte River about three miles northeast of the downtown City of Denver and passes through Stapleton Airport. Multiple photographs, taken during the special study period of November, 1973, and during other periods studied by this author, support the approximate elevations of the polluted layer tops as shown in the cross-section for the hours from 0800 through 1500. These depths of the polluted layer should be considered typical of days in which the temperature inversion is NOT broken. In the summer months the respective tops of the polluted layer may be slightly higher.

The ground level for most downtown buildings is approximately 5200 feet above mean sea level. The higher buildings extend slightly more than 400 feet above ground level. Thus, they extend approximately 270 feet above the runway elevation for Denver Airport, which is 5331 feet. The elevation of the polluted layer tops is shown as above ground level at Denver Airport since the surface temperatures used to help derive the elevation tops are those measured hourly at the airport. Temperature profiles from the 0500 rawinsonde at Denver have been used to support the findings shown in Fig. 16.

The most frequent pattern of spreading for the pollution layer from noon through 1500 is to the south and/or west of the downtown area. This is aided by upslope motion above the higher terrain located in that direction

from the city. For instance, North Table Mountain, South Table Mountain, and Green Mountain all extend above 6000 feet MSL. At the tops of these relatively flat protrusions the layer of stable air in early morning hours is very thin. Thus, a small amount of surface heating is required to eliminate the stable air layer. The stable layer is replaced by air which is well mixed vertically. In some instances a chimney-like airflow pattern is produced. Air which is heated and rises above the low foothills may move back toward the east above the temperature inversion over the valley. This upward motion of air above the higher terrain where the temperature inversion has been eliminated induces a movement of air coming first southward and then westward from the downtown area of Denver. Before it reaches the mountainous terrain, vertical mixing often has destroyed the temperature inversion and the upper edge of the polluted layer becomes quite diffuse.

The frequency with which the western edge of polluted layer reaches Rocky Flats is less than one-third of the days when relatively dense pollution can be noted in the downtown area of Denver. Likewise, there are very few instances when the polluted layer envlopes Buckley ANGB.

SEVERE WINDS

The occurrence of very strong winds at the Rocky Flats location is repeatable for many hours year after year. A special study has been made of all hours $\geq$ 10 mph at both Denver and Rocky Flats for the year 1973. In this instance the wind speeds which are reported in knots at Denver were adjusted to miles per hour to be directly comparable to the data at Rocky Flats. Also, the Denver Airport data were grouped into the same eight directions used at Rocky Flats. The results of this summary appear in Table III. This shows a total of 329 hours when winds were $\geq$ 20 mph at Denver Airport. There were 522 hours of such high winds at Rocky Flats.

At Denver Airport the highest octant of direction is from the north with the second highest from northwest. At Rocky Flats the highest octant is from the west with 246 hours and the second highest is northwest with 168 hours. Both of these direction frequencies at Rocky Flats are higher than the peak direction from the north at Denver.

When wind speeds are $\geq$ 30 mph soil particles can be picked up and moved for several miles. Lighter particles could move for hundreds of miles. The heavier particles would fall back to earth within distances of a few hundred feet to a few miles as permitted by the variations in the associated gustiness of the winds.

The time of day for strong wind occurrences is not the same at the two locations. The respective frequencies by hour of the day are shown in Fig. 17. There is a minor afternoon peak shown at Rocky Flats above the general level near 20 instances for each hour. The higher number of

TABLE III. FREQUENCY OF HOURS OF WINDS EQUAL TO OR GREATER THAN 20 MPH WITHIN EIGHT OCTANTS OF WIND DIRECTION FOR THE DENVER AIRPORT AND ROCKY FLATS, BASED ON 1973 DATA.

Month	N	NE	E	SE	S	SW	W	NW	Totals
				DENVER AIRPORT					
Jan.	24	1							25
Feb.									0
Mar.	20	7	1	2	5			8	43
Apr.	14	1			4	5	5	6	35
May	21						3	3	27
June	1			3	4		2	3	13
July	6			1	10		4		21
Aug.			1	1	11	2	1		16
Sept.	8	6			5	3	1	6	29
Oct.	9				1	2	4	20	36
Nov.	4	1					13	2	20
Dec.	40	1			4		5	14	64
Totals	147	17	2	7	44	12	38	62	329
				ROCKY FLATS					
Jan.	7						27	22	56
Feb.						1	2	2	5
Mar.	8	3					2	15	28
Apr.	5						16	18	39
May	10					1	14	3	28
June						10	27	6	43
July							5	2	7
Aug.	2		5	1	8		19	1	36
Sept.	4						10	3	17
Oct.	2	4				2	25	19	52
Nov.	1	1			1	2	34	28	67
Dec.	20					10	65	49	144
Totals	59	8	5	1	9	26	246	168	522

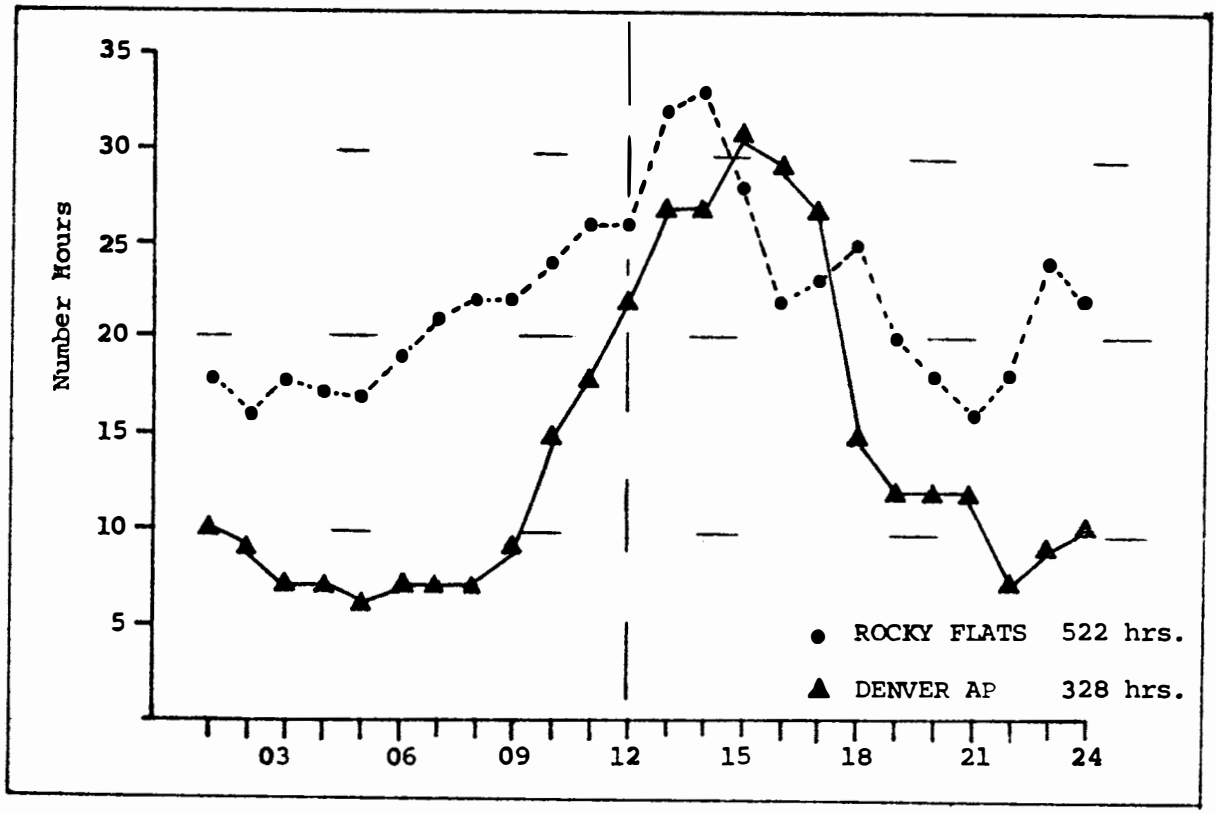


Figure 17. Comparative hourly frequency of wind speeds ≥20 mph at Rocky Flats and Denver Airport during 1973.

nighttime hours with strong winds at Rocky Flats than at Denver Airport is related to the higher frequency of "synoptic" type airflow.

At Denver Airport there are 10 hours or less per year with winds $\geq$ 20 mph between 2200 through 0900. By contrast there are more than 25 hours equal to or greater than 20 mph from 1300 through 1700. Several of the higher wind speeds at Denver Airport occur during summer thunderstorms which have a higher frequency at Denver than at Rocky Flats.

WIND FREQUENCY IN STABILITY CATEGORIES

Until such time as temperature profile measurements and wind gradient data through the lower 200 feet become available from the meteorological tower planned at Rocky Flats, estimates of stability conditions can be made using (1) time of day, (2) wind speed and direction, and (3) relationships with known stability sequences in the Denver metropolitan area. The estimates which are made in this report are based on such airflow characteristics.

A compilation showing wind distribution by Pasquill stability classes using the STAR Program originally designed by meteorologists working for the Environmental Protection Agency has been obtained for a five year record at Denver Airport. This compilation appears in arrays of 16 wind directions and six stability categories. For purposes of preliminary estimation in the analysis reported herein, only three categories were used for stability - STABLE, NEUTRAL and UNSTABLE. The 36 directions of wind records at Denver Airport were consolidated to 16 values and the eight directions initially available at Rocky Flats were expanded to cover 16 directions. The frequencies of winds in each stability group were developed from hourly wind and temperature records.

Tables IV and V show the estimated distribution of winds within each stability class at Denver and Rocky Flats. It is recommended that these data be used jointly in determining long term depositions of any effluent coming from Rocky Flats. The graphical presentation of the percentages in each of the three categories is presented in Figure 18.

TABLE IV. PERCENTAGE FREQUENCY OF WIND DIRECTION IN VELOCITY CLASSES FOR AIRFLOW BETWEEN THE SURFACE AND 200 METERS IN THE VICINITY OF STAPLETON INTERNATIONAL AIRPORT AT DENVER, COLORADO, BASED ON HOURLY AIRFLOW DATA 1972-74.

	STABLE (E+F) (meters/sec.)						NEUTRAL (D)						UNSTABLE (A+B+C)					
	1-2	3-4	5-6	7-8	≥9	Total	1-2	3-4	5-6	7-8	≥9	Total	1-2	3-4	5-6	7-8	≥9	Total
N	.1	.2	.1			.4	.1	1.2	2.9	2.4	.3	6.9		.3	.4	.1		.8
NNE		.1	.1			.2	.1	1.6	2.5	1.6	.2	6.0		.3	.4	.2		.9
NE	.1	.1				.2	.1	1.1	1.8	.6	.2	3.8		.4	.4	.2		1.0
ENE	.1	.2	.1			.4	.2	1.3	1.4	.5		3.4	.1	.5	.4	.2		1.2
E	.1	.2	.2			.5	.1	.8	1.4	.7		3.0	.1	.6	.6	.2		1.5
ESE	.1	.3	.2			.6		.5	1.1	1.0		2.6		.5	.4	.1		1.0
SE	.2	.5	.3			1.0		.3	.7	.4		1.4		.4	.3	.1		.8
SSE	1.0	2.2	1.4			4.6		.3	1.0	.7		2.0		.2	.2			.4
S	1.5	3.2	2.6			7.3		.3	1.3	1.2	.2	3.0		.1	.2			.3
SSW	2.5	6.0	3.3	.2		12.0	.1	.4	1.4	1.4	.1	3.4		.1	.1			.2
SW	1.2	3.1	1.6	.1		6.0		.2	1.1	.7		2.0		.1				.1
WSW	.4	2.0	.8			3.2		.2	1.0	.6		1.8		.1				.1
W	.2	.5	.3			1.0		.6	1.0	.7	.1	2.4		.1	.1			.2
WNW	.1	.2	.1			.4		.7	1.4	1.1	.3	3.5		.1	.1			.2
NW		.2	.1			.3		.8	1.6	1.2	.4	4.0		.2	.1			.3
NNW		.2	.1			.3		1.0	1.2	.6		2.8		.2	.3	.1		.6
	7.5	19.2	11.4	.3		38.4%	.7	11.3	22.8	15.4	1.8	52.0%	.2	4.2	4.0	1.2		9.6%
Average wind velocity						3.7 m/s						5.8 m/s						4.8 m/s
Average mixing depth												2400 meters						2400 meters

TABLE V. PERCENTAGE FREQUENCY OF WIND DIRECTION IN VELOCITY BY STABILITY CLASSES FOR AIRFLOW BETWEEN THE SURFACE AND 200 METERS IN THE VICINITY OF ROCKY FLATS, BASED ON HOURLY AIRFLOW DATA 1972-74.

	STABLE (E+F) (meters/sec.)						NEUTRAL (D)						UNSTABLE (A+B+C)					
	1-2	3-4	5-6	7-8	≥9	Total	1-2	3-4	5-6	7-8	≥9	Total	1-2	3-4	5-6	7-8	≥9	Total
N	.2	.3	.3	.2		1.0	.1	1.0	1.6	1.7	1.0	5.4		.1	.1			.2
NNE		.2	.2	.2		.6	.1	.9	1.5	1.6	.9	5.0		.1	.2	.1		.4
NE		.1	.1	.1		.3	.1	.8	1.4	1.5	.8	4.6	.1	.7	.6	.2		1.6
ENE			.1			.1	.2	.6	1.0	.2		2.0	.1	.6	.4	.2		1.3
E			.05			.05	.1	.3	.3			0.7	.1	.5	.4	.2		1.2
ESE			.05			.05	.1	.3	.4	.2		1.0	.1	.8	.9	.2		2.0
SE		.1	.1			.2	.2	.9	1.3	.8		3.2	.1	.7	.9	.3	.2	2.2
SSE	.1	.1	.2	.1		.5	.1	.7	1.1	.5		2.4		.5	.4	.1		1.0
S	.1	.1	.3	.1		.6	.1	.6	1.0	.4		2.1		.1				.1
SSW	.1	.2	.3	.1		.7		.4	1.0	.5	.2	2.1		.1				.1
SW	1.0	2.0	1.5	.4		4.9		.4	1.0	.4	.2	2.0						
WSW	1,2	2.4	1.9	.5		6.0		.2	1.0	.4	.6	2.2		.1				.1
W	1.2	2.5	2.0	.5		6.2		.4	1.4	1.2	1.4	4.4		.1				.1
WNW	1.4	2.8	2.2	.6		7.0		.8	2.4	1.2	1.6	6.0		.1				.1
NW	1.0	2.1	1.5	.4		5.0		.8	2.2	.9	1.1	5.0		.1	.1			.2
NNW	.6	1.2	1.0	.2		3.0		.8	2.2	.9	1.0	4.9		.1	.1			.2
	6.9	14.1	11.8	3.4		36.2%	1.1	9.9	20.8	12.4	8.8	53.0%	.5	4.7	4.2	1.3	.2	10.8%
	Average wind velocity					4.2 m/s						6.6 m/s						4.9 m/s
	Average mixing depth					450 meters						3200 meters						3200 meters

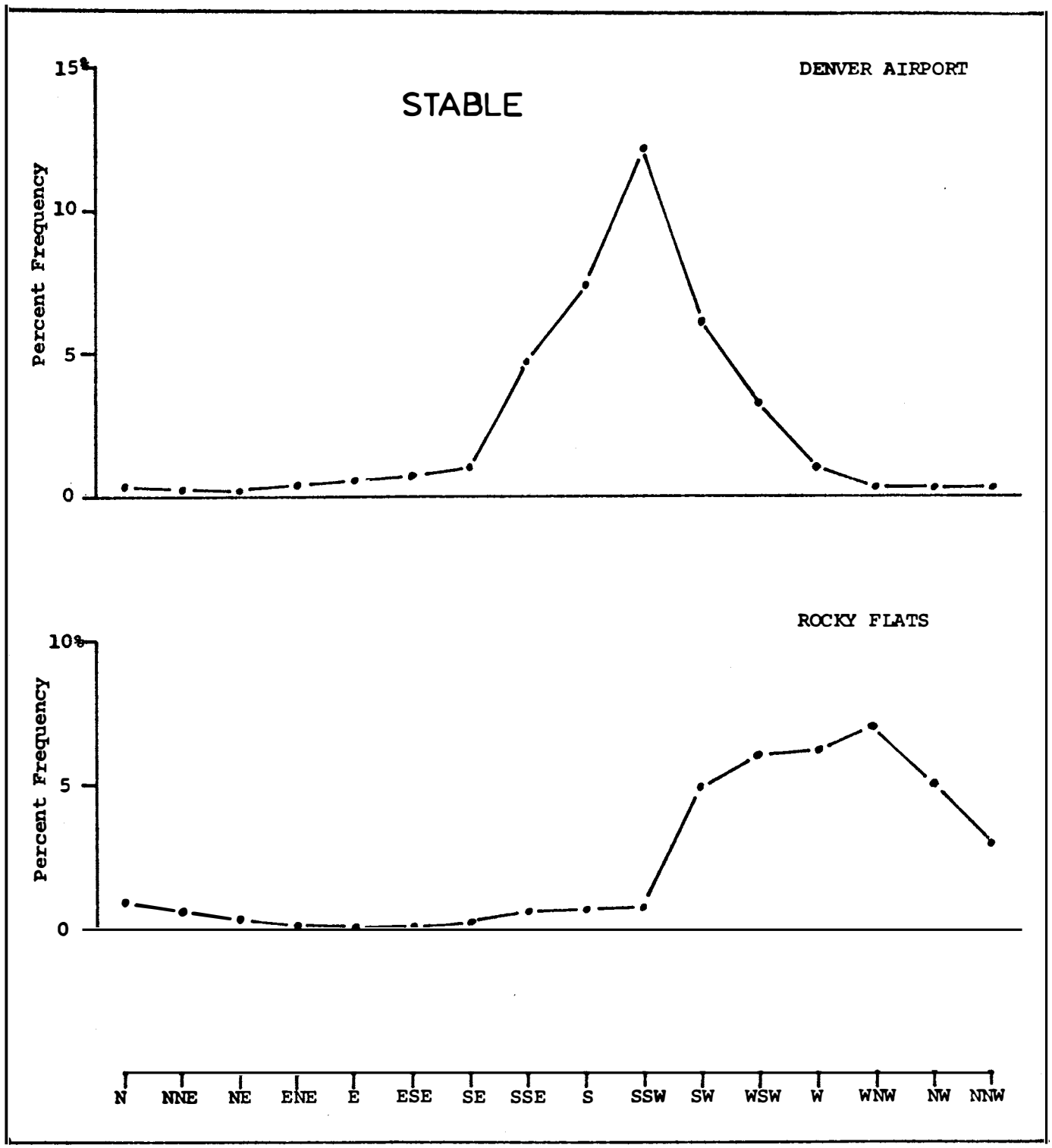
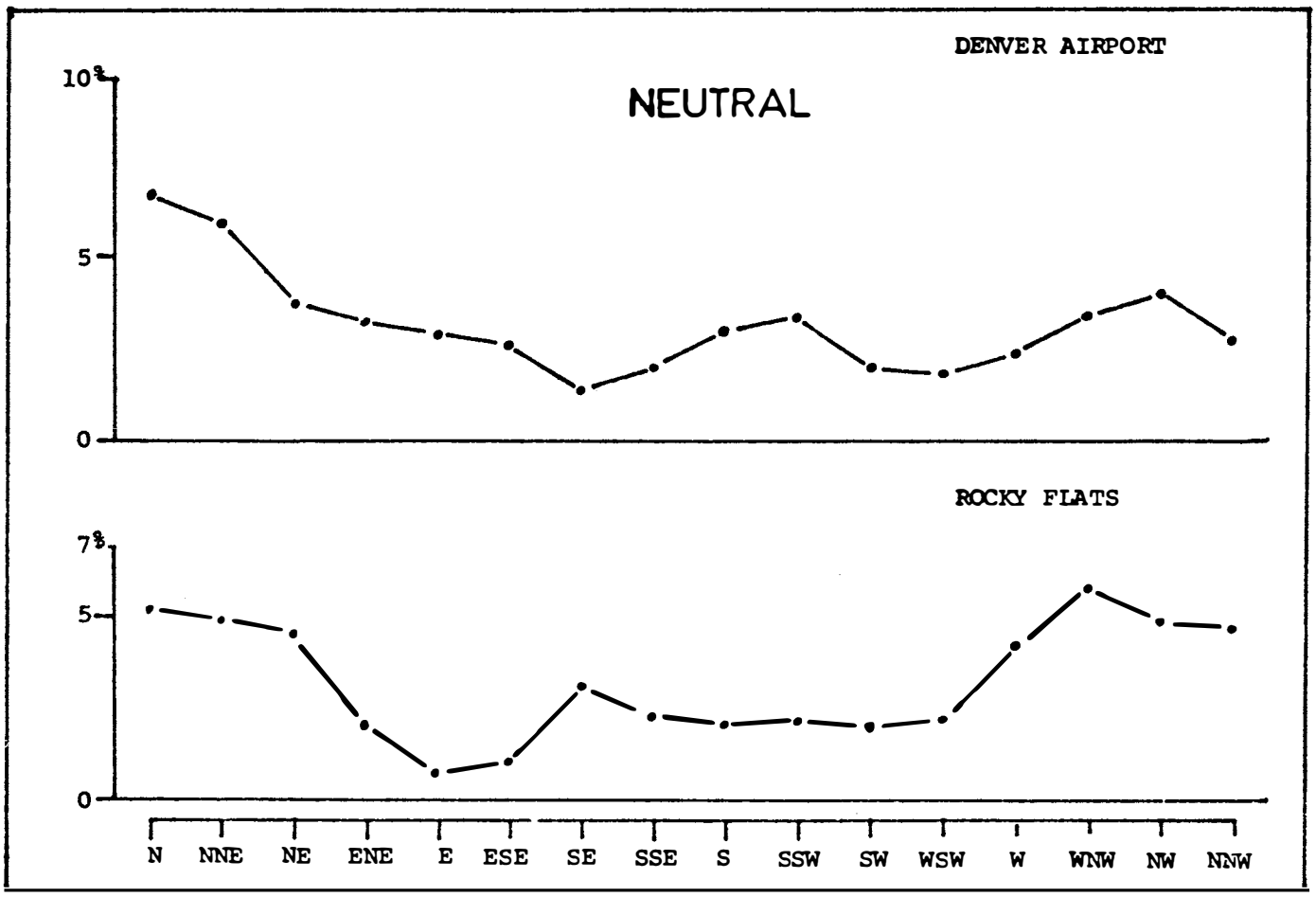


Figure 18. Estimates of annual frequency of wind direction under STABLE conditions at Denver Airport and Rocky Flats.



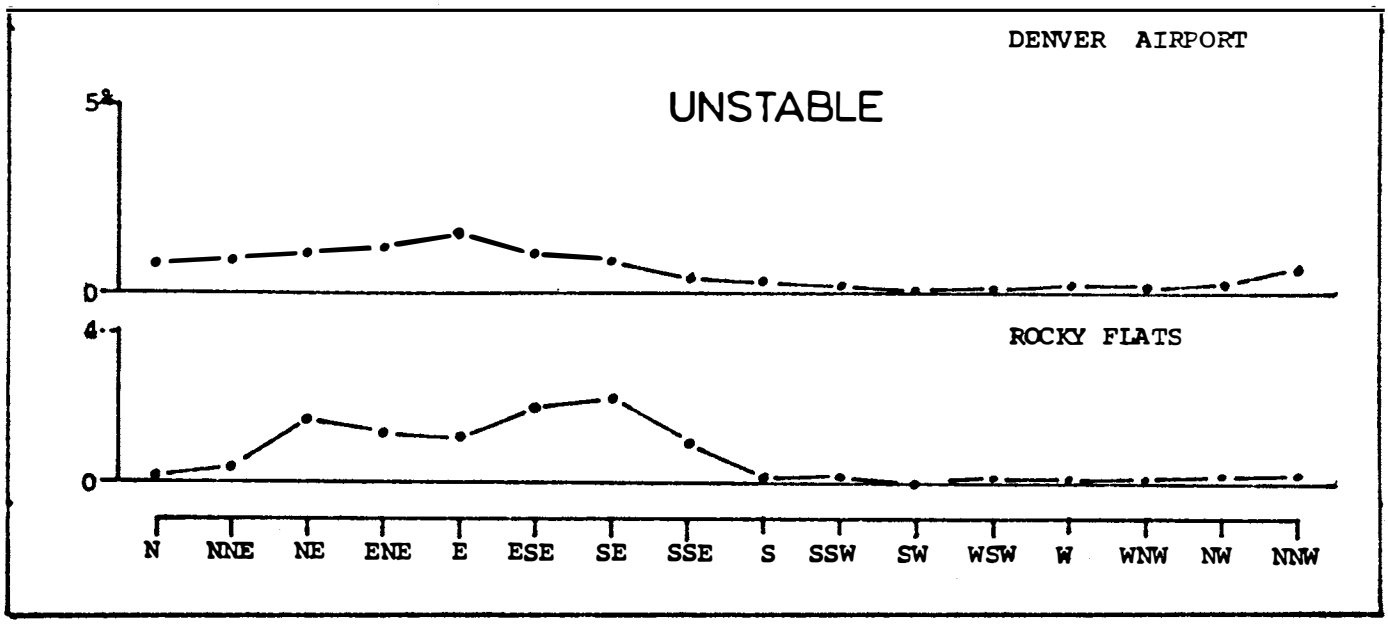


Figure 18 continued. Estimates of annual frequency of wind directions under NEUTRAL and UNSTABLE conditions at Denver Airport and Rocky Flats.

Under STABLE conditions there is a notable difference in airflow between Denver Airport and Rocky Flats. There is a prominent peak frequency of airflow from south-southwest at Denver. By contrast, the range of wind direction under STABLE conditions at Rocky Flats carries a broad level of nearly equal frequency from southwest through northwest. In most instances the STABLE air temperature near the ground above the lower portions of the Platte River Valley near the north end of Denver is colder during the morning hours than at Rocky Flats. STABLE but relatively warmer air moving past Rocky Flats would establish its own equivalent level of buoyancy and move toward the Platte River at a higher elevation than the colder air near the surface in the Denver metropolitan area. In other instances NEUTRAL stability conditions with corresponding rapid dispersal of effluents will prevail at Rocky Flats while colder STABLE air and its collected burden of pollutants will remain near the ground to the north of Denver. Under such circumstances there would be no mixing downward of effluents from Rocky Flats into the STABLE air below.

Under NEUTRAL and UNSTABLE conditions the frequency distribution of directions is somewhat similar at both locations. However, Rocky Flats has a greater frequency of UNSTABLE air motion ranging from the northeast through south-southeast directions. The relatively low frequency of UNSTABLE conditions with corresponding rapid vertical mixing should limit any surface deposition of material emanating from Rocky Flats to the first one to three miles from the source toward higher ground to the west of the plant.

Correction and improvement in these sets of estimated data should be expected when more reliable stability data become available.

REFERENCES

1. Boss, M.R., F. D. Hobbs, R. W. Loser, D. E. Michels, "Annual Environmental Monitoring Report Rocky Flats Plant", January through December 1972, Prepared under Contract AT(29-1)-1106 for the Albuquerque Operations Office, U. S. Atomic Energy Commission, 1973.

2. Riehl, H., L. W. Crow, "A Study of Denver Air Pollution", Technical Paper No. 33, Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado, 1962.

3. Djordjevic, N., W. Ehrman, G. Swanson, E. R. Reiter, "Further Studies of Denver Air Pollution", Atmospheric Science Paper No. 105, Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado, 1966.

4. Crow, L. W., "Airflow Related to Air Pollution at Colorado Springs, Denver, Durango, Grand Junction, and Pueblo", prepared for State Department of Public Health, State of Colorado, January 10, 1964.

5. "Air Pollution in the Denver Area", edited by L. W. Crow, published by Public Service Company of Colorado, 1967.

6. Crow, L. W., "Airflow Study Related to EPA Field Monitoring Program Denver Metropolitan Area, November, 1973", prepared for Chemistry and Physics Laboratory of Environmental Protection Agency, Feb. 1974.

APPENDIX A

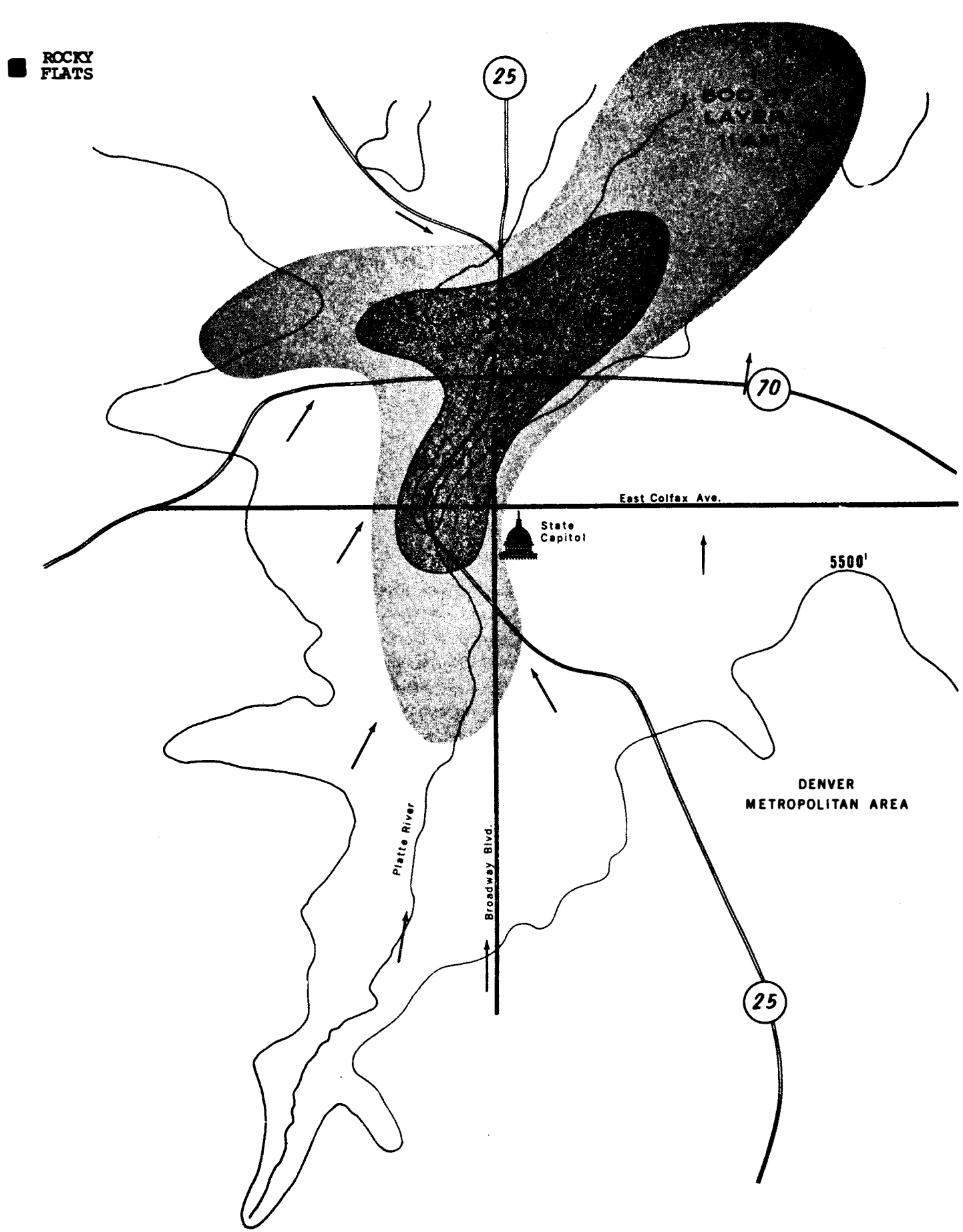
Duplication of material presented in the booklet "Air Pollution in the Denver Area" published in 1967 by Public Service Company of Colorado as an information booklet with text and diagram material furnished by consulting meteorologist, Loren W. Crow.

Where Does It Accumulate?

All daytime employees in the Denver Metropolitan area have many opportunities to observe some visible portion of this community's air pollution as they drive to work. At that time of day the most dense portion is located near and slightly north of the center of the city.

Most of the air pollution visible at 8:00 a.m. moved very slowly "down-slope" from other higher parts of the urban area during the hours of darkness. Some of this pollution may have been generated the previous day while the air motion was "up slope" from the valley floor toward higher ground. During the night it returned to its favorite early morning collection basin.

Each forenoon the supply of new pollution increases, and the temperatures near the ground become warmer. When wind velocities remain near calm, the layer of dense air pollution grows in both vertical and horizontal dimension. By 11:00 a.m. the layer may cover nearly half the urban area to a depth of 500 to 600 feet. This area is still closely related to low elevations along the Platte River and Clear Creek valleys.


ROCKY FLATS
25
70
East Colfax Ave.
State Capitol
5500'
DENVER METROPOLITAN AREA
Platte River
Broadway Blvd.
25

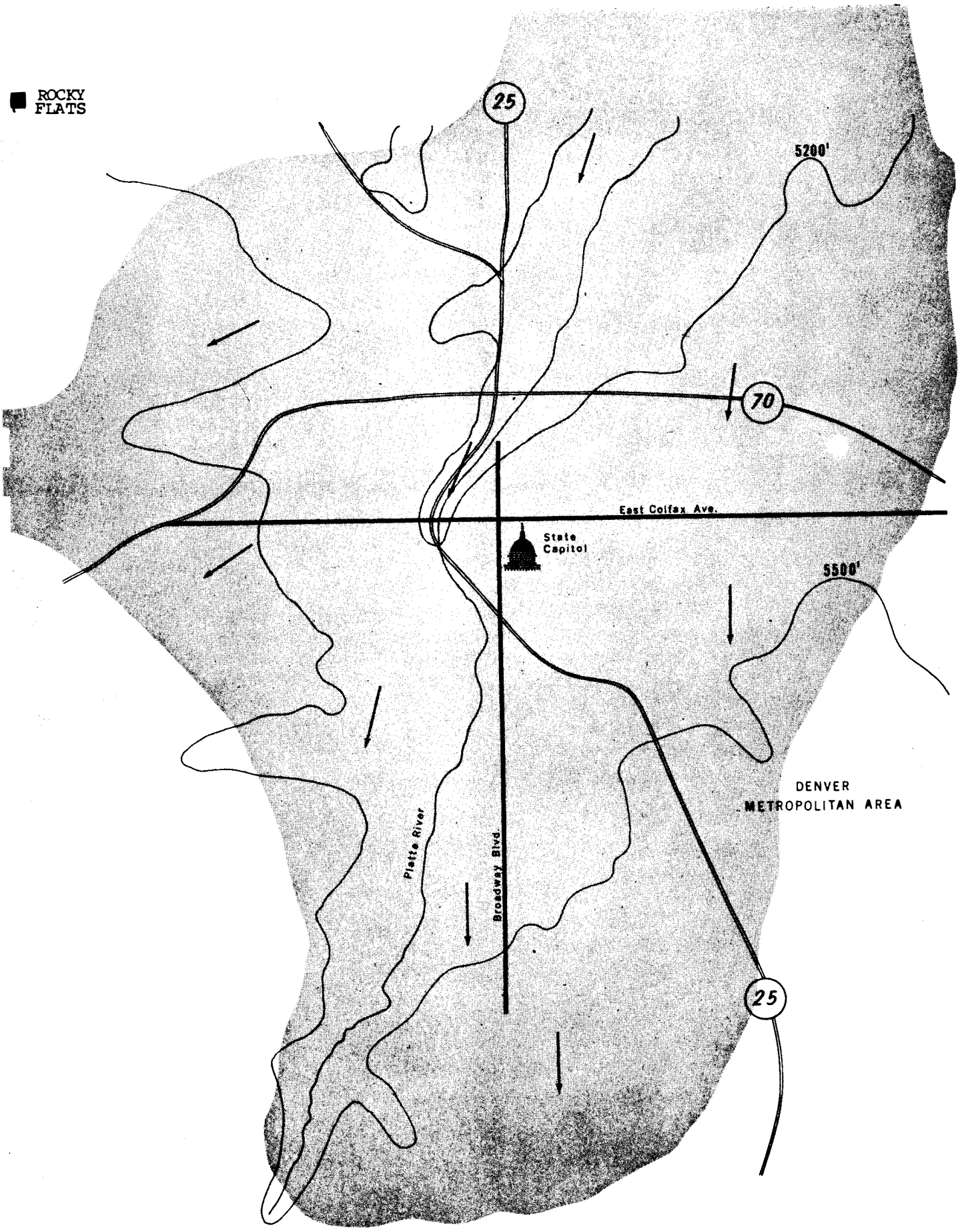
To Where Does It Spread?

During weather periods which permit near calm winds and heavy burdens of air pollution the air flow over Denver is largely controlled by its surrounding terrain. Surface cooling at night establishes down-slope motion toward Adams City. During the warmer part of the day a reversal takes place and the air motion is primarily from the lower parts of the city toward higher areas. Flags which indicated winds from the south-southwest at 6:00 a.m. will show that the air is moving from the north-northeast at 2:00 p.m.

This "back and forth" reversal of air flow tends to permit a passage of the same polluted air more than once across the Denver Metropolitan area.

By late afternoon the top of the polluted layer may be 1,000 to 1,200 feet above the valley floor and the outer edges may now have moved beyond the south, east, and western boundaries of the built-up urban area. The amount of pollution per unit volume is low at this time of day because it has been mixed with so much additional air.

The dense pollution of early forenoon is contained in only three to five cubic miles of air by late afternoon a somewhat heavier burden of pollution is mixed into 20 to 40 cubic miles of air.


ROCKY FLATS
25
5200'
70
East Colfax Ave.
State Capitol
5500'
DENVER METROPOLITAN AREA
Platte River
Broadway Blvd.
25

APPENDIX B-2

DIFFUSION ESTIMATES

Estimates of site dispersion parameters for the Rocky Flats Plant have been made from site meteorological data as presented in Section 2.3.6 of this Statement. No attempt has been made to modify calculated values by possible terrain effects or macro-meteorological effects at long distances from the site because quantification of such effects is extremely uncertain and is not significant within the accuracy of this type of calculation.

The discussion that follows presents the methodology, assumptions, and results of the diffusion estimates. Additional information relating to site-specific meteorology is contained in Appendix B-1 and in Section 2.3.6 of this Environmental Impact Statement.

Short-Term (or Instantaneous) Relative Concentrations (χ/Q)

The relative concentration of pollutants (χ/Q) (from a unit concentration release) downwind from an emitting source can be computed from the Gaussian form of solution to the diffusion equations. The symbol, χ, represents the concentration (usually in microcuries per cubic meter) and Q represents the source emission rate (usually in microcuries per second). The Gaussian distribution yields a peak value along the centerline of the emitted plume with the values falling off exponentially in both directions normal to the wind direction. The plume centerline concentration at ground level is given by

$$\frac{\chi}{Q} = \frac{1}{\pi \sigma_y \sigma_z \bar{u}} \exp\left[-\frac{1}{2}\left(\frac{h_s + h_p - h_g}{\sigma_z} \right)^2 \right] \frac{\text{sec}}{\text{m}^3}$$

(derived from Slade, 1968), where h_s is the stack height above terrain at the point of release, h_p is the plume rise, h_g is the height of the downwind terrain above the stack base, $\bar{u}$ is the mean wind speed between plume and ground, and σ_y and σ_z are the Gaussian distribution parameters (plume standard deviations) in the horizontal and vertical directions normal to the mean wind direction. The parameters σ_y and σ_z are functions of downwind distance from the source so that the above dispersion equation is implicitly a function of downwind distance. The values of σ_y and σ_z are obtained by the method of McMullen (McMullen, 1975). According to this method,

$$\sigma = \exp[I + J\ (\ln x) + K\ (\ln x)^2]$$

where σ is the standard deviation of the concentration in the horizontal (σ_y) or in the vertical (σ_z) directions in units of meters; ln x is the natural log of the downwind distance expressed in kilometers; and I, J, and K are empirical constants for a given stability condition, for each type of σ.

Values of I, J, and K are given in Tables B-2-1 and B-2-2 for σ_y and σ_z, respectively. The method of McMullen avoids the variability which can be expected from visual readings of the Pasquill curves and is used to obtain σ values in this impact statement.

Table B-2-1
Values of the Constants I, J, and K,
for σ_y as a function of downwind distance,
for six Pasquill Stability Classes

Stability Class	I	J	K
A	5.357	0.8828	-0.0076
B	5.058	0.9024	-0.0096
C	4.651	0.9181	-0.0076
D	4.230	0.9222	-0.0087
E	3.922	0.9222	-0.0064
F	3.533	0.9181	-0.0070

Table B-2-2
Values of the Constants I, J, and K,
for σ_z as a function of downwind distance,
for six Pasquill Stability Classes

Stability Class	I	J	K
A	6.035	2.1097	0.2770
B	4.694	1.0629	0.0136
C	4.110	0.9201	-0.0020
D	3.414	0.7371	-0.0316
E	3.057	0.6794	-0.0450
F	2.621	0.6564	-0.0540

If the mean wind speed and stability condition during any time period are known, the maximum average relative concentration during that time period for any distance downwind from the source may be calculated.

For the evaluation of short-term release of airborne effluent from the Rocky Flats Plant, the following conservative assumptions were made:

1. Ground-level release from a point source ($h_s = 0$, $h_p = 0$).
2. No depletion of the airborne effluent by washout, settling, or surface deposition.
3. No significant terrain changes near the Plant site ($h_g = 0$)
4. Plume-centerline, relative concentrations are determined.
5. Average diffusion conditions, Pasquill Category E, wind speed of 3.0 meters per second.
6. No credit for building wake dilution.
7. Relative concentrations weighted by the frequency of wind in each sector.

The resulting equation for relative concentration is

$$\frac{\chi}{Q} = \frac{1}{\pi \sigma_y \sigma_z \bar{u}}$$

Table B-2-3 gives the calculated, short-term relative concentrations as a function of distance, unweighted by sector frequencies. The maximum site-boundary χ/Q is 3.52×10^{-5} seconds per cubic meter. Table B-2-4 gives relative concentrations as a function of distance, weighted by the frequency with which the wind blows from each direction. These relative concentrations are used to determine the dispersion of airborne radioactive effluents from accidental Plant releases.

TABLE B-2-3

CALCULATED SHORT-TERM RELATIVE CONCENTRATIONS (χ/Q)
(Pasquill E, 3.0 m/sec)

Distance (miles)	χ/Q (sec/m^3)
1.2	3.52E-5*
2.0	1.63E-5
3.0	9.02E-6
4.0	5.98E-6
5.0	4.38E-6
10.0	1.72E-6
20.0	7.06E-7
30.0	4.30E-7
40.0	3.06E-7

*3.52E-5 = 3.52×10^{-5}

TABLE B-2-4

CALCULATED SHORT-TERM RELATIVE CONCENTRATIONS (χ/Q, sec/m^3)

(Sector Frequency Weighted) (Pasquill E, 3.0 m/sec)

Wind Source (sector)	Affected Sector	Average Annual Frequency	2 miles	3 miles	4 miles	5 miles	10 miles	20 miles	30 miles	40 miles
			1.63E-5*	9.02E-6	5.98E-6	4.38E-6	1.72E-6	7.06E-7	4.30E-7	3.06E-7
N	S	0.066	1.08E-6	5.95E-7	3.95E-7	2.89E-7	1.13E-7	4.66E-8	2.84E-8	2.02E-8
NNE	SSW	0.060	9.78E-7	5.41E-7	3.59E-7	2.63E-7	1.03E-7	4.24E-8	2.58E-8	1.83E-8
NE	SW	0.065	1.06E-6	5.86E-7	3.89E-7	2.85E-7	1.12E-7	4.59E-8	2.80E-8	1.99E-8
ENE	WSW	0.034	5.54E-7	3.07E-7	2.03E-7	1.49E-7	5.83E-8	2.40E-8	1.46E-8	1.04E-8
E	W	0.019	3.18E-7	1.76E-7	1.17E-7	8.54E-8	3.35E-8	1.38E-8	8.39E-9	5.96E-9
ESE	WNW	0.030	4.97E-7	2.75E-7	1.82E-7	1.34E-7	5.23E-8	2.15E-8	1.31E-8	9.32E-9
SE	NW	0.056	9.13E-7	5.05E-7	3.35E-7	2.45E-7	9.61E-8	3.96E-8	2.41E-8	1.71E-8
SSE	NNW	0.039	6.36E-7	3.52E-7	2.33E-7	1.71E-7	6.69E-8	2.76E-8	1.68E-8	1.19E-8
S	N	0.028	4.56E-7	2.52E-7	1.68E-7	1.23E-7	4.80E-8	1.98E-8	1.20E-8	8.56E-9
SSW	NNE	0.029	4.73E-7	2.61E-7	1.74E-7	1.27E-7	4.98E-8	2.05E-8	1.25E-8	8.86E-9
SW	NE	0.069	1.12E-6	6.22E-7	4.13E-7	3.02E-7	1.18E-7	4.87E-8	2.97E-8	2.11E-8
WSW	ENE	0.083	1.35E-6	7.48E-7	4.97E-7	3.63E-7	1.42E-7	5.86E-8	3.57E-8	2.54E-8
W	E	0.107	1.74E-6	9.65E-7	6.40E-7	4.69E-7	1.84E-7	7.56E-8	4.60E-8	3.27E-8
WNW	ESE	0.131	2.14E-6	1.18E-6	7.84E-7	5.74E-7	2.25E-7	9.25E-8	5.63E-8	4.00E-8
NW	SE	0.102	1.66E-6	9.20E-7	6.10E-7	4.47E-7	1.75E-7	7.21E-8	4.39E-8	3.12E-8
NNW	SSE	0.081	1.32E-6	7.30E-7	4.85E-7	3.55E-7	1.39E-7	5.72E-8	3.48E-8	2.48E-8
		1.000								

*The numbers in this horizontal row are multiplied by the frequency to obtain χ/Q.

1.63E-5 = 1.63×10^{-5}

Annual Average Relative Concentrations (χ/Q)

For annual average concentrations, a sector-averaged form of the diffusion equation is used. Averaging over a 22.5-degree sector eliminates the σ_y (horizontal dispersion term). The coefficient preceding the exponential term is replaced by $2.032/\sigma_z \bar{u} x$, where x is the downwind distance in meters (Slade, 1968).

For the evaluation of annual average releases of airborne effluents from the Rocky Flats Plant, the following conservative assumptions were made:

1. Ground level release from a point source ($h_s = 0$, $h_p = 0$).
2. No depletion of the airborne effluent due to washout, settling, or surface deposition.
3. No significant terrain changes near the Plant site ($h_g = 0$).
4. Wind direction averaged across individual sector for frequency of time wind is in that sector.
5. Values of χ/Q, calculated for each stability class, are combined as a weighted average, based on the frequency distribution of stability classes for each sector as determined from site data (Table 2.4-11 of Section 2.4.5).
6. No credit for building wake dilution.
7. Relative concentrations weighted by the frequency the wind blows in each direction.

The resulting equation for relative concentration is

$$\frac{\chi}{Q} = \frac{2.032}{\sigma_z \bar{u} x}$$

Table B-2-5 gives the calculated annual average concentrations as a function of distance, weighted by the frequency that the wind blows from that direction, and frequency of each stability class. The maximum sector χ/Q is 5.04×10^{-7} seconds per cubic meter in the east-southeast sector (west-northwest wind source) at two miles. These relative concentrations are used to determine the dispersion of airborne radioactive effluents from routine Plant releases.

TABLE B-2-5

CALCULATED ANNUAL AVERAGE RELATIVE CONCENTRATIONS (χ/Q, sec/m^3)

(Averaged Over Wind Direction and Plume Stability Class)

Wind Source (sector)	Affected Sector	Average Annual Frequency	2 miles	3 miles	4 miles	5 miles	10 miles	20 miles	30 miles	40 miles
N	S	0.066	1.47E-7*	7.65E-8	4.86E-8	3.44E-8	1.20E-8	4.40E-9	2.49E-9	1.68E-9
NNE	SSW	0.060	1.07E-7	5.53E-8	3.49E-8	2.45E-8	8.39E-9	2.99E-9	1.66E-9	1.11E-9
NE	SW	0.065	9.52E-8	4.85E-9	3.03E-8	2.12E-8	7.08E-9	2.46E-9	1.35E-9	8.91E-10
ENE	WSW	0.034	5.64E-8	2.85E-8	1.78E-8	1.23E-8	4.07E-9	1.40E-9	7.58E-10	4.96E-10
E	W	0.019	2.61E-8	1.30E-8	8.04E-9	5.55E-9	1.80E-9	6.07E-10	3.28E-10	2.13E-10
ESE	WNW	0.030	3.33E-8	1.65E-8	1.01E-8	6.98E-9	2.23E-9	7.46E-10	4.00E-10	2.59E-10
SE	NW	0.056	8.46E-8	4.29E-8	2.68E-8	1.86E-8	6.19E-9	2.14E-9	1.17E-9	7.69E-10
SSE	NNW	0.039	7.99E-8	4.13E-8	2.61E-8	1.84E-8	6.35E-9	2.30E-9	1.29E-9	8.71E-10
S	N	0.028	7.43E-8	3.88E-8	2.47E-8	1.75E-8	6.12E-9	2.25E-9	1.28E-9	8.63E-10
SSW	NNE	0.029	7.15E-8	3.75E-8	2.39E-8	1.70E-8	6.02E-9	2.24E-9	1.28E-9	8.71E-10
SW	NE	0.069	3.25E-7	1.74E-7	1.13E-7	8.12E-8	3.00E-8	1.17E-8	6.88E-9	4.79E-9
WSW	ENE	0.083	3.87E-7	2.07E-7	1.34E-7	9.67E-8	3.58E-8	1.40E-8	8.24E-9	5.73E-9
W	E	0.107	4.25E-7	2.27E-7	1.47E-7	1.06E-7	3.89E-8	1.51E-8	8.84E-9	6.14E-9
WNW	ESE	0.131	5.04E-7	2.69E-7	1.74E-7	1.25E-7	4.58E-8	1.77E-8	1.03E-8	7.17E-9
NW	SE	0.102	3.77E-7	2.01E-7	1.30E-7	9.29E-8	3.40E-8	1.31E-8	7.64E-9	5.29E-9
NNW	SSE	0.081	2.57E-7	1.36E-7	8.75E-8	6.25E-8	2.26E-8	8.62E-9	5.00E-9	3.44E-9
		1.000								

*1.47E-7 = 1.47×10^{-7}

REFERENCES

McMullen, R. W. "The Change of Concentration Standard Deviations with Distance." Journal of the Air Pollution Control Association, Vol. 25, No. 10, p. 1057, October, 1975.

Slade, D. H. Meteorology and Atomic Energy, 1968. U.S. Atomic Energy Commission, Division of Technical Information. July, 1968.

APPENDIX C
GEOLOGY AND SEISMOLOGY

This appendix contains three reports relating to geology and seismology. The first, Appendix C-1, is entitled "Summary of Non-Nuclear Remote Sensing at the Rocky Flats Site and Status of Analysis of Geological and Hydrological Indicators -- July 1975 through December 1975." This report was prepared by J. G. Lackey, E. B. Jones, and H. A. Wollenberg who are associated with EG&G, Inc. of Las Vegas, Nevada.

Appendix C-2, "Rocky Flats Reflection Seismic Project," was submitted by T. L. Davis from the Department of Geophysics, Colorado School of Mines, in Golden, Colorado.

The third report, Appendix C-3, is a "Soil Survey" from the Soil Conservation Service of the U. S. Department of Agriculture.

ASD-76-001
6 January 1976

TECHNICAL MEMORANDUM

Subject: Summary of Non-nuclear Remote Sensing at the Rocky Flats Site and Status of Analysis of Geological and Hydrological Indicators - July 1975 through December 1975

By: J. G. Lackey, E. Bruce Jones*, and H. A. Wollenberg**

1. GENERAL CONSIDERATIONS

1.1 Overview of the Program

During the interval of July 1975 through December 1975, EG&G and associated personnel were engaged in an ongoing program to do non-nuclear remote sensing of the ERDA Rocky Flats Site. This program is carried out with the cooperation and support of Rocky Flats personnel. Appropriate ground truth data to support and calibrate the remotely sensed data were also acquired during this interval.

This program was carried out for the purpose of assisting the Division of Operational Safety (DOS) of the Energy Research and Development Administration (ERDA) in carrying out its responsibilities. DOS has the responsibility to ensure that all ERDA programs and operations are conducted in a manner that will protect the public, ensure occupational safety and health, and preserve the environment in accordance with nationally accepted norms.

During this period of activity, EG&G personnel acquired a considerable catalog of remotely sensed data in the form of photographic and thermal infrared imagery. EG&G and associated personnel subsequently interpreted some possible geological and hydrological features of the site which were visually discernible on the photograph and infrared imagery.

Field investigation was carried out in cooperation with Rocky Flats personnel and personnel from the U. S. Geological Survey office in Denver for the purpose of verifying the geological and hydrological features and planning additional investigations necessary to resolve uncertainties by physical measurement.

---

*E. Bruce Jones, M. W. Bittinger & Associates, is retained as a consultant to EG&G.

**H. A. Wollenberg, Lawrence Berkeley Laboratory, is retained as a consultant to EG&G.

EG&G

A geological element of primary interest was the possible existence of a fault or shear zone on or near the site. The remotely sensed imagery is compatible with the interpretation that a fault or shear zone crossing the Rocky Flats Site may exist. Certain geological features visually observable on the ground are also compatible with this possibility. To test this hypotheses, the Colorado School of Mines was engaged to conduct seismic reflection surveys. These studies (Davis,10 and 29 December 1975) indicate little likelihood of appreciable vertical dislocation of lineaments in the eastern portion of the site.

The primary elements of hydrologic interest were seeps, springs, and general water-balance information for the immediate plant site and surrounding area. Various seeps and springs were noted on photographic and thermal infrared imagery along the three basic drainages flowing through the plant site. It appears that there is some concentration of springs and seeps in the vicinity of the plant. With the presently available information, it is impossible to determine whether or not this apparent concentration occurs naturally or was induced by the construction and operation of the plant.

1.2 Goals

The short term goals of the non-nuclear remote sensing program are summarized:

A. Provide remotely sensed data to document current status of the site and facilitate studies of future changes as they occur.

B. Supplement currently available data about the hydrological, geological, and ecological environment where appropriate by remote sensing.

The long term goals of the non-nuclear remote sensing program can be summarized as follows:

A. Define a long term data acquisition and presentation scheme.

B. Carry on repetitive data acquisition and presentation as appropriate.

C. Provide analysis and interpretation of data when requested to do so.

1.3 Reporting Procedure

1.3.1 Interim Outputs of the Ongoing Program

The non-nuclear remote sensing activities carried out at the Rocky Flats Site during the interval July 1975 through December 1975 are part of an ongoing program to support the DOS mission. Because they are part of a continuing program, the information presented here is limited to the following:

A. A description of the data acquisition plans and activities that produced all available imagery and data.

B. A description of the findings of the program to date relative to hydrological and geological indications.

C. A description of the field investigation performed to verify the interpretations and results of the investigation.

D. Interim recommendations for additional investigations necessary to resolve uncertainties identified to date.

1.3.2 The Plan for Final Reports

The time scale involved has precluded the generation of a formal report presenting the extensive remotely sensed data acquired during this interval. However, it is anticipated that the data will have a continuing usefulness in analyzing geological, hydrological, and ecological aspects of the Rocky Flats Site. Therefore, a formal report as referenced below will be issued and distributed.

EGG-1183-1680
Catalog of Remote Sensing and Ground Truth Data
for the ERDA Rocky Flats Site
by J. G. Lackey and R. A. Meibaum

Likewise, a report summarizing the current activities to interpret and verify some of the hydrological and geological features of the Rocky Flats Site will be issued. The report is referenced as follows:

EGG-1183-1679
Non-nuclear Remote Sensing and Analysis of Geological and Hydrological Indicators at the ERDA Rocky Flats Site
by J. G. Lackey, E. Bruce Jones, and H. A. Wollenberg

1.4 Description of the Rocky Flats Site

1.4.1 Location

The Rocky Flats Plant is located on a high plateau near the eastern foothills of the Rocky Mounts. It covers about 10 square miles (more than 6, 500 acres) near the north boundary of Jefferson County.

The plant is about 16 miles northwest of downtown Denver, situated almost equidistant and within 12 miles of Boulder, Golden and Arvada. Other nearby population centers include Broomfield, Louisville, and Lafayette.

The west edge of the facility is paralleled by Colorado Highway 93 which intersects Colorado Highway 72 about one mile south of the plant's west entrance. Indiana Avenue parallels the plant's east boundary and provides an east access to the facility.

1.4.2 Mission

The plant is a key facility for the production of nuclear components. Most of the work is directly related to national defense. The northern half of the plant is involved in processing plutonium and in general waste treatment. The southern half houses uranium, beryllium, and stainless steel component fabrication operations.

2. REMOTE SENSING PLANS AND ACTIVITIES

The principle features of the short term remote sensing plan were determined after discussions with Rocky Flats personnel and after making an on-site ground inspection reconnaissance. The main elements of the plan consisted of the following:

A. Conventional aerial photography

B. Four-camera system photography

C. Infrared thermal mapping

D. Ground truth operations

It was concluded that if the overall plan for remote sensing were carried out, it would allow the following data to be made available:

A. Detailed up-to-date aerial map.

B. Identification and classification of seeps and wet areas.

C. Data for use in multispectral data reduction alogrithims for classifying ecology and land use.

D. High quality images of all types to provide baseline information.

E. Ground truth to support the above.

2.1 Conventional Aerial Photography Plans and Operations

Rocky Flats personnel requested color aerial photography covering the area:

North through Boulder
South to Golden
West to Continental Divide
East to I-25

In support of this requirement, two aircraft photographic missions were flown on 15 August 1975 at an altitude of 18,000 ft and 7,000 ft above terrain. An additional mission was flown on 6 October at 19,000 ft above terrain. The three missions were flown in a Beechcraft A-100 aircraft using a Wild RC-8 aerial camera and color negative film. The three missions provided the necessary coverage, producing photographs with scales of 1:36,000, 1:14,000, and 1:38,000, respectively.

2.2 Multispectral (Four-Camera) Aerial Photography Plans and Operations

The multispectral photography plan involved the utilization of a camera system containing four 70mm Hasselblad cameras to photograph simultaneously in four different wavelength regions. The four channels used were:

	Film	Filter	Wavelength Region
1	Aerocolor 2445	W2A	4000 - 7000A
2	Infrared Aerochrome 2443	W12 + WCC30B	5000 - 9000A
3	Infrared Aerographic 2424	W89B	7000 - 9000A
4	Plus-X Aerographic 2402	W25	6000 - 7000A

The planned coverage included complete coverage of an area two miles in all directions from the plant and single frame coverage of the inner fence area.

Missions were flown on 16 August, 15 October, and 17 October to obtain the required coverage.

The 16 August mission was flown in the A-100 aircraft at 5,000 ft above terrain and covered an area two miles north, south, and west of the plant and as far east as Standley Lake. The scale of the photographs was 1:19,500.

Missions on 15 and 17 October were flown in a Martin-404 aircraft at 10,000 ft above terrain and single frame coverage of the immediate plant area was obtained. The scale of this imagery was 1:39,000.

2.3 Infrared Thermal Mapping Plans and Operations

The infrared thermal mapping plan was devised after inspection of color aerial photographs and an on-site ground reconnaissance. Particular attention was given to designing the coverage so as to be able to detect variations in ground moisture and variations in surface geology by means of thermal effects. The infrared thermal mapping plan can be summarized as follows:

A. High Altitude Long Wavelength Scan

1. Bendix scanner
2. 8-12.5μ detector
3. Approximately 10,000 ft altitude
4. Mid-afternoon - three east to west passes

B. Low Altitude Long Wavelength Scan

1. Bendix scanner
2. 8-12.5μ detector
3. Approximately 1,000 ft altitude

4. Mid-afternoon - selected passes
5. Dawn - overlapping passes of inner fence area
6. Dawn - flight lines along selected stream beds

C. Multispectral Multi-scan Data Set

1. 8-12.5μ and 3-5.5μ detectors
2. Approximately 1,000 ft altitude
3. Mid-afternoon and before sunrise - two flight lines over selected test area

The required coverage was obtained on 15, 16, and 17 October, using the Martin-404 aircraft and a Bendix thermal mapper Model LN-3. Due to variable windy weather on 16 October, some data acquisition runs for this date were repeated on 17 October.

2.4 Ground Truth Plans and Operations

Particular attention was given to the design of the ground truth plan because ground truth data were considered to be essential to the proper calibration and utilization of all types of remotely sensed data acquired by airborne operations.

It should be noted that the implementation of the ground truth plan was carried out in cooperation with, and with the support of, Rocky Flats personnel. Below is an itemization of the operations which constituted the ground truth plan and personnel assignments.

A. Water Level Measurements in Wells and Bore Holes - As Many As Possible (RFP personnel)

B. Photography of Plant Life Around Ground Seep Areas (EG&G personnel)

C. Thermal Infrared Radiometer Temperature Measurements (EG&G personnel)

1. Water surface
2. Wet poisoned seep
3. Asphalt
4. Open bare ground
5. Uniformly vegetated area

D. Soil Moisture Samples (personnel from all organizations)

1. ≈30 points at selected locations and times specified by EG&G consultants.

NOTE: All of the data described in this document in Sections 2.1 thru 2.4 will be further described and cataloged in report EGG-1183-1680 now in preparation.

3. HYDROLOGICAL AND GEOLOGICAL INDICATIONS

3.1 Geological and Hydrological Setting

The geologic setting of the Rocky Flats Site is dominated by the sedimentary and structural patterns of the Front Range urban corridor. The setting, covered briefly here, is described in detail by Hurr (1975) and in a report by URS/Blume & Associates (1974). Immediately west of the site, steeply upturned beds of the Fox Hills, Laramie, and Arapaho formations crop out, and then dip eastward beneath the site. The best aquifer of the group, the Fox Hills sandstone, occurs at a depth of approximately 800 ft beneath the plant area. Overcapping these bedrock units is a veneer (10 to 70 ft) of gravelly alluvial deposits, termed the Rocky Flats gravels. These gravels are considered by Hurr (1975) to be the remnants of alluvial fan material, debouched from Coal Creek Canyon. The gravels extend westward of, and occupy gaps in, the outcrop of the upturned Fox Hills beds. This permits percolation of some shallow groundwater through the Fox Hills outcrop, eastward on to the site area. Leakage from Cold Creek Canyon and the Boulder Diversion Canal could also furnish some water on site on the Rocky Flats gravels. Thus, water contribution to the site area, though greatly influenced by the plant's water system, and supplemented by rain and snowfall, likely has components from groundwater flow in the near-surface gravels. That ground water which flows off-site is largely confined to the gravels, but some may percolate to deeper aquifers through permeable zones in the Arapaho-Laramie, and through fault zones which may intersect these formations.

The contact (or interface) between the Rocky Flats gravels and the less-permeable underlying Arapaho Formation serves as the locus of natural and man-caused seeps, where the contact intersects the topographic surface on the sides of the stream-channel valleys. The mesa-like topography of the site; flat, gravel-capped surfaces incised by small streams, lends itself well to the formation of such seeps. Most flow from leakage (from both the solar evaporation ponds or other plant-site sources) probably surfaces at seeps on the sloping sides of the stream channel valleys. Subsurface leakage from the holding ponds is more

likely to reach the deep aquifers than leakage from the solar ponds. This could occur either directly by percolation through the Laramie-Arapaho, or by percolation through a fault or shear zone which may intersect the surface and the bedrock units at depth. Evidence for such a zone was reported by Hurr (1975), who suggested that the zone may be a southerly extension of the Eggleston Reservoir Fault, described by Spencer (1961).

3.2 Geological Indications

Of the imagery available to date, that most diagnostic for interpretation of geologic features is the high altitude (18,000 ft above terrain) natural color photography, obtained 15 August 1975, the high altitude (10,000 ft above terrain) mid-day thermal infrared mapping of 16 and 17 October, and the dawn lower altitude (about 1,000 ft) thermal infrared mapping of 16 and 17 October. A zone of lineaments, most of which are oriented NNW-SSE, is apparent in the eastern portion of the site on both the photo and thermal infrared imagery. The lineaments are expressed as topographic features such as stream orientations, cuts in mesa rims, and continuity of tributary stream alignments across main drainages. An example of preferential stream orientation, which may be influenced by faulting, is the NNW direction of the south fork of Coal Creek, near the 5,750 ft contour across the north-south line of sections 34 and 35. Orientations of cuts in mesa rims are exemplified in the northwest quarter of section 2, and just north of the east access road in section 12. A continuity of tributary alignment across a main drainage is indicated on the north fork of Walnut Creek in the southwest quarter of section 2.

The low-sun-angle photography, obtained shortly after sunrise on 16 October, though not extensive in coverage, shows good enhancement of diagnostic topographic features in the area south and east of the main plant site.

Dawn thermal infrared imagery indicates well the NNW trend of lineaments, as well as north-south trending features in the southwest quarter of section 2. Ground check of these reatures indicated very little topographic expression. Tone changes in mid-day and dawn thermal infrared imagery are evident on south-facing slopes north of holding pond A-2 and on relatively flat terrain south of the B holding ponds. These changes, near the distorted and offset bedding observed near these ponds, may reflect contrasts in ground moisture content and/or lithology on opposite sides of a fault zone.

Taken individually, the lineament features and dislocations of bedding observed on the ground may be attributed to the lenticular nature of sedimentary lithologic units, i.e., a sand bed may "lens out" to be replaced at the same stratigraphic level by shaley material. However, when plotted areally, as on the accompanying map, the overall zonation and general alignment of surface features infers that there is structural control to their orientation by a fault or shear zone.

3.3 Hydrological Indications

The airborne data collection was designed so that certain hydrologic features could be evaluated. The specific data collection, other than photographs of hydrologic interest, was the 8-12.5μ thermal infrared mappings carried out near sunrise and solar noon. To assist with this airborne data collection, hydrologic ground truth, in the form of soil moisture, was taken at selected locations.

The primary elements of hydrologic interest were seeps, springs, and general water-balance information for the immediate plant site and the surrounding area. Since the local geology controls much of the natural water balance of this area, the hydrologic and geologic elements were highly interrelated both in mission planning and preliminary interpretation.

3.3.1 Seeps and Springs

Various seeps and springs were noted on photographic and thermal infrared imagery along the three basic drainages flowing through the plant site. Closer inspection of some of these indicated that these springs and seeps apparently emerged from the interface of the Rocky Flats gravels and the lower more impervious Arapaho formation. It also initially appears that there is some concentration of springs and seeps in the vicinity of the plant site itself. With the present information available, it is impossible to determine whether or not this apparent concentration occurs naturally or was induced by the construction and operation of the plant.

If this concentration is not natural, then one should initially look at some obvious possibilities: (1) the plant is losing water through the "plumbing", (2) the construction of various facilities have allowed for concentration of groundwater through foundation drains, etc., or (3) a combination of the first two.

Rocky Flats personnel have sampled the water from selected springs and disclosed that with one exception, the water does not have the chemical or radiological characteristics of plant process waters. The exception is the seeps to the northeast of the solar evaporation ponds which contain large amounts of nitrates.

3.3.2 Water Balance Information

The natural water balance of an area is determined by the manner in which waters naturally enter and leave the area under consideration. At the Rocky Flats Plant site there are several opportunities for water to enter the system:

A. Precipitation

B. Seepage losses from the Boulder Diversion Canal to the west of the site which would enter the Rocky Flats gravels.

C. Ground-water seepage from the west from Coal Creek near the mouth of Coal Creek Canyon. This would primarily be through the upper or near-surface gravel formations.

Similarly water would tend to leave the area through:

A. Surface runoff - fed by seeps and springs as well as by direct runoff.

B. Evaporation

C. Evapotranspiration from the native vegetation.

D. Possible deep seepage to a lower aquifer (see the geologic report comments on this).

The information previously mentioned on seeps and springs indicates that the mission was quite helpful in locating these areas, but the airborne imaging techniques used are not capable of quantifying the flows. In addition to locating the seeps and springs, the airborne information also suggests that there is some hydrologic connection with Coal Creek at the mouth of the canyon. This is noted from the mid-day thermal infrared scan. One can note a dark pattern emerging from the north half of the Coal Creek alluvial fan. Although briefly field checked, no firm conclusions can be drawn at this point.

Inspection of the mid-day thermal infrared mapping indicates that the Boulder Diversion Canal does not appear to be leaking any pronounced amount of water into the gravels at specific points. The early morning scan lines did not cover this area.

4. FIELD INVESTIGATIONS

Field investigations were conducted on 13 and 14 November 1975 and on 10 December 1975 for the purpose of verifying some of the geological and hydrological indications which were noted in the remotely sensed imagery. Personnel from several organizations were present at each of these meetings. For this reason, the information relative to these meetings will be presented in the form of notes submitted by one of the available participants. Because of the evolving nature of the field investigations, they are presented here as a chronological sequence of activities.

4.1 Notes on Field Examination of the Rocky Flats Plant Area, 13 November 1975

Participants: R. T. Hurr, USGS; C. Illsley, RFP; E. B. Jones, Bittinger & Assoc.; and H. A. Wollenberg, LBL

Notes: by H. A. Wollenberg

The purpose of the examination was to field-check specific points of interest indicated by the multispectral aerial surveys, and to observe ground features which may be associated with faulting. The points visited are numbered on the accompanying map, Page 18.

(1) Surface indications of possible faulting, observed originally by R. T. Hurr (1975), were inspected in the deeply eroded drainage channel just south of the easternmost holding ponds (B-3 and B-4) on the south fork of Walnut Creek. At this location, strongly contorted clayey layers of the Arapaho formation occur stratigraphically above and below a hard, resistant medium-to-fine-grained sandstone layer, approximately 0.5m thick. Though mostly obscured by slumped material, the sand layer appears to be offset vertically, downward to the east, in several small steps eastward along the trench.

(2) Faulting is also suggested by the apparent vertical (downward to east) offset of a similar sandstone bed on the north shore of holding pond A-2 on the main fork of Walnut Creek.

(3) The location of the bright, roughly E-W trending linear feature on the dawn thermal infrared image was inspected. The feature is a sharp, south-facing scarplet on the south edge of the flat ridge-top gravel cap. This scarplet receives the first rays of the morning sun, causing a sharp temperature contrast with the flatter terrain above and below.

The area of subtle temperature contrasts on the south-facing slope just north of pond A-2, observed on both the mid-day and dawn thermal infrared imaging, was scanned from the ridge top at location 3. Though no sharp changes in vegetation are apparent, there are vegetational variations which may reflect changes in ground moisture.

An area spanning the north fork of Woman Creek was scanned from the ridge top north of pond A-2. This was to field check a north-south trending linear feature, apparent on the dawn thermal infrared image, and the color photograph. Ground observation indicates that there is no sharply apparent topographic expression of this feature, so that subtle changes in ground moisture and vegetation probably account for its appearance on the images.

(4) Roadcuts in the Arapaho formation were observed on Indiana Street, north of the intersection with the East Access Road. In this area, massive medium-to-fine-grained sandstone near the base of the Arapaho is over- and underlain by grayish clayey material. Some of the exposures show zones of iron-staining and occasional iron nodules.

(5) The terrain along and south of Rock Creek was observed from the county road bordering the north line of Sec. 36, T1S, R70W. Hurr speculates that in this area the sandstones of the lower Arapaho formation may be displaced 200 to 300 ft vertically by an ENE-trending fault. There is no surface evidence for the fault in this area, but well-log data and roadcuts farther east suggest its presence.

(6) The hummocky terrain on the slopes south of Rock Creek was observed from Colorado Highway 128 near the north border of Sec. 2, T2S, R70W. As well as sharp breaks in the rim-rock south of the creek, Hurr pointed out an apparent offset in spring lines in the clayey Arapaho. This area lines up along the projection of the strike of the possible NNW-trending fault/shear zone observed in the holding pond area.

(7) The Eggleston Reservoir area was visited, and a well-exposed outcrop of purportedly Fox Hills sandstone (Spencer, 1961) was inspected. This sandstone, where freshly exposed west of the reservoir, is light-colored,

fine grained, quartzo-feldspathic, with some dark lithic grains. In a more weathered exposure near the reservoir's right abutment, the sandstone is buff and iron stained. Ground inspection northeast of the reservoir showed no indication of the Eggleston fault, but slickensided clayey material, probably of the Laramie formation, in the deeply eroded natural "spillway" below the dam, indicated probable faulting.

It is concluded from this ground inspection that surficial features in the eastern portion of the plant area, as well as north of the plant area, suggest the presence of a fault or shear zone. The orientations of some sandstone and clayey units in the Arapaho/Laramie formation in this area strongly suggest vertical offsets, though the termination and reappearance of beds may also be attributed to the lenticular nature of this sedimentary sequence.

On 14 November, these findings were presented to Rocky Flats Plant personnel. As a result of this meeting, seismic reflectivity surveys were recommended to assist in confirming the existence of the Eggleston fault. Subsequently, arrangements were made by Rocky Flats Plant personnel to have the Colorado School of Mines perform the survey initially on site and then northward along the Eggleston fault as noted by Spencer (1961).

4.2 Notes of Meetings in Connection with Rocky Flats Project, 10 December 1975

Participants: M. Thompson, J. Cleveland, C. Illsley, E. B. Jones, and H. Wollenberg

Notes: by H. A. Wollenberg

Illsley reported on Colorado School of Mines (CSM) seismic surveys during the past weekend. CSM had not found evidence of subsurface faulting on their north vibroseis line. We would inspect the data in the afternoon at CSM.

Jones and Wollenberg emphasized the importance of obtaining samples and chemical analyses of well waters from the Fox Hills aquifer east of the plant site. Illsley said that the USGS has some analyses of these waters, and he would check to see if the data are available, and whether tritium were analyzed.

During the mid-morning, Wollenberg, Jones, and Illsley examined an area on the Rocky Flats gravels west of Highway 93, near and south from the small lake in the south center of Sec. 8, T2S, R70W. This was to observe on-site, ground conditions in an area of tone change on the 18 August 1975 color, and 17 October mid-day thermal infrared imagery. The prominent sharp ridge northwest of the lake is probably capped by an erosion remanent of pre-Rocky

Flats gravels; a similar band of angular boulders forms a low ridge north of the lake. The lake occupies a small depression at an elevation well above that of the closest portion of Coal Creek. No apparent difference was noted on the surface of the ground between areas of different image tone, south of the lake, and south across Woman Creek. There was no observable difference in ground conditions between the relatively cooler zone north of Woman Creek indicated on the thermal infrared imagery, and warmer ground south of the creek. The cooler area may represent a zone of near-surface groundwater flow from Coal Creek into and through the Rocky Flats gravels west of the plant site. The zone's infrared and color photograph "signature" suggest possible hydrologic communication between these gravels and those on the plant site.

The Colorado School of Mines was visited in the afternoon to see results of the 6 and 7 December vibroseis reflection surveys across the suspected fault/shear zone north and east of the plant area. Present were T. Davis and G. Keller of CSM, Cleveland and Illsley of RFP, and Jones and Wollenberg. Velocity diagrams from the two survey lines were inspected, and indicated no apparent offsets of Fox Hills, Pierre, or deeper sedimentary units beneath the plant site. This indicates no evidence of appreciable NNW-SSE faulting on the RFP site (Davis, 10 Dec 75). Previous seismic data of T. Davis showed offsets associated with Denver Basin growth faults, northeast of Eggleston Reservoir.

It was planned to continue reflection profiling, with two lines immediately north and south of Eggleston Reservoir, across the expected position of the Eggleston Reservoir fault; a third line 1 mile south of the Reservoir; and a north-south line along Indiana Avenue (the east boundary of RFP), to check the presence of faults which may project on-site from the northeast. Priority will be given to the confirmatory lines in the vicinity of Eggleston Reservoir, for comparison with data from lines on-site.

5. RECOMMENDATIONS

Recommendations for further studies of the Rocky Flats site can be divided into two categories: (1) geological studies to better determine the geological structure of the site and (2) hydrological studies to better understand the water balance of the site.

5.1 Geological Studies

Examination of airborne imagery and surface features strongly suggests the presence of a fault or shear zone in the eastern portion of the RFP site area. As indicated previously, Hurr (1975) suggested that such a zone may be the southern extension of the Eggleston Reservoir fault. Spencer (1961) stated that the Eggleston Reservoir Fault is a reverse fault, dipping steeply to the west, with beds offset 200 to 300 ft vertically. Where observed on the ground in the vicinity of the plant site holding ponds, offsets are probably less than 50 to 20 ft. Therefore, if the fault/shear zone in the eastern portion of the plant site is a southerly extension of the Eggleston Reservoir Fault, a substantially different degree of offsetting has occurred on the fault between the two locations. Subsequent studies should be designed to confirm or deny the presence of the fault, and if it is present, whether or not it provides communication between surface or shallow water at the plant site and aquifers at depth in the Laramie and Fox Hills Formations. Recommended procedures for the evaluations follow:

A. Chemical and radiometric analyses of water from wells penetrating the Laramie-Fox Hills aquifer, east of the plant site should be conducted.

B. A geophysical survey of the fault/shear zone area, utilizing seismic sounding techniques should be accomplished, to determine the presence and extent of offset or distortion of beds crossing the zone. Because of the inferred difference in magnitude of offsets, a seismic line should be oriented in the northern portion of the site area, as well as a line across the zone in the vicinity of the holding ponds.

C. It is strongly recommended that the north-south line along and north from Indiana Avenue also be surveyed as soon as possible. It is important to confirm or deny the presence of any faults that may underlie the RFP site.

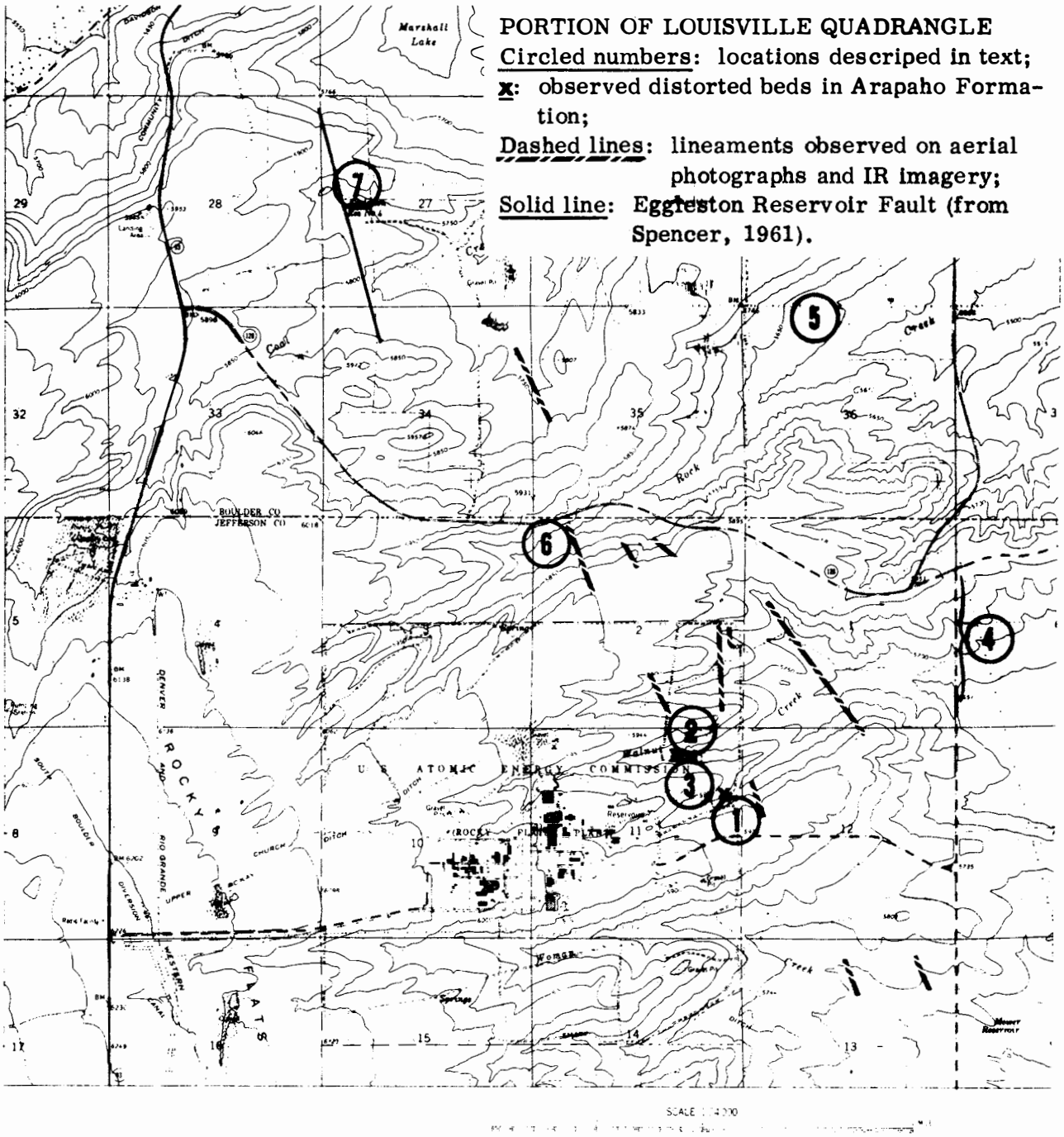
NOTE: Vibroseis reflection surveys conducted by the Colorado School of Mines during the period 13 through 21 December 1975, transecting the area of the suspected shear zone, indicated no apparent offsets of beds at depths exceeding 600 ft. (The resolution of the technique is stated to be $\approx$ 20 ft.) Similar vibroseis traverses on 28 December in the vicinity of Eggleston Reservoir

Fault (Davis, 29 December 1975; Spencer, 1961), indicated no apparent offsets of beds at depth in that area.

5.2 Suggested Hydrologic Studies

The work thus far has suggested two main thrusts for future hydrologic studies. First, the source of the water which appears as springs in the vicinity of the plant should be identified insofar as reasonably practical. Second, a monitoring program should be designed in order to continue to ensure knowledge of the sources and disposition of this water. (Some of this suggested effort is underway, and will be reported elsewhere.)

To accomplish the first task, one must not only have a water balance in the plant, but must also show how the water enters and leaves the surrounding area. Verbal communications with Rocky Flats personnel indicate that in-plant water-balance studies have been made -- thus a portion of this work is underway. The water balance of the surrounding area is considered to some extent by Hurr (1975) in the current U. S. Geological Survey draft dealing with this area. Conversations indicate that the current USGS report does not contain the detail that may ultimately be desired by Rocky Flats Plant personnel.


PORTION OF LOUISVILLE QUADRANGLE
Circled numbers: locations descriped in text;
x: observed distorted beds in Arapaho Formation;
Dashed lines: lineaments observed on aerial photographs and IR imagery;
Solid line: Eggleston Reservoir Fault (from Spencer, 1961).
Marshall Lake
Coal Creek
Rock Creek
Walnut Creek
Ponca Creek
BOULDER CO
JEFFERSON CO
U.S. ATOMIC ENERGY COMMISSION
ROCKY FLATS PLANT
DENVER
ROCKY
FLATS
1
2
3
4
5
6
7

6. REFERENCES

In view of the specialized nature of this technical memorandum, no exhaustive list of references has been prepared. However, attention is called to the following references which have been cited in the report or else are particularly related to the subject at hand.

Hurr, R. T., 1975, Hydrology of Rocky Flats, Jefferson and Boulder Counties, Colorado, Preliminary report, U. S. Geological Survey.

Spencer, F. D., 1961, Bedrock Geology of the Louisville Quadrangle, Colorado, U. S. Geological Survey, Map GQ-151.

URS/John A. Blume & Associates, 1974, Seismic and geologic investigations and design criteria for Rocky Flats plutonium recovery and waste treatment facility (rev. 1974).

Davis, T., 10 December 1975, Rocky Flats reflection seismic projects.

Davis, T., 29 December 1975, unpublished notes titled, "Eggleston Seismic Project."

ROCKY FLATS REFLECTION SEISMIC PROJECT

by

T. L. Davis

Department of Geophysics
Colorado School of Mines
Golden, Colorado

Tom Davis
April 6, 1976

OBJECTIVE

The purpose of this project was to investigate the possible existence of faults in the vicinity of the U.S. Atomic Energy Commission's Rocky Flats Plant.

INVESTIGATION PROCEDURE

During the time interval December 9-28, 1975 and February 10 through April 1, 1976, Rockwell International Inc., operator of the Rocky Flats Plant, contracted and financed the acquisition, processing and interpretation of 15 miles of seismic reflection data in the vicinity of the Rocky Flats Plant. The survey was performed through the Geophysics Fund Inc., under the direction of Tom Davis of the Department of Geophysics of the Colorado School of Mines.

The VIBROSEIS (trademark of Continental Oil Company) system of data acquisition was used throughout the project. The seismic source involved a truck-mounted servo-hydraulic vibrator which was made to sweep at a constant amplitude over a linear range of frequencies during a fixed period of time. Throughout the survey a 48 - 8 Hertz downsweep was used extending over an 8-second duration. Data was recorded for 11 seconds from the time of sweep initiation. The process by which the signal is recovered is similar to that of the chirp radar method. Field records from this seismic source show no discernible reflection information because the seismic pulse is spread over several seconds. The data must be computer cross-correlated with the original sweep of frequencies before reflection information may be viewed. The signal generated by this source was recorded by a 24-channel digital field system DFS-10000. The source pattern at each vibrator point (vp) consisted of 27 sweeps spaced over 10-foot intervals. Distance between source points (vps) varied from line

to line but was either 400 or 600 feet. The receiver pattern consisted of 15 geophones stretched over 200 feet. Information during each vibration was recorded by 24 sets of these geophone arrays. The spacing between the geophone groups varied from line to line but was either 200 or 300 feet. Data acquired was processed on the Geophysics Department's Phoenix minicomputer. A standard processing sequence of demultiplexing, summing, cross-correlating, and stacking was performed.

Seismic data was acquired in the general vicinity of the Rocky Flats Plant (lines 1-8) and Eggleston Reservoir north of Highway 128 (lines 1-3) as shown in Figure 1. These lines were located according to topographic considerations with the specific geologic objective in mind. One line traversed the entire extent of the plant (line 6). The ecological advantage of the VIBROSEIS technique was demonstrated throughout the project but most important during the Central Avenue traverse.

INTERPRETATION

Geologically, the Rock Flats Plant is situated as depicted in Figure 2. A stratigraphic column is illustrated in Figure 3. The Rocky Flats (Figures 4-11) and Eggleston (Figures 12-14) seismic lines were interpreted as shown. The data quality facilitated the interpretation. In addition, the seismic data was tied to the Tom Jordan Marshall Lake Well (22-1S-70W) for horizon control and subsurface velocity information. A synthetic seismogram (Figure 15) run from the sonic log in the well enabled a good seismic-well tie. Seismic data made available by Tom Jordan (Davis, 1974) was tied directly to the Rocky Flats data. Two maps (Figures 16 and 17) were prepared on the Top and Base of the Pierre Shale respectively.

The maps and related seismic sections illustrate that two types of fault systems are present in the Rocky Flats area. One fault system is locally restricted to the Upper Pierre Shale and Laramie-Fox Hills sections. It is depositional in nature and related in a growth fault manner documented by Davis (1974) and Weimer (1973). An associated basement-controlled fault system exists on the western and southern extremity of the shallow growth fault system. The basement-controlled fault system localized deposition of the Upper Pierre Shale and Laramie-Fox Hills intervals. Sedimentation rates and thickness accumulations were greatest within the downfaulted graben area to the north of the Rocky Flats Plant. The basement-controlled faults to the west and north of the Rocky Flats Plant exhibit a growth history as well. Displacement at the Niobrara level is approximately 150-200 feet whereas displacement at the Top of the Pierre is in the order of 50-75 feet. The Precambrian basement configuration conforms to the Top of the Niobrara structure map. It is located approximately 4000 feet beneath the Niobrara horizon. Displacements on the basement across the basement-controlled faults appears to be in the order of 300-350 feet. Displacement varies with lateral position on the basement-related faults as well. The north-south fault has more displacement than the northeast trending fault. In addition the north-south trending fault has more displacement in the southern portion of the map area than it has in the north; ie., the fault dies out to the north. The northeast trending fault has more displacement in the southwest and displacement diminishes in a northeasterly direction.

SUMMARY

Interpretation of 15 miles of seismic reflection data in the vicinity of the Rocky Flats Plan reveals:

a. Two distinct but associated fault systems exist in the area. A basement-controlled graben area to the north of the Rocky Flats Plant localized sedimentation in the form of a depocenter throughout Late Cretaceous time. Associated penecontemporaneous growth faulting exists in this graben area. These faults are northeast trending and do not trend into the plant area.

b. The Rocky Flats Plant is located on the stable, upthrown, horst block south of the graben area north of Highway 128. There is no evidence for shallow, penecontemporaneous, growth faults within this basic structural element. The structural block on which the plant is located is flanked one mile to the west and north by two basement-controlled faults which fault the entire sedimentary section. Near-surface displacement on these faults is in the order of 50 feet.

c. No faults exist within the immediate area of the Rocky Flats Plant.

REFERENCES

Davis, T. L., 1974, Seismic investigation of Late Cretaceous faulting along the East Flank of the Central Front Range, Colorado: Ph.D. Thesis 1681, Colorado School of Mines

Weimer, R. J., 1973, A guide to Uppermost Cretaceous stratigraphy, Central Front Range, Colorado: deltaic sedimentation, growth faulting, and Early Laramide crustal movement: Mtn. Geologist, v. 10, no. 3, p. 53-97

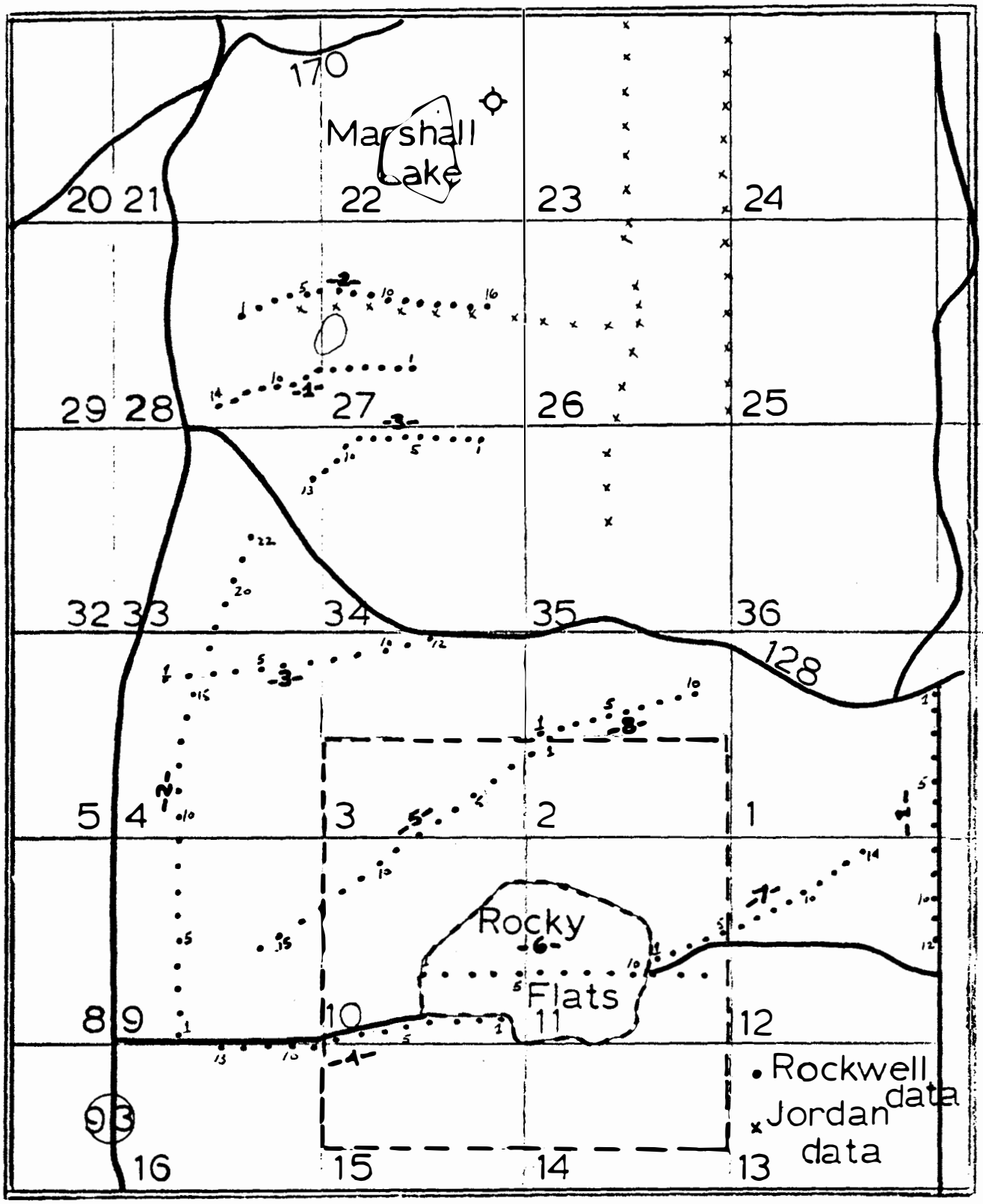


FIGURE 1. Seismic line location map

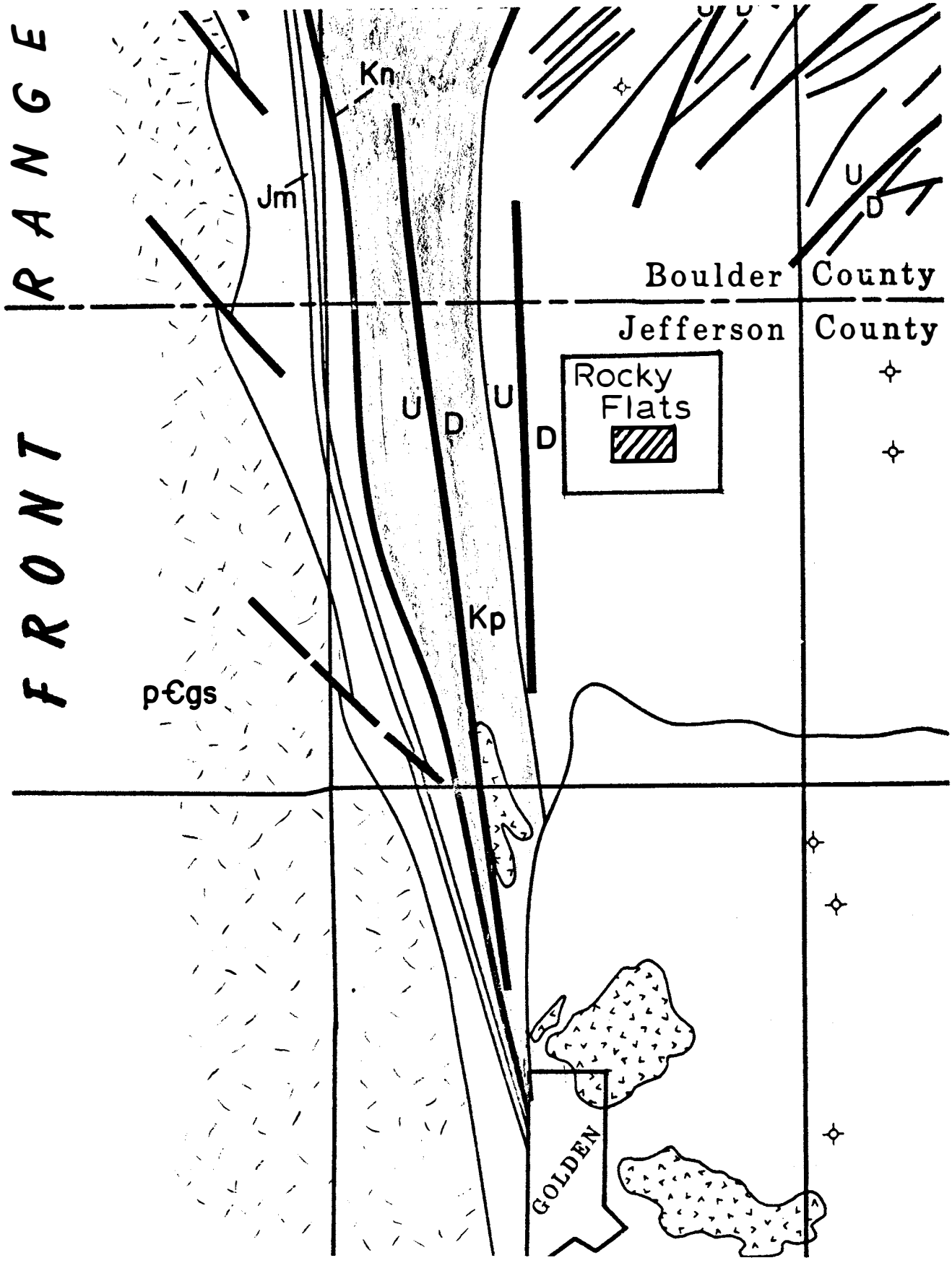


FIGURE 2. Tectonic map of Rocky Flats area

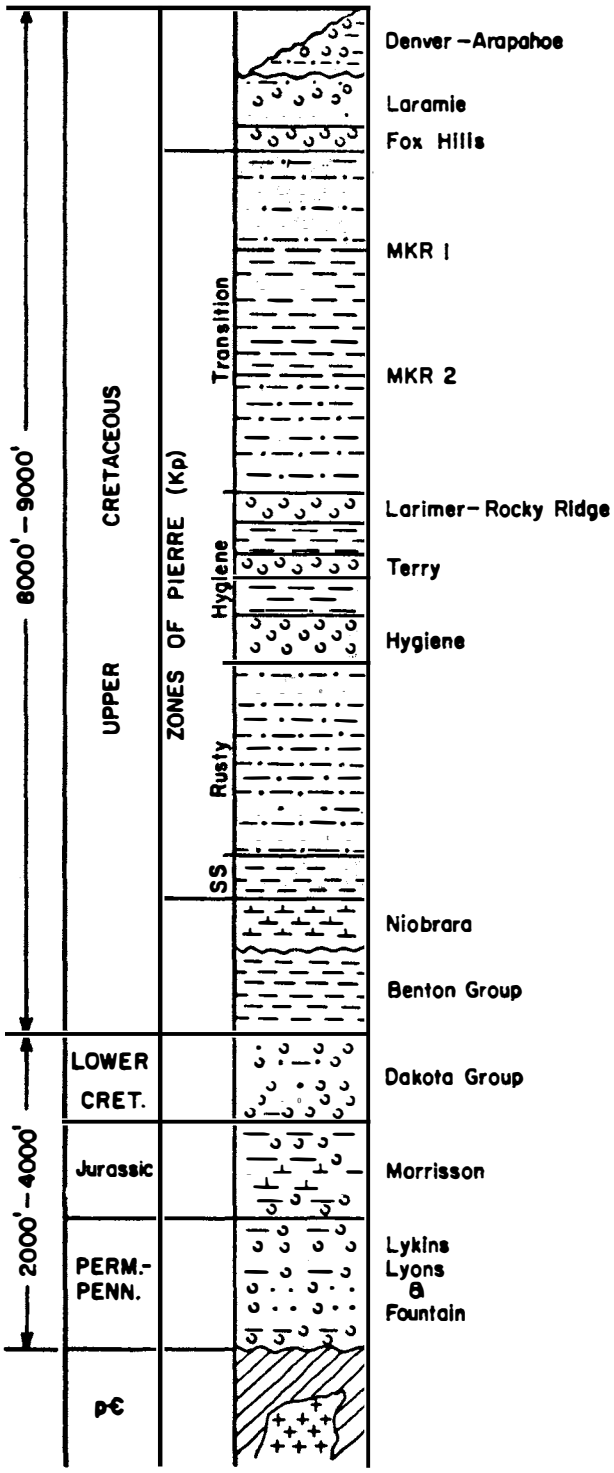
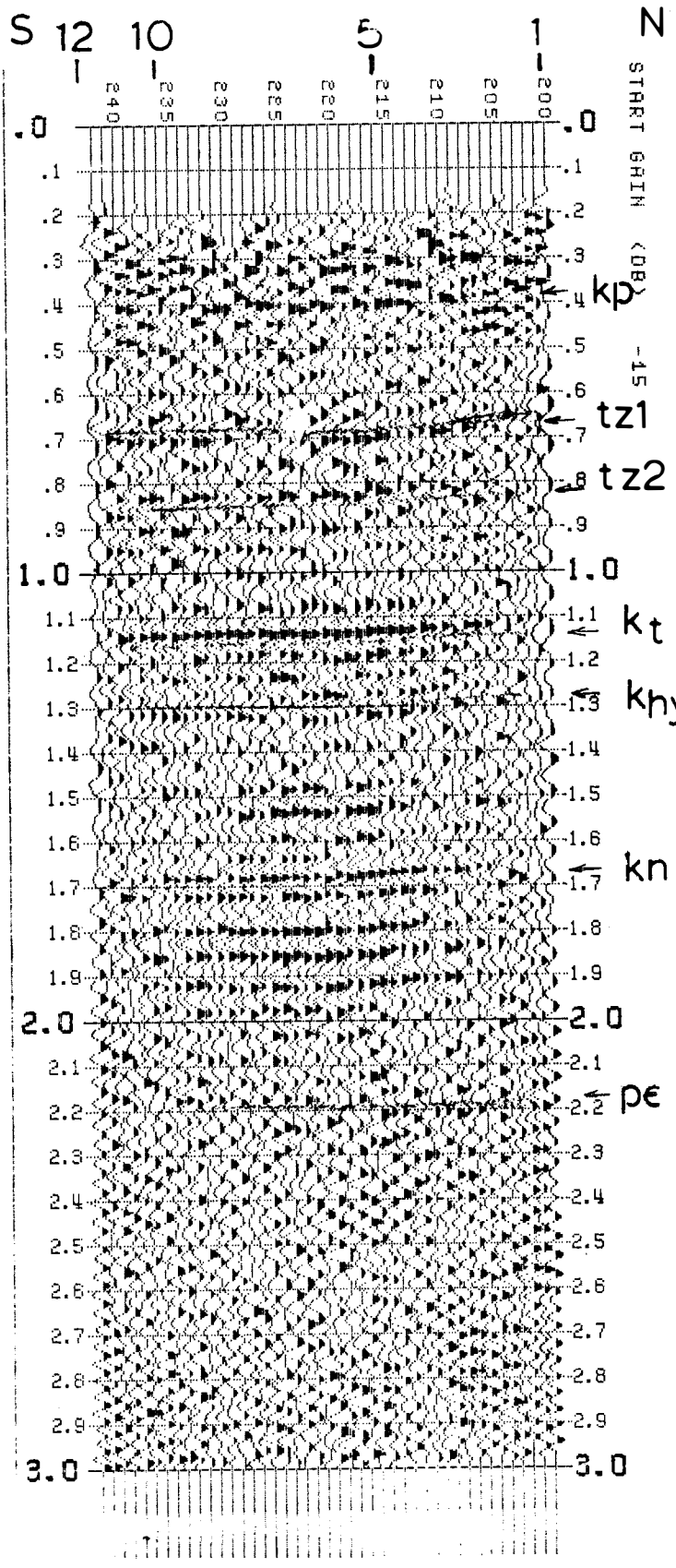


FIGURE 3. Stratigraphic column



LINE 1
FINAL DATUM = 6700'
V_R = 8,000 ft/s

FIGURE 4. Rocky Flats line 1

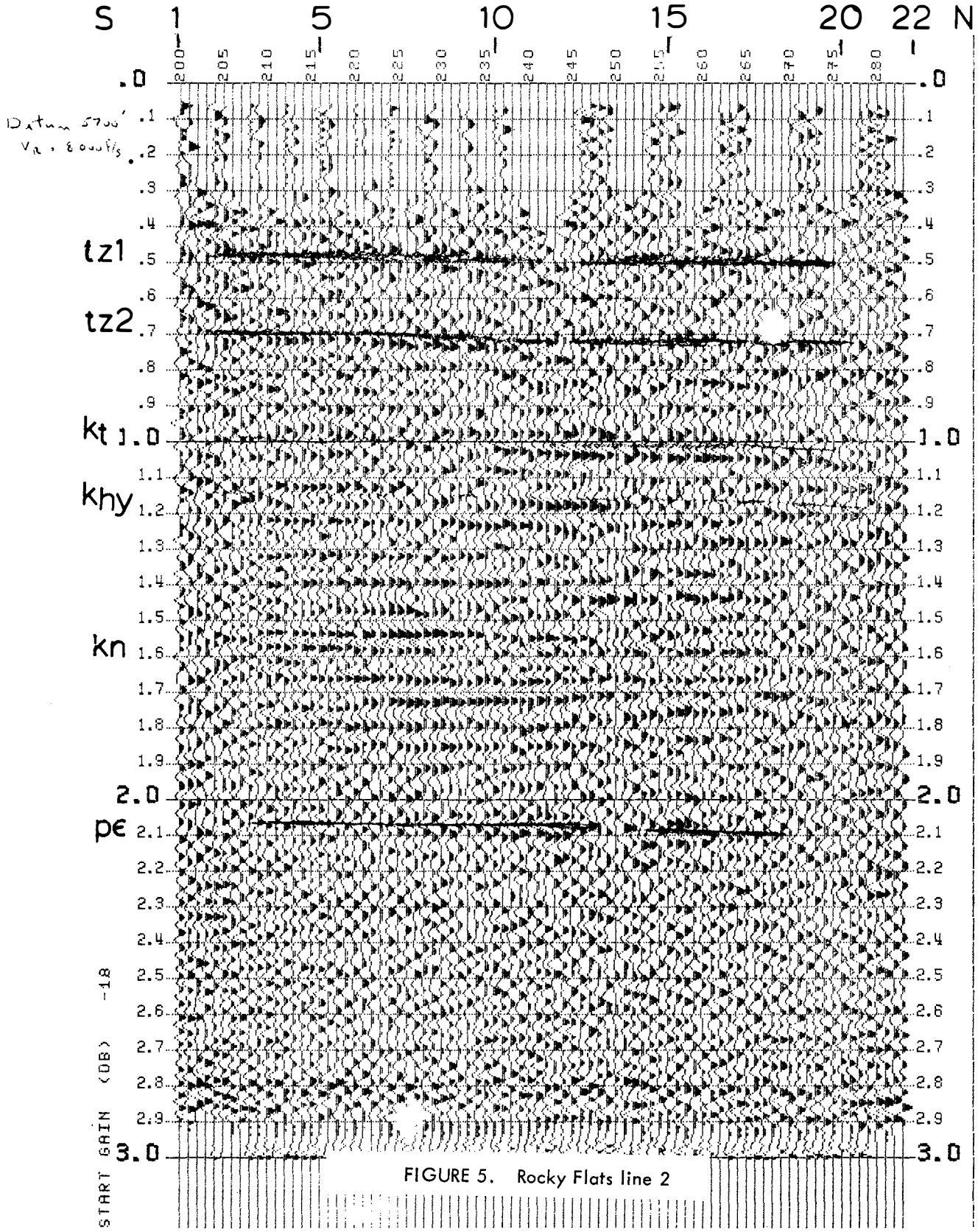


FIGURE 5. Rocky Flats line 2

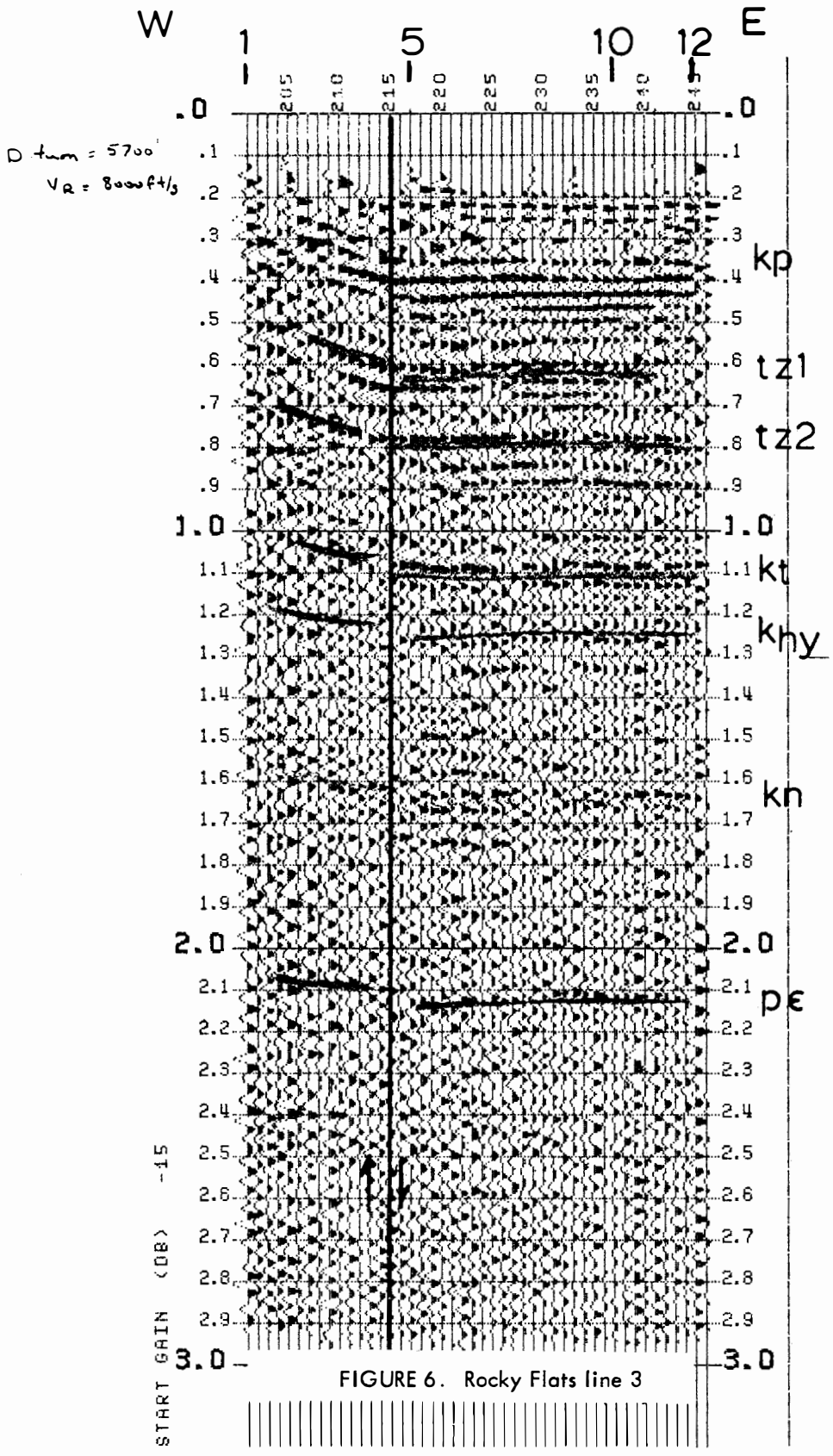


FIGURE 6. Rocky Flats line 3

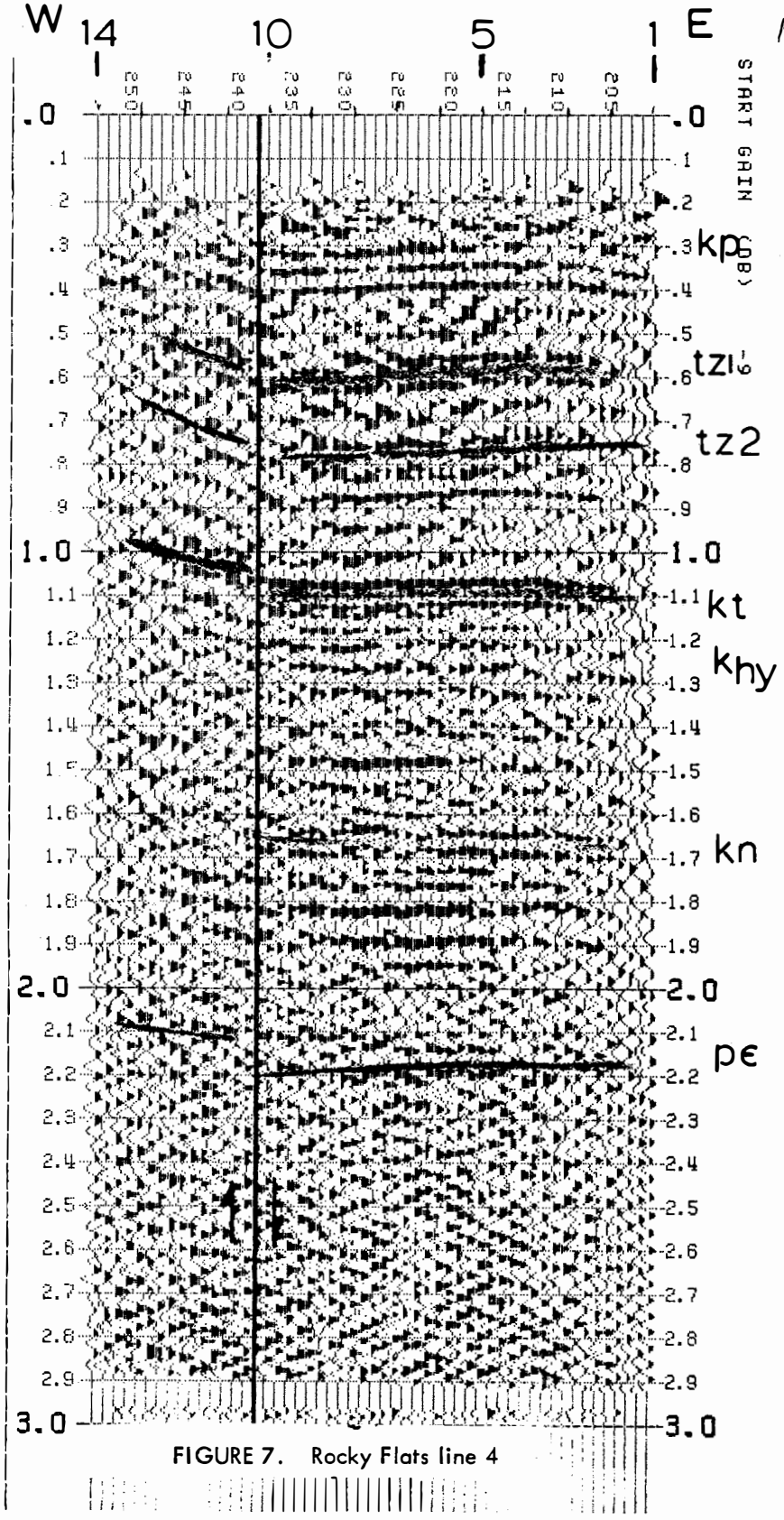


FIGURE 7. Rocky Flats line 4

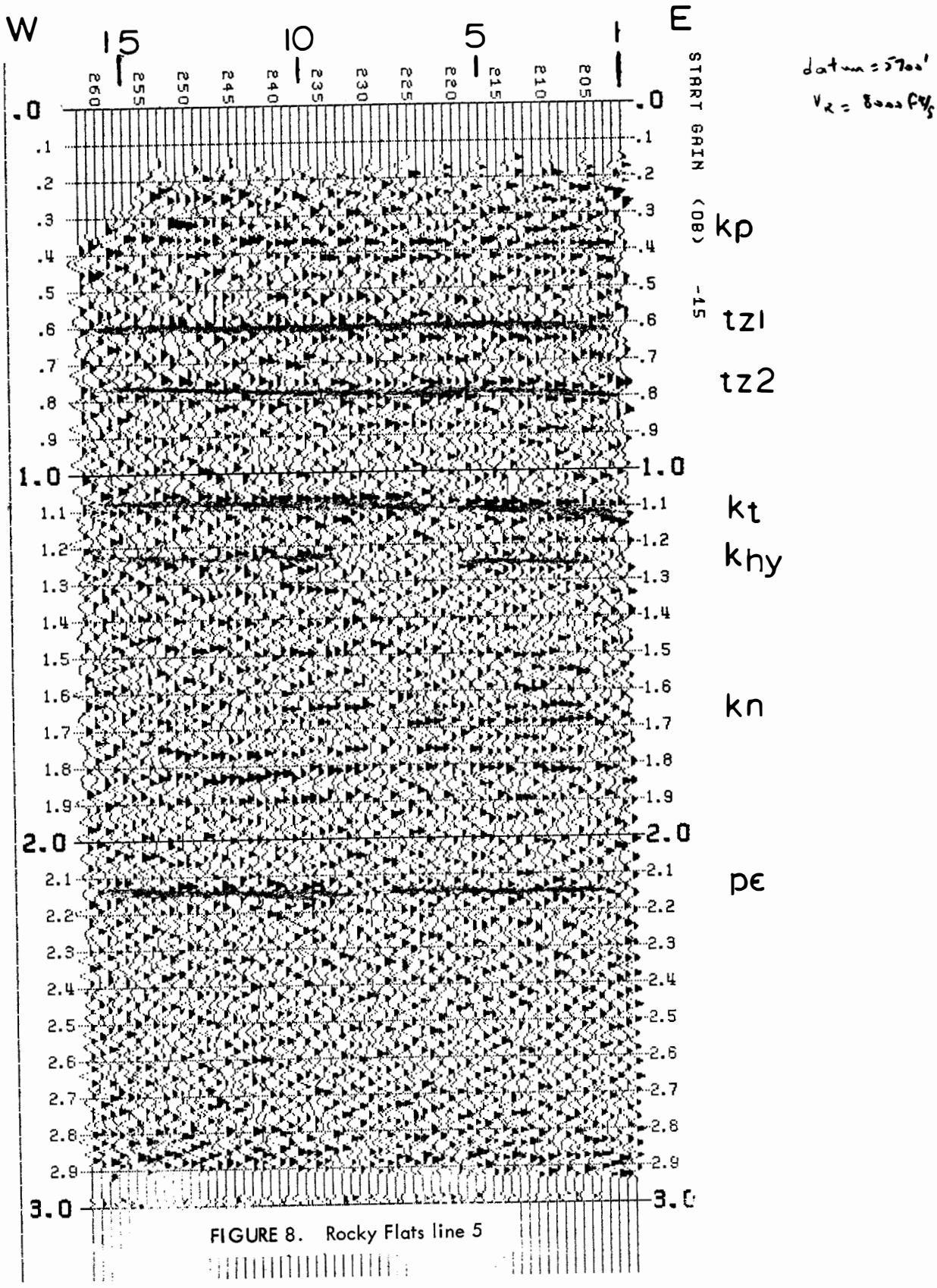


FIGURE 8. Rocky Flats line 5

FINAL
CENTRAL AV
+5700' datum
V_R 8000 ft/s

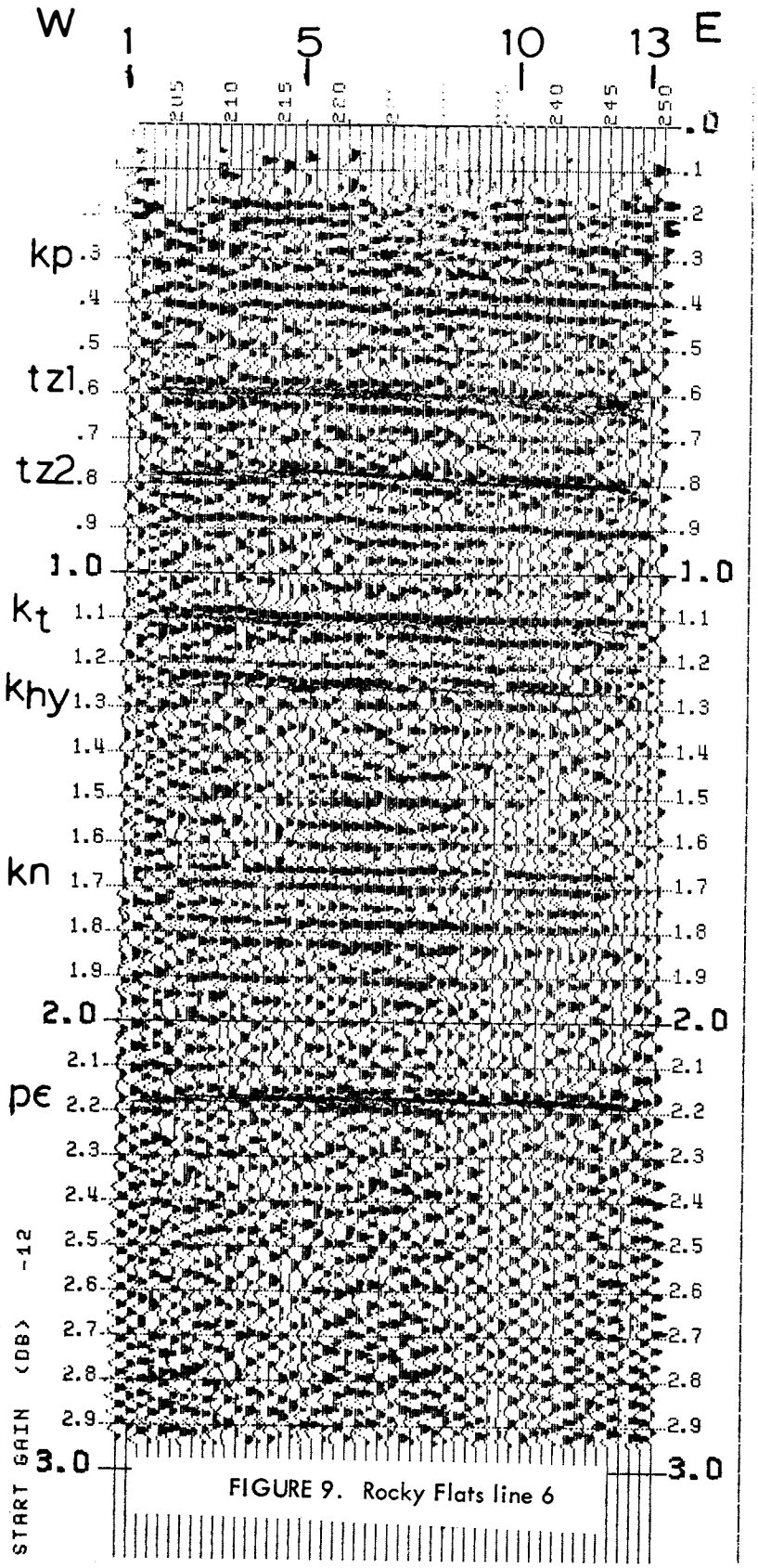


FIGURE 9. Rocky Flats line 6

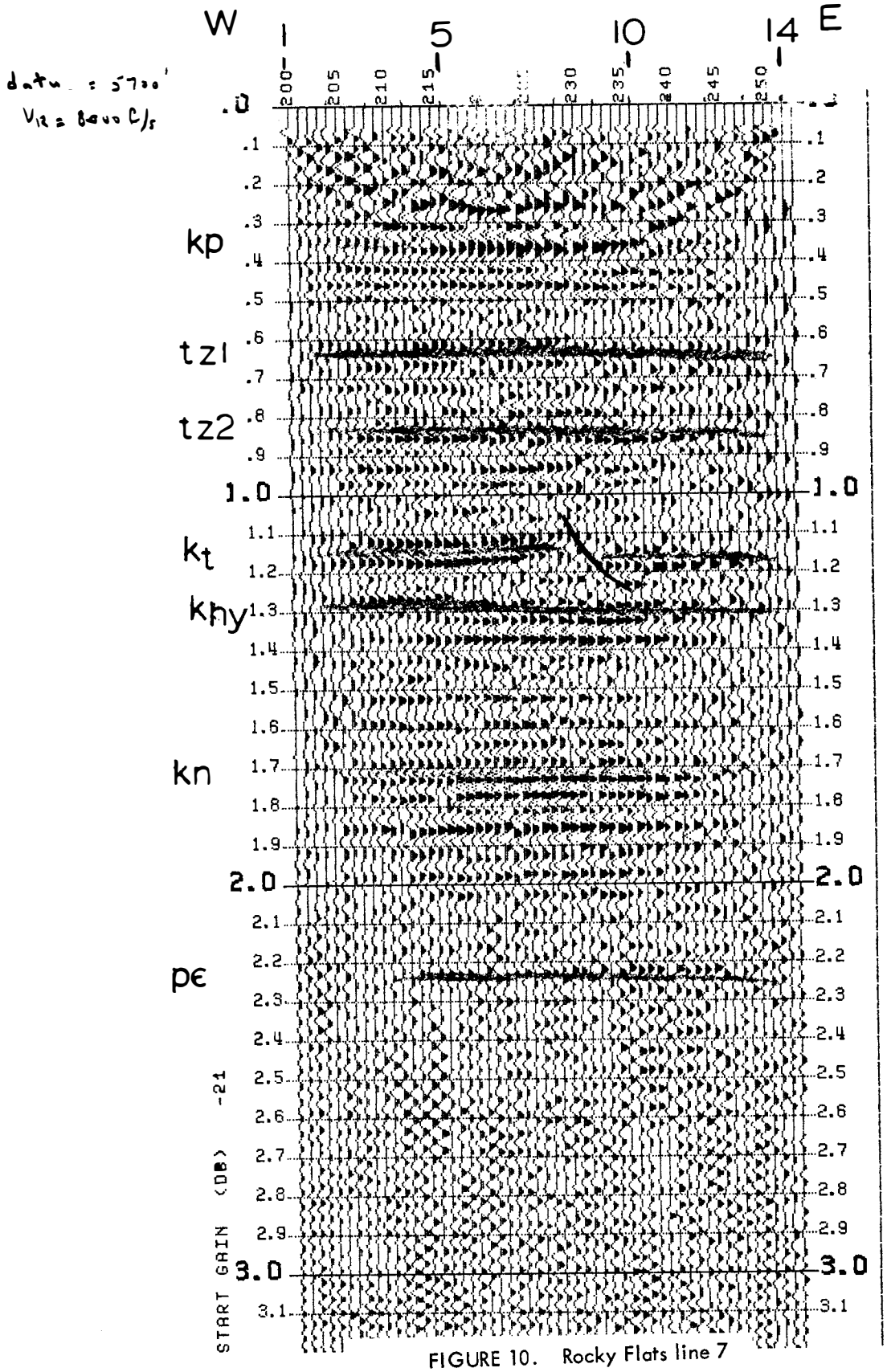


FIGURE 10. Rocky Flats line 7

datum = 5700'
V_R = 8000 ft/s

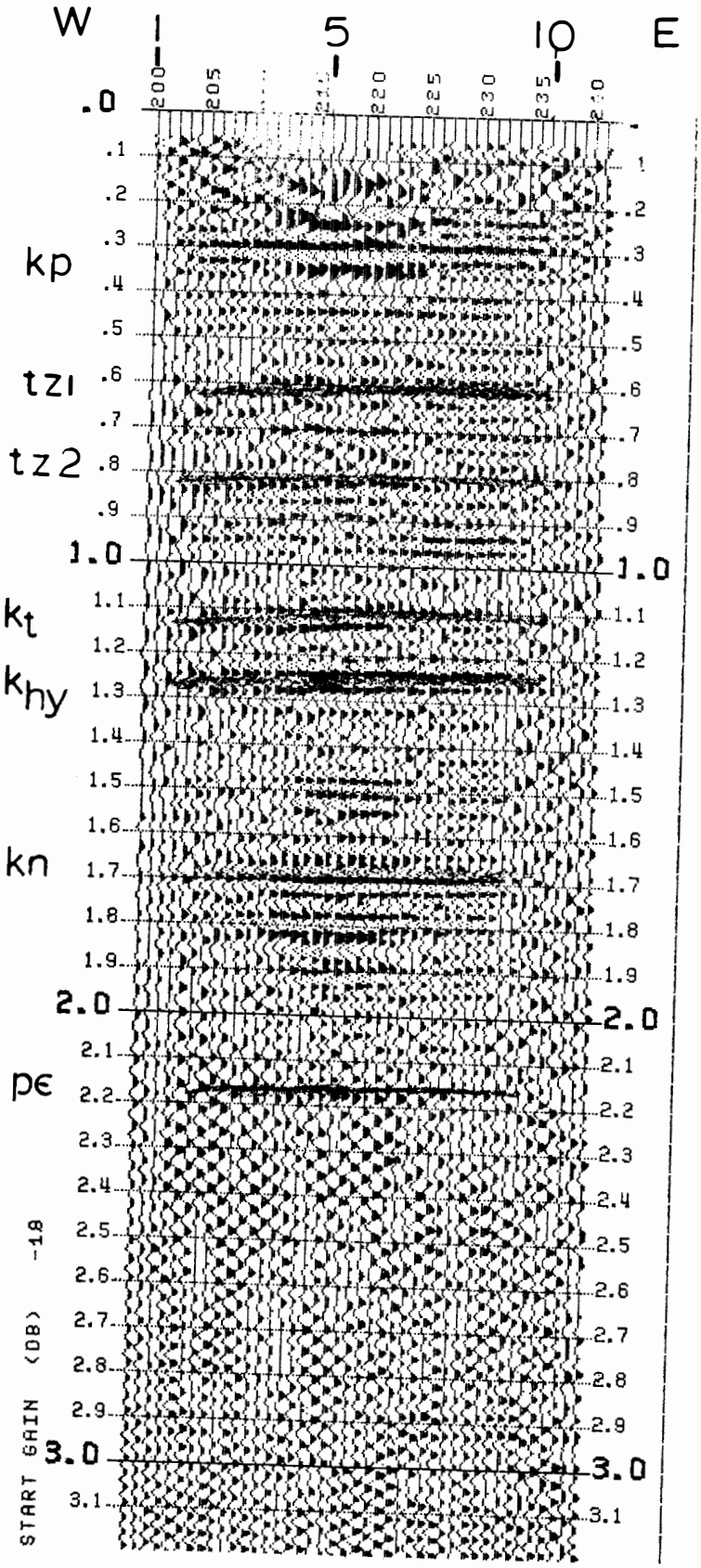
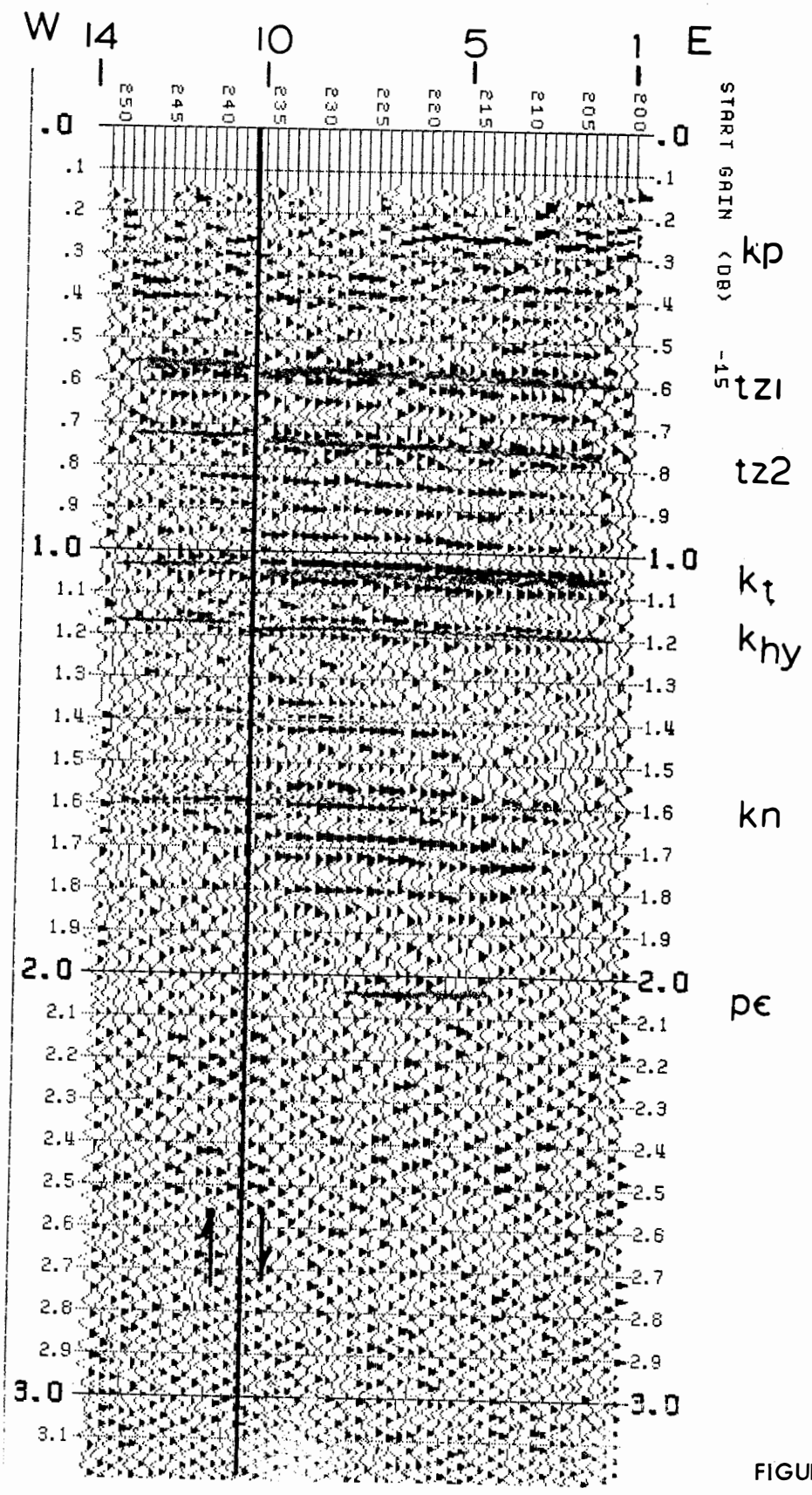


FIGURE 11. Rocky Flats line 8



Egg 1
+5700'

datum = 5700'
V_{R2} = 8000 fps

FIGURE 12. Eggleston line 1

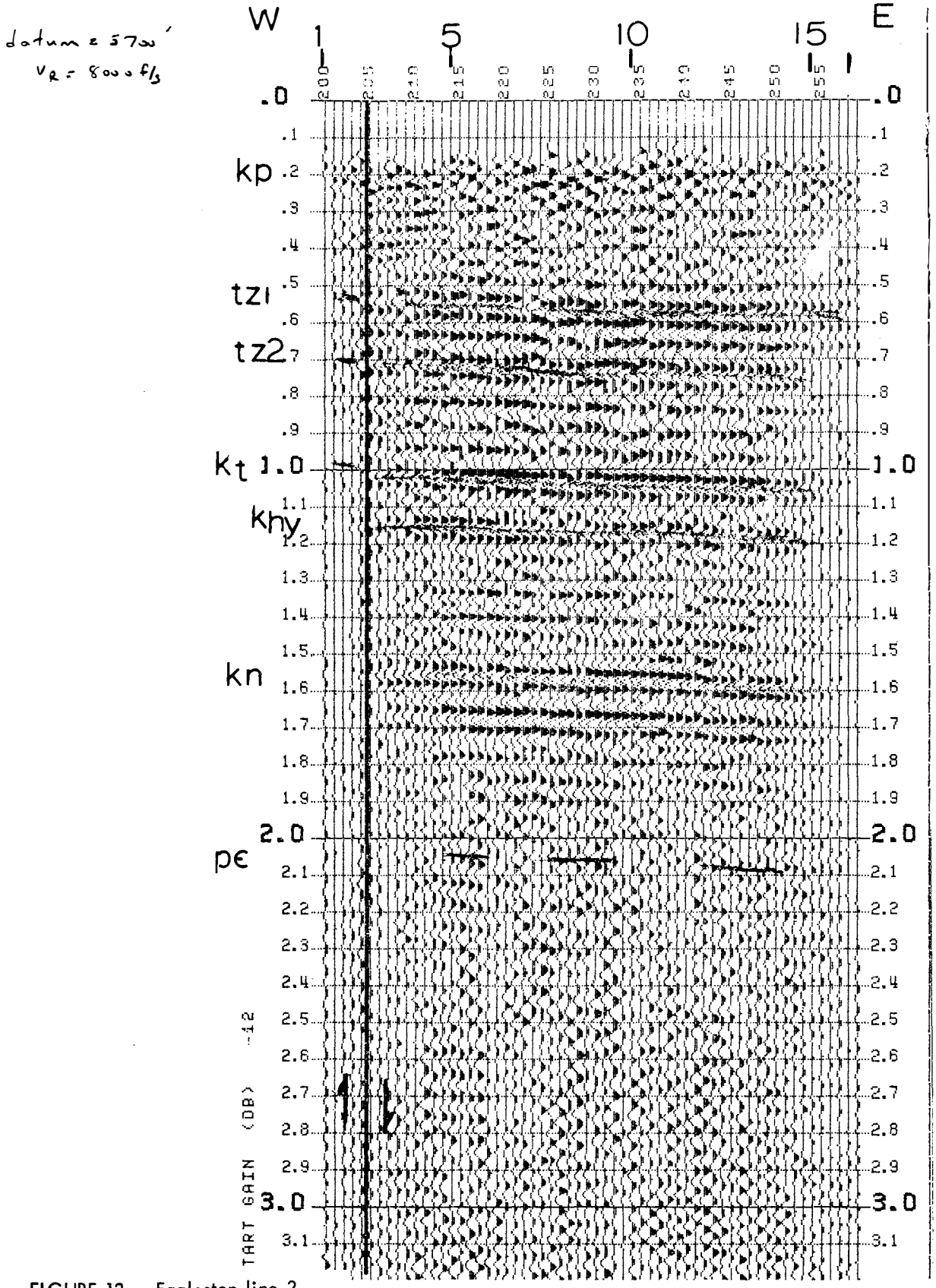
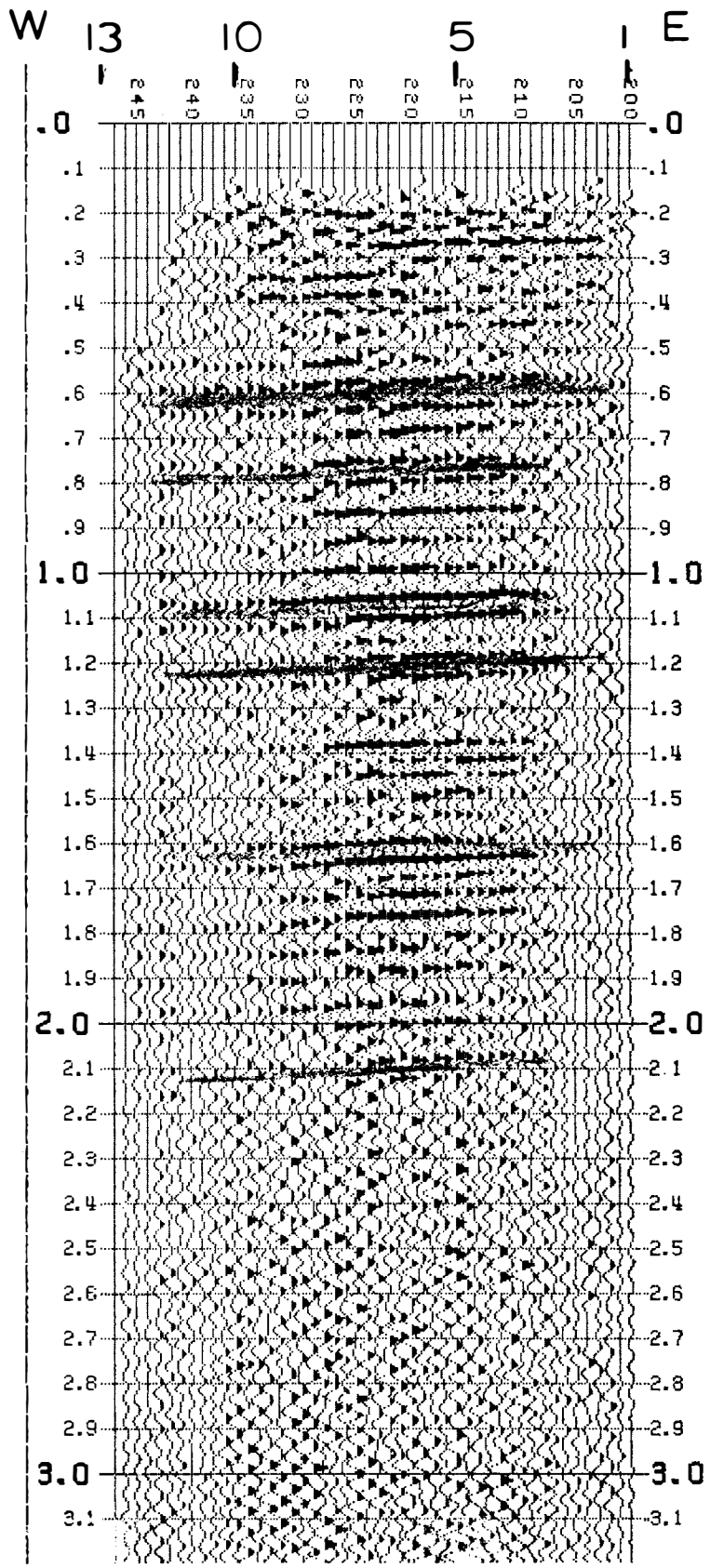


FIGURE 13. Eggleston line 2



EGG 3
5700'

datum = 5700'
V_R = 8000 ft/s

FIGURE 14. Eggleston line 3

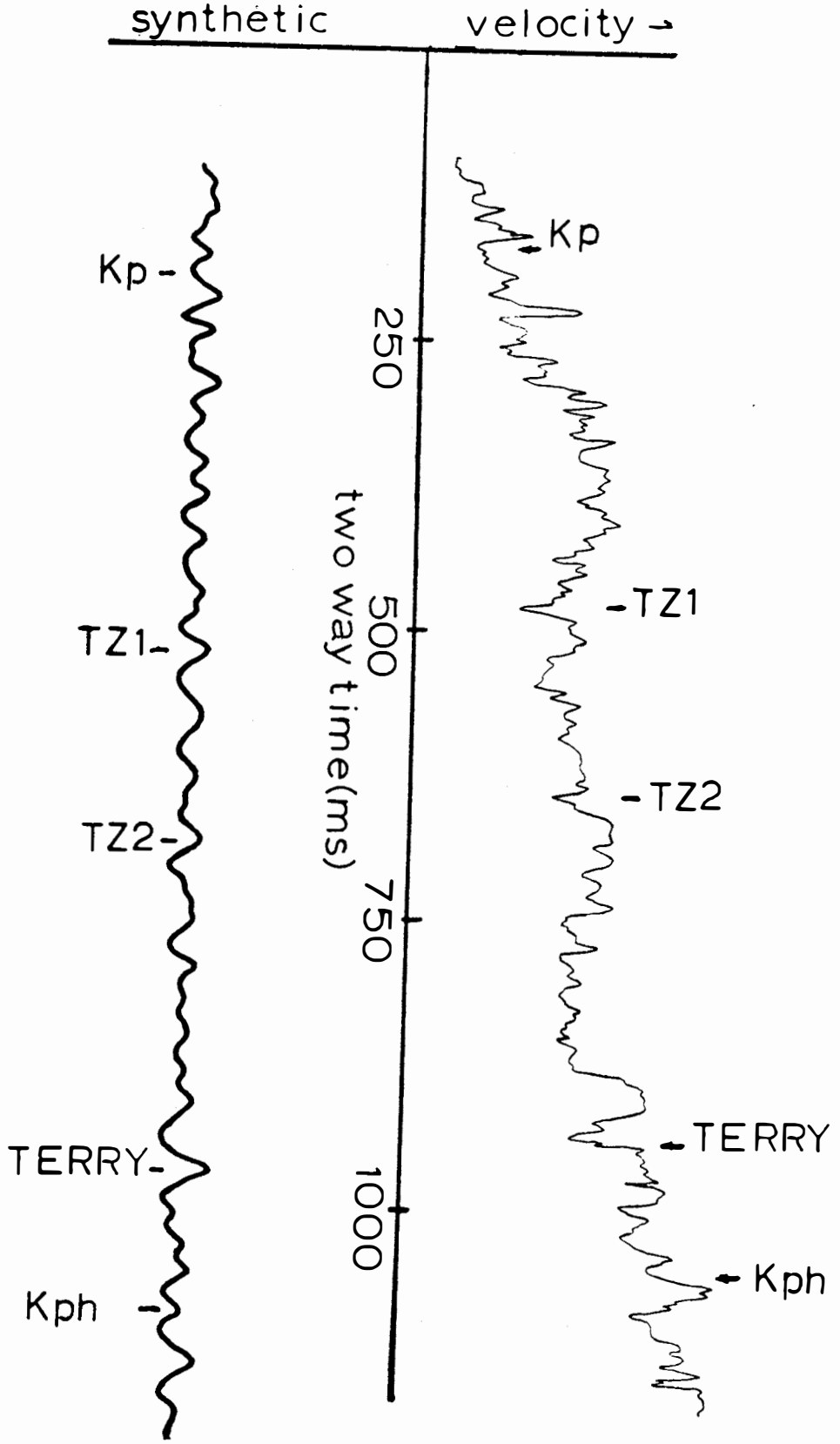


FIGURE 15. Synthetic seismogram from well 22-1S-70W

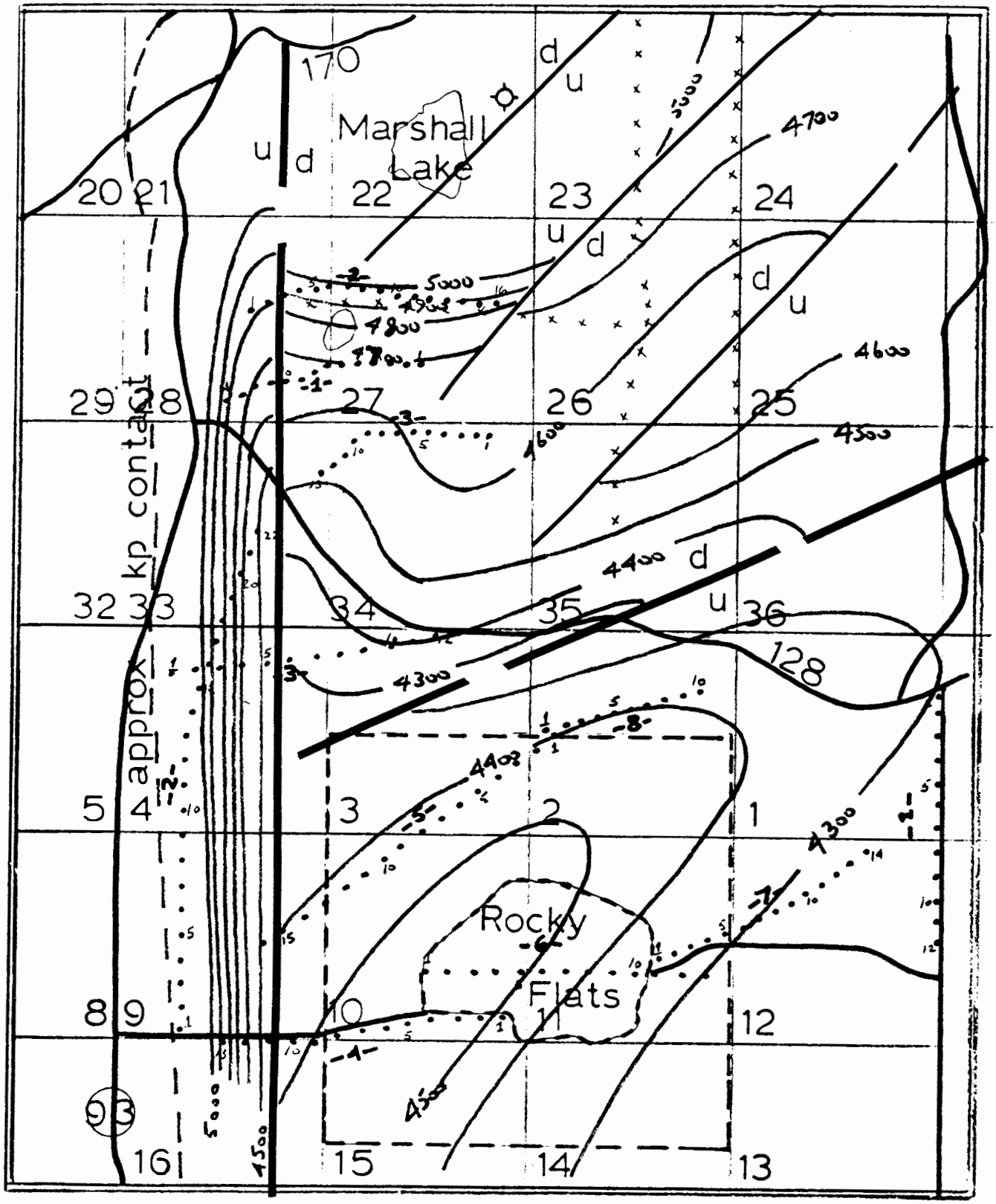


FIGURE 16. Structure contour map on the Top of the Pierre Shale (conversion velocity is 7500 ft/sec).

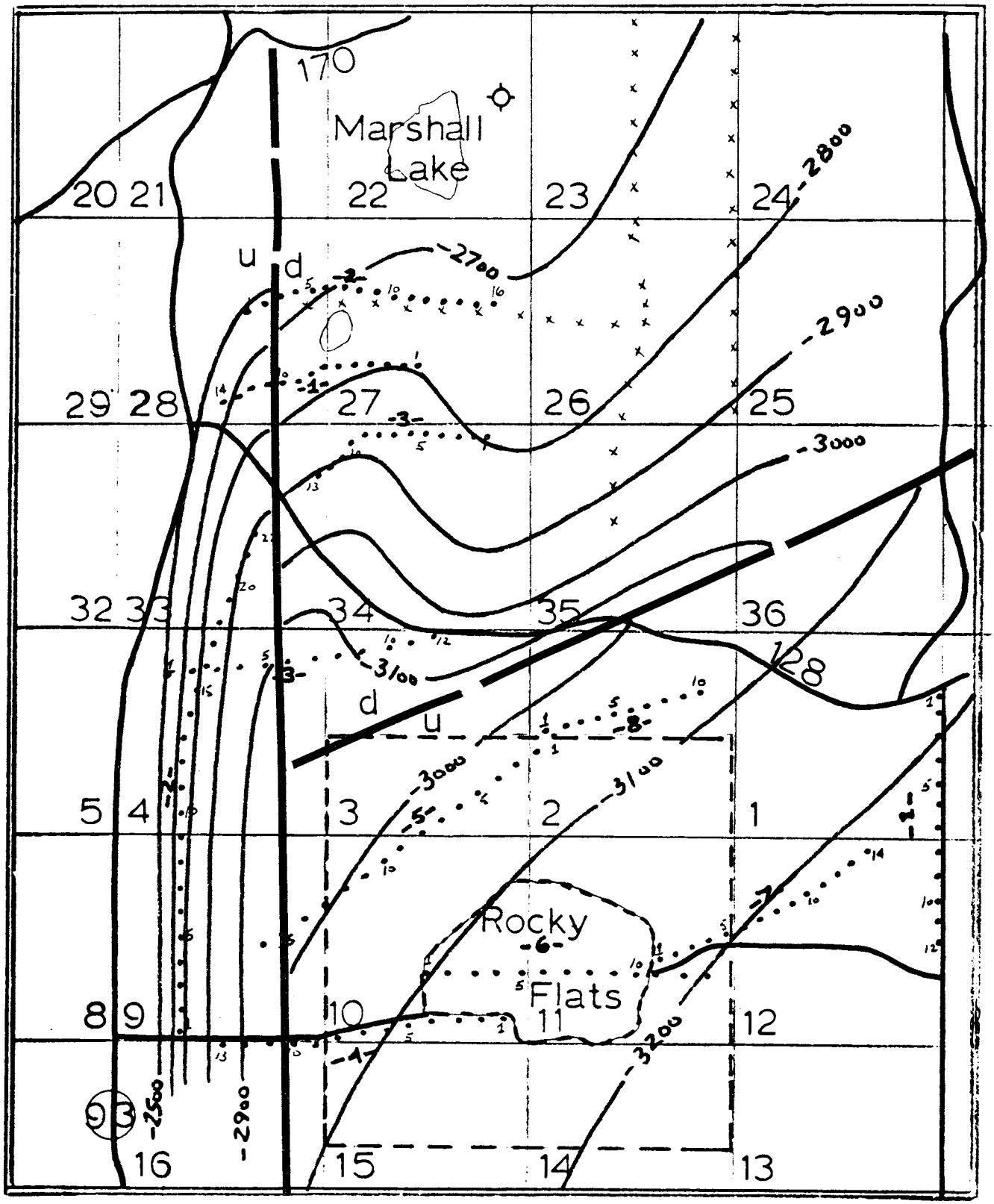


FIGURE 17. Structure contour map on the Top of the Niobrara (see Davis, 1974 for conversion velocity map).

CO-CONS-2 (formerly CO-42)
5/69
(file code CONS-14)

U. S. Dept. of Agriculture
Soil Conservation Service

CONSERVATION PLAN MAP AND SOIL AND CAPABILITY MAP LEGEND SHEET

Different kinds of soil, range sites, or woodland sites are separated on the map by solid black lines. Within each area is an identifying symbol or name. The following symbols are shown on your map:

Symbol or Site Name	Generalized Descriptions (Detailed descriptions are available in your Soil Conservation Service office.)
Overflow	In the potential plant community tall grasses form a major part of the vegetation with mid and short grasses intermixing to form an almost continuous cover. Switchgrass, lug bluestem, western wheatgrass, green needlegrass, Indiangrass, blue grama and Canada wildrye are the most abundant species. A number of other plants are present in small amounts. Production can reach 3000 pounds of air dry vegetation per acre per year.
Fair Condition	In fair condition western wheat, Kentucky bluegrass (an introduced species) and hairy grama are the dominant species. Rush, annual brome, switchgrass, junegrass, and needle and thread are present in lessor amounts. Numerous other plants are present in trace amounts. Present production is 1200-1300 pounds of air dry vegetation per acre per year.
Wet Meadow	In the potential plant community switchgrass, Indian grass, lug bluestem and prairie cordgrass are the dominant grasses. Sedges and rushes occur as an understory but are not prominent. A variety of other grasses and perennial forbs, along with shrubs such as wild rose, can be expected, but should be well scattered. Production can reach 4000+ pounds of air dry vegetation per acre per year.
Fair Condition (FC-)	In low fair condition Baltic rush is the dominant plant. Nebraska sedge, Kentucky bluegrass, slender wheatgrass, sleepy grass and canada thistle are also prominent. A number of other forbs appear in small amounts. Production is presently around 1800+ pounds of air dry vegetation per acre per year.

CO-CONS-2 (formerly CO-42)
5/69
(file code CONS-14)

U. S. Dept. of Agriculture
Soil Conservation Service

CONSERVATION PLAN MAP AND SOIL AND CAPABILITY MAP LEGEND SHEET

Different kinds of soil, range sites, or woodland sites are separated on the map by solid black lines. Within each area is an identifying symbol or name. The following symbols are shown on your map:

Symbol or Site Name	Generalized Descriptions (Detailed descriptions are available in your Soil Conservation Service office.)
Clayey Foothill	In the potential plant community, Western wheatgrass, green needlegrass and needle and thread dominate the site. Sandberg bluegrass, blue grama, buffalograss and Indian ricegrass are present in lesser amounts. A number of forbs are present in small amounts. Production can reach 1000+ pounds of air dry vegetation per acre per year.
Excellent Condition (EC)	In excellent condition western wheatgrass and green needle grass are the dominant grasses. Cheatgrass, biscutroot, curlycup gumweed, salsify, comandra and a number of other forbs are present in small amounts. Production is 1000-1400+ pounds of air dry vegetation per acre per year.
Good Condition (GC)	In good condition Western wheatgrass, junegrass, green needle grass, buffalograss and Kentucky bluegrass dominate the site. A large number of forbs appear in small amounts. Production is around 800-900 pounds of air dry vegetation per acre per year.
Fair Condition (FC)	In fair condition buffalograss, Kentucky bluegrass and western wheatgrass dominate this site. Small amounts of cheatgrass, salsify and other forbs are present. Production is 300-400 pounds of air dry vegetation per acre per year.

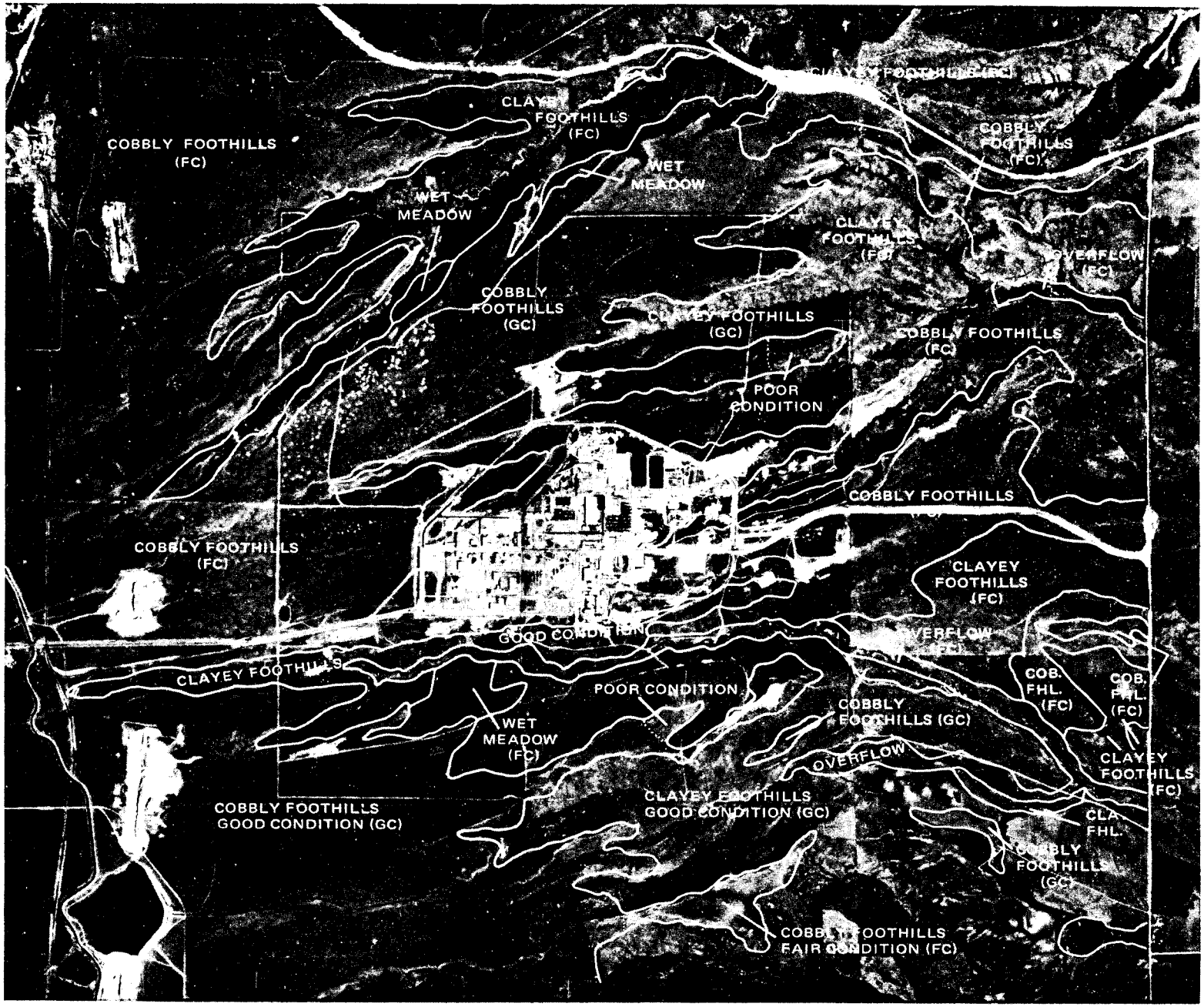
CO-CONS-2 (formerly CO-42)
5/69
(file code CONS-14)

U. S. Dept. of Agriculture
Soil Conservation Service

CONSERVATION PLAN MAP AND
SOIL AND CAPABILITY MAP LEGEND SHEET

Different kinds of soil, range sites, or woodland sites are separated on the map by solid black lines. Within each area is an identifying symbol or name. The following symbols are shown on your map:

Symbol or Site Name	Generalized Descriptions (Detailed descriptions are available in your Soil Conservation Service office.)
Cobbly Foothill	In the potential plant community lug bluestem, little bluestem, mountain muhly, sideoats grama, prairie dropseed, switchgrass, yellow indiangrass and needle and thread are the dominant grasses. They are mixed with lessor amounts of blue grama, junegrass, and western wheatgrass. Cudweed sage, hairy goldaster, winged buckwheat, sandwort, purple prairie clover, penstemon and a number of other forbs are present in small amounts. Production can reach 2,500 pounds of air dry vegetation per acre per year.
Excellent Condition (EC)	In excellent condition the composition is close to that listed above (near the potential) with small amounts of annual brome, prickly pear and fringed sage present. Production is near 2000 pounds of air dry vegetation per acre per year.
Good Condition (GC)	In good condition needle and thread is the dominant grass. Little bluestem, sedge, sideoats grama and blue grama are also prominent. A large number of forbs are present in small amounts. Production ranges from 1200-1500 pounds of air dry vegetation per acre per year.
Fair Condition (FC)	In fair condition needle and thread, junegrass, western wheatgrass, buffalograss, little bluestem and annual brome are the dominant grasses. Sedge is also prominent. A large number of forbs are present with hairy goldaster dominating some small areas. Production ranges from 600-900 pounds of air dry vegetation per acre per year.
Poor Condition (PC)	Disturbed areas where excavation, etc., has taken place fall into this condition. Cheatgrass, wormwood, sweetclover, snakeweed, western ragweed, in some areas annual rye (seeded), and many forbs dominate the site. Only trace amounts of the potential plant community appear. Production averages around 300 pounds of air dry vegetation per acre per year.


COBBLY FOOTHILLS (FC)
CLAYEY FOOTHILLS (FC)
WET MEADOW
WET MEADOW
COBBLY FOOTHILLS (FC)
CLAYEY FOOTHILLS (FC)
OVERFLOW (FC)
COBBLY FOOTHILLS (GC)
CLAYEY FOOTHILLS (GC)
COBBLY FOOTHILLS (FC)
POOR CONDITION
COBBLY FOOTHILLS
COBBLY FOOTHILLS (FC)
CLAYEY FOOTHILLS (FC)
GOOD CONDITION
OVERFLOW
CLAYEY FOOTHILLS
COB. FHL. (FC)
COB. FHL. (FC)
POOR CONDITION
COBBLY FOOTHILLS (GC)
WET MEADOW (FC)
OVERFLOW
CLAYEY FOOTHILLS (FC)
COBBLY FOOTHILLS GOOD CONDITION (GC)
CLAYEY FOOTHILLS GOOD CONDITION (GC)
CLA FHL.
COBBLY FOOTHILLS (GC)
COBBLY FOOTHILLS FAIR CONDITION (FC)

UNITED STATES DEPARTMENT OF AGRICULTURE

SOIL CONSERVATION SERVICE

SUBJECT: SOIL SURVEY - Soil Survey and Interpretations for Rockwell International - Rocky Flats Division Request DATE. 12-18-75

TO: Doug Lofstedt, Acting DC, Golden Field Office, SCS

Attached is the following:

1. Soil survey map on a scale of 1:24,000, mapped in accordance with current soil survey policy and procedure. (Also a negative of soil map.)

2. Soil map unit descriptions containing information concerning physiography, soil characteristics, use and management.

3. Soil series interpretations for Denver, Kutch, Nederland, Nunn and Valmont Series.

4. General description of soils for area.

Soil interpretations are from the draft manuscript for the Jefferson County Soil Survey which is now in progress and is to be completed December 1978. Draft manuscript materials for the soil survey are maintained in the Golden SCS Field Office and Jeffco Soil Survey Office located at the Denver Federal Center, Building 41.

Alan E. Amen

Alan E. Amen
Party Leader, Jeffco Soil Survey

SOIL SURVEY - ROCKY FLATS PLANT

A soil survey map of the area requested has been made on a scale of 1:24,000 in accordance with current soil survey policy and procedure.

Attached are the following Soil Interpretations:

(1) Soil map unit descriptions containing information concerning physiography, relief, soil characteristics, use and management.

(2) Soil Survey Interpretations for the Denver, Kutch, Netherland, Nunn and Valmont Soil Series.

Additional information for specific areas can be made available.

SOIL SURVEY LEGEND FOR ROCKY FLATS REQUEST

2A	Alluvial and Stream Channel Lands, 0 to 2 Percent Slope
8A	Nunn Cla Loam, 0 to 3 Percent Slope
8B	Nunn Clay Loam, 3 to 5 Percent Slope
8C	Nunn Clay Loam, 5 to 9 Percent Slope
14C	Denver Clay Loam, 5 to 9 Percent Slope
18A	Englewood Clay Loam, 0 to 3 Percent Slope
28	Midway Clay Loam, 5 to 28 Percent Slope
41D	Kutch-Denver Clay Loam, 9 to 18 Percent Slope
X41	Denver-Kutch-Midway Soils, 9 to 25 Percent Slope
50A	Nederland Cobbly Gravelly Sandy Loam, 0 to 3 Percent Slope
50E	Nederland Cobbly Gravelly Sandy Loam, 9 to 45 Percent Slope
51A	Valmont Gravelly Clay Loam, 0 to 3 Percent Slope
52D	Unnamed (Rocky Flats) Gravelly Loam, 9 to 28 Percent Slope
X52	Unnamed (Rocky Flats) - Nunn Complex, 5 to 9 Percent Slope
53D	Moderately Steep and Steep Gravelly Land, 15 to 45 Percent Slope
90	Arguistolls, Wet, 5 to 12 Percent Slope
101	Borrow Area-Shales and Clayey Soils
GP	Gravel Pit

CAPABILITY GROUPS OF SOILS

Capability classification is the grouping of soils to show, in a general way, their suitability for most kinds of farming. It is a practical classification based on limitations of the soils, the risk of damage when they are used, and the way they respond to treatment. The soils are classified according to degree and kind of permanent limitation, but without consideration of major and generally expensive landforming that would change the slope, depth, or other characteristics of the soils; and without consideration of possible but unlikely major reclamation projects.

Roman numerals are used to show the 8 broad Capability Classes and letters follow the class numeral to indicate the principal problem or hazard. Classes and sub-classes used are as follows:

Class I - Few or no limitations that restrict choice of crops or require conservation measures.

Class II - Some limitations that reduce the choice of crops or require moderate conservation measures.

Class III - Severe limitations that reduce choice of crops or require special conservation practices or both.

Class IV - Very severe limitations that restrict the choice of crops, require very careful management, or both.

Class V - Not suited for cultivation but has few or no hazards when used for pasture, range, woodland or wildlife.

Class VI - Not suited for cultivation. Severe limitations. Suited for range, pasture, woodland or wildlife with careful management and needed conservation practices.

Class VII - Not suited for cultivation. Very severe limitations. Suited for range, woodland or wildlife uses if carefully managed. Usually cannot apply physical practices such as pitting, furrowing, seeding, etc.

Class VIII - Not suited for cultivation, range, pasture or woodland. Suited only for recreation, wildlife, water supply or esthetic purposes.

e - Erosion by wind or water is the major problem.
w - Excessive water such as wetness, overflow, or high water table.
s - Major problem is in the soil. It may be too shallow, too heavy, stony, low in fertility, salty, alkaline or have low moisture capacity.
c - Climate is the major hazard. Growing season may be very short, there is a shortage of rainfall or both.

Examples:

IIIe - Class III land where erosion is the major hazard.

IVc - Class IV land where the climate is the major problem.

2A--Mixed Alluvial Lands Bordering Channels and Stream Courses

These are deep, well drained, frequently flooded loamy soils occurring along intermittent drainage channels and creeks. Soils are forming in stratified alluvial fill materials that are extremely variable in texture, including sandy loams, gravelly and cobbly materials, and loams, derived from mixed sources. Slopes are nearly level to gently sloping.

Included in this unit are channels and creek beds.

These lands are used primarily for grazing, and have aesthetic value in the landscape. These lands are not suited for urban uses because of the flooding hazard. They are not suited for cultivation in that they are divided by stream channels, subject to frequent flooding and have highly variable textures.

Permeability is moderate to rapid. Available water capacity is low to moderate. Effective rooting depth is 60 inches or more. Erosion hazards are severe.

The rangeland vegetation on this unit is typical of the Overflow Range Site. Dominant grasses are switchgrass, big bluestem, western wheatgrass, Indian grass, and blue grama. Controlled grazing is necessary to maintain vigor in key forage species. Periodic summer deferment of grazing will help improve or maintain range condition.

Capability Subclass: VIw

Overflow Range Site.

8A--Nunn Clay Loam, 0 to 3 Percent Slope

This is a deep, well drained soil formed in calcareous loamy mixed alluvium deposited on terraces, fans and uplands. Slopes are nearly level to gently sloping.

Included in this unit are Denver clay loams and Englewood clay loams on slopes of 0 to 3 percent.

Typically the surface layer is very dark grayish brown clay loam about 8 inches thick. The subsoil is dark grayish brown heavy clay loam or clay about 18 inches thick. The substratum is calcareous loam and light clay loam alluvium extending to 60 inches or more.

Permeability is slow. Effective rooting depth is 60 inches or more. Available water capacity is high. Surface runoff is slow, and wind and water erosion hazards are slight. These soils are somewhat difficult to till because of the clay loam surface and subsoil.

This soil is used for irrigated and nonirrigated cropland, grazing, and urban uses.

Management concerns in irrigated areas of this soil are efficient use of irrigation water, and preventing soil loss. This soil is suited to furrow and border irrigation.

In nonirrigated cropland areas the main objectives of management are conserving moisture and protecting the soil from erosion. Practices such as stubble mulch tillage and incorporating crop residues in and on the surface are needed to protect surface soil blowing and improve water infiltration. The number of tillage operations should be kept to a minimum. Tillage pans form easily if the soil is tilled when wet. Chiseling or subsoiling breaks up tillage pans and improves water infiltration.

Rangeland vegetation is mostly mid-grasses and cool season forbs typical of the clayey foothills range site. Dominant grasses are western wheatgrass, green needlegrass, blue grama, buffalo grass, Indian rice grass and native bluegrasses. Common forbs are winter fat, small pod vetch, fringed sage and arnica. Controlled grazing is needed to maintain vigor in key forage species. Periodic summer deferment of grazing will help improve or maintain range conditions. Fencing and careful location of livestock watering facilities improves grazing distribution.

Windbreaks and ornamental plantings are difficult to establish on this soil due to limited available water. Summer fallow a year before planting and supplemental watering are necessary for the survival and establishment of plantings.

This soil is limited for homesites and roads by high shrink-swell potential. This can be overcome by special building designs or backfilling with more suitable material.

Capability Subclass: IIe, irrigated.
IIIs, nonirrigated.

Clayey Foothills Range Site.

8B--Nunn Clay Loam, 3 to 5 Percent Slopes

This is a deep, well drained soil on gently sloping alluvial fans and valley sideslopes. It formed in calcareous clayey alluvial material. The average annual precipitation is 13 to 15 inches. Slopes are gently sloping.

Included in this unit are small areas of Denver soils.

Typically the surface layer is very dark grayish brown clay loam about 6 inches thick. The subsoil is dark grayish brown heavy clay loam and clay about 14 inches thick over brown calcareous clay loam about 5 inches thick. The substratum is calcareous loam and light clay loam alluvium extending to 60 inches or more.

Permeability is slow. Effective rooting depth is 60 inches or more. Available water capacity is high. Surface runoff is rapid, and wind and water erosion hazards are moderate. These soils are somewhat difficult to till because of the clay loam surface and subsoils. They have a moderate shrink-swell potential.

This soil is used for irrigated and nonirrigated cropland, grazing and urban uses.

Management concerns in irrigated areas of this soil are efficient use of irrigation water and preventing soil loss. Slopes on this unit require contour furrow or contour border irrigation.

Rangeland vegetation is mostly mid grasses and cool season forbs typical of the clayey foothills range site. Dominant grasses are western wheatgrass, green needlegrass, blue grama, buffalo grass, Indian ricegrass and native bluegrasses. Common forbs are winter fat, small pod vetch, fringed sage, and arnica. Controlled grazing is needed to maintain vigor in key forage species. Periodic summer deferment of grazing will help improve or maintain range conditions. Fencing and careful location of livestock watering facilities improves grazing distribution.

Windbreaks and ornamental plantings are difficult to establish on this soil due to limited available water. Summer fallow a year before planting and supplemental watering are necessary for the survival and establishment of plantings.

This soil is limited for homesites and roads by slope and high shrink-swell potential. These can be overcome by compensating measures such as special building designs or backfilling with more suitable materials.

Capability Subclass: IIIe, irrigated.
IIIe, nonirrigated.

Clayey Foothills Range Site.

8C--Nunn Clay Loam, 5 to 9 Percent Slope

This is a deep, well drained soil on moderately sloping valley sideslopes and ridges. It formed in calcareous clayey alluvium. The average annual precipitation is about 15 inches. Slopes are moderately sloping.

Included in this unit are small areas of Denver clay loam on 5 to 9 percent slopes.

Typically the surface layer is very dark grayish brown clay loam about 5 inches thick. The subsoil is dark grayish brown heavy clay loam and clay about 14 inches thick over brown calcareous clay loam about 5 inches thick. The substratum is calcareous loam and light clay loam alluvium extending to 60 inches or more.

Permeability is slow. Effective rooting depth is 60 inches or more. Available water capacity is high. Surface runoff is rapid, water erosion hazard is high and wind erosion hazard is moderate. These soils are somewhat difficult to till because of the clay loam surface and subsoil textures. They have a moderate shrink-swell potential.

This soil is used for irrigated and nonirrigated cropland, grazing and urban uses.

Management concerns in irrigated areas of this soil are efficient use of irrigation water and preventing soil loss. Slopes on this unit require contour furrow or contour border irrigation.

In nonirrigated cropland areas the main objectives of management are conserving moisture and protecting the soil from erosion. Practices such as stubble mulch tillage and incorporating crop residues in and on the surface are needed to protect surface soil blowing and improve water infiltration. The number of tillage operations should be kept to a minimum.

Tillage pans form easily if the soil is tilled when wet. Chiseling or subsoiling breaks up tillage pans and improves water infiltration.

Rangeland vegetation is mostly midgrasses and cool season forbs typical of the clayey foothills range site. Dominant grasses are western wheatgrass, green needlegrass, blue grama, buffalo grass, Indian rice grass and native bluegrasses. Common forbs are winter fat, small pod vetch, fringed sage and arnica. Controlled grazing is needed to maintain vigor in key forage species. Periodic summer deferment of grazing will help improve or maintain range conditions. Fencing and careful location of livestock watering facilities improves grazing distribution.

Windbreaks and ornamental plantings are difficult to establish on this soil due to limited available water. Summer fallow a year before planting and supplemental watering are necessary for the survival and establishment of plantings.

This soil is limited for homesites and roads because of high shrink-swell potential and slope. This can be overcome by special building designs or backfilling with more suitable material.

Capability Subclass: IVe, irrigated.
IVe, nonirrigated.

Clayey Foothills Range Site.

14C--Denver Clay Loam, 5 to 9 Percent Slopes

This is a deep, well drained soil on upland hills, ridges and side-slopes. It formed in calcareous, clayey alluvium.

Included in this unit are small areas of Kutch clay loam in crest positions on slopes of 5 to 9 percent.

Typically the surface layer is grayish brown clay loam about 4 inches thick. The subsoil is about 30 inches thick brown clay with pale brown calcareous clay in the lower part. The underlying material is very pale brown clay loam that is strongly calcareous extending to a depth of 60 inches or more.

Permeability is slow. Available water capacity is high. Effective rooting depth is 60 inches or more. Surface runoff is moderate, and water and wind erosion hazard is moderate. These soils have a high shrink-swell potential. They are moderately alkaline.

This soil is used for irrigated and nonirrigated cropland and grazing. Clayey surface and subsoil layers make tillage difficult.

Management concerns in irrigated areas of this soil are efficient use of irrigation water and preventing soil loss. Slopes on this unit require contour furrow or contour border irrigation. Shorter irrigation runs and smaller amounts of water are needed to minimize soil loss.

In nonirrigated areas, the main concerns of management are conserving moisture and protecting the soil from erosion. Practices such as stripcropping perpendicular to the prevailing wind, and leaving stubble mulch on soil not protected by a growing crop will help to prevent wind erosion. Incorporating crop residues in or on the surface is also an effective means of improving soil tilth and conserving available moisture.

Rangeland vegetation is mostly mid grasses and cool season forbs typical of the Clayey Foothills Range Site. Dominant grasses are western wheatgrass, green needlegrass, blue grama, buffalo grass, Indian ricegrass, and native bluegrasses. Common forbs are winterfat, small pod vetch, fringed sage, and arnica. Controlled grazing is needed to maintain vigor in key forage species. Periodic summer deferment of grazing will help improve or maintain range conditions. Fencing and careful location of livestock watering facilities improve grazing distribution.

Windbreaks and ornamental plantings are difficult to establish on this soil due to limited available water. Summer fallow a year before planting and supplemental watering are necessary for the survival and establishment of plantings.

This soil has moderate limitations for homesites and roads due to slope and high shrink-swell potential. These problems may be overcome with special designs and measures such as backfilling. Soil loss to erosion during construction can be minimized by emergency tillage or mulching.

Capability Subclass: IVe, irrigated.
IVe, nonirrigated.

Clayey Foothills Range Site.

18A--Englewood Clay Loam, 0 to 3 Percent Slopes

This is a deep, well drained soil forming on gently sloping alluvial fans, flood plains and drainage ways. It formed in calcareous clayey alluvial parent materials weathered from sedimentary rock. Average annual precipitation is 13 to 15 inches. Slopes are nearly level to gently sloping.

Included in this unit are small areas of Denver clay loam on slopes of 0 to 3 percent.

Typically the surface layer is very dark grayish brown clay loam about 5 inches thick. The subsoil is very dark grayish brown clay about 25 inches thick. The substratum is olive gray heavy clay loam with visible calcium carbonate concretions extending to depths of 60 inches or more.

Permeability is slow. Effective rooting depth is 60 inches or more. Available water capacity is high. Surface runoff is rapid, water erosion hazard and wind erosion hazards are slight. These soils are subject to occasional flooding during spring and summer months.

This soil is used for irrigated and nonirrigated cropland, range and urban uses. Tillage may be difficult due to the amount of clay in the soil, and operations should be kept to a minimum to prevent compaction.

Management concerns in irrigated areas of this soil are effecient use of irrigation water and measures to prevent salt buildup. Using irrigation only when needed will prevent excess upward salt movement. These soils are suitable for border and furrow irrigation.

In nonirrigated areas, the main concerns of management are conserving moisture and protecting the soil from erosion. Practices such as stripcropping perpendicular to the prevailing wind and leaving stubble mulch on soil not protected by a growing crop help to prevent wind erosion. Incorporating crop residues in or on the surface is also an effective means of improving soil tilth, conserving moisture, and protecting soil.

Rangeland vegetation is mostly midgrasses and cool season forbs, typical of the Clayey Foothills Ran Site. Dominant grasses are western wheatgrass, green needlegrass, blue grama, buffalo grass, Indian ricegrass, and native bluegrasses. Common forbs are winter fat, small pod vetch, fringed sage, and arnica. Controlled grazing is needed to maintain vigor in key forage species. Periodic summer deferment of grazing will help improve or maintain range conditions. Fencing and careful location of livestock watering facilities improves grazing distribution.

Windbreaks and ornamental plantings are difficult to establish on this soil due to limited available water. Summer fallow a year before planting and supplemental watering are necessary for the survival and establishment of plantings.

This soil is limited for homesites and roads by high shrink-swell potential. This can be overcome by compensating measures such as special building designs or backfilling with more suitable materials.

Capability Subclass: IIs, irrigated.
IIIe, nonirrigated.

Clayey Foothills Range Site.

28--Midway Clay Loam, 5 to 28 Percent Slope

This soil consists of shallow, well drained soils on upland ridges, knobs and sideslopes. It formed in mildly alkaline, loamy materials derived from interbedded shale. Slopes are moderately sloping to moderately steep.

In a representative profile the surface layer is a grayish brown, mildly alkaline clay loam about 4 inches thick. The underlying material is a light olive brown, mildly alkaline clay loam about 10 inches thick. At a depth of about 14 inches is an interbedded shale.

Permeability is moderate. Effective rooting depth is 9 to 20 inches and available water capacity is low. Surface runoff is medium to rapid. Erosion hazards are severe.

This soil is best suited for grazing. The native vegetation consists of grasses and forbs typical of the shaley foothills range site. Range management practices such as deferred grazing and proper grazing use are essential in maintaining forage production.

Soil depth and slope are severe limiting features when considering these soils for homesites, roads and urbanization.

Capability Subclass: VIIe.

Clayey Foothill Range Site.

X41--Denver-Kutch-Midway Soils, 9 to 25 Percent Slope

These strongly sloping to moderately steep soils are on upland ridges and valley side slopes bordering drainage ways. Areas are divided by many secondary drainage ways. The average annual precipitation ranges from 13 to 17 inches. Denver clay loam soils make up about 60 percent of the unit, Kutch clay loam about 25 percent and Midway clay loam about 15 percent. The Denver soil is on mid-slope and foot slope positions with slopes of 9 to 18 percent. The Kutch soils are on crest slope positions with 9 to 25 percent slopes. The Midway soils are on steeper knob-like areas with slopes of 18 to 25 percent, where shale lies near the surface, and commonly have 5 to 25 percent cobble scattered on the surface.

Included in this unit are small areas with slopes of 25 to 35 percent.

The Denver soil is a deep, well drained soil. It formed in calcareous, clayey alluvium.

Typically the surface layer is grayish brown clay loam about 5 inches thick. The subsoil is about 22 inches thick, brown clay and is calcareous in the lower part. The underlying material is very pale brown clay loam that is strongly calcareous extending to a depth of 60 inches or more.

Permeability is slow, available water capacity is high. Effective rooting depth is 60 inches or more. Surface runoff is rapid and erosion hazard is high.

The Kutch soil is a moderately deep, well drained soil. It formed in calcareous, clayey materials weathered from shale.

Typically the surface layer is grayish brown clay loam about 4 inches thick. The subsoil is dark grayish brown and light brownish gray clay about 17 inches thick. The substratum layer is light gray clay loam about 12 inches thick. Soft shale is at a depth of about 33 inches.

Permeability is slow. Effective rooting depth is 20 to 40 inches. Available water capacity is moderate. Surface runoff is rapid, water erosion hazard is high, and wind erosion hazard is moderate.

The Midway soil is a shallow, well drained soil. It formed in mildly alkaline, clay loam materials derived from shale.

Typically the surface layer is a grayish brown, mildly alkaline clay loam about 4 inches thick. The underlying material is a light olive brown, mildly alkaline clay loam about 10 inches thick. At a depth of about 14 inches is an interbedded shale.

Permeability is moderate. Effective rooting depth is 9 to 20 inches. Available water capacity is low. Surface runoff is rapid. Water erosion hazard is high.

These soils are used mainly for grazing. They are not suited for cropland.

Rangeland vegetation of this unit consists of grasses typical of the clayey foothills range site. Careful attention to proper grazing use is needed on this unit to prevent depletion because it is difficult to revegetate. Periodic deferment of grazing is an effective practice to help improve or maintain range conditions. Fencing and careful location of livestock watering facilities improve grazing distribution.

Windbreaks and environmental plantings are generally not suited on this unit. On-site investigation is needed to determine if plantings are feasible.

The primary limiting soil properties for homesites, urban developments and roads are slope, shrink-swell potential, slow permeability, and depth to bedrock in areas of midway and Kutch soils. Intensive and costly compensating measures are needed to minimize these limiting properties.

Capability Subclass: VIIe, nonirrigated.

Clayey Foothills Range Site (Denver and Kutch Soils)
Shaly Foothills Range Site (Midway Soils)

41D--Kutch-Denver Complex, 9 to 18 Percent Slopes

These strongly sloping to moderately steep soils are on uplands and valley sideslopes. The average annual precipitation is about 15 inches. Kutch clay loam, 9 to 18 percent slopes, makes up about 45 percent of the unit, and Denver clay loam, 9 to 18 percent slopes. makes up about 35 percent of the unit. The Kutch soils are on ridge crests and shale break areas where shale is within 40 inches of the surface. The Denver soils are in midslope and footslope positions where clayey alluvium locally weathered from shale has been deposited.

Included are small areas of Nunn clay loams on 5 to 9 percent slopes in foot slope positions. A few shallow Midway clay loams and shale outcrops occur in midslope and ridge crest positions on 9 to 25 percent slopes. Some shale exposures occur due to severe erosion in the unit.

The Denver soil is a deep, well drained soil. It formed in calcareous clayey alluvium.

Typically the surface layer is grayish brown clay loam about 5 inches thick. The subsoil is brown clay about 22 inches thick and is calcareous in the lower part. The underlying material is strongly calcareous very pale brown clay loam extending to 60 inches or more.

Permeability is slow. Effective rooting depth is 60 inches or more. Available water capacity is high. Surface runiff os rapid, water erosion hazard is high, and wind erosion hazard is moderate.

The Kutch soil is a moderately deep, well drained soil. It formed in calcareous clayey materials weathered from shale.

Typically the surface layer is grayish brown clay loam about 4 inches thick. The subsoil is dark grayish brown and light brownish gray clay about 17 inches thick. The substratum layer is light gray clay loam about 12 inches thick. Soft shale is at a depth of about 33 inches.

Permeability is slow. Effective rooting depth is 20 to 40 inches. Available water capacity is moderate. Surface runoff is rapid, water erosion hazard is high, and wind erosion hazard is moderate.

These soils are used mainly for grazing. They are not suited for cropland. Areas in cropland are best reseeded to grass.

The rangeland vegetation of this unit consists of grasses typical of the clayey foothills range site. Proper grazing use is necessary to prevent depletion of range because it is difficult to revegetate. Periodic deferment of grazing is an effective practice to help improve or maintain range conditions. Fencing and careful location of livestock watering facilities improves grazing distribution.

Windbreaks and environmental plantings are difficult to establish on this unit. Summer fallow a year before planting and supplemental watering will be necessary for the survival of plantings. On-site investigations are needed to determine site suitability.

The primary limiting soil properties for homesites, urban developments and roads are slope, shrink-swell potential, slow permeability and depth to bed rock. Compensating measures are necessary to overcome these limitations.

Capability Subclass: VIe, nonirrigated.
VIe, irrigated.

Clayey Foothills Range Site.

50A--Nederland Cobbly Gravelly Sandy Loam, 0 to 3 Percent Slopes

This is a deep, well drained soil on old high terraces and fans. It formed in calcareous, gravelly and cobbly loamy alluvium. The average annual precipitation is about 15 inches. Slopes are nearly to gently sloping.

Included in this unit are small areas of Valmont cobbly clay loam and Nunn clay loam, all on slopes of 0 to 3 percent.

Typically the surface layer is grayish brown, cobbly sandy loam about 4 inches thick. The upper part of the subsoil is brown cobbly sandy loam about 6 inches thick. The middle part of the subsoil is a brown cobbly sandy loam about 8 inches thick and the lower part is light brown calcareous, cobbly gravelly sandy loam. The substratum is calcareous, cobbly, gravelly loam extending to 60 inches or more. Percent of cobble ranges from 50 to 75 percent by volume.

Permeability is moderate. Effective rooting depth is 60 inches or more. Available water capacity is moderate. Surface runoff is slow and erosion hazards are slight.

This soil is used almost entirely for grazing. Some small areas are used for building sites and roads. The large amount of cobble on the surface and scattered throughout the profile limit the uses of this soil. It is not suited for cultivation.

Rangeland vegetation of this soil is typical of the cobbly foothills range site consisting mainly of Big bluestem, little bluestem, side-oats grama, mountain muhly, blue grama, switch grass, winged buck-wheat and nailwort. Proper grazing is needed to maintain quantity and quality of desirable vegetation. Combinations of stockwater develop-ment, fencing and deferred grazing help improve and maintain range condition.

Windbreaks and environmental plantings are difficult to establish on these soils. Limited available water and the large amount of cobble are the principal concerns in establishing tree and shrub plantings. Special care, consisting of summer fallow a year in advance of planting and supplemental water, is needed to insure establishment and survival of plantings.

The large amount of cobble and large stones are the primary limiting soil properties for building sites, urban development and roads.

Capability Subclass: VIIs.

Cobbly Foothills Range Site.

50E--Nederland Cobbly Gravelly Sandy Loam, 9 to 45 Percent Slopes

This is a deep, well drained soil on old high terraces, side slopes and fans. It formed in calcareous, cobbly and gravelly loamy alluvium. The average annual precipitation is about 15 inches. Slopes are strongly sloping to steep.

Included in this unit are small areas of Valmont cobbly clay loam on slopes of 9 to 18 percent in toe slope positions.

Typically the surface layer is grayish brown cobbly sandy loam about 4 inches thick. The upper part of the subsoil is a brown cobbly sandy loam about 12 inches thick. The lower part of the subsoil is light brown calcareous, cobbly gravelly sandy loam. The substratum is calcareous, cobbly gravelly loam extending to 60 inches or more. Percent of cobble ranges from 50 to 75 percent, by volume.

Permeability is moderate. Effective rooting depth is 60 inches or more. Available water capacity is moderate. Surface runoff is rapid. Water erosion hazard is severe and wind erosion hazard is slight.

This soil is used almost entirely for grazing. Some small areas are used for building sites and roads. This soil is not suited for cultivation. The large amount of cobble on the surface and scattered throughout the profile and slope limit the uses of this soil.

Rangeland vegetation of this s il is typical of the cobbly foothills range site, consisting mainly of big bluestem, little bluestem, side oats grama, mountain muhly, blue grama, switch grass, winged buckwheat and nail wart. Proper grazing is needed to maintain quantity and quality of desirable vegetation. Combination of stockwater development, fencing and deferred grazing help improve and maintain range condition.

Windbreaks and environmental plantings are difficult to establish on these soils. Limited available water and the large amount of cobble are the principal concerns in establishing trees and shrubs. Special care, consisting of summer fallow a year in advance of planting and supplemental water, is needed to insure establishment and survival of plantings.

The large amount of cobble and stones, and slope are the primary limiting factors for building sites, urban development and roads.

Capability Subclass: VIIe, nonirrigated.
Cobbly Foothill Range Site.

51A--Valmont Gravelly Clay Loam, 0 to 3 Percent Slopes

This deep, well drained soil is located on old high terraces and benches. It formed in gravelly and cobbly loamy alluvium. Average annual precipitation ranges from 13 to 15 inches. Average annual air temperature is 44° F. Slopes are nearly level to gently sloping.

Included are small areas of Nederland cobbly gravelly sandy loam, 0 to 3 percent slopes, and Nunn clay loam, 0 to 3 percent slopes.

Typically the surface layer is very dark grayish-brown gravelly clay loam about 8 inches thick. The subsoil is dark brown gravelly clay loam or gravelly clay about 14 inches thick. The underlying layers are calcareous, light brown gravelly loams and cobbly gravelly loams extending to 60 inches or more.

Permeability is moderately slow. Effective rooting depth is 60 inches or more. Available water capacity is moderate. Surface runoff is medium. The wind and water erosion hazard is slight to moderate.

This soil is used mainly for grazing. Some small areas are used for nonirrigated and irrigated cropland. Tillage is difficult due to cobbles and gravels.

Rangeland vegetation is mostly cool season grasses and forbs, as typical of the Cobbly Foothill Range Site. Dominant grasses are mountain muhly, blue grama, big bluestem, little bluestem, junegrass, sideoats grama, western wheatgrass, red threeawn, Indian grass, and switchgrass. Common forbs are aster, hairy gold aster, wild alfalfa, blazing star, sandwort and cudweed sage. Controlled grazing is needed on these soils to maintain the key forage species in good vigor. Periodic summer deferment is beneficial in reading the objectives of range improvement for maintenance of optimum range conditions. Fencing and careful location of livestock watering areas improves grazing distribution.

Management concerns in nonirrigated areas are conserving moisture and protecting the soil from erosion. Practices such as stripcropping perpendicular to the prevailing wind and leaving stubble on soil not covered with a growing crop help to prevent wind ercsion. Incorporating crop residues in and on the surface is also an effective means of improving soil tilth and increasing moisture.

In irrigated areas, the principal concerns of management are efficient use of irrigation water and controlling soil loss. These soils are suitable for border and furrow irrigation.

Windbreaks and ornamental plantings are difficult to establish on this soil, due to limited available water. Summer fallow a year in advance of planting and supplemental watering are necessary for the survival and establishment of plantings.

This soil has only minor limitations for homesites and roads. Cobbles and stones may hamper heavy equipment somewhat.

Capability Subclass: IIIc, nonirrigated.
IIIe, irrigated.

Cobbly Foothills Range Site.

52D - Unnamed (Rocky Flats) gravelly Loam, 9 to 28 Percent Slopes

This is a deep, well drained soil on knobs and hillsides of outwash terrace remnants. It formed in calcareous, cobbly, loamy alluvium. Average annual precipitation is about 15 inches. Slopes are strongly sloping to moderately steep.

Included are small areas of the Denver clay loam and Kutch clay loam soils on sideslopes and occasional areas underlain by shale and sandstone at depths of 10 to 20 inches on knob-like areas.

Typically the surface layer is very dark grayish brown loam about 3 inches thick. The subsoil is very dark grayish brown clay loam about 9 inches thick and is calcareous in the lower part. The substratum is very pale brown massive calcareous gravelly sandy loam extending to 60 inches.

Permeability is moderate. Effective rooting depth is 60 inches or more. Available water capacity is moderate. Surface runoff is medium to rapid, and wind and water erosion hazards are moderate to severe.

This soil is used mainly for grazing. Steep slopes and gravelly surface layers limit this soil for cultivation.

Rangeland vegetation is mostly cool season grasses and forbs, typical of the Cobbly Foothill Range Site. Dominant grasses are mountain muhly, blue grama, big bluestem, little bluestem, junegrass, sideoats grama, western wheatgrass, red threeawn, Indian grass and switchgrass. Common forbs are aster, hairy goldaster, wild alfalfa, blazingstar, sandwort and cudweed sage. Controlled grazing is needed on these soils to maintain vigor in key forage species. Periodic summer deferment of grazing will help improve or maintain range condition. Fencing and careful location of livestock watering facilities improves grazing distribution.

Windbreaks and ornamental plantings are difficult to establish on this soil due to limited available water and salinity. Summer fallow a year before planting and supplemental watering are necessary for the survival and establishment of plantings.

The construction of roads and buildings on this soil unit is limited by steep slopes and cobbles, and will require compensating designs. Soil loss due to erosion during construction should be minimized whenever possible.

Capability Subclass: VIe, irrigated.
VIe, nonirrigated.

Cobbly Foothills Range Site.

X52--Unnamed (Rocky Flats)--Nunn Complex, 5 to 9 Percent Slope

These moderately sloping soils are on upland ridges, sideslopes and hills. The average annual precipitation is about 15 inches. The unnamed (Rocky Flats) gravelly loam, 5 to 9 percent slope makes up about 55 percent of the unit. The Nunn clay loam, 5 to 9 percent slopes makes up about 35 percent. The unnamed (Rocky Flats) soils are on crests of ridges and hills. The Nunn soils are on mid and foot slope positions.

Included in mapping are small areas of Denver clay loam soils and Kutch clay loam, all on slopes of 5 to 9 percent.

Unnamed (Rocky Flats) is a deep, well drained soil on knobs and hillsides of outwash terrace remnants. It formed in calcareous, cobbly, loamy alluvium.

Typically the surface layer is very dark grayish brown gravelly loam about 3 inches thick. The subsoil is very dark grayish brown clay loam about 9 inches thick and is calcareous in the lower part. The substratum is very pale brown calcar us gravelly sandy loam extending to 60 inches.

Permeability is moderate. Effective rooting depth is 60 inches or more. Available water capacity is moderate. Surface runoff is medium to rapid, and wind and water erosion hazards are moderate.

The Nunn soil is a deep, well drained soil formed on moderately sloping alluvial fans and ridges. It formed in calcareous, clayey alluvial parent material.

Typically the surface layer is a very dark brown clay loam about 5 inches thick. The subsoil is very dark grayish brown heavy clay loam about 14 inches thick over brown calcareous clay loam about 5 inches thick. The substratum is yellowish brown calcareous clay loam extending to 60 inches or more.

Permeability is slow. Effective rooting depth is 60 inches or more. Available water capacity is high. Surface runoff is rapid, and wind and water erosion hazards are moderate. This soil is somewhat difficult to till because of the clay loam surface and subsoil layers. They have a moderate shrink-swell potential.

These soils are used mainly for grazing. Some areas are used for non-irrigated and irrigated cropland. They are best suited for native plants and grazing.

The rangeland vegetation of this unit consists of grasses typical of the cobbly foothills range site on the unnamed (Rocky Flats) soil and clayey foothills on the Nunn clay loam soil. Proper grazing use is necessary to prevent depletion of range. Periodic deferment of grazing is an effective practice to help improve or maintain range conditions. Fencing and careful location of livestock water facilities improves grazing distribution.

Windbreaks and environmental plantings are difficult to establish on this unit. Summer fallow a year before planting and supplemental watering are necessary for the establishment and survival of plantings.

The primary limiting soil properties for homesites, urban developments and roads are shrink-swell potential and slow permeability of the Nunn soil.

Capability Subclass: VIe, nonirrigated.
IVe, irrigated.

Cobbly Foothills Range Site - Unnamed (Rocky Flats) soil.
Clayey Foothills Range Site - Nunn Clay Loam Soil.

53D--Moderately Steep and Steep Gravelly Land, 15 to 45 Percent Slopes

These moderately deep well drained soils are on crest slopes and knobs. They are forming in cobbly and gravelly calcareous loamy alluvium overlying shale. Average annual precipitation is 15 inches. Slopes are moderately steep and steep.

Included are small areas of Heldt clay loams and Midway clay loams and shale exposures.

This land type is stratified and highly variable. It contains 15 to 40 percent waterworn cobbles and gravels. In most places the surface layer is a thin, dark colored gravelly sandy loam about 3 inches thick ranging to cobbly clay loam. The underlying material ranges from gravelly sandy loam to cobbly clay loam. Shale or partially consolidated calcareous gravelly alluvial material occurs between depths of 20 and 40 inches.

Permeability ranges from moderate to slow. Available water capacity is moderate. Runoff is rapid. The potential for water erosion is high, and for wind erosion is slight. The surface horizons are neutral in reaction, and the substratum is slightly to moderately alkaline.

This soil is generally in native vegetation and used for grazing. The major limiting factor of this soil unit is slope.

Capability Subclass: VIIe, nonirrigated.
Cobbly Foothills Range Site.

90--Argiustolls, Wet, Seeped, 5 to 12 Percent Slopes

These are deep, somewhat poorly drained soils on upland sideslopes. They are formed in loamy and clay loam alluvial deposits that are subjected to a seepage condition. Annual average precipitation is about 15 inches. Slopes are moderately sloping.

Included in this unit are Kutch clay loams and Denver clay loam soils on 5 to 9 percent slopes.

Permeability is slow. Effective rooting depth is 60 inches or more. Available water capacity is high. Surface runoff is moderate. Wind erosion hazard is slight, and water erosion hazard is moderate.

This soil unit is of small extent, and is used mainly for grazing. The soil is not suited to cultivation due to wetness.

The rangeland vegetation is dominated by tall grasses, principally switchgrass, Indian grass, big bluestem, and cordgrass. Sedges and rushes occur, but predominate only where water is at or near the surface most of the year. A variety of other grasses and forbs, including shrubs such as wild rose, are scattered in the unit. Cattails and bulrushes are on swampy spots. Ground cover is 60 percent or more. Controlled grazing is necessary to maintain vigor in key forage species. Periodic summer deferment of grazing will help improve or maintain range condition. Fencing and alternative livestock water and salt areas will help prevent livestock concentrations in these wet areas.

This soil is severely limited for homesites and roads due to wetness, high shrink-swell potential and slope. Costly compensating engineering measures are necessary to overcome these limitations.

Capability Subclass: IVw, Nonirrigated.

Wet Meadow Range Site.

101--Borrow Area - Shales and Clayey Soils

This unit consists of landscape that has been altered through cut operations and leveling. Material exposed is a clay shale. Some areas have a surface backfill ranging in depth of 4 to 12 inches of loam and clay loam. The sideslopes of these areas are steep to nearly vertical and are easily eroded. Depth of cut varies from 2 to 20 feet or more. The floor or bottom of these borrow areas is usually nearly level to gently sloping. With additional backfilling with loamy or sandy loam surface layers and additional shaping, vegetation can be successfully established and maintained. These materials are usually slightly to moderately alkaline.

APPENDIX D

NATIONAL POLLUTION DISCHARGE ELIMINATION SYSTEM PERMIT

The NPDES permit and revisions, which follow, concern aqueous effluent limitations and monitoring requirements for the Rocky Flats Plant. The original permit was effective September 6, 1974. It was revised on October 1, 1974 and July 17, 1975. The expiration date for this permit is June 30, 1979.

MI
Permit No. CO-0001333
Application No. CO-2SB-0XT-2-000331

AUTHORIZATION TO DISCHARGE UNDER THE NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM

In compliance with the provisions of the Federal Water Pollution Control Act, as amended, (33 U.S.C. 1251 et. seq; the "Act"),

The U.S. Atomic Energy Commission,

is authorized to discharge from a facility located at the Rocky Flats Plant between Boulder and Golden, Colorado,

to receiving waters named South Walnut Creek via Discharge 001, and
North Walnut Creek via Discharge 002, and
Woman Creek via Discharge 003,

in accordance with effluent limitations, monitoring requirements and other conditions set forth in Parts I, II, and III hereof.

This permit shall become effective on date of issuance.

This permit and the authorization to discharge shall expire at midnight, June 30, 1979.

Signed this 6 day of September, 1974.

JOHN A. GREEN
REGIONAL ADMINISTRATOR

EPA Form 3320-4 (10-73)

A. EFFLUENT LIMITATIONS AND MONITORING REQUIREMENTS

During the period beginning immediately and lasting through September 30, 1974, - the permittee is authorized to discharge from outfall(s) serial number(s) 001 (Continued to page 3).

Such discharges shall be limited and monitored by the permittee as specified below:

Effluent Characteristic	Discharge Limitations				Monitoring Requirements	
	kg/day (lbs/day)		Concentration mg/l			
	Daily Avg	Daily Max	Daily Avg	Daily Max	Measurement Frequency	Sample Type
Flow - M^3/Day (MGD)	N/A	N/A	N/A	N/A	3 X Week	Instantaneous
Total Suspended Solids b/	N/A	N/A	30	45	Weekly	Grab or Continous
Total Phosphorus (as P)	N/A	N/A	8	N/A	Weekly	Grab or Continuous
Nitrate (as N)	N/A	N/A	10	20	3 X Week	Grab or Continuous
Fluoride	N/A	N/A	N/A	1.7	Weekly	Grab or Continuous
Total BOD_5	N/A	N/A	30	45	Weekly	Grab or Continuous
Total Residual Chlorine	N/A	N/A	N/A	0.1 a/	3 X Week	Grab
Dissolved Oxygen	N/A	N/A	N/A	N/A	Weekly	Grab

a/ No sample shall be greater than this value.

b/ The limitations on Total Suspended Solids shall not apply during periods of surface runoff at the facility.

A. EFFLUENT LIMITATIONS AND MONITORING REQUIREMENTS

During the period beginning immediately and lasting through September 30, 1974.
the permittee is authorized to discharge from outfall(s) serial number(s) 001 (Continued from page 2).

Such discharges shall be limited and monitored by the permittee as specified below:

Effluent Characteristic	Discharge Limitations kg/day (lbs/day)		Concentration mg/l		Monitoring Requirements	
	Daily Avg	Daily Max	Daily Avg	Daily Max	Measurement Frequency	Sample Type
Fecal Coliforms - organisms/100 ml (See Definitions, Part I-3-e, page 8)		30 day average	200		Weekly	Grab
		7 day average	400			
Total Chromium	N/A	N/A	0.05	0.1	Weekly	Grab or Continuous

The concentration of Oil and Grease shall not exceed 10 mg/l in any sample and shall be monitored daily on a visual basis and weekly on a grab sample basis.

The pH shall not be less than 6.0 standard units nor greater than 9.0 standard units and shall be monitored daily on a grab sample basis.

There shall be no discharge of floating solids or visible foam in other than trace amounts.

Samples taken in compliance with the monitoring requirements specified above shall be taken at the following location(s): All parameters except Total Suspended Solids and Fecal Coliforms shall be monitored at the outfall from Pond B-4. Total Suspended Solids and Fecal Coliforms shall be monitored at the outfall of the Sanitary Sewer System.

A. EFFLUENT LIMITATIONS AND MONITORING REQUIREMENTS

During the period beginning October 1, 1974, and lasting through June 30, 1979, the permittee is authorized to discharge from outfall(s) serial number(s) 001 (Continued to page 5).

Such discharges shall be limited and monitored by the permittee as specified below:

Effluent Characteristic	Discharge Limitations kg/day (lbs/day) Daily Avg	Daily Max	Concentration mg/l Daily Avg	mg/l Daily Max	Monitoring Requirements Measurement Frequency	Sample Type
Flow - M^3/Day (MGD)	N/A	N/A	N/A	N/A	Daily	Instantaneous
Total Suspended Solids	34 (75)	57 (125)	15	25	Daily	Grab or Continuous
Total Phosphorus (as P)	N/A	N/A	8	N/A	Daily	Grab or Continuous
Nitrate (as N)	23 (50)	46 (100)	10	20	Daily	Grab or Continuous
Fluoride	N/A	N/A	N/A	1.7	Daily	Grab or Continuous
Total BOD_5	23 (50)	57 (125)	10	25	3 X Week	Grab or Continuous
Total Residual Chlorine	N/A	N/A	N/A	0.1 a/	3 X Week	Grab
Dissolved Oxygen (minimum)	N/A	N/A	4	2 b/	3 X Week	Grab

a/ No sample shall be greater than this value Total Residual Chlorine shall be monitored at the outfall from pond B-4.

b/ No sample shall be less than this value.

A. EFFLUENT LIMITATIONS AND MONITORING REQUIREMENTS

During the period beginning October 1, 1974, and lasting through June 30, 1979, the permittee is authorized to discharge from outfall(s) serial number(s) 001 (Continued from page 4).

Such discharges shall be limited and monitored by the permittee as specified below:

Effluent Characteristic	Discharge Limitations				Monitoring Requirements	
	kg/day (lbs/day)		Concentration			
			mg/l	mg/l	Measurement	Sample
	Daily Avg	Daily Max	Daily Avg	Daily Max	Frequency	Type
Fecal Coliforms - organisms/100 ml (See Definitions, Part I-3-e, page 10)		30 day average	200		3 X Week	Grab
		7 day average	400			
Total Chromium	N/A	N/A	0.05	0.1	Weekly	Grab or Continuous

The concentration of Oil and Grease shall not exceed 10 mg/l in any sample and shall be monitored daily on a visual basis and weekly on a grab sample basis.

The pH shall not be less than 6.0 standard units nor greater than 9.0 standard units and shall be monitored daily on a grab sample basis.

There shall be no discharge of floating solids or visible foam in other than trace amounts.

Samples taken in compliance with the monitoring requirements specified above shall be taken at the following location(s): All parameters except Total Residual Chlorine, shall be monitored at the outfall from Building 995, the Wastewater Treatment Plant. Total Residual Chlorine shall be monitored at the outfall from Pond B-4.

A. EFFLUENT LIMITATIONS AND MONITORING REQUIREMENTS

During the period beginning immediately and lasting through June 30, 1979, the permittee is authorized to discharge from outfall(s) serial number(s) 002.

Such discharges shall be limited and monitored by the permittee as specified below:

Effluent Characteristic	Discharge Limitations				Monitoring Requirements	
	kg/day (lbs/day)		Concentration			
	Daily Avg	Daily Max	mg/l Daily Avg	mg/l Daily Max	Measurement Frequency	Sample Type
Flow—m^3/Day (MGD)	N/A	N/A	N/A	N/A	Daily	Instantaneous
Nitrate (as N)	N/A	N/A	10	20	Daily	Grab or Continuous

This discharge shall consist only of runoff due to precipitation.

The pH shall not be less than 6.0 standard units nor greater than 9.0 standard units and shall be monitored daily on a grab sample basis.

There shall be no discharge of floating solids or visible foam in other than trace amounts.

Samples taken in compliance with the monitoring requirements specified above shall be taken at the following location(s): At the outfall from Pond A-3.

A. EFFLUENT LIMITATIONS AND MONITORING REQUIREMENTS

During the period beginning immediately and lasting through June 30, 1979, the permittee is authorized to discharge from outfall(s) serial number(s) 003.

Such discharges shall be limited and monitored by the permittee as specified below:

Effective immediately and lasting to no later than June 30, 1975, Discharge 003 shall consist only of surface runoff, Water Treatment Plant filter backwash and cooling tower blowdown. There shall be no change in operation that will significantly deteriorate the quality of the discharge below that presented in the permit application.

Effective as soon as reasonable and practical but no later than July 1, 1975, and lasting through June 30, 1979, Discharge 003 shall consist only of surface runoff.

Discharge 003 shall be monitored for the following parameters at the indicated frequency. All samples shall be taken at the outfall from Pond C-1:

Effluent Characteristic	Monitoring Requirements	
	Measurement Frequency	Sample Type
Nitrates (as N) mg/l	Monthly	Grab or Continuous
Total Dissolved Solids - mg/l	2 X Month	Grab or Continuous
pH - units	2 X Month	Grab or Continuous
Chemical Oxygen Demand - mg/l	Monthly	Grab or Continuous

B. SCHEDULE OF COMPLIANCE

1. The permittee shall achieve compliance with the effluent limitations specified for discharges in accordance with the following schedule:

The permittee shall submit to the permit issuing authority in less than ninety (90) days after the issuance of this permit, an implementation plan for an abatement program designed to achieve the effluent limitations specified in this permit for discharge from outfall(s) 003
The implementation plan shall consist of an outline of intended design, construction and operation, including a compliance schedule setting forth the dates by which compliance with the effluent limitations will be reached. The compliance schedule shall include, where appropriate, dates to accomplish the following:

(a) completion of preliminary plans
(b) completion of final plans
(c) award of contract(s)
(d) commencement of construction
(e) completion of major construction phases
(f) completion of all construction
(g) attainment of operational level

Upon approval of the implementation plan by the permit issuing authority, the schedule of compliance shall become conditions of this permit.

2. No later than 14 calendar days following a date identified in the above schedule of compliance, the permittee shall submit either a report of progress or, in the case of specific actions being required by identified dates, a written notice of compliance or noncompliance. In the latter case, the notice shall include the cause of noncompliance, any remedial actions taken, and the probability of meeting the next scheduled requirement.

C. MONITORING AND REPORTING

1. *Representative Sampling*

Samples and measurements taken as required herein shall be representative of the volume and nature of the monitored discharge.

2. *Reporting*

Monitoring results obtained during the previous 3 months shall be summarized for each month and reported on a Discharge Monitoring Report Form (EPA No. 3320-1), postmarked no later than the 28th day of the month following the completed reporting period. The first report is due on January 28, 1975. Signed copies of these, and all other reports required herein, shall be submitted to the Regional Administrator at the following address:

U.S. Environmental Protection Agency
Suite 900, 1860 Lincoln Street
Denver, Colorado 80203
Attention: Enforcement - Permits

3. *Definitions*

a. The "daily average" discharge means the total discharge by weight during a calendar month divided by the number of days in the month that the production or commercial facility was operating. Where less than daily sampling is required by this permit, the daily average discharge shall be determined by the summation of all the measured daily discharges by weight divided by the number of days during the calendar month when the measurements were made.

b. The "daily maximum" discharge means the total discharge by weight during any calendar day. (See CONTINUATION - next page)

4. *Test Procedures*

Test procedures for the analysis of pollutants shall conform to regulations published pursuant to Section 304(g) of the Act, under which such procedures may be required.

5. *Recording of Results*

For each measurement or sample taken pursuant to the requirements of this permit, the permittee shall record the following information:

a. The exact place, date, and time of sampling;

b. The dates the analyses were performed;

c. The person(s) who performed the analyses;

d. The analytical techniques or methods used; and

e. The results of all required analyses.

6. *Additional Monitoring by Permittee*

If the permittee monitors any pollutant at the location(s) designated herein more frequently than required by this permit, using approved analytical methods as specified above, the results of such monitoring shall be included in the calculation and reporting of the values required in the Discharge Monitoring Report Form (EPA No. 3320-1). Such increased frequency shall also be indicated.

7. *Records Retention*

All records and information resulting from the monitoring activities required by this permit including all records of analyses performed and calibration and maintenance of instrumentation and recordings from continuous monitoring instrumentation shall be retained for a minimum of three (3) years, or longer if requested by the Regional Administrator .

CONTINUATION

3. Definitions (continued)

b. (continued)

This limitation shall be determined by the analyses of a properly preserved composite sample composed of a minimum of four (4) grab samples collected at equally spaced two (2) hour intervals and proportioned according to flow at the time of sampling.

c. The "daily average" concentration means the average concentration during a calendar month. Where less than daily sampling is required by this permit, the average concentration shall be determined by the summation of all measured daily samples divided by the number of days during the calendar month when the measurements were made.

d. The "daily maximum" concentration shall be determined by the analysis of a properly preserved composite sample composed of a minimum of four (4) grab samples collected at equally spaced two (2) hour intervals and proportioned according to flow at the time of sampling.

e. Averages for fecal coliforms shall be determined by the geometric mean of a minimum of three (3) consecutive grab samples taken during separate weeks in a 30-day period for the 30-day average, and during separate days in a 7-day period for the 7-day average. (Minimum total of three (3) samples)

3. Definitions (continued)

f. "Net" value, noted under Effluent Characteristics are calculated on the basis of the net increase of the individual parameter over the quantity of that same parameter present in the intake water measured prior to any contamination or use in the process of this facility. Any contaminants contained in any intake water obtained from underground wells shall not be adjusted for as described above and therefore shall be considered as process input to the final effluent. Limitations in which "net" is not noted are calculated on the basis of gross measurements, of each parameter in the discharge irrespective of the quantity or quality of those parameters in the intake waters.

g. A "composite" sample, for monitoring requirements, is defined as a minimum of four (4) grab samples collected at equally spaced two (2) hour intervals and proportioned according to flow.

A. MANAGEMENT REQUIREMENTS

1. *Change in Discharge*

All discharges authorized herein shall be consistent with the terms and conditions of this permit. The discharge of any pollutant identified in this permit more frequently than or at a level in excess of that authorized shall constitute a violation of the permit. Any anticipated facility expansions, production increases, or process modifications which will result in new, different, or increased discharges of pollutants must be reported by submission of a new NPDES application or, if such changes will not violate the effluent limitations specified in this permit, by notice to the permit issuing authority of such changes. Following such notice, the permit may be modified to specify and limit any pollutants not previously limited.

2. *Noncompliance Notification*

If, for any reason, the permittee does not comply with or will be unable to comply with any daily maximum effluent limitation specified in this permit, the permittee shall provide the Regional Administrator and the State with the following information, in writing, within five (5) days of becoming aware of such condition:

a. A description of the discharge and cause of noncompliance; and

b. The period of noncompliance, including exact dates and times; or, if not corrected, the anticipated time the noncompliance is expected to continue, and steps being taken to reduce, eliminate and prevent recurrence of the noncomplying discharge.

3. *Facilities Operation*

The permittee shall at all times maintain in good working order and operate as efficiently as possible all treatment or control facilities or systems installed or used by the permittee to achieve compliance with the terms and conditions of this permit.

4. *Adverse Impact*

The permittee shall take all reasonable steps to minimize any adverse impact to navigable waters resulting from noncompliance with any effluent limitations specified in this permit, including such accelerated or additional monitoring as necessary to determine the nature and impact of the noncomplying discharge.

5. *Bypassing*

Any diversion from or bypass of facilities necessary to maintain compliance with the terms and conditions of this permit is prohibited, except (i) where unavoidable to prevent loss of life or severe property damage, or (ii) where excessive storm drainage or runoff would damage any facilities necessary for compliance with the effluent limitations and prohibitions of this permit. The permittee shall promptly notify the Regional Administrator and the State in writing of each such diversion or bypass.

6. *Removed Substances*

Solids, sludges, filter backwash, or other pollutants removed in the course of treatment or control of wastewaters shall be disposed of in a manner such as to prevent any pollutant from such materials from entering navigable waters.

7. *Power Failures*

In order to maintain compliance with the effluent limitations and prohibitions of this permit, the permittee shall either:

a. In accordance with the Schedule of Compliance contained in Part I, provide an alternative power source sufficient to operate the wastewater control facilities;

or, if such alternative power source is not in existence, and no date for its implementation appears in Part I,

b. Halt, reduce or otherwise control production and/or all discharges upon the reduction, loss, or failure of the primary source of power to the wastewater control facilities.

B. RESPONSIBILITIES

1. *Right of Entry*

The permittee shall allow the Regional Administrator and/or his authorized representatives, upon the presentation of credentials:

a. To enter upon the permittee's premises where an effluent source is located or in which any records are required to be kept under the terms and conditions of this permit; and

b. At reasonable times to have access to and copy any records required to be kept under the terms and conditions of this permit; to inspect any monitoring equipment or monitoring method required in this permit; and to sample any discharge of pollutants.

2. *Transfer of Ownership or Control*

In the event of any change in control or ownership of facilities from which the authorized discharges emanate, the permittee shall notify the succeeding owner or controller of the existence of this permit by letter, a copy of which shall be forwarded to the Regional Administrator and the State water pollution control agency.

3. *Availability of Reports*

Except for data determined to be confidential under Section 308 of the Act, all reports prepared in accordance with the terms of this permit shall be available for public

inspection at the offices of the State water pollution control agency and the Regional Administrator. As required by the Act, effluent data shall not be considered confidential. Knowingly making any false statement on any such report may result in the imposition of criminal penalties as provided for in Section 309 of the Act.

4. *Permit Modification*

After notice and opportunity for a hearing, this permit may be modified, suspended, or revoked in whole or in part during its term for cause including, but not limited to, the following:

a. Violation of any terms or conditions of this permit;

b. Obtaining this permit by misrepresentation or failure to disclose fully all relevant facts; or

c. A change in any condition that requires either a temporary or permanent reduction or elimination of the authorized discharge.

5. *Toxic Pollutants*

Notwithstanding Part II, B-4 above, if a toxic effluent standard or prohibition (including any schedule of compliance specified in such effluent standard or prohibition) is established under Section 307(a) of the Act for a toxic pollutant which is present in the discharge and such standard or prohibition is more stringent than any limitation for such pollutant in this permit, this permit shall be revised or modified in accordance with the toxic effluent standard or prohibition and the permittee so notified.

6. *Civil and Criminal Liability*

Except as provided in permit conditions on "Bypassing" (Part II, A-5) and "Power Failures" (Part II, A-7), nothing in this permit shall be construed to relieve the permittee from civil or criminal penalties for noncompliance.

7. *Oil and Hazardous Substance Liability*

Nothing in this permit shall be construed to preclude the institution of any legal action or relieve the permittee from any responsibilities, liabilities, or penalties to which the permittee is or may be subject under Section 311 of the Act.

8. *State Laws*

Nothing in this permit shall be construed to preclude the institution of any legal action or relieve the permittee from any responsibilities, liabilities, or penalties established pursuant to any applicable State law or regulation under authority preserved by Section 510 of the Act.

9. ***Property Rights***

The issuance of this permit does not convey any property rights in either real or personal property, or any exclusive privileges, nor does it authorize any injury to private property or any invasion of personal rights, nor any infringement of Federal, State or local laws or regulations.

10. ***Severability***

The provisions of this permit are severable, and if any provision of this permit, or the application of any provision of this permit to any circumstance, is held invalid, the application of such provision to other circumstances, and the remainder of this permit, shall not be affected thereby

NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM

DISCHARGE MONITORING REPORT

Form Approved
OMB NO. 158-R0073

(2-3)	(4-16)	(17-19)			
ST	PERMIT NUMBER	DIS	SIC	LATITUDE	LONGITUDE

	(20-21)	(22-23)	(24-25)		(26-27)	(28-29)	(30-31)
REPORTING PERIOD: FROM				TO			
	YEAR	MO	DAY		YEAR	MO	DAY

INSTRUCTIONS

1. Provide dates for period covered by this report in spaces marked "REPORTING PERIOD".
2. Enter reported minimum, average and maximum values under "QUANTITY" and "CONCENTRATION" in the units specified for each parameter as appropriate. Do not enter values in boxes containing asterisks. "AVERAGE" is average computed over actual time discharge is operating. "MAXIMUM" and "MINIMUM" are extreme values observed during the reporting period.
3. Specify the number of analyzed samples that exceed the maximum *(and/or minimum as appropriate)* permit conditions in the columns labeled "No. Ex." If none, enter "O".
4. Specify frequency of analysis for each parameter as No. analyses/No. days. *(e.g., "3/7" is equivalent to 3 analyses performed every 7 days.)* If continuous enter "CONT."
5. Specify sample type ("*grab*" or "___ *hr. composite*") as applicable. If frequency was continuous, enter "NA".
6. Appropriate signature is required on bottom of this form.
7. Remove carbon and retain copy for your records.
8. Fold along dotted lines, staple and mail Original to office specified in permit.

(32-37) PARAMETER		*(3 card only)* QUANTITY (38-45) MINIMUM	(46-53) AVERAGE	(54-61) MAXIMUM	UNITS	(62-63) NO. EX	*(4 card only)* CONCENTRATION (38-45) MINIMUM	(46-53) AVERAGE	(54-61) MAXIMUM	UNITS	(62-63) NO. EX	(64-68) FREQUENCY OF ANALYSIS	(69-70) SAMPLE TYPE
	REPORTED												
	PERMIT CONDITION												
	REPORTED												
	PERMIT CONDITION												
	REPORTED												
	PERMIT CONDITION												
	REPORTED												
	PERMIT CONDITION												
	REPORTED												
	PERMIT CONDITION												
	REPORTED												
	PERMIT CONDITION												
	REPORTED												
	PERMIT CONDITION												
	REPORTED												
	PERMIT CONDITION												

NAME OF PRINCIPAL EXECUTIVE OFFICER	TITLE OF THE OFFICER	DATE				
					I certify that I am familiar with the information contained in this report and that to the best of my knowledge and belief such information is true, complete, and accurate.	
LAST FIRST MI	TITLE	YEAR	MO	DAY		SIGNATURE OF PRINCIPAL EXECUTIVE OFFICER OR AUTHORIZED AGENT

T-40 (4-74)

ORIGINAL

PAGE OF

APPENDIX E

ACCIDENT AND RELEASE PROBABILITIES

This appendix consists of two reports prepared by Dr. J. E. Selvidge, a consultant to the Rocky Flats Plant contractor. The first of her reports, Appendix E-1, is entitled "Probabilities of Aircraft Crashes at Rocky Flats and Subsequent Radioactive Release."

The second document, Appendix E-2 is entitled "Natural Hazards That May Trigger a Radiological Release From a Plutonium Processing Facility."

Printed
April 12, 1977

RFP-2462
UC-13 GENERAL, MISCELLANEOUS,
AND PROGRESS REPORTS
(NONNUCLEAR)
TID-4500-R65

PROBABILITIES OF AIRCRAFT CRASHES AT ROCKY FLATS AND SUBSEQUENT RADIOACTIVE RELEASE

Judith E. Selvidge

Consultant

SUBJECT DESCRIPTORS

Accidents
Contamination
Hazards
Plutonium
Probability

ROCKWELL INTERNATIONAL
ATOMICS INTERNATIONAL DIVISION
ROCKY FLATS PLANT
P.O. BOX 464
GOLDEN, COLORADO 80401

Prepared under Contract EY-76-C-04-3533
for the
Albuquerque Operations Office
U. S. Energy Research and Development Administration

CONTENTS

PROBABILITIES OF AIRCRAFT CRASHES AT ROCKY FLATS AND SUBSEQUENT RADIOACTIVE RELEASE

Judith E. Selvidge

Consultant

Abstract. The probability of a small airplane from Jefferson County Airport (Jeffco) or Stapleton International Airport crashing into a plutonium area at the Rocky Flats Plant has been calculated at 1.4×10^{-4} and 4.2×10^{-6} per year, respectively. The probability of such a crash involving a large airplane from Jeffco or Stapleton is 3.5×10^{-6} and 1.1×10^{-6} per year, respectively. Overall, the chance of an aircraft of any size, or any type, and from any source crashing into a plutonium area at Rocky Flats is 2.88×10^{-4} per year. An event tree was developed to cover every plausible series of events leading to a release of plutonium in the range of 0 to 1000 grams. Selected results show an annual release probability of 3.9×10^{-5} for less than 0.5 grams, 5.8×10^{-6} for 50 to 70 grams, 5.6×10^{-8} for 200 grams, and 6.4×10^{-10} for 1000 grams. Calculations led to a weighted average release amount of 3.7×10^{-4} grams of plutonium per year. Because of conservative assumptions, it is estimated that these probabilities are high by a factor of about two for small aircraft and 10 for large aircraft.

INTRODUCTION

This study consists of three parts. First, the probability of an aircraft crashing into a building containing plutonium is computed. Secondly, the damage that such a crash might cause is estimated. The third part is an assessment of the amount of plutonium that could escape assuming the damage described were to occur.

Several categories of aircraft, all having different probabilities of crashing, are considered. Construction of the various buildings containing plutonium is taken into consideration as is the amount and form of plutonium that might be subject to release. Results of the study are summarized in probability tables and graphs that show different amounts of plutonium versus the probabilities of those amounts being released. Incorporated in these probabilities are the three principal types of uncertainties previously mentioned; namely, the probability of a crash, the probability of certain damage if a crash occurs, and the probability of a certain size of release if the damage occurs.

AIRCRAFT CRASH PROBABILITIES

Historical data concerning the probability of a crashing airplane striking a plant or other building has been collected in connection with safety studies of nuclear power plants.[1-4] These data, broken down according to the type of flight (air carrier or general aviation), size of aircraft (large or small), and distance of the crash site from an airport, are based on from 5 to 10 years of reports of aircraft accidents in the United States. To apply this information to the assessment of aircraft crash probabilities for Rocky Flats, air traffic in contact with the Jefferson County (Jeffco) Airport and with Stapleton International Airport are considered separately. In addition, the hazards from low-altitude, transient air traffic and from aircraft flying over the Rocky Flats Plant as part of normal Plant operations are evaluated.

Jefferson County Airport

Air traffic at Jeffco Airport involves about 233,000 movements (takeoffs, landings, and other radio contact with the control tower) per year. Apart

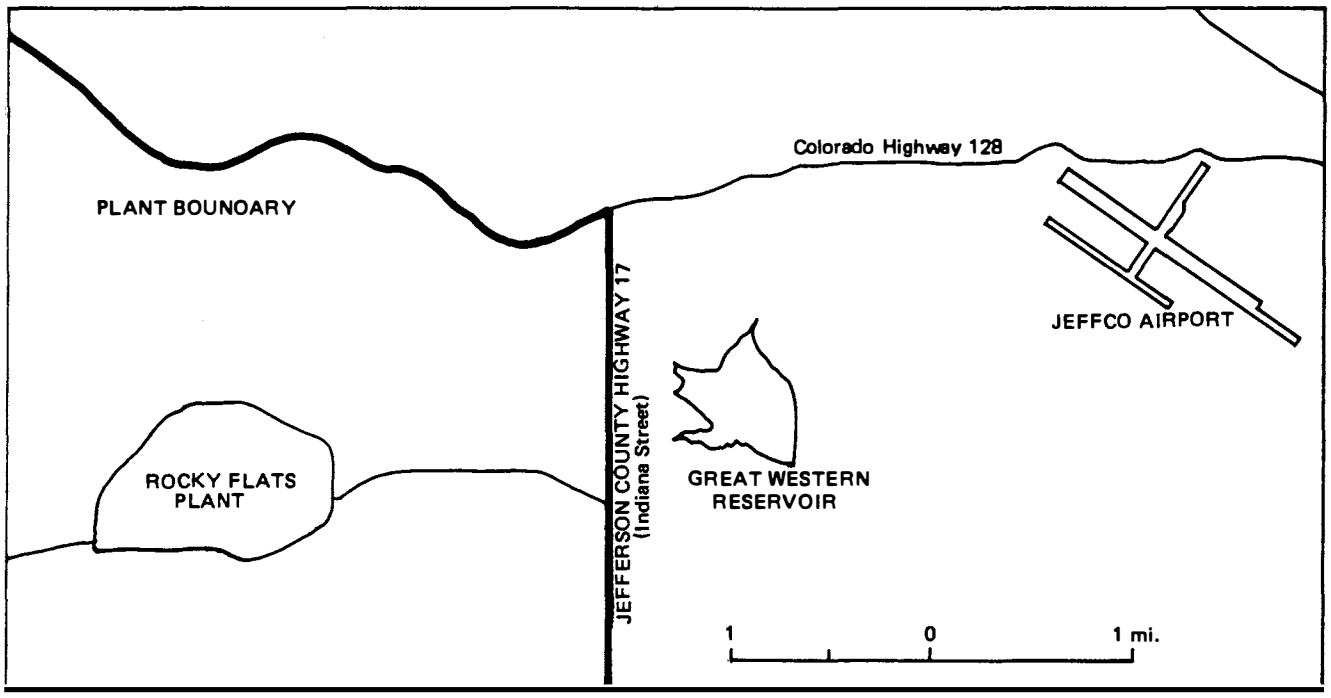


FIGURE 1. Geographical Relationship of Jeffco Airport to Rocky Flats

from a few air-carrier training flights, an occasional military flight, and about 300 small air-taxi flights, these movements are all by general aviation aircraft. Approximately 95 percent of these aircraft are classified as "small" (weight less than or equal to 12,500 lbs). The geographic relationship of Jeffco Airport to the Rocky Flats Plant is shown in Figure 1. The distance from Jeffco to the nearest part of the Rocky Flats controlled zone, the portion of the facility surrounded by a security fence, is 4.5 miles. The size of this zone is 0.608 square miles, and the part of that area that is considered a possible source of plutonium release is 0.05 square miles in size. This latter area was computed by adding the areas of buildings containing plutonium, the areas of those buildings' "shadows,"* and the area of an asphalt pad that covers contaminated soil at the southeast corner of the controlled zone.

*The shadow of a building is the additional vulnerable area created when a plane arrives while traveling at an angle rather than falling straight down. In this calculation, the assumption is made that a plane crashing out of control is traveling at an angle of 10° or greater to the horizontal.

Table 1 shows computations for the probabilities of fatal crashes at Rocky Flats involving large and small aircraft from Jeffco Airport. The overall probability per year of a crash into a plutonium area by a plane associated with Jeffco is seen to be approximately 1.4×10^{-4}. When large aircraft alone are considered, this figure is reduced to approximately 3.5×10^{-6}. Throughout this report, only crashes resulting in fatalities have been considered since away-from-the-airport landings with no fatalities are not believed to result in accidents of a severity that would damage Plant structures.

Stapleton Air Traffic

Rocky Flats lies 17 miles to the northwest of Stapleton International Airport. Generally such a distance would be considered too great for the presence of that airport to have an effect upon the probability of a plane crash at Rocky Flats. One of 13 airways into Stapleton passes near the Plant, however. For this reason, an estimate has been

TABLE 1. Computation of Fatal-Crash Probabilities at Rocky Flats for Aircraft Associated with Jeffco Airport

Aircraft Type	Number of Movements in the Airway Per Year (M)*	Crash Probability P(H)**	P(RF Controlled Zone)† of 0.608 square miles [M × P(H) × 0.608]	P(RF Plutonium Area)†† of 0.05 square miles [M × P(H) × 0.05]
General Aviation				
Small	221,065	1.220×10^{-8}	1.6397×10^{-3}	1.3485×10^{-4}
Large	11,635	5.952×10^{-9}	4.2105×10^{-5}	3.4625×10^{-6}
Air Taxi				
Small	300	1.905×10^{-7}	3.4747×10^{-5}	2.8575×10^{-6}
All Aircraft	233,000		1.7165×10^{-3}	1.4117×10^{-4}

*(M) = Movements.
**P(H) = Probability of a crash per movement per year per square mile at a distance of 4 to 5 miles from an airport, based on historical data. See Page 226 of Reference 1.
†P(RF Controlled Zone) = Probability of a crash per year inside the 0.608-sq-mi controlled zone at Rocky Flats.
††P(RF Plutonium Area) = Probability of a crash per year into the 0.05-sq-mi plutonium area at Rocky Flats.

TABLE 2. Computation of Fatal Crash Probabilities at Rocky Flats for Aircraft in the Nearby Stapleton Airway

Aircraft Type	Number of Movements in the Airway Per Year (M)*	Crash Probability P(H)**	P(RF Controlled Zone)† of 0.608 square miles [M × P(H) × 0.608]	P(RF Plutonium Area)†† of 0.05 square miles [M × P(H) × 0.05]
Air Carriers				
Large	16,500	1.2×10^{-9}	1.204×10^{-5}	9.900×10^{-7}
General Aviation				
Large	675	2.9×10^{-9}	1.190×10^{-6}	9.788×10^{-8}
Small	12,825	6.6×10^{-9}	5.146×10^{-5}	4.232×10^{-6}
All Aircraft	30,000		6.469×10^{-5}	5.320×10^{-6}

*(M) = Movements.
**P(H) = Probability of a crash per movement per year per square mile at a distance of 9 to 10 miles from an airport, based on historical data. See Page 226 of Reference 1 and Page 156 of Reference 4.
†P(RF Controlled Zone) = Probability of a crash per year inside the 0.608-sq-mi controlled zone at Rocky Flats.
††P(RF Plutonium Area) = Probability of a crash per year into the 0.05-sq-mi plutonium area at Rocky Flats.

made of the annual crash probability attributable to traffic in that air corridor. The annual number of aircraft movements was computed from the Stapleton controllers' estimates and from a sample survey of movements observed on Stapleton's traffic-control-area radar.

The probability of a fatal crash per movement per square mile is estimated in the calculation by taking the probability for distances of 9 to 10 miles from the airport (the furthest distance for which crash probabilities have been computed). These calculations appear in Table 2. Generally the results of these computations are accurate to about one significant figure; the second figure is partially significant. To minimize the rounding error, however, additional figures are carried at intermediate steps in the calculation. Overall

accuracy of the probabilities is discussed further in the "Conservative Assumptions" section of this report.

The probability of a crash into the plutonium area of Rocky Flats by a large aircraft, either an air carrier or general aviation plane, is seen to be approximately 1.1×10^{-6}; the probability for a small aircraft is approximately 4.2×10^{-6}. These probabilities are small when compared to crash probabilities already computed for Jeffco. (The overall crash probability of 5.3×10^{-6} at Rocky Flats is a factor of 25 less than that for Jeffco.) These probabilities are retained in this study, however, since the damage in the event of a crash at the Plant may be substantially greater because of greater size and/or speed for these planes than for aircraft associated with Jeffco.

TABLE 3. Summary of Aircraft Crash Probabilities at Rocky Flats

Aircraft Type	P(RF Controlled Zone)* 0.608 square miles	P(RF Plutonium Area)** 0.05 square miles
Large	5.534×10^{-5}	4.550×10^{-6}
Small	3.424×10^{-3}	2.834×10^{-4}
All Aircraft	3.479×10^{-3}	2.880×10^{-4}

*P(RF Controlled Zone) = Probability of a crash per year inside the 0.608-sq-mi controlled zone at Rocky Flats.
**P(RF Plutonium Area) = Probability of a crash per year into the 0.05-sq-mi plutonium area at Rocky Flats.

Rotorcraft Operations Over the Plant

Helicopters fly over the Rocky Flats facility from time to time to carry out work associated with Plant operation. These activities include spraying for weed control, taking aerial photographs, and making radiological measurements. These helicopters are in the air over the Rocky Flats controlled zone for about 60 hours per year. On the basis of four years of accident statistics* for rotorcraft operating in the U.S., the probability of a fatal crash per 100 hours of flying time is 2.830×10^{-3}. Multiplying this value by 0.6 (60 hours/100 hours) gives a probability per year of a fatal crash in the Rocky Flats controlled zone of 1.698×10^{-3}. This is added into general-aviation, small-aircraft, (since these helicopters are all <12,500 lbs.) accident probability. The Plant's plutonium area is 8.2 percent (0.05 sq mi/0.608 sq mi) of the controlled zone, so the additional crash probability for the plutonium area alone that is attributable to rotorcraft is 1.415×10^{-4} per year.

Other Traffic

There are occasional flights of small, general aviation planes traveling south and north to the west of Rocky Flats and that are below the 10,000-ft altitude of Stapleton's Traffic Control Area (TCA). This traffic amounts to about 3,000 movements per year (less than 10 per day). Taking as the crash probability for these planes the figure used for general aviation at five miles from an airport, the effect upon the small-plane crash probability per year for Rocky Flats is to increase it by $3{,}000 \times 1.22 \times 10^{-8} \times 0.05$ for a resulting 1.8300×10^{-6}.

Summary of Aircraft Crash Probabilities

Combining the crash probabilities of aircraft from all sources gives the values shown in Table 3.

The event with the greatest potential for damage, that of a large plane crashing into a plutonium area, is seen to have a probability of occurrence equal to 4.550×10^{-6}. For a small aircraft crashing into the plutonium area, the probability is 2.834×10^{-4}. These values correspond to an expected occurrence of the specified crash of once in about 220,000 years in the first case and once in about 3,500 years in the second case.

Conservative Assumptions

These probability values are believed to be "conservative;" that is, to err on the high side

*1970-1974. Source: National Transportation Safety Board Annual Review of U.S. General Aviation Accidents, Department of Transportation, Washington, D.C.

because of a few assumptions made to accommodate existing data. The assumptions concern historical crash probabilities, the number of aircraft in the vicinity of the facility, and the size of the vulnerable plutonium area.

Crash Probabilities

The probabilities of a fatal crash per aircraft movement are based on data from 1966 through 1970 but are applied to movements estimated for 1975.

There has been a steady improvement in aircraft safety over the years; for example, fatal accidents for U.S. air carriers in 1973 was 15 percent less than the average for the 1966 through 1970 period. Initial crash probabilities per movement consequently are likely to be 15 to 20 percent too high.

The large-aircraft crash probability for planes associated with Jeffco Airport assumes that these are all general aviation flights. Actually, some are military or air-carrier training flights—both of which have lower accident rates than general aviation.

Number of Aircraft

The historical probabilities for general aviation aircraft assume that planes are equally likely to leave or approach the airport from any direction. In the case of Jeffco Airport, however, the 30° sector containing Rocky Flats, where one would expect to find about 1/12th (or 8.3 percent) of the air traffic, receives only 1 to 5 percent of the activity. The reason is the surrounding terrain. As a result, the number of relevant aircraft movements is probably over-estimated by a factor that may be as large as eight.

Size of Plutonium Area

The size of that portion of the control zone of concern in case of a plane crash is computed by first taking the area of the buildings containing radioactive material. The area is then increased by an amount (the shadow) that allows for the height of the building and the approach of a crashing aircraft at other than a 90° angle with the horizontal. The conservative assumption made was that the craft impacts at a 10° angle. If a more realistic assumption is made that this angle will be anywhere between 90° and 10°, then the effective area is less by a factor of about six.*

Effect Upon the Probabilities

These more-realistic approximations could be incorporated into the probability calculations in place of the conservative counterparts. The effect would be that of reducing the final probability estimates for crashes in the plutonium area by a factor of about two for the small aircraft and about 10 for large aircraft. In this study, however, subsequent calculations of damage and overall probability of plutonium release are made using the original conservative figures.

RESULTS OF CRASH IMPACT

If an aircraft hits a part of the Plant designated as a plutonium area, the seriousness of the results of this impact, in terms of the amount of any plutonium release, depends on a number of factors: (1) whether or not pieces of the plane penetrate into the interior of the structure, (2) the kind of destruction caused in the interior of the structure, (3) the proportion of building containing plutonium, and (4) the quantity and form of the available plutonium. The damage to the structure will be considered next.

Penetration Probability

Whether or not the plane penetrates into the building depends on the strength of the barrier (thicknesses of the external walls, internal walls, roof, and ceiling) and the striking force of the plane. The barrier thickness, measured in inches

*The average angle would then be 50°. The shadow was computed using the tangent of the impact angle, and tan 50°/tan 10° = 6.75 ≅ 6.

of concrete, varies from one building to another. The striking force of a plane is mainly a function of its size and the velocity at which it is traveling. In a study by Chelapati, et al,[5] a computer simulation model was designed to calculate the penetration depth expected for the same four general classes of aircraft as distinguished here: small and large in size and associated with a nearby airport (Jeffco traffic) or with an airport at a distance of more than five miles (Stapleton and other traffic). The output from this simulation, expressed in terms of penetration probability for different thicknesses of concrete, is recreated in the appendix of this report. One assumption of this model was that the missile penetrating the building is the most resistant part of the plane; namely, the engine. Within each of the main-size categories, a range of possible aircraft-engine sizes and weights was considered in the simulation. The diameters of typical holes made by these missiles were taken to be 40 inches for the engine of a small plane and 60 inches for that of a large plane.

The probability of a plane penetrating a particular part of a particular building can be determined by tables in the appendix of this report. Compute the total thickness, in inches, of the concrete barriers (roof, ceiling, and wall) and use that total to find the applicable row in the appropriate table.

Probability of Crashing Into Plutonium Portion of Building

Given than an aircraft penetrates a building, its probability of striking a vulnerable part of the building; i.e., the area containing plutonium, is computed in the following manner. First, the size of these areas containing plutonium is computed and expressed as a percentage of the total building area. Missiles can reach locations on the first floor, for example, by passing through the first floor ceiling, or by passing through the roof and the first floor ceiling. It is assumed that small planes just penetrate the barrier and have little residual velocity. In passing through the first floor walls, small planes therefore will strike plutonium areas only if the areas are adjacent to the walls. For pieces of a large plane, on the other hand, some

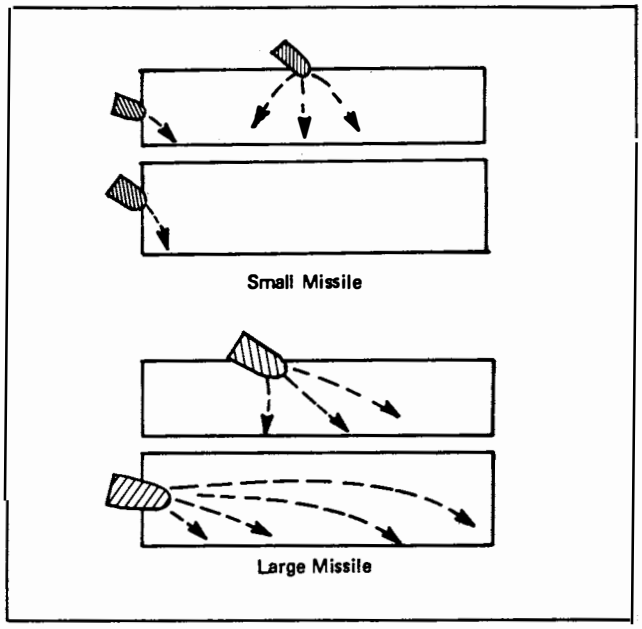


FIGURE 2. Penetration Paths

residual velocity is expected, and the assumption is made that the missile may land anywhere within the building (see Figure 2). The probability of striking a plutonium area is then equal to the ratio of the plutonium area to the total area of the building.*

Missles that reach the first floor by passing through (1) the second floor wall and the first floor ceiling or (2) through the roof and the first floor ceiling are also assumed to be equally likely to fall anywhere on the first floor; consequently, the probability of striking a plutonium area is again equal to the proportion of the floor space occupied by plutonium areas. This applies to both large and small aircraft. In a similar manner, the probability that a missile coming through the

*This probability calculation is conservative since the initial probability of striking the building was found by taking as the total target size, the building area plus the building's shadow to account for the plane's angle of impact. Use of this larger area– building area plus shadow– as the denominator in the plutonium-area probability would have given the probability a smaller value and would imply that the missile continued on its original line path after penetrating a barrier.

second-story wall or roof will hit a filter plenum on the second floor is calculated. This probability is equal to the proportion of the second floor occupied by the equipment. An exception is the case of a small plane entering through the second story wall. In the latter instance, only equipment adjacent to the wall is considered vulnerable.

Damage Scenarios

Damage from an aircraft missile penetrating a building containing plutonium can vary. Rather than consider all possible kinds and amounts of damage from this source or to consider the probabilities of such an event, several scenarios have been constructed. These fairly detailed scenarios describe damage patterns that are believed to be typical.

Scenario 1 (Small Plane)

A small plane crashes into the wall of a plutonium building. The plane's engine, weighing 400 pounds, penetrates into the building at the area adjacent to the wall. Some equipment is knocked over and is broken. About 50 gallons of gasoline (half the plane's load) spills into the building through the 40-inch hole made in the wall. This gasoline ignites and the fire spreads over a 250-square-foot area (diameter 18 ft). The fire burns for 5 to 10 minutes before burning out or being extinguished.

Scenario 2 (Small Plane)

A small plane passes through the roof or second-story wall of a plutonium building into the second-floor ventilation area and strikes a filter plenum. As described in Scenario 1, the plane makes a 40-inch hole to the exterior, and a fire is started over a 250-square-foot area.

Scenario 3 (Small Plane)

A small plane crashes into a plutonium building, and the engine penetrates both the second-story wall or roof *and* the first floor ceiling. The engine, weighing 400 pounds, comes to rest on the first-floor working area after having knocked over and broken some equipment. Gasoline, however, does not penetrate to this area, so there is no gasoline fire. Holes in wall, roof, and ceiling are 40 inches in diameter. Since this scenario postulates no fire in the plutonium area, it is assumed that no release will occur.

Scenario 4 (Large Plane)

A large aircraft crashes into a plutonium building, and an engine weighing two to three tons penetrates the wall and roof leaving a 60-inch-diameter hole to the exterior. Some equipment is broken up, crushed, and scattered. Two thousand gallons of fuel flowing from the plane into the building causes a fire of about 5,000 square feet in an area 80 feet in diameter. The fire burns for 20 to 30 minutes (this assumes that about 20 percent of the fuel typically available in the aircraft ignites inside the building).

Estimates were made of the amount of plutonium that would be released as a result of Scenarios 1, 2, and 4. The release also depends, of course, on the form of the plutonium and the total amount in the area where the damage occurs. These varied from one building to another.

Plutonium Available for Release

Within each building considered, the plutonium areas were subdivided according to the approximate amount of material present and its form. The following categories and descriptions were established:

1. Plutonium areas not presently in use.
2. Plutonium waste packaged in drums.
3. Plutonium waste packaged in fiberglass-covered plywood boxes.
4. Two to three kilograms of plutonium in oxide form.
5. Two to three kilograms of plutonium in metallic form.

TABLE 4. Proportion of Plutonium Dispersed in One Hour or Less During a Fire

Form of Plutonium	Source of Data	Amount Dispersed		
		Minimum (percent)	Average (percent)	Maximum (percent)
Metallic	Reference 6 and 7	0.005	0.02	0.1
Molten	Ten times that of "metallic" because of surface area	0.05	0.2	1.0
Plutonium Oxide	Reference 8	0.02	0.1	1.0
Plutonium Oxide in Waste	Reference 8	1.0	10	40
Plutonium Oxide on Asphalt Surface During Moderate Wind	Reference 9	–	0.5	1.0
Low Wind	–	–	0.05	0.1

6. Ten kilograms of plutonium in oxide form.

7. Ten kilograms of plutonium in metallic form.

8. Seventy to one-hundred kilograms of plutonium in oxide form.

9. One-hundred kilograms of plutonium in metallic form packaged and stored in a vault.

10. Eight-hundred kilograms of plutonium in metallic form packaged for shipping in containers averaging one to five kilograms of plutonium each.

The probabilities of an aircraft striking a plutonium area in a given building were computed separately for each plutonium building and for each category found in the building.

ASSESSMENTS OF THE AMOUNT OF PLUTONIUM RELEASED

General Considerations

Assessments of the amount of plutonium released were made by considering the uncertainty in three parts: (1) the amount and form of the material generally present in the area of the postulated accident, (2) the amount of material present that would be exposed; i.e., material that has its containment breached, by the postulated accident, and (3) the amount of exposed plutonium that would be dispersed to the exterior of the area. Building supervisors and other knowledgeable people at Rocky Flats estimated these three factors for the various combinations of amounts and forms of plutonium present in their buildings. Their estimates of the plutonium present were used directly in the analysis. Estimates of the percentages of material exposed and subsequently dispersed, however, were adjusted to be more comparable with results of various experimental studies. These experimental values and their sources are shown in Table 4 and can be summarized as follows: for metallic plutonium, the maximum release because of fire accompanying the accident would be about 0.1 percent of the material present. For experiments in which plutonium is heated to ignition but with no other burning material present, the maximum releases are about half this amount.

In the case of molten plutonium, which has a much larger surface, a maximum release of 1.0 percent is postulated. This is 10 times the amount postulated for metallic plutonium. For plutonium oxide, a light powder that would be widely scattered in the accident, a maximum release of 1.0 percent is also assumed, except when the

plutonium is contained in combustible contaminated waste. The amount released (entrained on small pieces of ash) may be as high as 40 percent. For plutonium outside a building (for example, the plutonium in the contaminated earth covered by the asphalt pad), the release depends mainly on the wind speed and the period of time the plutonium is exposed. During a period of 24 hours with moderate winds (20 to 25 mph), up to 1 percent of the material might be released.

Detailed Assessments

The percentage of the available material released would be greatest from a large fire and when the hole in the building is directly above or alongside the fire. For each area and accident combination, several release amounts and their probabilities of occurrence were assessed, conditional on the assumption that the accident occurred.

When assessing the possible release from areas of high plutonium concentration, the details of a postulated accident were considered. For example, if a missile penetrates into the area and scores a direct hit on a glove-box line where large quantities of plutonium oxide are being processed, what will be the amount of plutonium available for release, and what is the probability of such a direct hit? If, on the other hand, the missile lands in the area without actually striking the glove boxes, and starts a fuel fire on the floor around the glove boxes causing the gloves to burn off and the windows to crack, what will be the amount of release?

For plutonium in the form of solution or sludge, the assumption was made that a fire resulting from an aircraft crash would be extinguished before enough evaporation had taken place to release the plutonium.

Within the filter plenums, fires in the first or second filter stages were estimated to allow the release of from 1 to 40 percent of the material trapped on the filters. (These values are taken from studies of plutonium release from combustible waste and probably are overestimates of the release amounts.) No release is expected from a fire in the third or fourth filters, which essentially are uncontaminated. The escape of unfiltered air because of a rupture in the filtering system also is not considered a hazard. The reason is that a crash affecting the filters would cause a break in the system between the area where the contaminated air originates and the fans that draw the air through the filters. This means that little or no air would be drawn out of the contaminated area.

SUMMARY OF RESULTS

Event Tree

The previously discussed release estimates and their likelihood of occurrence are combined to give an overall impression of the risk attributable to an aircraft crashing into the Plant. One way of showing all combinations of occurrences that have been considered is an event tree in which the various events and their probabilities are presented in sequential form. This method is illustrated in Figure 3. Each pathway through the tree represents a different, specific series of events leading to a plutonium release in the range of 0 to 1,000 grams (the maximum release postulated from an aircraft crash).

The amount of release is shown at the last branch in the path. The probability associated with any of these releases is obtained by multiplying together all the conditional probabilities computed along the path leading to the final release branch. For example, the path marked by the dotted line assumes that a large aircraft from Stapleton crashes into Building 1, penetrates Area A and causes a release of y grams of plutonium. The probability of this release (y) therefore would be a mathematical combination of the probabilities of a crash by a large aircraft from Stapleton, hitting a building the size of Building 1, penetrating an area protected in the manner of Area A, and releasing a percentage of plutonium equal to y grams.

To simplify the presentation in Figure 3, only part of the event tree has been drawn in detail. Many branches have been omitted. In the actual event tree, each aircraft origin made, both for large and small aircraft, is developed to show (1) all the

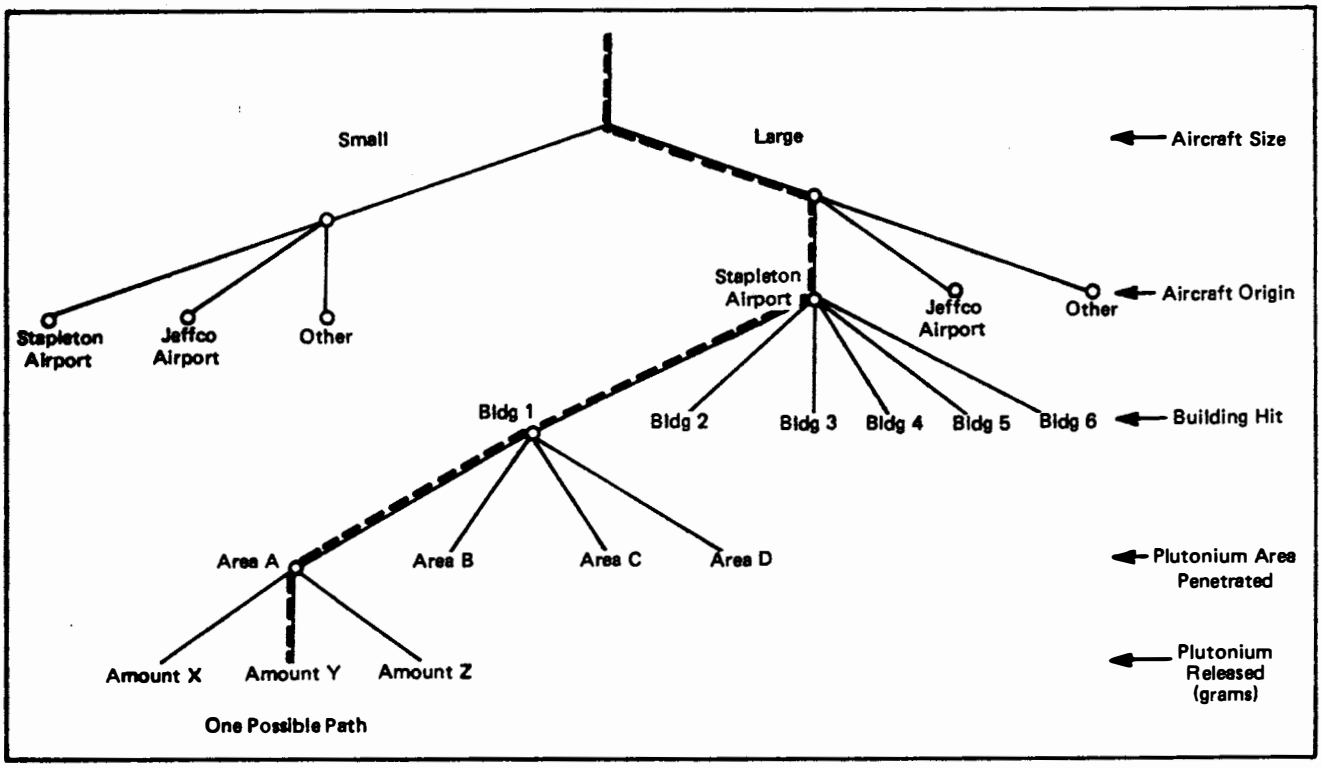


FIGURE 3. Partial Event Tree for Aircraft Crashes Into the Facility. One Possible Path Through the Tree is Indicated by the Dotted Line.

TABLE 5. Possible Amounts of Plutonium Released Because of Aircraft Accidents and Their Probabilities of Occurrence Per Year (grouped data)

Amount of Plutonium Released (grams)	Total Probability (per year)	Probability Broken Down by Aircraft Size and Origin*			
		Large Aircraft		Small Aircraft	
		Jeffco	Stapleton	Jeffco	Stapleton
Less than 0.5	3.9×10^{-5}	4.5×10^{-7}	1.4×10^{-7}	3.9×10^{-5}	5.3×10^{-7}
0.5 – 3	8.5×10^{-6}	4.8×10^{-7}	2.4×10^{-7}	7.1×10^{-6}	6.9×10^{-7}
5	1.8×10^{-6}	5.6×10^{-8}	1.4×10^{-8}	1.7×10^{-6}	3.1×10^{-8}
10	3.4×10^{-7}	3.0×10^{-8}	1.6×10^{-8}	2.9×10^{-7}	6.1×10^{-9}
15 – 25	2.7×10^{-7}	6.9×10^{-8}	3.9×10^{-8}	1.8×10^{-7}	3.3×10^{-9}
50 – 70	5.8×10^{-6}	7.9×10^{-9}	4.2×10^{-9}	5.7×10^{-6}	8.2×10^{-8}
100	1.3×10^{-7}	6.8×10^{-8}	1.2×10^{-8}	3.2×10^{-8}	4.3×10^{-10}
200	5.6×10^{-8}	1.4×10^{-9}	4.6×10^{-10}	5.6×10^{-8}	8.3×10^{-10}
400	3.7×10^{-9}	2.6×10^{-9}	1.1×10^{-9}	–	–
500	1.2×10^{-8}	–	–	1.2×10^{-8}	6.8×10^{-10}
1000	6.4×10^{-10}	3.2×10^{-10}	3.2×10^{-10}	–	–

*Sum of component probabilities may not equal total because of rounding and grouping.

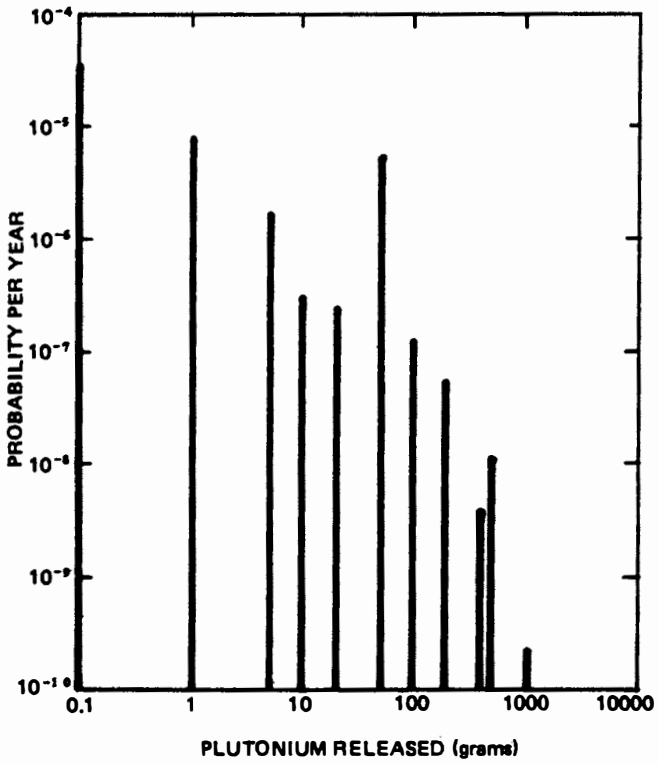


FIGURE 4. Amounts of Plutonium Releases (grams) and Their Probability Values (Caused by All Types of Aircraft Crashes)

TABLE 6. Weighted Average of the Plutonium Released Per Year Because of Aircraft Accidents

Type of Aircraft and Origin	Weighted Average of Plutonium Released* (grams per year)
Large Aircraft – Jeffco	1.2×10^{-5}
Stapleton	3.7×10^{-6}
Small Aircraft – Jeffco	3.3×10^{-6}
Stapleton	5.7×10^{-6}
Total** All Aircraft	3.7×10^{-4}

*The weighted average is equal to the amount of possible release times the probability of occurrence, summed over all release amounts. (Computed from ungrouped data)

**Second figure only partially significant due to rounding error.

buildings that could be hit, (2) all the different areas within each building, and (3) within each area, all of the different amounts of possible release. The label and number of these categories for areas within a building and releases from an area generally will differ from one building to another, depending on the types and amounts of plutonium present. The complete event tree for this study had 309 end points.

Release Amount Versus Probability

Possible amounts of release, and their probabilities of occurrence, are presented in tabular (Table 5) and graphical (Figure 4) form. As was described earlier, a probability and an amount of release are associated with each end point of the event tree.

The same release amount may appear at different end points. For example, 20 grams is the postulated release amount for several different paths through the tree. To summarize the results of calculations for all paths through the tree, the end-point release amounts are tabulated in order from the smallest quantity to the largest. Also included are their probabilities. When the same amount occurs more than once, its different probabilities are added to give the total probability of such a release. In this manner, a probability distribution over the release amounts is obtained. This distribution is shown in Table 5 and is drawn on a log-log chart in Figure 4. The weighted average of the release amount, which is a sum, was computed by multiplying each of the different releases by their probability of occurrence and then adding up these products. The result, as shown in Table 6, is 3.7×10^{-4} grams of plutonium.

This is the value taken as the "source term" from which the environmental effects are computed. The release category having the highest probability of occurrence is, according to Table 5, "less than 0.5 grams." The largest contributor to this category is a hypothesized outcome if a plane were to crash

into the asphalt pad area. This outcome is the release of 0.0005 grams of plutonium, and it has a probability of occurrence per year equal to 2.5×10^{-5}.

Maximum Release

The largest release noted in Table 5, 1000 grams, would result if particular spots in the following plutonium buildings were penetrated:

Release (grams)	Building*	Probability (per year) of Aircraft Impact and Release of Plutonium
1000	1	1.4×10^{-10}
1000	2	1.1×10^{-10}

Release by Plutonium Area

Breaking down the release figures according to which plutonium area is the source shows that Buildings 3 and 4 are the sources of greatest possible release. In both buildings, the hypothesized accident making the largest contribution to the weighted average is that of a small plane from Jeffco crashing into and setting fire to a filter plenum.

Building or Other Plutonium Area	Weighted Average of Possible Releases (grams plutonium per year)
3	1.4×10^{-4}
4	1.1×10^{-4}
6	7.4×10^{-5}
7	1.2×10^{-5}
8	6.9×10^{-6}
1	1.0×10^{-6}
2	3.4×10^{-7}
Asphalt Pad	1.1×10^{-7}
5	1.5×10^{-8}

*For security reasons, specific buildings at the Rocky Flats Plant have been assigned different identification numbers for this report.

REFERENCES

1. D. M. Boonin. "An Aircraft Accident Probability Distribution Function." *Trans. Amer. Nucl. Soc.* 18:225-226. June 1974.

2. D. G. Eisenhut. "Reactor Sitings in the Vicinity of Airfields." *Trans. Amer. Nucl. Soc.* 16:210-211. 1973.

3. I. B. Wall. "Probabilistic Assessment of Aircraft Risk for Nuclear Power Plants." *Nuclear Safety* 15:276-284. May-June 1974.

4. "Failure Data." *Reactor Safety Study* Appendix III (Draft), Pages 154-156. WASH-1400. U.S. Atomic Energy Commission. August 1974.

5. C. V. Chelapati, R. P. Kennedy, and I. B. Wall. "Probabilistic Assessment of Aircraft Hazards for Nuclear Power Plants." *Nucl. Eng. Des.* 19:333-364. 1972.

6. H. K. Hilliard. *Probable Volatilization of Plutonium During a Fire.* Hanford Laboratories, HW-71743. Page 7. Hanford Atomic Products Operation, Richland, Washington. December 1, 1961.

7. J. Mishima. *A Review of Research on Plutonium Releases During Overheating and Fires.* Hanford Laboratories, HW-83668. Page 8. Hanford Atomic Products Operation, Richland, Washington. August 1964.

8. J. Mishima and L. C. Schwendiman. *Amount and Characteristics of Plutonium Made Airborne Under Thermal Stress.* BNWL-SA-3379. Battelle-Northwest, Richland, Washington. October 1970.

9. J. Mishima and L. C. Schwendiman. *Some Experimental Measurements of Airborne Uranium (Representing Plutonium) in Transportation Accidents.* BNWL-1732. Battelle-Northwest, Richland, Washington. August 1973.

APPENDIX

COMPUTATIONAL DETAILS

Penetration Probabilities

The penetration probabilities from the simulation study by Chelapati, et al, (Reference 5) are reproduced in Tables A-1 through A-4. These tables reflect reported values (means and standard deviations) for each of four categories, and the distribution is assumed to be log normal. These probabilities and penetration depths (in inches) apply to reinforced concrete.

TABLE A-1. Penetration Probabilities for Small Plane from Jeffco (Mean = 6.3 inches; Standard Deviation = 1.8 inches)

Depth of Penetration Into Concrete (inches)	Cumulative Probability	Penetration Probability*
1.000	0.000	1.000
2.000	0.000	1.000
3.000	0.006	0.994
4.000	0.069	0.931
5.000	0.247	0.753
6.000	0.486	0.514
7.000	0.697	0.303
8.000	0.840	0.160
9.000	0.921	0.079
10.000	0.963	0.037
11.000	0.983	0.017
12.000	0.993	0.007
13.000	0.997	0.003
14.000	0.999	0.001
15.000	0.999	0.001
16.000	1.000	0.000

*Probability of penetration to the depth shown in the first column or to a greater depth. The probability is 1 minus the cumulative probability from Column 2.

TABLE A-2. Penetration Probabilities for Small Plane from Stapleton (Mean = 10.2 inches; Standard Deviation = 4.4 inches)

Depth of Penetration Into Concrete (inches)	Cumulative Probability	Penetration Probability*
1.000	0.000	1.000
2.000	0.000	1.000
3.000	0.003	0.997
4.000	0.020	0.980
5.000	0.064	0.936
6.000	0.141	0.859
7.000	0.240	0.760
8.000	0.351	0.649
9.000	0.462	0.538
10.000	0.563	0.437
11.000	0.651	0.359
12.000	0.726	0.274
13.000	0.786	0.214
14.000	0.835	0.165
15.000	0.873	0.127
16.000	0.903	0.097

*Probability of penetration to the depth shown in the first column or to a greater depth. The probability is 1 minus the cumulative probability from Column 2.

TABLE A-3. Penetration Probability Distribution for Large Plane from Stapleton (Mean = 54.9 inches; Standard Deviation = 26.4 inches)

Depth of Penetration Into Concrete (inches)	Cumulative Probability	Penetration Probability*
1.000	0.000	1.000
2.000	0.000	1.000
3.000	0.000	1.000
4.000	0.000	1.000
5.000	0.000	1.000
6.000	0.000	1.000
7.000	0.000	1.000
8.000	0.000	1.000
9.000	0.000	1.000
10.000	0.000	1.000
11.000	0.000	1.000
12.000	0.001	0.999
13.000	0.002	0.998
14.000	0.003	0.997
15.000	0.004	0.996
16.000	0.007	0.993

*Probability of penetration to the depth shown in the first column or to a greater depth. The probability is 1 minus the cumulative probability from Column 2.

TABLE A-4. Penetration Probabilities for Large Plane from Jeffco (Mean = 20.9 inches; Standard Deviation = 7.7 inches)

Depth of Penetration Into Concrete (inches)	Cumulative Probability	Penetration Probability*
1.000	0.000	1.000
2.000	0.000	1.000
3.000	0.000	1.000
4.000	0.000	1.000
5.000	0.000	1.000
6.000	0.000	1.000
7.000	0.002	0.998
8.000	0.006	0.994
9.000	0.015	0.985
10.000	0.030	0.970
11.000	0.053	0.947
12.000	0.084	0.916
13.000	0.125	0.875
14.000	0.172	0.828
15.000	0.226	0.774
16.000	0.284	0.716

*Probability of penetration to the depth shown in the first column or to a greater depth. The probability is 1 minus the cumulative probability from Column 2.

Printed
April 28, 1977

RFP-2523
UC-13 GENERAL, MISCELLANEOUS,
AND PROGRESS
REPORTS (NONNUCLEAR)
TID-4500-R65

NATURAL HAZARDS THAT MAY TRIGGER A RADIOLOGICAL RELEASE FROM A PLUTONIUM PROCESSING FACILITY

Judith E. Selvidge

Consultant

SUBJECT DESCRIPTORS

Accidents
Contamination
Hazards
Plutonium
Probability

ROCKWELL INTERNATIONAL
ATOMICS INTERNATIONAL DIVISION
ROCKY FLATS PLANT
P.O. BOX 464
GOLDEN, COLORADO 80401

Prepared under Contract EY-76-C-04-3533
for the
Albuquerque Operations Office
U. S. Energy Research and Development Administration

CONTENTS

NATURAL HAZARDS THAT MAY TRIGGER A RADIOLOGICAL RELEASE FROM A PLUTONIUM PROCESSING FACILITY

Judith E. Selvidge

Consultant

Abstract. Calculations show the probability of a tornado striking a plutonium area at Rocky Flats is 2.2×10^{-4} per year. The source term (expected value of plutonium release) should such an event occur is calculated at 3.3×10^{-7} grams. The source term for high-velocity, downslope winds is higher—2.2×10^{-3} grams. The probability of a meteorite that weighs one or more pounds (453 grams) striking a plutonium area is estimated at 8.88×10^{-7} per year. Because of this small probability and the remote chance that a plutonium release would occur even if a meteorite hit occurred, the hazard from meteorite impact is considered negligible. Conservative assumptions result in all calculated frequencies being almost certainly too high. Empirical observations have indicated lower frequencies than those calculated.

INTRODUCTION

Natural events that may cause damage leading to the release of radioactive material at Rocky Flats are tornadoes, downslope windstorms, earthquakes, and impact by meteorites. Floods, tidal waves, cyclones, hurricanes, and volcanoes are not considered to be hazards at the Rocky Flats site. For each of the natural hazards of interest, the probabilities are greater than about 10^{-8} per year. The damage that could result from the event and the subsequent radiological release should be assessed.

In this report, the probability of occurrence is computed for severe downslope windstorms and tornadoes. The possible damage and associated release of plutonium are also estimated as are the hazards from possible meteorite impact. The probabilities and possible release for earthquakes are still under study.

PROBABILITIES FOR DOWNSLOPE WINDSTORMS

The Front Range area of the State of Colorado from Colorado Springs to Fort Collins is subject to occasional, severe, downslope windstorms occurring in the lee of the Rocky Mountains. These storms generally are strongest and cause the most damage in the city of Boulder, about 10 miles north of Rocky Flats. Figure 1 shows schematically the wave-like character of the winds.* Rocky Flats, which lies between Boulder and Jefferson County Airport, can be expected to experience high winds at about the same time and with comparable maximum-wind velocities as those occurring in Boulder. Several studies of Boulder windstorms have dealt with the characteristics of the winds (their gustiness and maximum speeds), the frequency of occurrence of the storms, and the wind damage produced.[1-3] This report treats the winds at Rocky Flats in a similar manner.

Windstorm Frequency

The frequency of occurrence of reported windstorms** in Boulder over the 104-year period from 1869 to 1972 ranges from 0 to 14 storms per year.*** The number reported is greatest during the latter part of that period because of the city's expansion into previously open areas, particularly the Table Mesa section of that city.

The average number of storms from 1960 to 1972 was 6.08 per year. The value of six storms per year

*Reference 1, Page 4.

** A windstorm for the Boulder and Rocky Flats area is defined as a period when all of the National Center for Atmospheric Research (NCAR) wind-measuring stations in Boulder reported winds of greater than 50 mph, and at least one station reported speeds greater than 75 mph (hurricane force).

***Reference 1, Page 12.

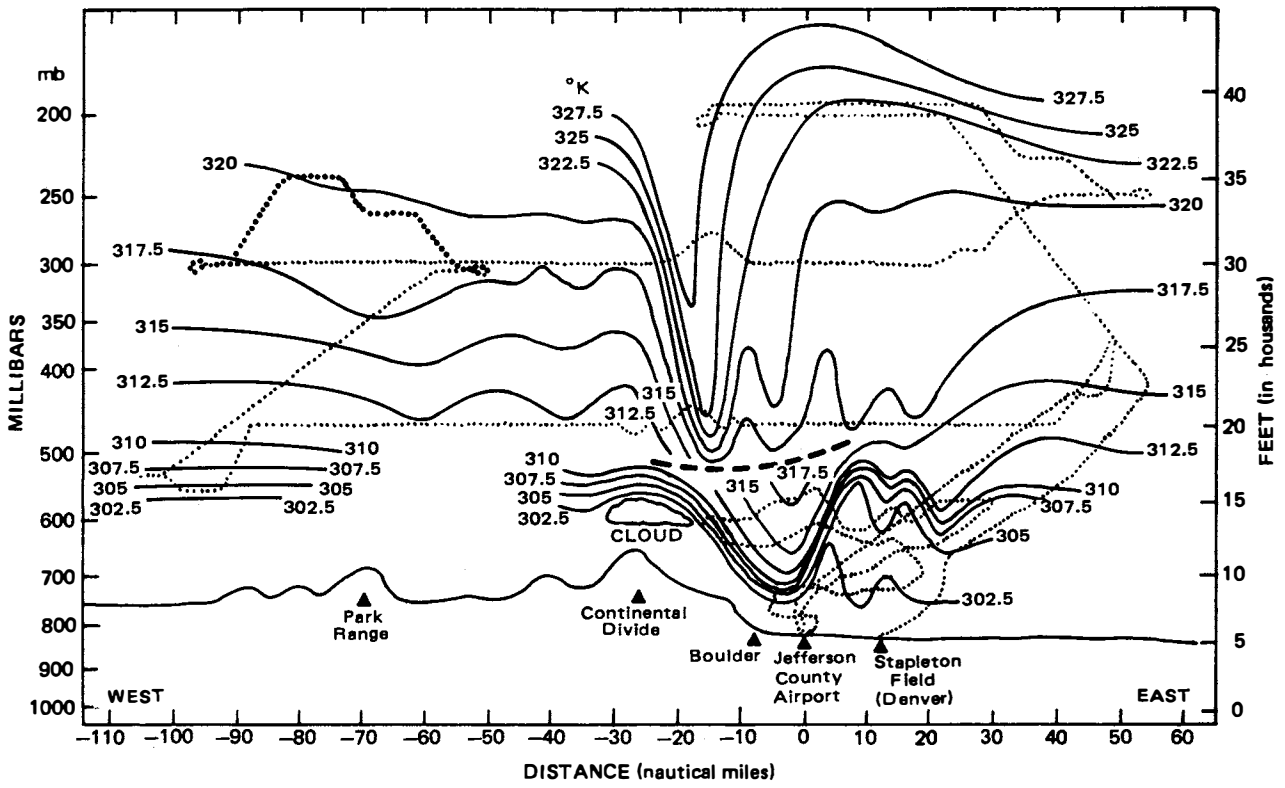


FIGURE 1. Cross Section of Potential Temperature (°K) During a Windstorm at Boulder, Colorado. The short dashed lines are flight paths of the aircraft that conducted the potential temperature survey. Lines of constant potential temperature can be considered as streamlines of atmospheric flow. (See Reference 3.)

will be used in this study as an estimate of the frequency of windstorms at Rocky Flats.

Maximum Wind Speed

Wind gusts of over 100 mph have been measured during downslope windstorms in the Boulder and Rocky Flats areas. The statistical theory of extremes makes use of past data on maximum gusts to estimate the probability of occurrence of high winds during future storms.[4] Following this theory, a particular probability distribution is fit to previously observed, maximum gusts and is projected to give the probability of high wind-speed values. In this study, the estimates are based on data collected during 32 recent storms representing a five-year period. The data are shown in Table 1.

Two distributions have been used here to fit these extreme wind values: the Fisher-Tippett Type I and the Fisher-Tippett Type II distributions.[2,4,5] The first distribution is appropriate when data having extremes that are of interest follow an exponential type distribution—the second when the *logarithms* of the data have this form. When each of these models is fit by the method of order statistics to this sample of peak gusts recorded at Rocky Flats, the following extreme distributions are obtained:

Type I: Probability (gust $\geq$ x mph)
$$= 1 - \exp(-\exp(-((x-\alpha)/\beta)))$$
with $\alpha = 71.0337$ and $\beta = 12.1785$

Type II: Probability (gust $\geq$ x mph)
$$= 1 - \exp(-(x/\beta)^{-\gamma})$$
with $\gamma = 6.27058$ and $\beta = 70.2809$

TABLE 1. Maximum gusts recorded at Rocky Flats

Year	Month	Day	Maximum Wind Speed (mph)
1969	1	7	98
	1	29	62
	1	31	100
	3	19	86
	4	7	71
1970	1	25	74
	2	3	97
	2	16	79
	11	21	62
	11	25	71
	11	28	62
	11	30	97
	12	31	67
1971	1	20	71
	1	23	66
	1	25	95
	1	29	76
	2	11	75
	3	4	71
	3	31	74
	12	20	62
1972	1	5	81
	1	9	56
	1	11	105
	1	21	68
	1	24	82
	1	28	91
	11	26	104
	12	1	68
1973	3	13	72
	11	1	70
	12	2	92

These formulae were used to compute the probability of attaining or exceeding a particular gust speed in a given storm. Multiplying that probability by the expected six storms per year gives the wind speed probabilities per year shown in Table 2.

As can be seen from Table 2, these probabilities differ depending on whether the Type I or Type II assumption is made. The Type II distribution has been used more often with wind data. Since it also gives larger probability values, the conservative assumption that the Type II model is the better one will be made in this study. Appendix A gives

TABLE 2. Estimates of the Maximum Wind Speed Probabilities

Wind Speed (mph)	Probability Per Year that the Peak Gust Equals or Exceeds the Wind Speed Shown: Type I Distribution	Type II Distribution
100	5.3×10^{-1}	6.2×10^{-1}
150	9.0×10^{-3}	5.1×10^{-2}
200	1.5×10^{-4}	8.4×10^{-3}

details of the calculation of these probabilities; Appendix A also presents graphs showing the entire probability distributions (from which an intermediate value can be read).

Probabilities can be computed theoretically for wind speeds greater than 200 mph; however, it is estimated that from a practical viewpoint, downslope winds cannot exceed 200 mph. Above 200 mph, a turbulent breakdown in the flow is expected, which would prevent a flow increase to greater speeds.[6]

FREQUENCY OF OCCURRENCE OF TORNADOES

The probability of a tornado striking the Rocky Flats facility is estimated primarily from historical data giving the number and sizes of tornadoes reported locally during a 21-year period. The presence of the Rocky Mountains, with the foothills being only four miles west of the plant, influences the meteorological conditions in the area. In particular, theories of tornado formation predict that storms that are intense enough to generate tornadoes will rarely occur this close to the mountains–also that any tornadoes generated will be smaller and weaker than those occurring in the plains to the east.* A study of all reported tornadoes in the State of Colorado during 1959-1972, for which wind speeds were recorded or estimated, supports these theories.** Figure 2 shows the

*Reference 7, Pages 4-5.
**Reference 7, Page 11.

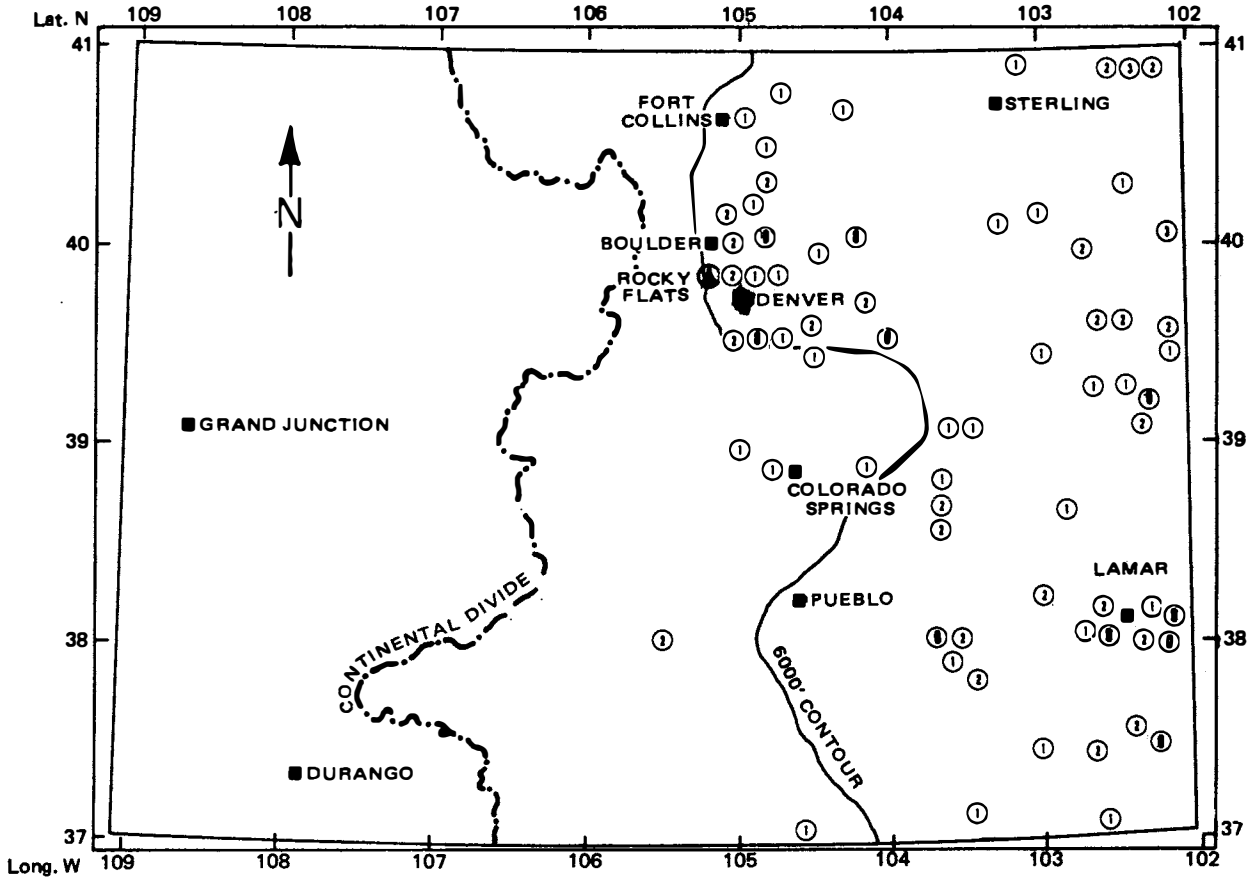


FIGURE 2. Geographical Distribution of Tornadoes in the State of Colorado During 1959-1972. Encircled numbers correspond to Fujita Scale damage specifications explained in the text (see Reference 7).

geographical distribution of these tornadoes. Each circle in Figure 2 represents the location of a tornado, and the number inside each circle is a measure of the storm's intensity on the Fujita Scale.[8] This scale is a way to correlate, approximately, wind speeds with reported damage. The scale is described more fully in the section of this report entitled Structural Damage to Rocky Flats Buildings.

Because of the dependence of tornado frequency and size on the proximity of the mountains, the tornado probability for Rocky Flats is assessed by means of a detailed study of the local area. The geographical area studied is a long, narrow, rectangular region approximately parallel to the mountains and with the plant in the center of the western edge. The north-south dimension is approximately 41 miles, and the east-west dimension is approximately 10 miles, giving a total area of 429 square miles. The region was defined in terms of its longitudinal and latitudinal coordinates so as to conform to the format in which data on tornado locations are reported.

Specifically, the region is the area from the plant site (39° 54′ north latitude, 105° 12′ west longitude) plus 0° 18′ to the north, minus 0° 18′ to the south, and minus 0° 24′ to the east. The area of interest therefore is bounded by 39° 36′ and 40° 12′ north latitude and 105° 12′ and 104° 48′ west longitude.

TABLE 3. Fujita Scale Damage Specifications (from Reference 15)

Fujita Scale	Wind Speed Range (mph)	Damage Classification	Damage Description
F0	40–72	Light	Some damage to chimneys and TV antennae; breaks twigs off trees; pushes over shallow rooted trees.
F1	73–112	Moderate	Peels surface off roofs; windows broken; light trailer houses pushed or overturned; some trees uprooted or snapped; moving automobiles pushed off the road. 73 mph is the beginning of hurricane wind speed.
F2	113–157	Considerable	Roofs torn off frame houses leaving strong upright walls; weak buildings in rural areas demolished; trailer houses destroyed; large trees snapped or uprooted; railroad boxcars pushed over; light object missiles generated; cars blown off highway.
F3	158-206	Severe	Roofs and some walls torn off frame houses; some rural buildings completely demolished; trains overturned; steel-framed hangar-warehouse type structures torn; cars lifted off the ground; most trees in a forest uprooted, snapped, or leveled.
F4	207–260	Devastating	Whole frame houses leveled, leaving piles of debris; steel structures badly damaged; trees debarked by small flying debris; cars and trains thrown some distances or rolled considerable distances; large missiles generated.

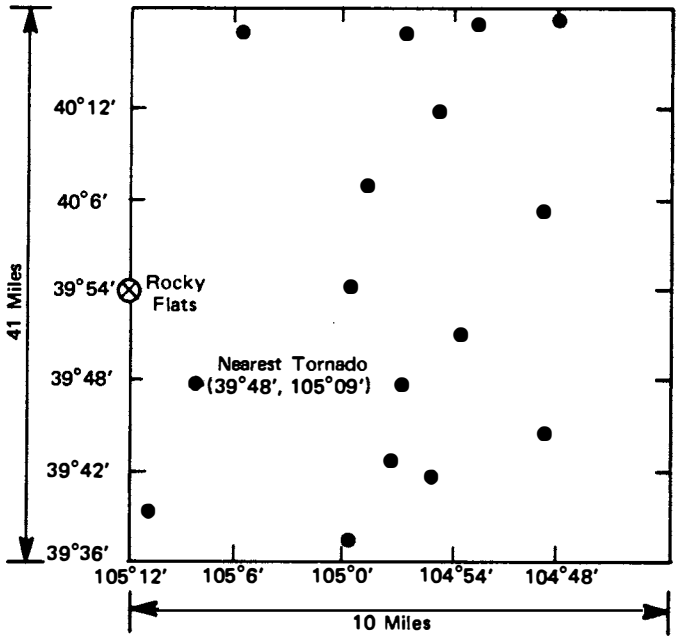


FIGURE 3. Schematic Representation of Locations of Reported Tornadoes (1954-1974) by Geological Coordinates and in Relation to Rocky Flats. (Notice that scale in miles is different for vertical and horizontal axes.)

Information from The Severe Storms Forecast Center at Kansas City and from a survey of the Environmental Data Services' *Monthly Bulletin of Storm Data* shows that during the 21 years from 1954 through 1974, eighteen tornadoes were reported within the geographical area selected. The intensities were reported for 12 of these and are all either F0 or F1 on the Fujita Scale (see Table 3). The location of these 18 tornadoes by geological coordinates and relative to Rocky Flats is shown schematically in Figure 3.

Probability of a Tornado at Rocky Flats

The average number of tornadoes per year in the region studied is 0.86. Its area is 429 square miles, giving a probability of about 2.0×10^{-3} per year for the occurrence of a tornado per square mile. The probability per year of a tornado striking one or more of the plutonium areas at Rocky Flats is found by multiplying 2.0×10^{-3} by the size of the vulnerable area within the plant site and by taking into account the typical dimensions of the tornado reported in this area. The probability must also be increased somewhat to allow for the supposition that some tornadoes are unreported. Details of

this computation are shown in Appendix B. The probability value obtained is 2.2×10^{-4} per year.

Tornadic Wind Speed at Building Height

The wind speed within a tornado is believed to vary depending on its height above ground and the distance from the tornado center.[9] Taking the height variation into account and assuming that the strongest tornado that could occur in this geographical location would be of strength F3 (see Table 3), the resulting wind speed at the heights of Rocky Flats' buildings would be in the range of 100 to 150 mph.

DAMAGE FROM DOWNSLOPE WINDS OR TORNADOES

Structural Failure

Information about high-wind damage to structures comes in part from reports of tornado damage and in part from theoretical wind-tunnel studies. For ordinary residential buildings, extensive failure of roofs, walls, and even foundations occur during wind speeds in the range of 150 and 200 mph.* At these speeds, however, reinforced concrete buildings usually are not damaged, except for possible interior damage to areas where windows are broken.** For example, when cyclone Tracy hit Darwin, Australia on Christmas, 1974, wind speeds of up to about 170 mph were measured. Descriptions of the damage included these observations: "Photographs show iron cladding stripped from steel frame hangers of the Air Force Base, and the unreinforced masonry buildings at the Naval Headquarters completely demolished as though they had been hit by an earthquake! On the other hand, concrete structures at the Travel Lodge Motel appear undamaged."[12] And "this type of structure (reinforced concrete) appeared to perform adequately although the failure of reinforced concrete columns at the Community College in the northern suburbs was an exception. The major reinforced-concrete buildings in the commercial centre suffered damage to brick infill, roof membranes and glazing but apparently no structural damage."[13]

Concrete block and other masonry structures are often damaged by wind speeds above 100 mph. A report on a Dallas, Texas tornado in 1957 contrasts the damage experienced by frame houses and by masonry structures.

> In studying damage to structures, two general modes of collapse, one typical for frame houses and the other for masonry structures could be distinguished. Masonry buildings responded to the internal force caused by the pressure reduction outside of the building, which pushed the walls outward and allowed the roof to fall in while frame houses with more ventilation and therefore more possibility for equalization of pressures showed rather the struggle to resist the sheer driving force of the wind. In the latter, the roofs were ripped off by wind motion, and the walls blown over and strewn along the tornado path. Masonry walls, exhibiting more rigidity, acted as a unit and were pushed over at once, while frame construction could give and therefore was not so frequently seriously damaged.*

The minimum wind speeds necessary to cause the collapse of masonry walls during this tornado were estimated at from 92 to 109 mph.**

A general description of the damage resulting from winds of different speeds is found in the Fujita Scale mentioned earlier. This scale classifies storms into five types as shown in Table 3.

Structural Damage to Rocky Flats Buildings

Using the Fujita Scale to classify the winds and applying the descriptive information gathered to

*See Pages 232-252 of Reference 10 for wind-tunnel test results. See Pages 35-43 of Reference 10 for reports on damage from the Topeka tornado of June 8, 1966.

**Eagleman, et al, in discussing the Topeka tornado of June 8, 1966 states, "The large reinforced concrete structures withstood the tornadic winds, although the contents and internal partitions were severely damaged." (Reference 10, Page 27). Melarango (Reference 11) reports that modern reinforced concrete buildings have survived tornado hits with only minor damage.

*Reference 14, Page 167.

**Reference 14, Page 174.

the plutonium buildings at Rocky Flats, the following estimates of the effects on structure from high-speed winds are obtained.

Case A – Winds 125-157 Miles Per Hour

At this speed, buildings having metal or asbestos siding would be expected to suffer some structural damage. Sheets of metal siding might be ripped off. Holes in the wall would allow equipment and stored material to be blown around in the interior of the building. Some of the walls of concrete block buildings may collapse.

Holes might be made in the walls of Building 4, siding might be torn loose from Building 8, and walls of Building 5 and 7 may partially collapse. A speed of 125 mph is used as the lower limit for this case since that value is the design basis wind for Buildings 4, 7, and 8.

Case B – Winds 158-206 Miles Per Hour

Damage to metal or asbestos buildings would be more extensive than that described under Case A. Asbestos siding may shatter in places, and large portions of the walls of masonry (concrete block) buildings may collapse. Doors on concrete structures might be blown in or out allowing some interior wind damage to occur.

Damage from Wind- or Tornado-Borne Missiles

In addition to structural damage during a high wind, buildings may be damaged by loose objects or pieces of more fragile buildings that are picked up and carried along by the wind. The higher the wind speed, the more likely an object is to become airborne and the greater its force when it crashes into anything in its path. Objects that are heavy enough to be a serious source of damage, however, require very fast wind speeds before they become airborne; furthermore, because of air resistance, these airborne missiles travel at speeds less than that of the wind that carries them along. As an example, film analyses of a 1957 tornado in Dallas indicated that although wind speeds reached 172 mph, none of the speeds of 400 pieces of debris travelling over paths that were observed exceeded 125 mph.[16] On the other hand, an example of an object unusual in that it is both heavy and yet "flies well" would be a steel reinforced beam attached to a carport roof that has been torn off its wall by the storm. During a 1973 tornado in Plainview, Texas, such a beam penetrated the exterior wall of a conventional brick-veneer residence and passed through several pieces of furniture inside the house.[15]

In safety studies for nuclear reactors, possible damage by missiles ranging from wooden planks to automobiles has been discussed.[11] The force with which a missile strikes a building depends on details of the physical characteristics of the object (its weight, size, and aerodynamic features), the speed of the wind, and the vertical and horizontal distances the object is carried. This information would be difficult to obtain for all likely objects and storms; furthermore, the theoretical formulae for penetration gives values that do not correspond closely to empirical data.[17] For these reasons, the following assumptions about types of airborne missiles and their damage will be made.

Missile Description	Damage Expected
Large wooden plank, 12-foot long, weighing about 200 pounds.	Would penetrate the exterior wall (which is 0.5-inch asbestos board) of Building 4.
Steel pipe, 10-feet long weighing about 100 pounds.	Would penetrate the exterior wall of Building 4. Could penetrate the roof of Building 5. (Minimum roof thickness is 2 inches of concrete.)
Automobile, 3000 pounds, rolling into building.	Would make a hole in the wall of Buildings 4, 5, 7, and 8.

It is hypothesized that the wooden plank would become airborne during a windstorm or a tornado at wind speeds in the upper end of the F2 range (about 140-158 mph). It is assumed that a plank hits each of the plutonium buildings when winds

are in that range. For winds above 158 mph, the effect of the missile damage will be ignored because of the more serious structural damage expected, which results in a greater contribution to any radioactive release.

A steel pipe missile is assumed to become airborne during the sustained winds of a tornado (but not during the gusts of a windstorm) and to hit the roof of every plutonium building.

An automobile would become a rolling missile at wind speeds above about 200 mph; however, as was the case for wooden planks, structural damage or failure would be more important at these speeds. For this reason, automobile damage will be omitted.

The assumption that one plank or pipe hits each building under the conditions specified is a compromise between scenarios where no missiles are available and those where many missiles hit each building.

RADIOACTIVE RELEASE

Radioactive Release Resulting from Missiles

Although the three types of missiles discussed would damage the buildings, in most cases no radioactive release would be expected to occur. A missile penetrating a roof would have to hit and make a hole in a filter plenum or in duct work leading to the plenum to cause a release. Such a missile would probably remain lodged in the hole created. If not, the airflow would be into rather than out of the hole as long as the filter's air pump was operating. During a tornado, however, negative pressure for a few seconds outside the building would draw out unfiltered air. Negative pressure also may occur during high winds because of the Bernoulli effect. The amounts of release and their probabilities for each building have been assessed, taking into account the proportion of the second floor that contains ducts and filter plenums. Missiles penetrating the walls of Building 4 will be considered as possibly causing a release (with probability = 0.01) if the hole made is near a glove-box area. In this case, the containment of the box and its duct work could be breached, which would allow the release of unfiltered air and chips of plutonium.

In the case of damage by missiles to buildings containing plutonium packaged for shipping, it is assumed that holes in the structure will not result in a plutonium release and that containers within the building that might be hit by missiles or blown around by the wind probably would not be broken open. Even if they were, no release of radioactivity from the building would be expected.

Radioactive Release Resulting from Structural Damage

Partial collapse of walls or the ripping off of metal siding from buildings containing packaged plutonium is not expected to lead to any release of radioactivity. For Building 4, the release from possible fracturing of the siding by winds that are in the F2 range of the Fujita Scale would be comparable to that occurring from missile damage. For F3 winds, damage to the walls will be assumed to occur in many locations.

SUMMARY OF HAZARDS

Probabilities

Tornado: The probability per year that a plutonium building will be hit by a tornado is found to be approximately 2.2×10^{-4}.

Maximum Downslope Wind: The probability that the maximum wind speed experienced during a storm will be any particular value is assumed to follow a Fisher-Tippet Type II (Frechet) distribution. The distribution was fit to maximum wind speed data collected at Rocky Flats during five years (32 wind storms). According to these data, the probabilities of high-speed wind gusts are as shown below.

Wind Speed (mph)	Probability (per year)	Return Period (years)
⩾100	0.62	1.6
⩾150	0.051	20
⩾200	0.0084	120

TABLE 4. Summary of Probabilities of Release, Release Amounts, and Weighted Average of Release for Tornadoes

Release Amount (g Pu)	Total Probability (per year)	Weighted Average of Release (g Pu)
0.6	1.1638×10^{-9}	6.9828×10^{-10}
0.7	6.2646×10^{-8}	4.3852×10^{-8}
1	1.0105×10^{-7}	1.0105×10^{-7}
3	6.2646×10^{-8}	1.8794×10^{-7}
Total Tornado Weighted Average of Release (Source Term)		~3.3 $\times 10^{-7}$

TABLE 5. Summary of Probabilities of Release, Release Amounts, and Weighted Average of Release for Downslope Winds

Building	Wind Speed	Total Probability (per year)	Release (g Pu)	Weighted Average of Release (g Pu)
4	F2	1.7392×10^{-5}	0.7	1.2174×10^{-5}
		1.2215×10^{-4}	1	1.2215×10^{-4}
		1.7392×10^{-5}	3	5.2176×10^{-5}
			F2 Total	(1.8650×10^{-4})
	F3	9.1785×10^{-5}	2.1	1.9275×10^{-4}
		2.7219×10^{-4}	3	8.1657×10^{-4}
		9.1785×10^{-5}	9	8.2607×10^{-4}
			F3 Total	(1.8354×10^{-3})
5	F2	1.1842×10^{-5}	0.6	7.1053×10^{-6}
	F3	7.8342×10^{-5}	1.8	1.4101×10^{-4}
			Total	(5.5103×10^{-4})
No release from other plutonium buildings		Grand Total Weighted Average of Release (Source Term)		2.1700×10^{-3}

Grouping the wind speeds into ranges to correspond to the Fujita wind speed scale produces the following results:

Wind Speed Range (mph)	Fujita Scale Number	Probability (per year)	Return Period (years)
125 – 157	F2	0.16	6.3
158 – 206	F3	0.032	31

Weighted Average of the Release

The amounts of plutonium released, given that a building is damaged, and the probabilities of these releases are assessed by considering the strength of the wind, the amount of plutonium available in the buildings, the distance of the plutonium from exterior walls, the element's form and its containment. Tables 4 and 5 show the total probability, release amount, and wind speed category for tornado and downslope winds. The last column in Tables 4 and 5 is the weighted average of the release (release amount times the total probability). The overall, total, weighted average of the release caused by tornadoes is 3.3×10^{-7} grams plutonium. For high winds, it is found to be 2.2×10^{-3} grams of plutonium (this is also called the "expected value of the release" and the "source term"). These figures show that downslope winds make the greatest contribution to the weighted average of releases.

Precision of Results

The computed weighted average of the release caused by high winds (2.2×10^{-3} grams) seems large. It is greater than that computed for aircraft crashes (3.7×10^{-4} grams) and tornadoes (3.3×10^{-7} grams). This value could be unrealistically high if the probabilities of the high winds are too large, if the postulated damage to the buildings is greater than would actually occur, if the assessment of the amount of plutonium released is too conservative, or if any combination of these is the case.

The wind probabilities are based on a well-known mathematical model; however, at some point this model will no longer apply since infinitely fast

winds do not occur. It is not known at what speeds true wind-speed probabilities begin to differ from theoretical ones, nor to what extent they differ. Computing the probabilities with several more years of data would be one way of improving the estimates.

The damage postulated to occur at various wind speeds is based on descriptions of what has happened to buildings of this general type under severe wind conditions. The Rocky Flats buildings may be stronger than the general class. This estimate of building strength could be improved by engineering tests.

Support for the argument that the probability or the damage estimates are too high comes from consideration of the "return period" for the F2 and F3 category winds. The F2 return period is estimated to be 6.3 years. This means that a wind gust in that range would be expected to occur about once every 6.3 years. Since measuring instruments used in the past at Rocky Flats were not designed to record values in excess of 100 mph, the frequency of F2-range winds cannot be verified. It is postulated that in such a wind, the exterior walls of Buildings 4 and 5 would be breached at some point, either by wind-borne missiles or because of structural failure. This damage has not been experienced since the buildings were constructed; consequently, it can be assumed that either the probabilities, the damage, or both are probably overestimated.

REFERENCES

1. C. D. Whiteman and J. G. Whiteman. *An Historical Climatology of Damaging Downslope Windstorms at Boulder, Colorado.* NOAA Technical Report ERL336-APCL35. U.S. Department of Commerce, Boulder, Colorado. November 1974.

2. A. Amr. *Final Report Windloading Criteria for Boulder County.* An unpublished report of The Western Interstate Commission on Higher Education, Intern Program, Boulder, Colorado. 1974.

3. W. A. R. Brinkmann. *A Climatological Study of Strong Downslope Winds in the Boulder Area.* NCAR Cooperative Thesis No. 27. University of Colorado, Boulder, Colorado. 1973.

4. E. J. Gumbel. *Statistics of Extremes.* Columbia University Press, New York. 1967.

5. H. C. S. Thom. "New Distributions of Extreme Winds in the United States," *Journal of the Structural Division, ASCE,* Vol. 94, No. ST7. July 1968.

6. Personal communication with W. Bergen, National Center for Atmospheric Research, Boulder, Colorado. November 1975.

7. J. R. McDonald and J. E. Minor. *Development of a Design Basis Tornado for the Rocky Flats Site, Colorado.* Prepared for C. F. Braun and Co., Alhambra, California. July, 1972.

8. T. T. Fujita. *Proposed Characterization of Tornadoes and Hurricanes by Area and Density.* SMRP Research Paper No. 91. Department of Geophysical Sciences, University of Chicago. February 1971.

9. W. H. Hoecker. "Wind Speed and Air Flow Patterns in the Dallas Tornado of April 2, 1957." *Monthly Weather Rev.,* Vol. 88, No. 5, pp 167-180. May 1960.

10. J. R. Eagleman, V. U. Murihead, and N. Willems. *Thunderstorms, Tornadoes, and Building Damage.* Lexington Books, D. C. Heath & Co., Lexington, Massachusetts. 1975.

11. M. G. Melarangno. *Tornado Forces and Their Effects on Buildings,* Kansas State University, Manhattan, Kansas. 1968.

12. B. A. Bolt. "Damage from the Darwin Cyclone, Christmas 1974." *Wind Engineering Council Newsletter,* Vol. 1, No. 1. May 1975.

13. B. J. Vickery. "A Report on Wind Damage Caused in Darwin by Cyclone Tracy," *Wind*

Engineering Research Council Newsletter, Vol. 1, No. 1, Page 27. May 1975.

14. *The Tornadoes at Dallas, Texas, April 2, 1957.* U. S. Department of Commerce Weather Bureau Research Paper No. 41. 1960.

15. J. R. McDonald, K. C. Mehta, and J. E. Minor. "Tornado-Resistant Design of Nuclear Power-Plant Structures." *Nuclear Safety,* Vol. 15, No. 4. July-August 1974.

16. P. L. Doan. "Tornado Considerations for Nuclear Power Plant Structures." *Nuclear Safety,* Vol. 11, No. 4. July-August 1970.

17. R. C. Gwlatney. "Missile Generation and Protection in Light-Water-Cooled Reactors." *Nuclear Safety,* Vol. 10, No. 4. July-August 1969.

18. J. Lieblein. *A New Method of Analyzing Extreme-Value Data.* NACA-TN-3053. National Advisory Committee for Aeronautics. January 1954.

19. V. E. Blake. *A Prediction of the Hazards from Random Impact of Meteorites on the Earth's Surface.* SC-RR-68-838. Clearing House for Federal Scientific and Technical Information, National Bureau of Standards, Springfield, Virginia.

APPENDIX A

DETAILS OF CALCULATIONS OF WIND-SPEED PROBABILITIES

This Appendix details the technique used to compute wind-speed probabilities of maximum gusts on the basis of sample data. The steps in the calculation are (1) The preparation of a probability graph of the data, (2) The fitting, by order statistics, of a straight line through the data. This is used in extrapolations to estimate probabilities for wind speeds greater than those observed in the sample, and (3) The determination of the confidence of probabilities estimated in Step (2). The theory behind these calculations is attributed mainly to Gumbel;[4] the application of the theory, especially the order statistics calculation, follows the method clearly presented by Lieblein.[18]

The data are analyzed by the two distributions, Fisher-Tippett Type I and Fisher-Tippett Type II (also called the Frechet distribution). The second of these assumes that the logarithm of the variable (wind speed), of which the extreme values (maximum gusts) are being studied, follows an expontential type of distribution. This is a commonly made assumption; thus, the Type II distribution will be taken as the correct distribution from which to estimate the maximum wind-speed probabilities. The Type I distribution is shown simply for purposes of comparison and because it was the distribution applied by Amr.[2] Further data must be collected and work done before anything further can be said on the relative merits of these two distributions.

For the Type I distribution, the cumulative probability of x, F(x), which is the probability of a value (in this example the wind speed) being less than or equal to x, is written as follows:

Type I:

$$P(\text{wind speed} \leq x) = F(x) = \exp\left(-\exp\left(-\left(\frac{x-a}{\beta_1}\right)\right)\right) \quad (1)$$

where a and β_1 are constants. The Type II distribution can be found either by substituting ln x for x or by rewriting the distribution as

Type II:

$$P(\text{wind speed} \leq x) = F(x) = \exp\left(-\left(\frac{x}{\beta_2}\right)^{-\gamma}\right) \quad (2)$$

The constants γ and β_2 can be expressed in terms of the Type I constants as

$$\gamma = \frac{1}{\beta_1} \text{ and } \beta_2 = \exp a.$$

The probability of a wind speed greater than the value x, in other words the probability of exceeding x, is equal to 1 − F(x) or,

Type I:

$$P(\text{wind speed} > x) = 1 - F(x) = 1 - \exp\left(-\exp\left(-\left(\frac{x-a}{\beta_1}\right)\right)\right) \quad (3)$$

and

Type II:

$$P(\text{wind speed} > x) = 1 - F(x) = 1 - \exp\left(-\left(\frac{x}{\beta_2}\right)^{-\gamma}\right) \quad (4)$$

For simplicity of notation, a transformation of x is made to y where $y = (x - a)/\beta$ so that, for example, the Type I distribution can be written

$$F(y) = \exp(-\exp(-y)).$$

TABLE A-1. Rocky Flats Wind Data Covering Five Years

Date*			Data: Original Order, Maximum Wind Speed (mph)	Data: Ordered in Groups of Six Observations (mph)	Data: Ordered from Minimum to Maximum (mph)	Rank
Year	Month	Day				
1969	1	7	98	62	56	1
	1	29	62	71	62	2
	1	31	100	74	62	3
	3	19	86	86	62	4
	4	7	71	98	62	5
1970	1	25	74	100	66	6
	2	3	97	62	67	7
	2	16	79	62	68	8
	11	21	62	71	68	9
	11	25	71	79	70	10
	11	28	62	97	71	11
	11	30	97	97	71	12
	12	31	67	66	71	13
1971	1	20	71	67	71	14
	1	23	66	71	72	15
	1	25	95	75	74	16
	1	29	76	76	74	17
	2	11	75	95	75	18
	3	4	71	56	76	19
	3	31	74	62	79	20
	12	20	62	71	81	21
1972	1	5	81	74	82	22
	1	9	56	81	86	23
	1	11	105	105	91	24
	1	21	68	68	92	25
	1	24	82	68	95	26
	1	28	91	72	97	27
	11	26	104	82	97	28
	12	1	68	91	98	29
1973	3	13	72	104	100	30
	11	1	70	70	104	31
	12	2	92	92	105	32

*Dates correspond to Boulder-area wind storms.

This is analogous to the use of a standardized variate $t = (x-\mu)/\sigma$ in the normal distribution. This y is referred to as the "reduced variate."

Probability Graph

A probability graph is prepared from data that have been put in order from smallest to largest. The rank of an observation is then taken as an estimate of its cumulative probability. For example, Table A-1 shows the observed, maximum, wind speed recorded in each of 32 storms. Column 2 lists the data according to original observations. In Column 4, the data have been recordered from smallest to largest. The rank order of each observation is shown in Column 5. The information to be plotted on the probability graph is the ordered

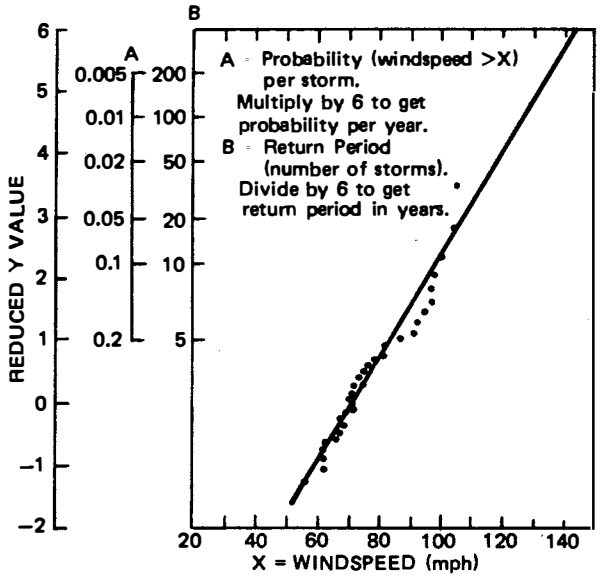


FIGURE A-1. Fitting the Data to a Fisher-Tippett Type I Distribution

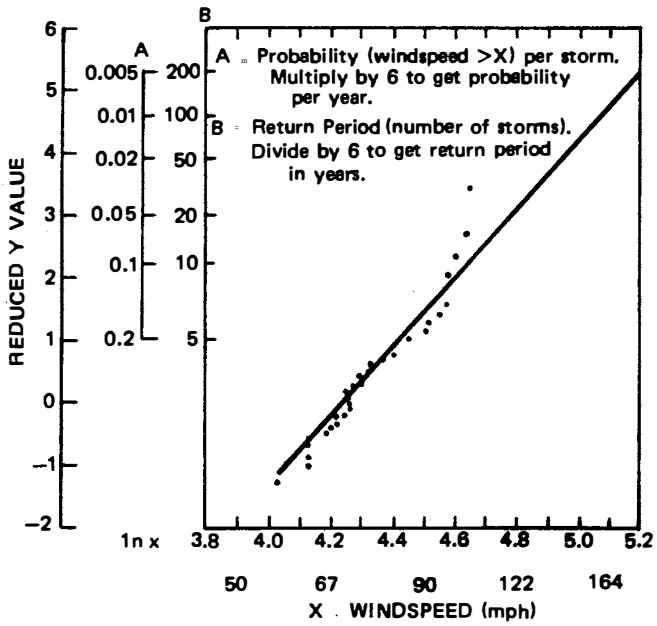


FIGURE A-2. Fitting the Data to a Fisher-Tippett Type II Distribution

observations, x_i, i = 1 to n, versus their cumulative probability estimate taken to be i/(n+1), where i is the rank and n the total number of observations (here n = 32). The x values are plotted on a uniform scale along the horizontal axis. The i/(n+1) values are plotted on a distorted vertical axis, designed in such a manner that the extreme value distribution, exp(−exp(−y)) will plot as a straight line. To obtain this feature on ordinary graph paper, the value plotted along the vertical axis is

$$y = -\ln(-\ln(i/(n+1)))).$$

Wind data graphed in this manner are presented in Figures A-1 and A-2. Two additional scales have been drawn in to permit one to read directly from the graphs the probability of exceeding any wind speed and the corresponding "return period" (the reciprocal of the probability, interpreted as the expected number of storms or years between the occurrence of winds this high or higher). For greater precision the probabilities should be computed from Equation 1 and 2 or Equation 3 and 4 using the constants developed in the next section.

Fitting a Line to the Data

Once the observations have been plotted on an extreme-value probability graph, as described above, a line can be fit by eye to the data. This will provide an approximate method for finding (by interpolation or extrapolation) the probabilities associated with wind speeds other than those observed in the sample. A better way to fit a line to the data, however, is mathematically by means of order statistic as described by Lieblein.[18] The first step in the procedure is to order the data within groups of six observations (Column 3, Table A-1). For details of the rest of the method, see Reference 18. This method yields estimates of the constants in Equation 1 and 2 so that once a model for the process has been chosen (it is concluded here that Equation 2, the Type II model, is appropriate), the cumulative probability values for any x (wind speed) can be determined from the equation. For these data, the constants were computed to be:

Equation 1 $\alpha = 71.0337$

$\beta_1 = 12.1785$

Equation 2 $\gamma = 6.27058$

$\beta_2 = 70.2809$

So, for example, applying the Type II distribution for a wind speed of 150 mph results in (from Equation 4)

$$P(\text{wind speed} > 150) = 1 - F(x)$$
$$= 1 - \exp\left(-\left(\frac{150}{70.2809}\right)^{-6.27058}\right)$$
$$= 1 - \exp(-0.008618)$$
$$= 1 - 0.99142$$
$$= 8.5806 \times 10^{-3}$$
$$\sim 8.6 \times 10^{-3}$$

This is the probability of a wind >150 mph *per storm.* To convert to probability per year, we multiply by 6, the estimated number of storms per year.

Confidence of the Estimates

When a line is fit statistically to data as described above and shown in the figures, it is possible to calculate the degree of confidence one should have in that line compared to an ideal line that would be obtained if an infinite amount of data were available. Uncertainty about the accuracy of the position of the fitted line—whether, for example, its slope should be slightly steeper or less steep—will have a large effect upon values obtained by extrapolating the line far beyond the observed points. For example, using the Type II distribution in Figure A-2 and converting the probabilities to probabilities of occurrence per year, the maximum wind speed of 200 mph is found to have a probability of about 8.4×10^{-3}.

For that probability, however, the corresponding, maximum wind speed would be quite different if the slope of the line changed. It is possible to compute for each probability, the wind speed range about the line, which is plus or minus two standard deviations from the line position. For 200 mph and probability equaling 8.4×10^{-3}, the wind speed range is from about 140 mph to 290 mph. This means it might be correct to say the probability per year of a wind exceeding 140 mph is 8.4×10^{-3} (e.g., the line should be steeper and high value winds are less likely than implied by the present line) or, on the contrary, that the probability per year of a wind exceeding 290 mph is 8.4×10^{-3} (e.g., the line is less steep and higher speed winds are more likely than shown). Consequently, there is a great deal of uncertainty associated with these figures. Nevertheless, the lines as shown are the best estimates of the correspondence between maximum winds and probabilities that can be found from the available sample of 32 storms. There is no statistical reason to assume that the line should be in the steeper part of the range (implying a lessened wind hazard) rather than in the less steep part of the range.

APPENDIX B

DETAILS OF CALCULATIONS OF TORNADO PROBABILITY

Vulnerable Area

The size of the area vulnerable to tornado is taken to be 0.0884 square mile. This figure is computed by adding the "extended areas" of the plutonium buildings. These extended areas are increasing the building dimensions by 145 feet in every direction to account for the fact that the tornado, which is treated as a point in the probability calculation, actually has a width and length. This is the same as saying that if the center of the tornado passes within 145 feet of a building, the building will be assumed to be hit by the tornado. The value of 145 feet is an estimate of the tornado size, based on reported tornadoes in the area and allowing for the possible orientation of the tornado.

Unreported Tornadoes

It is estimated that 80 percent of the tornadoes occurring in this geographical area are reported. An estimate of the actual tornado frequency, therefore, can be obtained by multiplying the observed frequency by 1.25.

Computation of Annual Probabilities per Square Mile

Nearby area = 429 square miles

Years of observation = 21

Tornadoes observed = 18

Tornadoes per square mile per year = $18/429/21 \cong 2.0 \times 10^{-3}$

Factor to account for unreported tornadoes = ~1.25

Annual probability of a tornado, per square mile $= 2.0 \times 10^{-3} \times 1.25 = 2.4975 \times 10^{-3}$

At Rocky Flats' Plutonium Areas

2.4975×10^{-3} per square mile $\times$ 0.0884 miles of vulnerable area = $2.2074 \times 10^{-4} \approx 2.2 \times 10^{-4}$ per year

APPENDIX C

TECHNICAL NOTE ON THE HAZARD AT ROCKY FLATS FROM POSSIBLE METEORITE IMPACT

The probability per year of a meteorite striking a plutonium building at Rocky Flats is computed to be approximately 8.88×10^{-7}. This implies that such a meteorite impact would be expected less than once in a million years. Because of the small probability of this occurrence and the presumption that even if a meteorite were to hit a plutonium building, there is little chance that a release of plutonium would result, the hazard at Rocky Flats from meteorite impact is considered negligible.

The probability of meteorite impact was computed following the general method proposed by V. E. Blake.[19] Only meteorites having a size greater than or equal to one pound are considered. It has been estimated that about 3,500 such meteorites strike the earth every year. It is assumed that they strike the earth at random; that is, that are equally likely to hit any part of the earth.

Details of the Calculation

The total surface of the earth is approximately equal to 1.97×10^8 square miles. The part of Rocky Flats composed of buildings containing plutonium has an area equal to 0.05 square miles; therefore, the fraction of the earth's surface occupied by these plutonium buildings at Rocky Flats is

$$\frac{0.05}{1.97 \times 10^8}$$

The proportion of the earth *not* occupied by those buildings is then

$$1 - \frac{0.05}{1.97 \times 10^8}$$

Since a meteorite is assumed to strike the earth at a random location, this proportion is also equal to the probability that any particular meteorite hits the earth elsewhere than at a Rocky Flats plutonium building. If there are 3,500 meteorites equal to or larger than one pound striking the earth per year, the probability that *none* of them hits Rocky Flats is the product of all these probabilities or

$$\left(1 - \frac{0.05}{1.97 \times 10^8}\right)^{3,500}$$

Consequently, the probability that one or more of the meteorites hits Rocky Flats is equal to one minus the probability that none does, or,

$$1 - \left(1 - \frac{0.05}{1.97 \times 10^8}\right)^{3,500}$$

To solve for this quantity, we first find the probability that none strikes Rocky Flats, using the series expansion:

$$(1-a)^n = 1 - na + \frac{n(n-1)a^2}{2!} - \frac{n(n-1)(n-2)a^3}{3!} + \ldots$$

or

$$\left(1 - \frac{0.05}{1.97 \times 10^8}\right)^{3,500} = (1 - 2.54 \times 10^{-10})^{3,500}$$

$$= 1 - 3,500\,(2.54 \times 10^{-10}) + \frac{3,500\,(3,499)\,(2.54 \times 10^{-10})^2}{2!} - \ldots$$

$$= 1 - 8.88 \times 10^{-7} + 7.89 \times 10^{-13} - \ldots$$

The terms in this expansion after the first two are negligible, so we have

$$1 - 8.88 \times 10^{-7}$$

for the probability per year of no meteorite impact at Rocky Flats. The probability per year of one or more such impacts then becomes

$$1 - (1 - 8.88 \times 10^{-7})$$

or

$$8.88 \times 10^{-7}$$

APPENDIX F

DOSE CALCULATION METHODOLOGY

By
R. B. Falk
J. M. Langsted

December 31, 1978

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (continued)

INTRODUCTION

It is intended that the information presented in this Appendix will be sufficient to allow a person with no knowledge of radiation dosimetry but with mathematical skills to be able to reproduce any dose value presented in this Impact Statement. Where computer codes are used to generate dose conversion factors, the codes are referenced, inputs to the codes are described, and the dose conversion factors are tabulated. Where equations are derived specifically for calculations in this Impact Statement, the derivations are presented in this Appendix. Considerations, assumptions, and methodology for each type of dose calculation are discussed. Sample calculations are presented.

F.1 Dosimetry for Routine Releases

F.1.1 Inhalation Pathway

This section describes the methods for calculating doses to off-site persons by way of inhalation of airborne radionuclides. The methods involve defining the air concentration at the point of interest, defining the quantity inhaled, and determining the dose received by the organs over time.

F.1.1.1 Dose from Inhalation

The organ dose for a given radioisotope is the product of the source term S (curies released), the dispersion term χ/Q* (seconds per meter^3) and the dose conversion factor F_I (rem per curie inhaled multiplied by the breathing rate in meters^3 per second). The equation is then:

$$\text{Organ Dose (rem)} = S \left(\frac{\chi}{Q}\right) F_I \qquad (1)$$

where S = Source term (curies released)

χ/Q = dispersion factor (s/m^3)

F_I = dose conversion factor for inhalation (rem/Ci inhaled multiplied by the breathing rate in m^3/s).

The total organ dose is the sum for all radionuclides of interest.

Source Term

The source term S has two components, the source term for the annual airborne release and the source term for the material deposited off-site from the initial release and then resuspended. (This off-site resuspension is not to be confused with the on-site resuspension, which is included in the airborne source term). The values

*Throughout this discussion, χ/Q is used to represent χ/Q', where χ is the ground level air concentration in Ci/m^3 and Q' is the rate of release at the source in Ci/s (neglecting radioactive decay) as given in Houston, et. al. (1976).

for the first component of the source term are obtained from Table 3.1.2-1, multiplied by 70 to obtain the source term over a 70-year period.

Values for the second component of the source term are a factor 0.97 (the resuspension ratio) times the source terms in the first component, except for ^{241}Am. For ^{241}Am there is an additional component resulting from the ingrowth of ^{241}Am from ^{241}Pu. This factor is 0.0047 times the source term in Table 3.1.2-1 for ^{241}Pu. The derivation of these factors is shown below.

Derivation of the Resuspension Ratio

This derivation is to determine the ratio of the integrated air concentration from resuspension to the integrated air concentration from the initial release, for a chronic release over 70 years.

First, determine the air concentration at time t resulting from resuspension. This air concentration is given by

$$\text{Air Concentration at } t = \int_0^t k(t - \tau)\, S_r\, V_d\, d\tau \qquad (2)$$

where $k(t - \tau)$ = resuspension factor (m^{-1})
S_r = air concentration at the point of interest from the continuous airborne release (Ci/m^3)
V_d = deposition velocity (m/d)
τ = time of deposition from the start of release (days)
t = time since the start of the continuous deposition (days)

The resuspension factor is the ratio of the air concentration (Ci/m^3) from resuspension to the surface concentration (Ci/m^2) on the soil. The expression for the resuspension factor used here is the one developed by Anspaugh, et al. (Anspaugh, et.al., 1975), which has the form

$$k = 10^{-4} e^{-0.15\sqrt{t}} + 10^{-9} \quad (m^{-1}) \qquad (3)$$

for undisturbed soil. To consider the possibility of disturbed soil, the equilibrium value of 10^{-9} was modified by a factor of 100 to a value of 10^{-7}, following the approach of the Colorado Department of Health (CDH, 1976). To simplify integration, the expression $e^{-0.15\sqrt{t}}$ is approximated by the sum of four exponentials,

$$e^{-0.15\sqrt{t}} \simeq 0.55e^{-5.5 \times 10^{-2}t} + 0.30e^{-6.1 \times 10^{-3}t} + 0.055e^{-2.0 \times 10^{-3}t} + 1.22 \times 10^{-3}\, e^{-8.0 \times 10^{-4}t} \qquad (4)$$

The deposition velocity V_d is the apparent speed at which the particles settle from the air. For particles with activity median aerodynamic diameter (AMAD) of 0.3 μm, a value of V_d = 0.001 m/s is used.

Using these values, the integration of equation 2 yields the air concentration from resuspension at time t:

$$\text{Air Concentration at t} = 86.4\ S_r\ [1.00 \times 10^{-3}\ (1-e^{-5.5 \times 10^{-2} t}) + 4.92 \times 10^{-3}\ (1-e^{-6.1 \times 10^{-3} t}) + 2.75 \times 10^{-3}\ (1-e^{-2.0 \times 10^{-3} t}) + 1.53 \times 10^{-4}\ (1-e^{-8.0 \times 10^{-4} t}) + 10^{-7} t] \quad (5)$$

Next, the integrated air concentration from resuspension over time t needs to be determined. This determination is accomplished by integrating equation 5 over t, yielding

$$\text{Integrated Air Concentration } Y = 86.4\ S_r\ [8.82 \times 10^{-3} t - 1.82 \times 10^{-2}\ (1-e^{-5.5 \times 10^{-2} t}) - 0.806\ (1-e^{-6.1 \times 10^{-3} t}) - 1.38\ (1-e^{-2.0 \times 10^{-3} t}) - 0.191\ (1-e^{-8.0 \times 10^{-4} t}) + 5.00 \times 10^{-8}\ t^2] \quad (6)$$

Equation 6 is the numerator of the desired resuspension ratio. The denominator (the integrated air concentration from the initial release) is given by $S_r t$, which is the product of the air concentration for the initial release and the time since the start of the release. The ratio $Y/S_r t$, evaluated for 70 years (t = 25567.5 days), equals 0.86 and applies to routine chronic releases from 70 years of Plant operation, starting with no initial radioactivity. When this ratio is multiplied by the integrated 70-year source term, the result is the integrated air concentration from resuspension.

When applying this factor, note that mathematically it makes no difference whether the factor is applied before or after considering dispersion. The above derivation is made for conditions after dispersion. The air concentration S_r can also be considered to be the airborne source term given in Table 3.1.2-1, since S_r appears in both the numerator and denominator of the ratio $Y/S_r t$ and any modifying factors for S_r cancel. Calculations for this impact statement are more easily made by determining a total airborne source term S equal to 1.97 times (and 70 times) the values listed in Table 3.1.2-1 (except for tritium). Note also that the same factor can be applied for all radioisotopes (except ^{3}H), since no radioactive decay is assumed. This is a conservative assumption for those radioisotopes with half-lives short compared to the 70 years.

For ^{241}Am there is an additional component to the total source term, that is the contribution from ^{241}Am ingrown from the decay of ^{241}Pu and then resuspended. The derivation of this factor is similar to that for the simple resuspension case, but slightly more complex. In this case the ^{241}Pu is deposited chronically, ^{241}Am grows in from the decay of the ^{241}Pu, and the ^{241}Am is resuspended at a rate governed by the time since deposition of the ^{241}Pu. The end factor is the ratio of the integrated air concentration of ^{241}Am to the integrated air concentration of ^{241}Pu from the initial releases.

The derivation is as follows. Let P_o be the ground concentration (grams/meter^2) of ^{241}Pu deposited at t=0. Consider this to be an acute deposition. (A chronic release will be approximated by integrating a large number of acute releases.) The rate of change of the air concentration of ^{241}Am is given by

$$\frac{dA}{dT} = k\lambda_1 P_o e^{-\lambda_1 t} \tag{7}$$

where A = air concentration of ^{241}Am (g/m^3) at time t
k = resuspension factor (m^{-1})
λ_1 = physical decay constant for ^{241}Pu (d^{-1}) = 1.322×10^{-4} d^{-1}
t = time since the deposition of ^{241}Pu (d)

Using the modified Anspaugh expression for k (containing the exponential approximation) and integrating yields the air concentration of ^{241}Am at time t:

$$\begin{aligned} A = \lambda_1 P_o [&9.98 (1-e^{-5.51 \times 10^{-2} t}) + 48.1 (1-e^{-6.23 \times 10^{-3} t}) \\ &+ 25.8 (1-e^{-2.13 \times 10^{-3} t}) + 1.31 (1-e^{-9.32 \times 10^{-4} t}) \\ &+ \frac{10^{-7}}{\lambda_1} (1-e^{-\lambda_1 t})] \end{aligned} \tag{8}$$

The integrated air concentration of ^{241}Am over time t from the deposition of ^{241}Pu at time t=0 is obtained by integrating equation 8.

$$\begin{aligned} \text{Integrated A } (A_{INT}) = P_o [&1.13 \times 10^{-2} t + 2.39 \times 10^{-2} (e^{-5.51 \times 10^{-2} t} - 1) \\ &+ 1.02 (e^{-6.23 \times 10^{-3} t} - 1) + 1.60 (e^{-2.13 \times 10^{-3} t} - 1) \\ &+ 0.186 (e^{-9.32 \times 10^{-4} t} - 1) + 7.56 \times 10^{-6} (e^{-\lambda_1 t} - 1)] \end{aligned} \tag{9}$$

The amounts of ^{241}Am and ^{241}Pu used in these equations are in terms of mass (grams). To convert to activity (curies) multiply A_{INT} by the specific activity for ^{241}Am (3.42 Ci/g) and P_o by 103.5 Ci/g for ^{241}Pu. The value of P_o pertains to the surface concentration of ^{241}Pu on the ground at t=0. To convert to the initial amount of ^{241}Pu released P_Q, divide P_o by the deposition velocity (V_d=0.001 m/s) and by unit dispersion (χ/Q = 1 s/m^3). The result of these conversions is to modify equation 9 so that the ratio of the integrated ^{241}Am activity concentration in the air, from ingrowth and resuspension, to the initial ^{241}Pu source term, for an acute release, is obtained:

$$A_{INT}(\text{activity}) = 3.30 \times 10^{-5} P_Q \frac{A_{INT}}{P_o} (\text{mass}) \tag{10}$$

To obtain the total integrated activity A_T of the resuspended ^{241}Am over a period of time T, equation 10 is integrated from t=0 to T, yielding equation 11.

$$\begin{aligned} A_T = 3.30 \times 10^{-5} P_Q [&5.65 \times 10^{-3} T^2 - 2.83T + 0.436 (1-e^{-5.51 \times 10^{-2} T}) \\ &+ 164 (1-e^{-6.23 \times 10^{-3} T}) + 751 (1-e^{-2.13 \times 10^{-3} T}) \\ &+ 200 (1-e^{-9.32 \times 10^{-4} T}) + 0.0572 (1-e^{-\lambda_1 T})] \end{aligned} \tag{11}$$

The resuspension ratio for ^{241}Am is the ratio of the total integrated activity A_T to the activity of ^{241}Pu released over T, P_QT. Evaluated for T=2.55675 x 10^4 days (70 years), the ratio $A_T/P_QT = 4.7 \times 10^{-3}$. When this ratio is multiplied by the 70-year source term for ^{241}Pu, the result is the total integrated air concentration of ingrown ^{241}Am.

Dispersion Term

The values of the dispersion term χ/Q are calculated and presented in Appendix B-2. For chronic emissions the appropriate values are those calculated for meteorological conditions averaged over the year and weighted according to the fraction of the time the wind blows towards a given sector. These values are presented in Table B-2-5. The radionuclide concentration in air for the centerline of the plume is assumed for all persons in a sector. Also assumed is that there is no depletion of the plume by deposition of particles before the plume reaches the person.

Dose Conversion Factors

Values of the dose conversion factors F_I (except for tritium) are generated by the DACRIN computer code developed at Battelle-Pacific Northwest Laboratories (Houston, et al., 1974). For tritium the dose conversion factor is derived from data in a document by Hoenes and Soldat (Hoenes and Soldat, 1975).

The DACRIN computer code is used to calculate the effective organ dose or dose commitment to any of 23 organs or tissues based on the model of the respiratory tract developed by the ICRP Task Group on Lung Dynamics (ICRP, 1966). Organ uptake of radionuclides from the blood and clearance of the radionuclides from the organ are modeled according to ICRP Publications #2 (ICRP, 1959) and #19 (ICRP, 1972).

Inputs to the DACRIN code used to generate the dose conversion factors are duration of intake dose period following the end of uptake, organs of interest, radionuclides of interest, radionuclide release rate, particle size (AMAD), solubility class, breathing rate, and specific dispersion model to be used. The code contains a data library in which are stored values of parameters such as organ mass, clearance rate, and partition fraction within the body. Values in the data library may be altered if desired.

Specific values of the inputs and alterations to the data library are as follows. For the 70-year dose from 70 years of uptake, the uptake time is 2.209 x 10^9 seconds (70 years) followed by 0.1 seconds of extra dose accumulation. (The DACRIN code requires both inputs, so, in the case of a chronic uptake, a negligibly short period of dose accumulation is used.) For the calculation of the 70-year dose from one year of chronic uptake, the uptake time is 3.156 x 10^7 seconds (one year) followed by a dose accumulation time of 2.177 x 10^9 seconds (69 years).

Organs of interest for routine releases are the total body, liver, bone, and lungs.

Solubility class W, defined by the ICRP Task Group on Lung Dynamics, as material with a maximal clearance half-time from the lungs ranging from a few days to a few months, is used for radionuclides in the total body, liver, and bone. Solubility Class Y, used by the ICRP to describe materials retained in the lungs, with a maximal biological half-time ranging from 6 months to several years, is used for the lungs. Obviously, the inhaled material cannot be both Class W and Class Y simultaneously as this treatment suggests. However, since the exact solubility of the inhaled material is not known, this treatment is conservatively used to yield a maximum dose to any of these organs regardless of the actual solubility.

A particle size of 0.3 μm AMAD is used, because the filter systems at Rocky Flats have a minimum efficiency at this value. Note that even if the particle size were as small as 0.01 μm AMAD the deposition in the pulmonary region of the respiratory tract (about 75%) would only be double that for the 0.3 μm AMAD particles, resulting in dose conversion factors which would be almost doubled. Even with 100% deposition in the pulmonary region, an unlikely occurrence for any particle size, the dose conversion factor resulting from the ICRP modeling would only increase by less than 2.7 over the value obtained for the 0.3 μm particle size. Therefore, no matter what the particle size actually is, the organ dose would not be underestimated by more than a factor of 2.7, based on ICRP modeling. For maximum intake, a breathing rate of 3.59×10^{-4} m^3/s, derived from ICRP #23 (ICRP, 1975), is used.

The breathing rate for a chronic exposure is taken to be 2.66×10^{-4} m^3/s, based on data for reference man for total air breathed over 24 hours (ICRP, 1974).

The DACRIN code contains a provision for calculating atmospheric dispersion. This part of the code was bypassed by inputting a value of unit χ/Q at a distance of 1 meter. Dispersion factors specific to Rocky Flats are used separately in the calculation of the organ dose (see Equation 1).

The radionuclides of interest are those listed in Table 3.1.2-1, except for tritium (^3H). The dose conversion factors are calculated for an activity of one curie released chronically over the period of uptake.

Organ masses are obtained from reference man data in ICRP #23: Total body mass = 70,000 g, liver mass = 1,800 g, bone (mineral) mass = 5,000 g, and lung mass = 570 g.

Values in the organ data library are based on recommendations of the ICRP (ICRP #2, #6, #19, and #23). Changes were made in the values for the fraction of plutonium and americium in the blood which is transferred to the bone, liver, and total body.

The fractions used are obtained from ICRP #19 (ICRP, 1972). They are 0.45 for both the bone and liver, and 0.1 for the total body. (The value of 0.1 actually pertains to "other tissues and excreta", according to ICRP #19. For this Impact Statement, to be conservative, all of the 0.1 is considered to pertain to the other tissues of the total body. The total body "organ" for plutonium and americium therefore refers to all tissues of the body except the mineral bone and the liver. For all other radionuclides the total body refers to all the tissues of the body, including the bone and liver. For internal depositions, the appropriate concept of the total body for dose calculations is all tissues and organs except those for which a separate dose is calculated and for which there is a concentration of the radionuclide. When the amounts of the radionuclides that are concentrated in one or several organs are also considered to be distributed uniformly among all the tissues and organs of the total body, the resulting total body dose is artificially, but conservatively, high. Conceptually, the total body dose in this Impact Statement refers to all tissues and organs except the bone, liver, and lung. Mathematically, the "total body" dose is a hybrid of the two concepts.)

Table 3.1.2-1 lists three items for which the dose conversion factors are not generated by the DACRIN code. The items are tritium, ^{236}U, and the miscellaneous alpha emitting isotopes. For tritium the dose conversion factor of 2.40×10^{-2} rem per Ci inhaled is derived from NUREG-0172, Table 8 (Hoenes, 1977). The value of 1.58×10^{-7} mrem/50 yr per pCi inhaled given in NUREG-0172 converts to the value 2.40×10^{-2} rem/Ci inhaled as follows. Since tritium has an effective half-time in the body which is very short compared to one year (12 days, ICRP #2), the activity inhaled chronically during the year delivers nearly all the dose in that year. The NUREG-0172 value therefore also pertains to the dose in one year, i.e. 1.58×10^{-7} mrem/yr per pCi inhaled. The same argument pertains to the activity inhaled over 70 years, so that one obtains a value of 1.58×10^{-7} mrem per pCi inhaled over 70 years. Multiplying by the chronic breathing rate of 2.66×10^{-4} m^3/s and converting mrem to rem and pCi to Ci yields the value of 4.20×10^{-2} $(rem \cdot m^3)/(Ci \cdot s)$ or 4.20×10^{-2} rem/Ci inhaled for unit χ/Q for all tissues and organs of the total body. As stated in NUREG-0172, "the radiation dose due to absorption through the skin has been included in the inhalation dose commitment factors for tritium."

For the dose conversion factor for "miscellaneous alpha emitting isotopes" (Table 3.1.2-1), the dose conversion factor for curium-242 is used, since this isotope yields the largest factors for the liver, bone, and lungs, compared to other reasonable choices. The dose conversion factors for ^{242}Cm are generated for this Impact Statement by multiplying the dose conversion factor for ^{241}Am by the ratio of values of the effective energy deposition per disintegration, given in ICRP #2, of ^{242}Cm to ^{241}Am. The dose conversion factors for ^{236}U are obtained by comparison with ^{234}U using the same method as above for values for ^{242}Cm.

Values of the dose conversion factors for the inhalation pathway for chronic releases are presented in Tables F-1 and F-2. These dose conversion factors are in terms of rem per curie released multiplied by the breathing rate (m^3/s) and by a dispersion factor (χ/Q equal to unity) with units s/m^3. Since the value of χ/Q is unity, these dose conversion factors are numerically equal to factors that have not been multiplied by a dispersion factor. The dose conversion factors presented here, therefore, can be considered to have units of either rem/Ci or $(rem \cdot m^3)/(Ci \cdot s)$, where the curie activity refers to the activity released to the atmosphere. One can obtain values of dose conversion factors in terms of rem per curie inhaled by dividing the factors presented here by the breathing rate, 2.66×10^{-4} m^3/s.

Dose conversion factors for a maximum intake rate of 3.59×10^{-4} m^3/s can be derived from factors in Table F-1 or F-2 by multiplying those factors by the ratio of the breathing rates, 1.35.

TABLE F-1

DOSE CONVERSION FACTORS FOR THE 70-YEAR DOSE FROM 70 YEARS OF CHRONIC INTAKE VIA INHALATION

Particle Size = 0.3μm AMAD

Breathing Rate = 2.66×10^{-4} m^3/s

Dose Conversion Factor $(\frac{rem \cdot m^3}{Ci \cdot s})$

	Class W			Class Y
Radionuclide	Total Body	Liver	Bone	Lungs
^{3}H	4.20×10^{-2}	*	*	*
^{234}U	1.679×10^{2}	*	3.755×10^{3}	1.796×10^{5}
^{235}U	1.576×10^{2}	*	3.599×10^{3}	1.686×10^{5}
^{236}U	1.610×10^{2}	*	3.599×10^{3}	1.723×10^{5}
^{238}U	1.473×10^{2}	*	3.442×10^{3}	1.576×10^{5}
^{231}Th	2.539×10^{-3}	4.389×10^{-3}	7.741×10^{-2}	6.674×10^{-1}
^{234}Th	4.051×10^{-1}	7.791×10^{-1}	1.963×10^{1}	9.126×10^{1}
^{238}Pu	1.306×10^{3}	1.775×10^{5}	3.803×10^{5}	2.059×10^{5}
^{239}Pu	1.430×10^{3}	1.898×10^{5}	4.295×10^{5}	1.943×10^{5}
^{240}Pu	1.428×10^{3}	1.895×10^{5}	4.288×10^{5}	1.942×10^{5}
^{241}Pu	2.560×10^{1}	3.671×10^{3}	8.785×10^{3}	3.417×10^{2}
^{242}Pu	1.377×10^{3}	1.827×10^{5}	3.979×10^{5}	1.869×10^{5}
^{241}Am	1.241×10^{3}	1.986×10^{5}	4.317×10^{5}	2.083×10^{5}
^{242}Cm**	1.742×10^{3}	2.718×10^{5}	6.167×10^{5}	2.339×10^{5}

*The value for the dose conversion factor is taken to be equal to that for the total body.

**^{242}Cm is used for "miscellaneous alpha-emitting isotopes."

TABLE F-2

DOSE CONVERSION FACTORS FOR THE 70-YEAR DOSE
COMMITMENT FROM ONE YEAR OF CHRONIC INTAKE VIA INHALATION

Particle Size = 0.3μm AMAD

Breathing Rate = 2.66×10^{-4} m^3/s

Dose Conversion Factor ($\frac{rem \cdot m^3}{Ci \cdot s}$)

Radionuclide	Class W			Class Y
	Total Body	Liver	Bone	Lungs
^{3}H	4.20×10^{-2}	*	*	*
^{234}U	1.692×10^{2}	*	3.828×10^{3}	1.848×10^{5}
^{235}U	1.588×10^{2}	*	3.669×10^{3}	1.735×10^{5}
^{236}U	1.623×10^{2}	*	3.669×10^{3}	1.773×10^{5}
^{238}U	1.485×10^{2}	*	3.509×10^{3}	1.622×10^{5}
^{231}Th	2.539×10^{-3}	4.389×10^{-3}	7.742×10^{-2}	6.674×10^{-1}
^{234}Th	4.058×10^{-1}	7.804×10^{-1}	1.966×10^{1}	9.137×10^{1}
^{238}Pu	2.298×10^{3}	2.777×10^{5}	6.502×10^{5}	2.118×10^{5}
^{239}Pu	2.724×10^{3}	3.165×10^{5}	7.919×10^{5}	1.999×10^{5}
^{240}Pu	2.717×10^{3}	3.158×10^{5}	7.899×10^{5}	1.999×10^{5}
^{241}Pu	3.343×10^{1}	4.578×10^{3}	1.134×10^{4}	3.506×10^{2}
^{242}Pu	2.623×10^{3}	3.048×10^{5}	7.338×10^{5}	1.924×10^{5}
^{241}Am	2.132×10^{3}	3.269×10^{5}	7.842×10^{5}	2.144×10^{5}
^{242}Cm**	2.992×10^{3}	4.473×10^{5}	1.120×10^{6}	2.407×10^{5}

*The value for the dose conversion factor is taken to be equal to that for the total body.

**^{242}Cm is used for "miscellaneous alpha-emitting isotopes."

F.1.1.2 Sample Calculation

Calculate the 70-year bone dose to a person living to the ESE of the Rocky Flats Plant at a distance of 2 miles for routine releases via inhalation (average intake)

Step 1: Obtain the radionuclides and the total activity released per year from Table 3.1.2-1. These activities are in microcuries. Convert to curies by dividing by 10^6. Convert to curies released over 70 years by multiplying by 70 years.

Step 2: Include the resuspension over 70-years by multiplying each of the values from Step 1 by 1.86. For americium-241, add in the product of 4.7×10^{-3} times the value for plutonium-241 obtained at the end of Step 1.

Step 3: From Table F-1 obtain the dose conversion factor for bone for each of the radionuclides. Multiply each of the values from Step 2 by the corresponding dose conversion factor.

Step 4: Sum all values obtained from Step 3.

Step 5: From Table B-2-5, obtain the value of the dispersion factor χ/Q for a distance of 2 miles in the ESE direction. This value is 5.04×10^{-7} s/m^3. Multiply this value by the sum obtained in Step 4. This result, 0.18 rem, is the 70-year bone dose from 70 years of releases from routine Plant operation via inhalation for a person living continuously for 70 years at 2 miles ESE of the Plant.

This calculation is summarized in Table F-3.

TABLE F-3
TABULATION FOR THE SAMPLE INHALATION DOSE CALCULATION

Radionuclide	Total Airborne Release Rate (μCi/yr)	70-Year Release (Ci)	70-Year Release Plus Resuspension (Ci)	Dose Conversion Factor ($\frac{rem \cdot m^3}{Ci \cdot s}$)	Dose for Unit χ/Q ($\frac{rem \cdot m^3}{s}$)
^{3}H	5×10^{6}	3.5×10^{2}	6.5×10^{2}	4.20×10^{-2}	2.7×10^{1}
^{234}U	106	7.4×10^{-3}	1.4×10^{-2}	3.755×10^{3}	5.3×10^{1}
^{235}U	4	2.8×10^{-4}	5.2×10^{-4}	3.599×10^{3}	1.9
^{236}U	0.4	2.8×10^{-5}	5.2×10^{-5}	3.599×10^{3}	1.9×10^{-1}
^{238}U	89	6.2×10^{-3}	1.2×10^{-2}	3.442×10^{3}	4.2×10^{1}
^{231}Th	4	2.8×10^{-4}	5.2×10^{-4}	7.741×10^{-2}	4.0×10^{-5}
^{234}Th	89	6.2×10^{-3}	1.2×10^{-2}	1.963×10^{1}	2.4×10^{-1}
^{238}Pu	105	7.4×10^{-3}	1.4×10^{-2}	3.803×10^{5}	5.5×10^{3}
^{239}Pu	3583	2.5×10^{-1}	4.7×10^{-1}	4.295×10^{5}	2.0×10^{5}
^{240}Pu	812	5.7×10^{-2}	1.1×10^{-1}	4.288×10^{5}	4.8×10^{4}
^{241}Pu	22883	1.6	3.0	8.785×10^{3}	2.6×10^{4}
^{242}Pu	7.3×10^{-2}	5.1×10^{-6}	9.5×10^{-6}	3.979×10^{5}	3.8
^{241}Am	930	6.5×10^{-2}	1.2×10^{-1}	4.317×10^{5}	5.2×10^{4}
Misc.	1	7.0×10^{-5}	1.3×10^{-4}	6.167×10^{5}	8.0×10^{1}
					3.3×10^{5}

70-year Bone Dose (rem) = $3.3 \times 10^{5} \frac{rem \cdot m^3}{s} \times 5.04 \times 10^{-7}$ s/m^3 = 1.7×10^{-1} rem

F.1.2 Food Ingestion Pathway

This section describes the methods for calculating doses to off-site persons from ingesting food containing radionuclides released from routine Plant operations. The methods involve defining the amount of the person's diet contaminated by these releases, where the food is produced and consumed, the modeling of uptake by plants or animals, and the modeling of the internal deposition in the person. The modeling has been developed at Battelle-Pacific Northwest Laboratories (Baker, et al., 1976; Baker, 1977; Brenchley, et al., 1977) and is incorporated in the FOOD computer code, which generates the dose conversion factors. This discussion, therefore, includes a discussion of this code, the inputs to the code, and the values of the dose conversion factors generated from these inputs.

F.1.2.1 Dose from Food Ingestion

The dose to the organs of a person from a given radionuclide ingested from food is given by the equation

$$\text{Organ Dose (rem)} = S \left(\frac{\chi}{Q}\right) F_f \qquad (12)$$

where S = source term for the radioisotope (curies released)
χ/Q = dispersion factor (s/m^3)
F_f = dose conversion factor for food ingestion $\left(\frac{rem \cdot m3}{Ci \cdot s}\right)$

The total organ dose is the sum for all radionuclides of interest.

Source Term

The source term for food contamination has only one component, the source term for the initial airborne release. These source terms are obtained from Table 3.1.2-1.

Dispersion Factor

The appropriate dispersion factor is the χ/Q to the location of food production. For this Impact Statement, the location of food production is considered to coincide with the location of food consumption for locally produced food. This assumption is reasonable and conservative, since most of the major food producing locations in the 50-mile vicinity of the Plant are more remote from the Plant than the major population areas and since a portion of a person's food may be produced at his home. The values of the dispersion factors are obtained from Table B-2-5.

Dose Conversion Factors

Values of the dose conversion factor F_f are generated by the FOOD computer code, and by a modification of FOOD called PABLM. These codes are based on a model derived by Soldat (Fletcher and Dotson, 1971) which estimates the transfer of radionuclides to food products (except for tritium) from irrigation water or from air deposition to plants through both leaves and roots. The published version of the FOOD code is designed to calculate the annual internal dose to man from uptake of various foods, such as produce, eggs, milk, and meats. A total of 14 food categories (combined into seven categories for the PABLM version) can be selected for which values are specified for the consumption rate, growth period, crop yield, hold-up time (the time between harvest and consumption), and dispersion factor.

The PABLM version of the FOOD code uses identical modeling but executes the calculation of the cumulative radiation dose to persons from continuous ingestion of food containing radionuclides over a period of many years, using an iterative process. For each year through the end of the dose period, the dose and the dose commitment to the end of the period resulting from the radionuclide intake during the year are computed. These doses and commitments are added together to compute the cumulative dose. The FOOD model conservatively assumes that the only mechanism for removal of the radionuclides from the soil is by radioactive decay. No soil/air resuspension model is presently available to assess this uptake route. For tritium the model assumes that the plants are at 10% of equilibrium with the residual amounts of radionuclides in the soil.

The data libraries associated with the FOOD and PABLM codes contain data pertaining to uptake by plants and animals and organ dose modeling for 220 radionuclides, the total body, and 22 internal organs. Values of parameters used to calculate doses to the organs are taken from ICRP recommendations found in ICRP Publications #2, #6, and #19. Alterations to this data library are the same as those to the data library of the DACRIN code. In addition, the values for the transfer from the G.I. tract to the blood for plutonium and americium are those used by the EPA (EPA, 1977) for oxide. These values are 1×10^{-4} for ^{239}Pu and ^{240}Pu and 1×10^{-3} for ^{238}Pu, ^{241}Pu, and ^{241}Am. The value for ^{242}Pu is taken to be the same as for ^{239}Pu, 1×10^{-4}.

Inputs to the FOOD and PABLM codes are given in Table F-4 for both the average and the maximum intake rates of food. The input data are either specific for the vicinity of the Plant, based on an analysis of food production in the area, or are obtained from recommendations by the Nuclear Regulatory Commission (USNRC, 1977).

TABLE F-4

INPUT VALUES FOR THE FOOD AND PABLM CODES

Food Category	Consumption* (kg/yr) Maximum	Consumption* (kg/yr) Average	Growing Period** (days)	Yield** (kg/m^2)	Holdup** (days) Maximum(1)	Holdup** (days) Average
Leafy Vegetables	30	0	90	1.5	1	14
Other Above Ground Veg.	30	10	60	0.7	1	14
Root Vegetables	182	19	90	4.0	10	14
Fruit	335	0	90	2.0	10	14
Grain	88	76	90	1.0	10	14
Eggs	30	0.30	90	0.84	1	18
Milk	274†	10†	30	1.3	1	4
Meat	98	22	90	0.84	15	34

*Locally-produced food only.
**In the case of animal products, the values pertain to the forage or feed grain.
†-Units are ℓ/yr.
(1)Maximum refers to values that yield a maximum intake of radionuclides.

Dose conversion factors F_f for food ingestion for the 70-year dose from 70 years of chronic releases and food consumption are given in Tables F-5 and F-6 for average and maximum intakes, respectively. These values are calculated for unit χ/Q and for a release of 1 Ci (over 70 years) for each radionuclide. The units are either $(rem \cdot m^3)/(Ci \cdot s)$ or rem/Ci for unit χ/Q, as for the dose conversion factors for inhalation. For calculations using equation 12, the unit $(rem \cdot m^3)/(Ci \cdot s)$ is appropriate. Dose conversion factors for ^{236}U and ^{242}Cm are obtained by analogy to ^{234}U and ^{241}Am, respectively, as for the inhalation pathway.

F.1.2.2 Sample Calculation

Calculate the 70-year bone dose to the person living to the ESE at a distance of 2 miles for routine releases via food ingestion (average intake).

Step 1: Obtain the radionuclides and the total activity released per year from Table 3.1.2-1. These activities are in microcuries. Convert to curies by dividing by 10^6. Convert to curies released over 70 years by multiplying by 70 years.

Step 2: From Table F-5 obtain the dose conversion factor for bone for each of the radionuclides. Multiply each of the values from Step 1 by the corresponding dose conversion factor.

Step 3: Sum all values obtained from Step 2.

Step 4: From Table B-2-5 obtain the value of the dispersion factor χ/Q for a distance of 2 miles in the ESE direction. This value is 5.04×10^{-7} s/m^3. Multiply this value by the sum obtained in Step 3. This result, 1.4×10^{-4} rem, is the 70-year bone dose (rem) from 70 years of release from routine Plant operation via food ingestion.

This calculation is summarized in Table F-7.

TABLE F-5

DOSE CONVERSION FACTORS FOR THE 70-YEAR DOSE FROM 70 YEARS OF CHRONIC INTAKE VIA FOOD INGESTION - AVERAGE INTAKE

Dose Conversion Factor ($\frac{rem \cdot m^3}{Ci \cdot s}$)

Radionuclide	Total Body	Liver	Bone	Lungs
^{3}H	5.4×10^{-2}	5.4×10^{-2}	*	5.4×10^{-2}
^{234}U	9.3	*	2.0×10^{2}	*
^{235}U	8.9	*	2.0×10^{2}	*
^{236}U	9.0	*	2.0×10^{2}	*
^{238}U	6.4	*	1.3×10^{1}	*
^{231}Th	2.1×10^{-11}	3.7×10^{-11}	6.4×10^{-10}	*
^{234}Th	1.3×10^{-4}	2.6×10^{-4}	6.4×10^{-3}	*
^{238}Pu	5.7	7.6×10^{2}	1.7×10^{3}	*
^{239}Pu	6.1×10^{-1}	8.1×10^{1}	1.9×10^{2}	*
^{240}Pu	6.1×10^{-1}	8.1×10^{1}	1.9×10^{2}	*
^{241}Pu	1.1×10^{-1}	7.6	4.3×10^{1}	*
^{242}Pu	6.1×10^{-1}	8.1×10^{1}	1.7×10^{2}	*
^{241}Am	5.4	8.6×10^{2}	1.9×10^{3}	*
^{242}Cm**	7.6	1.2×10^{3}	2.7×10^{3}	*

*The value for the dose conversion factor is taken to be equal to that for the total body.

**^{242}Cm is used for "miscellaneous alpha-emitting isotopes."

TABLE F-6

DOSE CONVERSION FACTORS FOR THE 70-YEAR DOSE FROM 70 YEARS OF CHRONIC INTAKE VIA FOOD INGESTION - MAXIMUM INTAKE

Dose Conversion Factor ($\frac{rem \cdot m^3}{Ci \cdot s}$)

Radionuclide	Total Body	Liver	Bone	Lungs
^{3}H	1.1	1.1	*	1.1
^{234}U	5.7×10^{1}	*	1.3×10^{3}	*
^{235}U	5.5×10^{1}	*	1.2×10^{3}	*
^{236}U	5.5×10^{1}	*	1.2×10^{3}	*
^{238}U	3.9×10^{1}	*	9.1×10^{2}	*
^{231}Th	2.5×10^{-7}	4.3×10^{-7}	7.6×10^{-6}	*
^{234}Th	9.6×10^{-4}	1.8×10^{-3}	4.6×10^{-2}	*
^{238}Pu	3.2×10^{1}	4.4×10^{3}	9.4×10^{3}	*
^{239}Pu	3.6	4.7×10^{2}	1.1×10^{3}	*
^{240}Pu	3.6	4.7×10^{2}	1.1×10^{3}	*
^{241}Pu	6.6×10^{-1}	4.3×10^{1}	2.5×10^{2}	*
^{242}Pu	3.4	4.5×10^{2}	9.9×10^{2}	*
^{241}Am	3.1×10^{1}	4.9×10^{3}	1.1×10^{4}	*
^{242}Cm**	4.3×10^{1}	6.7×10^{3}	1.5×10^{4}	*

*The value for the dose conversion factor is taken to be equal to that for the total body.

**^{242}Cm is used for "miscellaneous alpha-emitting isotopes."

TABLE F-7

TABULATION FOR THE SAMPLE FOOD DOSE CALCULATION

Radionuclide	Total Airborne Release (μCi/yr)	70-Year Release (Ci)	Dose Conversion Factor ($\frac{rem \cdot m^3}{Ci \cdot s}$)	Dose for Unit Dispersion ($\frac{rem \cdot m^3}{s}$)
^{3}H	5×10^{6}	3.5×10^{2}	5.4×10^{-2}	1.9×10^{1}
^{234}U	106	7.4×10^{-3}	2.0×10^{2}	1.5
^{235}U	4	2.8×10^{-4}	2.0×10^{2}	5.6×10^{-2}
^{236}U	0.4	2.8×10^{-5}	2.0×10^{2}	5.6×10^{-3}
^{238}U	89	6.2×10^{-3}	1.3×10^{1}	8.1×10^{-2}
^{231}Th	4	2.8×10^{-4}	6.4×10^{-10}	1.8×10^{-13}
^{234}Th	89	6.2×10^{-3}	6.4×10^{-3}	4.0×10^{-5}
^{238}Pu	105	7.4×10^{-3}	1.7×10^{3}	1.6×10^{1}
^{239}Pu	3583	2.5×10^{-1}	1.9×10^{2}	4.8×10^{1}
^{240}Pu	812	5.7×10^{-2}	1.9×10^{2}	1.1×10^{1}
^{241}Pu	22883	1.6	4.3×10^{1}	6.9×10^{1}
^{242}Pu	7.3×10^{-2}	5.1×10^{-6}	1.7×10^{2}	8.7×10^{-4}
^{241}Am	930	6.5×10^{-2}	1.9×10^{3}	1.2×10^{2}
Misc.	1	7.0×10^{-5}	2.7×10^{3}	1.9×10^{-1}
				2.85×10^{2}

70-Year Bone Dose (rem) = 2.85×10^{2} ($\frac{rem \cdot m^3}{s}$) x 5.04×10^{-7} s/m^3 = 1.4×10^{-4} rem

F.1.3 Water Ingestion Pathway

This section describes the methods for calculating doses to off-site persons from ingesting water containing radionuclides from both waterborne and airborne releases from routine Plant operations. For waterborne releases, concentrations of radionuclides in off-site water supplies are determined by measurements of radionuclides in tap water from these water supplies. For airborne releases, concentrations of radionuclides in off-site water supplies are determined by calculating airborne dispersion to, and deposition into, the lake or reservoir. The method for calculating the dose conversion factors is developed in this section.

F.1.3.1 Dose from Ingestion of Water Containing Radionuclides from Waterborne Releases

The organ dose to a person ingesting water containing a given radionuclide is given by the equation,

$$\text{Organ Dose (rem)} = 10^{-6}\, C_w\, I_w\, F_w \qquad (13)$$

where C_w = concentration of the radionuclide in the water (pCi/ℓ)
I_w = water intake rate (ℓ/d)
F_w = dose conversion factor for water ingestion [(rem·d)/μCi]
10^{-6} = conversion factor from pCi to μCi (10^{-6} μCi/pCi)

The values C_w for the concentration of the radionuclide in the water are obtained from Table 3.1.2-2. The water intake rate I_w is derived from data for reference man (ICRP, 1975). The values used in this Impact Statement are 1.65 ℓ/day for average uptake and 2.28 ℓ/day for maximum uptake rates for adult man.

Dose Conversion Factors

The dose conversion factor F_w for a given organ and radionuclide is calculated from the equation

$$F_w \left(\frac{\text{rem}}{\mu\text{Ci/day ingested}}\right) = 51.15\, \frac{\varepsilon f_2' f_1}{m \lambda_e} \left[t + \frac{1}{\lambda_e}\left(e^{-\lambda_e t} - 1\right)\right] \qquad (14)$$

where ε = effective energy (MeV) deposited in the organ per disintegration ($\varepsilon = \Sigma$ EF(RBE)n in ICRP #2)
m = mass of the organ of interest (g)
f_1 = transfer fraction from the G.I. tract to the blood
f_2' = transfer fraction from blood to the organ of interest
t = time (days) over which the ingestion occurs
λ_e = effective removal constant from the organ (d^{-1}) = $\lambda_b + \lambda$
where λ_b = ln 2/(biological half-time in days)
λ = ln 2/(physical half-life in days).

Values for these parameters are obtained from ICRP #2 and #19 unless noted otherwise.

Values for the transfer from the G.I. tract to the blood f_1 for plutonium and americium are those used by the EPA (USEPA, 1977) for oxide, as was done for food ingestion. The values of the dose conversion factors F_w and the parameters used in equation 14 are given in Table F-8.

The derivation of equation 14 for the dose conversion factor is as follows. For a chronic intake the rate of change in the activity of the radionuclide in the organ of interest results from the input rate into the organ ($f_1 f_2' S_w$) minus the removal rate ($\lambda_e X$). The differential equation is

$$\frac{dX}{dt} = f_1 f_2' S_w - \lambda_e X \tag{15}$$

where X = activity (μCi) of the radionuclide in the organ of interest at time t
S_w = intake rate (μCi/day) of the radionuclide into the G.I. tract
f_1, f_2', λ_e = as defined for equation 14.

Solving this differential equation for X and assuming no initial activity in the organ yields the activity X(t) in the organ as a function of time

$$X(t) = \frac{f_1 \, f_2' \, S_w}{\lambda_e} (1-e^{-\lambda_e t}). \tag{16}$$

The integrated activity in the organ Q(t) (μCi·days) is obtained by integrating X(t) over time t

$$Q(t) = \int_0^t X(t) \, dt. \tag{17}$$

Integration yields

$$Q(t) = \frac{f_1 f_2' S_w}{\lambda_e} [t + \frac{1}{\lambda_e} (e^{-\lambda_e t} - 1)]. \tag{18}$$

The dose to the organ is the product of the integrated activity Q(t) and the effective energy deposited per disintegration of the radionuclide ε, divided by the mass of the organ m, with the proper conversion factors: 3.7×10^4 disintegrations/(μCi·s), 8.64×10^4 s/d, 1.60×10^{-6} ergs/MeV, 10^{-2} (rem·g)/erg. The dose to the organ is then given by

$$\text{Organ Dose (rem)} = 51.15 \frac{\varepsilon}{m} \frac{f_1 f_2' S_w}{\lambda_e} [t + \frac{1}{\lambda_e} (e^{-\lambda_e t} - 1)]. \tag{19}$$

TABLE F-8

DOSE CONVERSION FACTORS FOR THE 70-YEAR DOSE FROM A CHRONIC INGESTION OF WATER FOR 70 YEARS OF RELEASES FROM ROUTINE PLANT OPERATION

Radionuclide	Organ	Values of Parameters					Dose Conversion Factor ($\frac{rem \cdot d}{\mu Ci}$)
		f_1	f_2'	$\lambda_e(d^{-1})$	ε(MeV)	m(g)	
^{3}H	Total Body & All Organs	1.0	1.0	5.78×10^{-2}	0.0058(1)	70000	1.87
^{234}U	Total Body	1×10^{-4}	1.0	6.93×10^{-3}	49	70000	5.14×10^{-4}
	Liver						*
	Bone	1×10^{-4}	0.33	2.31×10^{-3}	240	5000	0.104
	Lungs						*
^{235}U	Total Body	1×10^{-4}	1.0	6.93×10^{-3}	46	70000	4.82×10^{-4}
	Liver						*
	Bone	1×10^{-4}	0.33	2.31×10^{-3}	230	5000	0.100
	Lungs						*
^{236}U	Total Body	1×10^{-4}	1.0	6.93×10^{-3}	47	70000	4.93×10^{-4}
	Liver						*
	Bone	1×10^{-4}	0.33	2.31×10^{-3}	230	5000	0.100
	Lungs						*
^{238}U	Total Body	1×10^{-4}	1.0	6.93×10^{-3}	43	70000	4.51×10^{-4}
	Liver						*
	Bone	1×10^{-4}	0.33	2.31×10^{-3}	220	5000	0.0958
	Lungs						*
^{231}Th	Total Body	1×10^{-4}	1.0	0.648	0.18	70000	2.03×10^{-8}
	Liver	1×10^{-4}	0.05	0.648	0.16	1800	3.51×10^{-8}
	Bone	1×10^{-4}	0.7	0.648	0.56	5000	6.19×10^{-7}
	Lungs						*

*The value for the dose conversion factor is taken to be equal to that for the total body.

(1)The value for the effective energy per disintegration for ^{3}H is an updated value derived at Battelle-Pacific Northwest Laboratories (Kennedy, 1978).

TABLE F-8 (Continued)

Radionuclide	Organ	Values of Parameters					Dose Conversion Factor $(\frac{rem \cdot d}{\mu Ci})$
		f_1	f_2'	$\lambda_e(d^{-1})$	ε(MeV)	m(g)	
^{234}Th	Total Body	1×10^{-4}	1.0	2.88×10^{-2}	0.91	70000	2.31×10^{-6}
	Liver	1×10^{-4}	0.05	2.88×10^{-2}	0.90	1800	4.43×10^{-6}
	Bone	1×10^{-4}	0.7	2.88×10^{-2}	4.5	5000	1.12×10^{-4}
	Lungs						*
^{238}Pu	Total Body	1×10^{-3}	0.10	3.23×10^{-5}	57	70000	1.05×10^{3}
	Liver	1×10^{-3}	0.45	6.91×10^{-5}	57	1800	1.43×10^{5}
	Bone	1×10^{-3}	0.45	4.06×10^{-5}	280	5000	3.07×10^{5}
	Lungs						*
^{239}Pu	Total Body	1×10^{-4}	0.10	1.07×10^{-5}	53	70000	1.16×10^{2}
	Liver	1×10^{-4}	0.45	4.75×10^{-5}	53	1800	1.54×10^{4}
	Bone	1×10^{-4}	0.45	1.91×10^{-5}	270	5000	3.48×10^{4}
	Lungs						*
^{240}Pu	Total Body	1×10^{-4}	0.10	1.10×10^{-5}	53	70000	1.16×10^{2}
	Liver	1×10^{-4}	0.45	4.77×10^{-5}	53	1800	1.53×10^{4}
	Bone	1×10^{-4}	0.45	1.93×10^{-5}	270	5000	3.47×10^{4}
	Lungs						*
^{241}Pu	Total Body	1×10^{-3}	0.10	1.43×10^{-4}	2.3	70000	2.20×10^{1}
	Liver	1×10^{-3}	0.45	1.80×10^{-4}	1.0	1800	1.43×10^{3}
	Bone	1×10^{-3}	0.45	1.51×10^{-4}	14	5000	8.15×10^{3}
	Lungs						*
^{242}Pu	Total Body	1×10^{-4}	0.10	1.07×10^{-5}	51	70000	1.11×10^{2}
	Liver	1×10^{-4}	0.45	4.74×10^{-5}	51	1800	1.48×10^{4}
	Bone	1×10^{-4}	0.45	1.90×10^{-5}	250	5000	3.22×10^{4}
	Lungs						*

*The value for the dose conversion factor is taken to be equal to that for the total body.

TABLE F-8 (Continued)

Radionuclide	Organ	Values of Parameters					Dose Conversion Factor ($\frac{rem \cdot d}{\mu Ci}$)
		f_1	f_2'	$\lambda_e(d^{-1})$	ε(MeV)	m(g)	
^{241}Am	Total Body	1×10^{-3}	0.10	1.50×10^{-5}	57	70000	1.20×10^{3}
	Liver	1×10^{-3}	0.45	5.18×10^{-5}	57	1800	1.60×10^{5}
	Bone	1×10^{-3}	0.45	2.33×10^{-5}	280	5000	3.49×10^{5}
	Lungs						*
^{242}Cm**	Total Body	1×10^{-3}(2)	0.10(2)	4.29×10^{-3}	80	70000	3.45×10^{1}
	Liver	1×10^{-3}(2)	0.45(2)	4.28×10^{-3}	78	1800	5.90×10^{3}
	Bone	1×10^{-3}(2)	0.45(2)	4.49×10^{-3}	400	5000	1.04×10^{4}

*The value for the dose conversion factor is taken to be equal to that for the total body.

**^{242}Cm is used for "miscellaneous alpha-emitting isotopes."

(2)These values for ^{242}Cm are set equal to those for ^{241}Am.

Dividing by the intake rate S_w yields the equation for the dose conversion factor F_w (rem per μCi/day ingested), which is equation 14.

Note that equations 17 and 14 are valid for any type of ingestion (food or water) once the radionuclide reaches the G.I. tract.

Sample Calculation

Calculate the 70-year bone dose to a person drinking water (average ingestion rate) from Great Western Reservoir for 70-years for routine Plant operations.

NOTE: Separate values of the activity per liter are not given for the plutonium (alpha) and uranium isotopes. However, since the dose conversion factors for the isotopes of these nuclides (except for ^{241}Pu) are essentially the same, the dose conversion factors for ^{239}Pu and ^{238}U are used in the plutonium and uranium values, respectively.

Step 1: Obtain the radionuclides and the activity per liter for Great Western Reservoir from Table 3.1.2-2. In addition, the activity for ^{241}Pu is calculated from the activity for Pu(alpha). This value is equal to 5.1 times the activity for the Pu(alpha) (see Table 2.7.2-2). Multiply these values by 10^{-6} to convert to μCi/ℓ.

Step 2: Multiply by the water intake rate (1.65 ℓ/d) to obtain the activity intake rate (μCi/d) for each radionuclide.

Step 3: Multiply by the dose conversion factor F_w from Table F-8. The result is the contribution to the organ dose for each radionuclide. Sum these values to obtain the total organ dose, 7.08×10^{-2} rem.

A tabulation of this calculation is given in Table F-9.

TABLE F-9

TABULATION OF THE SAMPLE CALCULATION OF THE BONE DOSE FOR WATER INGESTION FOR WATERBORNE RELEASES

Radionuclide	Concentration (pCi/ℓ)	Concentration (μCi/ℓ)	Intake Rate (μCi/d)	Dose Conversion Factor (rem·d/μCi)	70-Year Bone Dose (rem)
Pu (alpha)	0.1	1.0×10^{-7}	1.65×10^{-7}	3.48×10^{4}	5.74×10^{-3}
^{241}Am	0.1	1.0×10^{-7}	1.65×10^{-7}	3.49×10^{5}	5.76×10^{-2}
U	2.0	2.0×10^{-6}	3.30×10^{-6}	0.0958	3.16×10^{-7}
^{3}H	200	2.0×10^{-4}	3.30×10^{-4}	1.87	6.17×10^{-4}
^{241}Pu	0.51	5.1×10^{-7}	8.42×10^{-7}	8.15×10^{3}	6.86×10^{-3}
					7.08×10^{-2}

F.1.3.2 Dose from Ingestion of Water Containing Radionuclides from Airborne Releases

The organ dose to a person ingesting water containing a given radionuclide is given by equation 13, for waterborne releases. The values for the concentration of the radionuclide in the water C_w may be obtained in two different ways. It may be measured and corrected for other sources, or it can be estimated from airborne dispersion modeling. In this section, the value for C_w for airborne releases is calculated from airborne dispersion modeling to the water storage reservoir. The equation to calculate this value C_w is

$$C_w(\text{pCi}/\ell) = 10^6 \, S_a \, (\tfrac{\chi}{Q}) \, A \, V_d \, (\tfrac{1}{V}) \qquad (20)$$

where S_a = activity of the radionuclide released (μCi) from the Plant via airborne during the period of one complete turnover of the water in the reservoir

χ/Q = dispersion factor ($\frac{s}{m^3}$) to that reservoir

A = surface area of the reservoir (m^2)

V_d = deposition velocity ($\frac{m}{s}$) of the radionuclide from the air

V = volume of the water supply (ℓ)

10^6 = conversion factor from μCi to pCi (10^6pCi/μCi).

For this analysis, the assumption is made that water in each reservoir is completely cycled once each year. Therefore, values of S_a are obtained directly from Table 3.1.2-1. If the turnover rate is more frequent than once a year, the doses calculated for this pathway would be conservatively high. The converse is also true.

The value of the dispersion factor χ/Q is calculated specifically for the water supply of interest. For this impact statement, calculations are done for the two water supplies for which deposition of radionuclides from airborne releases would be most significant. These supplies are Great Western Reservoir and Standley Lake. Concentrations of radionuclides from airborne releases to other supplies are considered to be less than for these two supplies. The value of χ/Q to Great Western Reservoir, calculated according to methods discussed in Appendix B-2, for an effective stack height of 120 m and for a distance of 4.0 km to the ENE, is 2.95×10^{-8} s/m^3. The value of χ/Q to Standley Lake, for an effective stack height of 150 m and for a distance of 7.2 km to the SE, is 1.31×10^{-8} s/m^3. These values apply to chronic releases and are averaged over the wind direction and Pasquill stability class in the same manner as for the values presented in Table B-2-5.

The surface area of Great Western Reservoir is 6.08×10^5 m^2 with a volume of 3.79×10^9 ℓ. The surface area of Standley Lake is 4.71×10^6 m^2 with a volume of 5.23×10^{10} ℓ.

The deposition velocity V_d is taken to be 0.001 m/s for all radionuclides except tritium and the halogens (Baker, 1977). A value of 0.01 m/s is used for tritium, even though a value of zero is used by Baker, to match the value of 0.01 m/s for the halogens and to be conservative.

Using these values, the concentration of the radionuclides in the water of Great Western Reservoir and Standley Lake can be calculated using equation 29, and the organ doses can be calculated using equation 13. The results of these calculations for the bone are presented in Table F-10.

For water supplies other than Great Western Reservoir and Standley Lake, the concentrations of radionuclides in the water from airborne releases are taken to be equal to those for Standley Lake, although the radionuclide concentrations are expected to be somewhat less than those for Standley Lake. Note, however, that in comparison with the total dose presented in Table 3.1.2-3, the dose contribution from this pathway is negligible.

TABLE F-10

CONCENTRATIONS OF RADIONUCLIDES IN GREAT WESTERN RESERVOIR AND STANDLEY LAKE FROM ROUTINE PLANT AIRBORNE RELEASES AND THE RESULTING 70-YEAR BONE DOSE TO PERSONS (AVERAGE INTAKE RATES) DRINKING THIS WATER FOR 70 YEARS

Radionuclide	Water Concentration (pCi/ℓ) Great Western	Standley	70-Year Bone Dose (rem) Great Western	Standley
^{3}H	2.4×10^{-1}	5.9×10^{-2}	7.4×10^{-7}	1.8×10^{-7}
^{234}U	5.0×10^{-7}	1.3×10^{-7}	8.6×10^{-14}	2.2×10^{-14}
^{235}U	1.9×10^{-8}	4.7×10^{-9}	3.1×10^{-15}	7.8×10^{-16}
^{236}U	1.9×10^{-9}	4.7×10^{-10}	3.1×10^{-16}	7.8×10^{-17}
^{238}U	4.2×10^{-7}	1.1×10^{-7}	6.6×10^{-14}	1.7×10^{-14}
^{231}Th	1.9×10^{-8}	4.7×10^{-9}	1.9×10^{-20}	4.8×10^{-21}
^{234}Th	4.2×10^{-7}	1.1×10^{-7}	7.8×10^{-17}	2.0×10^{-17}
^{238}Pu	5.0×10^{-7}	1.2×10^{-7}	2.5×10^{-7}	6.0×10^{-8}
^{239}Pu	1.7×10^{-5}	4.2×10^{-6}	9.8×10^{-7}	2.4×10^{-7}
^{240}Pu	3.8×10^{-6}	9.6×10^{-7}	2.2×10^{-7}	5.5×10^{-8}
^{241}Pu	1.1×10^{-4}	2.7×10^{-5}	1.5×10^{-6}	3.6×10^{-7}
^{242}Pu	3.5×10^{-10}	8.6×10^{-11}	1.9×10^{-11}	4.6×10^{-12}
^{241}Am	4.4×10^{-6}	1.1×10^{-6}	2.5×10^{-6}	6.3×10^{-7}
Misc.	4.7×10^{-9}	1.2×10^{-9}	8.1×10^{-11}	2.1×10^{-11}
			6.2×10^{-6}	1.5×10^{-6}

F.1.4 Ground Plane Irradiation

This section describes the methods for calculating doses to off-site persons irradiated by radionuclides deposited on the ground. The chronic buildup of the surface concentration (Ci/m^2) over 70 years is determined for each radionuclide. Dose conversion factors, with units of $(rem \cdot m^2)/(Ci \cdot s)$, are obtained from the EXREM computer code, developed at Oak Ridge National Laboratory (Trubey, 1973).

F.1.4.1 Dose from Ground Plane Irradiation

The dose to the organs of a person for a given radionuclide from chronic surface deposition over time t is given by the equation

$$\text{Organ Dose (rem)} = 43.2 \left(\frac{\chi}{Q}\right) S_g F t^2 \qquad (21)$$

where S_g = radionuclide (airborne) release rate (Ci/day)

F = dose conversion factor $[(rem \cdot m^2)/(Ci \cdot s)]$

χ/Q = dispersion factor (s/m^3)

t = duration of the chronic deposition (days)
(The duration t also is the period of dose accumulation)

43.2 = product of $(8.64 \times 10^4$ s/d)(1/2)(V_d) where V_d is the deposition velocity and is set equal to 0.001 m/s. The units of this constant are m/d.

This equation is derived in Section F.1.4.2.

For the ingrowth of a daughter radionuclide from the physical decay of its parent, which is deposited chronically, the organ dose resulting from the daughter radionuclide is given by

$$\text{Organ Dose (rem)} = \frac{(SA)_d}{(SA)_p} (8.64 \times 10^4) \left(\frac{\chi}{Q}\right) V_d F_d (S_g)_p \left(\frac{1}{2} t^2 - \frac{1}{\lambda_p^2} e^{-\lambda_p t} + \frac{1}{\lambda_p^2} - \frac{1}{\lambda_p} t\right) \quad (22)$$

where $(SA)_d$ = specific activity (Ci/g) of the daughter radionuclide
$(SA)_p$ = specific activity (Ci/g) of the parent radionuclide
$(S_g)_p$ = airborne release rate (Ci/d) of the parent
8.64×10^4 = s/d
F_d = dose conversion factor for the daughter radionuclide
λ_p = physical decay constant (d^{-1}) for the parent radionuclide.

Other terms are defined as for equation 21.

For the ingrowth of ^{241}Am from ^{241}Pu, the only significant case for Plant effluents, and for t = 25567.5 d (70 years), $(SA)_d$ = 3.42 Ci/g, $(SA)_p$ = 103.5 Ci/g, $\lambda_p = 1.322 \times 10^{-4}$ d^{-1}, and V_d = 0.001 m/s, equation 22 reduces to

$$\text{Organ Dose (rem)} = 5.39 \times 10^8 \left(\frac{\chi}{Q}\right) F_d (S_g)_p. \quad (23)$$

Values of the airborne release rates are obtained from Table 3.1.2-1 by dividing the values in Ci/yr by 365.25 d/yr. Values of the dispersion factor (χ/Q) for a chronic release are obtained from Table B-2-5. Values of the dose conversion factor F are presented in Table F-11. These values are generated from the Oak Ridge EXREM code. The values of F are for the total body. Values for all other organs are considered to be equal to those for the total body.

F.1.4.2 Derivation of Equations

The derivation of equation 21 is as follows. For a chronic release the rate of buildup of the surface concentration G (Ci/m^2) of the radionuclide on the ground (neglecting radiological decay) is described by the differential equation

$$\frac{dG}{dt} = \left(\frac{\chi}{Q}\right) V_d S_g \quad (24)$$

where all terms have been defined previously. Solving for G yields the value of the surface concentration at any time t,

$$G = \left(\frac{\chi}{Q}\right) V_d S_g t. \quad (25)$$

TABLE F-11

DOSE CONVERSION FACTORS FOR GROUND PLANE IRRADIATION

Radionuclide	Dose Conversion Factor $(\frac{rem \cdot m^2}{Ci \cdot s})$
^{3}H	0
^{234}U	1.5×10^{-5}
^{235}U	9.0×10^{-4}
^{236}U	1.0×10^{-5}
^{238}U	1.0×10^{-5}
^{231}Th	4.1×10^{-4}
^{234}Th	5.3×10^{-5}
^{238}Pu	1.0×10^{-5}
^{239}Pu	4.3×10^{-6}
^{240}Pu	9.0×10^{-6}
^{241}Pu	0
^{242}Pu	8.6×10^{-6}
^{241}Am	2.4×10^{-4}
^{242}Cm*	9.2×10^{-6}

*^{242}Cm is used for the "miscellaneous alpha-emitting isotopes."

The dose H over time t from exposure to the ground concentrations as it builds up is obtained by solving the differential equation

$$\frac{dH}{dt} = 8.64 \times 10^4 \, G \, F \qquad (26)$$

where the value 8.64×10^4 is the conversion factor s/d. Substituting equation 25 for G and solving yields

$$H = 4.32 \times 10^4 \left(\frac{X}{Q}\right) V_d \, S_g \, F \, t^2. \qquad (27)$$

For the radionuclides of interest V_d = 0.001 m/s. Using this value in equation 27 yields equation 21. Note that no weathering into the soil or physical decay is included. Weathering into the soil would decrease the dose from ground plane irradiation because of the shielding of the soil over weathered radionuclides. Loss of radionuclides by physical decay would also lower the dose.

The derivation of equation 22 is as follows. The rate of daughter ingrowth from the physical decay of the parent is given by

$$\frac{dA}{dt} = \lambda_p \, P \qquad (28)$$

where A = mass surface concentration (g/m^2) of the daughter at time t (d)
P = mass surface concentration (g/m^2) of the parent at time t (d)
λ_p = physical decay concentration (d^{-1}) of the parent

Loss by physical decay of the daughter is not included, for simplicity and conservatism.

The value for P needs to be derived before equation 28 can be solved. The rate change of P is equal to the deposition rate [$(\chi/Q)\ V_d\ S_p$] minus the rate of loss by physical decay ($\lambda_p P$). This differential equation is

$$\frac{dP}{dt} = (\frac{\chi}{Q})\ V_d\ S_p - \lambda_p P \tag{29}$$

where S_p is the airborne release rate (g/d) in terms of mass of the parent and all other terms are as defined previously. Solution of equation 29 yields the value of P at time t

$$P = \frac{1}{\lambda_p}\ (\frac{\chi}{Q})\ V_d\ S_p(e^{-\lambda_p t} - 1). \tag{30}$$

Substitution for P in equation 28 and solving yields the value of the daughter mass surface concentration at time t,

$$A = (\frac{\chi}{Q})\ V_d\ S_p\ (t + \frac{1}{\lambda_p} e^{-\lambda_p t} - \frac{1}{\lambda_p}). \tag{31}$$

Converting to activity by multiplying by the specific activity (Ci/g) of the daughter and parent yields A in terms of activity surface concentration (Ci/m^2)

$$A(\text{activity}) = \frac{(SA)_d}{(SA)_p}\ (\frac{\chi}{Q})\ V_d\ (S_g)_p\ (t + \frac{1}{\lambda_p} e^{-\lambda_p t} - \frac{1}{\lambda_p}) \tag{32}$$

where $(S_g)_p$ is the activity release rate (Ci/d) of the parent and $(SA)_d$ and $(SA)_p$ are the specific activities (Ci/g) of the daughter and parent, respectively.

The organ dose H over time t from exposure to A(activity) as it builds up is obtained by solving the differential equation

$$\frac{dH}{dt} = 8.64 \times 10^4\ F_d\ A(\text{activity}) \tag{33}$$

Solution of equation 33 for H yields equation 22.

For ingrowth of ^{241}Am from ^{241}Pu, equation 23 is obtained by evaluating equation 22 using the following values: t = 25567.5 d, V_d = 0.001 m/s, and $\lambda_p = 1.322 \times 10^{-4}$ d^{-1}.

F.1.4.3 Sample Calculation

Calculate the 70-year organ dose (all organs) to a person living in the ESE at a distance of 2 miles for routine releases from ground plane irradiation.

Step 1: Obtain from Table 3.1.2- 1 the radionuclides and the total airborne activity released per year. Convert these activities to Ci/d by multiplying by 10^{-6} Ci/μCi and then dividing by 365.25 d/yr.

Step 2: From Table F-11 obtain the values of the dose conversion factor F for each radionuclide. Multiply each value from Step 1 by the value of F for the corresponding radionuclide. Also multiply each value by 43.2 (from equation 21) and by 6.54×10^{8} (this value is t^2).

Step 3: Multiply the value of ^{241}Pu from step 1 by the value of F for ^{241}Am and by 5.39×10^{8} (equation 23).

Step 4: Sum all values from steps 2 and 3.

Step 5: From Table B-2-5 obtain the values of the dispersion factor χ/Q for a distance of 2 miles in the ESE direction. This value is 5.04×10^{-7} s/m^3. Multiply this value by the sum obtained in step 4. The result, 1.46×10^{-5} rem, is the 70-year dose (rem) to any organ from 70 years of airborne releases from routine Plant operation from ground plane irradiation.

This calculation is summarized in Table F-12.

F.1.5 Miscellaneous Calculations

This section describes the methodology for various calculations pertaining to chronic releases from routine Plant operation. These calculations are: (1) age-specific doses (Table 3.1.2-4), (2) comparison of the 70-year dose commitment from 1 year of exposure to the 70-year dose from 70 years of exposure (Table 3.1.2-7), (3) population doses (Table 3.1.2-8), and (4) the effect of a hypothetical high-density population to the east of the Plant (Table 3.1.2-9).

F.1.5.1 Age-Specific Doses for Chronic Intakes

The doses assessed in this Impact Statement are generally for organs of the reference adult male and are calculated for his standard organ masses and intake rates. This section describes the methodology to calculate organ doses to persons who begin the 70-year chronic exposure period as other than adult male. In particular, this section develops the methodology by which values in Table 3.1.2-4 are obtained. These values are the ratio of the organ dose for the person who begins the 70-year chronic exposure period younger than age 20 or as an adult female to the organ dose for the adult reference man. This ratio is determined for both inhalation and ingestion uptake pathways (ground plane irradiation will be dealt with only briefly, since the ratios are all unity).

TABLE F-12

TABULATION FOR THE SAMPLE CALCULATION FOR GROUND PLANE IRRADIATION

Radionuclide	Release Rate (Ci/d)	Dose Conversion Factor F $(\frac{rem \cdot m^2}{Ci \cdot s})$	Dose Per Unit χ/Q $(\frac{rem \cdot m^3}{s})$
^{3}H	1.37×10^{-2}	0	0
^{234}U	2.90×10^{-7}	1.5×10^{-5}	1.23×10^{-1}
^{235}U	1.10×10^{-8}	9.0×10^{-4}	2.80×10^{-1}
^{236}U	1.10×10^{-9}	1.0×10^{-5}	3.11×10^{-4}
^{238}U	2.44×10^{-7}	1.0×10^{-5}	6.89×10^{-2}
^{231}Th	1.10×10^{-8}	4.1×10^{-4}	1.27×10^{-1}
^{234}Th	2.44×10^{-7}	5.3×10^{-5}	3.65×10^{-1}
^{238}Pu	2.87×10^{-7}	1.0×10^{-5}	8.10×10^{-2}
^{239}Pu	9.80×10^{-6}	4.3×10^{-6}	1.19
^{240}Pu	2.22×10^{-6}	9.0×10^{-6}	5.64×10^{-1}
^{241}Pu	6.27×10^{-5}	0	0
^{242}Pu	2.00×10^{-10}	8.6×10^{-6}	4.86×10^{-5}
^{241}Am	2.55×10^{-6}	2.4×10^{-4}	1.73×10^{1}
Misc.	2.74×10^{-6}	9.2×10^{-6}	7.12×10^{-1}
^{241}Am(Ingrown)	0	2.4×10^{-4}	8.11
Total			2.89×10^{1}

Organ Dose (rem) = 2.89×10^{1} $(\frac{rem \cdot m^3}{s})$ x 5.04×10^{-7} $(\frac{s}{m^3})$ = 1.46×10^{-5} rem

General Approach

For persons who begin a chronic exposure at ages younger than 20, the intake rate, the gastrointestinal uptake rate, and the organ mass change with time. After age 20 these parameters are considered to remain at the reference values given in ICRP #23 for the adult male and female. Mathematical equations describing the increase in the intake rates and organ masses from birth to age 20 are not available. Even if such equations were available, integration of those equations into a mathematical model to obtain organ doses for inhalation and ingestion would be prohibitively complex. Therefore, the following approach is used. The 70-year chronic intake is considered to consist of 70 separate acute intakes, one at the start of each year. The dose to the organ is calculated for each successive year up through the 70th year after the first intake. For example, the dose from the first acute intake is assessed for each of the subsequent 70 years. For the second acute intake, the dose for each of 69 years is calculated, and so on until doses for 70 acute intakes have been calculated. Each acute intake occurs in proportion to the intake rate corresponding to the age and gender of the person. Each yearly dose is calculated for an organ mass corresponding to the age and gender of the person at that time. Increased gastrointestinal uptake is included for the newborn. This approach

is also used to calculate the values for the adult male and female. Even though exact equations are available for this case, the same methodology is used for both the numerator and the denominator of the age-specific dose ratio.

Data for Age-Specific Intake Rate and Organ Mass

The data for values of the intake rate and organ mass from birth to age 20 and for adults are derived from tables and graphs presented in ICRP #23, "Report of the Task Group on Reference Man," (ICRP, 1975).

The values of the age-specific breathing rate, presented in Table F-13, are obtained by graphing the values presented on page 346 of ICRP #23 (converted to units of m^3/s) and obtaining values from a smooth curve through the graphed points.

The values of the age-specific ingestion rate, also presented in Table F-13, are obtained by summing values discerned from Figures 68, 69, and 70 of ICRP #23.

TABLE F-13
AGE-SPECIFIC INTAKE RATES

Age (Years)	Ingestion Rate (g/d)		Breathing Rate (m^3/s)	
	Male	Female	Male	Female
Birth	75	75	9×10^{-6}	9×10^{-6}
1	187	187	4.4×10^{-5}	4.4×10^{-5}
2	237	237	7.2×10^{-5}	7.2×10^{-5}
3	272	272	9.2×10^{-5}	9.2×10^{-5}
4	300	300	1.08×10^{-4}	1.08×10^{-4}
5	328	328	1.20×10^{-4}	1.20×10^{-4}
6	353	353	1.32×10^{-4}	1.32×10^{-4}
7	376	376	1.42×10^{-4}	1.42×10^{-4}
8	401	400	1.53×10^{-4}	1.53×10^{-4}
9	416	410	1.63×10^{-4}	1.63×10^{-4}
10	447	435	1.74×10^{-4}	1.74×10^{-4}
11	467	450	1.82×10^{-4}	1.82×10^{-4}
12	492	468	1.91×10^{-4}	1.91×10^{-4}
13	512	480	2.01×10^{-4}	1.99×10^{-4}
14	532	491	2.10×10^{-4}	2.07×10^{-4}
15	546	497	2.19×10^{-4}	2.14×10^{-4}
16	550	497	2.29×10^{-4}	2.21×10^{-4}
17	553	496	2.38×10^{-4}	2.28×10^{-4}
18	554	494	2.47×10^{-4}	2.32×10^{-4}
19	553	490	2.56×10^{-4}	2.38×10^{-4}
Adult	605	421	2.66×10^{-4}	2.43×10^{-4}

Although these values are specifically for food intake, it is considered that the relative values of the age-specific food ingestion rate should well approximate the relative values of the water ingestion rate for the same age and gender.

A 100 fold relative increase in plutonium and americium gastrointestinal uptake f_1 in the newborn is taken from an EPA Guidance (USEPA, 1977).

The age-specific organ masses, presented in Table F-14, are obtained as follows. The values for the total body are discerned from Figure 5 in ICRP #23. The values for the liver are taken from Table 60 of ICRP #23. The values for the bone are discerned from Figure 41 of ICRP #23. The values for the lungs are taken from Table 65 of ICRP #23. Note that the bone mass for an adult is twice the value of the mineral bone (5000 g) used in other bone dose calculations in this Impact Statement. Also the mass of the lung for adult man (1000 g) is greater than the mass of 570 g (lung mass minus venous and arterial blood) used in other lung dose calculations. However, the use of these values (in Table F-14) has no effect on the value of the desired ratio if the factor of 2 in the values of bone mass and the ratio of 1000g/ 570 g for the lung masses is assumed to hold for all ages.

Equations for Inhalation

The dose to the lungs from an acute inhalation is given by

$$\text{Lung Dose (rem)} = 51.15 \frac{\varepsilon}{m} \frac{P_o}{\lambda} (1-e^{-\lambda t}) \tag{34}$$

where P_o = the activity (μCi) initially deposited in the pulmonary regions of the lungs and clears with a biological half-time of 500 days (for Class Y).
λ = the effective clearance constant (d^{-1}) for the lungs
ε = effective energy (MeV) deposited per disintegration
m = mass of the lungs
t = time (d) since the deposition

The value of P_o is proportional to the breathing rate B_r. Since the desired value is a ratio, all constant values will cancel and, therefore, can be disregarded. Therefore, equation 32 can be simplified to

$$\text{Lung Dose} \propto \frac{B_r}{m} (1-e^{-\lambda t}). \tag{35}$$

The lung dose per year from an acute inhalation is, for year number ($t_2/365.25$) after the intake,

$$\text{Lung Dose per Year} \propto \frac{B_r}{m(t_1)} (e^{-\lambda t_1} - e^{-\lambda t_2}) \tag{36}$$

where t_1 = number of days since the start of exposure
$t_2 = t_1 + 365.25$ in units of days.

TABLE F-14
AGE-SPECIFIC ORGAN MASSES

Age	Organ Mass							
	Total Body (kg)		Liver (g)		Bone (g)		Lungs (g)	
(Years)	Male	Female	Male	Female	Male	Female	Male	Female
Birth	3.5	3.4	134.3	136.5	600	600	51.7	50.9
1	10.4	9.4	342.5	322.1	1600	1400	170.3	175.3
2	12	11.5	458.8	428.9	1800	1600	245.9	244.3
3	14.5	14	530.6	490.7	1950	1700	304.7	265.5
4	17	16	566.6	559.0	2050	1800	314.2	311.7
5	20	18	591.8	591.1	2250	1950	260.6	319.9
6	22.5	20.5	660.7	603.5	2500	2100	399.5	357.5
7	25	23	691.3	682.5	2750	2250	365.4	404.4
8	27	26	808.0	732.5	2900	2400	405.0	382.1
9	29.5	29	804.2	862.5	3200	2550	376.4	358.4
10	32	32	931.4	904.6	3500	2800	474.5	571.2
11	35.5	37	901.8	840.4	3800	3000	465.6	535.0
12	39	42	986.6	1048.1	5000	3400	458.8	681.7
13	45	46.5	1103	997.7	6500	3900	504.5	602.3
14	51.5	51	1166	1209	8000	4400	692.8	517.0
15	57	53	1228	1349	8500	5000	691.7	708.8
16	62	54	1448	1414	8900	5500	747.3	626.5
17	65	55	1515	1417	9300	5900	776.9	694.5
18	68	56	1702	1541	9700	6200	874.7	654.9
19	69	57	1570	1433	9900	6500	1035.6	785.2
20	70	58	1800	1400	10000	6800	1000	800

Values from equation 36 are calculated for each value of the breathing rate from the onset of the chronic exposure to 70 years, with the proper value of the lung mass for each year of the period. There are 70 calculations for the first year of intake, 69 calculations for the second year of intake, 68 calculations for the third year intake, and so on. Note, however, as a simplification one can group the years past age 20 when both the breathing rate and organ mass are constant. For the adult male and female one can simplify the process to a mere 70 calculations for each. Values for all calculations are then summed to obtain the value of the relative age-specific dose to the lung for a simulated 70-year chronic intake.

The dose to the other organs (total body, liver, and bone) from an acute inhalation based on the ICRP Task Group lung model (ICRP, 1966) for Class W solubility is given by

$$\text{Organ Dose (rem)} = 51.15 \frac{\varepsilon}{m} f_2' \{ P_o \left[\frac{A}{\lambda_x} (1-e^{-\lambda_x t}) - \frac{A}{\lambda} (1-e^{-\lambda t}) - \frac{D}{\lambda^2} (\lambda t + 1) e^{-\lambda t} + \frac{D}{\lambda^2} \right] + \frac{P_{ac}}{\lambda_x} (1-e^{-\lambda_x t}) \} \quad (37)$$

where $A = \frac{f_e \lambda_b}{\lambda - \lambda_x} + \frac{f_h \lambda_b^2}{(\lambda - \lambda_x)^2}$

$D = \frac{f_h \lambda_b^2}{\lambda - \lambda_x}$

P_{ac} = initial activity in the naso-pharynx and tracheobronchial compartments which goes to the blood via pathways a and c (μCi)

λ_x = effective removal constant (d^{-1}) from the organ of interest

λ = effective clearance constant (d^{-1}) from the pulmonary compartment = $\lambda_p + \lambda_b$

λ_b = biological clearance constant (d^{-1}) from the pulmonary compartment

λ_p = physical decay constant (d^{-1})

f_e = fraction of the activity in the pulmonary compartment translocating via pathway e (f_e = 0.25 for solubility Class W)

f_h = fraction of the activity in the pulmonary compartment translocating via pathway h (f_h = 0.0833 for solubility Class W).

Pathways a and c in the ICRP Task Group lung model refer to clearance from the naso-pharynx to the blood and from the tracheobronchial compartment to the blood, respectively. Pathway e refers to clearance from pulmonary region to the blood. Pathway h refers to clearance from the pulmonary region to the lymph nodes.

Both P_o and P_{ac} are proportional to the breathing rate B_r, but with different proportions. For a particle size of 0.3 μm AMAD, $P_o = 0.222\ B_r$ and $P_{ac} = 0.048\ B_r$. The organ dose per year from the acute inhalation is, for year number $(t_2/365.25)$ after the intake,

$$\text{Organ Dose per Year} \propto \frac{B_r}{m(t_1)} \{ 0.222 \left[\frac{A}{\lambda_x} (e^{-\lambda_x t_2} - e^{-\lambda_x t_1}) - \frac{A}{\lambda} (e^{-\lambda t_2} - e^{-\lambda t_1}) - \frac{D}{\lambda^2} (\lambda t_1 + 1) e^{-\lambda t_1} \right. \quad (38)$$

$$\left. + \frac{D}{\lambda^2} (\lambda t_2 + 1) e^{-\lambda t_2} \right] + \frac{0.048}{\lambda_x} (e^{-\lambda_x t_2} - e^{-\lambda_x t_1}) \}$$

The use of this equation is the same as described for the lung dose calculation. Values of the parameters for use in equation 36 are presented in Table F-15 for ^{239}Pu.

TABLE F-15

VALUES OF PARAMETERS USED TO CALCULATE THE RELATIVE ORGAN DOSE PER YEAR FOR PLUTONIUM-239

	Value of Parameters			
Organ	λ (d^{-1})	λ_x (d^{-1})	A	D
Total Body	1.39×10^{-2}	1.07×10^{-5}	0.3336	-1.159×10^{-3}
Liver	1.39×10^{-2}	4.75×10^{-5}	0.3347	-1.161×10^{-3}
Bone	1.39×10^{-2}	1.91×10^{-5}	0.3339	-1.159×10^{-3}
Lungs	1.39×10^{-3}	1.39×10^{-3}	-	-

Derivations of equations 36 and 37, based on modeling recommended by the ICRP Task Group on Lung Dynamics (ICRP, 1966), are as follows. For an acute exposure the activity in the pulmonary region of the lungs P at time t after intake is given by

$$P = P_o\, e^{-\lambda t}. \tag{39}$$

The amount clearing from the lungs with an effective half-time of one day or less is considered to be negligible. The lung dose is given by (see discussion leading to equation 19)

$$\text{Lung Dose (rem)} = 51.15\, \frac{\varepsilon}{m}\, Q. \tag{40}$$

where Q is the integrated activity in the lung, in units of μCi·days and is given by integrating P (equation 39) over time t

$$Q = \int_o^t P\,dt = \frac{P_o}{\lambda}\,(1-e^{-\lambda t}). \tag{41}$$

Substitution of the expression for Q into equation 40 yields equation 34.

For the total body, liver, and bone the activity Y in organ x by pathway e (from lung to blood to organ) and pathway h (from lung to lymph nodes to blood to organ) is governed by the differential equation

$$\frac{dY}{dt} = f_2' f_e \lambda_b P + f_2' \lambda_{Lb} L - \lambda_x Y \tag{42}$$

where L = activity in the lymph nodes at time t (μCi)
λ_{Lb} = biological clearance constant from the lymph nodes (d^{-1})
Y = activity in organ x at time t (μCi)

and all other parameters are defined previously. The term $f_2' f_e \lambda_b P$ is the rate of input into organ x from the lungs via pathway e; the term $f_2' \lambda_{Lb} L$ is the rate of input into organ x from the lymph nodes; and the term $\lambda_x Y$ is the rate at which activity leaves organ x.

Before equation 42 can be solved, it is first necessary to obtain equations for P and L. The activity P is given by equation 39. The equation for L is obtained as follows (for Class W compounds). The rate of change of the activity in the lymph nodes is given by the differential equation

$$\frac{dL}{dt} = f_h \lambda_b P - \lambda L \tag{43}$$

where the term $f_h \lambda_b P$ is the rate of input into the lymph nodes from the lungs in pathway h and λL is the rate of removal from the lymph nodes. Solving equation 43 for L yields

$$L = f_h \lambda_b P_o \, t \, e^{-\lambda t}. \tag{44}$$

Substitution of these expressions for P and L into equation 42 and solving yields the equation for the activity in organ x at time t via pathway e and h

$$Y = f_2' P_o \, (Ae^{-\lambda_x t} - Ae^{-\lambda t} + Dt \, e^{-\lambda t}). \tag{45}$$

The activity in organ x from pathway a (from the naso-pharynx NP to the blood to organ x) and from pathway c (from the tracheobronchial TB compartment to the blood to organ x) is assumed to be directly deposited in organ x, since the half-time in the NP and TB compartments is much less than one day. The activity in organ x from pathway a and c is therefore given by

$$Y = f_2' \, P_{ac} \, e^{-\lambda t}. \tag{46}$$

The total activity in organ x is the sum of equations 45 and 46.

The integrated activity Q_x is obtained by integration of the total activity in organ x.

$$Q_x = f_2' P_o \left[\frac{A}{\lambda_x} (1-e^{\lambda_x t}) - \frac{A}{\lambda} (1-e^{-\lambda t}) - \frac{D}{\lambda^2} (\lambda t + 1) \, e^{-\lambda t} + \frac{D}{\lambda^2} \right] + \frac{f_2' P_{ac}}{\lambda_x} (1-e^{-\lambda_x t}) \tag{47}$$

The dose to organ x is given by

$$\text{Organ Dose (rem)} = 51.15 \frac{\epsilon}{m} Q_x. \tag{48}$$

Substitution of equation 47 into equation 48 yields equation 37.

Equations for Ingestion

The dose to the organs from an acute ingestion is given by

$$\text{Organ Dose (rem)} = 51.15 \frac{\epsilon}{m} \frac{f_2' f_1}{\lambda_x} \, S_I \, (1-e^{-\lambda_x t}) \tag{49}$$

where S_I is the intake (μCi) at time t. Other parameters are defined as for equation 14. Since the desired value is a ratio, all constant values will cancel and can be disregarded. Therefore, equation 49 can be simplified to

$$\text{Organ Dose} \propto \frac{f_1 S_I}{m} (1-e^{-\lambda_x t}). \tag{50}$$

The organ dose per year for the year number ($t_2/365.25$) after the intake is

$$\text{Organ Dose per Year} \alpha \frac{f_1 S_I}{m} (e^{-\lambda_x t_1} - e^{-\lambda_x t_2}) \quad (51)$$

where $t_2 = t_1 + 365.25$ in units of days. The methods for calculating the age-specific organ dose for ingestion are the same as described for inhalation. The values of λ_x are given in Table F-16 for ^{239}Pu, ^{241}Am, and ^{3}H.

TABLE F-16

VALUES OF THE EFFECTIVE REMOVAL CONSTANTS FOR THE ORGANS FOR PLUTONIUM-239, AMERICIUM-241, AND TRITIUM

Effective Removal Constant λ_x (d^{-1})

Radionuclide	Total Body	Liver	Bone	Lungs	
				Class W	Class Y
^{239}Pu	1.07×10^{-5}	4.75×10^{-5}	1.91×10^{-5}	1.39×10^{-2}	1.39×10^{-3}
^{241}Am	1.50×10^{-5}	5.18×10^{-5}	2.33×10^{-5}	1.39×10^{-2}	1.39×10^{-3}
^{3}H	5.78×10^{-2}	-	-	-	-

Derivation of equation 49 is as follows. If the ingested activity S_I is considered to go immediately to the organ of interest following the acute uptake and then to leave the organ at an exponential rate governed by the effective removal constant λ_x, the activity y in the organ at time t is

$$Y = f_2' f_1 S_I e^{-\lambda_x t} \quad (52)$$

where the term $f_2' f_1 S_I$ defines the amount in the organ immediately after the acute ingestion at t = 0. The organ dose is given by

$$\text{Organ Dose (rem)} = 51.15 \frac{\epsilon}{m} Q \quad (53)$$

where Q is the integrated activity in μCi days and is given by integrating Y (equation 52) over time t

$$Q = \int_0^t Y dt = \frac{f_2' f_1 S_I}{\lambda_x} (1 - e^{-\lambda_x t}). \quad (54)$$

Substitution of equation 54 into equation 53 yields equation 49.

Sample Calculation

Calculate the age-specific bone dose ratio for the newborn and 10 year old males resulting from chronic ingestion of ^{239}Pu.

Step 1: Calculate the relative bone dose commitment to reference man from each of the acute intakes as follows. For each of the years from 70 to 1 calculate the relative bone dose to reference man using equation 50. The intake rate S_I is obtained from Table F-13 for the adult male (605 g/d). The bone mass is obtained from Table F-14 for adult male (10000 g). The effective removal rate constant is obtained from Table F-16 for ^{239}Pu bone (1.906×10^{-5} d^{-1}), and f1 = 1. Sum these doses for the years 70 through 1. Also sum the results for years 60 through 1, and 50 through 1.

Step 2: Calculate the relative bone dose to the growing individual from each of the acute intakes as follows.

a. Calculate the relative bone dose for the year of exposure and each succeeding year of life until age 70, for the first intake as follows. Use equation 51, ingestion rate S_I obtained from Table F-13 for the male, bone mass m obtained from Table F-14 for the male, and the effective removal rate constant obtained from Table F-16 for ^{239}Pu and bone. The relative gastrointestinal uptake factor is taken from Section F.1.5.1 Data for Age-Specific Intake Rate and Organ Mass as 100 for the newborn, and 1 for all other ages. For the first year of exposure, calculate the relative bone dose for that year by using the ingestion rate for the newborn, the bone mass for the newborn, and t_1=0 d. The result is 8.67×10^{-2}. Calculate the relative bone dose for the second year (the first year following the intake) using the same ingestion rate, the bone mass for the one year old, and t_1=365.25 d. This result is 3.23×10^{-2}. Continue this process for each successive year through t_1=19 x 365.25 d. Calculate the relative bone dose for the adult years following the ingestion using the same ingestion rate, the adult bone mass t_1=20 x 365.25 d, and t_2=70 x 365.25 d. This value is 1.92×10^{-1}. Sum each of these results.

b. Calculate the relative bone dose for the year of intake and each succeeding year of life until age 70 for the second intake as follows. For the year of intake (which is age 1-2) calculate the relative bone dose using the ingestion rate for the one year old, the bone mass for the one year old and t_1=365.25d. The result is 8.11×10^{-4}. Calculate the relative bone dose for the second year using the same ingestion rate, the bone mass for the 2 year old, and t_1=2 x 365.25d. This result is 7.16×10^{-4}. Continue this process through t_1=19 x 365.25d. Calculate the relative bone dose for the adult years following this ingestion using the same ingestion rate, the adult bone mass, t_1=20 x 365.25d and t_2=69 x 365.25d. This value is 4.82×10^{-3}. Sum each of these results.

c. Continue this process through intake number 20. Sum all the results from Steps 2a, 2b, and 2c. Also sum the results of Step 2c for intakes number 11 through 20.

Step 3: Calculate the ratio of the relative bone dose to the newborn and 10 year old male to that of reference man as follows.

a. For the newborn male, add the total relative bone dose from birth to age 20 from Step 2c and the total relative bone dose from age 20 to 70 (years 50 to 1) from Step 1. This result is the relative bone dose over the lifetime of the individual when chronic exposure starts as a newborn. The desired ratio is obtained by dividing this result by the total relative bone dose to reference man over the entire 70 years, obtained from Step 1.

b. For the 10 year old male, add the total relative bone dose for intakes number 11 through 20 from Step 2c and the total relative bone dose to reference man for years 60 through 1 from step 1. This result is the relative bone dose over 70 years to the individual when exposure starts at age 10. The desired ratio is obtained by dividing this result by the total relative bone dose for reference man from Step 1.

The results of these calculations are tabulated in Table F-17.

TABLE F-17
TABULATION OF SAMPLE CALCULATION OF AGE-SPECIFIC BONE DOSE FOR CHRONIC INGESTION
Tabulation for Step 1: Relative Bone Dose for Reference Man

Years Remaining	Relative Bone Dose	Years Remaining	Relative Bone Dose	Years Remaining	Relative Bone Dose	Years Remaining	Relative Bone Dose
70	2.33×10^{-2}	50	1.78×10^{-2}	30	1.14×10^{-2}	10	4.07×10^{-3}
69	2.31×10^{-2}	49	1.75×10^{-2}	29	1.11×10^{-2}	9	3.67×10^{-3}
68	2.28×10^{-2}	48	1.72×10^{-2}	28	1.07×10^{-2}	8	3.28×10^{-3}
67	2.25×10^{-2}	47	1.69×10^{-2}	27	1.04×10^{-2}	7	2.88×10^{-3}
66	2.23×10^{-2}	46	1.66×10^{-2}	26	1.00×10^{-2}	6	2.47×10^{-3}
65	2.20×10^{-2}	45	1.63×10^{-2}	25	9.66×10^{-3}	5	2.07×10^{-3}
64	2.17×10^{-2}	44	1.60×10^{-2}	24	9.31×10^{-3}	4	1.66×10^{-3}
63	2.15×10^{-2}	43	1.56×10^{-2}	23	8.95×10^{-3}	3	1.25×10^{-3}
62	2.12×10^{-2}	42	1.53×10^{-2}	22	8.59×10^{-3}	2	8.36×10^{-4}
61	2.09×10^{-2}	41	1.50×10^{-2}	21	8.23×10^{-3}	1	4.20×10^{-4}
60	2.07×10^{-2}	40	1.47×10^{-2}	20	7.86×10^{-3}		
59	2.04×10^{-2}	39	1.44×10^{-2}	19	7.49×10^{-3}	Total (70 through 1)	
58	2.01×10^{-2}	38	1.41×10^{-2}	18	7.12×10^{-3}	8.94×10^{-1}	
57	1.98×10^{-2}	37	1.37×10^{-2}	17	6.75×10^{-3}	Total (60 through 1)	
56	1.95×10^{-2}	36	1.34×10^{-2}	16	6.38×10^{-3}	6.73×10^{-1}	
55	1.92×10^{-2}	35	1.31×10^{-2}	15	6.00×10^{-3}	Total (50 through 1)	
54	1.90×10^{-2}	34	1.27×10^{-2}	14	5.62×10^{-3}	4.79×10^{-1}	
53	1.87×10^{-2}	33	1.24×10^{-2}	13	5.23×10^{-3}		
52	1.84×10^{-2}	32	1.21×10^{-2}	12	4.85×10^{-3}		
51	1.81×10^{-2}	31	1.17×10^{-2}	11	4.46×10^{-3}		

TABULATION FOR STEP 2: RELATIVE BONE DOSE FOR NEWBORN MALE

Dose Year	Dose For Exposure Number 1	2	3	4	5	6	7
1	8.67×10^{-2}	8.11×10^{-4}	9.13×10^{-4}	9.67×10^{-4}	1.02×10^{-3}	1.01×10^{-3}	9.79×10^{-4}
2	3.23×10^{-2}	7.16×10^{-4}	8.37×10^{-4}	9.14×10^{-4}	9.18×10^{-4}	9.04×10^{-4}	8.84×10^{-4}
3	2.85×10^{-2}	6.56×10^{-4}	7.91×10^{-4}	8.27×10^{-4}	8.21×10^{-4}	8.16×10^{-4}	8.33×10^{-4}
4	2.61×10^{-2}	6.20×10^{-4}	7.16×10^{-4}	7.39×10^{-4}	7.41×10^{-4}	7.68×10^{-4}	7.49×10^{-4}
5	2.47×10^{-2}	5.61×10^{-4}	6.39×10^{-4}	6.67×10^{-4}	6.98×10^{-4}	6.91×10^{-4}	6.80×10^{-4}
6	2.23×10^{-2}	5.01×10^{-4}	5.77×10^{-4}	6.28×10^{-4}	6.28×10^{-4}	6.28×10^{-4}	6.22×10^{-4}
7	2.00×10^{-2}	4.52×10^{-4}	5.44×10^{-4}	5.65×10^{-4}	5.70×10^{-4}	5.74×10^{-4}	4.70×10^{-4}
8	1.80×10^{-2}	4.26×10^{-4}	4.89×10^{-4}	5.13×10^{-4}	5.22×10^{-4}	4.33×10^{-4}	3.59×10^{-4}
9	1.70×10^{-2}	3.83×10^{-4}	4.44×10^{-4}	4.70×10^{-4}	3.94×10^{-4}	3.31×10^{-4}	2.89×10^{-4}
10	1.53×10^{-2}	3.48×10^{-4}	4.06×10^{-4}	3.54×10^{-4}	3.01×10^{-4}	2.67×10^{-4}	2.71×10^{-4}
11	1.39×10^{-2}	3.18×10^{-4}	3.07×10^{-4}	2.71×10^{-4}	2.43×10^{-4}	2.50×10^{-4}	2.57×10^{-4}
12	1.27×10^{-2}	2.40×10^{-4}	2.34×10^{-4}	2.18×10^{-4}	2.27×10^{-4}	2.37×10^{-4}	2.44×10^{-4}
13	9.57×10^{-3}	1.84×10^{-4}	1.89×10^{-4}	2.04×10^{-4}	2.15×10^{-4}	2.25×10^{-4}	2.32×10^{-4}
14	7.31×10^{-3}	1.48×10^{-4}	1.77×10^{-4}	1.94×10^{-4}	2.04×10^{-4}	2.14×10^{-4}	2.26×10^{-4}
15	5.90×10^{-3}	1.38×10^{-4}	1.68×10^{-4}	1.84×10^{-4}	1.95×10^{-4}	2.08×10^{-4}	
16	5.51×10^{-3}	1.31×10^{-4}	1.59×10^{-4}	1.75×10^{-4}	1.89×10^{-4}		
17	5.23×10^{-3}	1.25×10^{-4}	1.52×10^{-4}	1.70×10^{-4}			
18	4.97×10^{-3}	1.19×10^{-4}	1.48×10^{-4}				
19	4.73×10^{-3}	1.16×10^{-4}					
20	4.60×10^{-3}						
20-70	1.92×10^{-1}	4.82×10^{-3}	6.15×10^{-3}	7.10×10^{-3}	7.89×10^{-3}	8.68×10^{-3}	9.41×10^{-3}
Total	5.57×10^{-1}	1.18×10^{-2}	1.40×10^{-2}	1.52×10^{-2}	1.58×10^{-2}	1.62×10^{-2}	1.65×10^{-2}

TABULATION FOR STEP 2: RELATIVE BONE DOSE FOR NEWBORN MALE
(Continued)

Dose Year	Dose for Exposure Number 8	9	10	11	12	13	14
1	9.48×10^{-4}	9.59×10^{-4}	9.02×10^{-4}	8.86×10^{-4}	8.52×10^{-4}	6.83×10^{-4}	5.46×10^{-4}
2	8.93×10^{-4}	8.63×10^{-4}	8.19×10^{-4}	8.10×10^{-4}	6.43×10^{-4}	5.21×10^{-4}	4.41×10^{-4}
3	8.04×10^{-4}	7.84×10^{-4}	7.49×10^{-4}	6.12×10^{-4}	4.91×10^{-4}	4.21×10^{-4}	4.12×10^{-4}
4	7.30×10^{-4}	7.17×10^{-4}	5.65×10^{-4}	4.67×10^{-4}	3.97×10^{-4}	3.93×10^{-4}	3.91×10^{-4}
5	6.67×10^{-4}	5.41×10^{-4}	4.32×10^{-4}	3.77×10^{-4}	3.71×10^{-4}	3.73×10^{-4}	3.71×10^{-4}
6	5.04×10^{-4}	4.13×10^{-4}	3.48×10^{-4}	3.52×10^{-4}	3.52×10^{-4}	3.54×10^{-4}	3.54×10^{-4}
7	3.85×10^{-4}	3.33×10^{-4}	3.26×10^{-4}	3.34×10^{-4}	3.34×10^{-4}	3.37×10^{-4}	3.44×10^{-4}
8	3.10×10^{-4}	3.12×10^{-4}	3.09×10^{-4}	3.18×10^{-4}	3.18×10^{-4}	3.28×10^{-4}	
9	2.90×10^{-4}	2.96×10^{-4}	2.93×10^{-4}	3.02×10^{-4}	3.09×10^{-4}		
10	2.75×10^{-4}	2.81×10^{-4}	2.79×10^{-4}	2.94×10^{-4}			
11	2.62×10^{-4}	2.67×10^{-4}	2.72×10^{-4}				
12	2.49×10^{-4}	2.60×10^{-4}					
13	2.42×10^{-4}						
20-70	1.01×10^{-2}	1.08×10^{-2}	1.13×10^{-2}	1.23×10^{-2}	1.29×10^{-2}	1.37×10^{-2}	1.43×10^{-2}
Total	1.67×10^{-2}	1.69×10^{-2}	1.66×10^{-2}	1.70×10^{-2}	1.70×10^{-2}	1.71×10^{-2}	1.72×10^{-2}

TABULATION FOR STEP 2: RELATIVE BONE DOSE FOR NEWBORN MALE
(Continued)

Dose Year	Dose for Exposure Number 15	16	17	18	19	20
1	4.61×10^{-4}	4.46×10^{-4}	4.29×10^{-4}	4.12×10^{-4}	3.96×10^{-4}	3.87×10^{-4}
2	4.31×10^{-4}	4.23×10^{-4}	4.07×10^{-4}	3.93×10^{-4}	3.85×10^{-4}	
3	4.09×10^{-4}	4.02×10^{-4}	3.88×10^{-4}	3.82×10^{-4}		
4	3.89×10^{-4}	3.82×10^{-4}	3.77×10^{-4}			
5	3.70×10^{-4}	3.72×10^{-4}				
6	3.60×10^{-4}					
20-70	1.50×10^{-2}	1.55×10^{-2}	1.57×10^{-2}	1.59×10^{-2}	1.61×10^{-2}	1.61×10^{-2}
Total	1.74×10^{-2}	1.75×10^{-2}	1.73×10^{-2}	1.71×10^{-2}	1.68×10^{-2}	1.65×10^{-2}

TOTAL (1 through 20) 8.67×10^{-1}

TOTAL (11 through 20) 1.73×10^{-1}

TABULATION FOR STEP 3: CALCULATION OF AGE-SPECIFIC RATIOS

Newborn Male: $$\frac{8.67 \times 10^{-1} + 4.79 \times 10^{-1}}{8.94 \times 10^{-1}} = 1.51$$

10 Year Old Male: $$\frac{1.73 \times 10^{-1} + 6.73 \times 10^{-1}}{8.94 \times 10^{-1}} = 0.946$$

Equations for Ground Plane Irradiation

It is assumed that organ doses from ground plane irradiation are not dependent on the age, gender, or organ size of the person, since the origin of the radiation is external to the body and self-shielding of the person's body is not included for dose to adults. All ratios to reference man are therefore unity.

F.1.5.2 Ratio of the 70-Year Dose to the 70-Year Dose Commitment

The ratio of the 70-year dose from 70 years of Plant operation to the 70-year dose commitment from one year of Plant operation is presented in Table 3.1.2-7 for inhalation, ingestion, and ground plane irradiation. Since a ratio of two types of doses is the desired value, all constant values appearing in both the numerator and in the denominator cancel. The desired ratio is, therefore, given by the ratio of the dose conversion factors, for the same intake rate.

For inhalation, the ratio is obtained by multiplying the dose conversion factor, given in Table F-1, by 70 and dividing by the dose conversion factor for the corresponding radionuclides and organ, given in Table F-2. The multiplication by 70 is necessary to adjust the intake rate of 1 Ci/70 yr for the values in Table F-1 to be for an intake rate of 1 Ci/yr, which is the intake rate for values in Table F-2. For example, the ratio for the bone dose from ^{239}Pu is equal to $(4.295 \times 10^5 \times 70)/(7.919 \times 10^5)$ or 38.0.

For ingestion, the bone dose conversion factor for the 70-year dose from 70 years of Plant operation is given in Table F-5. The dose conversion factors for the 70-year dose commitment from one year of Plant operation are obtained from the FOOD code as described in Section F.1.2.1 and are presented in Table F-18. The ratio is obtained by multiplying the dose conversion factor in Table F-5 by 70 and dividing by the dose conversion factor in Table F-18 for the corresponding radionuclide and organ. For example, the ratio for the bone dose for ^{241}Am is equal to $(1.9 \times 10^3 \times 70)/(3.4 \times 10^3)$ or 39.1. The ratios based on the dose conversion factors for food ingestion also are considered to be valid for water ingestion, since the modeling from the GI tract to the organ of interest is identical for the two ingestion pathways.

TABLE F-18

DOSE CONVERSION FACTORS FOR THE 70-YEAR DOSE
FROM ONE YEAR OF CHRONIC PLANT RELEASE
FOR 70 YEARS OF FOOD INGESTION - AVERAGE INTAKE

	Dose Conversion Factor ($\frac{rem \cdot m^3}{Ci \cdot s}$)			
Radionuclide	Total Body	Liver	Bone	Lungs
^{3}H	5.4×10^{2}	5.4×10^{2}	*	5.4×10^{2}
^{234}U	1.1×10^{1}	*	2.6×10^{2}	*
^{235}U	6.6	*	1.5×10^{2}	*
^{236}U	1.1×10^{1}	*	2.5×10^{2}	*
^{238}U	6.2	*	1.3×10^{1}	*
^{231}Th	2.1×10^{11}	3.7×10^{11}	6.5×10^{10}	*
^{234}Th	1.3×10^{4}	2.5×10^{4}	6.4×10^{3}	*
^{238}Pu	1.0×10^{1}	1.2×10^{3}	2.8×10^{3}	*
^{239}Pu	1.2	1.4×10^{2}	3.3×10^{2}	*
^{240}Pu	1.2	1.4×10^{2}	3.3×10^{2}	*
^{241}Pu	1.5×10^{1}	9.7	5.7×10^{1}	*
^{242}Pu	1.2	1.3×10^{2}	3.2×10^{2}	*
^{241}Am	9.4	1.4×10^{3}	3.4×10^{3}	*
^{242}Cm**	1.3×10^{1}	1.9×10^{3}	4.9×10^{3}	*

*The value for the dose conversion factor is taken to be equal to that for the total body.

**^{242}Cm is used for the "miscellaneous alpha-emitting isotopes."

For ground plane irradiation, the 70-year dose from 70 years of Plant operation is given by equation 21. The 70-year dose from one year of Plant releases followed by 69 years of exposure to ground contaminated by that release is given by

$$\text{Organ Dose (rem)} = 8.01 \times 10^{8} \left(\frac{\chi}{Q}\right) S_g F. \qquad (55)$$

The ratio of equation 21 (for t = 25567.5 days) to equation 55 is 35.3. Note that these equations neglect loss of the radionuclide by radioactive decay or weathering into the soil. This ratio is assumed to apply to all the radionuclides, except ^{241}Am.

For ^{241}Am there is a second component resulting from ingrowth from ^{241}Pu. For this component, the 70 year dose from one year of plant releases is given by

$$\text{Organ Dose (rem)} = 8.01 \times 10^{8} \left(\frac{\chi}{Q}\right) (S_g)_A F_d + 1.87 \times 10^{7} \left(\frac{\chi}{Q}\right) (S_g)_p F_d \qquad (56)$$

where $(S_g)_p$ is the release rate (Ci/d) for ^{241}Pu and $(S_g)_p$ is the release rate (Ci/d) for ^{241}Am. F_d is as defined for equation 22.

The 70-year dose from 70 years of Plant operations for ^{241}Am is given by the sum of equation 21, evaluated for ^{241}Am, and equation 23. This result is

$$\text{Organ Dose (rem)} = 2.82 \times 10^{10} \left(\frac{\chi}{Q}\right)(S_g)_A F_d + 5.39 \times 10^{8} \left(\frac{\chi}{Q}\right)(S_g)_p F_d. \quad (57)$$

The ratio of equation 57 to equation 56 is

$$\text{Ratio} = \frac{2.82 \times 10^{10}(S_g)_A + 5.39 \times 10^{8}(S_g)_p}{8.01 \times 10^{8}(S_g)_A + 1.87 \times 10^{7}(S_g)_p}. \quad (58)$$

For values of $(S_g)_A = 2.55 \times 10^{-6}$ Ci/d and $(S_g)_p = 6.27 \times 10^{-5}$ Ci/d (from Table F-12), the ratio for ^{241}Am is 32.9.

Derivation of equation 55, for the organ dose from a chronic release over one year followed by 69 years of exposure only to ground contaminated by that release, is as follows. The organ dose consists of two components, the dose from the first year of chronic releases, during which the ground surface concentration is increasing, and the dose from the remaining 69 years, during which the ground surface concentration is assumed to be constant, with no loss from radiological decay or weathering. The first component H_1 is obtained by evaluating equation 21 for t = 365.25 days.

$$H_1 = 5.76 \times 10^{6}\left(\frac{\chi}{Q}\right) S_g F \quad (59)$$

The second component H_{69} is obtained as follows. First, the ground surface concentration G_1 at the end of the first year is determined. This value is given by equation 25 for t = 365.25 days and V_d = 0.001 m/s. The dose H_{69} from exposure to the constant surface concentration G_1 is given by

$$H_{69} = 8.64 \times 10^{4} G_1 F t \quad (60)$$

where the constant 8.64×10^{4} is the conversion factor seconds per day and t is in days. Substituting for G_1 and solving for $t = 2.52 \times 10^{4}$ days (69 years) yields

$$H_{69} = 7.95 \times 10^{8} \left(\frac{\chi}{Q}\right) S_g F. \quad (61)$$

Summing the two components H_1 and H_{69} yields the total dose over 70 years, given by equation 55.

Derivation of equation 54, for the case of the dose from ^{241}Am ingrown from one year of release of ^{241}Pu in addition to the dose from the released ^{241}Am is as follows. The dose from ingrown ^{241}Am consists of two components. These components are the dose H_1 from the ^{241}Am grown in during the year of chronic releases of the ^{241}Pu and the dose H_{69} from the ^{241}Am which continues to grow in during the remaining

69 years. The first component H_1 is obtained by evaluating equation 20 for t = 365.25 days, $(SA)_d$ = 3.42 Ci/g, $(SA)_p$ = 103.5 Ci/g, $\lambda_p = 1.322 \times 10^{-4}$ d^{-1}, and V_d = 0.001 m/s.

$$H_1 = 3.03 \times 10^3 \left(\frac{\chi}{Q}\right)_g (S)_p F_d \tag{62}$$

where $(S_g)_p$ is the release rate (Ci/d) for ^{241}Pu and F_d is the dose conversion factor for ^{241}Am.

The second component H_{69} is obtained as follows. The concentration of the parent ^{241}Pu on the ground at one year, in terms of mass (g/m^2), is obtained by evaluating equation 25 for t = 365.25 days

$$P_o = 3.65 \times 10^{-1} \left(\frac{\chi}{Q}\right) S_p \tag{63}$$

where S_p is the mass release rate (g/d) for the ^{241}Pu. The rate of ingrowth of ^{241}Am from the deposited ^{241}Pu is given by the differential equation

$$\frac{dA}{dt} = \lambda_p P(\tau) \tag{64}$$

where A = mass surface concentration for ^{241}Am at time τ from ingrowth from this component of the ^{241}Pu.

λ_p = decay constant for ^{241}Pu = 1.322×10^{-4} d^{-1}

$P(\tau)$= mass surface concentration for ^{241}Pu (g/m^2) at time τ (d) after the end of the first year (τ = 0 at t = 365.25d).

The value of $P(\tau)$ decreases with time from radiological decay and is given by

$$P(\tau) = P_o e^{-\lambda_p \tau}. \tag{65}$$

Substituting equation 65 and 63 into equation 62 and solving yields

$$A = 3.65 \times 10^{-1} \left(\frac{\chi}{Q}\right) S_p (1-e^{-\lambda_p \tau}). \tag{66}$$

Converting to activity by A = A(activity)/$(SA)_d$ and $S_p = (S_g)_p/(SA)_p$, where $(SA)_d$ = 342 Ci/g for ^{241}Am, $(SA)_p$ = 103.5 Ci/g for ^{241}Pu, and $(S_g)_p$ is the activity release rate (Ci/d) for ^{241}Pu, equation 67 for the ^{241}Am surface concentration (Ci/m^2) is obtained from equation 66.

$$A(\text{activity}) = 1.21 \times 10^{-2} \left(\frac{\chi}{Q}\right)(S_g)_p (1-e^{-\lambda_p \tau}) \tag{67}$$

The 69-year dose H_{69} is obtained by solving the differential equation

$$\frac{dH_{69}}{d\tau} = 8.64 \times 10^4 \, A(\text{activity}) \, F_d \tag{68}$$

where A(activity) is given by equation 67 and F_d is the dose conversion factor for ^{241}Am. Solving for H_{69} yields

$$H_{69} = 1.04 \times 10^3 \left(\frac{\chi}{Q}\right)(S_g)_p F_d \left(\tau + \frac{1}{\lambda_p} e^{-\lambda_p \tau} - \frac{1}{\lambda_p}\right). \quad (69)$$

Evaluating equation 69 for $\tau = 2.52 \times 10^4$ days (69 years) yields

$$H_{69} = 1.87 \times 10^7 \left(\frac{\chi}{Q}\right) (S_g)_p F_d. \quad (70)$$

Summing equations 62 and 70 yields the 70-year dose from ^{241}Am ingrown from ^{241}Pu released chronically during the first year. This result is the second term in equation 56. The first term in equation 56 is equation 55, where S_g is the release rate for ^{241}Am $(S_g)_A$ and F is the dose conversion factor for ^{241}Am F_d.

F.1.5.3 Population Doses

The population organ doses, presented in Table 3.1.2-8, are obtained by multiplying the number of people at each of the 16 directions and 8 distances from the plant, as presented in Figure 2.3.3-1 for the population in 1977 and in Figure 2.3.3-2 for the projected population in year 2000, by the organ dose for the corresponding direction and distance (Table 3.1.2-3). The values for a given organ are then summed to give the total population organ dose, in units of man-rem.

There is one refinement to this calculation involving the sections in which the population is considered to drink water supplied from Standley Lake. The total number of persons drinking water supplied from Standly Lake in 1977 is 118,500 or 45% of the total population in those sections. For the sections identified in Table 3.1.2-3 as containing persons drinking water supplied from Standley Lake, 45% of the population was considered to drink that water and receive the dose presented in Table 3.1.2-3. The remaining 55% receive the dose presented in Table 3.1.2-3 minus the dose contribution from the drinking water supplied from Standley Lake. For the year 2000 projected population, the value of 45% is assumed to remain valid, and the same procedure is used. The dose contribution from drinking water supplied from Standley Lake to persons in those sections are 5.28×10^{-4} rem to the total body, 2.95×10^{-2} rem to the liver, 6.43×10^{-2} rem to the bone, and 5.28×10^{-4} rem to the lungs.

For the contribution to the population dose from the sections containing persons drinking water supplied from Standley Lake, the procedure is as follows.

1. Multiply the population in the section by 0.45.
2. Multiply that result by the organ dose presented in Table 3.1.2-3 for that section.
3. Multiply the population in the section by 0.55.
4. Subtract the organ dose contribution of Standley Lake drinking water (from the preceding paragraph) from the corresponding value in Table 3.1.2-3.

5. Multiply the result of Step 3 by the result of Step 4.
6. Sum the values from Step 2 and Step 5. This sum is the population organ dose for that section.

F.1.5.4 Population Dose for a Hypothetical High Density Population East of the Plant

The population bone dose is presented in Table 3.1.2-9 for the projected population for year 2000 plus a hypothetical high density population in the eastern sectors at distances between 2 and 5 miles from the center of the Plant. This section presents the considerations for that calculation.

The value of 7296 persons per square mile is used as the hypothetical high-density population. This value is obtained as follows. Based on the subdivisions of Countrydale and Countryside, east of the Plant, the average number of dwellings per acre is 4.03. Based on data from the Denver Regional Council of Governments (DRCOG), the average family size is 2.83. At one family per dwelling, the number of persons per acre is 11.4, and, at 640 acres/mi^2, the number of persons per $mile^2$ is 7296.

Next, the section (for sector direction and at distance r_2-r_1) area is determined, where r_2 and r_1 are the outer and inner distance (miles) of the section boundaries from the center of the Plant. From basic geometry the section area is (/16)(r_2^2-r_1^2).

Multiplication of the section area by the value 7296 persons/mi^2 yields the hypothetical population for that section for year 2000. Note that when calculation is done for any section, the result is at least 1.56 times greater than the year 1977 population for any section, even for the section containing the center of Denver. No credit is taken for large bodies of water, such as the SE sector containing Standley Lake.

The population dose is obtained using the procedure described in Section F.1.5.3.

Note that these procedures can be used to calculate the population organ dose to hypothetical population densities for any section or groups of sections. The eastern sections out to 5 miles were chosen for this impact analysis to illustrate the possible impact to the population dose from potential nearby developments over and above that projected by DRCOG for year 2000.

F.2 Accidental Releases

F.2.1 Assessment of Risk Dose

The risk dose from accidental releases is determined for reference man as a function of direction and distance from the Plant. The risk dose is the sum of the risk doses for the pathways of inhalation, food and water ingestion, ground plane irradiation, and plume shine (for releases from criticality accidents). The organ risk dose to the thyroid as well as to the total body, liver, bone, and lungs is calculated.

In general, the concept of the risk dose requires that the release over a period of years be treated as an acute* release at the start of each of the years. The series of acute releases can be well-approximated by a chronic release over that period of years. The rate of release equals the magnitude of the release (Ci) if the accident occurred multiplied by the probability of occurrence per year.

F.2.1.1 Inhalation Pathway

The organ risk dose via inhalation is obtained in the same manner as described in Section F.1.1 for routine releases. Refer to that section for the details of the methodology.

The source terms are obtained from Table 3.2.3-1 (right column). These values are in terms of μCi/yr and need to be converted to Ci over 70 years by multiplying by 7.0×10^{-5}. The total of 314 μCi/yr for plutonium also needs to be adjusted for resuspension (multiply by 1.97) and apportioned among the isotopes of plutonium. The distribution among the isotopes of plutonium is based on the isotopic composition by weight for Rocky Flats plutonium given in Table 2.7.2-2, converted to isotopic composition by activity. These conversions are accomplished as shown in Table F-19 to obtain the desired source terms over 70 years for the plutonium isotopes and americium. The alpha activity of ^{241}Am is taken to be 20% of the plutonium alpha activity (the 314 μCi/y refers to plutonium alpha activity only). Although the value of 20% exceeds the maximum of ingrowth of ^{241}Am in Rocky Flats plutonium, further ingrowth is considered for the ^{241}Am for these calculations, as was described for the routine releases (Section F.1.1.1).

The dispersion factors χ/Q** to off-site locations are presented in Table B-2-4 of Appendix B-2. For the "chronic" releases from the postulated accidents, the dispersion factors are calculated for Pasquill E conditions with a wind speed of

*The word "acute" is meant to imply a release of very short duration and not necessarily requiring urgent attention.

**Throughout this discussion, χ/Q is used to represent E/Q, where E is the time integrated air concentration in $(Ci \cdot s)/m^3$ and Q is the total release in Ci, as discussed by Houston (Houston, et al., 1976).

TABLE F-19

CONVERSION OF THE SOURCE TERM FOR PLUTONIUM ISOTOPES AND FOR AMERICIUM

Isotope	Relative Weight (g)	Specific Activity (Ci/g)	Relative Activity[1] (Ci)	Fraction of Pu Alpha Activity[2]	Risk Source Term[4] (μCi/yr)	Total Risk Source Term Over 70 Years[5] (Ci)
^{238}Pu	0.01	17.1	0.00171	0.0233	7.32	1.01×10^{-4}
^{239}Pu	93.79	0.0622	0.05834	0.7962	250	3.45×10^{-2}
^{240}Pu	5.80	0.228	0.01322	0.1804	56.6	7.81×10^{-3}
^{241}Pu	0.36	103.5*	0.37260	5.085	1597*	2.20×10^{-1}
^{242}Pu	0.03	0.00393	1.18×10^{-6}	1.61×10^{-5}	5.06×10^{-3}	6.97×10^{-7}
^{241}Am	--	--	--	0.20[3]	62.8	9.19×10^{-3} [6]

* Beta Activity.

(1) Obtained by multiplying the percent by weight by the specific activity.

(2) Obtained by dividing the relative activity by the sum of the relative activities for the plutonium alpha emitters.

(3) The value for ^{241}Am is taken to be 20% of the plutonium alpha activity.

(4) Obtained by multiplying the fraction of the Pu alpha activity by the value of 314 μCi/yr.

(5) Obtained by multiplying the risk source term (μCi/y) by 7.0×10^{-5} (Ci·yr)/μCi and by 1.97 to include the component from 70 years of resuspension.

(6) For ^{241}Am the component of the amount of resuspended ^{241}Am ingrown from ^{241}Pu is included. This additional component is equal to 4.7×10^{-3} times the risk source term for ^{241}Pu, i.e., 5.25×10^{-4} Ci.

3.0 m/s and are weighted by the frequency with which the wind blows into the sector of interest. One can argue persuasively that the factors should also be weighted according to the frequency of each Pasquill stability class, as was done for the dispersion of routine releases. However, use of Pasquill E stability class results in a more conservative assessment of the dispersion, an approach which is appropriate for the assessment of risk from accidental releases.

The dose conversion factors for the 70-year dose from 70 years of chronic intake via inhalation for the plutonium isotopes and for ^{241}Am are those presented in Table F-1.

The dose conversion factors for fission products released from criticality accidents are also obtained from the DACRIN computer code and are presented in Table F-20. These factors are generated by the DACRIN code using specific values of the source terms and are a composite sum for the fission products listed in Table 3.2.3-2. A solubility class D (clearance from the lungs with a half-time of up to a few days) is assumed for the generation of the dose conversion factors for all organs (except

TABLE F-20

COMPOSITE 70-YEAR RISK DOSE* FOR UNIT DISPERSION FOR RADIONUCLIDES RELEASED FROM POTENTIAL CRITICALITY ACCIDENTS VIA INHALATION

Distance (miles)	Dose for Unit Dispersion ($\frac{rem \cdot m^3}{s}$) Total Body	Liver	Bone	Lungs	Thyroid
2	7.24×10^{-1}	1.52	2.92	4.34×10^{1}	3.62×10^{2}
3	7.14×10^{-1}	1.50	3.02	4.14×10^{1}	3.51×10^{2}
4	6.99×10^{-1}	1.49	3.08	3.97×10^{1}	3.42×10^{2}
5	6.84×10^{-1}	1.47	3.13	3.81×10^{1}	3.34×10^{2}
10	6.19×10^{-1}	1.41	3.17	3.22×10^{1}	2.95×10^{2}
20	5.19×10^{-1}	1.31	3.13	2.56×10^{1}	2.50×10^{2}
30	4.62×10^{-1}	1.26	3.09	2.21×10^{1}	2.21×10^{2}
40	4.20×10^{-1}	1.22	3.07	1.98×10^{1}	2.01×10^{2}

*These values are specific for the source terms and values of the probability of occurrence for the criticality accidents postulated in this Impact Statement.

the lungs) for the fission products from criticality accidents. A solubility Class W is assumed for the lungs. The factors are presented as a function of distance, since the DACRIN code computes the decrease in the source term from radiological decay plus the ingrowth of daughter radionuclides during the time for the radionuclides to travel from the plant site to the distance of interest, traveling at a speed of 3.0 m/s. No resuspension is included for these radionuclides, which, except for the plutonium and americium, are noble gases and short-lived isotopes of iodine and bromine.

F.2.1.2 Food Ingestion Pathway

The organ risk dose via food ingestion is obtained in the same manner as described in Section F.1.2 for routine releases. Refer to that section for the details of the methodology.

Source terms for plutonium and americium are obtained as discussed for the inhalation pathway (Section F.2.1.1). The only fission products of consequence for this pathway are the isotopes of iodine and bromine-82. Source terms for these isotopes are obtained from Table 3.2.3-2. Source terms for plutonium and americium are converted to Ci released over 70 years by multiplying by 7.0×10^{-5}.

For the fission products, the source terms are converted to Ci released over 70 years by multiplying by 70. The dispersion terms are obtained as described for the inhalation pathway (Section F.2.1.1).

The dose conversion factors are generated by the FOOD computer code described in Section F.1.2.1 and are presented in Table F-5 for plutonium and americium and in Table F-21 for the significant fission products. These factors pertain to a release of one curie over 70 years.

TABLE F-21

DOSE CONVERSION FACTORS FOR FISSION PRODUCTS
USED IN RISK DOSE CALCULATIONS VIA FOOD INGESTION

70-Year Chronic Release and Food Consumption at the Average Intake Rate

Radionuclide	Dose Conversion Factor $(\frac{rem \cdot m^3}{Ci \cdot s})$				
	Total Body	Liver	Bone	Lungs	Thyroid
^{82}Br	4.9×10^{-2}	*	*	*	*
^{131}I	1.0	1.7	1.7	*	5.9×10^{2}
^{132}I	2.1×10^{-16}	5.6×10^{-16}	3.1×10^{-16}	*	7.7×10^{-14}
^{133}I	1.1×10^{-3}	*	*	*	6.6×10^{-1}
^{134}I	**	**	**	**	**
^{135}I	2.0×10^{-7}	*	*	*	7.3×10^{-5}

* The value for the dose conversion factor is taken to be that for the total body.

** No calculation was made by the FOOD code for input values for this radionuclide because the dose from this radionuclide is considered to be negligible.

F.2.1.3 Water Ingestion Pathway

The risk dose from water ingestion results from "chronic" airborne releases and from the risk of the impoundment failure releasing water to Great Western Reservoir.

Airborne Releases

The risk dose from airborne releases is obtained in the same manner as described in Section F.1.3.2. Refer to that section for details of the methodology.

The source terms for plutonium and americium in units of μCi/yr are obtained from Table F-19, column 6. For fission products, the source terms are obtained from Table 3.2.3-2 and are multiplied by 10^6 to convert to units of μCi/yr. No radioactive decay is included for the time between the release and the consumption.

The dispersion factor is weighted by the wind direction frequency and is calculated using the methodology in Appendix B-2 with the values of parameters given in Section F.1.3.2. The dispersion factor to Great Western Reservoir is 1.46×10^{-7} s/m^3 and to Standley Lake, is 9.80×10^{-8} s/m^3.

The dose conversion factors for plutonium and americium are those presented in Table F-8. The dose conversion factors for the isotopes of iodine and bromine-82 are calculated using equation 14 and values of parameters from ICRP #2. These factors are presented in Table F-22.

Risk Dose from Risk of an Impoundment Failure

The risk dose from ingesting water supplied from Great Western Reservoir resulting from the risk of an impoundment failure is obtained as follows. The "expected" annual release (μCi/yr) is obtained from Table 3.2.3-1. The values are 87 μCi/yr for plutonium isotopes, 82 μCi/yr for ^{241}Am, and 485 μCi/yr for uranium isotopes. The activity values for the plutonium and uranium isotopes are first apportioned among the isotopes. For plutonium this distribution is accomplished as shown in Table F-19. For uranium the distribution is based on the ratios of the activities in Table 3.1.2-1. All of the released activity is assumed to go into the 3.79×10^9 ℓ volume of Great Western Reservoir, with an assumed turnover rate of once per year. The water concentration C_w (pCi/ℓ) for each radionuclide is then given by

$$C_w = 10^6 S_e \left(\frac{1}{V}\right) \tag{71}$$

where C_w = radionuclide concentration in the water of the reservoir (pCi/ℓ)
S_e = "expected" activity released in a year for a given radionuclide (μCi)
V = reservoir volume (ℓ) = 3.79×10^9 ℓ for Great Western Reservoir
10^6 = conversion factor from μCi to pCi (10^6 pCi/μCi)

It is assumed that the activity concentration in the finished drinking water is the same as that in the reservoir water C_w. No credit is taken for possible removal in the water treatment process.

Once the value of C_w is obtained, the organ risk dose can be calculated using equation 13. The intake rate I_w is 1.65 ℓ/d for reference man. Values of dose conversion factors are obtained from Table F-8. This calculation is done for each of the radionuclides, and the results are summed for each organ.

F.2.1.4 Ground Plane Irradiation

The risk dose from ground plane irradiation is calculated from a chronic buildup, as described in Section F.1.4. In this case the isotopes of iodine are of interest as well as the isotopes of plutonium and ^{241}Am. The risk dose for the isotopes of plutonium and ^{241}Am can be calculated from equation 21 (plus equation 23 for ^{241}Am). However, equation 21 assumes no radioactive decay, an assumption that is not appropriate for the isotopes of iodine. When radioactive decay is included, the equation for the organ dose is given by

TABLE F-22

DOSE CONVERSION FACTORS FOR WATER INGESTION FOR FISSION PRODUCTS FOR RISK DOSE CALCULATIONS

Radionuclide	Organ	Values of Parameters					Dose Conversion Factor ($\frac{rem \cdot d}{\mu Ci}$)
		f_1	f_2'	$\lambda_e(d^{-1})$	ε(MeV)	m(g)	
^{82}Br	Total Body	1.0	1.0	0.533	1.8	70000	6.31×10^{1}
	Liver						*
	Bone						*
	Lungs						*
	Thyroid						*
^{131}I	Total Body	1.0	1.0	9.12×10^{-2}	0.44	70000	9.01×10^{1}
	Liver	1.0	0.12	0.186	**	1800	2.06×10^{2}
	Bone	1.0	0.07	0.136	**	5000	5.92×10^{1}
	Lungs						*
	Thyroid	1.0	0.3	9.12×10^{-2}	0.23	20	4.95×10^{4}
^{132}I	Total Body	1.0	1.0	7.15	1.7	70000	4.44
	Liver	1.0	0.12	7.22	**	1800	2.05×10^{1}
	Bone	1.0	0.07	7.22	**	5000	4.31
	Lungs						*
	Thyroid	1.0	0.3	7.15	0.65	20	1.78×10^{3}
^{133}I	Total Body	1.0	1.0	0.797	0.84	70000	1.97×10^{1}
	Liver	1.0	0.12	0.900	**	1800	8.14×10^{1}
	Bone	1.0	0.07	0.845	**	5000	1.82×10^{1}
	Lungs						*
	Thyroid	1.0	0.3	0.797	0.54	20	1.33×10^{4}
^{134}I	Total Body	1.0	1.0	19.3	1.5	70000	1.45
	Liver	1.0	0.12	19.8	**	1800	6.60
	Bone	1.0	0.07	19.3	**	5000	1.42
	Lungs						*
	Thyroid	1.0	0.3	19.3	0.82	20	8.33×10^{2}
^{135}I	Total Body	1.0	1.0	2.48	1.3	70000	9.79
	Liver	1.0	0.12	2.57	**	1800	4.41×10^{1}
	Bone	1.0	0.07	2.57	**	5000	9.26
	Lungs						*
	Thyroid	1.0	0.3	2.48	0.52	20	4.11×10^{3}

* The value for the dose conversion factor is taken to be that for the total body.
** The value for the effective energy deposition is taken to be that for the total body.

$$\text{Organ Dose (rem)} = 864 \left(\frac{\chi}{Q}\right) S_g F \left(\frac{t}{\lambda} + \frac{1}{\lambda^2} e^{-\lambda t} - \frac{1}{\lambda^2}\right) \quad (72)$$

where the variables are defined as for equation 21, and λ is the radioactive decay constant (d^{-1}). A deposition velocity of 0.01 m/s is used for iodine. For the iodine isotopes (of importance) the values of the radioactive decay constant and the reductions of equation 72 for t = 25567.5 days are given in Table F-23. Dose conversion factors F generated by the EXREM computer code, are also presented in Table F-23.

TABLE F-23

VALUES FOR THE EVALUATION OF THE 70-YEAR ORGAN DOSE FROM GROUND PLANE IRRADIATION FOR THE ISOTOPES OF IODINE FOR A CHRONIC RELEASE

Isotope	Decay Constant λ (d^{-1})	Organ Dose (rem)	Dose Conversion Factor F (rem·m^2/Ci·s)
^{131}I	0.0861	2.56×10^{8} (χ/Q) SF	1.6×10^{-3}
^{132}I	7.23	3.06×10^{6} (χ/Q) SF	9.1×10^{-3}
^{133}I	0.792	2.79×10^{7} (χ/Q) SF	2.7×10^{-3}
^{135}I	2.48	8.91×10^{6} (χ/Q) SF	6.8×10^{-3}

The total organ dose is the sum of the organ doses for all the radionuclides of interest, using source terms given in Tables 3.2.3-1 and 3.2.3-2, converted to units of μCi/day. The assumption is made that the person is exposed 24 hours a day for 70 years. This assumption is conservative by at least a factor of three, since the average person is not likely to spend more than 8 hours per day outdoors.

Derivation of equation 72 is as follows. For a chronic release the rate of buildup of the surface concentration G (Ci/m^2) of the radionuclide, including radioactive decay, is described by the differential equation

$$\frac{dG}{dt} = \left(\frac{\chi}{Q}\right) V_d S_g - \lambda G \quad (73)$$

where all variable have been defined previously. The term $(\chi/Q)\ V_d\ S_g$ is the rate of deposition of the radionuclide from the airborne release and the term λG is the rate of loss by radioactive decay. Solving for G yields the value of the surface concentration at any time t

$$G = \frac{1}{\lambda} \left(\frac{\chi}{Q}\right) V_d S_g \left(1 - e^{-\lambda t}\right) \quad (74)$$

The organ dose H over time t from continuous exposure to the ground concentration is obtained by solving the differential equation

$$\frac{dH}{dt} = 8.64 \times 10^{6}\ G\ F \quad (75)$$

where t is in days, λ is d^{-1}, and 8.64×10^4 is the conversion factor s/d. Substituting G from equation 74 and solving yields

$$H = 8.64 \times 10^4 \left(\frac{\chi}{Q}\right) V_d S_g F \left(\frac{t}{\lambda} + \frac{1}{\lambda^2} e^{-\lambda t} - \frac{1}{\lambda^2}\right) \quad (76)$$

For V_d = 0.01 m/s for the iodines, equation 72 is obtained.

F.2.1.5 Plume Shine Irradiation

Plume shine refers to the irradiation received by a person from external radionuclides in the air. This pathway is significant only for certain fission products for criticality accidents. Dose conversion factors for plume shine are generated by the SUBDOSA computer code, developed at Battelle-Pacific Northwest Laboratories (Strenge, et al., 1975). Input to this code is the value of activity released for each radionuclide from the postulated metal and solution criticality accidents (Tables 3.2.2-3 and 3.2.2-4). Although the calculation of the dose conversion factor is done for an acute release, the value is the same for a chronic release (of the same magnitude), since the total dose delivered from radionuclides external to the body is the same as long as the product of the activity and the time is the same for both exposures. For example, exposure to 365 units of activity for one unit of time results in the same dose as exposure to one unit of activity for 365 units of time. The dose conversion factors used in this Impact Statement are for the gamma dose at a depth of 1 cm for the total body. These factors are used for all other organs as well (a conservative assumption). These dose conversion factors are a function of distance, since there is both radioactive decay and daughter ingrowth during the time of airborne transit from the plant to the location of interest.

The 70-year organ risk dose from plume shine is given by

$$\text{Organ Risk Dose (rem)} = 70 \left(\frac{\chi}{Q}\right) (0.0008\ F_{pm} + 3.65 \times 10^{-5} F_{ps}) \quad (77)$$

where F_{pm} = dose conversion factor (rem·m^3/s) for the metal criticality accident

F_{ps} = dose conversion factor (rem·m^3/s) for the solution criticality accident

0.0008 = probability per year of the maximum credible metal criticality accident

3.65×10^{-5} = $(1 \times 10^{-7} + 0.008 \times \frac{1}{220})$ where 1×10^{-7} is the probability per year of the maximum credible solution criticality accident and 0.008 is the probability per year of the maximum probable solution criticality accident (at a magnitude of 1/220 of the maximum credible solution criticality accident)

70 = number of years for which the release and dose are considered

χ/Q = dispersion factor (s/m^3) obtained from Table B-2-4.

The values of the dose conversion factors F_{pm} for the metal criticality accident and F_{ps} for the solution criticality accident are presented in Table F-24.

TABLE F-24

DOSE CONVERSION FACTORS FOR PLUME SHINE RESULTING FROM THE POSTULATED CRITICALITY RELEASES

Distance (Miles)	Dose Converson Factor* $(\frac{rem \cdot m^3}{s})$	
	Metal Criticality	Solution Criticality
1.2	452.5	1.065×10^5
2	382.7	9.005×10^4
3	325.8	7.651×10^4
4	281.1	6.586×10^4
5	243.4	5.689×10^4
10	122.3	2.826×10^4
20	40.93	9.241×10^3
30	20.73	4.617×10^3
40	13.38	2.967×10^3

*Calculated for a depth of 1 cm in the body but is applied to all organs.

F.2.1.6 Sample Calculation of the Risk Dose

Calculate the 70-year risk dose to the bone of reference man living at a distance of 2 miles in the southeast direction.

Step 1. Calculate the risk dose for unit χ/Q via inhalation as follows.

a. For plutonium and americium, obtain the risk source terms over 70 years from Table F-19. Multiply these values by the dose conversion factors from Table F-1 for corresponding radionuclides. Sum the results.

b. For radionuclides released by criticalities, the composite dose per unit χ/Q is obtained directly from Table F-20. The value for this calculation is 4.17×10^{-2} $(rem \cdot m^3)/s$.

c. Sum the results of Steps 1a and 1b.

Step 2. Calculate the risk dose for unit χ/Q for food ingestion as follows.

a. For plutonium and americium, obtain the risk source term over 70 years by multiplying the values of the risk source term ($\mu Ci/yr$) from Table F-19 by 7.0×10^{-5}. Multiply these values by the dose conversion factors from Table F-5 for corresponding radionuclides. Sum the results.

b. For radionuclides from criticalities, multiply the source terms in Table 3.2.3-2 by 70 and by the dose conversion factors presented in Table F-21. Sum the results.

c. Sum the results of Steps 2a and 2b.

Step 3. Calculate the risk dose for water ingestion as follows.

a. For airborne plutonium and americium, obtain the risk source terms (μCi/yr) from Table F-19. Calculate the concentration (pCi/ℓ) in Standley Lake by multiplying the risk source term by 8.83×10^{-9} (equation 20) for each radionuclide. Multiply these values by the average intake rate (1.65 ℓ/d), by 10^{-6} μCi/pCi, and by the dose conversion factor, presented in Table F-8, for the corresponding radionuclide. Sum the results.

b. For airborne iodine and ^{82}Br, obtain the source terms from Table 3.2.3-2 and multiply by 10^{6}. As in Step 3a (but for V_d = 0.01 m/s), multiply by 8.83×10^{-9}, by 1.65, by 10^{-6} and by the dose conversion factor, presented in Table F-22, for the corresponding radionuclide. Sum the results.

c. Sum the results of Steps 3a and 3b.

Step 4. Calculate the risk dose for ground plane irradiation for unit dispersion as follows.

a. For plutonium and americium, divide the risk source term (μCi/yr), from Table F-19, by 365.25 and multiply by 10^{-6} to obtain the risk source term in units of Ci/d. Based on equation 21, multiply the risk source term for each radionuclide by 43.2 and by 6.54×10^{8}. Multiply the result by the value of the dose conversion factor, from Table F-11, for the corresponding radionuclide. Include the contribution from ingrowth of ^{241}Am from deposited ^{241}Pu by multiplying the risk source term (Ci/d) for ^{241}Pu by 5.39×10^{8} (from equation 23) and by the dose conversion factor, from Table F-11, for ^{241}Am. Sum all results.

b. For the iodine isotopes, divide the risk source terms from Table 3.2.3-2 by 365.25 to convert to units of Ci/d. Multiply by the constants presented in Table F-23 (2.56×10^{8} for ^{131}I, and so on) and by the value of the dose conversion factor, also presented in Table F-23, for the corresponding isotope. Sum all results.

c. Sum the results of Steps 4a and 4b.

Step 5. Calculate the risk dose from plume shine irradiation for unit χ/Q as follows, based on equation 77. Obtain the dose conversion factor for the metal criticality for a distance of 2 miles, from Table F-24. This value is 382.7. Multiply by 0.0008, yielding 0.306. Multiply the value (9.005×10^{4}), from Table F-24 for the solution criticality at 2 miles, by 3.65×10^{-5}, yielding 3.29. Sum the two results (3.60) and multiply by 70, yielding $2\ 52 \times 10^{2}$ $(rem \cdot m^{3})/s$.

Step 6. Sum the totals from Steps 1c, 2c, 4c, and 5. Obtain the value of the dispersion factor for 2 miles in the SE direction from Table B-2-4. Multiply this factor (1.66×10^{-6}) by the sum. To this result, add the risk dose from water ingestion. Round off to 2 significant figures. The result (4.1×10^{-2} rem) is the 70-year risk bone dose.

The results of these calculations are tabulated in Table F-25.

TABLE F-25

TABULATION FOR THE SAMPLE CALCULATION OF THE RISK DOSE

Radionuclide	Airborne Source Term (Over 70 Years) Initial (Ci)	With Resuspension (Ci)	Risk Dose For Unit Dispersion: Inhalation ($\frac{rem \cdot m^3}{s}$)	Food Ingestion ($\frac{rem \cdot m^3}{s}$)	Ground Plane Irradiation ($\frac{rem \cdot m^3}{s}$)	Plume Shine Irradiation ($\frac{rem \cdot m^3}{s}$)	Concentration In Water (pCi/ℓ)	Risk Dose From Water Ingestion (rem)
^{238}Pu	5.12×10^{-4}	1.01×10^{-3}	3.84×10^{2}	8.70×10^{-1}	5.66×10^{-3}	-	6.46×10^{-8}	3.27×10^{-8}
^{239}Pu	1.75×10^{-2}	3.45×10^{-2}	1.48×10^{4}	3.33	8.32×10^{-2}	-	2.21×10^{-6}	1.27×10^{-7}
^{240}Pu	3.96×10^{-3}	7.81×10^{-3}	3.35×10^{3}	7.52×10^{-1}	3.94×10^{-2}	-	5.00×10^{-7}	2.86×10^{-8}
^{241}Pu	1.12×10^{-1}	2.20×10^{-1}	1.93×10^{3}	4.82	-	-	1.41×10^{-5}	1.90×10^{-7}
^{242}Pu	3.54×10^{-7}	6.97×10^{-7}	2.77×10^{-1}	6.02×10^{-5}	3.37×10^{-6}	-	4.47×10^{-11}	2.37×10^{-12}
^{241}Am	4.40×10^{-3}	9.19×10^{-3}	3.97×10^{3}	8.36	1.17 (+0.57)	-	5.55×10^{-7}	3.20×10^{-7}
Subtotal			2.44×10^{4}	1.81×10^{1}	1.87			6.98×10^{-7}
^{82}Br	7.98×10^{-4}	-	-	3.91×10^{-5}	-	-	1.01×10^{-12}	1.05×10^{-16}
^{131}I	1.58×10^{-1}	-	-	2.69×10^{-1}	2.52	-	1.99×10^{-10}	1.04×10^{-14}
^{132}I	1.86×10^{1}	-	-	5.77×10^{-15}	2.03×10^{1}	-	2.35×10^{-8}	1.67×10^{-13}
^{133}I	2.68	-	-	2.95×10^{-3}	7.90	-	3.38×10^{-9}	1.02×10^{-13}
^{134}I	6.36×10^{1}	-	-	-	-	-	8.03×10^{-8}	8.74×10^{-13}
^{135}I	5.68×10^{1}	-	-	1.14×10^{-5}	1.82×10^{1}		9.71×10^{-9}	1.48×10^{-13}
Subtotal			2.92	2.72×10^{-1}	4.89×10^{1}	2.52×10^{2}		1.31×10^{-12}
TOTAL			2.44×10^{4}	1.33×10^{1}	5.55×10^{1}	2.52×10^{2}		6.98×10^{-7}

Sum of Risk Dose for Unit Dispersion $= 2.47 \times 10^{4} \frac{rem \cdot m^3}{s}$

Multiply by the Dispersion Factor: Dose (rem) $= 1.66 \times 10^{-6} \frac{s}{m^3} \times 2.47 \times 10^{4} \frac{rem \cdot m^3}{s} = 4.10 \times 10^{-2}$ rem

Add in Dose from Water Ingestion: Total Bone Risk Dose (rem) $= (4.10 \times 10^{-2} + 4.98 \times 10^{-7})$ rem

Round to 2 significant figures: Total Bone Risk Dose (rem) $= 4.1 \times 10^{-2}$ rem

F.2.2 Assessment of Dose Downwind from Accidents

The organ doses to persons downwind following an accidental release are calculated for each type of maximum credible accident. There are three categories of accidents for which the methodology is discussed: 1) accidents releasing airborne plutonium, 2) criticality accidents releasing airborne fission products (and some plutonium), and 3) impoundment failure resulting in waterborne releases. These releases are all considered to be acute releases, and the organ dose calculated is the 70-year dose commitment. The pathways considered are the same as those for the risk dose assessment, and the methodologies are similar.

F.2.2.1 Accidents Releasing Airborne Plutonium

Accidents releasing airborne plutonium are the spill, mechanical failure, fire, explosion, aircraft impact, tornado, and high wind. Once the assessment of dose is made for one of these accident types, the assessment can be made for any other of these types by multiplying by the ratio of the activities released.

Inhalation Pathway

The organ dose is obtained in the same manner as described in Section F.1.1. Source terms are obtained from Table 3.2.3-1. The activity is in terms of μCi plutonium released and needs to be apportioned among the isotopes of plutonium as discussed in Section F.2.1.1. The value for ^{241}Am is taken to be 20% of the plutonium alpha activity. The activity is converted to curies by multiplying by 10^{-6} Ci/μCi.

As for chronic releases, there is resuspension of material deposited from acute releases to consider. This factor, which is the ratio of the integrated activity from resuspension to the activity in the initial release, is 0.97 (as for chronic releases). The derivation of this factor is as follows. The activity deposited on the surface of the ground from an acute release is given by

$$G_a = S_o \, V_d \, (\frac{\chi}{Q}) \qquad (78)$$

where G_a = surface activity (Ci/m^2)
S_o = activity acutely released (Ci)
V_d = deposition velocity (m/s)
χ/Q = dispersion factor (s/m^3).

The air concentration C_a, from resuspension at time t after deposition, is

$$C_a = G_a \, k(t) \qquad (79)$$

where k(t) is the modified Anspaugh resuspension expression discussed in Section F.1.1.1. The integrated air concentration C_{aI} from resuspension over time t is given by integrating equation 79,

$$C_{aI} = \int_{o}^{t} G_a \, k(t) \, dt \, . \tag{80}$$

Integration over 70 years (t = 25567.5 days) yields

$$C_{aI} = 1.122 \times 10^{-2} \, G_a . \tag{81}$$

Substituting for G_a from equation 78 and for V_d = 0.001 m/s, the integrated air concentration from resuspension is

$$C_{aI} = 1.122 \times 10^{-5} \, S_o \, (\tfrac{\chi}{Q}) \tag{82}$$

with units of (Ci·days)/m^3. This result is the numerator of the resuspension ratio.

The denominator of the resuspension ratio is activity in the initial release S_o (Ci) multiplied by χ/Q (s/m^3) and by 1.16 x 10^{-5} days/s to give the "integrated" air concentration C_o from the initial release in terms of (Ci·days)/m^3

$$C_o = 1.157 \times 10^{-5} \, S_o(\tfrac{\chi}{Q}) . \tag{83}$$

The ratio of equation 82 divided by equation 83 is equal to 0.97. This factor, when multiplied by the initial airborne activity, gives the source term for the component from resuspension. For ^{241}Am there is an additional component, as for the chronic releases. This component is the resuspended ^{241}Am which had ingrown from the radioactive decay of ^{241}Pu. This factor, for the acute release, is 9.4 x 10^{-3} times the initial airborne source term for ^{241}Pu and is obtained by evaluating equation 10 for t = 25567.5 days (70 years).

The dispersion factors χ/Q for the acute releases are those given in Table B-2-3 in Appendix B-2. The Pasquill E stability class with a wind speed of 3.0 m/s is used to calculate the dispersion factors for all the postulated accidental releases, including releases from the tornado and high wind accidents. If the dispersion from a high wind of 158 mph (70.6 m/s) is calculated for a Pasquill D stability class, the dispersion factor is a factor of 50 to 70 less than the χ/Q for Pasquill E conditions, with a wind speed of 3.0 m/s, at distances of 2 miles to 40 miles downwind, respectively.

The dose conversion factors are generated by the DACRIN computer code for acute releases and are presented in Table F-26. Input values to generate these factors are: uptake time = 600 seconds (10 minutes), dose time = 2.209 x 10^9 seconds (70 years), breathing rate = 333 cm^3/s, particle size = 0.3 μm, dispersion = 1, distance = 1 m, activity per radionuclide = 1 Ci.

TABLE F-26

DOSE CONVERSION FACTORS FOR THE 70-YEAR DOSE COMMITMENT FROM AN ACUTE RELEASE VIA INHALATION

Particle Size = 0.3 μm AMAD

Breathing Rate = 3.33×10^{-4} m^3/s

	Dose Conversion Factor $(\frac{rem \cdot m^3}{Ci \cdot s})$			
	Class W			Class Y
Radionuclide	Total Body	Liver	Bone	Lungs
^{238}Pu	2.891×10^{3}	3.486×10^{5}	8.175×10^{5}	2.651×10^{5}
^{239}Pu	3.432×10^{3}	3.977×10^{5}	9.971×10^{5}	2.502×10^{5}
^{240}Pu	3.423×10^{3}	3.968×10^{5}	9.946×10^{5}	2.502×10^{5}
^{241}Pu	4.188×10^{1}	5.733×10^{3}	1.421×10^{4}	4.389×10^{2}
^{242}Pu	3.305×10^{3}	3.830×10^{5}	9.240×10^{5}	2.408×10^{5}
^{241}Am	2.680×10^{3}	4.107×10^{5}	9.871×10^{5}	2.683×10^{5}

Food Ingestion Pathway

The organ dose commitment is obtained in the same manner as described in Section F.1.2.1. Source terms are obtained as described for the inhalation pathway, excluding resuspension. The dispersion factors are the same as for the inhalation pathway.

The dose conversion factors are generated by the FOOD computer code for acute releases and are presented in Table F-27. Intake values (Table F-4) for the average individual are used for all distances except 1.2 miles. At the distance of 1.2 miles, intake values for the maximum individual are used. Consumption of food produced at the site of interest is considered to continue over the 70 years. The acute release is considered to occur at the time just prior to harvest of each type of food, resulting in maximum contamination of the plant or animal food products at the time of consumption. Values of the dose conversion factors are for 1 Ci released and for unit dispersion for each radionuclide. The fractions transferred from the G.I. tract to the blood are those used by the EPA (EPA, 1977), as discussed in Section F.1.2.1.

Water Ingestion Pathway

The organ dose commitment is obtained in the same manner as described in Section F.1.3.2 for airborne releases, modified as follows. The 70-year dose commitment to the organs is given by the equation

$$\text{Organ Dose (rem)} = 6.03 \times 10^{4} \, C_w \, F_{wa} \qquad (84)$$

TABLE F-27

DOSE CONVERSION FACTORS FOR THE 70-YEAR DOSE COMMITMENT FOR AN ACUTE RELEASE VIA FOOD INGESTION

	Dose Conversion Factor ($\frac{rem \cdot m^3}{Ci \cdot s}$) for Average Intake			
Radionuclide	Total Body	Liver	Bone	Lungs
^{238}Pu	1.8×10^{2}	2.2×10^{4}	5.0×10^{4}	*
^{239}Pu	2.1×10^{1}	2.5×10^{3}	6.3×10^{3}	*
^{240}Pu	2.1×10^{1}	2.5×10^{3}	6.3×10^{3}	*
^{241}Pu	2.8	1.7×10^{2}	1.0×10^{3}	*
^{242}Pu	2.1×10^{1}	2.4×10^{3}	5.7×10^{3}	*
^{241}Am	1.7×10^{2}	2.6×10^{4}	6.1×10^{4}	*

	Dose Conversion Factor ($\frac{rem \cdot m^3}{Ci \cdot s}$) for Maximum Intake			
Radionuclide	Total Body	Liver	Bone	Lungs
^{238}Pu	9.0×10^{2}	1.1×10^{5}	2.5×10^{5}	*
^{239}Pu	1.1×10^{2}	1.2×10^{4}	3.1×10^{4}	*
^{240}Pu	1.1×10^{2}	1.2×10^{4}	3.1×10^{4}	*
^{241}Pu	1.4×10^{1}	8.7×10^{2}	5.3×10^{3}	*
^{242}Pu	1.0×10^{2}	1.2×10^{4}	2.9×10^{4}	*
^{241}Am	8.3×10^{2}	1.3×10^{5}	3.0×10^{5}	*

*The value for the dose conversion factor is taken to be that for the total body.

where C_w = concentration of the radionuclide in the water (pCi/ℓ) obtained from equation 20

F_{wa} = dose conversion factor for water ingestion from acute releases (rem/μCi)

6.03×10^{-4} = conversion factor (10^{-6} μCi/pCi) x 365 days x 1.65 ℓ/day intake rate.

Source terms are obtained from Table 3.2.3-1 in units of μCi, and the activity is apportioned among the plutonium isotopes as discussed in Section F.2.1.1. The value for ^{241}Am is taken to be 20% of the plutonium alpha activity.

The dispersion factor is calculated specifically for Great Western Reservoir for downwind, Pasquill E conditions (wind speed = 3.0 m/s) by the method presented in Appendix B-2. The value of the dispersion factor to Great Western Reservoir is 6.63×10^{-7} s/m^3. To conservatively estimate the doses to persons downwind from accidents, all these people are assumed to drink water from Great Western Reservoir.

The dose conversion factors are generated as follows. Assuming a one-year turnover rate of the water in the reservoir, all of the uptake of activity would occur in the first year. For simplicity and conservativism, let all the activity ingested in the year be ingested acutely at the time of the release (at t = 0). The activity Y in the organ at time t = 0 is then

$$Y = f_1 f_2' S_I \tag{85}$$

where Y = activity in the organ at time t (μCi)
S_I = activity (μCi) ingested at time t = 0
f_1 = transfer fraction from the G.I. tract to the blood
f_2' = transfer fraction from the blood to the organ of interest.

For an exponential removal from the organ with an effective removal constant λ_x, the activity in the organ at any time t after the intake is

$$Y(t) = f_1 f_2' S_I e^{-\lambda_x t} \tag{86}$$

The integrated activity Q(t) in the organ (μCi·days) is obtained by integrating equation 86

$$Q(t) = \frac{f_1 f_2' S_I}{\lambda_x} (1-e^{-\lambda_x t}). \tag{87}$$

As in the discussion of equation 17 in Section F.1.3.1, the organ dose is given by

$$\text{Organ Dose (rem)} = 51.15 \frac{\varepsilon}{m} Q(t) \tag{88}$$

The dose conversion factor for water ingestion from an acute release is given by substitution of equation 87 into equation 88 and dividing both sides of the resulting equation by S_I.

$$\text{Dose Conversion Factor (rem/μCi)} = 51.15 \frac{\varepsilon f_1 f_2'}{m\lambda_x} (1-e^{-\lambda_x t}). \tag{89}$$

Dose conversion factors for the plutonium isotopes, for ^{241}Am, and for the uranium and thorium isotopes, calculated from equation 89 for t = 25567.5 days (70 years) and using values from Table F-8, are presented in Table F-28.

TABLE F-28

DOSE CONVERSION FACTORS FOR THE 70-YEAR DOSE COMMITMENT FROM AN ACUTE RELEASE VIA WATER INGESTION

Radionuclide	Dose Conversion Factor ($\frac{rem}{\mu Ci}$) Total Body	Liver	Bone	Lungs
^{238}Pu	7.25×10^{-2}	8.75	2.05×10^{1}	*
^{239}Pu	8.66×10^{-3}	1.00	2.51	*
^{240}Pu	8.63×10^{-3}	1.00	2.51	*
^{241}Pu	1.14×10^{-3}	7.03×10^{-2}	4.18×10^{-1}	*
^{242}Pu	8.34×10^{-3}	9.66×10^{-1}	2.33	*
^{241}Am	8.84×10^{-2}	1.03×10^{1}	2.48×10^{1}	*
^{234}U	5.17×10^{-4}	*	3.51×10^{-2}	*
^{235}U	4.85×10^{-4}	*	3.36×10^{-2}	*
^{236}U	4.96×10^{-4}	*	3.36×10^{-2}	*
^{238}U	4.53×10^{-4}	*	3.22×10^{-2}	*
^{231}Th	2.03×10^{-8}	3.51×10^{-8}	6.19×10^{-7}	*
^{234}Th	2.31×10^{-6}	4.44×10^{-6}	1.12×10^{-4}	*

*The value of the dose conversion factor is taken to be equal to that for the total body.

Ground Plane Irradiation

The 70-year organ dose from radionuclides deposited on the ground from an acute release is given by

$$\text{Organ Dose (rem)} = 2.21 \times 10^{6}\ S_o\ (\tfrac{\chi}{Q})\ F \qquad (90)$$

where S_o = activity released (μCi)

χ/Q = dispersion factor (s/m^3)

F = dose conversion factor for surface activity [$(rem \cdot m^2)/(Ci \cdot s)$]

$2.21 \times 10^{6} = 8.64 \times 10^{4}$ s/d x 2.55675×10^{4} d x 0.001 m/s (The unit is m.)

The values for the source term S_o are obtained as described for the inhalation pathway, excluding resuspension. The dispersion factors χ/Q are the same as for the inhalation pathway. The dose conversion factors F are obtained from Table F-11.

The derivation of equation 90 is as follows. The value of the surface activity G_a (Ci/m^2) is given by

$$G_a = S_o\ (\tfrac{\chi}{Q})\ V_d. \qquad (91)$$

Assuming no radioactive decay, the value of G_a is constant over 70 years so that the organ dose H, obtained by integrating equation 91 overtime t and multiplying by the dose conversion factor F, is given by

$$H(rem) = 8.64 \times 10^4 \; G_a \; F \; t. \tag{92}$$

Solving for t = 2.55675×10^4 days (70 years) and V_d = 0.001 m/s yields equation 90.

The 70-year organ dose from ^{241}Am ingrown from ^{241}Pu acutely released is given by

$$\text{Organ Dose (rem)} = 5.20 \times 10^4 \; (\tfrac{\chi}{Q})(S_o)_p \; F \tag{93}$$

where $(S_o)_p$ is the activity (Ci) of the ^{241}Pu acutely released. The derivation of equation 93 is as follows. The rate of ingrowth of ^{241}Am from the ^{241}Pu on the ground is given by equation 28,

$$\frac{dA}{dt} = \lambda_p P. \tag{94}$$

In the case for a single release of ^{241}Pu at time t = 0, the amount (mass) of ^{241}Pu at time t is governed only by the radioactive decay of the ^{241}Pu, so that P is given by

$$P = P_o e^{-\lambda_p t} \tag{95}$$

where P_o is the initial amount (g/m^2) of ^{241}Pu on the surface of the ground. Substitution of equation 95 into equation 94 and solving for A yields

$$A = P_o \; (1-e^{-\lambda_p t}). \tag{96}$$

Conversion from mass to activity, using the specific activities (3.42 Ci/g for ^{241}Am and 103.5 Ci/g for ^{241}Pu), yields

$$A \text{ (activity)} = 3.30 \times 10^{-2} \; P_{oa} \; (1-e^{-\lambda_p t}) \tag{97}$$

where P_{oa} is the initial activity (Ci/m^2) of ^{241}Pu on the surface of the ground and is equal to $[(\chi/Q) \; V_d \; (S_o)_p]$ where $(S_o)_p$ is the activity (Ci) of the ^{241}Pu acutely released. The organ dose H is obtained by solving equation 33, using equation 97 for A (activity),

$$H = 2.85 \times 10^3 \; (\tfrac{\chi}{Q}) \; V_d (S_a)_p \; F \; (t + \frac{1}{\lambda_p} e^{-\lambda_p t} - \frac{1}{\lambda_p}) \tag{98}$$

where the conversion factor F refers to the factor for the daughter (^{241}Am). Evaluation of equation 98 for ^{241}Am, using V_d = 0.001 m/s, λ_p = 1.322 x 10^{-4} d^{-1}, and t = 25567.5 d (70 years) yields equation 93.

Sample Calculation

Calculate the 70-year dose commitment to a person 2 miles downwind from the maximum credible release from an aircraft impact.

Step 1. From Table 3.2.3-1 obtain the amount of activity released (7.3 x 10^6 μCi of plutonium alpha activity). Apportion the activity among the isotopes of plutonium and for ^{241}Am and convert to the unit of Ci by multiplying by 10^{-6} Ci/μCi. Multiply the activity for each radionuclide by 1.97 to include resuspension, plus (9.4 x 10^{-3} x ^{241}Pu activity) for ^{241}Am (this calculation is used only for the inhalation pathway).

Step 2. For the inhalation pathway, multiply the result from Step 1 by the dose conversion factor for each radionuclide from Table F-26. Sum values for all radionuclides.

Step 3. For the food ingestion pathway, multiply the result from Step 1 (not including resuspension) by the dose conversion factor for each radionuclide from Table F-27. Sum values for all radionuclides.

Step 4. For the water ingestion pathway, calculate the radionuclide concentration in the water using equation 20 and the values for Great Western Reservoir. Equation 20 reduces to: C_w = 1.06 x 10^{-7} S_o. Multiply the values (with no resuspension) from Step 1 by 10^6 (to convert back to μCi) and by 1.06 x 10^{-7} to obtain C_w (pCi/ℓ) for each radionuclide. Using equation 84, multiply each value C_w by 6.03 x 10^{-4} and by the dose conversion factor for the corresponding radionuclide from Table F-28. Sum the result for all radionuclides. This sum, 0.00469 rem, is the bone dose (rem) from water ingestion.

Step 5. For ground plane irradiation, multiply the result from Step 1 (not including resuspension) by 2.21 x 10^6 and by the value of the dose conversion factor for the corresponding radionuclide, obtained from Table F-11. Multiply the result from Step 1 (not including resuspension) for ^{241}Pu by 5.20 and by the value of the dose conversion factor for ^{241}Am. Sum values for all radionuclides.

Step 6. Sum the results of Steps 2, 3, and 5. Obtain the dispersion factor χ/Q from Table B-2-3 for a distance of 2 miles. Multiply this value

(1.63×10^{-5}) by the sum of the results of Steps 2, 3, and 5. This result, 306 rem, is the bone dose (rem) from inhalation, food ingestion, and ground plane irradiation.

Step 7. Sum the results of Steps 4 and 6. This result, 306 rem, is the total bone dose. Round off to 2 significant figures to give 310 rem.

Note that once this calculation is done for one type of accident resulting in an airborne release of plutonium, the bone dose for any other accident releasing only airborne plutoniume is obtained simply by dividing this result by the value 7.3×10^{6} by then multiplying by the activity released from the other accident of interest.

This calculation is summarized in Table F-29.

F.2.2.2 Criticality Accidents

Criticality accidents release fission products as well as plutonium and americium. The methodology for the two types of criticality accidents, the metal and the solution criticalities, is the same although dose conversion factors generated by DACRIN, FOOD and SUBDOSA codes are specific for each type. The pathways considered include plume shine as well as inhalation, food and water ingestion, and ground plane irradiation.

Inhalation Pathway

The organ dose via inhalation is given by the product of the source term, the dispersion factor, and the dose conversion factor (see equation 1).

The dispersion factors χ/Q are obtained from Table B-2-3 in Appendix B-2.

For the two types of criticality accidents, the organ dose is calcaulated for the composite inventory of the released radionuclides instead of for each radionuclide separately. The dose conversion factors are generated by the DACRIN computer code as described in Section F.2.1.1, based on the source terms in Table 3.2.2-3 for the maximum credible metal criticality and in Table 3.2.2-4 for the maximum credible solution criticality. These dose conversion factors, for an acute release, are presented in Table F-30.

Food Ingestion Pathway

The organ dose commitment is obtained in the same manner as described in Section F.1.2.1, that is, the product of the source term, dispersion factor, and the dose conversion factor.

TABLE F-29

TABULATION FOR THE SAMPLE CALCULATION FOR THE RELEASE OF AIRBORNE PLUTONIUM FROM THE AIRCRAFT IMPACT

Radionuclide	Activity Released (Ci)	Activity Released Plus Resuspension (Ci)	Dose Via Inhalation for Unit Dispersion ($\frac{rem \cdot m^3}{s}$)	Dose via Food Ingestion for Unit Dispersion ($\frac{rem \cdot m^3}{s}$)	Radionuclide Concentration in Water (pCi/l)	Dose via Water Ingestion (rem)	Dose From Ground Plane Irradiation for Unit Dispersion ($\frac{rem \cdot m^3}{s}$)
^{238}Pu	0.171	0.337	2.75×10^{5}	8.55×10^{3}	1.81×10^{-2}	2.24×10^{-4}	3.78
^{239}Pu	5.83	11.5	1.15×10^{7}	3.67×10^{4}	6.18×10^{-1}	9.35×10^{-4}	5.54×10^{1}
^{240}Pu	1.32	2.60	2.59×10^{6}	8.32×10^{3}	1.40×10^{-1}	2.12×10^{-4}	2.63×10^{1}
^{241}Pu	37.3	73.4	1.04×10^{6}	3.73×10^{4}	3.95	9.96×10^{-4}	0
^{242}Pu	1.18×10^{-4}	2.32×10^{-4}	2.14×10^{2}	6.73×10^{-1}	1.25×10^{-5}	1.76×10^{-8}	2.24×10^{-3}
^{241}Am	1.465	3.24	3.19×10^{6}	8.94×10^{4}	1.55×10^{-1}	2.32×10^{-3}	7.77×10^{2}
			1.86×10^{7}	1.80×10^{5}		4.69×10^{-3}	+ 4.66×10^{2} = 1.32×10^{3}

Sum of Dose per unit dispersion for inhalation, food ingestion and ground plane irradiation = $1.88 \times 10^{7} \frac{rem \cdot m^3}{s}$

Dispersion Factor χ/Q = $1.63 \times 10^{-5} \frac{s}{m^3}$

Bone Dose (rem) from inhalation, food ingestion, and ground plane irradiation = $1.88 \times 10^{7} \times 1.63 \times 10^{-5} = 306$

Total Bone Dose (rem) = 306 + 0.00469

Total Bone Dose (rem) rounded to 2 significant figures = 310

TABLE F-30

DOSE CONVERSION FACTORS FOR THE 70-YEAR DOSE COMMITMENT FROM ACUTE RELEASES FROM THE MAXIMUM CREDIBLE METAL AND SOLUTION CRITICALITY ACCIDENTS VIA INHALATION

Metal Criticality

Distance (miles)	Dose Conversion Factor $(\frac{rem \cdot m^3}{s})$				
	Total Body	Liver	Bone	Lungs	Thyroid
1.2	1.78	3.86×10^{1}	9.43×10^{1}	1.12×10^{2}	7.53×10^{2}
2	1.76	3.86×10^{1}	9.45×10^{1}	1.08×10^{2}	7.34×10^{2}
3	1.74	3.85×10^{1}	9.47×10^{1}	1.05×10^{2}	7.12×10^{2}
4	1.71	3.85×10^{1}	9.49×10^{1}	1.01×10^{2}	6.92×10^{2}
5	1.68	3.85×10^{1}	9.49×10^{1}	9.79×10^{1}	6.74×10^{2}
10	1.54	3.83×10^{1}	9.50×10^{1}	8.58×10^{1}	6.00×10^{2}
20	1.35	3.81×10^{1}	9.49×10^{1}	7.25×10^{1}	5.07×10^{2}
30	1.23	3.80×10^{1}	9.49×10^{1}	6.55×10^{1}	4.50×10^{2}
40	1.14	3.79×10^{1}	9.48×10^{1}	6.07×10^{1}	4.08×10^{2}

Solution Criticality

Distance (miles)	Dose Conversion Factor $(\frac{rem \cdot m^3}{s})$				
	Total Body	Liver	Bone	Lungs	Thyroid
1.2	3.23×10^{2}	2.21×10^{2}	2.17×10^{2}	1.97×10^{4}	1.66×10^{5}
2	3.19×10^{2}	2.16×10^{2}	2.67×10^{2}	1.89×10^{4}	1.62×10^{5}
3	3.14×10^{2}	2.09×10^{2}	3.12×10^{2}	1.81×10^{4}	1.57×10^{5}
4	3.08×10^{2}	2.02×10^{2}	3.41×10^{2}	1.73×10^{4}	1.52×10^{5}
5	3.02×10^{2}	1.95×10^{2}	3.59×10^{2}	1.66×10^{4}	1.48×10^{5}
10	2.72×10^{2}	1.66×10^{2}	3.80×10^{2}	1.39×10^{4}	1.32×10^{5}
20	2.30×10^{2}	1.25×10^{2}	3.61×10^{2}	1.10×10^{4}	1.12×10^{5}
30	2.03×10^{2}	9.82×10^{1}	3.46×10^{2}	9.44×10^{3}	9.90×10^{4}
40	1.84×10^{2}	8.11×10^{1}	3.36×10^{2}	8.40×10^{3}	8.99×10^{4}

Values of the source terms are obtained from Table 3.2.2-3 for the maximum credible metal criticality and from Table 3.2.2-4 for the maximum credible solution criticality.

The dispersion factors χ/Q are obtained from Table B-2-3 in Appendix B-2.

The dose conversion factors are generated by the FOOD computer code only for those radionuclides which contribute significantly to the organ dose from food intake. The dose conversion factors for plutonium and americium are presented in Table F-27 and in Table F-31 for the fission products of significance for this pathway.

TABLE F-31

DOSE CONVERSION FACTORS FOR THE 70-YEAR DOSE COMMITMENT
FROM AN ACUTE RELEASE FROM CRITICALITY ACCIDENTS VIA FOOD INGESTION

Radionuclide	Dose Conversion Factor $(\frac{rem \cdot m^3}{Ci \cdot s})$ for Average Intake				
	Total Body	Liver	Bone	Lungs	Thyroid
^{82}Br	4.3×10^{1}	*	*	*	*
^{131}I	7.8×10^{1}	1.3×10^{2}	1.3×10^{2}	*	4.4×10^{4}
^{132}I	2.0×10^{-3}	5.3×10^{-3}	2.9×10^{-3}	*	7.4×10^{-1}
^{133}I	4.8	*	*	*	3.0×10^{3}
^{134}I	8.2×10^{-9}	*	*	*	3.0×10^{-6}
^{135}I	4.9×10^{-1}	*	*	*	1.7×10^{2}

Radionuclide	Dose Conversion Factor $(\frac{rem \cdot m^3}{Ci \cdot s})$ for Maximum Intake				
	Total Body	Liver	Bone	Lungs	Thyroid
^{82}Br	1.1×10^{3}	*	*	*	*
^{131}I	1.2×10^{3}	2.0×10^{3}	2.1×10^{3}	*	7.0×10^{5}
^{132}I	4.9×10^{-2}	1.3×10^{-1}	7.3×10^{-2}	*	1.8×10^{1}
^{133}I	1.2×10^{2}	*	*	*	7.5×10^{4}
^{134}I	2.1×10^{-7}	*	*	*	7.5×10^{-5}
^{135}I	1.2×10^{1}	*	*	*	4.3×10^{3}

*The value of the dose conversion factor is taken to be equal to that for the total body.

Based on the proposed guidance of the U.S. Food and Drug Administration (USHEW, 1978), the food affected by releases from a criticality accident is considered to be controlled if the dose from food ingestion is 1.5 rem or greater to the thyroid for maximum intake values and for the maximum individual (in this case, the infant male). The dose to the thyroid is, therefore, calculated for each distance for maximum intake values and is multiplied by the factor 5.76 (from Table 3.2.4-3) for the newborn male. The result of this calculation is compared to the 1.5 rem value to determine if the food would be controlled at that distance. If the calculated value is greater than or equal to 1.5 rem, the affected food would be controlled and no actual dose from the food pathway would be received. If the calculated value is less than 1.5 rem, the affected food would not be controlled. The organ doses from the food pathway for that distance are then calculated using average intake values.

Water Ingestion Pathway

For the organ dose commitment from water ingestion, the only radionuclides of significance are some isotopes of iodine and ^{82}Br. For these radionuclides radioactive decay is significant. The organ dose commitment is given by

$$\text{Organ Dose (rem)} = 1.65 \times 10^{-6} \frac{1}{\lambda} (1 - e^{-3.65 \times 10^2 \lambda}) (C_w)_o F_{wa} \quad (99)$$

where $(C_w)_o$ = concentration of the radionuclide (pCi/ℓ) in the water at time t = 0 for an acute release, obtained from equation 20

λ = radioactive decay constant (d^{-1})

1.65×10^{-6} = conversion factor (10^{-6} μCi/pCi) x 1.65 ℓ/d intake rate

The values of the radioactive decay constant are presented in Table F-23, except for ^{134}I (λ = 1.92 d^{-1}) and ^{82}Br (λ = 0.471 d^{-1}).

The term $(1/\lambda)(1-e^{-3.65 \times 10^2 \lambda})(C_w)_o$ represents the integrated water concentration over one year, in units of (pCi·d)/ℓ, and is obtained by integrating the water concentration at time t, given by $(C_w)_o e^{-\lambda t}$.

Other considerations are the same as those presented in Section F.2.2.1. For the halogens a value of 0.01 m/s is used for the deposition velocity V_d when calculating the value of $(C_w)_o$.

Values of the source term are obtained from Table 3.2.2-3 for the maximum credible metal criticality and from Table 3.2.2-3 for the maximum credible solution criticality. These values are converted to units of μCi by multiplying by 10^6.

Dose conversion factors are calculated using equation 89 and values of parameters from Table F-22. These values are presented in Table F-32.

Ground Plane Irradiation

The organ dose from ground plane irradiation for an acute release is obtained for plutonium and americium as described in Section F.2.2.1. Source terms, in units of Ci, are obtained from Tables 3.2.2-3 and 3.2.2-4 for the maximum credible metal and solution criticalities, respectively.

For the isotopes of iodine (^{82}Br is not significant for ground plane irradiation) for which radioactive decay is significant, the organ dose over time t is given by the equation

$$\text{Organ Dose (rem)} = 8.64 \times 10^4 \frac{S_a (\frac{\chi}{Q}) V_d F}{\lambda} (1-e^{-\lambda t}) \quad (100)$$

TABLE F-32

DOSE CONVERSION FACTORS FOR THE 70-YEAR DOSE COMMITMENT
FROM WATER INGESTION OF FISSION PRODUCTS FOR AN ACUTE RELEASE

Radio-nuclide	Dose Conversion Factor ($\frac{rem \cdot d}{\mu Ci}$)				
	Total Body	Liver	Bone	Lungs	Thyroid
^{82}Br	2.47×10^{-3}	*	*	*	*
^{131}I	3.53×10^{-3}	8.07×10^{-3}	2.32×10^{-3}	*	1.93
^{132}I	1.74×10^{-4}	8.03×10^{-4}	1.69×10^{-4}	*	6.97×10^{-2}
^{133}I	7.70×10^{-4}	3.18×10^{-3}	7.12×10^{-4}	*	5.20×10^{-1}
^{134}I	5.62×10^{5}	2.58×10^{4}	5.57×10^{5}	*	3.26×10^{2}
^{135}I	3.83×10^{4}	1.72×10^{3}	3.62×10^{4}	*	1.61×10^{1}

*The value of the dose conversion factor is taken to be equal to that for the total body.

where S_o = activity (Ci) acutely released
λ = radioactive decay constant (d^{-1})
and the other parameters as they are defined in Section F.2.2.1.

Derivation of equation 100 is as follows. The surface activity G(t) at time t after an acute release at time t=0, including radioactive decay, is given by

$$G(t) = G_o e^{-\lambda t} \tag{101}$$

where G_o is the activity (Ci/m^2) on the surface at time t=0 and is equal to S_o (χ/Q) V_d (see equation 91). The differential equation for the organ dose is equation 33. Substituting equation 101 for G in equation 26 and solving for H yields equation 100.

Equation 100 can be evaluated for the isotopes of iodine, using the values V_d = 0.01 m/s, t = 25567.5 d (70 years), and the values of λ presented in Table 23. The values of the dose conversion factor are also obtained from Table F-23. Values of the dispersion factor are obtained from Table B-2-3.

Plume Shine Irradiation

The 70-year organ dose commitment from plume shine is given by

$$\text{Organ Dose (rem)} = \left(\frac{\chi}{Q}\right) F_p \tag{102}$$

where F_p is the dose conversion factor for plume shine generated specifically for the source terms in Table 3.2.2-3 for the maximum credible metal criticality or for the source terms in Table 3.2.2-4 for the maximum credible solution criticality. These dose conversion factors are presented in Table F-24. See Section F.2.1.5 for a further discussion of these dose conversion factors.

The dispersion factors χ/Q are obtained from Table B-2-3.

Sample Calculation

Calculate the 70-year thyroid dose commitment from the release from the maximum credible solution criticality accident to a person (reference man) 2 miles downwind.

Step 1. The 70-year thyroid dose commitment for inhalation is obtained directly from Table F-30, for unit dispersion. The desired value is 1.62×10^5 $(rem \cdot m^3)/s$.

Step 2. Obtain the 70-year thyroid dose commitment for food ingestion as follows. Multiply the activity (Ci) released from Table 3.2.2-4 by the value of the dose conversion factor for the corresponding radionuclide from Table F-31, for maximum intake and by 5.76, from Table 3.2.4-3 for the newborn male. For the thyroid dose the contribution from plutonium and americium is negligible. Sum all products. Multiply by the dispersion factor at 2 miles from Table B-2-3 ($\chi/Q = 1.63 \times 10^{-5}$ s/m^3). This result, 1.2×10^4 rem, is greater than 1.5 rem so the affected food would be controlled, and the dose from the food pathway would approximate zero. (If the result is less than 1.5 rem, the procedure is to multiply the activity released by the value of the dose conversion factor for the corresponding radionuclide for average intake, sum the values, and include the result in Step 6.)

Step 3. Obtain the 70-year thyroid dose commitment for water ingestion as follows. Using equation 20 and the values for Great Western Reservoir (with $\chi/Q = 6.63 \times 10^{-7}$ s/m^3), calculate the water radionuclide concentration C_w. (Equation 20 reduces to $C_w = 1.06 \times 10^{-6}$ S_o, where the values of S_o are obtained from Table 3.2.2-4, converted to units of μCi by multiplying by 10^6.) Evaluate equation 99 with the value of λ given in Table F-23 or in the text accompanying equation 99, for each value of $(C_w)_o$ obtained from equation 20 and for the value of the dose conversion factor F_{wa} from Table F-32, for the corresponding radionuclide. Plutonium and americium contributions are neglegible. Sum the resulting values.

Step 4. The thyroid dose from ground plane irradiation is obtained using equation 100 for each of the isotopes of iodine, using the values t = 25567.5 d (70 years), V_d = 0.01 m/s, S_a from Table 3.2.2-4, and λ from Table F-23, and χ/Q = 1 for unit dispersion. Sum the resulting values.

Step 5. The thyroid dose from plume shine irradiation is obtained from equation 102. For unit dispersion, the value is given as a composite for all the radionuclides from Table F-24. The value at 2 miles is 9.005×10^4 rem per unit χ/Q.

Step 6. Sum the values from Steps 1, 2, 4, and 5. This sum is 2.70×10^5 rem per unit dispersion. Multiply by the dispersion factor for 2 miles downwind from Table B-2-3 ($\chi/Q = 1.63 \times 10^{-5}$). This result is 4.40 rem.

Step 7. Add the results of Steps 3 and 6. The result (4.4 rem) is the 70-year thyroid dose commitment from the maximum credible solution criticality accident to reference man 2 miles downwind, with the affected food controlled at this distance.

This calculation is tabulated in Table F-33.

F.2.2.3 Impoundment Failure

The postulated impoundment failure involves a waterborne release of plutonium, americium, and uranium isotopes to Great Western Reservoir. The dose assessment, therefore, involves the determination of the 70-year dose commitment to persons drinking water supplied from Great Western Reservoir for one year following the release.

The methodology used is described in Section F.2.1.3, with the following modifications. The release is considered to be an acute release with all released activity deposited in Great Western Reservoir. The released activity is postulated to be 87,000 μCi of plutonium, 82,000 μCi of americium, and 485,000 μCi of uranium. Activities of the plutonium and uranium are apportioned amoung their isotopes as described in Section F.2.1.3. The radionuclide concentration C_w in the water is obtained from equation 71, where S_w now refers to the activity (μCi) released acutely from each radionuclide.

TABLE F-33

TABULATION FOR THE SAMPLE CALCULATION OF THE 70-YEAR THYROID DOSE COMMITMENT TO REFERENCE MAN 2 MILES DOWNWIND

	70-Year Thyroid Dose for Unit Dispersion [(rem·m³)/s]				Water Ingestion	
Radionuclide	Inhalation	Food Ingestion	Ground Plane Irradiation	Plume Shine Irradiation	Initial Radionuclide Concentration $(C_w)_o$ (pCi/l)	Thyroid Dose (rem)
^{82}Br	-	3.47×10^{2}	-	-	3.32×10^{-1}	2.87×10^{-9}
^{131}I	-	3.91×10^{7}	8.98×10^{2}	-	5.93×10^{1}	2.61×10^{-5}
^{132}I	-	1.19×10^{5}	7.21×10^{3}	-	7.03×10^{3}	1.02×10^{-3}
^{133}I	-	7.19×10^{7}	2.82×10^{3}	-	1.02×10^{3}	3.52×10^{-4}
^{134}I	-	1.70	-	-	2.41×10^{4}	5.22×10^{-4}
^{135}I		1.17×10^{7}	6.47×10^{3}		2.89×10^{3}	1.63×10^{-3}
Total	1.62×10^{5}	1.23×10^{8}	1.74×10^{4}	9.01×10^{4}		3.55×10^{-3}

Multiply the total for Food Ingestion by 5.76 and by $\chi/Q = 1.65 \times 10^{5}$ s/m³. The result, 1.2×10^{4} rem, is greater than 1.5 rem so the food is considered to be controlled, and the contribution from Food Ingestion is not included.

Sum the values for Inhalation, Ground Plane Irradiation, and Plume Shine Irradiation = $2.70 \times 10^{5} \frac{\text{rem}\cdot\text{m}^3}{\text{s}}$

Multiply by the Dispersion Factor (1.63×10^{-5} s/m³): Dose (rem) = $2.70 \times 10^{5} \frac{\text{rem}\cdot\text{m}^3}{\text{s}} \times 1.63 \times 10^{-5}$ s/m³
= 4.40 rem

Add the Dose from Water Ingestion to this dose:

Total Dose (rem) = 4.40 rem + 0.000355 rem = 4.40 rem

Round off to 2 significant figures: 70-year Dose Commitment to the Thyroid = 4.4 rem for Reference Man 2 Miles Downwind

F.2.3 Assessment of the Impact of the Maximum Credible Accident

The impact of the maximum credible accident on individuals and populations are assessed in Section 3.2.4.2. This section presents the methodology used for those calculations.

F.2.3.1 Dose to Persons Downwind

The dose to persons downwind and towards the southeast of the Plant is calculated as described in Section F.2.2.1, except for the consideration of the dispersion factors. For this calculation the dispersion factors are calculated using an effective stack height which is equal to the difference in altitude between the Plant and the terrain to the southeast at the various distances. Dispersion factors are also calculated for Pasquill stability class D, using the methodology presented in Appendix B-2.

F.2.3.2 Dose to the Population Downwind

The dose to the population downwind and southeast of the Plant is calculated by multiplying the dose to the person, obtained as described in Section F.2.3.1, by the population in each section, obtained from Figure 2.3.3-1 for the 1977 population and from Figure 2.3.3-2 for the projected year 2000 population. The dispersion factor for the distance of the near edge of the section is used for all persons in that section.

F.2.3.3 Impact on a Hypothetical High Density Population

The population density for the sections 2 to 5 miles from the Plant is determined as described in Section F.1.5.4. The population dose is then determined as discussed in Section F.2.3.2, using the population projected for year 2000. Dispersion factors are based on Pasquill stability class D because use of this class results in the highest population dose and is, therefore, more conservative.

F.2.4 Age-Specific Dose from Acute Intakes

The age-specific dose from an acute intake is obtained as a subset of the calculation of the age-specific dose for chronic releases, described in Section F.1.5.1. As for chronic intakes, the desired value is the ratio of the organ dose commitment for the person, who is exposed at an age younger than 20 or as an adult female, to the organ dose commitment for the person exposed as the adult reference man. This ratio is determined for the inhalation and ingestion intake pathways. The ratios for ground plane and plume shine irradiations are unity.

F.2.4.1 General Approach

The general approach is that discussed for chronic intakes (Section F.1.5.1) with the following modification. In this case, only one intake is involved, and that intake occurs in the first year. Therefore, the dose to the organ is calculated for each of the 70 years following that intake. The intake rate is the one for the age and gender of the person at the time of the intake. The organ mass is considered to change up to age 20 and to remain constant thereafter at the reference value for the adult.

F.2.4.2 Data for Age-Specific Intake Rate and Organ Mass

The values of the intake rate and organ mass are obtained as discussed in Section F.1.5.1 and are presented in Table F-13 and F-14, respectively. In addition, the thyroid is included here for acute intakes. The mass of the thyroid as a function of age is obtained from Table 83 of ICRP #23. These values are presented in Table F-34. The relative thyroid uptake* of iodine for the newborn is 2.33 (derived from USHEW, 1978).

F.2.4.3 Inhalation Pathway

The dose to the lungs is obtained using equation 36 where B_r refers to the breathing rate at the age and gender at the acute intake. One either can do the 70 calculations using equation 36 or can use the following simplification. After doing the number of calculations necessary to reach age 20, set t_2 equal to 25567.5 days (70 years) and do one final calculation. Using this simplification, the age-specific lung dose for the adult reference male and female can be accomplished in a single calculation. (This simplification also can be used for other organs and for the ingestion pathway.) Results of all the calculations are summed and then divided by the age-specific value for the adult reference man to obtain the desired ratio. The dose to the other organs is obtained using equation 38 and following the same procedure.

F.2.4.4 Ingestion Pathway

The organ dose from an acute ingestion is obtained using equation 51 where S_I refers to the intake rate for that gender at the age of the acute intake. The procedure is the same as described in Section F.2.4.3 for the inhalation pathway.

F.2.4.5 Sample Calculation of Age-Specific Organ Dose From Acute Exposure

Calculate the age-specific bone dose ratio for the newborn and 10-year-old males resulting from acute ingestion of ^{239}Pu.

*The reference does not make clear if this increased uptake is from the G.I. tract to the blood f_1, or from the blood to the thryoid f_2'. It is mathematically equivalent to use either factor, so f_1 is used here.

TABLE F-34

AGE-SPECIFIC MASS OF THE THYROID

Age (Years)	Thyroid Mass (g) Male	Female
Birth	1.0	1.1
1	1.8	2.1
2	1.8	2.1
3	2.6	2.5
4	2.6	2.5
5	4.6	4.9
6	4.6	4.9
7	4.6	4.9
8	4.6	4.9
9	4.6	4.9
10	10.2	(10.2)*
11	10.2	(10.2)*
12	10.2	(10.2)*
13	10.2	(10.2)*
14	10.2	(10.2)*
15	14.0	12.4
16	14.0	12.4
17	14.0	12.4
18	14.0	12.4
19	14.0	12.4
Adult	20.0	17.0

*Value is taken to be equal to that for the male.

Step 1. Calculate the relative 70-year bone dose commitment to reference man following an acute ingestion as follows. Using the methodology of Section F.1.5.1 as illustrated in Step 1 of the associated sample calculation, calculate the relative bone dose for 70 years remaining. As shown in Table F-17 this value is 2.33×10^{-2}.

Step 2. Calculate the relative 70-year bone dose commitment to the individual following an acute ingestion, when that individual is newborn as follows. Using methodology of Section F.1.5.1 as illustrated in Step 2a of the associated sample calculation, calculate the relative bone dose for 70 years after an acute ingestion as a newborn. As shown in Table F-17 this value is 5.57×10^{-1}.

Step 3. Calculate the relative 70-year bone dose commitment to the individual following an acute ingestion, when that individual is 10 years old, as follows. Using the methodology of Section F.1.5.1 as illustrated in Step 2b of the associated sample calculation, calculate the relative bone dose for 70 years after an acute ingestion as a 10 year old as partially illustrated in Table F-17. Column 11 of that table shows the 60 year dose commitment. Ten years are added to the final entry of that column by evaluating equation 51 using the ingestion rate for age 10, the organ mass for reference man, the effective removal rate constant for ^{239}Pu from bone, t_1 = 10 x 365.25 d, and t_2 = 70 x 365.25 d. The result of this calculation replaces the last entry of that column. Sum the values in this column.

Step 4. Calculate the desired ratios as follows.

a. For the newborn divide the result of Step 2 by the result of Step 1.

b. For the 10-year-old divide the result of Step 3 by the result of Step 1.

The results of these calculations are tabulated in Table F-35.

TABLE F-35

TABULATION OF SAMPLE CALCULATION OF
AGE-SPECIFIC BONE DOSE FOR ACUTE INGESTION

Tabulation for Step 1.

The relative 70-year bone dose commitment to reference man is

$$\frac{605}{10000} - [1 - e^{-(1.906 \times 10^{-5})(70)(365.25)}] = 2.33 \times 10^{-2}$$

Tabulation for Step 2.

From the total of Column 1 of the tabulation of Step 2, Table F-17, the relative 70-year bone dose commitment to newborn is 5.57×10^{-1}.

Tabulation for Step 3.

The relative 70-year bone dose commitment to 10 year old:

Dose Year	Exposure Number 11
1	8.86×10^{-4}
2	8.10×10^{-4}
3	6.12×10^{-4}
4	4.67×10^{-4}
5	3.77×10^{-4}
6	3.52×10^{-4}
7	3.34×10^{-4}
8	3.18×10^{-4}
9	3.02×10^{-4}
10	2.94×10^{-4}
20-70	1.42×10^{-2}
Total	1.90×10^{-2}

Tabulation for Step 4.

For desired ratios:

a. For the newborn male: $\frac{5.57 \times 10^{-1}}{2.33 \times 10^{-2}} = 23.9$

b. For the 10-year old male: $\frac{1.90 \times 10^{-2}}{2.33 \times 10^{-2}} = 0.815$

F.2.5 Dose to Persons Living on Soil Containing Radionuclide Deposited from Past Releases

The dose to persons living on soil containing radionuclides deposited from past releases is assessed for inhalation of resuspended radionuclides, ingestion of food grown on the soil, ingestion of some of the soil, and irradiation by the radionuclides on the ground. An assessment is made of the 70-year organ dose received by persons living continuously for 70 years on soil with a surface concentration of 0.003 to 0.01 $\mu Ci/m^2$. These surface concentrations correspond to the contours identified by Krey (Krey and Hardy, 1970) for off-site soil contamination (see Figure 2.3.9-1).

F.2.5.1 Inhalation of Resuspended Radionuclides

The 70-year organ dose resulting from inhalation of resuspended radionuclides is given by

$$\text{Organ Dose (rem)} = 2.21 \times 10^3 \; k \; G \; F_I \qquad (103)$$

where G = radionuclide concentration ($\mu Ci/m^2$) on the surface of the soil
k = resuspension factor (m^{-1})
F_I = dose conversion factor ($rem \cdot m^3/Ci \cdot s$) for inhalation
$2.21 \times 10^3 = 10^{-6}$ Ci/μCi x 70 yr x 3.156×10^7 s/yr .

The radionuclide concentration G pertains to the surface concentration of the radionuclide after site preparation and land development for construction of the person's residence, since it is reasonably assumed that the person is not going to be dwelling in a teepee on undisturbed and undeveloped soil for the 70 years. Following the approach of the Colorado Department of Health (CDH, 1976), a reduction by a factor of 10 in the amount of the radionuclides available for resuspension is considered to result from site preparation and development.

The value of G is obtained by apportioning the initial surface concentration among the isotopes of plutonium as described in Section F.2.1.1. The initial activity of ^{241}Am is taken to be 20% of the initial plutonium alpha activity, representing a conservative approximation of the maximum ingrowth of the ^{241}Am from ^{241}Pu. The values are also divided by the factor of 10, resulting from site preparation and development.

The value of resuspension factor k is taken to be 10^{-7} m^{-1}. Following the approach of the Colorado Department of Health (CDH, 1976), the value of 10^{-9} m^{-1} for undisturbed contaminated soil is increased by a factor of 100 to adjust for conditions where local disturbances are routine and frequent.

The value of the dose conversion factor F_I is obtained from Table F-1.

F.2.5.2 Ingestion of Food Grown on Soil Containing Radionuclides

The 70-year organ dose resulting from the ingestion of food grown on soil containing radionuclides is given by

$$\text{Organ Dose (rem)} = 10^{-6}\ G\ F_c \qquad (104)$$

where F_c = dose conversion factor [(rem·m^2)/Ci] for ingestion of food grown on soil containing radionuclides
G = radionuclide concentration (μCi/m^2) on the surface of the soil
10^{-6} = conversion factor (10^{-6} Ci/μCi).

The value of G is obtained as described in Section F.2.5.1.

The values of the dose conversion factor F_c are generated by the PABLM computer code for 70 years of food consumption for the average individual. See Section F.1.2.1 for a discussion of inputs to this code. Values of the dose conversion factors are presented in Table F-36.

TABLE F-36

DOSE CONVERSION FACTORS FOR THE 70-YEAR ORGAN DOSE FROM INGESTION OF FOOD GROWN ON SOIL WITH A SURFACE CONCENTRATION OF 1 Ci/m^2

	Dose Conversion Factor ($\frac{\text{rem}\cdot\text{m}^2}{\text{Ci}}$)			
Radionuclide	Total Body	Liver	Bone	Lungs
^{238}Pu	2.9×10^{-10}	4.0×10^{-8}	8.3×10^{-8}	*
^{239}Pu	4.0×10^{-11}	5.0×10^{-9}	1.1×10^{-8}	*
^{240}Pu	4.0×10^{-11}	5.0×10^{-9}	1.1×10^{-8}	*
^{241}Pu	2.6×10^{-12}	1.7×10^{-10}	9.7×10^{-10}	*
^{242}Pu	3.7×10^{-11}	5.0×10^{-9}	1.1×10^{-8}	*
^{241}Am	3.2×10^{-10}	5.1×10^{-8}	1.1×10^{-7}	*

*The value of the dose conversion factor is taken to be equal to that for the total body.

F.2.5.3 Ingestion of Soil Containing Radionuclides

The 70-year organ dose resulting from ingestion of soil containing radionuclides is given by

$$\text{Organ Dose (rem)} = I_s\ R\ F_s \qquad (105)$$

where I_s = rate of soil ingestion (g/d)
R = activity of the radionuclide per gram of soil (μCi/g)
F_s = dose conversion factor for direct radionuclide ingestion [(rem·d)/μCi].

The rate of soil ingestion is taken to be the one gram per day throughout the 70 year period following the approach of the Colorado Department of Health (CDH, 1976). This is probably a very conservative assumption, although the deliberate ingestion of soil can occur for young children (Healy, 1977). The EPA (EPA, 1977) considers that

> "for this pathway to be as significant as the inhalation pathway, extreme assumptions of soil consumption rates would be required..."

The activity of the radionuclide per gram of soil R is obtained by considering that 2 disintegrations per minute (d/m) per gram of soil for alpha-emitting plutonium is equivalent to a surface activity of 0.01 $\mu Ci/m^2$ (CDH, 1976). The value 2 d/m per gram converts to 9.01×10^{-7} $\mu Ci/g$ soil. This activity is apportioned among the isotopes of plutonium and to ^{241}Am as described in Section F.2.1.1. For values of surface activity other than 0.01 $\mu Ci/m^2$, the activity is multiplied by the ratio of the desired surface concentration to 0.01 $\mu Ci/m^2$.

The values of the dose conversion factor F_s are obtained from Table F-8. Although these factors are derived for water ingestion, they are also valid for the direct ingestion of the radionuclides in food or in any other ingestion medium.

F.2.5.4 Ground Plane Irradiation

The 70-year organ dose from ground plane irradiation is given by

$$\text{Organ Dose (rem)} = 7.36 \times 10^2 \; G \; F \qquad (106)$$

where G = radionuclide concentration ($\mu Ci/m^2$) on the surface of the soil
F = dose conversion factor [$(rem \cdot m^2)/(Ci \cdot s)$]
$7.36 \times 10^2 = (10^{-6}$ Ci/μCi x 2.55675×10^4 d x 8.64×10^4 s/d)(1/3).

The values of the dose conversion factor F are obtained from Table F-11.

No further ingrowth of ^{241}Am is included, since the value apportioned to the ^{241}Am already represents a maximum activity from ingrowth.

The ground plane irradiation is considered to occur for 8 hours per day, since an average individual might be outdoors and exposed to the ground only 8 hours per day. A factor of 1/3 is, therefore, included in equation 106.

F.2.5.5 Sample Calculation

Calculate the 70-year bone dose to a person dwelling continuously for 70 years on soil with a surface concentration of 0.01 $\mu Ci/m^2$ plutonium.

Step 1. For the dose from inhalation of resuspended radionuclides, apportion the activity among the isotopes of plutonium as described in Section F.2.1.1. The activity of ^{241}Am is 20% or 2.0×10^{-3} $\mu Ci/m^2$. Divide the value for each radionuclide by 10 for site preparation and multiply by a resuspension factor of 10^{-7}, by 2.21×10^{3} (from equation 103) and by the value of the dose conversion factor, from Table F-1, for corresponding radionuclides. Sum all results.

Step 2. For the dose from ingesting food grown on the soil, multiply the apportioned activity (from Step 1) by 10^{-6} and by the value of the dose conversion factor, from Table F-35, for corresponding radionuclides. Sum all results.

Step 3. For the dose from ingesting soil directly, the value 9.01×10^{-7} $\mu Ci/g$ is the activity per gram of soil for the surface concentration of 0.01 $\mu Ci/m^2$. Apportion this value among the isotopes as described in Section F.2.1.1. Multiply by 1 g/d and by the value of the dose conversion factor, from Table F-8, for corresponding radionuclides. Sum all results.

Step 4. For the dose from ground plane irradiation, multiply the value of the apportioned suface concentration ($\mu Ci/m^2$) by 7.37×10^{2} and by the value of the dose conversion factor, from Table F-11, for corresponding radionuclides. Sum all results.

Step 5. Sum the results from Steps 1 through 4. This sum, 0.26 rem, is the total 70-year bone dose from dwelling continuously (8 hours per day) for 70 years on soil containing 0.01 $\mu Ci/m^2$ plutonium.

The results of this sample calculation are tabulated in Table F-37.

TABLE F-37

TABULATION OF THE SAMPLE CALCULATION OF THE DOSE TO PERSONS LIVING ON SOIL CONTAINING RADIONUCLIDES DEPOSITED FROM PAST RELEASES

Soil Surface Concentration = 0.01 $\mu Ci/m^2$ Plutonium (alpha activity)

Radionuclide	Surface Concentration ($\mu Ci/m^2$)	Activity in Soil ($\mu Ci/g$)	70-Year Bone Dose (rem)			
			Inhalation	Food Ingestion	Soil Ingestion	Ground Plane Irradiation
^{238}Pu	2.34×10^{-4}	2.10×10^{-8}	1.97×10^{-3}	1.9×10^{-17}	6.44×10^{-3}	1.73×10^{-6}
^{239}Pu	7.96×10^{-3}	7.18×10^{-7}	7.56×10^{-2}	8.8×10^{-17}	2.50×10^{-2}	2.52×10^{-5}
^{240}Pu	1.80×10^{-3}	1.63×10^{-7}	1.71×10^{-2}	2.0×10^{-17}	5.64×10^{-3}	1.19×10^{-5}
^{241}Pu	5.08×10^{-2}	4.58×10^{-6}	9.86×10^{-3}	5.0×10^{-17}	3.74×10^{-2}	-
^{242}Pu	1.61×10^{-7}	1.45×10^{-11}	1.42×10^{-6}	1.8×10^{-21}	4.66×10^{-7}	1.02×10^{-9}
^{241}Am	2.00×10^{-3}	1.80×10^{-7}	1.91×10^{-2}	2.2×10^{-16}	6.28×10^{-2}	3.54×10^{-4}
Total			1.24×10^{-1}	4.0×10^{-16}	1.37×10^{-1}	3.92×10^{-4}

Total 70-Year Bone Dose = 0.26 rem

F.3 Dosimetry for Transportation

Normal operation of the transportation associated with Rocky Flats will result in direct radiation exposure to some individuals, but no release of beryllium (a nonradioactive material) or any radioactive isotopes into the environment. Releases are expected should an accident occur, however. The expected yearly release rate from accidents is calculated for truck transport, air transport, rail transport and the connecting delivery vehicle transport.

F.3.1 Nonradiological Effects

An atmospheric dispersion calculation is used to determine the maximum air concentration that would result from a beryllium shipment accident. For the air concentration, a comparison is made with established standards. Beryllium metal shipments can result in environmental releases if fires result in oxidation of the beryllium. In conditions where a gasoline fire may be involved, it is possible that some of the beryllium would be oxidized. The oxidation formed on beryllium at temperatures above 1472°F is in a dispersible form; that formed at temperatures below 1472°F stays strongly attached to the metal and is not readily dispersible. Since the exact temperature history of a fire that could result in an accident is not known, a conservative assumption is made that a transport fire results in all of the beryllium becoming completely oxidized in a dispersible form.

An intense fire such as is assumed in this accident would create an updraft which would carry the beryllium oxide aloft and have the effect of releasing it from an appreciable height. A release height of 100 meters is assumed.

As in other accident calculations in this document, meteorological conditions of Pasquill stability class E and a wind speed of 3.0 meters per second are assumed (see Section F.2.1.1 for further discussion).

Using equation 107 (derived from Turner, 1970), which properly accounts for an elevated plume release, the maximum χ/Q is determined by trial and error. The result is 1.82×10^{-6} sec/m^3 at a distance of 3.55 miles.

$$\frac{\chi}{Q} = \frac{1}{2\pi\sigma_y\sigma_z\mu}\left(\exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]\right) \qquad (107)$$

where χ = air concentration of plume (Ci/m^3)
Q = source term (Ci/sec)
σ_y = calculated as outlined in appendix B-2
σ_z = calculated as outlined in appendix B-2
μ = wind velocity (m/sec)
z = height of receptor above ground (taken as 0 meters)
H = height of plume release (m)

The amount of beryllium carried in a Rocky Flats weapon shipment is reasonably assumed to be 150 grams in this calculation. This amount of beryllium is oxidized in the fire and released over a period of time. Although this would probably be over a several hour period, a conservative value of one hour was assumed. Equation 108 shows the air concentration calculation.

$$\left[150g \div (60\ min \cdot 60\ \frac{s}{min})\right] \cdot 1.82 \times 10^{-6}\ \frac{s}{m^3} = 7.58 \times 10^{-8}\ \frac{g}{m^3} \qquad (108)$$

F.3.2 Radiological Effects

Four modes of transportation associated with Rocky Flats are considered in this analysis: transport truck, delivery vehicle, air cargo plane, and rail. Transport truck is responsible for the majority of the transportation entering and leaving the Plant. Although a large portion of this truck transportation utilizes DOE-owned Safe Secure Trailers, which have inherent safety features, the conservative assumption is made that all transport truck shipments are via commercial carriers. All shipments are made in appropriate DOT-approved containers, however.

Delivery vehicle shipments connect from the airport at either end of the shipment to the origin or destination facility. Again, these trucks are usually DOE-owned vehicles, but for the impact assessment a commercial delivery vehicle is assumed. A delivery vehicle shipment is assumed to take place at each end of the air cargo shipment. The incidence of delivery vehicle stops and storage of the packages is reduced by a factor of two, however, to more accurately describe the security precautions taken with these shipments.

No radioactive materials are shipped to or from Rocky Flats via passenger carrying airlines. All air shipments are made via commercial cargo aircraft.

Rail shipments of radioactive materials associated with Rocky Flats are all made via Government owned ATMX rail cars. These cars act as a large type B shipping container as outlined in the Safety Analysis Report for Packaging (Adcock, 1974). These cars are, however, treated as standard rail cars by the rail companies. No special treatment of these cars is assumed.

F.3.2.1 Normal Operations

By making the often conservative assumption that all Rocky Flats shipments are made by commercial carrier, it is possible to use the methodology and transportation parameters given in the NRC document entitled "Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes" (USNRC,1977). This report documents a methodology for assessing the risk dose to the U.S. population from various portions of the transportation cycle. The population dose resulting

from normal operation and accidents of transportation associated with Rocky Flats is expected to be spread more or less evenly across the United States, rather than being limited to the Denver area. The U.S. population is expected to receive doses from different aspects of the transportation process. The doses assessed in this analysis are:

1) dose to persons surrounding the transport link while the shipment is moving,
2) dose to persons surrounding the transport vehicle while it is stopped,
3) dose to warehouse personnel while the shipment is in storage,
4) dose to crewmen operating the transport vehicle,
5) dose to persons in vehicles sharing the transport link with the shipment and moving in the opposite direction,
6) dose to persons in vehicles sharing the transport link with the shipment and moving in the same direction, and
7) dose to package handlers moving a shipment between transportation modes.

In addition to the methodology, the NRC document gives parameters for each shipping mode dealing with speeds, distances, and times spent by vehicles in rural, suburban, and urban transportation environments. For derivations of the equations and explanations of the source of the parameters, the reader is referred to the NRC document.

Equations for determination of the dose from each portion of the transport cycle are given in Table F-38 (equations 109 thru 116). Equations 109 thru 115 apply to each of the transportation modes. Several equations incorporate parameter substitutions for some of the transportation modes, however. In the air transportation analysis, only equations 110, 112, and 116 are used because of the large separation distance between the moving aircraft and any surrounding population. Equation 116 is applicable only to the movement of air cargo from the air transport mode to the delivery vehicle transport mode. Any dose to the handlers has been credited to the air transport mode, and any dose obtained during storage time has been credited to the delivery vehicle transport mode.

Parameters used in equations 109 thru 116 are given in Table F-39. All of these parameters except K, SPY, FMPS, and P come from the NRC document. K is derived from equation 11 assuming the DOT limit of 10 mrem/hr at 6 feet from the exclusive use vehicle.

$$D(d) = \frac{Ke^{-\mu d} B(d)}{d^2} \qquad (117)$$

where $D(d)$ = dose rate at a distance d (mrem/hr)
d = distance from source (ft)
μ = absorption coefficient for air ($0.00118\ ft^{-1}$)
$B(d)$ = Berger buildup factor in air, where in this case $B(d) = 0.0006d + 1$ (dimensionless)
K = dose rate factor ($mrem \cdot ft^2/hr$)

TABLE F-38
EQUATION FOR THE CALCULATION OF DOSE
TO THE POPULATION FROM NORMAL TRANSPORTATION*

$$D_{move} = Q_1 \cdot K \cdot SPY \cdot FMPS \cdot \left(\frac{f_r \cdot PD_r}{V_r} + \frac{f_s \cdot PD_s}{V_s} + \frac{f_s \cdot PD_u}{V_u} \right) (f_o + 1.636\, f_1) \quad (109)$$

$$D_{stop} = Q_2 \cdot K \cdot SPY \cdot \Delta T_r \cdot PD_r + \Delta T_s \cdot PD_s \cdot \Delta T_u \cdot PD_u \quad (110)$$

for Air: $K = K_o \cdot TIS$
for Delivery Vehicle: $SPY = SPY/2$

$$D_{store} = Q_3 \cdot K \cdot SPY \cdot \Delta T_{store} \cdot PD_{store} \quad (111)$$

leave for Delivery Vehicle: $K = K_o \cdot TIS$
$SPY = SPY/2$

$$D_{crew} = Q_4 \cdot K \cdot SPY \cdot N_c \cdot \frac{e^{-\mu d_B(d)}}{d^2} \cdot \Delta T_{ship} \quad (112)$$

leave for Truck: $K = 2$
leave for Delivery Vehicle: $\frac{e^{-\mu d_B(d)}}{d^2} = 1$

leave for Air: $K = K_o \cdot TIS$

$$D_{opp} = Q_5 \cdot K \cdot SPY \cdot FMPS \cdot P \cdot F_{opp} \quad (113)$$

$$D_{same} = Q_6 \cdot K \cdot SPY \cdot FMPS \cdot P \cdot F_{same} \quad (114)$$

$$F_a = f_r \frac{N_r' I^a_{fwy}}{(V_r)^2} + f_s \frac{f_{rh} 2N_s' I^a_{fwy}}{(V_s/2)^2} + \frac{f_n N_s' I^a_{fwy}}{(V_s)^2} + f_u \, f_{fwy} \frac{f_{rh} 2N_u' I^a_{fwy}}{(V_s/2)^2}$$
$$+ \frac{f_n N_u' I^a_{fwy}}{(V_r)^2} + f_{4\ell} \frac{f_{rh} 2N_u' I^a_{4\ell}}{(V_s/2)^2} + \frac{f_n N_u' I^a_{4\ell}}{(V_s)^2} + f_{cs} \frac{f_{rh} 2N_u' I^a_{cs}}{(V_u/2)^2}$$
$$+ \frac{f_n N_u' I^a_{cs}}{(V_u)^2} \quad (115)$$

$$D_{handler} = Q_7 \cdot TIS \cdot SPY \quad (116)$$

*See Table F-39 for definition of variables

Dose from the aircraft transportation mode is assessed using K_o and TIS. It is considered that the external dose rate of cargo aircraft is more reasonably described by the transport index limit than by any measured external dose rate limit. The number of shipments per year SPY is found in Section 3.3.1.1. The average distance per shipment FMPS is found by taking the total radioactive transport mileage divided by the SPY for that transport mode. P values were obtained from studies quoted by the Colorado State Highway Department and Amtrack. The results of these calculations are shown in Table F-40.

To calculate the health effects of this external exposure to the population, the conservative assumption is made that all the organs of the body are exposed to the same level as the external exposure. Using the health effect risk estimates of Table 3.1.2-10 the maximum health effect estimate is calculated in equations 118 thru 122.

TABLE F-39

VALUES OF PARAMETERS USED FOR NORMAL TRANSPORTATION DOSE ASSESSMENT

		Transport Truck	Delivery Vehicle	Air	Rail	Unit
Q_1	Constant	3.47×10^{-10}	3.47×10^{-10}	-	3.47×10^{-10}	$(mi^2 \cdot rem)/(ft^2 \cdot mrem)$*
Q_2	Constant	9.81×10^{-10}	9.81×10^{-10}	9.81×10^{-10}	9.8×10^{-10}	$(rem \cdot mi^2)/(mrem \cdot ft^2)$*
Q_3	Constant	2.77×10^{-9}	2.77×10^{-9}	-	2.77×10^{-9}	$(rem \cdot km^2)/(mrem \cdot ft^2)$*
Q_4	Constant	10^{-3}	10^{-3}	10^{-3}	10^{-3}	rem·mrem
Q_5	Constant	1.89×10^{-7}	1.89×10^{-7}	-	1.89×10^{-7}	(rem·mi)/(mrem·ft)
Q_6	Constant	3.79×10^{-7}	3.79×10^{-7}	-	3.79×10^{-7}	(rem·mi)/(mrem·ft)*
Q_7	Constant	-	-	2.5×10^{-4}	-	(person·rem·hr)/mrem*
K	dose rate factor (based on 10 mrem/hr @ 6 ft)	361	361	-	361	$(mrem \cdot ft^2)/hr$
K_o	dose rate factor (for type B package)	-	16	16	-	ft^2
f_r	fraction of distance in rural	0.9	0	-	0.9	unitless
f_s	fraction of distance in suburban	0.05	0.6	-	0.05	unitless
f_u	fraction of distance in urban	0.05	0.4	-	0.05	unitless
PD_r	population density (rural)	16	16	16	16	$persons/mi^2$
PD_s	population density (suburban)	1862	1862	1862	1862	$persons/mi^2$
PD_u	population density (urban)	10000	10000	10000	10000	$persons/mi^2$
V_r	avg. velocity (rural)	55	55	-	40	mi/hr
V_s	avg. velocity (suburban)	25	25	-	25	mi/hr
V_u	avg. velocity (urban)	15	15	-	15	mi/hr
f_o	fraction of urban travel on freeway or 4 lane roads	0.95	0.3	-	1.0	unitless
f_1	fraction of urban travel on city streets	0.05	0.7	-	0.0	unitless
SPY	shipments per year	500	400	200	100	shipment/yr
FMPS	avg. distance per shipment	1068	25	-	1497	mi/shipment
ΔT_r	total stop time in rural	2.0	0.0	0.0	24	hr/shipment
ΔT_s	total stop time in suburban	5.0	0.0	1.0	0.0	hr/shipment
ΔT_u	total stop time in urban	1.0	0.5	0.0	0.0	hr/shipment

*Constants include additional unitless factors from derivation.

	Transport Truck	Delivery Vehicle	Air	Rail	Unit
TIS total TI per shipment	-	50	50	-	mrem/(hr·shipment)
ΔT_{store} storage time per shipment	2.0	2	-	24	hr/shipment
PD_{store} population density in warehouse	900	900	-	25	person/km^2
N_c number of crew per shipment	2.0	2.0	3.0	5.0	person
ΔT_{ship} avg. time per shipment	23.17	1.27	2.0	39.4	hr/shipment
μ absorbtion coeff for air	0.00118	0.00118	0.00118	0.00118	ft^{-1}
d distance from source	-	7.0	20.0	500	ft
B(d) Berger buildup factor	-	1.042	1.012	1.300	unitless
P persons per vehicle	2.49	2.49	-	26.3	person/vehicle
ΔT_{stop} average time of stop	-	-	1.0	-	hr
PD_{stop} population density around stop	-	-	720	-	person/km^2
N'_r vehicle count in rural	470	470	-	1.21	vehicle/hr
N'_s vehicle count in suburban	780	780	-	1.21	vehicle/hr
N'_u vehicle count in urban	2800	2800	-	1.21	vehicle/hr
I^{opp}_{fwy} exposure distance integral	0.029	0.029	-	0.15	ft^{-1}
$I^{opp}_{4\ell}$ exposure distance integral	0.048	0.048	-	0.15	ft^{-1}
I^{opp}_{CS} exposure distance integral	0.15	0.15	-	0.15	ft^{-1}
I^{same}_{fwy} exposure distance integral	0.008	0.008	-	0.097	ft^{-1}
$I^{same}_{4\ell}$ exposure distance integral	0.031	0.031	-	0.097	ft^{-1}
I^{same}_{CS} exposure distance integral	0.097	0.097	-	0.097	ft^{-1}
f_{rh} fraction of distance in rush hour traffic	0.08	0.08	-	0.0	unitless
f_n fraction of distance in normal traffic	0.92	0.92	-	1.0	unitless

		Transport Truck	Delivery Vehicle	Air	Rail	Unit
$f_{4\ell}$	fraction of distance on 4-lane streets	0.1	0.05	-	0.0	unitless
f_{cs}	fraction of distance on city streets	0.05	0.65	-	1.0	unitless
f_{fwy}	fraction of distance on freeways	0.85	0.25	-	0.0	unitless

$$69.55 \text{ man-rem/yr} \cdot 70 \text{ yr} \cdot 2.0 \times 10^{-4} \frac{\text{cancer mortality}}{\text{man-rem to total body}} = 9.7 \times 10^{-1} \text{ cancer mortalities} \quad (118)$$

$$69.55 \text{ man-rem/yr} \cdot 70 \text{ yr} \cdot 2.0 \times 10^{-6} \frac{\text{cancer mortality}}{\text{man-rem to liver}} = 1 \times 10^{-2} \text{ cancer mortalities} \quad (119)$$

$$69.55 \text{ man-rem/yr} \cdot 70 \text{ yr} \cdot 6.0 \times 10^{-6} \frac{\text{cancer mortality}}{\text{man-rem to bone}} = 3 \times 10^{-2} \text{ cancer mortalities} \quad (120)$$

$$69.55 \text{ man-rem/yr} \cdot 70 \text{ yr} \cdot 4.0 \times 10^{-5} \frac{\text{cancer mortality}}{\text{man-rem to lungs}} = 2.0 \times 10^{-1} \text{ cancer mortalities} \quad (121)$$

$$\text{Total} \qquad 1.2 \text{ cancer mortalities}$$

$$69.55 \text{ man-rem/yr} \cdot 70 \text{ yr} \cdot 3.0 \times 10^{-4} \frac{\text{genetic defects}}{\text{man-rem to total body}} = 1.5 \text{ genetic defects} \quad (122)$$

TABLE F-40

DOSE TO POPULATION GROUPS FROM NORMAL OPERATIONS

(man·rem/yr)

Population Group	Truck	Delivery*	Air	Rail	Total
Off-link pop. while moving	2.56	0.54	-	0.70	3.80
Surrounding pop. while stopped	3.42	0.35	0.29	0.01	4.07
Warehouse personnel during storage	0.90	0.80	2.50***	0.06	4.26
Crew while shipping	46.34	2.03	2.37	0.02	50.76
On link pop. while moving**	3.48	3.09	-	0.09	6.66
opposite direction	(1.85)	(1.37)	-	(0.04)	(3.26)
same direction	(1.63)	(1.72)	-	(0.05)	(3.40)
Total	56.70	6.81	5.16	0.88	69.55

*Delivery vehicle from airport to destination.
**Total of same and opposite direction.
***Handler dose from transfer between air and delivery vehicle transport modes, any storage is credited to delivery vehicle transport mode.

The values for the U.S. population background dose to the organ of interest are derived from the same source as the background organ dose for the Denver area population. NCRP #45 (Table 44) supplies the individual yearly organ dose. The U.S. population figure comes from the World Almanac (1978) and is taken as 216,817,000 persons on July 1, 1977.

The maximum individual dose is assessed for several situations associated with Rocky Flats transportation. The first individual considered is someone who lives near the entrance to the Plant and resides 30 meters (100 ft) from the road along which all Rocky Flats transport truck shipments pass, going into and out of the Plant. The dose is calculated using equations 123 and 124. Equation 123 is evaluated for K=1, V=1, and x=100 ft

$$D = 2 \frac{K}{V} I(X) \tag{123}$$

$$I(X) = \int_{x}^{\infty} \frac{e^{-\mu r} B(r)\, dr}{r(r^2 - x^2)^{1/2}} \tag{124}$$

where r = integration variable
x = distance from source at closest point
all other = (see Table F39)

by use of a graph (Figure D-1) in the NRC document. This value is 3×10^{-6} mrem. Correcting for K and V and assuming 500 truck passages per year for 70 years, equation 125 gives the 70 year dose.

$$\frac{3 \times 10^{-6} \cdot 361}{24.8} = 4.37 \times 10^{-5} \frac{\text{mrem}}{\text{truck passage}} \cdot 500 \frac{\text{truck passage}}{\text{yr}} \cdot 70 \text{ yr} = 1.53 \text{ mrem} \tag{125}$$

To evaluate the dose to the individual that would follow a Rocky Flats transport truck along the public roadways, equation 126 is used. Assuming an average following distance of 30 meters,

$$D(d) = \frac{K e^{-\mu d} B(d)}{d^2} \tag{126}$$

an average shipment period of 23.17 hours, and a buildup factor as calculated by equation 127; the dose to that individual from one shipment is calculated in equation 127.

$$B(d) = 0.006 \cdot d + 1 \tag{127}$$

$$3.52 \times 10^{-2} \frac{\text{mrem}}{\text{hr}} \cdot 23.17 \text{ hr} = 0.82 \text{ mrem} \tag{128}$$

The dose to truck drivers is calculated assuming the DOT limit of 2 mrem per hour at the drivers compartment, 23.17 hour average shipment time, and 30 shipments per year for one driver. Equation 129 shows this calculation:

$$2 \frac{\text{mrem}}{\text{hr}} \quad 23.17 \frac{\text{hr}}{\text{shipment}} \quad 30 \frac{\text{shipment}}{\text{yr}} = 1.39 \frac{\text{rem}}{\text{yr}} . \tag{129}$$

Delivery vehicle driver dose is calculated in the same way assuming 1.27 hours per shipment and one driver taking all the delivery vehicle shipments at the Rocky Flats Plant for an entire year. This calculation is shown in equation 130.

$$2 \frac{\text{mrem}}{\text{hr}} \quad 1.27 \frac{\text{hr}}{\text{shipment}} \quad 200 \frac{\text{shipment}}{\text{yr}} = 508 \frac{\text{mrem}}{\text{yr}} \tag{130}$$

In this analysis transportation workers are considered to be the individuals receiving dose from the warehouse and the crew catagories of Table F40.

F.3.2.2 Accidental Releases

Population Risk Dose

In this assessment a risk dose to the United State population is determined. The U.S. population is again considered, rather than the population surrounding the Rocky Flats Plant, because accidents are assumed to occur uniformly along transportation routes spread across a large portion of the country.

The transportation accident analysis is based on a transportation model developed for this document. Amounts, frequencies, and routes are classified information when related to the U.S. defense program. Therefore, reasonable assumptions were made in the development of this model.

The transportation model used is outlined in Table F41. The model is based upon the example of Rocky Flats transportation given in Table F39. Small amounts of radio nuclides not included in this model are shipped to and from Rocky Flats but are not included in the model because of their negligible impact to the overall population dose.

Data from Table F37 are presented in columns 1, 2, 3, 4, and 9 of Table F-41. The container type used to ship these materials (column 5) is taken to be the type thought appropriate for the type and quantity of materials shipped (refer to section 2.6.10.2). The amount contained in each container (column 6) is conservatively taken as the maximum allowed by the various applicable regulations (column 7). Amounts carried in LSA shipments are based on the LSA concentration limit of section 2.6.10.1 multiplied by the maximum legal weight of a truck, 40,000 pounds. For rail shipments the amount is calculated as 10 times the LSA waste concentration times the maximum

TABLE F-41

ROCKY FLATS TRANSPORTATION MODEL

Nuclide (1)	Form (2)	Mode (3)	Amount of Radionuclide (4)	Container Type (5)	Amount Per Container (g) (6)	Reference for Amount/Container (7)	Containers Per Vehicle (8)	Vehicle-Miles Per Year (9)
Am-241	Oxide	Truck	g	B	5.8	Table 2.6.10-5	12[15]	38900
	Waste	Rail	g	B[6]	1.34	[7]	1[16]	66980
Be	Metal	Air	kg	LSA	20000	[8]	1[17]	255000
	Scrap	Truck	lb	LSA	91000	[8]	10[17]	6604
NP-237	Metal	Air	g	B	500	[9]	12	2500
	Oxide	Truck	g	B	500	[9]	12	1200
		Air	g	B	500	[9]	12	1300
Pu[1]	Metal	Truck	kg	B	4500	[10]	12	37300
			g	B	273	Table 2.6.10-5	12	11420
	Oxide	Truck	g	B	273	Table 2.6.10-5	12	12700
	Metal+ Oxide	Truck	kg	B	4500	[10]	12	35400
			g	B	273	Table 2.6.10-5	12	57800
	Nitrate	Truck	g	B	273	Table 2.6.10-5	12	48000
	Waste	Truck	g	LSA	2.05	[11]	1[18]	107000
		Rail	g	B[6]	52	[7]	1[16]	66980
Pu+U[2]	Metal	Truck	kg	B	4500	[10]	12	58240
	Waste	Truck	g	B	500	[9]	12	3700
U-233	Oxide	Truck	g	A	5.17	Table 2.6.10-5	12	1600
	Waste	Rail	g	B[6]	500	[9]	1[16]	2364
U-235[3]	Metal	Truck	kg	B	13500	[10]	12	35300
		Air	kg	B	13500	[10]	12	6500
			g	B	500	[9]	12	14700
	Oxide	Truck	kg	B	6000	[12]	12	3200
	Nitrate	Truck	g	B	500	[9]	12	740
U-238[4]	Metal	Truck	kg	A	73000	[13]	12	67030
		Air	kg	A	73000	[13]	12	77000
			g	A	500	[9]	24[17]	1200
U-235[4]+ U-238	Metal	Truck	kg	B	13500	[10]	12	2600
	Waste	Truck	kg	LSA	2000	[14]	1[18]	11800
		Rail	g	B[6]	500	[9]	1[16]	13396

1 Rocky Flats isotope mixture including Am-241 at 20% of plutonium alpha activity
2 Considered to be all Rocky Flats plutonium mixture
3 Enriched uranium isotope mixture
4 Depleted uranium isotope mixture
5 Considered to be all enriched uranium mixture
6 All rail shipments are by ATMX car which is itself a type B container
7 Ten times LSA concentration limit (see text)
8 Typical Rocky Flats shipment
9 Conservative estimation based upon column (4)

Footnotes for Table F-41 (continued)

10 Model 1518 contents limit (see page 2-152)
11 LSA concentration limit (see text)
12 Model 1518 container SARP (Adcock, 1968)
13 DOT 6C container gross weight limit 49 CFR 178.99
14 SNM strategic quantities limit
15 12 containers per truck and airplane generally assumed for this statement
16 One package per rail car because rail car is considered one large type B container
17 Assumed because of weight of container
18 Amount per container based upon one container per truck

payload limit of the ATMX car (Adcock, 1974). If any of these limits yields an unreasonably high limit, a conservative value of 500 grams is assumed. This number is still thought to be a quite conservative value. The number of containers per vehicle (column 8) is usually taken as 12 for air and truck transport. This column as well as the rest of the table is footnoted to explain the source of many of the entries, and to note several other, often conservative, assumptions used.

Delivery vehicles are not specifically included in Table F-41. They are assumed to connect with both ends of air shipments, however. To model this aspect of Rocky Flats related transportation a 25 mile delivery vehicle shipment is assumed with the frequencies outlined in Table F-42. The container types and amounts are the same as for the air shipments to which the delivery vehicles connect.

It is considered that, although the exact type of shipping container and amounts contained in them are not available, the model used in this transportation accident risk assessment is accurate enough to give estimates upon which meaningful decisions can be made.

In this analysis accidents are broken into eight severity categories. Each succeeding category involves a greater combination of crash force and fire severity. A fraction of occurrence is given for each category. These frequencies are further broken down into the fraction of time that the accident of each severity class occurs in an area of low, medium, or high density population. These population zones correspond to rural, suburban, and urban areas. These values along with the overall vehicle accident rate are shown in Tables F42, F43, F44, and F45. These values are all derived from the NRC Transportation Environmental Impact Statement (USNRC, 1977).

The amount released from a container is dependent upon the type of container, and the severity of the accident. Table F47 shows the release model used in this analysis which is also derived from the USNRC document. In this analysis every container within a vehicle involved in an accident is assumed to behave in a similar manner. In addition, no credit is taken for containment of the vehicle. Both of the previous assumptions are quite conservative.

TABLE F-42

DELIVERY VEHICLE TRANSPORT MODEL

Nuclide	Form	Amount of Radionuclide	Fraction of Radioactive Air Shipment Mileage	Number of Delivery Vehicle Trips*
Be	Metal	kg	-	400
Np-237	Metal	g	0.02	8
	Oxide	g	0.01	4
U-235	Metal	kg	0.06	24
		g	0.14	56
U-238	Metal	kg	0.75	300
		g	0.01	4

*Based upon two delivery vehicle trips per air shipment.

TABLE F-43

FRACTIONAL OCCURRENCES* FOR TRANSPORT TRUCK ACCIDENTS BY ACCIDENT SEVERITY CATEGORY AND POPULATION DENSITY ZONE

Accident Severity Category	Fractional Occurrences	Fractional Occurrences According to Population Density Zones		
		Low	Medium	High
I	0.55	0.1	0.1	0.8
II	0.36	0.1	0.1	0.8
III	0.07	0.3	0.4	0.3
IV	0.016	0.3	0.4	0.3
V	0.0028	0.5	0.3	0.2
VI	0.0011	0.7	0.2	0.1
VII	8.5×10^{-5}	0.8	0.1	0.1
VIII	1.5×10^{-5}	0.9	0.05	0.05

*Overall Accident Rate = 6.6×10^{-7} accidents/mile.

TABLE F-44

FRACTIONAL OCCURRENCES FOR RAIL ACCIDENTS BY ACCIDENT SEVERITY CATEGORY AND POPULATION DENSITY ZONE

Accident Severity Category	Fractional Occurrences	Fractional Occurrences According to Population Density Zones		
		Low	Medium	High
I	0.50	0.1	0.1	0.8
II	0.30	0.1	0.1	0.8
III	0.18	0.3	0.4	0.3
IV	0.018	0.3	0.4	0.3
V	0.0018	0.5	0.3	0.2
VI	1.3×10^{-4}	0.7	0.2	0.1
VII	6.0×10^{-5}	0.8	0.1	0.1
VIII	1.0×10^{-5}	0.9	0.05	0.05

*Overall Accident Rate = 5.8×10^{-7} railcar accidents/railcar·mile.

TABLE F-45

FRACTIONAL OCCURRENCES* FOR DELIVERY VEHICLE ACCIDENTS BY ACCIDENT SEVERITY CATEGORY AND POPULATION DENSITY ZONE

Accident Severity Category	Fractional Occurrences	Fractional Occurrences According to Population Density Zones		
		Low	Medium	High
I	0.55	0.01	0.39	0.60
II	0.36	0.01	0.39	0.60
III	0.07	0.01	0.39	0.60
IV	0.016	0.01	0.50	0.49
V	0.0028	0.01	0.50	0.48
VI	0.0011	0.01	0.50	0.49
VII	8.5×10^{-5}	0.01	0.60	0.39
VIII	1.5×10^{-5}	0.01	0.60	0.39

*Overall Accident Rate = 6.6×10^{-7} accidents/mile.

TABLE F-46

FRACTIONAL OCCURRENCES* FOR AIRCRAFT ACCIDENTS BY ACCIDENT SEVERITY CATEGORY AND POPULATION DENSITY ZONE

Accident Severity Category	Fractional Occurrences	Fractional Occurrences According to Population Density Zones		
		Low	Medium	High
I	0.447	0.05	0.9	0.05
II	0.447	0.05	0.9	0.05
III	0.0434	0.1	0.8	0.1
IV	0.0107	0.1	0.8	0.1
V	0.0279	0.3	0.6	0.1
VI	0.0194	0.3	0.6	0.1
VII	0.0046	0.98	0.01	0.01
VIII	0.0003	0.98	0.01	0.01

*Overall Accident Rate = 8.9×10^{-9} accidents/mile for commercial aircraft

TABLE F-47

RELEASE FRACTIONS

Severity Category	LSA	Type A	Type B
I	0	0	0
II	0.01	0.01	0
III	0.1	0.1	0
IV	1.0	1.0	0
V	1.0	1.0	0
VI	1.0	1.0	0.01
VII	1.0	1.0	0.05
VIII	1.0	1.0	0.1

The solid form in which many of the final products from Rocky Flats are shipped would prevent all of the material released from becoming airborne as respirable sized particles. Table F48 shows the fraction used and the transport categories to which they apply. This table is based upon assumptions used in the USNRC analysis.

TABLE F-48
AEROSOL PARAMETERS

Nuclide	Form	Mode	Amount	Aerosolized Fraction	Fraction of Respirable Size
Pu	Metal	Truck	kg	0.05	0.2
			g		0.2
	Metal + Oxide	Truck	kg	0.05	0.2
			g		0.2
Pu + U	Metal	Truck	kg		0.2
U-233	Oxide	Truck	g	0.05	0.2
U-235	Oxide	Truck	kg	0.05	0.2
	All other categories			1.00	1.0

Dispersion of the radioactive material, once it has been released and become airborne is derived from the USNRC document. The dispersion model is based on Gaussian diffusion, a technique widely used in analysis of atmospheric transport and diffusion. Accidents that involve a release of dispersible material are assumed to produce a cloud of aerosolized debris instantaneously at the accident site. For risk dose calculations, the initial distribution of aerosol mass with height is assumed to be a line source extending from the ground to a height of 10 meters. The initial concentration increases with height in a manner consistent with data obtained in experimental detonations of simulated weapons (Church, 1970). The use of such an initial distribution is justified for accidents in which fires or residual energy provide an aerosol cloud to be released from the accident site. Since the dose from a 10-meter-high line source is indistinguishable from that of a point source at downwind distances greater than about 100 meters, the initial distribution with height is unimportant. Doses calculated using this model are conservative, since most potential accidents involve energy releases that may carry aerosolized materials to heights greater than 10 meters. The degree of conservatism increases as the height of release increases and is especially conservative for elevated sources such as a release that might result from midair aircraft collisions.

A year or more of meteorological data was taken from each of two separate sites in the United States. These data (presented in Figure 5-7 of the USNRC document) were used to derive a list of areas in which a given dilution factor (Ci inhaled/Ci released) would not be exceeded 95% of the time. This is in effect throwing out the

worst (5% of the total) meteorological conditions and assuming that the accident occurs during the worst case conditions of that remaining. These areas and dilution factors are given in Table F-49. The dilution factors are then multiplied by the population in the area affected for low, medium, and high population densities. The sum of these values for each of the population density zones is used in the population dose assessment calculation.

TABLE F-49
DISPERSION FACTORS FOR POPULATION EXPOSURE FROM TRANSPORTATION ACCIDENTS

Dilution Factor (Ci inhaled/Ci released)	Area (m^2)	Population x Dilution Factor Population Density Zone		
		Low	Medium	High
1.2×10^{-6}	4.9×10^{2}	3.5×10^{-9}	4.2×10^{-7}	2.3×10^{-6}
5.6×10^{-7}	1.3×10^{3}	2.7×10^{-9}	3.3×10^{-7}	1.8×10^{-6}
2.7×10^{-7}	3.7×10^{3}	3.9×10^{-9}	4.7×10^{-7}	2.5×10^{-6}
1.2×10^{-7}	1.0×10^{4}	4.5×10^{-9}	5.4×10^{-7}	2.9×10^{-6}
5.6×10^{-8}	3.2×10^{4}	7.4×10^{-9}	8.9×10^{-7}	4.8×10^{-6}
2.7×10^{-8}	7.5×10^{4}	7.0×10^{-9}	8.3×10^{-7}	4.5×10^{-6}
1.2×10^{-8}	1.5×10^{5}	5.4×10^{-9}	6.5×10^{-7}	3.5×10^{-6}
5.6×10^{-9}	4.4×10^{5}	9.7×10^{-9}	1.2×10^{-6}	6.3×10^{-6}
2.7×10^{-9}	7.5×10^{5}	5.0×10^{-9}	6.0×10^{-7}	3.2×10^{-6}
1.2×10^{-9}	2.4×10^{6}	1.2×10^{-8}	1.5×10^{-6}	7.9×10^{-6}
5.6×10^{-10}	4.2×10^{6}	6.0×10^{-9}	7.2×10^{-7}	3.9×10^{-6}
2.7×10^{-10}	1.0×10^{7}	9.4×10^{-9}	1.1×10^{-6}	6.0×10^{-6}
1.2×10^{-10}	2.1×10^{7}	7.9×10^{-9}	9.5×10^{-7}	5.1×10^{-6}
5.6×10^{-11}	5.2×10^{7}	1.0×10^{-8}	1.2×10^{-6}	6.7×10^{-6}
2.7×10^{-11}	1.4×10^{-8}	1.4×10^{-8}	1.7×10^{-6}	9.2×10^{-6}
1.2×10^{-11}	1.2×10^{9}	7.9×10^{-8}	9.5×10^{-6}	5.1×10^{-5}
Population Dilution Factor		1.9×10^{-7}	2.3×10^{-5}	1.2×10^{-4}

In the cases were nuclide mixtures such as Rocky Flats plutonium, enriched uranium, and depleted uranium are shipped, the dose assessment is carried out based upon the nuclide mixture shown in Tables 2.7.2-2, and 2.7.2-4.

The conversion from mass to activity in this assessment uses the specific activity factors shown in Table F-50. Throughout this transportation risk assessment the plutonium mixture is assumed to contain an activity of ^{241}Am equal to 20% of the plutonium alpha activity. This value is conservatively greater than the maximum americium ingrowth possible with Rocky Flats plutonium.

TABLE F-50
SPECIFIC ACTIVITY OF ISOTOPE TRANSPORTED

Nuclide	Specific Activity (Ci/g)
Am-241	3.42
Be	(non-radioactive)
Np-237	7.06×10^{-4}
Pu-238	1.71×10^{1}
Pu-239	6.22×10^{-2}
Pu-240	2.28×10^{-1}
Pu 241	1.04×10^{2}
Pu-242	3.93×10^{-3}
U-233	6.66×10^{-3}
U-234	6.18×10^{-3}
U-235	2.14×10^{-6}
U-236	6.34×10^{-5}
U-238	3.37×10^{-7}

Equation 131 is used to calculate the 70 year population risk dose. This equation is applied separately for each radioactive nuclide of each transportation category shown in Table F-41 for each of the organs of interest. Population risk doses are then summed separately for each transportation mode to get the total population dose, as shown in Table 3.3.2-2. Exposure risk to beryllium is determined in an analogous manner.

Table F-51 summarizes the population risk dose calculation in a slightly different fashion than explained above. The activity of each nuclide inhaled by the population on a yearly basis is presented. This is calculated using equation 131 with the terms in the square brackets deleted. This activity is then corrected for the resuspension factor, dose factor, and 70-year time period. The risk dose is shown in Table F-51 for each of the organs.

The sum of the doses from all the nuclides is the number used to determine the maximum health effect to the population. These calculations are shown in equations 132 thru 136.

$$\sum_{pz}\sum_{sc} AR \cdot FOS_{sc} \cdot FOP_{pz} \cdot FR_{sc} \cdot VMPY \cdot APC \cdot CPV \cdot FA \cdot FRS \cdot SPA \cdot PDF_{pz} \cdot [RF \cdot (CDF \div IR) \cdot 70\ yr] = PDR_{70} \quad (131)$$

where AR = accident rate (Tables F-43 thru F-46)

FOS_{sc} = fractional occurrence of given severity class (Tables F-43 thru F-46)

FOP_{pz} = fractional occurrence in a given population zone (Tables F-43 thru F-46)

FR_{sc} = release fraction (Table F-47)

VMPY = vehicle mile per year (Table F-41)

APC = amount per container (Table F-41)

CPV = container per vehicle (Table F-41)

FA = fraction aerosolized (Table F-48)

FRS = fraction of that aerosolized of respirable size (Table F-47)

SPA = specific activity (Table F-50)

PDF_{pz} = population dilution factor (Table F-49)

RF = resuspension factor (Section F.1.1.1)

CDF = chronic dose factor (Table F-38)

IR = inhalation rate (3.33×10^{-4} m^3/sec)

PRD_{70} = population dose over 70 years (rem)

$$6.1 \times 10^{1} \frac{\text{man-rem}}{70 \text{ year}} \cdot 2.0 \times 10^{-4} \frac{\text{cancer mortalities}}{\text{man-rem}} = 1.2 \times 10^{-2} \frac{\text{cancer mortalities}}{70 \text{ year}} \quad (132)$$

$$1.2 \times 10^{4} \frac{\text{man-rem}}{70 \text{ year}} \cdot 4.0 \times 10^{-5} \frac{\text{cancer mortalities}}{\text{man-rem}} = 4.9 \times 10^{-1} \frac{\text{cancer mortalities}}{70 \text{ year}} \quad (133)$$

$$7.8 \times 10^{3} \frac{\text{man-rem}}{70 \text{ year}} \cdot 2 \times 10^{-6} \frac{\text{cancer mortalities}}{\text{man-rem}} = 2 \times 10^{-2} \frac{\text{cancer mortalities}}{70 \text{ year}} \quad (134)$$

$$1.8 \times 10^{4} \frac{\text{man-rem}}{70 \text{ year}} \cdot 6 \times 10^{-6} \frac{\text{cancer mortalities}}{\text{man-rem}} = 1 \times 10^{-1} \frac{\text{cancer mortalities}}{70 \text{ year}} \quad (135)$$

$$\text{Total} \qquad 6.3 \times 10^{-1} \frac{\text{cancer mortalities}}{70 \text{ year}}$$

$$6.1 \times 10^{1} \frac{\text{man-rem}}{70 \text{ year}} \cdot 3.0 \times 10^{-4} \frac{\text{genetic defects}}{\text{man-rem}} = 1.8 \times 10^{-2} \frac{\text{genetic defects}}{70 \text{ year}} \quad (136)$$

Although the ground plane dose to the population was not used in the transportation risk dose assessment, it is calculated. The methodology used is outlined in section F.1.4. The ground plane dose was evaluated separately for each population zone because of the differences in the population density. A summary of the calculation results is shown in Table F-52.

TABLE F-51

POPULATION RISK DOSE CALCULATION SUMMARY

Nuclide	Activity inhaled per year (Ci)	70 Year Population Risk Dose (man-rem/70 year) Total Body	Lung	Liver	Bone
Pu-238	1.7×10^{-9}	9.2×10^{1}	1.5×10^{2}	1.3×10^{2}	2.7×10^{2}
Pu-239	5.8×10^{-8}	3.4×10^{1}	4.6×10^{3}	4.5×10^{3}	1.0×10^{4}
Pu-240	1.3×10^{-8}	7.8	1.1×10^{3}	1.0×10^{3}	2.4×10^{3}
Pu-241	3.7×10^{-7}	3.9	5.2×10^{1}	5.6×10^{2}	1.3×10^{3}
Pu-242	1.2×10^{-12}	6.6×10^{-4}	9.0×10^{-2}	8.8×10^{-2}	1.9×10^{-1}
Am-241	3.8×10^{-8}	1.0×10^{1}	1.7×10^{3}	1.6×10^{3}	3.5×10^{3}
U-233	2.5×10^{-11}	1.8×10^{-3}	1.9	1.8×10^{-3}	4.1×10^{-2}
U-234	1.1×10^{-8}	6.9×10^{-1}	7.9×10^{2}	7.4×10^{-1}	1.7×10^{1}
U-235	1.0×10^{-9}	6.6×10^{-2}	7.1×10^{1}	6.6×10^{-2}	1.5
U-236	1.6×10^{-10}	1.1×10^{-2}	1.2×10^{1}	1.1×10^{-2}	2.4×10^{-1}
U-238	6.0×10^{-8}	3.7	3.9×10^{3}	3.7	8.6×10^{1}
Th-231	1.0×10^{-9}	1.1×10^{-6}	2.8×10^{-4}	1.8×10^{-6}	3.2×10^{-5}
Th-234	6.0×10^{-8}	1.0×10^{-2}	2.3	2.0×10^{-2}	4.9×10^{-1}
Total	-	6.1×10^{1}	1.2×10^{4}	7.8×10^{3}	1.8×10^{4}

TABLE F-52

POPULATION RISK DOSE FROM GROUND PLANE IRRADIATION

Nuclide	Activity Released in Each Population Zone (Ci/yr) Low	Medium	High	70-Year Population Risk Dose (man-rem)
Pu-238	4.1×10^{-5}	1.4×10^{-5}	1.1×10^{-5}	4.9×10^{-3}
Pu-239	1.4×10^{-3}	4.9×10^{-4}	3.8×10^{-4}	7.2×10^{-2}
Pu-240	3.2×10^{-4}	1.1×10^{-4}	8.7×10^{-5}	3.4×10^{-2}
Pu-241	9.0×10^{-3}	3.1×10^{-3}	2.4×10^{-3}	0
Pu-242	2.9×10^{-8}	9.8×10^{-9}	7.7×10^{-9}	2.9×10^{-6}
Am-241	5.5×10^{-4}	1.7×10^{-4}	1.2×10^{-4}	1.3
U-233	2.2×10^{-7}	1.9×10^{-7}	1.8×10^{-7}	1.8×10^{-4}
U-234	6.8×10^{-5}	7.9×10^{-5}	7.3×10^{-5}	4.6×10^{-2}
U-235	5.9×10^{-6}	7.3×10^{-6}	7.0×10^{-6}	2.6×10^{-1}
U-236	1.3×10^{-6}	1.2×10^{-6}	1.1×10^{-6}	4.7×10^{-4}
U-238	3.3×10^{-4}	4.3×10^{-4}	4.2×10^{-4}	1.8×10^{-1}
Th-231	5.9×10^{-6}	7.3×10^{-6}	7.0×10^{-6}	1.2×10^{-1}
Th-234	3.3×10^{-4}	4.3×10^{-4}	4.2×10^{-4}	9.3×10^{-1}
				3.0

Downwind Dose

Estimates of the dose downwind from an accident involve diffusion calculation based on short term meteorological conditions rather than long term average conditions as were used in previous risk dose calculations. For all accidents, meteorological conditions were assumed to be Pasquil stability class E with a wind velocity of 3.0 meters per second.

As was done in the beryllium accident analysis a fire was assumed, resulting in a plume release height of 100 meters. Using equation 107 the relative concentrations (χ/Q) as a function of distance downwind from the accident is shown in Table F-53.

TABLE F-53
ATMOSPHERIC DISPERSION FACTORS DOWNWIND FROM A TRANSPORTATION ACCIDENT

Distance	$(\frac{\chi}{Q})$ (sec/m^3)
100 meters	0
1.2 mile	3.2×10^{-7}
2	1.3×10^{-6}
3	1.8×10^{-6}
3.55	1.82×10^{-6}
4	1.8×10^{-6}
5	1.7×10^{-6}
10	1.0×10^{-6}
20	5.3×10^{-7}
30	3.5×10^{-7}
40	2.5×10^{-7}

The worst case accident is assumed to be a severity class VIII accident involving a transport truck containing type B containers loaded with Rocky Flats plutonium. The amount released is calculated in equation 137. The parameters for this equation come from Tables F-41, F-47, and F-48.

$$4500 \frac{\text{grams}}{\text{container}} \cdot 12 \frac{\text{container}}{\text{vehicle}} \cdot 0.05 \text{ aerosolized} \cdot 0.2 \text{ of respirable size} \cdot 0.1 \text{ released from container} = 54 \text{ g} \qquad (137)$$

Equation 138 is then applied to the isotopic breakdown of the amount released to determine the organ dose commitment resulting from each nuclide.

$$D = R \cdot SpA \cdot RF \cdot ADF \cdot (\frac{\chi}{Q}) \qquad (138)$$

where

D = organ dose commitment (rem)
R = amount of nuclide released (equation 136)
SpA = specific activity (table F-50)
RF = resuspension factor (section F.1.1.1)
ADF = Acute dose factors (table F-26)
χ/Q = dispersion factor (table F-53)

The result of the above calculation carried out for each organ of interest and summed for each of the nuclides involved is shown in Table 3.3.2-3 as a function of distance downwind.

To assess the health effects to the population as a result of the maximum credible accident it is necessary to assess the population dose commitment. The population dose commitment will be dependent upon the population zone in which the accident is assumed to occur. The population dose commitment is determined by calculating the number of people living in one sector between two distances (the population densities are found in Table F-39). All the people in a given sector and distance range are assumed to receive a dose equal to the person residing at the closest distance of that range. In addition, all individuals in that sector are assumed to be exposed to the plume centerline air concentration, even though the plume always remains narrower than the sector itself.

The population bone doses for the three population zones are shown in Table F-54 as a function of distance downwind. The sums of these three columns are used to assess the health risks based upon the factors of Table 3.1.2-10. These calculations are shown in equation 139 thru 141.

TABLE F-54

POPULATION BONE DOSE COMMITMENT FROM WORST CASE TRANSPORTATION ACCIDENT

Distance (Mi)	Population Bone Dose Commitment (man-rem) Population Density Zone Low	Medium	High
2-3	1.9×10^2	2.4×10^4	1.2×10^5
3-4	3.8×10^2	4.4×10^4	2.4×10^5
4-5	5.0×10^2	5.8×10^4	3.2×10^5
5-10	3.8×10^3	4.6×10^5	2.4×10^6
10-20	9.4×10^3	1.1×10^6	6.0×10^6
20-30	8.0×10^3	9.6×10^5	5.2×10^6
30-40	7.2×10^3	8.8×10^5	4.6×10^6
40-50	7.0×10^3	8.4×10^5	4.4×10^6
Total	3.6×10^4	4.4×10^6	2.4×10^7

3.6×10^{4} man-rem · 6×10^{-6} $\frac{\text{bone cancer mortalities}}{\text{man-rem}}$ = 0.22 bone cancer mortalities (139)

4.4×10^{6} man-rem · 6×10^{-6} $\frac{\text{bone cancer mortalities}}{\text{man-rem}}$ = 26 bone cancer mortalities (140)

2.4×10^{7} man-rem · 6×10^{-6} $\frac{\text{bone cancer mortalities}}{\text{man-rem}}$ = 1.4×10^{1} bone cancer mortalities (141)

Urban (Max/Min) Accident

The analysis of what is referred to as a max/min accident is carried out. Max/min refers to the fact that this accident would result in maximum consequence if it occurred, but that it has a minimum probability of occurrence. The consequence is so high, however, that an assessment needs to be made no matter how slight the probability.

To do this assessment, the methodology of Transport of Radionuclides in Urban Environs (DuCharme, 1978) was used. This document utilizes dispersion models and dosimetric methodologies specifically designed for the urban environment. Because the models are quite complex and computer oriented, hand calculations for a specific example are difficult. Instead, the max/min accident corresponding to that in the Rocky Flats transportation assessment was taken from the Sandia document and corrected for Rocky Flats specific transportation parameters.

The corresponding max/min accident from the Sandia document is an accident involving a 1.13×10^{6} Ci shipment of Special Nuclear Material. The model predicts 3964 latent cancer fatalities as a result of this accident.

The analysis of latent cancer fatalities is based upon analysis of dose to the organs shown in Table F-55 from a 50 year dose commitment. Also included in the table are the other parameters required to determine the overall Latent Cancer Fatality rate per μCi inhaled by the population.

TABLE F-55

HEALTH EFFECT ASSESSMENT FROM SANDIA MAX/MIN ACCIDENT CASE

Organ	LCF* / mrem·50yr	mrem·50yr / μCi deposited †	μCi deposited† / μCi inhaled	LCF / μCi inhaled
Lung	22.2×10^{-9}	9.51×10^{5}	0.22	4.64×10^{-3}
Blood Forming Organ	28.4×10^{-9}	4.2×10^{3}	0.22	2.62×10^{-5}
Gastrointestinal Tract	3.4×10^{-9}	1.6×10^{2}	0.22	1.20×10^{-7}
Thyroid	13.4×10^{-9}	1.8	0.22	5.31×10^{-9}
Bone	21.0×10^{-9}	2.461×10^{6}	0.22	1.14×10^{-2}
				1.61×10^{-2}

*LCF = latent cancer fatality.
†In Pulmonary Lung.

Once this cancer rate is determined, it is possible to calculate the fraction of the shipment that is ultimately inhaled by the population over a 50 year period. These calculations are shown in equations 142 and 143.

$$6.22 \times 10^{1} \frac{\mu Ci \text{ inhaled}}{LCF} \cdot 3964 \text{ LCF} = 2.47 \times 10^{5} \mu Ci \text{ inhaled} \quad (142)$$

$$2.47 \times 10^{5} \mu Ci \text{ inhaled} \div 1.13 \times 10^{12} \mu Ci \text{ shipped} = 2.19 \times 10^{-7} \text{ fraction inhaled} \quad (143)$$

This factor is now the basis upon which the Rocky Flats max/min accident assessment is made. Inherent in this number is the fraction released and aerosolized in respirable sized particles, the dispersion of the material in the urban environment, and the resuspension over 50 (not 70 as used in the Rocky Flats assessment) years.

The Rocky Flats assessment is based on a loaded plutonium transport truck. The amount inhaled by the population is calculated in equations 144 and 145.

$$4.5 \frac{Kg}{Container} \cdot 12 \frac{container}{vehicle} \cdot 2.19 \cdot 10^{-7} \text{ fraction inhaled} = 1.18 \times 10^{-2} g \text{ inhaled/50 years} \quad (144)$$

$$1.18 \times 10^{-2} g \text{ inhaled/50yr} \cdot \frac{1.97}{1.6} \frac{\text{inhaled/70yr}}{\text{inhaled/50yr}} = 1.45 \times 10^{-2} g \text{ inhaled/70yr} \quad (145)$$

This value is then broken down into the isotopic mixture by activity based upon Tables 2.7.2-2 and F-50. Although the exposure shown here is an acute exposure at the time of the accident, followed by a 70 year chronic exposure from resuspended material, this assessment used the conservative acute dose factors. These dose factors (Table F-26) corrected for the inhalation rate inherent in them (divide by 3.33×10^{-4} m^3/sec) are multiplied by the release activities and summed for each organ, as shown in Table F-56.

TABLE F-56

ORGAN DOSE COMMITMENTS FROM MAX/MIN TRANSPORTATION ACCIDENT

Nuclide	Activity inhaled in 70 years (Ci)	70-Year Organ Dose (man-rem) Total Body	Lung	Liver	Bone
Pu-238	2.5×10^{-5}	2.2×10^{2}	2.0×10^{4}	2.6×10^{4}	6.1×10^{4}
Pu-239	8.5×10^{-6}	8.8×10^{3}	6.4×10^{5}	1.0×10^{6}	2.5×10^{6}
Pu-240	1.9×10^{-6}	2.0×10^{3}	1.4×10^{5}	2.3×10^{5}	5.8×10^{5}
Pu-241	5.4×10^{-3}	6.8×10^{2}	7.1×10^{3}	9.3×10^{4}	2.3×10^{5}
Pu-242	1.7×10^{-8}	1.7×10^{-1}	1.2×10^{1}	2.0×10^{1}	4.8×10^{1}
Am-241	2.3×10^{-4}	1.9×10^{3}	1.9×10^{5}	2.9×10^{5}	6.9×10^{5}
		1.4×10^{4}	1.0×10^{6}	1.6×10^{6}	4.1×10^{6}

The health effects of this population dose commitment are calculated in equations 146 thru 150. A similar calculation is done for an enriched uranium shipment. The resulting health effects are shown in Table F-57.

$$1.4 \times 10^{4} \frac{\text{man-rem}}{70 \text{ years}} \cdot 2.0 \times 10^{-4} \frac{\text{cancer fatalities}}{\text{man-rem}} = 2.8 \frac{\text{cancer fatalities}}{70 \text{ years}} \quad (146)$$

$$1.0 \times 10^{6} \frac{\text{man-rem}}{70 \text{ years}} \cdot 4.0 \times 10^{-5} \frac{\text{cancer fatalities}}{\text{man-rem}} = 4.0 \times 10^{1} \frac{\text{cancer fatalities}}{70 \text{ years}} \quad (147)$$

$$1.6 \times 10^{6} \frac{\text{man-rem}}{70 \text{ years}} \cdot 2 \times 10^{-6} \frac{\text{cancer fatalities}}{\text{man-rem}} = 3.2 \frac{\text{cancer fatalities}}{70 \text{ years}} \quad (148)$$

$$4.1 \times 10^{6} \text{ man-rem} \cdot 6 \times 10^{-6} \frac{\text{cancer fatalities}}{} = 2.5 \times 10^{1} \frac{\text{cancer fatalities}}{} \quad (149)$$

$$\text{Total:} \quad 71 \frac{\text{cancer fatalities}}{70 \text{ years}}$$

$$1.4 \times 10^{4} \frac{\text{man-rem}}{70 \text{ years}} \cdot 3.0 \times 10^{-4} \frac{\text{genetic defects}}{\text{man-rem}} = 4.2 \frac{\text{genetic defects}}{70 \text{ years}} \quad (150)$$

TABLE F-57

HEALTH EFFECTS FROM MAX/MIN ACCIDENT INVOLVING ENRICHED URANIUM

Organ	Cancer Fatalities	Genetic Defects
Total Body	3.5×10^{-3}	5.2×10^{-3}
Lung	7.6×10^{-1}	
Liver	3.5×10^{-3}	
Bone	2.4×10^{-3}	
	7.7×10^{-1}	5.2×10^{-3}

Calculation of the decontamination cost resulting from a radioactive release is carried out in the Sandia document. For the Rocky Flats plutonium accident, equation 151 calculates the activity released.

$$4500 \frac{\text{g}}{\text{container}} \cdot 12 \frac{\text{containers}}{\text{vehicle}} \cdot 0.879 \frac{\text{Ci}}{\text{g}} \cdot 0.05 \text{ aerosoized} = 2.4 \times 10^{2} \text{ Ci} \quad (151)$$

Graph 4-7 in the Sandia document shows a decontamination cost of 1.72×10^{8} dollars from such a release.

The probability of this max/min accident occuring is very low. Tables F-41 and F-42 give the probability as calculated in equation 152.

$$6.6 \times 10^{-7} \frac{\text{accident}}{\text{mile}} \quad 1.5 \times 10^{-5} \text{ Class VIII accident} \cdot 5 \times 10^{-2} \text{ in high population density zone}$$
$$\cdot 6.2 \times 10^{5} \frac{\text{miles}}{\text{year}} = 3.1 \times 10^{-7} \text{ year}^{-1} = \text{once in } 3.3 \times 10^{6} \text{ years} \quad (152)$$

F.4 REFERENCES

Adcock, F. E. and W. F. Wackler. RFD Container -- Model 1518 For Fissile Class II and Class III Shipments. RFP-1042, April 8, 1968.

Adcock, F. E. and J. D. McCarthy. ATMX - 600 Railcar Safety Analysis Report For Packaging (SARP). RFP-2244, Oct. 1974.

Anspaugh, L. R., J. H. Shinn, P. L. Phelps and N. C. Kennedy. "Resuspension and Redistribution of Plutonium in Soils." Health Physics, Vol. 29, No. 4, October, 1975.

Baker, D. A., User Guide for Computer Program FOOD. BNWL-2209. Battelle Pacific Northwest Laboratories. February, 1977.

Baker, D. A., G. H. Hoenes and J. K. Soldat. "FOOD - An Interactive Code To Calculate Internal Radiation Doses from Contaminated Food Products." Environmental Modeling and Simulation, Proceedings of a Conference Held in Cincinnati, OH, April 20-22. USEPA, Washington, DC., 1976.

Brenchley, D. L., J. K. Soldat, J. A. McNeese and E. C. Watson. Environmental Assessment Methodology for the Nuclear Fuel Cycle. BNWL-2219. Battelle Pacific Northwest Laboratories. July, 1977.

CDH. A Risk Evaluation for the Colorado Plutonium-in-Soil Standard. Colorado Department of Health. January, 1976.

Church, H. W., R. E. Luna and S. M. Milly. Operation Roller Coaster: Near Ground Level Air Sampler Measurements. SC-RR-69-788. Sandia Laboratories. February, 1970.

DuCharme, A. R., R. E. Akins, S. L. Daniel, D. M. Ericson, Jr., B. H. Finley, N. N. Finley, P. D. Kaestner, D. D. Sheldon, J. M. Taylor and M. S. Tierney. Transport of Radionuclides in Urban Environs: Working Draft Assessment. SAND 77. Sandia Laboratories, Albuquerque, New Mexico, May, 1978.

Flectcher, J. F. and W. L. Dotson (compilers). HERMES - A Digital Computer Code for Estimating Regional Radiological Effects from the Nuclear Power Industry. HEDL-TME-71-168. 1971.

Healy, J. W.. An Examination of the Pathways from Soil to Man for Plutonium. LA-6741-MS. Los Alamos Scientific Laboratories. April, 1977.

Hoenes, G. R. and J. K. Soldat. Age - Specific Radiation Dose Commitment Factors for a One-Year Chronic Uptake. NUREG-0172. Battelle Pacific Northwest Laboratories for U.S. Nuclear Regulatory Commission. November, 1977.

Houston, J. R., D. L. Strenge and E. C. Watson. DACRIN - A Computer Program for Calculating Organ Dose from Acute or Chronic Radionuclide Inhalation. BNWL-B-389. Battelle Pacific Northwest Laboratories. December, 1974, (Reissued April, 1976).

ICRP. Radiation Protection, Recommendations of the International Commission on Radiological Protection, Report of Committee II on Permissible Dose for Internal Radiation. ICRP Publication 2. Pergamon Press, New York, 1959.

ICRP. Radiation Protection. International Commission on Radiological Protection (ICRP) Publication 6. 1962.

ICRP. Task Group on Lung Dynamics. "Deposition and Retention Models for Internal Dosimetry of the Human Respiratory Tract". Health Physics, Vol. 12. 1966.

ICRP. The Metobolism of Compounds of Plutonium and Other Actinides. International Commission on Radiological Protection (ICRP) Publication 19. 1972.

ICRP. Report of The Task Group on Reference Man. International Commission on Radiological Protection (ICRP) Publication 23. 1975.

Kennedy, Jr., W. E.. Private Correspondence. Battelle Pacific Northwest Laboratories. September, 1978.

Krey, P. W. and E. P. Hardy. Plutonium in Soil Around the Rocky Flats Plant. HASL-235. U.S. Atomic Energy Commission, Health and Safety Laboratory, New York, New York. August, 1970.

Strenge, D. L., E. C. Watson and J. R. Houston. SUBDOSA - A Computer Program for Calculating Doses from Accidental Atmospheric Releases of Radionuclides. BNWL-B-351. Battelle Pacific Northwest Laboratories. June, 1975.

Turbey, D. K. and S. V. Kaye. The EXREM-III Computer Code for Estimating External Radiation Doses to Populations from Environmental Releases. ORNL-TM-4322. Oak Ridge National Laboratory. December, 1973.

Turner, B. D. Workbook of Atmospheric Dispersion Estimates. U.S. Environmental Protection Agency. 1970.

USEPA. Proposed Guidance on Dose Limits for Persons Exposed to Transuranium Elements in The General Environment, Summary Report, Annex III: Risk to Health Due to The Inhalation and Ingestion of Transuranium Nuclides. U.S. Environmental Protection Agency. September, 1977.

USHEW. Supporting Documentation for Proposed Recommendations In Case of the Accidental Radiation Contamination of Food and Animal Feeds. Department of Health, Education, and Welfare, Food and Drug Administration, Bureau of Radiological Health. Rockville, Maryland. May, 1978.

USNRC. Technology, Safety, and Costs of Decommissioning a Reference Nuclear Fuel Reprocessing Plant. NUREG-0278. U.S. Nuclear Regulating Commission. October, 1977.

USNRC. Final Environmental Statement on The Transportation of Radioactive Material by Air and Other Modes. NUREG-0170. U.S. Nuclear Regulatory Commission. December, 1977.

World Almanac. World Almanac and Book of Facts. Newspaper Enterprises Association, Inc. New York, New York. 1978.

APPENDIX G

PLUTONIUM TOXICITY

Appendix G consists of four reports dealing with health effects related to plutonium toxicity.

Appendix G-1 entitled "Health Effects from Transuranic Element Exposure" was prepared by R. C. Thompson and W. J. Bair.

Appendix G-2 entitled "Cancer Risk from Focal Deposits of Alpha-Emitting Radionuclides in Lung Tissue" was prepared by R. G. Cuddihy and W. C. Griffith.

Appendix G-3 entitled "Nontechnical Discussion of Plutonium and the basis of its Health Standards" was prepared by R. E. Yoder.

Appendix G-4 is entitled "Rocky Flats Facility Technical Assessment Document" and was prepared by the U.S. Environmental Protection Agency.

APPENDIX G-1

Health Effects from Transuranic Element Exposure

R. C. Thompson and W. J. Bair

Prediction of the human health consequences attributable to the release of plutonium and americium to the environment from Rocky Flats operations is necessarily indirect and highly uncertain. There is a lack of any positive information on effects of these elements in either man or experimental animals at the very low exposure levels anticipated. There also is a lack of understanding of the mechanisms by which such effects occur. This understanding, if available, would aid in the extrapolation of data obtained at much higher exposure levels. Data relevant to such predictions are considered in this Appendix under four general headings: (1) experience with transuranic elements in man, (2) experience with natural radiation in man, (3) data from animal experiments on plutonium toxicity, and (4) data on effects of other types of radiation on man. Consideration will be given to the general problems of extrapolation from animal to man, and extrapolation from the exposure levels producing observable effects, to the very much lower exposure levels predicted to result from Rocky Flats operations. The controversy regarding the influence of spatial distribution of dose on resultant biological effects will also be addressed.

The general approach followed in this appendix is that of Appendix II.G of the LMFBR Environmental Statement[1] with modifications reflecting the newer information now available.

G.1 EXPERIENCE WITH TRANSURANIC ELEMENTS IN MAN

No life-threatening effects attributable to transuranic elements have been observed in man. Evidence of effects at the cellular level (e.g. histologically observed effects surrounding a plutonium-contaminated wound[2,3] and possible increases in chromosome aberrations following accidental exposure[4]) cannot be related to exposure levels in any manner useful to predictive analysis. A recent accident in which a radiation worker in Hanford, Washington was exposed to gross external and substantial internal contamination with ^{241}Am resulted in pain and disablement, however these effects are attributed primarily to the isolation required and to treatment procedures for acid burns and for removal of americium and nonradioactive foreign materials.[5] Consideration must therefore be directed toward the kind and magnitude of exposures that have occurred without evidencing effects. Such exposures arise from two principal sources: the world-wide plutonium fallout from atmospheric testing of nuclear weapons and other devices, and the accidental exposure of plutonium workers.

Exposure to Fallout Plutonium

As the result of atmospheric testing of nuclear weapons, an estimated 320 kilocuries of long-lived plutonium isotopes have been deposited on the surface of the earth, of which about 250 kilocuries is deposited on the northern hemisphere and 16 kilocuries on the United States.[6,7] Measurements of this plutonium in the air, in soil, in foods, and in man constitute a "natural" experiment of pertinence to the estimation of the biological behavior of transuranic elements released from Rocky Flats.

Estimates of human organ burdens and doses resulting from fallout plutonium have been made by Bennett, employing the ICRP lung model and the data on New York City plutonium air concentrations (measured since 1965 and estimated prior to that date by analogy with measured strontium-90).[8] Assuming no intake subsequent to 1972 and calculating cumulative dose to the Year 2000, Bennett arrived at the estimates given in Table G-1. These estimates assume no intake by ingestion and involve a cumulative inhalation intake from 1954 to 1972 of 42 picocuries (1 picocuries = 10^{-12} curies) per person, or 8 millicuries total for a present U.S. population of about 2×10^8. For comparison, Table G-1 also lists the estimated dose from 70 years of routine Rocky Flats Plant releases. Though the true periods are not the same, this comparison helps to achieve some perspective. Note also that the estimates of dose from fallout are based upon measured values, while the estimates of dose from Rocky Flats releases are based upon conservative assumptions.

TABLE G-1
ESTIMATED RADIATION DOSE TO THE 1977 ROCKY FLATS AREA POPULATION
FROM FALLOUT PLUTONIUM AND FROM 70 YEARS OF ROUTINE PLANT RELEASES
(million man-rem)

Organ	Dose Equivalent to the Year 2000 from Fallout Pu[a]	Dose Equivalent from 70 Years of Routine Releases[b]
Lung	0.029	0.008
Bone	0.061	0.028
Liver	0.031	0.012

a. Per capita estimate of Bennett, based on New York City air concentrations,[8] multiplied by 1.8 million population within 50-mile radius of Rocky Flats Plant (see Table 2.3.3-2 in Chapter 2).
b. Taken from Table 3.1.2-8 in Chapter 2.

Direct measurements have been made of fallout plutonium in autopsy samples. Because the plutonium levels are at the lower limits of analytical capabilities, many of the earlier values reported were highly uncertain. A recent summary of carefully evaluated autopsy data collected from many states over a period extending from 1959

to 1976 provides the data shown in Table G-2.[9] The measured organ concentrations listed are 50th percentile values (50% of individual samples are lower) from more than 170 autopsies. Also shown in Table G-2 are computed estimates of plutonium concentration in tissues based on the New York plutonium air concentrations and the ICRP lung model. The agreement is quite good, except for lymph nodes. The low measured value in lymph nodes may reflect a greater solubility of fallout plutonium than assumed in the model. Proportionately larger amounts of plutonium are observed in the lymph nodes of experimental animals and plutonium workers exposed to insoluble plutonium oxide.

TABLE G-2
CONCENTRATION OF FALLOUT PLUTONIUM IN MAN
(pCi/kg)

Organ	Autopsy Data[9] 1959-1976	Computed Estimates[8] 1964	1974
Bone (vertebra)	0.50	0.08	0.20
Liver	0.58	0.23	0.54
Lung	0.24	2.48	0.12
Lymph Nodes	2.42	43.0	27.0
Kidney	0.06	0.03	0.06
Gonads	0.13	0.02[a]	0.12[a]

[a] Estimated on the assumption that 0.05% of the total body burden is present in 10 g of ovaries.

While these data on fallout plutonium in man cannot be linked to any measured effects, they do indicate that such unmeasurable effects in the general population around the Rocky Flats site will be more numerous than the most conservatively estimated effects from Rocky Flats operations.

Occupational Exposure

The U.S. Transuranium Registry was established in 1968 to obtain information on persons occupationally exposed to plutonium and other transuranium elements. It is operated by the Hanford Environmental Health Foundation, with cooperation from Pacific Northwest Laboratory, Los Alamos Scientific Laboratory, and the Rocky Flats Plant. The Registry seeks to identify potentially exposed workers, obtain their health physics and medical records, and their permission for postmortem sampling. Registry operations are summarized in Table G-3.[10] More than 14,000 persons have been specifically identified as having been employed in operations that might lead to significant plutonium exposure. Note that Rocky Flats has contributed more than half of all autopsies performed to date for the Transuranium Registry; Rocky Flats continues to

encourage all workers to participate in the Transuranium Registry. Permission for postmortem sampling and for access to medical records is at the workers' discretion. The accumulating autopsy data are in general agreement with data on the distribution of plutonium in experimental animals, and thus support the extrapolation of animal toxicity data to man.

TABLE G-3
STATISTICS ON OCCUPATIONAL EXPOSURE FROM THE U.S. TRANSURANIUM REGISTRY
OCTOBER, 1977[10]

	Number of Persons for whom Registry Has:			
Location	Specific Identification	Release of Health Physics and Medical Records	Authority For Autopsy	Autopsy Performed
Hanford	7,079	2,244	535	24
Rocky Flats	2,129	1,960	209	42
Los Alamos	3,025	258	126	4
Savannah River	1,683	167	92	0
Mound	334	9	10	1
Oak Ridge	14	0	0	1
Elsewhere	122	106	13	1
Total	14,386	4,744	985	73

An epidemiologic study of workers exposed to plutonium at DOE installations has been underway since 1974.[11] Data on mortality and morbidity in these workers are being collected and followup through at least 1990 is anticipated. The numbers of exposed workers, grouped according to estimated deposition level, are shown in Table G-4. Additional workers potentially exposed to plutonium, but with estimated deposition levels lower than 1 nanocurie, will be studied as controls.

TABLE G-4
DOE CONTRACTOR EMPLOYEES WITH ESTIMATED PLUTONIUM DEPOSITIONS
IN EXCESS OF 1 NANOCURIE AS IDENTIFIED FOR EPIDEMIOLOGIC STUDY[11]

Number of Persons	Estimated Deposition Range (10^{-9} Ci)
141	20 or more
885	4 - 20
3,725	1 - 4

One group of exposed persons is of particular interest because of their early exposure, their relatively high level of exposure, and the thoroughness of the follow-up studies.[12] These 25 laboratory workers were exposed during 1944 and 1945 while working at what is now the Los Alamos Scientific Laboratory, under conditions that would be judged crude and unacceptable by today's standards. Their individual body

burdens are estimated to range from 5 to 420 nanocuries, totaling, in the aggregate, about 2.5 microcuries. These burdens have now been retained for more than 30 years. One of the 25 died of a coronary occlusion at age 33, and another died as the result of an automobile accident. None have shown medical findings attributable to internally deposited plutonium.

Another group of plutonium workers of particular interest are the 25 workers with initial lung burdens greater than 0.04 microcuries who were exposed during the Rocky Flats Plant fire of 1965.[13] Aside from the cytogenetic effects noted below, there have been no detectable medical effects observed in these workers.

An increased incidence of chromosome aberrations in lymphocyte culture is a very sensitive indicator of radiation exposure. An increased incidence of such chromosome aberrations has been reported in plutonium-exposed Rocky Flats Plant employees.[4] Even though continuing studies on these workers indicate a linear dose-response relationship between systemic plutonium burden and aberration frequency, the results do not appear to be useful for predicting ultimate health effects. An increased incidence of chromosome aberrations was also observed in English plutonium workers, but could not be differentiated from possible effects of external irradiation.[14] In any case, the occurrence of these chromosome aberrations in cultured lymphocytes is not known to relate, in any way, to ultimate biological effects influencing survival.

In view of the relatively small number of persons with sizable plutonium depositions, it seems unlikely that statistically valid inferences with regard to toxic effects will ever be made. This would not be true, however, if plutonium were markedly more toxic than is currently believed. Thus, the 2.5 microcuries presently retained by the Los Alamos subjects must have amounted to about 10 microcuries originally deposited, which, after 30 years, should have shown significant effects if the cancer risk were as high as postulated by Tamplin and Cochran.[15] This point was convincingly made in a paper by Cave and Freedman.[16]

G.2 EXPERIENCE WITH NATURAL RADIATION IN MAN

Experience with transuranic elements in man is limited to the present generation. Other alpha-emitting elements, however, are a natural part of man's environment. He has lived with these internally deposited radioelements and with radiation from other natural sources throughout the history of the species. An estimate of the radiation doses to Denver area residents from these natural sources is presented in Table 3.1.2-6 of Chapter 3.[17] Whether one compares the maximum exposed individual or the average Denver area resident, the estimated radiation exposure due to Rocky Flats operations is a very small fraction of this natural background exposure.

G.3 EFFECTS OF TRANSURANIC ELEMENTS IN EXPERIMENTAL ANIMALS

Direct information on the toxicity of transuranic elements is available only from studies in experimental animals. The radiobiological literature suggests that the biological effects observed in such animal experiments will at least qualitatively approximate those that would occur in man exposed under the same conditions. For this reason, it is important to look to the extensive results of animal experimentation for guidance in estimating the health risks from exposure to transuranic elements.

The acute toxicity of injected plutonium is due primarily to destructive effects on the blood-forming system, resulting from irradiation of the bone marrow by plutonium deposited on bone surfaces, or released from these surfaces into the marrow.[18,19] In the case of inhaled plutonium, acute death in experimental animals results from pulmonary edema, hemorrhage, and inflammatory destruction of the functional tissue of the lung.[19,20]

Acute toxicity is conventionally expressed in terms of an "LD_{50}" dose; i.e., the dose required to kill 50% of the animals within some specified period of time, usually 30 days. For intravenously injected tetravalent plutonium-239 citrate, in rats, the $LD_{50/30}$ is about 70 microcuries per kilogram. A similar value was observed for mice. A somewhat lower value, 20 microcuries per kilogram was observed in dogs; however, this was with injected hexavalent plutonium. The $LD_{50/30}$ for inhaled plutonium in rats and dogs was not very different from the values for injected plutonium. All of these dose values will vary somewhat depending on the compound administered and the valence state of the plutonium. It seems unlikely, however, that acute death would result from an internally deposited dose of less than 10 microcuries per kilogram, which translates to 700 microcuries for a 70-kilogram man. This amounts to about 10 milligrams of plutonium-239, or about 40 micrograms of plutonium-238.[19]

Long-term effects occur at very much lower exposure levels than those required to produce acute death, and it is these long-term effects that are the only concern at the very low exposure levels that might result from Rocky Flats releases. The incidence of cancer appears to be the most sensitive measure of these long-term effects. The organs in which plutonium is retained in highest concentrations are the bone, liver, lung, and lymph nodes. In all of these organs, tumor formation has been observed in animals as a result of plutonium deposition, most significantly in bone and lung.

Effects in Bone

An informative experiment on the toxic effects of plutonium in bone is the beagle study in progress at the University of Utah. This experiment was initiated in 1952 and was designed to compare the long-term effects of intravenously injected plutonium and radium. The comparison with radium is of particular interest because extensive data are available on the toxicity of radium in man.

Table G-5 shows the status of the plutonium-injected animals in this experiment.[21] In the earliest injected groups, all animals are now dead. In all of these groups, there was a very substantial incidence of bone cancers. With decreasing dose, the time to tumor appearance increased until, in the lowest dose group, the average life span was not significantly different from that of the controls. Additional groups at lower dose levels were exposed beginning in 1964. Several bone tumors have been observed in these groups, but most of the animals are still alive and no estimate of incidence is meaningful at this time.

TABLE G-5
PLUTONIUM-INDUCED BONE CANCERS IN UTAH DOG STUDY[21]

Injected Dose (μCi/kg)[a]	Dogs with Bone Cancer			
	Tumor Incidence	Years to Death	Dose to Skeleton[b] (rad)	(rem)
2.9	7/9 = 78%	4.1	4710	235,500
0.9	12/12 = 100%	3.6	1410	70,500
0.3	12/12 = 100%	4.5	581	29,050
0.1	10/12 = 83%	7.2	231	11,550
0.05	10/14 = 71%	8.9	135	6,750
0.016	4/14 = 29%	9.9	55	2,750
Controls	0	11.5 (for all control dogs)		

a. Additional studies are in progress at dose levels of 0.016, 0.006, 0.002, and 0.0006 microcurie per kilogram.

b. Cumulative dose to one year before death.

Of more interest than absolute cancer incidence figures, is the finding in the Utah studies that plutonium-239 is radiologically 16 times more toxic than radium-226, on the basis of the same total energy delivered to bone.[21] This difference is attributable to the more hazardous localization of plutonium on bone surfaces, near the cells from which bone tumors originate.

A number of long-term studies in rodents have also pointed to bone cancer as the most sensitive indicator of the toxicity of injected plutonium. Cancer incidence data from some of these studies are summarized in Table G-6. These data were selected from a more extensive tabulation by Bair,[22] and include only experiments or experimental groups meeting the following criteria: (1) radiation dose to bone was evaluated in the study, (2) more than one exposure level was studied, (3) cancer incidence did not exceed 50 percent, and (4) life shortening was not excessive. These criteria should help to exclude results showing a misleadingly low cancer incidence due to saturation effects or early death from other causes.

It should be noted that calculation of the rem doses listed in Table G-6 involves the use of a quality factor of 10 and a distribution factor of 5; rem doses are therefore 50 times the rad doses. The bone cancer incidence per rem shows rather close agreement, both within and between experiments. This suggests that cancer incidence is an approximately linear function of radiation dose to bone over the ranges studied, that it is not greatly influenced by the compound or route of administration, and that mice, rats, and dogs show a similar sensitivity, although dogs appear to be more sensitive than rodents. These similarities of behavior lend confidence to the use of these numbers for the estimation of effects in man.

TABLE G-6

PLUTONIUM-INDUCED BONE CANCERS IN EXPERIMENTAL ANIMALS[22]

Species	Administration		Bone Dose Equivalent (rem)	Bone Cancer Incidence	
	Compound	Route		Fractional	Per rem
Mouse	Citrate	Intravenous	2000	0.039	2.0×10^{-5}
			4200	0.08	1.9×10^{-5}
			6500	0.180	2.7×10^{-5}
			20000	0.430	2.2×10^{-5}
Rat	Citrate	Inhaled	830	0.013	1.6×10^{-5}
			1640	0.056	3.4×10^{-5}
			3820	0.025	0.7×10^{-5}
			6700	0.032	
			12200	0.11	0.9×10^{-5}
			17800	0.19	1.0×10^{-5}
Rat	Citrate	Oral	1650	0.03	1.8×10^{-5}
			2850	0.074	2.6×10^{-5}
Rat	Citrate	Intra- and Subcutaneous	2600	0.04	1.5×10^{-5}
			25650	0.25	1.0×10^{-5}
Rat	Carbonate	Inhaled	180	0.01	5.6×10^{-5}
			320	0.011	3.4×10^{-5}
			1260	0.031	2.5×10^{-5}
			6000	0.12	2.0×10^{-5}
Rat	Nitrate	Intratracheal	2565	0.016	0.6×10^{-5}
			5850	0.04	0.7×10^{-5}
			20900	0.09	0.4×10^{-5}
			44000	0.13	0.3×10^{-5}
Dog[a]	Citrate	Intravenous	2750	0.29	10.5×10^{-5}
			6750	0.71	10.5×10^{-5}
			11550	0.83	7.2×10^{-5}

a. Data of Reference 22 altered to reflect more recent data reported in Reference 21.

Effects in Lung

The toxicity of inhaled plutonium may be illustrated with data from an experiment conducted at Pacific Northwest Laboratory, involving the inhalation of $^{239}PuO_2$ by beagle dogs.[23] This experiment was initiated in the late 1950's; it involved some 65 dogs, the last of which died in 1973. Of the 21 dogs that survived more than 4.5-years postexposure, 20 had malignant lung tumors. Tumor incidence figures are therefore of little help in interpreting these results. Life-shortening, however, showed a dose-effect relationship, as indicated in Figure G-1. Each point in this figure represents a dog. Most of the dogs died early, within a year or two following plutonium exposure, with symptoms of respiratory distress occasioned by severe pulmonary fibrosis. There appears to be about a 3-year minimum latency period before a lung cancer can develop; a longer latency period is associated with smaller doses. A line fitted to all of these points intersects the normal life span of the beagle dog at a deposition of about 5 nanocuries per gram of lung. This extrapolation is very uncertain, however. If one draws the best line through the closed circles (the tumor-bearing animals), a steeper slope is obtained. Clearly, more data are needed from dogs exposed at lower levels. Experiments to obtain these data are in progress.[23]

The utility of the Pacific Northwest Laboratory beagle data is limited because of the relatively few animals in the study and the high exposure levels, which resulted in essentially 100% lung cancer incidence. These data are included only to illustrate the relationship between latency prior to the appearance of lung tumors and the quantity of plutonium inhaled--a relationship which suggests that at lower concentration levels, the latency period may exceed the normal life span of these animals.

Data on the induction of lung tumors in rats that inhaled compounds of plutonium or americium were recently reviewed by Bair and Thomas.[24] Their conclusions are summarized in Table G-7. The rem doses for lung are 10 times the rad doses, reflecting a quality factor of 10, but no distribution factor. The incidence per rem is substantially higher for lung tumors in rats than for bone tumors in rats (See Table G-6).

Effects in Other Organs

In terms of plutonium content and radiation dose received, liver is in the same class with bone and lung. However, the liver seems less radiosensitive than bone and lung. Malignant liver tumors were the primary cause of death in two of 96 plutonium dogs in the Utah experiment.[25] Small, benign, bile duct tumors were incidental findings at autopsy in eight other dogs, but such tumors were also seen in controls at a somewhat lower incidence. The liver tumors showed a typically long latent period, which suggests that at lower dose levels, and lower incidences of bone and lung tumors, liver tumors might become more important relative to bone and lung tumors.

TABLE G-7

LUNG CANCER IN RATS FOLLOWING INHALATION OF ALPHA-EMITTING PLUTONIUM OR AMERICIUM COMPOUNDS[a]

Chemical Form Inhaled	Cancer Incidence Per Rem		
	Mean	Maximum[b]	Minimum[b]
"soluble"	8×10^{-5}	10×10^{-5}	6×10^{-5}
"insoluble"	16×10^{-5}	20×10^{-5}	13×10^{-5}

a. Data from Reference 24.

b. 95% confidence interval.

Lymph nodes draining the lung, or sites of intramuscular plutonium deposition, may accumulate plutonium concentrations many times higher than concentrations seen elsewhere in the body. Various histopathologic changes have been observed in the tracheobronchial lymph nodes of dogs that inhaled plutonium, but these changes were not obviously detrimental. Tumors have been seen only rarely, and their relationship to plutonium exposure is uncertain. Indirect effects on immune capability or on lymph drainage are considered most unlikely at the low levels of exposure projected.[22,23] The ICRP, while recognizing the higher burdens and dose commitments in the lymph nodes relative to the lungs, skeletal system, and liver, has not considered the thoracic lymph nodes to be a critical organ.[26]

Effects on the production or survival of the various types of blood cells have been studied in many of the experiments on plutonium toxicity. A variety of such effects are noted at high exposure levels.[19] The most sensitive of these effects is probably the reduction in blood lymphocytes following deposition of plutonium in the lung.[23] One cannot rule out the possibility of a relationship between this effect on lymphocytes, lymph node pathology, decreased immunological capability, and the pathogenesis of plutonium-induced lung tumors.

Since plutonium on bone surfaces will irradiate portions of the bone marrow, concern has been expressed that leukemia might be an important delayed effect of plutonium exposure. Although leukemias have, in rare instances, been reported to result from plutonium exposure, they have occurred only following rather large doses, and at a much lower incidence than bone tumors.[18,27]

Plutonium deposited in testes or ovaries would be of concern only because of possible genetic effects. While studies of multi-generation genetic effects have not been performed, an investigation of cytogenetic effects in the testes of hamsters showed no significant increase in the frequency of chromosome aberrations after calculated radiation doses of 1 and 4 rads.[28] The exposures employed in this study would result in significant life shortening and cancer induction, suggesting that

genetic risks are small compared to somatic risks. Studies of chromosome aberrations in the germ cells of male mice after protracted exposure to ^{239}Pu, with doses ranging from 14 to 44 rads, showed significant effects, in agreement with predictions based on previous studies with gamma ray and neutron exposures and assumed radiobiological effectiveness (RBE) and distribution factors.[29] On the other hand, a study comparing the effectiveness of tritium and ^{239}Pu in producing chromosome aberrations in the insect chironomus riparius showed no evidence for a higher relative biological effectiveness for plutonium.[30] Recent studies in mice have indicated that the critical spermatogonial stem cells of the testis may receive a 2 to 2.5 times higher dose from deposited plutonium than the average for the testis, due to the inhomogeneities of distribution;[31] however, such an enhanced effect is not expected in man because of the greater amount of interstitial tissue in human testes.[32] For the ovary, data from studies in the hamster indicate that the genetically significant dose rate to viable oocytes is likely to be lower than the average dose rate to the organ as a whole.[33] In any case, the total deposition of transuranics in the gonads is low, in all animal species studied, and dose to sensitive gonadal cells would not be expected to exceed the total body average.[34]

G.4 EFFECTS OF OTHER TYPES OF RADIATION IN MAN

In the absence of data on the effects of transuranic elements in man, some inferences regarding these effects may be drawn from observations of the effects from other forms of ionizing radiation in man. Such inferences would be based on data derived from medical, occupational, accidental, or wartime exposure of humans to different radiation sources: external X radiation, atomic-bomb gamma and neutron radiation, radium, radon and radon daughters, etc. Such information has been summarized by the National Academy of Sciences - National Research Council Committee on the Biological Effects of Ionizing Radiations,[35] and more recently by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR),[36] and by the International Commission on Radiological Protection (ICRP).[37] All of these risk estimates are linearly extrapolated from human experience at relatively high dose rates and total doses; the validity of such extrapolations will be discussed later in this Appendix.

Cancer Effects

The extensive human data considered in the BEIR report will not be reviewed here; it should be noted, however, that effects of irradiation from external rather than internal sources, in particular the data from Japanese atomic bomb survivors and irradiated spondylitics, were heavily weighted in arriving at risk estimates. The BEIR report makes estimates of both absolute risk and relative risk and for each of these assumes either a 30-year or a duration-of-life interval following the latent period, during which risk remains elevated. This leads to four risk estimates. Only the two estimates which lead to the lowest and the highest predictions of cancer

mortality are considered here; the lowest being the absolute risk model with a 30-year plateau, referred to as the "absolute model," and the highest being the relative risk model with a lifetime plateau, referred to as the "relative model." Each of these models makes separate risk estimates for the in utero, 0-9 years, and 10+ years age periods, reflecting age differences in the sensitivity to irradiation. The derivation of these risk estimates and their application to the U.S. population is summarized in tables on pp. 169 and 171 of the BEIR report,[35] where the excess deaths due to cancers other than leukemia for the U.S. population, per 0.1 rem, per year, are predicted as 1,210 by the "absolute model" and 8,340 by the "relative model."

The fraction of these non-leukemia cancers that are bone cancers is given as 0.04, and the fraction that are lung cancers is given as 0.26. No fraction is given for liver cancers, which fall in the BEIR report's "GI including stomach" category, which is 0.20 of the non-leukemia cancers. It is assumed that these cancers will be induced in direct proportion to their incidence in the Hiroshima-Nagasaki survivors, where primary liver cancers accounted for about 0.08 of the GI cancers. Therefore, 0.016 (the product of 0.08 and 0.20) is considered the fraction of the total non-leukemia risk that is attributed to liver cancers.

Taking the fraction of the predicted non-leukemia cancers attributable to each cancer type and converting population dose to a man-rem basis, one arrives at the risk estimates shown in Table G-8. Leukemia risks were not estimated because dose to bone marrow from bone-deposited transuranic elements is small compared to the dose to other organs, and because leukemia has been only infrequently seen in animal experiments with plutonium.[18,27]

The cancer risk from irradiation of thoracic lymph nodes was also neglected, even though these nodes, in experimental animals, receive a radiation dose from plutonium that is higher than the dose to any other organ.[22] The incidence of lymphosarcoma, reticulosarcoma, Hodgkin's disease, and/or multiple myeloma has been observed to be increased in Japanese atomic bomb survivors,[38-40] in patients receiving radiotherapy for ankylosing spondylitis,[41] and in radiologists who entered practice in the days preceding current restrictions on occupational exposure.[42] For this reason, the lymphoid and reticular tissues were classified by an ICRP Task Group[43] as being "apparently" high in susceptibility to the carcinogenic effects of radiation; however, it was noted by the Task Group that at least some of the neoplasms included in this group (e.g. multiple myeloma) appear to arise in the bone marrow. Whether, in fact, any of these neoplasms is attributable to transformation of cells in lymphoid tissues, as opposed to transformation of precursor cells in the bone marrow, is debatable in light of current concepts of cell population kinetics in the lymphatic and reticular system. At present, therefore, in the absence of evidence that localized irradiation of lymphatic tissue is carcinogenic in human or animal populations, it seems inappropriate to attempt to estimate such cancer risks.

TABLE G-8

DERIVATION OF CANCER MORTALITY RISK ESTIMATES FROM BEIR REPORT ESTIMATES[1]

1	2	3	4	5
Cancer Type	Risk Model[a]	Fraction of Non-Leukemia Cancers[b]	Predicted Excess Deaths per Year per 0.1 Rem per Year Continuous Exposure of U.S. Population[c]	Predicted Excess Deaths per Man-Rem[d]
Non-leukemia	"Absolute"	1.0	1,210	
	"Relative"	1.0	8,340	
Lung	"Absolute"	0.26	315	16×10^{-6}
	"Relative"	0.26	2,168	110×10^{-6}
Bone	"Absolute"	0.04	48	2×10^{-6}
	"Relative"	0.04	334	17×10^{-6}
Liver	"Absolute"	0.016	19	1×10^{-6}
	"Relative"	0.016	133	7×10^{-6}

a. "Absolute" refers to BEIR report absolute risk model with 30-year plateau following latent period during which risk remains elevated. "Relative" refers to BEIR report relative risk model with lifetime plateau.

b. Fractions given in BEIR report (p. 171) for age 10 or more assumed to apply to all categories. Fraction for liver cancers is not given in BEIR report, but estimated as explained in text.

c. Non-leukemia deaths taken from BEIR report (p. 169). Others calculated by application of fractions listed in Column 3.

d. Calculated from numbers in Column 4 by multiplying by 10 (converting to rem basis) and dividing by 2×10^8 (U.S. population total employed in derivation of Column 4 numbers).

The BEIR report cancer risk estimates are compared in Table G-9 with risk estimates derived from several other sources. The recommendations of the ICRP[37] were largely based upon, and therefore agree closely with, the numbers published by UNSCEAR in 1977.[36] The UNSCEAR risk estimates generally fall between the high and low estimates of the BEIR report. While the BEIR report gave no specific estimate of liver cancer risk, UNSCEAR derives such a number, based largely on recently summarized data, on the induction of liver cancer by "Thorotrast," a preparation of thorium dioxide.[44] England's Medical Research Council (MRC) published risk estimates which it considered to be specifically applicable to plutonium;[45] these are listed in Table G-9, and do not differ markedly from the UNSCEAR numbers.

TABLE G-9

COMPARISON OF TRANSURANIC HEALTH RISK ESTIMATES

(Cancer death or genetic defects per 10^6 organ-rem.)

	Human Risk Estimates							
	BEIR[35]							
	High[a]	Low[a]	UNSCEAR[36]	ICRP[37]	MRC[45]	Mays[50,74]	New-combe[49]	Data From Animals
Lung Tumors	100	16	25-50	20	25	20		60-200[c]
Bone Tumors	17	2	2-5[b]	5[b]	5	4		10-100[d]
Liver Tumors	7	1	10	10	20	10		
Genetic Defects[e]	1500	60	185	200	300		10	

a. As derived in Table G-8.

b. Expressed as risk per 10^6 rad of low level radiation to endosteal cells, which should be roughly equivalent to risk per 10^6 rem of alpha radiation averaged throughout bone.

c. Data from Reference 24 (see Table G-7).

d. Data from Reference 21 (see Table G-6).

e. Defects in all subsequent generations, including specific genetic defects and defects with complex etiology (see Table G-10).

Also of interest are recently accumulated data on the carcinogenicity or radium-224 in human bone.[46,47] These data are particularly relevant to risks from plutonium since radium-224 has a very short half-life (3.62 days) and, because of this, irradiates only the surface layer of bone, in much the same manner as plutonium. When administered repeatedly, as it was to a large number of German patients shortly after the Second World War, the resultant exposure of bone should closely mimic that received from plutonium. Based on these data, Mays, et al., estimate a bone cancer risk of 4×10^{-6} per man-rem; and present convincing arguments for concluding that, at the high dose level employed, this estimate cannot be too high or too low by more than a factor of ten.[21]

Also shown for comparison in Table G-9 are the cancer risk estimates derived from animal experiments. These estimates are somewhat higher than most of those based on human data. The problems of extrapolation of animal data to men are discussed later in this Appendix.

Genetic Effects

The genetic risks considered in the BEIR report include the full spectrum of genetic defects seen in the U.S. and other Western nations. Their effects upon the carrier may range from a lethal action occurring at any time of life (from before

birth until death), to minor metabolic consequences that may be nearly undetectable. The genetic spectrum ranges from dominant single gene mutants whose effects may be categorically recognized, to subtle genetic contributions to disease conditions that are predominantly of environmental or non-genetic origin. As a consequence, it is not appropriate to compare or equate estimates of genetic risk directly with cancer risks, where case incidence and case mortality are substantially one-to-one.

The BEIR report (pp. 54-57) summarizes its risk estimates for genetic defects in terms of a 5 rem per generation dose to a population of one million.[35] Converting these numbers to a man-rem basis, one obtains the risk estimates of Table G-10. The range of these estimates reflects a 10-fold uncertainty in the value of the mutation rate doubling dose, which is assumed to lie in the range of 20-200 rem. There is a further uncertainty with regard to the magnitude of the genetic component of the defects with complex etiology.

An additional category of genetic risk discussed in the BEIR report is that concerned with general "ill health" of uncertain genetic determination. This risk was conservatively estimated as a 0.5 to 5.0 percent increase in the equilibrium incidence of ill health per 5 rem per generation. Thus, for the total U.S. population, 10^9 man-rem per generation would increase ill health by 0.5 to 5 percent.

TABLE G-10
DERIVATION OF GENETIC DEFECT RISK ESTIMATES
FROM BEIR REPORT ESTIMATES[1]

1	2	3
Type of Risk	Predicted Defects per Million Persons per 5 Rem per Generation at Equilibrium[a]	Predicted Defects per Man-Rem[b]
Specific Genetic Defects[c]	250 - 2500	50×10^{-6} to 500×10^{-6}
Defects with Complex Etiology[d]	50 - 5000	10×10^{-6} to 1000×10^{-6}

a. Values taken from Table 4, Page 57 of BEIR report.[35]
b. Equal to values of Column 2 divided by 5×10^6.
c. Includes dominant diseases, chromosomal and recessive diseases.
d. Includes congenital anomolies, anomolies expressed later, constitutional and degenerative diseases.

Many uncertainties are involved in these genetic risk estimates, as reflected in the following statement from page 59 of the BEIR report:[35]

> It is clear that these estimates are subject to great uncertainty. The ranges of plausible values are broad, and there is no assurance that the true values are within these ranges. We are well aware that future information will necessitate revisions. The estimates are presented, not as accurate scientific information (as scientists we would prefer to defer judgment until the information is solid), but as reasonable values based on current knowledge which, crude and uncertain as they are, may serve as a better guide to rational uses of radiation than no estimates at all.

Some of the uncertainty referred to above would seem to have been resolved by recent data gleaned from the vital statistics records of the Canadian province of British Columbia.[48] These exceptionally well-organized statistics covering two million people indicate an incidence of simple dominant hereditary disease of 0.08 percent as compared to the 1 percent incidence employed in obtaining the BEIR Report risk estimates. Newcombe has argued persuasively that "the bulk of the most directly pertinent experimental studies thus fail to demonstrate any important effect of irradiation on the irregularly inherited diseases, or on general health and well being," and concludes that only the dominant hereditary diseases "are likely to increase in direct proportion to the mutation rate...."[49] On this basis, Newcombe's estimate of total genetic risk is 10×10^{-6} per man-rem.[49] UNSCEAR, in its 1977 report,[36] felt that the range of uncertainty stated in the BEIR report could be substantially narrowed, but retained a considerably larger estimate of genetic risk than that suggested by Newcombe. These various genetic risk estimates are compared in Table G-9.

G.5 ESTIMATION OF THE EFFECTS OF TRANSURANIC ELEMENTS IN MAN

Data relevant to the estimation of health effects in man have been presented in the preceding sections of this Appendix. These data, or for that matter, any experimentally obtainable data, are not adequate for the precise prediction of such possible health effects. Many assumptions must be employed, and the conclusions that are reached are meaningful only in the light of these assumptions. Particularly critical are the assumptions involved in the various extrapolations required and the assumptions involved in reducing plutonium exposure to the common denominator of radiation dose. A discussion of these problems is presented in this section.

Extrapolation from Animal to Man and to Very Low Exposure Levels

Estimation of the human risks associated with the uptake of very low levels of transuranic elements involves several kinds of extrapolation. Whether based on observations in experimental animals or man, there is the problem of extrapolating to

much lower exposure levels than are covered by the data. The available human data are for types of radiations that do not include internally deposited transuranic elements; one must extrapolate from experience with external irradiation. Experimental animal data are available for transuranic element toxicity, but then one must extrapolate from animal to man.

The extrapolation of toxicity data from animal to man is the most familiar of these extrapolation processes. That such extrapolation can be justified is an underlying assumption of most toxicological research. Where data from several animal species are in reasonable agreement, it is assumed, in the absence of conflicting evidence, that man will behave similarly. This assumption is more confidently made in the case of acute effects. For long-term effects, species differences have more opportunity to manifest themselves, and differences in life span may be of significance.

Fortunately, for the case of bone-deposited alpha-emitters, one can make some direct comparisons between human and experimental animal toxicity data. Table G-11 compares data on radium toxicity in man and in experimental animals.[21,50] In most studies, the incidence of bone cancers per rad is higher in animals than in man. For radium, the extrapolation error, from animal to man, would thus result in a conservative overestimate of effect in man. While such a conclusion cannot be confidently assumed to apply to the case of transuranium elements, the experience with radium is at least encouraging.

As noted in the previous section, the data on the effects of ^{224}Ra in man are the most applicable data for the estimation of plutonium effects in man. This is because ^{224}Ra, with its short half-life (3.62 days), irradiates only the surface layer of bone, as does plutonium.[21]

Aside from the human radium data, experience with alpha-emitters in man is of little help in these evaluations. Data on alpha-radiation-induced lung tumors in uranium miners, and liver tumors in thorotrast patients, suffer from inherent dosimetric complexities that seriously limit their usefulness. Recent studies have shown no significant excess of lung cancer in uranium miners in the dose range of 120 Working Level Months.[35,51] This dose of 120 WLM has been variously related to doses ranging from 60 rad[35] to 1,800 rad[52] to the basal cell layer of the respiratory epithelium, with 240 to 840 rad often being the range suggested.[51-53] The uranium miner data were, nevertheless, considered as one source of input in the derivation of BEIR Report risk estimates for radiation induced lung cancer.

The thorotrast-injected patients do show an increased liver cancer and leukemia incidence; however, this incidence results from the very inhomogeneous deposition of about 5 grams of thorium in the liver, which bears little dosimetric relationship to a plutonium deposition. The UNSCEAR report derives an incidence estimate of 10×10^{-6} per man-rem, based on the thorotrast data.[36]

TABLE G-11

COMPARISON OF RADIUM TOXICITY DATA IN EXPERIMENTAL ANIMALS AND MAN

	Bone Cancer Incidence per 10^6 Bone-Rad			
Radionuclide	Male Mice	Female Mice	Dog	Man
^{226}Ra	77[a]	70[a]	320[a]	
^{228}Ra		430[b]	1300[b]	
$^{226+228}Ra$				6-53[a]
^{224}Ra	73[b]	120[b]		100-200[a]

a. Data summarized in Reference 21.

b. Data summarized in Reference 50.

All observations on radiation effects, whether in animals or in man, have been made for total radiation doses, and for radiation dose rates that are much higher than the average tissue doses and dose rates that might result from releases of transuranic elements from Rocky Flats. The low incidence of effects that might still be of concern when applied to large populations are simply unmeasurable in either animal experiments or human epidemiological studies. It is necessary, therefore, to interpolate between the doses from which data on effects are available and zero dose, where zero effect can be assumed. For the estimates of health effects made in this Statement, we have based this interpolation on an assumed linear dose-effect relationship. The BEIR report (page 97) justifies such a procedure in the following words:[35]

> In view of the gaps in our understanding of radiation carcinogenesis in man, and in view of its more conservative implications, the linear, non-threshold hypothesis warrants use in determining public policy on radiation protection; however, explicit explanation and qualification of the assumptions and procedures involved in such risk estimates are called for to prevent their acceptance as scientific dogma. Furthermore, the linear hypothesis is the only one which permits the selection of the mean accumulated tissue dose to characterize the radiation exposure of a group under conditions of nonuniform exposure and exposure rate. The mean accumulated tissue dose is the only practical quantity that can be used to estimate the risk of cancer in such populations until the influence of the many interacting variables can be better specified.

While agreeing with the practical utility of this procedure, it is most important that the results not be accepted as "scientific dogma." It is not the objective of this Environmental Statement to "determine public policy on radiation protection." Its objective is to present all of the evidence, so that public policy, as eventually determined, may reflect all relevant risks and benefits. In this light, it must be

emphasized that the interpolated risk estimates do rest on conservative assumptions, and that there is no direct experimental evidence on which to base a choice between these estimates and an estimate of zero effect.

Pertinent to the assumption of a linear dose-effect relationship is the recent caution voiced by the NCRP:

> "The NCRP wishes to caution governmental policy-making agencies of the unreasonableness of interpreting or assuming "upper limit" estimates of carcinogenic risks at low radiation levels, derived by linear extrapolation from data obtained at high doses and dose rates, as actual risks, and of basing unduly restrictive policies on such an interpretation or assumption."[54]

Because there is considerable experimental evidence to indicate that low-dose-rate exposures are less damaging, rad-for-rad, than high-dose-rate exposures, it has been often suggested that linearly extrapolated estimates of effects at very low dose rates should be corrected by some "dose-effectiveness factor." Such an approach was taken in the Reactor Safety Study[55] (Rasmussen Report), where it was recommended that at dose rates of less than 1 rem per day, or at total doses of less than 10 rem, the effect estimated by linear extrapolation should be reduced by a factor of five. The credibility of this approach is supported by an Advisory Group on Health Effects, including among its 17 members, five who also served on the BEIR Committee.

Application of the "risk-effectiveness factor" as employed in the Rasmussen Report was not limited to low-LET (linear energy transfer) radiation. Most of the experimental support for the concept, however, derives from studies with low-LET radiation. From theory, one may argue convincingly that the high LET of alpha radiation, and consequent lack of repair of cellular effects, demands a linear relationship at low dose between cells killed or damaged and alpha particles traversing the tissue. This linear relationship would not necessarily apply to the total process of carcinogenesis, however, since there is no accepted theory (linear or nonlinear) which describes the process by which dead or damaged cells lead to the production of cancers. Because of this uncertainty in their applicability to high-LET radiation, risk effectiveness factors have not been employed in this Environmental Statement. The probable conservatism of this approach must be kept in mind.

Spatial Averaging of Doses

Throughout this Environmental Statement, each estimated radiation dose has been calculated as a spatially averaged value for the total organ. Such doses are, in fact, not uniformly distributed throughout the organ. In particular, the transuranic elements are inhaled and deposited in the lung as particles exhibiting a distribution of sizes and shapes, which leads to an obviously nonuniform distribution of dose.

The validity of this spatial averaging of dose has been the subject of recent controversy, stimulated in large part by a petition from the Natural Resources Defense Council (NRDC) to the Atomic Energy Commission and the Environmental Protection Agency. This petition requested a reduction of the maximum permissible concentration of plutonium in air by a factor of 115,000 when this plutonium was present in the form of "hot particles."[15] The petition was presented in February 1974; it was denied by the Nuclear Regulatory Commission, as successor to the Atomic Energy Commission, in April 1976.[56] In their denial of the NRDC petition, the Nuclear Regulatory Commission expressed the following conclusions with respect to the validity of averaging organ doses:

> "In summary, the uniform dose model is generally recognized by the scientific community and supported by experimental evidence as a conservative basis for standards for personnel protection. The NRC finds, in agreement with the recommendations of the organizations quoted, that available data support the use of the uniform dose assumption as an appropriately conservative approach. That is, the available data indicate that while the biological risk from a uniform lung dose of 15 rems per year is low, an equivalent dose delivered in a nonuniform manner is at least as low. Therefore, standards for insoluble, alpha-emitting radionuclides, as based on a uniform dose assumption, are believed to be adequately conservative."[56]

As noted in the above quotation, several organizations have studied the "hot particle" problem and have, without exception, concluded that the NRDC proposal is without merit.[57] The ICRP has given the problem repeated consideration;[43] the NCRP has published a recent report on the subject,[58] as have also the National Radiological Protection Board,[59] the Medical Research Council[44] in England, and the German Ministry of the Interior.[60] The conclusions of these groups were reviewed by the Nuclear Regulatory Commission and are summarized in their denial of the NRDC petition.[56]

Aside from the highly publicized "hot particle hypothesis," other questions have been raised concerning the conservatism of exposure limits, or health risk estimates, based on average organ dose. Martell has argued that naturally occurring, very small, alpha-emitting, insoluble particles, in the 10^{-16} to 10^{-18} curie activity range, are responsible for the carcinogenicity of tobacco smoke.[61] By analogy, he concludes that very small plutonium particles should have a similar effect, and has proposed a reduction in plutonium "...air concentration and lung burden standards by a factor of between 100 and 1000..."[62] This highly speculative hypothesis is supported by no experimental or clinical verification of substantial accumulation of such radioactive particles in radiosensitive regions of the lung, and upon no evidence of a causal relationship between such particles and human lung cancer. It is opposed by considerable evidence for the involvement of other carcinogens known to be present in tobacco smoke.

Gofman has postulated a greatly enhanced carcinogenicity for plutonium in cigarette smokers, whose impaired ciliary clearance mechanisms will, he contends, result in a greatly increased dose to the radiosensitive bronchial epithelium.[63,64] Again, this speculation is supported by no relevant experimental or clinical evidence, and is opposed by specific data attesting to the slight effect of cigarette smoking on clearance from the lung.[65,66]

Recent suggestions by Morgan for reduction of plutonium exposure limits, seem appropriately considered at this point, since they are, in part, concerned with questions of spatial distribution of dose.[67] Morgan suggests a 240-fold reduction in permissible plutonium burden, based on four factors which he argues imply a greater hazard to bone than is envisioned by present standards. The first of these factors relates to new information on the relative toxicity of ^{239}Pu and ^{226}Ra in dogs. As noted in Section G.3, this toxicity ratio, on the basis of average dose to bone, is 16, whereas current standards are based on a ratio of five.[21] Morgan does not consider the fact that current standards are also based on an assumed 90 percent deposition of systemic plutonium in bone, rather than ICRP's presently preferred estimate of 45 percent deposition.[26] The net effect of these two changes would be a 1.5-fold reduction in the permissible body burden based on bone as critical organ, rather than the factor of three proposed by Morgan.

Morgan's second reduction factor, with a value of two, is based on his conclusion that "...the surface-to-volume ratio for the trabecular bone of the dog...is about twice that for man. Thus the same amount of ^{239}Pu in man would have twice the concentration of ^{239}Pu near the trabecular surface as that in the dog."[67] There is, in fact, no present basis for defending a significant difference in this parameter between man and dog. Lloyd and Hodges have reported data that would support Morgan's contention,[68] but more recent data of Spiers and Whitwell show essentially identical ratios in man and dog.[69]

Morgan's third reduction factor, with a value of 10, is based on the estimate of a 10-fold higher rate of turnover of surface deposited plutonium in dog bone as compared to human bone. Accepting this uncertain estimate, it does not follow that the same initial concentration of surface-deposited plutonium should be 10 times as hazardous in man as in the dog. The hazard is assumed to result from a lifetime of exposure, and man has five times the lifespan of the dog. A 10-fold higher absolute turnover rate in the dog therefore decreases the relative lifespan turnover rate, compared with man, by only a factor of two. The situation is more complex than this, however. The same processes that bury plutonium on bone surfaces, also will bury radium on bone surfaces; and these same turnover processes will release plutonium and radium to redeposit on other surfaces. These complex interactions have been estimated by Marshall and Lloyd to increase the relative hazard of plutonium to radium in man, as compared to dog, by a factor of three (not 10 as claimed by Morgan).[70] Spiers and

Vaughan, on the other hand, proceeding from human dosimetric considerations, without relation to the dog, conclude that the present permissible body burden for plutonium "...is not in need of major revision in respect to bone."[71]

Morgan's fourth reduction factor, with a value of four, is based on a presumed four-fold greater radiation sensitivity of man relative to dogs. This presumption he derives from a preliminary report of results from PuO_2 inhalation studies in baboons.[72] These results involved acute effects in lung and are therefore hardly applicable to considerations of long-term effects in bone. Moreover, extended observations indicate that the baboon is less sensitive than the dog at survival times in excess of 1000 days.[73]

Morgan's overall factor of 240 would therefore, more realistically, be re-evaluated as something between one and five. His is, moreover, only a partial approach to the evaluation of plutonium hazards; many other factors might be considered. All such factors are under continual review by national and international bodies charged with the responsibility for such evalutions. While some changes in plutonium exposure standards may be expected to result from the continuing accumulation of better data, there is no present indication that such changes will be large.

Conclusions

As detailed in Chapter 3, estimates have been made of the cancer mortalities and genetic defects that may result from predicted releases of radionuclides from the Rocky Flats Plant. Because the number of predicted health effects is so small, it is perhaps unnecessary to stress that they are based upon conservative estimates of exposure, multiplied by conservative estimates of the risk from this exposure, and that whether the actual risk approaches these numbers, or is zero, can in no way be inferred from our present knowledge. Whether one should place any credence in the absolute value of these numbers is an arguable proposition. Of perhaps greater validity for decision making purposes are those gross comparisons of relative radiation exposure that require no uncertain extrapolations and that make no pretense to absolute prediction. In this category are the comparisons of exposures from Rocky Flats releases with the exposures from natural background radiation and from fallout plutonium. The predicted exposure of Denver-area residents from Rocky Flats releases is only a small fraction of that received from fallout plutonium and a very much smaller fraction of the radiation exposure from natural background.

REFERENCES

1. USAEC, Proposed Final Environmental Statement - Liquid Metal Fast Breeder Reactor Program, Doc. WASH-1535, 1974.

2. C. C. Lushbaugh and J. Langham, "A Dermal Lesion from Implanted Plutonium," Arch. Dermatol. 86, pp. 461-464, 1962.

3. C. C. Lushbaugh, R. J. Cloutier, G. Humason, J. Langham, and S. Guzak, "Histopathologic Study of Intradermal Plutonium Metal Deposits: Their Conjectured Fate," Ann. N.Y. Acad. Sci. 145, pp. 791-797, 1967.

4. W. F. Brandom, R. W. Bistline, A. D. Bloom, and P. G. Archer, "Somatic Cell Chromosome Changes in Humans Exposed to ^{239}Plutonium," Radiation Research 59, p. 206, 1974.

5. Anon. "Riddled by Isotopes," Newsweek, March 21, 1977, p 49.

6. E. P. Hardy, P. W. Krey, and H. L. Volchok, "Global Inventory and Distribution of Fallout Plutonium," Nature 241, pp. 444-445, 1973.

7. E. P. Hardy, "Worldwide Distribution of Plutonium," in Plutonium and Other Transuranium Elements: Sources, Environmental Distribution and Biomedical Effects, Doc. WASH-1359, pp. 115-128, 1974.

8. D. G. Bennett, "Fallout ^{239}Pu Dose to Man," Fallout Program Quarterly Summary Report, Doc. HASL-278, 1974.

9. J. F. McInroy, H. A. Boyd, B. C. Eutsler, M. W. Steward and G. L. Tietjen, "Determination of Plutonium in Man," Doc. LA-6898-PR, pp. 42-50, 1977.

10. B. D. Breitenstein, Jr., C. E. Newton, Jr., and W. D. Norwood, "United States Transuranium Registry Annual Report October 1, 1976 to October 1, 1977," Doc. HEHF-25, 1978.

11. G. L. Voelz, J. H. Stebbins, L. K. Haxton and D. A. York, "Epidemiologic Studies of Persons Exposed to Plutonium," in Biomedical and Environmental Research Program of the LASL Health Division, Doc. LA-7254-PR, pp. 53-56, 1978.

12. L. H. Hemplemann, W. H. Langham, C. R. Richmond, and G. L. Voelz, "A Twenty-seven Year Study of Selected Los Alamos Plutonium Workers," Health Physics 25, pp. 461-479, 1973.

13. J. R. Mann and R. A. Kirchner, "Evaluation of Lung Burden Following Acute Inhalation Exposure to Highly Insoluble PuO_2," Health Physics 13, pp. 877-882, 1967.

14. G. W. Dolphin, "Biological Problems in the Radiological Protection of Workers Exposed to Plutonium-239," Health Physics 20, 549-557, 1971.

15. A. R. Tamplin and T. B. Cochran, "Radiation Standards for Hot Particles," Natural Resources Defense Council, Washington, D. C., 1974.

16. L. Cave and L. Freedman, "A Statistical Evaluation of the Radiotoxicity of Inhaled Plutonium in Insoluble Form," in Transuranium Nuclides in the Environment, IAEA, Vienna, 1976.

17. NCRP Report No. 45, "Natural Background Radiation in the United States," National Council on Radiation Protection and Measurements, Washington, D.C., 1975.

18. J. Vaughan, B. Bleaney, and D. M. Taylor, "Distribution, Excretion, and Effects of Plutonium as a Bone-seeker," in Uranium, Plutonium, Transplutonic Elements, (H. C. Hodge, J. N. Stannard and J. B. Hursh, Eds.), Springer-Verlag, New York, pp. 349-502, 1973.

19. R. C. Thompson, "Biological Factors," in Plutonium Handbook: A Guide to The Technology, Vol. 2 (O. J. Wick, Ed.), Gordon and Breach, New York, pp. 785-829, 1967.

20. W. J. Bair, J. E. Ballou, J. F. Park, and C. L. Sanders, "Plutonium in Soft Tissues with Emphasis on the Respiratory Tract," in Uranium, Plutonium, Transplutonic Elements, (H. C. Hodge, J. N. Stannard, and J. B. Hursh, Eds.) Springer-Verlag, New York, pp. 503-568, 1973.

21. C. W. Mays, H. Spiess, G. N. Taylor, R. D. Lloyd, W. S. S. Jee, S. S. McFarland, D. H. Taysam, T. W. Brammer, D. Brammer, and T. A. Hollard, "Estimated Risk to Human Bone from ^{239}Pu" in Health Effects of Plutonium And Radium, (W. S. S. Jee, Ed.), Salt Lake City, pp. 343-362, 1976.

22. W. J. Bair, "Toxicology of Plutonium," in Advances in Radiation Biology, Vol. 4, Academic Press, New York, pp. 255-315, 1974.

23. J. F. Park, W. J. Bair, and R. H. Busch, "Progress in Beagle Dog Studies with Transuranium Elements at Battelle-Northwest," Health Physics 22, pp. 803-810, 1972.

24. W. J. Bair and J. M. Thomas, "Prediction of the Health Effects of Inhaled Transuranium Elements from Experimental Animal Data," in Transuranium Nuclides in the Environment, IAEA, Vienna, pp. 569-585, 1976.

25. C. W. Mays and T. F. Dougherty, "Progress in the Beagle Studies at the University of Utah," Health Physics 22, pp. 793-801, 1972.

26. International Commission on Radiological Protection - Task Group of Committee 2, "The Metabolism of Compounds of Plutonium and Other Actinides," ICRP Publication 19, Pergamon Press, New York, NY, 59 p., 1972.

27. J. P. M. Bensted, D. M. Taylor, and F. D. Sowby, "The Carcinogenic Effects of ^{241}Am and ^{239}Pu in the Rat," Brit. J. Radiol. 38, pp. 920-925, 1965.

28. A. L. Brooks, D. K. Mead, and R. F. Peters, "Distribution and Retention of Monomeric ^{239}Pu Citrate in the Chinese Hamster and Its Cytogenetic Effect on the Testes," Lovelace Foundation Report LF-46, pp. 240-243, 1974.

29. C. V. Beechey, D. Green, E. R. Humphreys, and A. G. Searle, "Cytogenetic Effects of Plutonium-239 in Male Mice," Nature 256, 577-578, 1975.

30. B. G. Blaylock and J. R. Trabalka, "Effectiveness of Tritium and ^{239}Pu in Producing Chromosome Aberrations in Chironomous Riparius," in Biological and Environmental Effects of Low-Level Radiation. Vol. 2., IAEA, Vienna, pp. 45-50, 1976.

31. D. Green, G. R. Howells, E. R. Humphreys, and J. Vennart, "Localization of Plutonium in Mouse Testes," Nature 255, p. 77, 1975.

32. A. L. Brooks, J. H. Diel, and R. O. McClellan, "The Distribution, Retention and Cytogenetic Effects of ^{239}Pu Citrate in the Testes of the Chinese Hamster," Doc. LF-56, pp. 399-403, 1976.

33. N. D. Priest and S. Jackson, "The Uptake and Redistribution of ^{241}Pu within the Gonads," Int. J. Radiat. Biol. 34, pp. 49-65, 1978.

34. C. R. Richmond and R. L. Thomas, "Plutonium and Other Actinide Elements in Gonadal Tissues of Man and Animals," Health Physics 29, pp. 241-250, 1975.

35. U. S. National Academy of Sciences - National Research Council, "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation," Report of the Advisory Committee on the Biological Effects of Ionizing Radiations, Washington, D.C., 1972.

36. U. N. Scientific Committee on the Effects of Atomic Radiation, "Sources and Effects of Ionizing Radiation," United Nations, NY, 1977.

37. International Commission on Radiological Protection, "Recommendations of the International Commission on Radiology Protection," ICRP Publication 26, Pergamon Press, Oxford, 1977.

38. R. Anderson and K. Ishida, "Malignant Lymphoma in Survivors of the Atomic Bomb in Hiroshima," Ann. Intern. Med. 61, pp. 853-862, 1964.

39. K. Shimizu, "Epidemiological Study on Malignant Lymphoma Among A Bomb Survivors in Hiroshima," Hiroshima J. Med. Sci. 15, pp. 201-211, 1966.

40. H. Nishiyama, R. E. Anderson, T. Ishimaru, K. Ishida, I. Yohei, and N. Okabe, "Malignant Lymphoma and Multiple Myeloma in Atomic Bomb Surviviors, Hiroshima-Nagasaki 1945-46," ABCC Technical Report 4-71, 1971.

41. W. M. Court-Brown and R. Doll, "Mortality from Cancer and Other Causes After Radiotherapy for Ankylosing Spondylitis," Brit. Med. J. 2, pp. 1327-1332, 1965.

42. E. B. Lewis, "Leukemia, Multiple Myeloma, and Aplastic Anemia in American Radiologists," Science 142, pp. 1492-1494, 1963.

43. International Commission on Radiological Protection, "Radiosensitivity and Spatial Distribution of Dose, Reports Prepared by Two Task Groups of Committee 1 of the International Commission on Radiological Protection," ICRP Publ. 14, Pergamon Press, Oxford, 1969.

44. M. Faber, "Dose Effect Relations in Hepatic Carcinogenesis," In: Proceedings of the 3rd International Meeting on the Toxicity of Thorotrast (M. Faber, ed.), Riso Report No. 294, Danish Atomic Energy Establishment, pp. 308-315, 1973.

45. Medical Research Council, "The Toxicity of Plutonium," Her Majesty's Stationery Office, London, 1975.

46. H. Spiess and C. W. Mays, "Bone Cancers Induced by ^{224}Ra(ThX) in Children and Adults," Health Phys. 19, 713-729, 1970; plus Addendum, Health Phys. 20, 543-545, 1971.

47. H. Spiess and C. W. Mays, "Protraction Effect on Bone Sarcoma Induction of ^{224}Ra in Children and Adults," In: Radionuclide Carcinogenesis (C. L. Sanders, et al., eds.), USAEC Doc CONF-720505, NTIS, Springfield, VA., pp. 437-450, 1973.

48. B. K. Trimble and J. H. Doughty, "The Amount of Hereditary Disease in Human Populations," Ann. Hum. Genet. 38, pp. 199-223, 1974.

49. H. B. Newcombe, "Mutation and the Amount of Human Ill Health," In: Radiation Research: Biomedical, Chemical and Physical Perspectives (O. F. Nygaard, et al., eds.) Academic Press, New York, pp. 937-946, 1975.

50. C. W. Mays and R. D. Lloyd, "Bone Sarcoma Incidence vs. Alpha Particle Dose," In: Radiobiology of Plutonium (B. J. Stover and W. S. S. Jee, Eds.) J. W. Press, Salt Lake City, pp. 409-439, 1972.

51. F. E. Lundin, J. K. Wagoner and V. E. Archer, "Random Daughter Exposure and Respiratory Cancer Quantitative and Temporal Aspects," National Institute for Occupational Safety and Health/National Institute of Environmental Health Sciences, Joint Monograph No. 1, USDHEW, 1971.

52. H. M. Parker, "The Dilemma of Lung Dosimetry," Health Phys. 16, 553, 1969.

53. U. S. National Academy of Sciences - National Research Council - National Academy of Engineering; "Radiation Exposure of Uranium Miners," Report of an Advisory Committee from the Division of Medical Sciences, Washington, DC, 1968.

54. NCRP Report No. 43, "Review of the Current State of Radiation Protection Philosophy," National Council on Radiation Protection and Measurements, Washington, DC, 1975.

55. U. S. Nuclear Regulatory Commission, "Reactor Safety Study. An Assessment of Accident Risks in U. S. Commercial Nuclear Power Plants," Doc. WASH-1400 (NUREG-75/014), Appendix VI. Calculation of Reactor Accident Consequences, 1975.

56. U. S. Nuclear Regulatory Commission, "Natural Resources Defense Council. Denial of Petition for Rule Making," Federal Register 41, 15371-15379, 1976.

57. W. J. Bair, C. R. Richmond, and B. W. Wachholz, "A Radiobiological Assessment of the Spatial Distribution and Radiation Dose from Inhaled Plutonium" WASH-1320, 1974.

58. Alpha-Emitting Particles in Lungs; NCRP Report No. 40: August 15, 1975.

59. G. W. Dolphin, "The Hot Particle Problem," Radiol. Prot. Bull. 1975 (12), 18-19, 1975.

60. German Ministry of the Interior (Bonn), "On the Toxicity of Inhaled Hot Particles with Special Reference to Plutonium," Radiat. Environ. Biophys. 15, pp. 1-11, 1978.

61. E. A. Martell, "Tobacco Radioactivity and Cancer in Smokers," Amer. Sci. 63, 404-412, 1975.

62. E. A. Martell, "Basic Considerations in the Assessment of the Cancer Risks and Standards for Internal Alpha Emitters," In Proceedings of Public Hearings: Plutonium and the Other Transuranium Elements, Vol. 2, 413-438, USEPA Doc. ORP/SCD-75-1, 1975.

63. J. W. Gofman, "The Cancer Hazard from Inhaled Plutonium," Committee for Nuclear Responsibility, Dublin, California, 1975.

64 J. W. Gofman, "The Plutonium Controversy," J. Amer. Med. Assoc. 236, 284-286, 1976.

65. R. E. Albert, H. T. Peterson, D. E. Bohning and M. Kippmann, "Short-term Effects of Cigarette Smoking on Bronchial Clearance in Humans," Arch. Envron. Health 30, 361-367, 1975.

66. R. V. Lourenco, M. F. Klimek and C. J. Borowski, "Deposition and Clearance of 2 μ Particles in the Tracheobronchial Tree of Normal Subjects - Smokers and Nonsmokers," J. Clin. Invest. 50, 1411-1420, 1971.

67. K. Z. Morgan, "Suggested Reduction of Permissible Exposure to Plutonium and Other Transuranium Elements," Amer. Indust. Hyg Assoc. J. 36, 567-575, 1975.

68. E. Lloyd and D. Hodges, "Quantitative Characterization of Bone: A Computer Analysis of Microradiographs," Clin. Orthopaedics 78, 230-250, 1971.

69. F. W. Spiers and J. R. Whitwell, "Dosimetry of ^{239}Pu and ^{226}Ra in Man and Animals," In: Biological Effects of Plutonium and Radium (W. S. S. Jee, Ed.) J. W. Press, Salt Lake City, 537-552, 1976.

70. J. H. Marshall and E. Lloyd, "Effect of the Remodeling of Bone upon the Relative Toxicity of Radium and Plutonium in Man and Dog," In: Radionuclide Carcinogenesis (C. L. Sanders, et al., Eds.) USAEC Doc. CONF-720505, 421-436, 1973.

71. F. W. Spiers and J. Vaughan, "Hazard of Plutonium with Special Reference to the Skeleton," Nature 259, 531-534, 1976.

72. H. Metivier, D. Nolibe, R. Masse and J. Lafuma, "Excretion and Acute Toxicity of $^{239}PuO_2$ in Baboons," Health Phys. 27, 512-514, 1974.

73. H. Metivier, D. Nolibe, R. Masse and J. Lafuma, "New Data on Toxicity and Translocation of Inhaled $^{239}PuO_2$ in Baboons," Health Phys. 35, 401-404, 1978.

74. C. W. Mays, "Estimated Risk from ^{239}Pu to Human Bone, Liver and Lung," In: Biological and Environmental Effects of Low Level Radiation. Vol. II (International Atomic Energy Agency, Vienna) 373-384, 1976.

APPENDIX G-2

Cancer Risks from Focal Deposits of Alpha-Emitting Radionuclides in Lung Tissue

R. G. Cuddihy and W. C. Griffith

Appendix G-1 of this Environmental Impact Statement contains an analysis of the human health risks from exposures to alpha-emitting transuranium elements used at the Rocky Flats facility. Subsequent to the development of this analysis special concerns were raised as to the potential for uniquely high health risks being associated with particles or focal sources of alpha-emitting radioactivity in lung tissue. The alleged risks for radioactive particles were 100,000 or 1,000,000 times higher than those derived from studies of more uniformly distributed radioactivity in lung tissue. This Appendix reviews current scientific information and shows that there is considerable experience from studies of inhaled or instilled radio-activity in laboratory animals or previous accidental exposures of people to determine the health risks from different distributions of radiation dose to lung tissue. Particulate or focal sources of alpha-emitting radiation have not been shown to have uniquely higher risks than uniformly distributed radioactivity. Thus, current radiation risk estimators appear to be adequate for projecting the risks from transuranium materials handled at the Rocky Flats facility.

Hypotheses on Radiation Risks to Lung Tissue

Projecting quantitative relationships between levels of exposure to ionizing radiations and risks for developing neoplastic disease involves substantial assimilation of information from studies in human populations and in laboratory animals. In general, studies of accidently exposed people and medical patients are used to derive the primary measures of the absolute

sensitivities of human organs, tissues or cells for radiation induced neoplastic transformation. However, the human experience is very limited and there are many physical and biological factors related to different types of radiation exposures that may modify the absolute magnitudes of the related cancer risks. These factors can not normally be evaluated in studies of exposed human populations so that the potential dose modifying factors must be investigated in studies with laboratory animals. Use of information from both clinical studies and laboratory animal studies provides the best means for developing useful radiation protection guidelines.

An important assumption in developing radiation dose-effect relationships is that the cancer risk is related to the magnitude of the exposure and is likely to be expressed in those tissues receiving the highest levels of radiation. Perhaps the simplest relationships which can be developed are for single brief radiation exposures in which whole organs are uniformly irradiated. Tumors which may result are most likely to involve the most sensitive cell populations in the irradiated tissue. The response may be modified if the radiation dose is protracted over long periods of time and is delivered at changing dose rates; if the exposure is to high LET (linear energy transfer) radiation such as alpha particles rather than to gamma or X-ray; and if the radiation results from internally-deposited radionuclides that produce very non-uniform distributions of radiation dose in the tissues.

Absorbed radiation doses in internal body organs from external X-ray or gamma radiation can be estimated by readily accepted mathematical expressions. Radiation doses in areas of internally deposited radionuclides are more difficult to estimate. Often they are calculated from the total amount of energy deposited in the organs per unit of organ weight. This is called the average

organ radiation dose. However, if the radioactivity is concentrated near particularly sensitive cell populations within the organs, then it is also appropriate to calculate the microscopic doses in these areas when deriving dose-effect relationships. This is frequently done for radionuclides that deposit predominantly on bone surfaces and irradiate cells in these areas which are thought to be transformed to yield bone cancers. It can also be done for insoluble particles that contain alpha-emitting radionuclides and are deposited in lung tissue. Doses from inhaled alpha-emitting radionuclides can be calculated as average organ doses, as doses to alveolar or bronchial epithelial cells or even in terms of the number of times alpha particles pass through single cells or cell nuclei. These are all valid expressions of radiation doses. However, the expressions of dose used in developing the dose-effect relationships must also be used in re-applying the relationships back to human risk evaluations.

Particles containing alpha-emitting radionuclides deposited in the lung deliver the highest radiation doses to the nearby cells. Due to the very short range of alpha emissions in tissue, inhalation of a small number of particles may result in irradiation of only a small fraction of the total lung. For this reason, some individuals have suggested that the average organ dose should not be used to evaluate the health risks. They have also postulated that the health risks could be sustantially greater than is estimated from the average dose to lung. Tamplin and Cochran (1974) postulated that single particles having more than 0.07 pCi of long-lived alpha-emitting activity deposited in lung have a risk of 1/2000 of producing a lung tumor. These have been called "hot particles" though the definition was later changed to refer to particles with more than 0.6 pCi of alpha-emitting radionuclides.

The basis for the Tamplin-Cochran hypothesis on "hot particles" was developed from studies of Albert et al. (1967) with irradiated rat skin. Albert et

al. showed that electron irradiation of rat skin produced atrophic hair follicles and epithelial skin tumors. About one tumor was produced for each 2000 to 4000 atrophic follicles. The tumor response was seen at doses above 230 rad, increasing abruptly at 2000 rad and reaching a maximum at about 4000 rad. Thus, Tamplin and Cochran reasoned that alpha radiation doses greater than 1000 rad would produce atrophic foci in lung tissue also with the potential of 1/2000 of resulting in a lung tumor. Such doses are produced in the tissue volumes adjacent to "hot particles."

Later, Martell (1977) postulated that the greatest risks for producing lung tumors would result from particles containing alpha-emitting radionuclides that irradiate the surrounding cells at a rate of one hit per day. This, Martell said, would occur with particles containing less than 0.01 pCi of long-lived alpha-emitting radionuclides. He also postulated that radioactivity in these "warm particles" would have an associated cancer risk one million times greater than the same amount of radioactivity distributed uniformly in lung tissue. He contended that all previous studies with inhaled alpha radioactivity used very much higher activity particles that sterilized the surrounding lung cells and that the enhanced risk from "warm particles" was, thus, not observed.

Both the "hot particle" and "warm particle" hypotheses suggest that very specific levels of focal sources of radioactivity in lung tissue have uniquely higher risks for producing tumors than has been observed previously. This Appendix reviews these hypotheses in relation to the dosimetry of inhaled alpha-emitting radioactivity and in the light of current investigations of the toxicity of inhaled plutonium in people and in laboratory animals.

Deposition and Clearance of Inhaled Particles

The hazards to people from exposures to airborne radioactive particles depend on 1) the amount of radioactivity in the particles, 2) the fraction

of the particles that can be inhaled and deposited, 3) their location in the respiratory tract and 4) how rapidly they can be removed by the body's natural clearance mechanisms. In nature, aerosols never consist of particles having a single size. The mechanisms of aerosol formation in the environment, such as combustion and comminution, result in particles which have a range of sizes. Table 1 illustrates these size ranges for typical particles in tobacco smoke, fly ash, different types of soil particles and atmospheric dust.

A schematic illustration of an atmospheric aerosol particle size distribution is shown in Figure 1 and includes the principal modes of particle sizes and the main sources of mass for each mode. Fine particles are usually produced from combustion and other processes that inject gases and vapors into the atmosphere. These tend to coagulate in time increasing the number of particles with diameters between 0.1 μm and 1μm (1 μm = 1 x 10^{-6} m). Larger particles are also produced directly from combustion, from mechanical grinding processes and from wind resuspension of soil. These are usually in the range from 1 μm to 100 μm in diameter. The larger particles settle out more rapidly than smaller particles, hence their concentrations in air are quickly reduced. Exposures of people to aerosols in the atmosphere or in work places will involve different ranges of particle sizes depending upon the manner in which the particles were produced.

Plutonium released to the environment, such as that from the Rocky Flats facility, can also have a wide range of particle sizes. In time, the released radioactivity becomes associated with soil particles by surface adsorption or by exchange into the actual soil chemical matrix. Table 2 contains measurements by the Environmental Protection Agency (EPA) which indicate that the size distribution of soil particles around Rocky Flats and the amount of plutonium associated with each soil size fraction varies considerably with location. The character of this size distribution influences the potential for mechanical

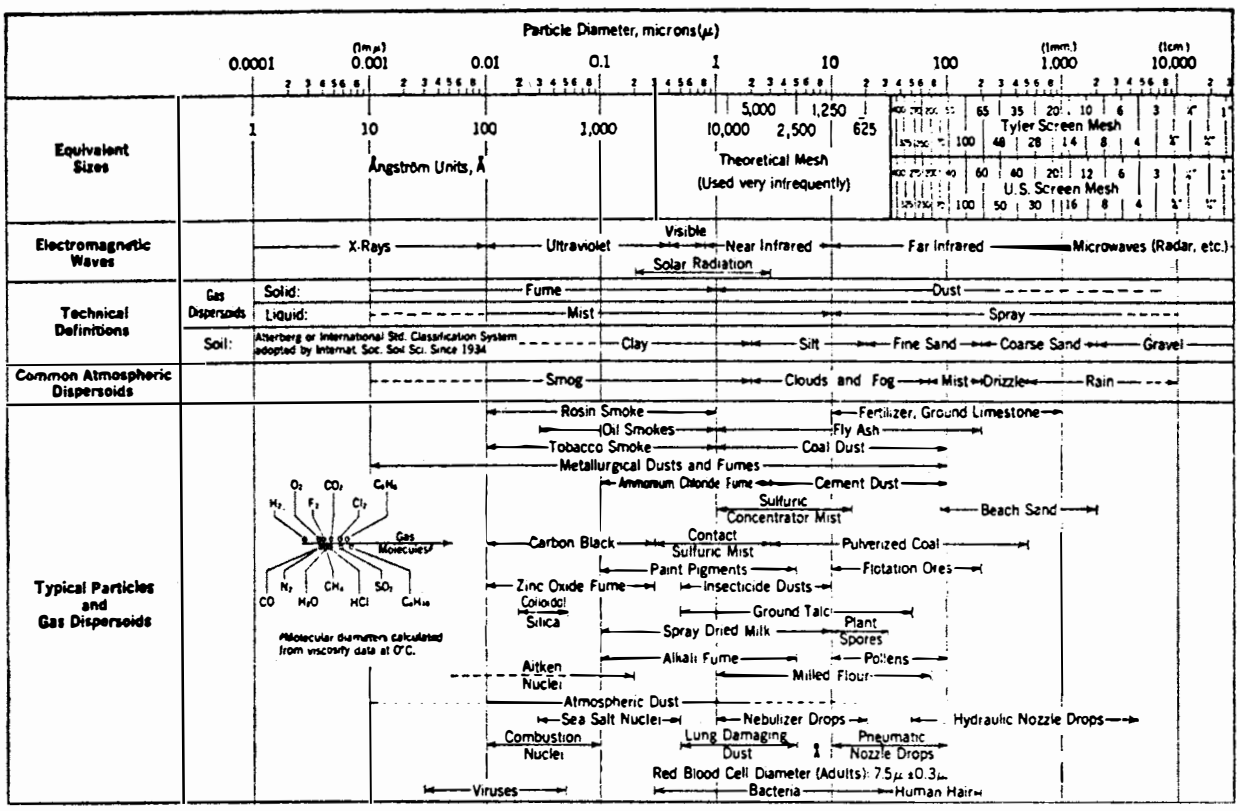


Table 1. Size Range of Typical Particles and Gas Dispersoids. (Lapple, 1961)

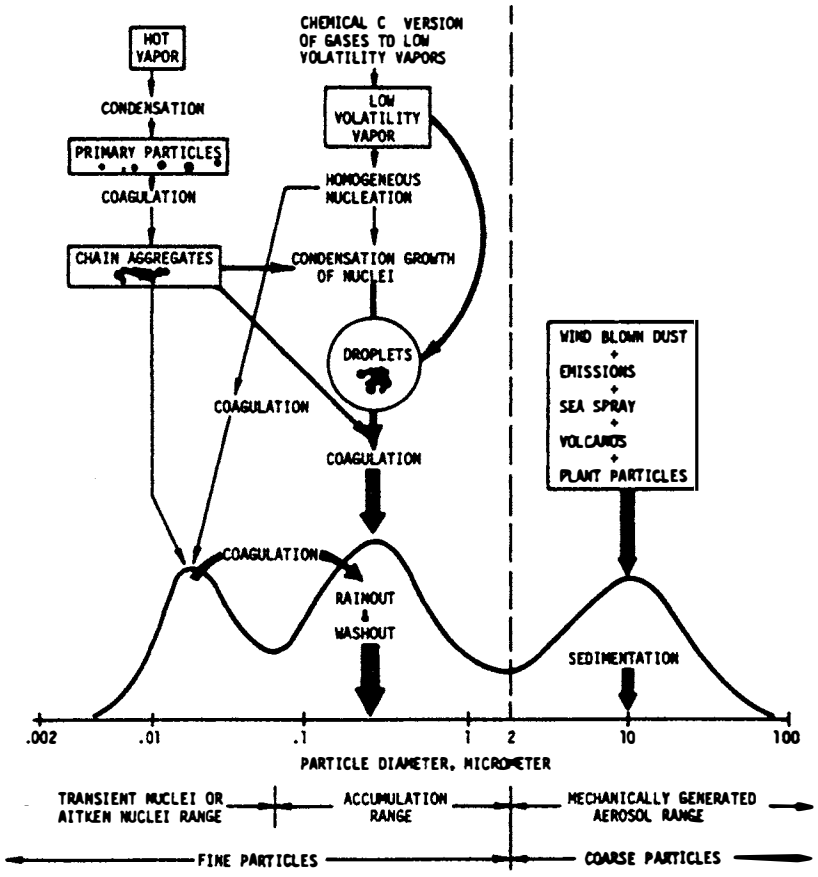


Figure 1. Schematic of an atmospheric aerosol surface area distribution showing principal modes, main sources of mass for each mode, and the principal processes involved in inserting mass in each mode and the principal removal mechanisms.
(Whitby and Cantrell, 1976)

Table 2

Plutonium Content of Various Soil Particle Sizes in the Rocky Flats Area[a]

EPA Soil Sample Number	Soil Particle Size Increment (μm)	Fraction of Soil Mass in Size Increment	Fraction of Plutonium Activity in Size Increment
RF 1A	2000-105	0.62	0.07
	105-10	0.18	0.40
	< 10	0.20	0.53
RF 1B	2000-105	0.63	0.39
	105-10	0.17	0.06
	< 10	0.20	0.55
RF 1C	2000-105	0.64	0.43
	105-10	0.16	0.08
	< 10	0.20	0.49
RF 2A	2000-105	0.46	0.13
	105-10	0.34	0.37
	< 10	0.20	0.50

[a]EPA, 1977.

resuspension of the soil particles and for inhalation of the plutonium by people. It should be re-emphasized, however, that people would not be exposed to single sizes of particles or single levels of particle radioactivity such as those defined as "hot particles" or "warm particles." The particles containing plutonium would vary in size and levels of radioactivity just as those occurring in nature containing natural radioactivity or nuclear weapons fallout radionuclides, or those which have been used in laboratory animal studies.

To describe the deposition and retention of particles inhaled by people, the respiratory tract is usually divided into three regions. The nasopharyngeal region extends from the nose to the larynx; the tracheobronchial region extends from the larynx to the terminal bronchioles; and the pulmonary region includes the structures from the respiratory bronchioles to the alveoli. Deposition of inhaled particles in the different regions of the respiratory tract varies with particle size as shown in Figure 2. The particle size is given as the mass median aerodynamic diameter. The aerodynamic diameter of a particle of arbitrary shape and density is defined as the equivalent real diameter of a unit density sphere which has the same terminal settling velocity under gravity as the particle in question. Two particles with the same aerodynamic diameter may have different densities and real sizes, but they will exhibit the same behavior in air and in their deposition in the respiratory tract. Particles such as plutonium oxide may have densities as high as 10 g/cm^3 and have aerodynamic diameters about three times their real diameters. Plutonium adsorbed onto soil particles may be resuspended, inhaled and deposited in people depending upon the physical characteristics of the soil. Soil particles have densities of 2 to 3 g/cm^3.

Knowing the aerodynamic size distribution of aerosol particles, it is possible to estimate the fraction of the particles which will be deposited in the respiratory tract. It can be seen in Figure 2 that more than 80% of the

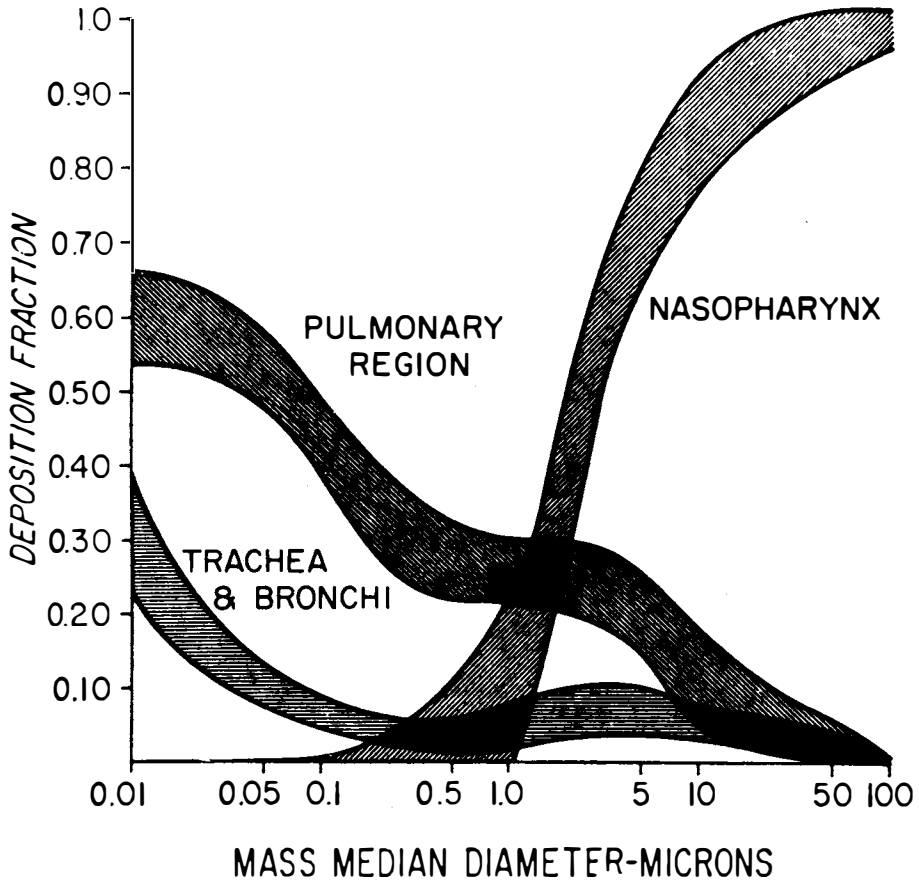


Figure 2. Particle deposition fraction as a function of particle mass median diameter. Each of the shaded areas indicates the variability of deposition for a given mass median aerodynamic diameter in each compartment when the geometric standard deviation of the aerosol particle sizes varies from 1.2 to 4.5 and the tidal volume is 1450 ml. (ICRP Task Group on Lung Dynamics, 1966)

particles with aerodynamic diameters greater than 5 μm will deposit in the nasopharyngeal region. Particles smaller than 0.1 μm deposit primarily in the pulmonary region with efficiencies approaching 50% or greater. Referring back to the particle size distributions in Figure 1 and Table 2, a sizeable fraction of the mass or activity in each distribution is associated with particles which are too large to be inhaled and deposited efficiently in the lung.

Once particles have been deposited in the respiratory tract their behavior is no longer influenced by aerodynamic diameter. The significant properties are real physical size, mass, surface area, shape, solubility, chemical composition and location. Clearance from the nasopharynx occurs by sneezing or blowing, absorption into the systemic blood or rapid clearance to the gastrointestinal tract by mucociliary transport and swallowing. Clearance by each of these mechanisms is competing and the relative fractions cleared by the specific pathways depend on the solubility of the material. Clearance of particles from the trachea and bronchi is also by absorption into the blood and mucociliary transport to the gastrointestinal tract. Clearance of particles deposited in the nasopharynx and the trachea and bronchi occur with half-times of less than two days. The airways of the pulmonary region are unciliated and clearance can only occur by mechanisms such as absorption into the blood or lymph systems, or slow clearance to the bronchi by phagocytic cell activity. Clearance of insoluble plutonium particles from the pulmonary region occurs with a half-time of about 500 days (ICRP, 1972).

Plutonium released into the environment is likely to be found in relatively insoluble chemical forms. The more soluble forms which may be released can oxidize or adsorb onto soil particles and exhibit low solubility in aqueous fluids. Bennett (1974) described the low uptake of nuclear weapons fallout plutonium in plants and its long retention time in lung tissues after inhalation

by people. The chemical solubility of plutonium in soil samples obtained near the Nevada Test Site, Mound Laboratory and Oak Ridge National Laboratory was studied by Tamura (1976). Less than half of the plutonium in these samples was extracted by treatment with citric acid indicating a relatively insoluble form for much of the plutonium in these samples.

Alpha Irradiation of Lung Cells

The amount of injury to lung cells from particles containing alpha-emitting radionuclides deposited in the lower respiratory tract depends upon the number of alpha emissions that hit the cells. This depends upon the range of the alphas emitted, the number of particles in the lung and the quantity of radioactivity in each particle.

The range of alpha radiations in lung tissue is determined by the density of the tissue through which they pass. Lung cells, themselves, have a density of 1 g/cm^3 but the average density of the whole lung is about 0.2 g/cm^3 because of the large amount of air filled space. The range of alpha radiations in solid tissue is approximately 40 μm but in air the range is about 4 cm for alpha radiations near 5 Mev in energy. Thus, because of the air spaces in lung tissue, the average range for alpha radiations from plutonium is approximately 200 μm. Inhaled particles may be deposited and retained near less dense structures while others may be near more solid tissues so that the ranges of the alpha radiations are highly variable in lung tissues. Breathing itself also changes the average lung density.

Ranges of alpha radiations in tissue are illustrated in Figure 3 for two simplified models. The first is for solid tissues with a density of 1 g/cm^3. The second is for tissue of uniform density, 0.2 g/cm^3, but does not consider the fine structure as exists in actual lung tissue. The number of alpha emissions passing through a unit volume of tissue in a given time decreases with increasing

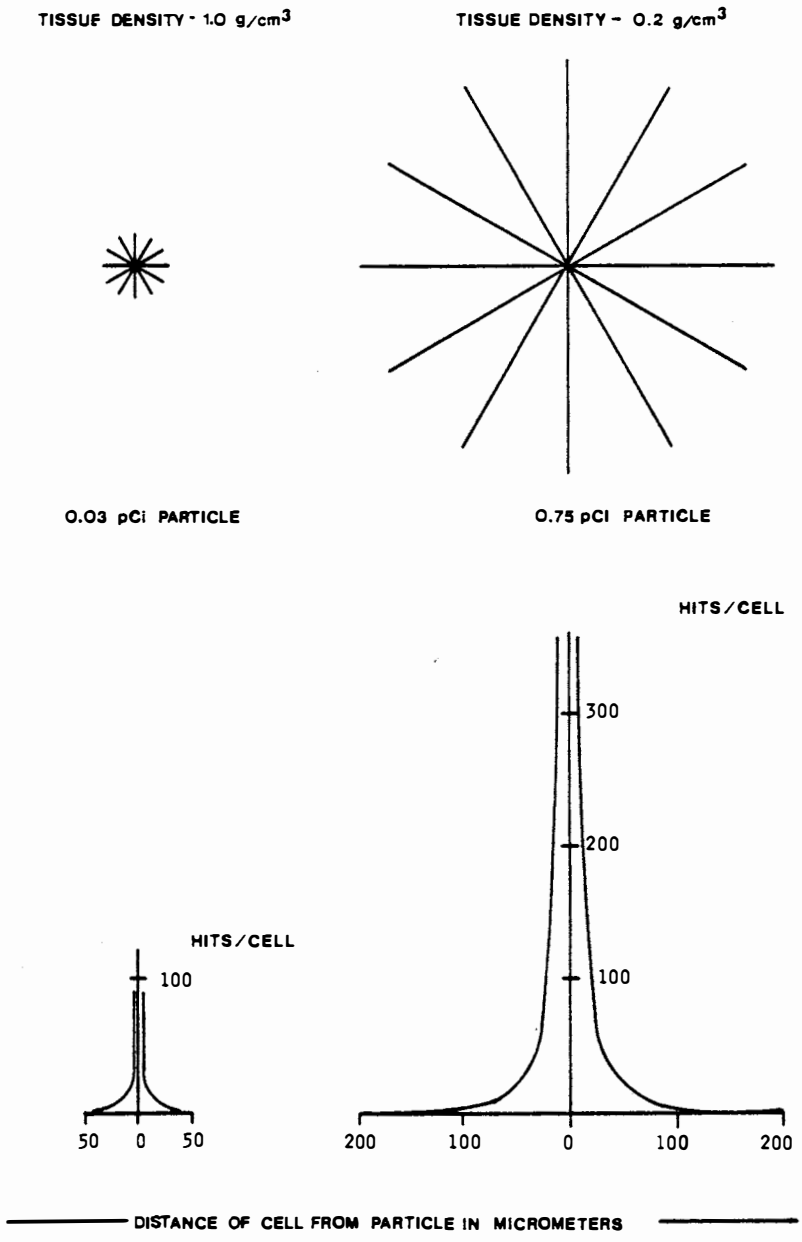


Figure 3. Example of the range of alpha radiation in unit density (1 g/cm^3) and less dense (0.2 g/cm^3) tissue. The alpha range is 40 μm in the unit density tissue and 200 μm in the less dense tissue. The particle activities of 0.75 pCi and 0.03 p Ci have been chosen to yield one hit per day to the cells located near the end of the corresponding alpha range.

distance from the particle. If we assume a cross sectional area for lung cells, then the number of cell hits can be calculated as a function of distance from a particle with a given amount of radioactivity. A sample calculation is also shown in Figure 3 for cells with a cross section of 225 μm^2 (assuming cubic cells 15 μm on a side). Actual lung cells are irregular in shape and can have much larger or smaller cross sectional areas for some aspects but the alpha radiation may be incident from any direction.

From these simplified models, it can be seen that the number of cell hits per unit time varies greatly for any group of cells within the range of the alpha radiations. For a particle containing 0.75 pCi, cells beyond 100 μm will be hit only a few times per day. This illustration was chosen because the cells near the end of the range of the alpha radiations receive approximately 1 hit per day. These are the dose rates that are postulated to be of most concern in the "warm particle" hypothesis. It should also be noted that about 90 percent of the cells within 200 μm of a particle are also more than 100 μm from the particle. For particles of lower activity, the cells that receive about 1 hit per day are just closer to the particle.

Several reports have described the radiation dose rates near alpha-emitting, radioactive particles in lung tissue (Sanders and Dionne, 1970; Anderson et al., 1973; Diel, 1978). Diel projected the actual tissue structures in the neighborhood of particles deposited in the lungs of Syrian hamsters. A typical projection is shown in Figure 4. Using these projections and assuming unit density for spaces filled by lung cells, Diel calculated alpha particle ranges in the alveolar region. These are also shown in Figure 4. Here the ranges extended out to 400 μm and the dose rates around the particle varied by several orders of magnitude.

The previous exposures of people and laboratory animals to plutonium have generally involved polydisperse aerosols, ie., aerosols containing a wide range

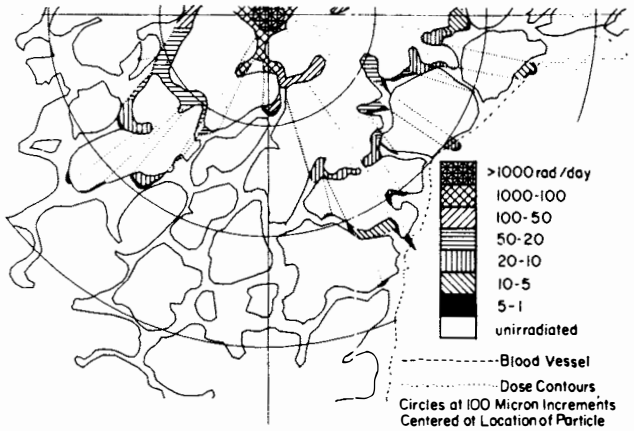


Figure 4a. Dose rate as a function of position around a 0.2 μm real diameter $^{238}PuO_2$ particle located in the deep lung of a Syrian Hamster. (Diel, 1978)

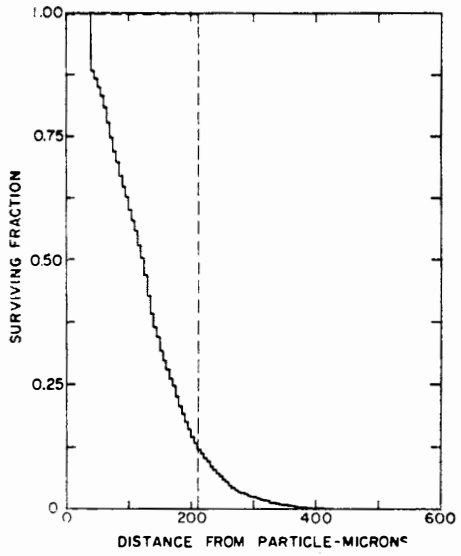


Figure 4b. Fraction of alpha particles penetrating a given distance from a 0.2 μm real diameter $^{238}PuO_2$ particle in the alveolar region of a Syrian hamster. Average over six different regions in three different animals (2160 alpha tracks). Dashed line represents 0.2 g/cm^3 uniform density tissue. (Diel, 1978)

of particle sizes. Monodisperse plutonium aerosols, those which contain particles of only one size, can only be produced with some difficulty in the laboratory but never occur in the environment. In all the previous inhalation exposures which form a basis for our health risk estimates, some lung cells have been irradiated at very high rates, some at low rates and some not at all, depending upon their proximity to particles containing the varied amounts of radioactivity. Typically, 1,000 to 10,000,000 particles were deposited in the lower respiratory tract. As described above, the particles are cleared by mechanical movement up the respiratory tract or to lymph nodes with retention times between 1 and 1000 days. The particles deposited in the lung also fragment and dissolve in time creating an ever changing radiation dose pattern in the surrounding cell populations. All of this occurs in an expanding and contracting lung volume with cells having varied lifespans. No exposures have ever occurred wherein lung cells have received only one type of radiation dose pattern or dose rate, nor will such exposures ever occur in the future for plutonium dispersed in the environment. Conversely, many inhalation exposures of people and laboratory animals to insoluble particles containing alpha-emitting radionuclides have occurred in the past and included particles which fit the definitions of "hot particles" and "warm particles". These exposures have provided the basis for determining quantitative risk factors for irradiation of lung tissues.

Hazards Associated with Nonuniform Irradiation

In 1972, the National Academy of Sciences Advisory Committee on the Biological Effects of Ionizing Radiation (BEIR) completed its quantitative assessment of the hazards of radiation exposures to people. Their review of radiation induced health effects included studies of the Japanese atomic bomb survivors, German patients treated for ankylosing spondylitis, children irradiated for enlarged thymus glands, ^{226}Ra exposed "Dial Painters", early fluoroscoped patients,

U. S. uranium miners, Newfoundland fluorspar miners and cancers caused by prenatal irradiation. The incidences of health effects were plotted as functions of radiation dose levels and the slopes of these lines were given as the number of cases per million people per year for each rem to the population. These recommended health risk estimators were principally for cancers and genetic defects and they are currently the most widely used risk information on radiation exposures. However, the BEIR Committee also considered the issue of "hot spots" or particulate sources as possible enhanced inducers of lung cancer.

In 1974, a report was published by Tamplin and Cochran requesting a reduction in the current radiation standards governing the internal exposure of man to insoluble alpha-emitting radionuclides. They concluded that these radiation protection guidelines should be reduced by a factor of 115,000. Tamplin and Cochran pointed out:

> "It would take 53,000 particles...(1 μm in diameter, 0.28 pCi) ... to reach the MPLB (Maximum Permissible Lung Burden) of 0.016 μCi which results in 15 rem/yr to the entire (1000 g) lung. However... these particles would irradiate only 3.4 g of this 1000 g lung, but at a dose rate of 4000 rem/yr ... these particles result in an intense but highly localized irradiation. A fundamental question is, then: is this intense but localized irradiation more or less cancinogenic than uniform irradiation?"

The "hot particle" question was reviewed by the National Academy of Sciences, BEIR Committee in a report published in October 1976. The summary of their evaluation of the Tamplin-Cochran rationale follows:

> "The exposure pattern in the deep lung to insoluble alpha-emitting particles always involves focal irradiation. Particles deposited in the alveoli are transported through the lymphatics and concentrated around the respiratory and terminal bronchioles. Hence, the problem for insoluble

particles does not represent a comparison of uniform and focal exposures, but a comparison of the relative effects of greater numbers of small particles compared to smaller numbers of large particles for the same total lung burden.

Radiobiologic theory supports the concept that for respirable-sized particles distributed in a tissue, the number of cells traversed by alpha radiation, and probably also the carcinogenic risk, increases with increasing particle size or particle activity and reaches a maximum at a given particle size or particle activity. At particle sizes or particle activities above this maximum the probability of multiple traversals of single cells increases, thus increasing lethality. This results in a reduced carcinogenic risk since dead cells cannot become cancer cells.

On the other hand, radiobiologic theory also supports the concept that if the alpha activity is distributed throughout the tissue, the number of cells that receive only single traversals or sublethal events of some nature increases with the amount of alpha-emitters present in the lungs and the cancer risk increases similarly. Of course, at very high concentrations of alpha-emitters the number of cells receiving multiple traversals increases and the risk of radiation pneumonitis and fibrosis becomes more significant, while the cancer risk decreases. Experimental efforts to verify these concepts are continuing, but results to date do not contradict this description.

In experimental animals the carcinogenic risk is reasonably independent of the geometric distribution of the particles in the lungs. In a complex organ like the lung it is possible that particle size may affect the distribution, and hence the risks, among various tissues. However, experimental evidence suggests that because of competing tendencies in this distribution, the overall tumorigenic response for a variety of particle sizes is a function of the total radioactive dose

involved and is relatively insensitive to differences in the distribution in various tissues.

The Geesaman Hypothesis, on which the Tamplin-Cochran rationale is based, has merit only to the extent that tissue damage which results in permanent structural disorganization can have an enhancing effect on the tumorigenic response to carcinogen exposure. The postulate that structural disorganization, per se, produces tumors has been shown to be true only in the endocirine system where hormonal feedback-regulating mechanisms operate from one organ to another (e.g., the ovary and pituitary glands). Under these circumstances gross destruction of organs (not microscopic focal derangements) can be a condition for a tumorgenic response.

Geesaman's postualte, that the damage produced in the lung by a single plutonium particle would have the same probability of causing lung cancer as that observed in the irradiated rat skin, makes the following unwarranted assumptions about the pathogenesis of radiation-induced tumors in the rat skin: a) that atrophic follicles, per se, cause skin tumors (i.e., that structural disorganization of this type is tumorigenic) at a relatively low probability of 1 in 2,000; and b) that focal irradiation of hair follicles, as would occur from stationary plutonium particles adjacent to hair follicles, causes atrophic follicles and skin tumors. Since the Geesaman Hypothesis could hardly be taken as the basis for predicting the yield of tumors, even in the rat skin, from imbedded plutonium particles, it would be purely fortuitous if it accurately predicted the response of the human lung to plutonium particles. Therefore, the rationale for the NRDC petition appears indefensible."

To a large extent, the conclusions of the National Academy of Sciences Committee on "Hot Particles" are based upon studies of lung tumor development in laboratory animals that received alpha-emitting radionuclides by inhalation or

intratracheal instillation. The Committee summarized and compared the results of these studies to determine the relative tumor risks for the differnt dose distributions of the internally deposited radionuclides. No attempt will be made here to review all of this evidence but other studies that have been completed since the National Academy of Sciences report will be included in this discussion to present the most current scientific views on the toxicity of alpha-emitting radionuclides in the lung.

Sanders and Mahaffey (1978) have recently reviewed their previous studies of the relative toxicities of inhaled $^{238}PuO_2$, $^{239}PuO_2$ and $^{244}CmO_2$ in rats and have summarized the dose-effect relationships for producing lung tumors. Particles of $^{244}CmO_2$ were much more soluble than either $^{239}PuO_2$ or $^{238}PuO_2$. After clearance of some of the $^{244}CmO_2$ by dissolution and absorption, the remaining radioactivity was more uniformly distributed than after inhalation of either $^{238}PuO_2$ or $^{239}PuO_2$. This was demonstrated by autoradiography. The least uniform dose distribution resulted from exposures to $^{238}PuO_2$. The specific activity of $^{238}PuO_2$ is 275 times that of $^{239}PuO_2$ and hence a particle of $^{238}PuO_2$ contains 275 times as much radioactivity as a $^{239}PuO_2$ particle of the same size. Hence, for the same size aerosols and the same total amount of radioactivity deposited, rats inhaling $^{239}PuO_2$ had about 275 times the number of particles as those inhaling $^{238}PuO_2$ and a larger fraction of the total lung irradiated. Therefore, for the same average dose to lung tissue, $^{238}PuO_2$ resulted in the least uniform irradiation of lung cells with $^{239}PuO_2$ being more uniform and $^{244}CmO_2$ producing the most uniform irradiation of the lung cells.

Sanders and Mahaffey plotted lung tumor frequencies in these studies vs. average radiation doses in the rats exposed to the three aerosols. This is reproduced in Figure 5. The lung tumor incidences at radiation doses less than 100 rads were higher for rats that inhaled $^{244}CmO_2$ or $^{239}PuO_2$ than for rats that

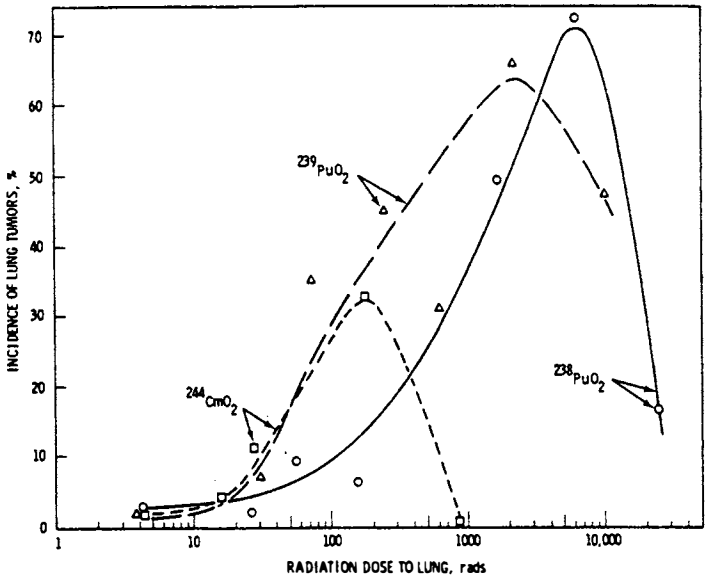


Figure 5. Relationship between incidence of lung tumors and absorbed radiation dose to lung for Wistar rats inhaling freshly prepared, high-fired transuranic oxides. Reproduced from Sanders and Mahaffey (1978).

inhaled $^{238}PuO_2$. The authors concluded that the more uniform radiation dose distributions produced the highest tumor frequencies per rad of radiation.

Little et. al. (1978) studied lung tumor production in Syrian hamsters after intratracheal instillation of ^{210}Po. The dose distribution in lung tissue was varied by instilling either a saline solution of ^{210}Po to produce a uniform dose or ^{210}Po absorbed onto Fe_2O_3 particles to produce a highly nonuniform dose. The mass of carrier particles was varied, either 3 mg or 0.3 mg, and the lung doses were between 50 rad and 2700 rad. The observed tumor incidence in the low dose animals, 55 rad to 75 rad, was 4 to 8 times greater per rad than observed in the high dose animals, 1500 to 2700 rad, but the uniform distribution of ^{210}Po was as effective or more effective than the nonuniform distribution in producing lung tumors, Table 3.

The studies of both Sanders and Mahaffey (1978) and of Little et. al. (1978) used particles to concentrate the radionuclides into focal or point sources of alpha radiation. The particles were not a single size but were polydisperse in sizes so that the focal sources varied widely in their radioactivity contents. The range of particle activities extended beyond "hot particles" on the high end of the radioactivity concentrations and below "warm particles" on the low end.

More recent studies by Brooks (1979) used monodisperse size particles of $^{239}PuO_2$ to study the development of liver related cancers in Chinese hamsters. He injected the $^{239}PuO_2$ particles intravenously causing them to deposit in the hamster livers as focal sources of alpha radiation. The particles ranged in activity from 6 to 710 alpha emissions per particle per day such that the local dose rates varied from 2.4 to 220 rads/day, Table 4. Brooks also injected ^{239}Pu citrate to produce uniform alpha irradiation of the liver. The resulting tumors included hemangiosarcomas, bile duct adenomas, hepatocellular neoplasms, and carcinomas. Tumor frequencies and average liver doses are also shown in Table 4. Although the particles covered a range of activities including both "warm particles"

Table 3

Incidence of Lung Tumors in Syrian Hamsters Given ^{210}Po by Intratracheal Instillation (Little et al., 1978).

Treatment	Radiation Dose (rads)	Number of Animals	Number of Tumors	Tumor Incidence	Tumor Incidence per rad
^{210}Po in Saline					
	1500	38	22	0.58	0.00038
	55	99	9	0.09	0.00160
^{210}Po on Fe_2O_3 Particles[a]					
(3 mg)	2700	37	24	0.65	0.00024
(0.3 mg)	1700	34	15	0.44	0.00026
(3 mg)	75	82	10	0.12	0.00160

a. Amount of Fe_2O_3 carrier instilled.

Table 4. Incidence of Liver Cancers in Chinese Hamsters Injected with ^{239}Pu Citrate or $^{239}PuO_2$ Particles (Brooks, et al., 1979).

Chemical Form	Particle Size (um)	Alpha/day per particle	Injected Activity (uCi/g body wt.)	Median Survival (days)	Average Dose (rads)	Number of Animals	Number of Tumors	Net Tumor Incidence	Net Tumor Incidence per rad
Citrate	--	--	2×10^{-3}	526	1380	52	19	0.33	.00024
	--	--	6×10^{-4}	789	660	8	5	0.59	.00074
	--	--	2×10^{-4}	933	270	20	8	0.37	.00140
	--	--	2×10^{-5}	850	26	19	1	0.02	.00077
	--	--	2×10^{-6}	1075	6	19	0	0.00	.00000
Oxide	0.24	6	2×10^{-3}	675	3540	37	14	0.34	.00010
	0.24	6	2×10^{-4}	1020	518	17	5	0.26	.00050
	0.24	6	2×10^{-5}	1020	44	18	1	0.02	.00045
	0.17	35	2×10^{-3}	750	3720	13	6	0.43	.00012
	0.60	100	2×10^{-3}	600	3720	19	1	0.02	.00001
	0.84	710	2×10^{-3}	860	3720	27	13	0.45	.00012
Control	--	--	0	1020	--	30	1		

and "hot particles" the greatest numbers of tumors per rad of dose were produced by low dose, uniform irradiation of hamster liver cells.

Many other studies of the carcinogenicity of plutonium in the lungs of rats, rabbits, mice and dogs were summarized by Bair et. al. (1974). These will not be discussed in detail here except to emphasize that inhalation of plutonium citrate, carbonate, nitrate, acetate and oxide particles all resulted in similar tumor incidences per rad of dose. Thus, in the hundreds of exposures of laboratory animals to different forms and doses of alpha-emitting radionuclides, no dose distributions have been identified with greatly different risks for producing lung tumors.

Currently, studies are in progress at the Battelle Pacific Northwest Laboratories in Richland, Washington and at the Inhalation Toxicology Research Institute (ITRI), in Albuquerque, New Mexico with inhaled plutonium oxide aerosols. Beagle dogs have been exposed by inhalation resulting in initial lung burdens ranging from 0.002 to 5.6 μCi. The studies at ITRI involve monodisperse aerosols of $^{238}PuO_2$ and $^{239}PuO_2$ which range in particle activities from 0.001 to 50 pCi/particle. This range of activities includes particles a factor of 10 lower in activity than 0.01 pCi "warm particles" to particles 700 times higher in activity than 0.07 pCi "hot particles." Some of these studies have been in progress for more than 3 years to date. Studies at the Battelle Pacific Northwest Laboratories also involve inhalation exposures of Beagle dogs to $^{239}PuO_2$ aerosols but these aerosols are polydisperse in particle sizes. A comparison of the studies being conducted at these two laboratories will ultimately delineate the relative hazards of different sizes of PuO_2 particles but these lifespan studies will require approximately ten years to complete. Preliminary comparisons between these studies have not indicated a greatly enhanced risk for developing lung cancer from inhaling specific sizes of plutonium oxide particles.

At the present time, there is no scientific basis in laboratory animal inhalation studies for postulating very high lung cancer risks from inhaling discrete sizes of plutonium oxide particles. As noted above, the "hot particle" hypothesis was formulated from studies of tumors produced in irradiated rat skin. The tumors developed from cells at the base of hair follicles. These are rapidly dividing cells and the optimum doses for producing tumors were just above 1000 rad. It is interesting to note that the irradiation of epithelial cells surrounding the hair follicles did not result in the formation of a significant number of tumors, even at the high doses. Thus, in these studies and in many others, different cell types have shown different sensitivities for neoplastic changes. Different cell sensitivities have been noted even for lung cells in two different animal species. Inhalation of plutonium aerosols by Syrian hamsters results in fewer lung tumors for equal radiation doses than is observed in rats (Sanders, 1977). Thus, knowing the relationship between radiation doses and tumor development in rat skin hair follicles is not a strong basis for projecting the relationships between radiation doses to lung cells and lung tumor development. This is especially true in light of the many studies of lung tumor formation caused by internally deposited alpha-emitting radionuclides.

The exceptional hazard attributed to "warm particles" by Martell (1977) is based upon mathematical modeling of lung tumor incidences in cigarette smoking people. His model depends upon the assumption that lung cancers in cigarette smokers are primarily caused by ^{210}Po. However, it is known that cigarette smoke also contains chemical compounds that are carcinogenic when in contact with lung cells (Stanton, et. al. 1974). The mathematical relationships used by Martell in predicting the occurrence of lung cancers in cigarette smokers would apply equally well to the chemical carcinogens as to ^{210}Po radioactivity.

Thus, the high radiation risks alleged in the "warm particle" hypothesis for focal sources of alpha-emitting radionuclides in lung tissue have never been

observed in any of the previous studies with laboratory animals. Because most of these studies included exposures to particles described by Martell as "warm particles," it is not likely that the postulated high risks actually occur for particles having specific levels of radioactivity.

Studies of Alpha-Emitting Radioactivity in People

Studies of health risks for people who accidently inhaled particles containing alpha-emitting radionuclides are continuing at the present time. Currently, no information is available to suggest that particles having discrete levels of radioactivity are more hazardous than more uniform irradiation of lung tissue. None of the exposures of people have been to aerosols of single sizes, but many of the exposures contained particles that fit the definitions of "warm particles" and "hot particles."

The BEIR Report (1972) summarized data on lung cancer incidences in uranium miners, fluorspar miners, spondylitis patients and atomic bomb survivors. The two groups of miners were exposed to alpha irradiation in lung tissues while the other groups were exposed to external irradiation. The BEIR Committee derived one risk factor, 1.3 lung tumor deaths/10^6 people/year/rem of exposure or a lifetime risk of about 1×10^{-4}/rem. This risk factor is consistent with lung tumor incidences observed in the studies with laboratory animals exposed to plutonium by inhalation.

The exposures of uranium and fluorspar miners were to radon and radon daughter nuclides either as gases or attached to the surfaces of dust particles. This resulted in irradiation of all lung cell types although most of the tumors developed from cells in the upper bronchial airways. These observations stimulated the suggestion that the bronchial epithelium contained the most sensitive cells for lung tumor development. However, other studies by Cihak et. al. (1974) on Japanese atomic bomb survivors showed that lung cancers develop from

many different lung cell types after uniform radiation exposures. Lung cancer development in uranium miners was also shown to be related to cigarette smoking by Archer et. al. (1976). Thus, lung cancer development in these human populations probably resulted from a mixture of chemical and physical agents and can not be used to delineate the relative hazards of particles or uniformly distributed radiations.

Several other groups of people were exposed to aerosols of plutonium, one dating back to the early days of the Manhattan Project. A summary of all of the studies which are being done with workers that inhaled plutonium was given by Richmond (1974). These studies include several hundred individuals with body burdens ranging up to 0.4 μCi of plutonium. The Manhattan Project exposures occurred over 30 years ago and to date, no lung cancers have developed in these people related to the plutonium exposures. Even larger groups of workers are being studied at the Los Alamos Scientific Laboratory in long-term epidemiology studies (Voelz et. al., 1978). These studies may eventually include over 20,000 individuals with more than 140 having body burdens greater than 20 nCi and 885 with body burdens between 4 and 20 nCi of plutonium. Lung cancer incidences will be followed in these plutonium workers to determine the levels of risk over their lifetimes.

Perhaps the largest group of people with elevated exposures to alpha-emitting radionuclides and well documented incidences of lung cancers is cigarette smokers. Exposures to alpha radiations occur in smokers because of the presence of ^{210}Po in cigarettes. Each cigarette contains about 0.4 pCi of ^{210}Po, of which 25 percent is inhaled in the mainstream smoke (Radford and Hunt, 1964). Deposition of smoke particles containing ^{210}Po in the respiratory tracts results in non-uniform radiation exposures of lung tissues with significant concentrations of ^{210}Po being measured in the bronchial epithelium near airway bifurcations. The average concentration of ^{210}Po at these bifurcations measured by Little et. al.

(1965) was 4.5 pCi/g. The average concentration of ^{210}Po in the whole lung due to cigarette smoking was 0.01 pCi/g. Using the dosimetry methods of Haque (1966) for alpha-emitting radionuclides deposited on bronchial epithelium, the calculated dose to the basal cells of the bronchial epithelium from ^{210}Po in cigarette smoke is between 5 and 15 rem per year. This dose was estimated to be about 10 rem per year by Little et. al. (1965).

Annual death rates from lung cancers in males are shown in Figure 6 for cigarette smokers and non-smokers. In cigarette smokers, the annual death rate increases with age to about 1200 deaths per year in a cohort of 100,000 men. This rate then seems to decline after 80 years of age. In non-smokers, the annual death rate also increases with age to about 250 deaths per year for 100,000 men at the age of 80 years. The third line in Figure 6 assumes the normal death rates for lung cancer in non-smokers and adds the risk of additional bronchial carcinomas which could be attributed to the levels of ^{210}Po present on the bronchial epithelium of smokers. This additional risk was estimated using an annual alpha radiation dose rate of 10 rem/yr to the basal cells of the bronchial epithelium, a risk factor of 1.3×10^{-6} lung cancers per year per rem and a latent period of 20 years. Thus, at the age of 80 years, male cigarette smokers have a potential risk of 950 more lung cancer deaths per 100,000 men than non-smokers. About 50 of these deaths per 100,000 men could be caused by ^{210}Po in cigarettes. Assuming that there were no other carcinogens in cigarette smoke, the alpha radiation cancer risk estimator could not be more than 950/50 or 19 times higher than estimated by the BEIR committee to account for all the additional lung cancers in cigarette smoking men.

It is generally accepted that there are many carcinogenic chemical compounds in cigarette smoke (Lee et. al., 1977). These include polycyclic aromatic hydrocarbons and their heterocyclic analogs. They were usually extracted from

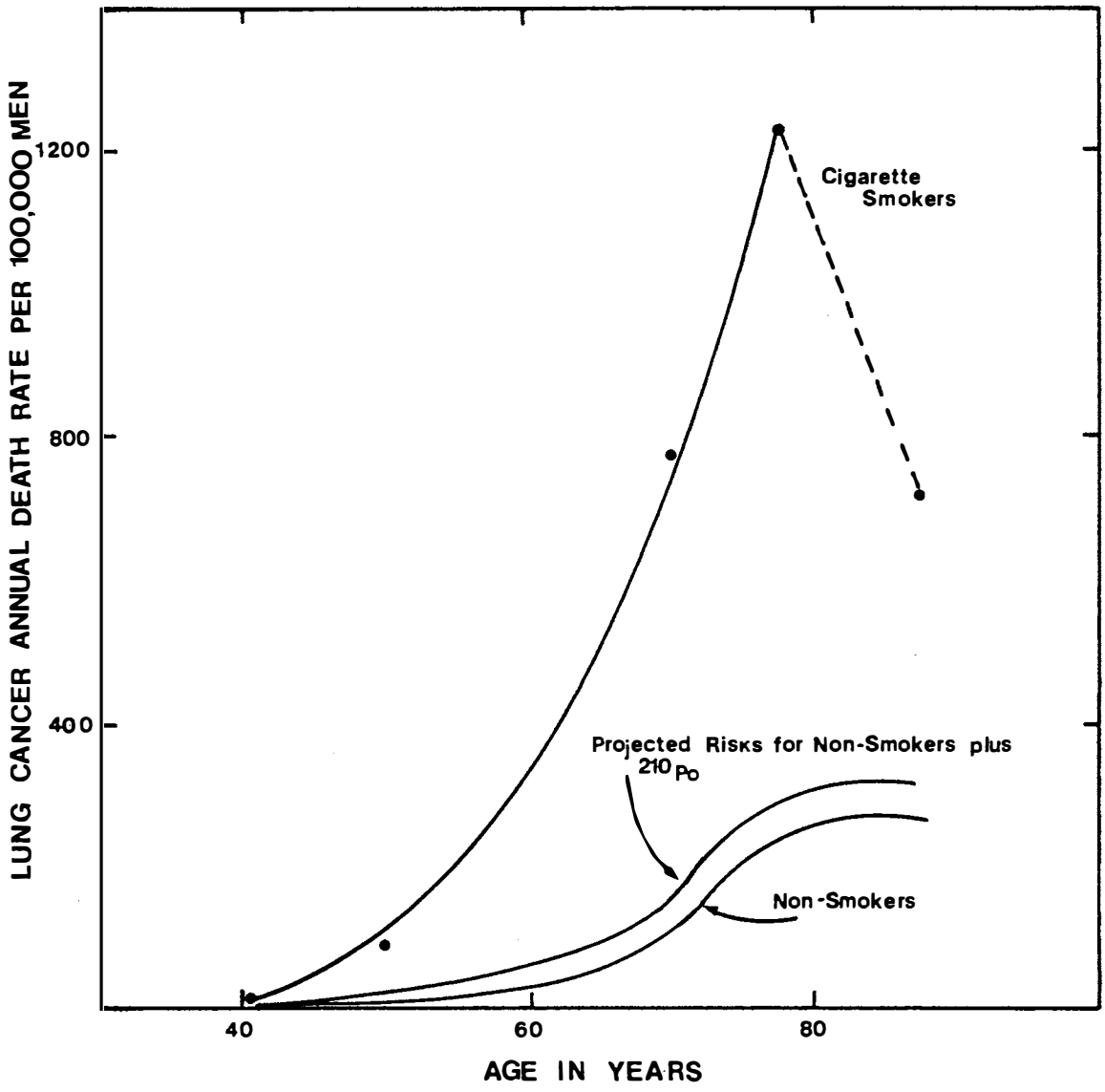


Figure 6. Annual lung cancer death rates related to age in cigarette smokers and non-smokers derived from a study of British doctors (Doll, 1978). Projected lung cancer incidences from ^{210}Po in cigarette smoke was added to the non-smoker incidence rates and is also shown. The projected incidence due to ^{210}Po was calculated by using the BEIR estimator for lung cancer (1.3×10^{-6} cancers/yr/rem), a latent period of 20 yr and an annual dose rate of 10 rem/yr to the basal cells of the bronchial epithelium (Little et al. 1965)

cigarette smoke condensates and were tested in studies with laboratory animals, often by painting them on the skin of mice. Although it is not possible to extrapolate absolute risk factors from mouse skin to other tissues, it is possible to identify which agents are potential carcinogenic agents by using this model. Chemical initiation and promotion of cancers in lung tissue are likely to be a very important part of the total carcinogenic potential of cigarette smoke and it would not be appropriate to relate all of these cancers to radiation alone.

Summary

Risk estimators applicable to alpha radiation in lung tissue have been developed by the National Academy of Sciences BEIR Committee. The data used in these evaluations were taken from uranium miners, fluorspar miners, atomic bomb survivors and irradiated spondylitis patients. The absolute values of the risk estimators are in general agreement with lung tumor incidences seen in studies with laboratory animals that inhaled or were injected with alpha-emitting radionuclides. The studies in laboratory animals also showed no difference in the number of tumors produced per rad of radiation dose to the whole organ that depended upon whether the radioactivity was concentrated in particles or distributed uniformly throughout the tissue.

All of the previous exposures of people and laboratory animals to insoluble particles of ^{239}Pu, ^{238}Pu, or ^{210}Po included particles which fit the definitions of "hot particles" and "warm particles." The BEIR radiation risk estimators are consistent with the observations made of lung tumor incidences in all of these studies. Although these studies included many hundreds of exposures to different forms of alpha-emitting radionuclides, none resulted in markedly different tumor frequencies per unit of radiation dose in the low dose ranges of greatest interest. Thus, there is no basis in studies of lung tumor development in people or

laboratory animals that would suggest uniquely high risks attributable to discrete levels of focal radiation sources such as insoluble "hot particles" or "warm particles" of plutonium.

REFERENCES

Albert, R. E., F. J. Burns and R. D. Heimback, The Association Between Chronic Radiation Damage of the Hair Follicles and Tumor Formation in the Rat, Radiation Research, 30, 590-599, 1967.

Anderson, E. C., P. N. Dean, D. M. Matsakis and H. J. Trussel, Dosimetry, Annual Report of the Biological and Medical Research Group of the Los Alamos Scientific Laboratory, Health Division, LA-5227-Pr, 5-9, Los Alamos Scientific Laboratory, PO Box 1663, Los Alamos, NM 87545, 1973.

Archer, V. E., J. D. Gillam and J. K. Wagoner, Respiratory Disease Mortality Among Uranium Miners, Occupational Carcinogenesis, Annals New York Academy of Sciences, 271, 280-293, 1976.

Bair, W. J., C. R. Richmond and B. W. Wachholz, A Radiobiological Assessment of the Spatial Distribution of Radiation Dose From Inhaled Plutonium, WASH-1320, U.S. Atomic Energy Commission, Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 20402, 1974.

Bennett, B. G., Environmental Pathways of Transuranic Elements in Plutonium and Other Transuranium Elements, (compiled by B. W. Wachholz) WASH-1359, 131-155, 1974.

Brooks, A. L., S. A. Benjamin, D. G. Brownstein and R. O. McClellan, Induction of Cancer and Chromosome Abberations in the Liver of Chinese Hamsters by $^{239}PuO_2$ Particles or ^{239}Pu Citrate, Presented at the 6th International Congress of Radiation Research, Tokyo, Japan, May 13-19, 1979.

Cihak, R. W., T. Ishimaru, A. Steer and A. Yamada, Lung Cancer at Autopsy in A-Bomb Survivors and Controls, Hiroshima and Nagasaki 1961-1970: I. Autopsy Findings and Relation to Radiation, Cancer, 33, 1580-1588, 1974.

Diel, J. H., Local Dose to Lung Tissue from Inhaled $^{238}PuO_2$ Particles, Radiation Research, 75, 348-372, 1978.

Doll, R., An Epidemiological Perspective of the Biology of Cancer, Cancer Research, 38, 3573-3583, 1978.

EPA, Guidance on Dose Limits for Persons Exposed to Transuranium Elements in the General Environment, U.S. Environmental Protection Agency, Office of Radiation Programs, Washington, D.C., 20006, 1977.

Geesaman, D. P., An Analysis of the Carcinogenic Risk from an Insoluble Alpha-Emitting Aerosol Deposited in Deep Respiratory Tissue. Report and Addendum, UCRL-50387, Lawrence Radiation Laboratory, Livermore, National Technical Information Service, Springfield, VA 22151, 1968.

Hague, A.K.M.M., Energy Expended by Alpha Particles in Lung Tissue, Br. J. Appl. Phys., 17, 905-916, 1966.

International Commission on Radiological Protection (ICRP), Task Group of Committee 2, The Metabolism of Compounds of Plutonium and other Actinides: ICRP Publication 19, Permagon Press, Oxford, 1972.

International Commission on Radiation Protection (ICRP), Deposition and Retention Models for Internal Dosimetry of the Human Respiratory Tract. Report of the Task Group on Lung Dynamics for Committee II of the International Commission on Radiation Protection, Health Phys., 12, 173-207, 1966.

Lapple, C. E., The Little Things in Life, Stanford Res. Inst. J., 5, 95, 1961.

Lee, P. N., K. Rothwell, J. K. Whitehead, Fractionation of Mouse Skin Carcinogens in Cigarette Smoke Condensate, Br. J. Cancer, 35, 730-742, 1977.

Little, J. B., E. P. Radford, H. L. McCombs and V. R. Hunt, Distribution of Polonium-210 in the Pulmonary Tissues of Cigarette Smokers, New Eng. J. of Med., 273, 1343-1351, 1965.

Little, J. B., A. R. Kennedy and R. B. McGandy, Effect of Dose Distribution on the Induction of Experimental Lung Cancer by Alpha Radiation, Health Physics, 35, 595-606, 1978.

Martell, E. A., Alpha-Radiation-Induced Lung Cancer, The Warm-Particle Hypothesis, National Center for Atmospheric Research, Boulder, CO 80307, 1977.

National Academy of Sciences Committee on "Hot Particles", Health Effects of Alpha Emitting Particles in the Respiratory Tract, Report of the Ad Hoc Committee on "Hot Particles" of the Advisory Committee on the Biological Effects of Ionizing Radiation, EPA 520/4-76-013, National Academy of Sciences National Research Council, Office of Radiation Programs, U.S. Environmental Protection Agency, Washington, D.C., 20006, 1976.

National Academy of Sciences-National Research Council, The Effects on Populations of Exposure to Low Levels of Ionizing Radiation, Report of the Advisory Committee on the Biological Effects of Ionizing Radiation (BEIR), Washington, D.C., 20006, 1972.

Radford, E. P. and V. R. Hunt, Polonium-210: A Volatile Radioelement in Cigarettes, Science, 143, 247-249, 1964.

Richmond, C. R., Biomedical Effects of Plutonium on Humans, in Plutonium and Other Transuranium Elements, compiled by B.W. Wachholz (WASH-1359), 235-270, 1974.

Sanders, C. L., Inhalation Toxicology of $^{238}PuO_2$ and $^{239}PuO_2$ in Syrian Golden Hamsters, Radiation Research, 70, 334-344, 1977.

Sanders, C. L. and P. N. Dionne, Distribution of Alpha Energy in Alveoli Following Deposition of $^{239}PuO_2$ Particles, Pacific Northwest Laboratory Annual Report, 1968, BNWL-1050 Part 1, 3.40, 1970.

Sanders, C. L., G. E. Dagle, W. C. Cannon, D. K. Craig, G. J. Powers and D. M. Meier, Inhalation Carcinogenesis of High-Fired $^{239}PuO_2$ in Rats, Radiation Research, 68, 349-360, 1976.

Sanders, C. L., G. E. Dagle, W. C. Cannon, G. J. Powers and D. M. Meier, Inhalation Carcinogenesis of High-Fired $^{238}PuO_2$ in Rats, Radiation Research, 71, 528-546, 1977.

Sanders, C. L. and J. A. Mahaffey, Inhalation Carcinogenesis of High-Fired $^{244}CmO_2$ in Rats, Radiation Research, 76, 384-401, 1978.

Stanton, M. F., M. W. Layard and E. Miller, Squamous Carcinoma of the Lung from Cigarette Smoke Condensate in Implanted Beeswax Pellets, in Experimental Lung Cancer, E. Karbe, J.F. Bark, eds., Springer-Verlag, New York, 1974.

Tamplin, A. R. and T. B. Cochran, A Report on the Inadequacy of Existing Radiation Protection Standards Related to Internal Exposure of Man to Insoluble Particles of Plutonium and Other Alpha Emitting Hot Particles, National Resources Defense Council, 1710 N Street, NW, Washington, D.C., 20036, 1974.

Tamura, T., Physical and Chemical Characteristics of Plutonium in Existing Contaminated Soils and Sediments, Proceedings of the IAEA Symposium on Transuranium Nuclides in the Environment, International Atomic Energy Agency, Vienna, 213-229, 1976.

Volez, G. L., J. H. Stebbings, L. K. Haxton and D. A. York, Epidemiologic Studies of Persons Exposed to Plutonium. Biomedical and Environmental Research Program of the LASL Health Division. Jan.-Dec. 1977, LA-7254-PR, Los Alamos Scientific Laboratory, PO Box 1663, Los Alamos NM 87545, 1978.

Whitby, K. T. and B. Cantrell, Atmospheric Aerosols--Characteristics and Measurements, In Session 29, Fine Particles, In International Conference on Environmental Sensing and Assessment. Las Vegas, Nevada, Sept. 14-17, 1975. New York: Institute of Electrical and Electronics Engineers, 1976.

APPENDIX G-3

NONTECHNICAL DISCUSSION OF PLUTONIUM AND THE BASIS OF ITS HEALTH STANDARDS

R. E. Yoder

INTRODUCTION

The element plutonium has a fascinating attraction for the public for several reasons which include:

a) It is the first man-made element produced in any significant quantity.
b) It extends the availability of natural fissile materials (uranium), when used as a reactor fuel.
c) It is used as an energy source in heart pacemakers.
d) It is very radiotoxic and a potent cancer producer.
e) It remains radioactive for a very long time, a property which requires extraordinary care in its disposal.
f) It can be used for nuclear explosives.

In this discussion an attempt is made to discuss in layman's terms some of the information known about plutonium which may assist the reader of this Environmental Impact Statement. Specific references are not supplied but the interested reader can use the general references noted at the end of the section as a guide to the more technical literature.

PRODUCTION OF PLUTONIUM

In nuclear reactors, the element uranium (which is the fuel) undergoes numerous nuclear reactions, some of which lead to elements not found in nature in detectable quantities. One of these elements is plutonium.

Several types of nuclear reactors have been developed. Nuclear reactors operate by placing fissile material, such as uranium, in a suitable physical arrangement to permit a self-sustaining reaction by efficiently using neutrons produced by the fission reactions. Basically they all operate similarly but are designed differently because of the purpose they are intended to meet. Originally, reactors were fueled with high-purity natural uranium, which is made up mostly of uranium-235 and uranium-238, embedded in graphite (carbon). Enriched uranium contains more uranium-235 than is present in the natural element. The availability of the rarer uranium isotope, uranium-235, has permitted the construction of (1) power reactors, using low-enriched uranium, (2) fast reactors, using nearly pure uranium-235, and (3) experimental reactors, using many enriched levels of uranium. Plutonium is produced in all of these reactors; however, the quantity produced varies.

Plutonium production is initiated in a nuclear reactor when an atom of uranium-238 absorbs a neutron to become an unstable atom of uranium-239, which decays by beta emission to become neptunium-239. Neptunium decays by beta emission to plutonium-239. Figure 1 depicts the production of plutonium from uranium. These radioactive decays occur while the fuel is in the nuclear reactor, and the parent atoms are subject to further interactions with neutrons. Thus, neptunium-239 can absorb a neutron to become neptunium-240, and plutonium-239 can absorb a neutron to become plutonium-240. In this complex manner several plutonium isotopes are produced. Figure 2 identifies the isotopic mixture of plutonium produced in a reactor operating at a specific power level for several periods of time. For military purposes one desires to maximize the fraction of plutonium-239 in the mixture, so that a 100-day irradiation would produce an isotopic mixture suitable for use at Rocky Flats. Longer periods of irradiation would produce plutonium with a smaller fraction of plutonium-239.

After the appropriate time in the reactor, the uranium fuel, the fission products, the neptunium, and the plutonium are removed from the reactor and set aside to allow any existing neptunium-239 to decay to plutonium-239 (about 30 days). To allow time for fission products to decay, thus simplifying reprocessing operations, the fuel elements may be held longer. Reprocessing includes dissolving the uranium fuel element in a strong acid, such as nitric acid, and chemically separating the uranium, plutonium, and other fission products. The uranium can be reused in other fuel elements but the fission products are waste which require disposal.

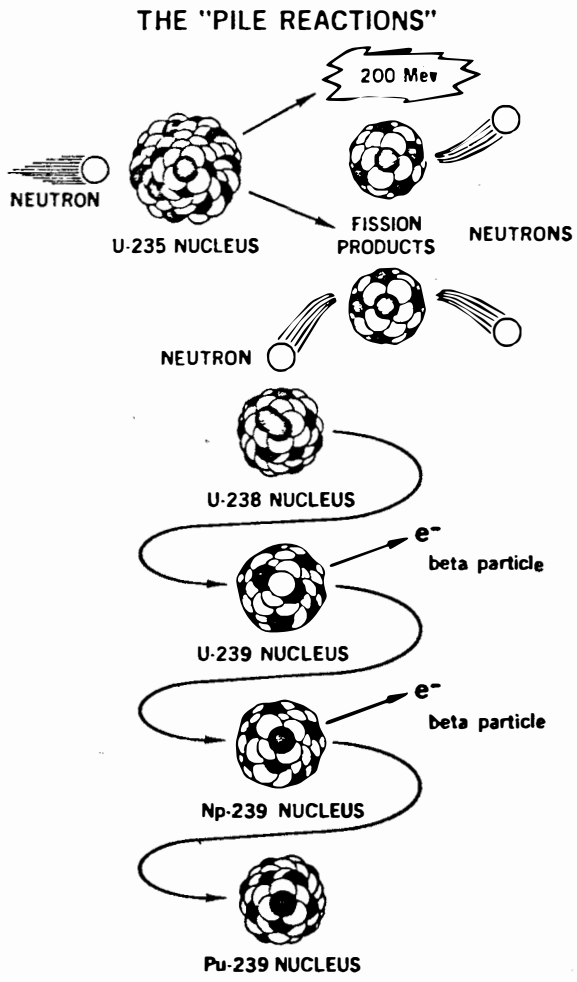
HANDLING TECHNIQUES

At Rocky Flats, plutonium metal produced by the described nuclear cycle is an essential ingredient in many manufacturing processes. Plutonium is worked by the normal operations encountered in any metal working industry. However, as described in Chapter 2 of this EIS, there are extensive measures taken to prevent the metal from coming into contact with people. At Rocky Flats, plutonium ingots are received in sealed containers. When needed, the containers are placed inside glove-boxes in which the plutonium is removed from the sealed container. From this point on, the metal remains in gloveboxes until its final assembly permits its removal in a sealed container.

Because plutonium is expensive and cannot be wasted, all chips, furnace residues, powders, and other scrap produced in the production operations are carefully collected for reuse. If the material is sufficiently pure, it is reintroduced into the melting furnace with additional new ingots or, if impure, it is sent to chemical recovery where the metal is dissolved, purified, and reduced to metal again.

Reactive forms of plutonium, as with many other metals, including steel, are easily ignited under certain conditions (i.e., machine turnings, finely divided powder, etc.). Therefore, many operations are conducted in an inert atmosphere using dry nitrogen, argon, or helium, rather than air. This reduces the risk of fire.

FIGURE 1



When a uranium-235 atom captures a neutron in its nucleus, it fissions to produce two radioactive nuclei of fission-product elements, an average of 2.5 neutrons, and 200 Mev of energy. Although the energy produced is important, the production of more than one neutron for the one captured is even more important because that is what makes possible the rapid buildup of a chain reaction. The radioactive uranium-239 nucleus, formed when a uranium-238 nucleus captures a neutron, decays with a half-life of 23.5 minutes by emitting a beta particle (essentially an electron) to form neptunium-239 having a half-life of 2.35 days. In turn, the neptunium-239 nucleus also emits a beta particle, and is thus converted to long-lived plutonium-239.

FIGURE 2

FRACTIONAL DISTRIBUTION OF PLUTONIUM ISOTOPES IN A NUCLEAR REACTOR OPERATING AT 33,000 MWD/T

Plutonium Isotope	Fraction of Mixture by Weight for Days in Reactor			
	110 Days	330 Days	660 Days	1100 Days
Pu-238	0.0002	0.0017	0.0063	0.0183
Pu-239	0.944	0.8393	0.7057	0.5841
Pu-240	0.0517	0.1318	0.1863	0.2428
Pu-241	0.0037	0.0252	0.0698	0.1155
Pu-242	0.0001	0.002	0.0126	0.0393

Plutonium Isotope	Decay Type	Half Life(1)	Daughter Isotope
Pu-238	α	87.79 yrs.	U-234
Pu-239	α	24,082 yrs.	U-235
Pu-240	α	6,537 yrs.	U-236
Pu-241	β	14.35 yrs.	Am-241

(1) "American National Standard Calibration Techniques for the Calorimetric Assay of Plutonium-Bearing Solids Applied to Nuclear Materials Control," ANSI N15.22-1975, American National Standards Institute, Inc., June, 1975.

HEALTH IMPLICATION

Plutonium decays by alpha particle emission except for the isotope plutonium-241, which decays by beta particle emission. Alpha particles are nuclei of helium atoms. Plutonium is not the only alpha particle-emitting radioactive element. There are many elements which similarly decay; for example, uranium, thorium, radium, polonium, bismuth, and lead. All of these are naturally occurring, which means they are found in nature, and all are in man, because they are present in the food we eat, the water we drink, and the air we breathe. At the time of emission from plutonium nuclei the alpha particles are electrically charged and moving very fast. These charged particles leave a dense trail of ionized atoms in the medium even though they travel only a very short distance. This secondary ionization in living tissue may result in health effects.

After the discovery of radioactivity in 1896 by Becquerel, Madame Curie in 1898 separated radium from uranium ores mined in Czechoslovakia. Radium, an alpha- and a gamma-emitter, was discovered to exist in natural hot springs which frequently were developed into spas in the early 1900's for use in the healing arts. Radium also was shown to be a fluorescent activator of zinc sulfide which, when the two were mixed together in a binder of glue and applied to aircraft instruments or wristwatches, enabled people to read the dials in the dark. During and after World War I, the United States was a prime manufacturer of radium dials for military and commercial purposes.

The workers who painted the numbers or letters on these instrument dials kept their paintbrush tips pointed by touching them to their tongue. It was soon noticed that lip, buccal (cheek), lung, and bone cancer was developing in some of the workers. In time, these observed changes were traced to the radioactive material used in the paint. Several types of radioactive materials were used in the United States in compounding the luminescent paints, and the final determination of the dose received by each employee in the painting process is still incomplete. Based on the observations of the radium dial painters, individuals treated with X-rays, the health profiles of radiologists, animal experiments, people who used radium for therapy, and others, sufficient information has been accrued to permit the establishment of radiation exposure limits which are safe for industrial workers.

Thus, it has been documented that no significant health effects such as cancer, have been observed in any individual who assimilated less than 1 microgram of radium or its equivalent radioactivity. This quantity is presumed to be the limit below which significant effects are not observed. Because all people have not been traced in the radium study and because an initially healthy population is assumed, an absolute statement cannot be made regarding a lower (threshold) limit which produces health effects.

This background discussion regarding radium is important because plutonium health limits are in part based upon the above mentioned

studies, human observation, animal studies, and biological analysis. The radioactive elements heavier than lead tend to move in the body as described below. Each element behaves differently in the body and may concentrate to different degrees in the several body organs. The facts known regarding the effects of bone depositing alpha-emitting radioactive materials have pointed to a conclusion that in a working lifetime of 50 years if one does not accumulate a radioactive material in the body which produces a dose exceeding that produced by 0.1 microgram of radium, then deleterious effects should not be observed. (This is one-tenth of the value at which health effects have been observed.) The limits of all bone depositing radioactive elements are based upon an equivalence with radium. These limits are the primary dose standard and embody the concepts of radiation damage, energy deposited in a body organ, and time. Plutonium, which is included among bone depositing elements, is limited to 0.040 microcurie deposited in the bone. This quantity will produce no additional effects than would be produced by 0.1 microgram of radium. The difference between the numerical value of the quantities of the two materials lies principally in their different radioactive decay rates, and their different final deposition patterns.

Operationally, to assure the primary standards are not exceeded, secondary or derived standards are developed. These derived standards can be used on a day to day basis to limit the intake of radioactive materials via inhalation or ingestion so that the primary standard is not exceeded. Regarding plutonium, it is helpful to describe some biological transport concepts to relate more clearly the relationship between the primary standard and the secondary standard.

A. Ingestion

Ingestion describes all modes of body intake which involve material being transported to the stomach, the small intestines, and the large intestines. Insoluble materials are those which merely pass through the digestive tract with no uptake. They are not transported from the digestive tract to the blood and are chemically unaffected by the body acids or enzymes. Soluble materials, however, are those which can be chemically transported from the digestive tract to the blood. Soluble materials include those that are ingested as soluble materials or those that can be rendered soluble by the action of body acids, enzymes, etc. Plutonium may be in forms which may be either soluble or insoluble. For conservatism, it is usually assumed to be soluble. This assumption maximizes the quantity which could enter the blood and be transported to other organs.

Soluble plutonium, like other materials, is actively transported from the digestive tract to the blood, which distributes the materials to the various body organs, where it is deposited. The blood circulates to every body organ to provide oxygen (transferred in the lungs to the blood), nutrients (transferred from the digestive tract to the blood), and remove waste (transferred from the blood to the kidneys or lungs in the case of carbon dioxide). Body cells remove from the blood those materials it needs or can assimilate. Plutonium is removed from the blood by the bone (~45%), by the liver (~45%), and other organs (~10%).

Some is removed by the kidneys and appears in the urine. Therefore, to determine how much plutonium can get to a point of deposition, one must determine how much can get from the digestive tract to the blood. EPA suggests 10^{-4} (1/10,000) of the soluble material in the digestive tract may get to the blood (the ICRP recommends a transfer value of 3×10^{-5}). Animal experiments conducted under varying conditions have yielded values ranging from 1/100 to 1/1,000,000. Considering the variability of human biology, the variability of plutonium solubilities and other experimental variables, a value of 1/10,000 has been selected by the radiobiologists most aware of the entire set of data now available.

A demonstration calculation involves determining what quantity of water or food a person ingests each day. For this discussion, water intake only is analyzed. The average person drinks about 1000 cc (~1 quart) of water each day. In seventy years (25,568 days) 25,568,000 cc of water (25,568 liters) is ingested. If there were no elimination of plutonium from the body and the limiting quantity of plutonium in the bone is taken as 0.04 μCi (0.0025 μg) then the quantity, Q, which must not be exceeded in water is

$$Q = \frac{.04(\mu Ci)}{25{,}568(l)} \times \frac{1}{10^{-4}} \text{ (fraction to blood)} \times \frac{1}{.45} \text{ (fraction to bone)}$$

$$\times 10^{6} \left(\frac{pCi}{\mu Ci}\right) = 34{,}765 \frac{pCi}{l}$$

For the general public this value is reduced by a factor of 30 so that Q = 1,158 pCi/l.

NOTE: This calculation ignores radioactive decay and some body elimination and is introduced to be illustrative of methodology only.

The quantity of radioactivity in water can be measured and used as an indicator to project a total uptake of material. The standards generally referred to in the popular press and most scientific journal articles refer to the specific values of the derived standards and do not directly refer to the primary standard. For plutonium, the present value of the maximum quantity in water for the general public is 1666 pCi/l--a value near that derived above which is based upon the several simplifying assumptions. In 1977 the EPA promulgated a drinking water radioactivity standard of 15 pCi/ℓ of alpha radioactivity (except uranium and radon) as the limit for public water supplies and thus has set aside the limit calculated above.

B. Inhalation

The accumulation of materials in the body via this route of intake is more complex because the lung is a far more complicated structure than the digestive tract. The quantity of plutonium transferred from

the air we breathe to the blood is complicated by the difference of behavior, and lung deposition locations, of different sized airborne particles. Particles greater than ~15 micron diameter (0.0059 inches) do not pass the nose. Particles 100 times smaller than this may penetrate to the deepest part of the lung and particles of in-between sizes deposition in the several compartments of the respiratory tract; i.e., the nose, the trachea, the bronchia, and the alveoli. In each of the deposit locations, the lung removes particles by different mechanisms.

Soluble materials are transferred from the alveoli to the blood. Materials deposited in the upper respiratory tract are flushed to the esophagus where it is swallowed and considered in digestive uptake. Insoluble materials are transferred to the tracheobronchial and pulmonary lymph nodes where over time some may be transferred to the blood. The maximum quantity of plutonium permissible in the lung, including the lymph nodes of workers has been set at ~ 0.016 microcuries, because of the relatively long resident time in the lungs of insoluble plutonium compounds.

Even though the process is much more complex in the lung than in the digestive tract, models exist which permit the calculation of the limiting or maximum quantity of plutonium in the air which will not permit exceeding the body limit of 0.04 microcurie. This calculated value of radioactivity per unit volume of air is then a derived standard. Its value is 2 picocuries per cubic meter for workers and 0.001 picocuries per cubic meter for the general population. Note that the lower air concentration value for the general public is one two-thousandth of the limit applied to occupational workers.

In summary, it is important to note that the limiting quantity of plutonium in the body is reached only after a lifetime, and that if intake is reduced to zero at any time, no further accumulation or deposition occurs. If one consumes or breathes plutonium at the limiting value, no overexposure will occur and for most people the limiting value will not be reached because food and water are derived from many different sources, none of which ever approach a limiting value. Actually measured values in air and water around Rocky Flats are only a few percent of the derived standard at most.

REFERENCES

1. William N. Miner, Plutonium, U.S. Atomic Energy Commission, Division of Technical Information.

2. Report of the ICRP Committee 11 on Permissible Dose for Internal Radiation 1959. Health Physics, Volume 3, June 1960.

3. The Metabolism of Compounds of Plutonium and Other Actinides. A report by a Task Group of Committee 2 of the International Commission on Radiological Protection May 1972. Pergamon Press, New York.

4. Deposition and Retention Models for Internal Dosimetry of the Human Respiratory Tract. Health Physics, Volume 12, 1966.

5. The Effects on Populations of Exposure to Low Levels of Ionizing Radiation. National Academy of Sciences, National Research Council, Washington, D.C., November 1972.

APPENDIX G-4

ROCKY FLATS FACILITY/TECHNICAL ASSESSMENT DOCUMENT

September 1977

U. S. Environmental Protection Agency
Office of Radiation Programs
Washington, D.C. 20460

Table of Contents

A. Introduction

The purpose of this report is to present an analysis of the potential hazards to individuals in the general population as a result of present levels of the transuranium elements existing in the environs of the USERDA Rocky Flats Plant. The various pathways by which exposures might occur under present and projected land usages are examined and interpreted in light of EPA's proposed guidelines for exposures to the transuranium elements.

B. Inhalation Pathway

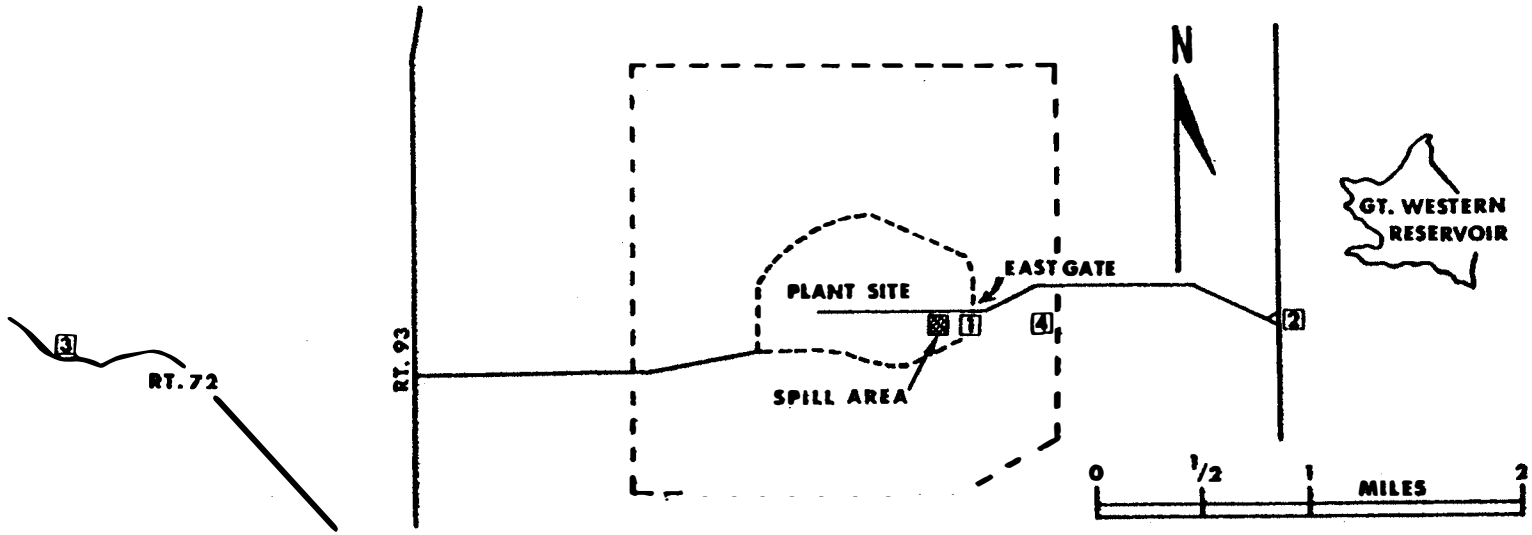
1. Ambient Air Concentrations

Under normal operating conditions, minute quantities of plutonium and other radionuclides are released per year to the atmosphere from the Rocky Flats Plant. These releases are of small magnitude and originate from the plant's ventilation and filtration system. Measurements of airborne radioactivity in the vicinity of Rocky Flats and the neighboring communities are made on a continuous basis. In addition to monitoring the effluent air from production and research facilities, the Rocky Flats facility maintains a system of high-volume ambient air samplers within the plant boundary, at off-site locations in the immediate vicinity of the plant, and in several communities nearby. Altogether the system comprises 21 air samplers operating continuously within and on the perimeter of the Rocky Flats security area, and another 25 samplers located at various distances and directions from the plant. The data from this network are reported on a monthly basis to the Rocky Flats Area Office of ERDA, the Division of Occupational and Radiological

Health of the Colorado Department of Health, the Denver Regional Office of the EPA, the Health Departments of Boulder and Jefferson Counties, and city officials in several communities near the plant.

In addition to the surveillance network maintained by the Rocky Flats Plant, the Health and Safety Laboratory (HASL) of ERDA has conducted a program of continuous air sampling for plutonium at the Plant since June 1970 in response to the discovery of elevated levels of plutonium found in soils at location which were then off-site. The HASL network consists of four sampling locations (Figure 1), three of which are downwind (east) from the original location of the oil drum storage site and the fourth air sampler is located off-site and upwind from the Rocky Flats Plant (1). Air concentration data in attocuries of Pu-239 per cubic meter of air (aCi/m^3)*, as reported by this network on a monthly basis from June 1970 to March 1976, are given in Table I. A significant downward trend with time in the level of plutonium in air at the stations downwind from the plant can be seen. It has been suggested by HASL that this downward trend is attributable to the weathering of the contaminated soil in the on-site vicinity of the original oil drum storage site. This weathering may be due to the movement of the plutonium from the surface down into the soil, as well as changes in the characteristics of the plutonium remaining on the surface. In addition to showing a decrease with time the data indicate a decrease in concentration with increasing distance downwind from the site of the original spill area. Based upon air and soil sampling, as well as the direction of the prevailing winds around Rocky Flats, HASL concluded in 1972 (2).

*1 attocurie 10^{-18} curie



MAP OF ROCKY FLATS PLANT AND VICINITY
INDICATING CONTINUOUS AIR SAMPLING SITES (1).

FIGURE 1

that the original spill area was the primary source of plutonium in the Rocky Flats environment.

The current levels of airborne plutonium at the downwind edge of the Facility's buffer zone (Indiana Street) are approximately the same level as reported at the monitoring station upwind from the plant. Although these levels are about twice that expected from background radioactivity in the Rocky Flats area, the effect of the spill area upon the off-site environment has been much reduced from earlier levels.

Comparison of the most recent HASL data (1976) for the Indiana Street location (site 2) with the 1975 data reported by the Rocky Flats Plant (Table II) for the same general area shows the two networks to agree within a factor of about 2. The values reported by HASL range between 12 to 23 aCi/m^3, while Rocky Flats reported an average of 37 aCi/m^3.

2. Calculation of Inhalation Doses Due to On-Site Contamination

An assessment can be made of the doses received through inhalation by individuals residing off-site based upon the considerable amount of air monitoring data that is available for the Rocky Flats Plant. In carrying out this assessment, a deliberate effort has been made to choose assumptions which are most likely to result in an overestimate of dose. These are:

1) Inhaled plutonium is considered to be in an insoluble form. (Chemical solubility of an aerosol determines its residence time in the lung with insoluble compounds being retained the longest.)

2) The plutonium aerosol is assumed to have a lognormal distribution with an activity median aerodynamic diameter (AMAD) of 1 micrometer. (According to the ICRP (3) this implies that approximately 25% of the aerosol will be deposited in the pulmonary compartment of the lung. HASL (4) has reported 25% of the airborne activity being in the respirable range around Rocky Flats, while Sehmel (5) has reported a 20% respirable fraction).

3) The individual is considered to be exposed continuously for 70 years at the currently observed air concentration. (No further reduction in airborne activity as a result of weathering or remedial actions is assumed.)

4) All plutonium measured was assumed to contribute to the dose, with no correction being made for ambient background levels of plutonium.

The PAID code developed by EPA (6) was used to calculate the annual dose rate. Tables III and IV have been generated by the PAID code and relate years of exposure to the resultant dose rate for various organs. Values in the tables are normalized to an aerosol concentration of 1.0 femtocurie per cubic meter of air (fCi/m^3)* with a 1 m AMAD.

Indiana Street Location

Indiana Street is the nearest location to the Rocky Flats Plant where an individual in the general population could presently live and be exposed as a result of transuranium contamination originating from the Plant. This location is in the downwind direction of the prevailing winds that blow across the Rocky Flats Plant (7) and, therefore, it represents a worst case for offsite exposure.

* 1 femtocurie $=10^{-15}$ curie.

From Figure 2 it can be seen that stations S-35, S-36, S-37, S-38, and S-39 are located along Indiana Street. The station reporting the highest annual average for 1975 0.056 fCi/m^3 was S-37 (Table II). Assuming this level to continue for the next 70 years, the 70th year dose rates to lung and bone can be calculated.

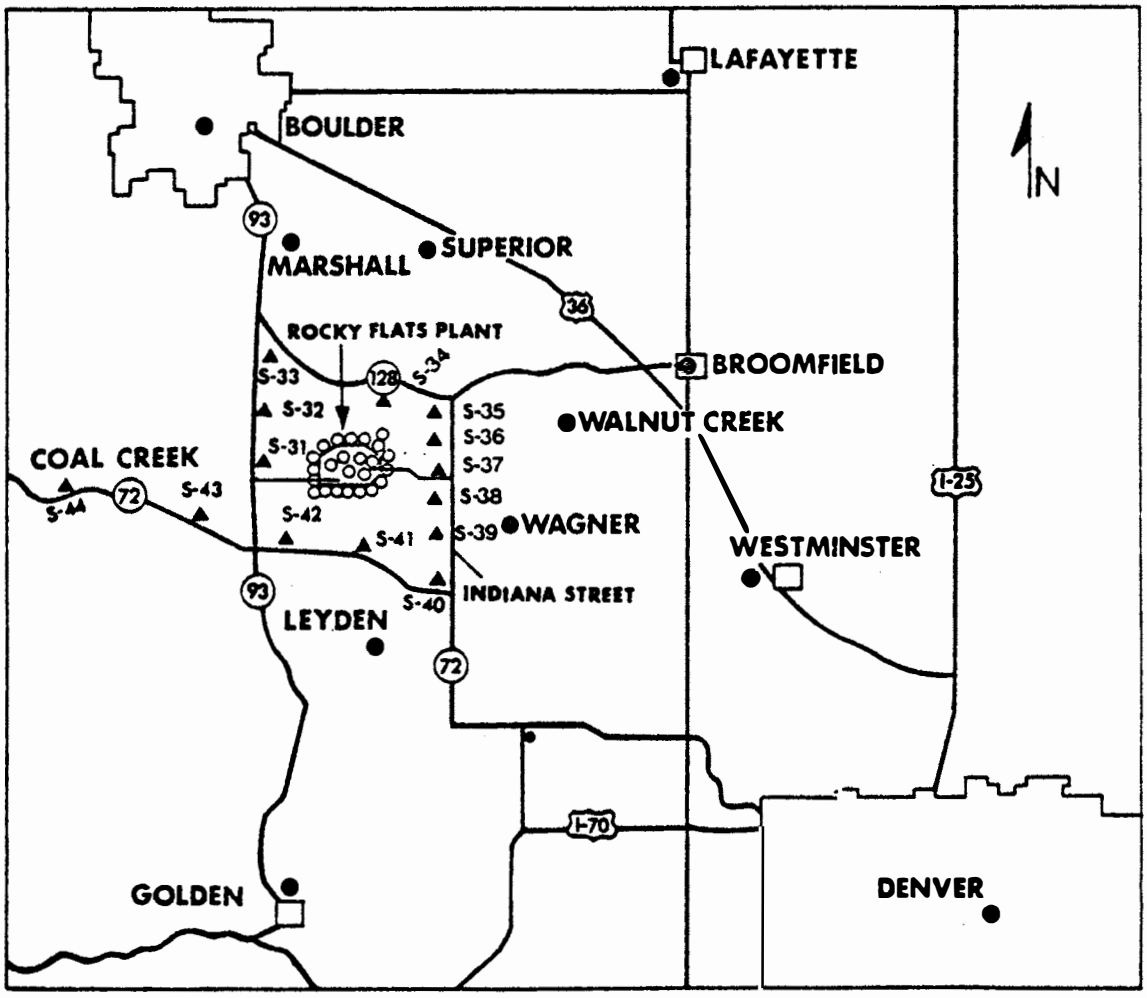
As shown in Table III, an air concentration of 1.0 fCi/m^3 for 1 μm AMAD aerosols of Pu-239 would produce a 70th year dose rate to the pulmonary compartment of 0.38 mrad/yr; therefore, proportionally, a concentration of 0.056 fCi/m^3 (S-37) will produce a 70th yr dose rate of 0.02 mrad/yr. The bone dose rate associated with this level of Pu-239 according to Table IV will be 0.009 mrad/yr in the 70th year.

Data on the air concentration of Am-241 have been reported by HASL (7) for the years 1970 through 1974. These data show the americium levels, measured at the perimeter fence of the Plant, to be approximately 11% of the Pu-239 levels. HASL has also projected that the Am-241 activity level will reach its maximum value arising from the decay of Pu-241 in the year 2033 at which time it will amount to 18% of the Pu-239 activity. For the calculation of the dose rate from Am-241, it is assumed that Am-241 is at the maximum of 18% of the Pu-239. The 70th year dose rate corresponding to a concentration of 1 fCi/m^3 of Am-241 is 0.4 mrad/yr; proportionally, an air concentration of (0.18) (0.056 fCi/m^3) would produce 0.004 mrad/yr to the pulmonary compartment. The associated bone dose would be approximately 0.002 mrad/yr.

Based upon these calculations, the total pulmonary dose rate after 70 years of exposure for an individual living along Indiana Street

FIGURE 2

LOCATION OF OFF-SITE AMBIENT AIR SAMPLERS (8).



LEGEND

- o ON-SITE AIR SAMPLERS
- ▲ AIR SAMPLERS, 3 TO 6 KILOMETERS (2 TO 4 MILES) DISTANCE
- ● COMMUNITY AIR SAMPLERS

would be 0.024 mrad/yr, while the associated bone dose would be 0.01 mrad/yr. These dose rates are approximately 2.5% and 0.35% respectively of the lung and bone dose rates recommended as guides by EPA (10). Individuals living further away from the Rocky Flats Plant should receive even lower doses than these due to the lower air concentrations reported for the nearby communities. Based upon the preceding analysis, the direct impact of the onsite contamination upon the off-site environment can be judged to be small and well within the EPA guidance limits.

3. Calculation of Inhalation Doses Due to Off-site Contamination

A complete assessment of the inhalation pathway for the Rocky Flats vicinity must also consider the potential hazard from the low levels of contaminated soil which already exist off-site. Questions have been raised as to the effect of this material in producing localized exposures which are not necessarily reflected in the data obtained through the air monitoring network around Rocky Flats. These inhalation exposures can arise through various mechanisms including: wind resuspension of contaminated soil, vehicular and mechanical disturbances of soil, accumulation and resuspension of dust within the home, as well as the resuspension of contaminated soil attached to clothing. The following analysis will attempt to investigate these exposure mechanisms and assess their potential impact.

3.1 Wind Resuspension

Figure 3 shows the off-site soil contamination contours reported by HASL in 1970 (2). More recent soil sampling programs in 1975 (8) have not shown these contours to have changed significantly from the 1970

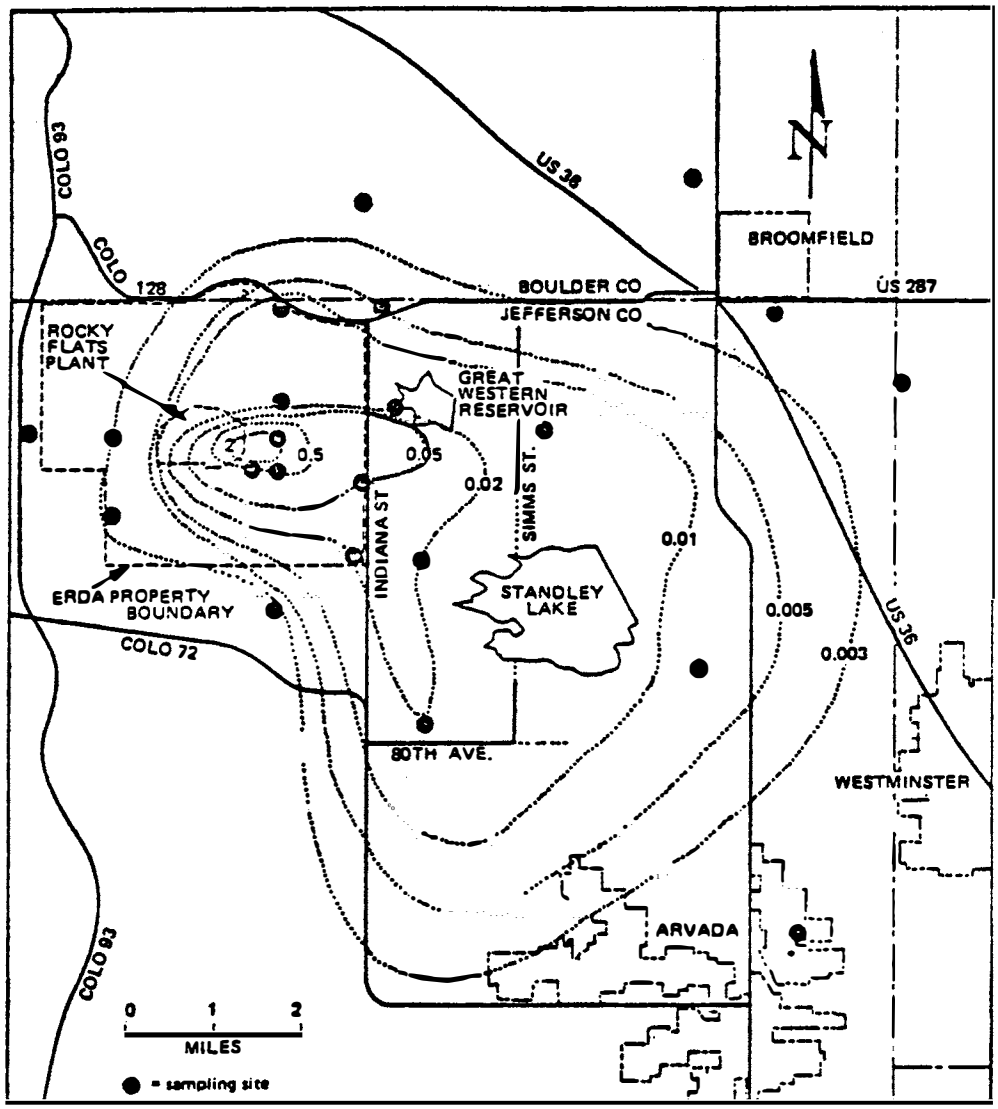


FIGURE 3 Plutonium-239 Contours Around Rocky Flats ($\mu Ci/m^2$)
(adapted from Krey, 1970)

report. The highest off-site contour shown by the HASL data is 0.05 $\mu Ci/m^2$. These contours were developed based upon an inventory sample to a depth of 20 centimeters. What is important in assessing the resuspension of soil, however, is only the material existing near the surface. In the derivation of EPA's guidance, the layer subject to erosion was considered to be the top one centimeter. Based upon the HASL soil depth profiles, Anspaugh (9) has stated that approximately 20% of the total activity is contained within this first centimeter. Therefore, the highest contour value of 0.05 $\mu Ci/m^2$ would correspond to 0.01 $\mu Ci/m^2$ when corrected for a 1 cm. depth. On a mass basis, 0.01 $\mu Ci/m^2$ is equivalent to approximately 2 disintegrations per minute per gram of soil, i.e., 2 DPM/gm. The off-site area bounded by this contour is approximately two square kilometers and soil within that area would be projected to be at or above 2 DPM/gm. Beyond this area, off-site soil will generally be below this value.

In developing its guidance (10) to other Federal agencies on environmental levels of the transuranium elements, EPA utilized the mass loading approach as an indicator of the general resuspension by wind over large land areas. Because of technical shortcomings identified with the mass loading approach (10), the Agency modified the concept to assess small areas of contamination (area correction factor) and to reflect a nonuniform distribution of radioactivity with soil particle size (enrichment factor). This latter modification is particularly important because transuranium activity associated with soil particles within the respirable range is a greater hazard than it would be if associated with the larger particle sizes.

The mass loading approach assumes the loading of the air with particulates to be an index of resuspension and derives the airborne concentration of a specific radionuclide by a comparison with its concentration on the adjacent surface (11). Specifically,

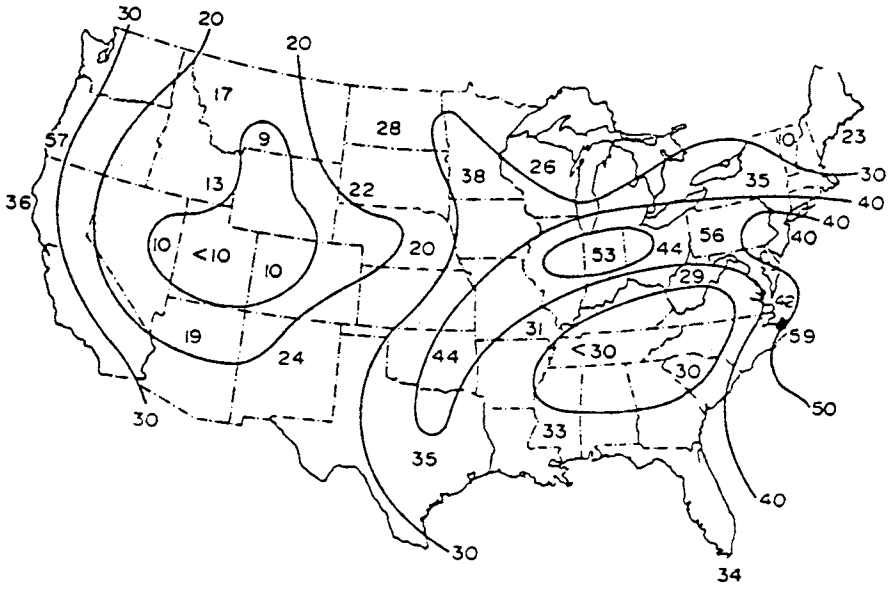
$$\text{Air Concentration } (fCi/_m3) = \text{Soil Concentration } (^{\mu Ci}/_{m^2}) \times \text{Mass Loading } (^{\mu g}/_{m^3}) \times \text{U.C.}* \qquad \text{Eq. 1.}$$

Airborne particulate mass loading is one of the criteria for clean air standards and measurements are widely available for urban and nonurban locations through the National Air Surveillance Network (NASN). The data recorded at nonurban stations are a better indicator of the levels of resuspended material than are urban measurements. In general, annual mean mass concentrations of airborne particulate material at the nonurban stations range from 5-50 micrograms per cubic meter (Figure 4); the mean arithmetic average for 1966 of all 30 nonurban NASN stations was $38\mu g/m^3$(11). From Figure 4 an estimate can be made of the average mass loading for the general area in which Rocky Flats is located. It would appear that 15 $\mu g/m^3$ is reasonably representative of this area on an annual basis.

Simple application of the mass loading approach without consideration of the activity distribution as a function of particle size is not appropriate, however, since that would imply a uniform distribution of activity with particle size as well as a uniform

---

*Where U.C. is the units conversion factor based upon the depth of sampling and the soil density.



ANNUAL MEAN MASS CONCENTRATIONS ($\mu g/m^3$) OF AIRBORNE PARTICLES FROM NON-URBAN STATIONS OF THE U.S. NATIONAL AIR SAMPLING NETWORK. 1964 . 1965

FIGURE 4

resuspension of all particle sizes. This has not been found to be the case at Rocky Flats (12) or at other plutonium contaminated sites (13). In addition, an important consideration in assessing the potential exposure due to contaminated soil is the amount of activity associated with particles within the respirable size range. Johnson (14) has suggested that sampling of only those particles in a soil sample which are within the inhalable size range (generally < 10 μm) would give the best measure of risk to the public health around Rocky Flats. However, the weight fraction of particles in the less than 10 μm range is small in most soils, and sampling, separation, and analysis techniques are correspondingly more difficult and inaccurate. There is also considerable evidence that some of the larger particles really consist of aggregates and are relatively easily broken down into smaller ones, so that an instantaneous measurement of a single size range may not give a good picture of long-term trends. Also a substantial contribution to other possible pathways (e.g. ingestion) may be via larger particle sizes and measurement of the contribution of only the inhalable fraction would not provide all the information that is required.

In order to adequately assess the potential hazard of the inhalable fraction of soils, while retaining the advantages and convenience of analyzing the entire soil sample, the Agency modified the mass loading approach by use of an "enrichment factor". While such a concept does not have universal acceptance, and the scope of its applicability has not yet been determined, the Agency believes that it represents a useful method for the purpose intended and it has therefore been used in this evaluation.

3.1.1 Enrichment Factor

The "Enrichment Factor" is intended to 1) give a mathematical view of the different fractions of the total radioactivity associated with particles of different size ranges, and 2) address the problem of the nonuniform resuspension of particle sizes.

The inhalable fraction of the soil is weighted by considering the relative distribution of activity and soil mass as a function of particle size for representative samples of soil. To accomplish this, the sample of contaminated soil is segregated into "n" size increments and the activity and mass contained within each size increment is determined. The factor g_i is then defined as the ratio of the fraction of the total activity contained within an increment "i" to the fraction of the total mass contained within that increment. A value greater than 1 for g_i implies an enrichment of activity in relation to mass, while a value less than 1 indicates a dilution of the activity with respect to mass. For g_i equal to 1, the fractions of the activity and of the total mass contained within increment "i" are the same.

The nonuniform resuspension of particle sizes is also considered by measuring the mass loading as a function of particle size. The fraction of the airborne mass contained within each size increment "i" is then calculated and designated as f_i. The factors of f_i and g_i are then incorporated into the mass loading formulation as follows:

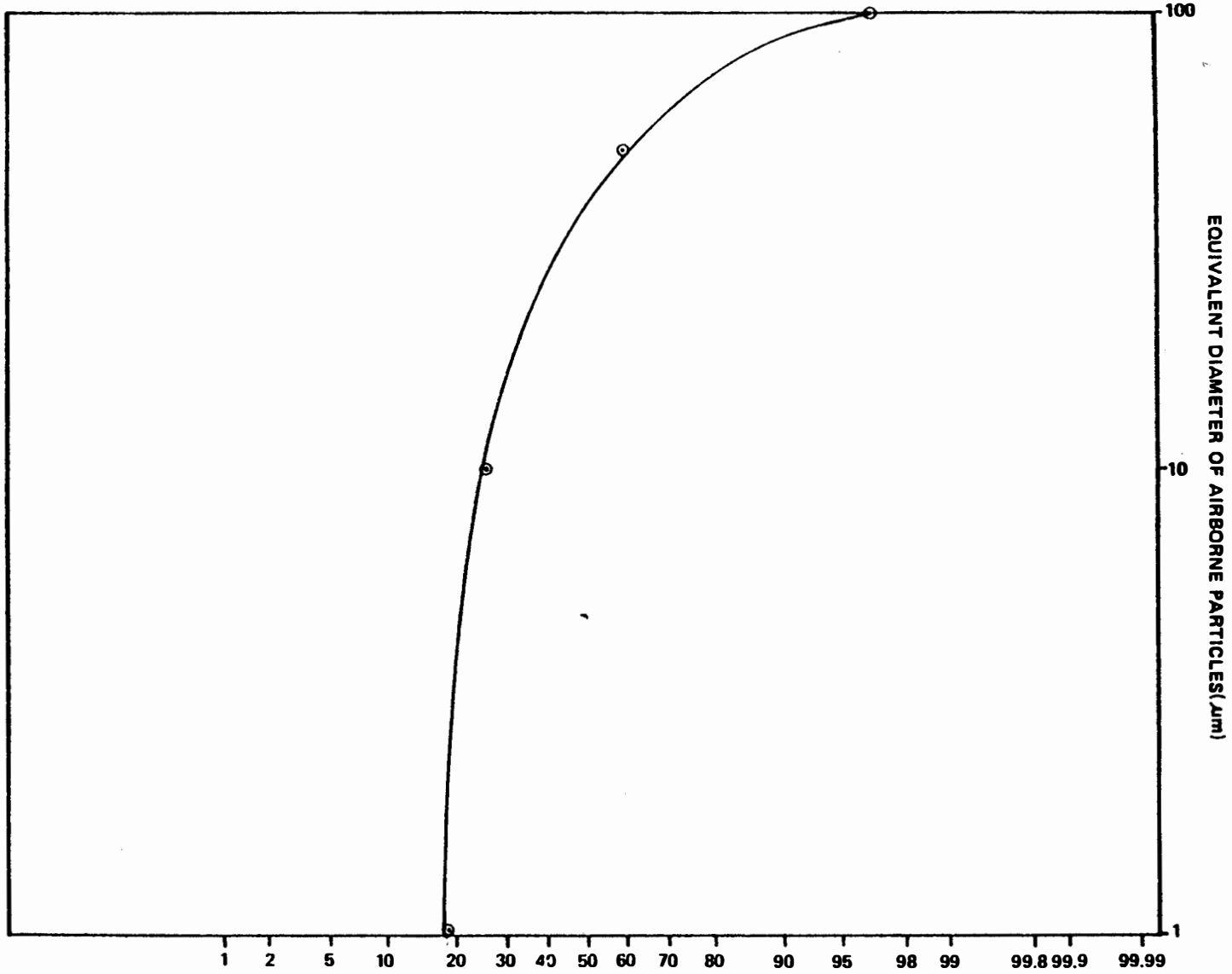
$$\text{Air Concentration}_i = \text{Air Mass Loading} \times f_i \times \text{Soil Concentration} \times g_i \qquad \text{Eq. 2}$$

Summation over all the size increments results in the total air concentration:

$$\text{Air Concentration} = \text{Air Mass Loading} \times \text{Soil Concentration} \times \sum_{i=1}^{n} f_i g_i \qquad \text{Eq. 3}$$

The term $\sum_{i=1}^{n} f_i g_i$ weights the contribution of the plutonium from each soil size fraction to the total resuspended material, thereby, taking into account both the nonuniform resuspension of particles sizes as well as the nonhomogeneous distribution of activity with particle size. $\sum_{i=1}^{n} f_i g_i$ is the "enrichment factor."

Data on the distribution of plutonium with soil particle size has been obtained by the EPA (12) for the vicinity around Rocky Flats (Table V). The ratio, g_i, has been calculated for each size increment and indicates an enrichment of activity to mass associated with soil particles within the respirable size range. To obtain, f_i, the data obtained by Chepil (15) for fields undergoing wind erosion in Colorado and Kansas were used. The results of his findings have been conveniently plotted by Slinn (16) and reproduced as Figure 5. Comparison of Chepil's data with another study substantiates the applicability to the Rocky Flats situation. Chepil found 30% of the airborne mass to be below 10 μm versus a study by Willeke (17) in an area outside Denver where approximately 33% of the measured airborne mass was below 10 μm. Values for f_i used in this analysis are included in Table V.



PARTICLE SIZE DISTRIBUTION OF RESUSPENDED SOIL

FIGURE 5

3.1.2 Correction for Area Size

Use of the mass loading approach implies that the air concentration is at equilibrium with the ground surface, i.e., a steady state situation exists in which the amount of material coming up from the surface is balanced by the rate at which material is depositing back onto the surface. In the strictest sense this limit can only be achieved for source areas approaching infinite dimensions. For sources of finite dimensions, a correction must be applied for area size.

Although many techniques are presently under development to calculate the air concentration arising from an area source, no generally accepted method has yet been identified. Usually, these approaches make use of a standard diffusion equation, modified to handle area sources. One such equation is the Sutton-Chamberlain diffusion equation:

$$\frac{\chi}{Q_A} = \frac{1}{V_d}\left[\exp\left(-\frac{4\ V_d\ D_1^{n/2}}{\sqrt{\pi}\ C_2\ n\ \mu}\right) - \exp\left(\frac{4\ V_d\ D_2^{n/2}}{\sqrt{\pi}\ C_z\ n\ \mu}\right)\right] \qquad \text{Eq.4}$$

where χ is the air concentration, Ci/m^3

Q_A is the amount of activity resuspending per unit area, per unit time, Ci/m^2 sec

V_d is the particle deposition velocity, m/sec

D_1 and D_2 are the distances from the receptor to the nearest and furthermost edges respectively of the source area, meters

μ is average wind speed, m/sec

C_z and n are Sutton parameters representing the meteorological conditions.

If the receptor is placed at the downwind edge or within the source area, $D_1 = 0$ and Eq. 4 reduces to:

$$\frac{\chi}{Q_A} = \frac{1}{V_d}\left[1 - \exp\left(-\frac{4\ V_d\ D_2}{\sqrt{\pi}\ C_z\ n\ \mu}\right)^{n/2}\right] \qquad \text{Eq.5.}$$

For source areas approaching infinite depth, $D_2 \to \infty$ and Eq. 5 becomes:

$$\frac{\chi}{Q_A} = \frac{1}{V_d} \qquad \text{Eq.6.}$$

Comparing Equation 5 with Equation 6 shows that

$\left[1 - \exp\left(-\frac{4V_d\ D_2}{\sqrt{\pi}\ C_z\ n\ \mu}\right)^{n/2}\right]$ is the correction term to be applied for areas of finite size.

The area under consideration in this analysis has been described earlier. It is bounded by Indiana Street and the 0.05 $\mu Ci/m^2$ isopleth (Figure 3) with a width in the downwind direction of approximately 1 kilometer. This is the most highly contaminated off-site area and includes sites of projected residential development. The meteorology for the Rocky Flats area has been described (8) to have neutral stability at least 50% of the time with a mean wind speed of 4.2 m/sec in 1975. Healy (18) has suggested values for the parameters required in Equation 4: for the situation of neutral stability, Healy suggests $C_z = .1$ and $n = .25$, while the ratio V_d/μ, which depends upon the

surface roughness, ranges between 0.003 and 0.008 for grassland, 0.005 will be assumed. Therefore, from Equation 5 the correction factor for the area under consideration is 0.66.

3.1.3 Calculation of the Average Air Concentration Due to Wind Resuspension

The average soil concentration for the area is not known, but it would be somewhere between 0.05 $\mu Ci/m^2$ and the next higher isopleth of 0.5 $\mu Ci/m^2$. For calculational purposes, 0.25 $\mu Ci/m^2$ will be assumed or approximately 10 DPM/g (based upon 20% of the radioactivity within the first centimeter). By using the parameters developed in the previous sections for the Rocky Flats area, one can estimate the average air concentration due to wind resuspension:

Mass Loading x Soil Concentration x Enrichment Factor x Area Correction = Air Concentration

$$15 \frac{\mu g}{m^3} \times 10 \frac{DPM}{g} \times 1.49 \times .66 \times \frac{10^{-6} g}{\mu g} \times \frac{Ci}{2.22 \times 10^{12} DPM} = \text{Air Concentration}$$

$$0.066 \frac{fCi}{m^3} = \text{Air Concentration}$$

This calculated value of 0.066 fCi/m^3 agrees within a factor of 2 with the data obtained for the sampling stations along Indiana Street and, as demonstrated earlier, this level of airborne plutonium would produce exposures well below EPA's guidance limits.

Inherent in the above calculation were some conservative assumptions. First of all, the wind was assumed to be blowing 100% of the time across

the contaminated area in the direction of the receptor. In reality, the reported (8) wind rose for Rocky Flats indicates that the wind blows from the westerly direction only about 50% of the time; the remaining time it will be blowing from the direction of less contaminated land and, therefore, less radioactivity would be available for resuspension. Secondly, in deriving the area correction factor the effect of breathing height was ignored with the ground level concentration being calculated. This is a conservative assumption since the airborne concentration will decrease as a function of the height above the ground. Although such refinements could have been incorporated in the calculation, it was not felt to be necessary because even these conservative assumptions resulted in air concentrations well below the Agency's proposed guidance.

3.2 Resuspension of Soil by Mechanical Disturbances

The use of land contaminated with transuranium elements in the vicinity of Rocky Flats for agricultural or building purposes can result in localized resuspension and presents a potential inhalation hazard to individuals in the immediate vicinity of the operation. In the vicinity of Rocky Flats, there is some farming of wheat and the raising of corn for livestock feed. Future development of the land for residential purposes is also being advocated. Although only a limited amount of experimental data are currently available to base an assessment of the inhalation hazard from such activities, some conclusions and recommendations can be made.

In assessing the agricultural situation, data obtained by Milham (19) have been utilized. In that study, a field contaminated

with plutonium near the Savannah River Facility was subjected to various plowing and seeding activities associated with planting wheat. The increase in the airborne activity above that from normal wind resuspension was monitored at the location of the tractor operator and at the downwind edge of the field during the various activities. An average increase of a factor of 30 was observed in the level of resuspended plutonium at the location of the tractor operator and an increase of a factor of 5 at the edge of the field. Based upon these observations, the average air concentration for the year can be calculated for these two locations, assuming that the field is cultivated 30 days of the year 8 hrs/day. Again the area under consideration will be that area of highest off-site contamination described earlier with an average soil contamination level of 10 DPM/g. In the previous discussion of wind resuspension, this level of soil activity produced an air concentration of .066 fCi/m^3. From Milham's data, this activity level would increase to 2.0 fCi/m^3 at the location of the tractor operator and to 0.33 fCi/m^3 at the edge of the field during the agricultural operations. The annual average concentration at each location is therefore:

1. Tractor Location, Average Annual Air Concentration

$$2.0\ fCi/m^3 \times \frac{8}{24} \times \frac{30}{360} + .066\ fCi/m^3 \times \frac{16}{24} \times \frac{30}{360} + .066\ fCi/m^3 \times \frac{330}{360} = 0.07\ fCi/m^3$$

When these annual Pu-239 concentrations are compared to the value of 2.6 fCi/m^3 which was calculated by the PAID code to correspond with

EPA's dose limits, one can conclude that agricultural operations in the area of Rocky Flats would produce activity levels well within EPA's guidelines. In addition, after the first plowing cycle, the surface concentration should be diluted by mixing with soil from below the surface and subsequent plowings would produce air concentration lower than that of the first year.

Regarding building activities, one can make projections based upon the agricultural situation examined above. There does not appear to be any reason why building activities, such as excavation and grading, should produce higher instantaneous air concentrations than those observed during agricultural plowing and, therefore, should not present a more restrictive situation. In addition although the building activity might take place for greater than the 30 days assumed in the plowing situation, it must be kept in mind that the EPA guidelines are based upon a chronic exposure for 70 years. Certainly, the bulldozer operator would not be engaged in a building operation in an area of transuranium contamination for that number of years.

3.3 Resuspension of Dust Within the Home

The total amount of soil continuously in the home is not known but an assumption of 10 g/m^2 has been made (20). This amounts to about 3 lbs of soil in a modest 1500 ft^2 house. Because the floors are harder and smoother than outside surfaces, the resuspension from these surfaces will be higher. Resuspension factors of 10^{-6} m^{-1} have been used in the past to predict exposures in the work place and studies of PuO_2 deposited on indoor surfaces have been consistent with a resuspension factor of 10^{-6} m^{-1} (21).

The following exposure situation is postulated: the individual is exposed to contaminated dust in the home for 24 hrs/day, 7 days/wk, for 70 years. The dust in the home has the same activity/gram as outside soil and has an areal distribution within the home of 10 g/m^2. The air concentration resulting from resuspended dust at 10 DPM/g would be:

$$10 \frac{DPM}{g} \times \frac{Ci}{2.22 \times 10^{12} DPM} \times \frac{10g}{m^2} \times \frac{10^{-6}}{m} = \text{airborne dust concentration}$$

$$0.045 \text{ fCi}/m^3 = \text{airborne dust concentration}$$

Again the level of airborne activity would result in dose rates well within EPA's guidance limits.

3.4 Resuspension of Dust from Contaminated Clothing

Healy (18) has assumed that in a desert environment there will be 1 mg/cm^2 ($10_g/m^2$) of dust on clothing. While it would certainly be less for nondesert environments, this value will also be assumed for Rocky Flats. Because of the proximity of the contamination to the nose and the mouth, a resuspension factor higher than the normal outdoor resuspension factor will be assumed. For this calculation, a value of 10^{-6} m^{-1} will be assumed to be sufficiently conservative (10^{-6} m^{-1} is 3-4 orders of magnitude higher than values of wind resuspension factors observed at Rocky Flats). Therefore, the resultant air concentration is:

$$\frac{10_g}{m^2} \times 10 \frac{DPM}{g} \times \frac{Ci}{2.22 \times 10^{12} DPM} \times \frac{10^{-6}}{m^{-1}} = \text{air concentration}$$

$$0.045 \text{ fCi}/m^3 = \text{air concentration}$$

In addition to this air concentration being much lower than EPA's guidelines, the period of exposure would not be continuous since the clothing would be removed at least during sleeping. Therefore this pathway would present no apparent hazard.

4. Conclusion

Of any of the inhalation pathways considered applicable in the environs surrounding the Rocky Flats Facility none has resulted in doses close to the limits recommended by this Agency for the transuranium elements. In fact, even if the conservative assumption were made that these exposures were occurring simultaneously, the combination of pathways would amount to only a few percent of the EPA guide limits. Even though every conceivable inhalation pathway could not be covered, it does not seem likely that one exists which would have a combination of resultant air concentration and period of exposure to produce significant inhalation exposures at the levels of transuranium activity currently existing in the environs around Rocky Flats.

C. Ingestion Pathway

1. Plutonium and Americium in Drinking Water

Wastewater discharged from the Rocky Flats Plant as well as surface runoff from the Plant site is collected in a number of holding ponds where it is monitored for its radioactivity content before being discharged into either Walnut or Woman Creek. Walnut Creek empties into the Great Western Reservoir which provides part of the drinking water supply for the City of Broomfield, while Woman Creek eventually empties into Standley Lake which is a drinking water supply for the City of Westminster.

The Rocky Flats water monitoring program consists of 1) effluent monitoring of the water being discharged from the holding ponds into Walnut and Woman Creeks, 2) the monitoring of groundwater and 3) the monitoring of the regional water supplies. In monitoring public water supplies, samples are collected and analyzed from the drinking water reservoirs (Great Western and Standley Lake) as well as the finished water in several nearby communities. As with the air monitoring, the results of this sampling program are reported regularly to the responsible Federal, State, and local government agencies and published on a yearly basis. According to the 1975 published data (8) the average concentrations of plutonium and americium in finished water for the region were $< .027 \times 10^{-9}$ μCi/ml and $< .032 \times 10^{-9}$ μCi/ml, respectively. The concentration levels of plutonium and americium in the drinking water of the various communities surrounding Rocky Flats are given in Table VI. Included in this Table are results obtained by Poet and Martell (22) in 1970. Limited comparison of the two sets of data shows little change in the activity levels in the drinking water during this five year period. As with the airborne concentrations, these environmental levels need to be put into the perspective of EPA's guidance limits.

2. Bone Dose Resulting Due to Ingestion of Water

Assuming that the concentrations of Pu-239 and Am-241 in drinking water are those reported for the city of Broomfield (the highest concentrations reported for the more immediate surrounding communities) and that the consumption rate of water is 1.2 liters/day (ICRP Committee

II) the annual water ingestion rates are:

Pu-239, Annual Ingestion Rate

$$0.04 \times 10^{-9} \frac{\mu Ci}{ml} \times 1200 \frac{ml}{day} \times \frac{365d}{yr} = 18 \text{ pCi/yr}$$

Am-241, Annual Ingestion Rate

$$0.029 \times 10^{-9} \frac{\mu Ci}{ml} \times 1200 \frac{ml}{day} \times \frac{365d}{yr} = 13 \text{ pCi/yr}$$

Conversion of the above ingestion rates into dose rates can be achieved through the use of Table VII and VIII. The development of these tables has been described in Annex III of EPA's guidance document (10). Table VIII has been normalized to an ingestion rate of 1000 pCi/yr of various transuranium oxides and relates the years of ingestion to the resulting dose rate. Since plutonium and americium found in tap water would probably be in a chemical form other than the oxide, e.g. the hydroxide or some colloidal form, the solubility and, therefore, the transfer from the GI tract to the blood would be greater than for the oxide form. For non-oxide forms, as shown in Table VII, the values listed in Table VIII should be increased by a factor of 10 for plutonium, while the americium values remain the same. Based upon these conversion factors, the bone dose rate after 70 years of ingestion of drinking water would be 8.8×10^{-3} mrad/yr for Pu-239 and 6.2×10^{-3} mrad/yr from Am-241. These values are considerably below EPA's guidance recommendation of 3 mrad/yr to bone from the transuranium elements.

3. Bone Dose Due to Ingestion of Foodstuffs

At present limited agricultural production is carried out in the environs of Rocky Flats. Most of the food consumed locally is produced

at considerable distances from the Rocky Flats Plant. Other than a few family garden plots, the only crops grown locally are wheat and alfalfa. A few cattle also are raised in the Plant vicinity. Since future residential development is projected for the Rocky Flats area, it would be reasonable to project a concurrent increase in family gardening. Therefore, an assessment has been carried out of the possible dose rates associated with the consumption of foodstuffs which might be produced locally. Because no food sampling data are presently available for the Rocky Flats area, estimation of the potential doses are based upon data developed in other areas contaminated with transuranium elements and from laboratory experiments of transuranium uptake by foodstuffs. It is not expected that conditions at Rocky Flats would be such that they would invalidate the use of data developed in these other environments nor produce higher dose rate estimates.

For purposes of this assessment, the ingestion rate of the transuranium elements by man is considered to be the product of the rates at which different contaminated materials are ingested and the concentration of the transuranium elements in each material.

To place these calculations into perspective, we have adopted the formulation of Martin and Bloom (23) which relates the ingestion rate H for a particular nuclide to the average concentration of that nuclide in soil C_s through the following formulation:

$$H = C_s I_i D_i \qquad \text{Eq. 7.}$$

where I_i is the ingestion rate of a particular item 1 and D_i is the discrimination ratio between that substance and soil. This formulation makes for easy translation of environmental levels into dose rates and, thereby, direct comparison with EPA's guidance limits.

The soil concentration used in this assessment is the same as that developed for the inhalation pathway calculations, i.e., 0.25 $\mu Ci/m^2$ for Pu-239 and 0.045 $\mu Ci/m^2$ for Am-241 (18% of Pu-239 levels at the time of maximum ingrowth). If as a result of plowing, this activity is evenly distributed throughout the top 20 cm, the average concentration, C_s, in units of pCi/g would be:

$$0.25 \frac{\mu Ci}{m^2} \times 10^6 \frac{pCi}{\mu Ci} \times \frac{cm^3}{1g} \times \frac{1}{20\ cm} \times \frac{m^2}{10^4\ cm^2} = 1.25\ pCi/g\ Pu\text{-}239$$

and 0.22 pCi/g Am-241.

The materials considered to be produced on this land and consumed by individuals living in the area are: leafy vegetables, other food plants, cow milk, and beef. Also the casual and deliberate ingestion of contaminated soil will be considered.

3.1 Leafy Vegetables and Other Food Plants

Plants grown in soil containing the transuranium elements can become contaminated through uptake by the roots and systemic incorporation; in addition, the outer surfaces of the plant can have contaminated soil deposited upon them as a result of resuspension. Numerous studies have been conducted and several reviews (24, 25, 26) have been published covering the range of discrimination factors that have been observed in laboratory and field studies. Generally, the discrimination ratio for

incorporation of Pu-239 into the plant is between 10^{-4} to 10^{-6} on a fresh weight basis and 10^{-1} to 10^{-2} for deposition on the plant surface. In the case of americium-241, the internal incorporation may be as much as 50 times higher than plutonium due to its greater solubility. Generally, uptake factors for garden vegetables are at the upper end of the range, therefore, for calculational purposes a discrimination ratio of 10^{-4} will be assumed for internal deposition and 10^{-1} for external deposition when computing the intake of Pu-239, and a ratio of $5x10^{-3}$ for internal deposition and 10^{-1} for external deposition in the case of Am-241. Since the calculations are for food in a table-ready condition, decontamination of the food during processing must also be recognized. In doing so, the assumption of Bloom and Martin (23) will be employed; namely, 90% of the contamination is washed off leafy vegetables and 99% of the contamination is removed from other food plants during washing, peeling, etc. Likewise, the consumption rates of foodstuffs obtained by Martin and Bloom from the USDA have been utilized after conversion to a fresh weight basis (on the basis that vegetation is 70% water). Table IX contains the resultant ingestion rates and discrimination ratios used in this assessment.

Equation 7 was used to convert the ingestion rates and discrimination factors of Table IX into annual intakes of plutonium and americium. In carrying out the food pathway calculations, the assumption was made that 25% of the entire intake for an individual arises from foodstuffs produced locally on land contaminated with transuranium elements.

The resultant ingestion doses are given in Table X. In converting the annual radionuclide intake to dose rates, Table VII and VIII were used with the following assumptions:

1. the duration of ingestion is 70 years
2. externally deposited material is in the oxide form

and 3. material biologically incorporated in plants and animals is assumed to have a greater fraction transferred from the G.I. tract to the blood. For plutonium, according to Table VII, this results in an increase of a factor of 50 in the resulting bone dose and a factor of 5 for americium.

3.2 Ingestion of Cow Milk

Martin and Bloom have developed a discrimination factor for dairy cows of 3.2×10^{-8} based upon assumptions of soil and vegetation consumption by cattle. Using this value and again assuming that 25% of one's diet is locally produced, one can calculate the ingestion rates of Pu-239 and Am-241 as a result of milk consumption:

$$H\ (\text{Pu-239}) = C_s\ ID$$

$$= 1.25\ \frac{pCi}{g} \times \frac{436\ g}{day} \times .25 \times 365\ \frac{days}{yr} \times 3.2 \times 10^{-8}$$

$$H\ (\text{Pu-239}) = 1.6 \times 10^{-3}\ pCi/yr$$

$$H\ (\text{Am-241}) = .18\ H\ (\text{Pu-239})$$

$$H\ (\text{Am-241}) = .28 \times 10^{-3}\ pCi/yr$$

Since these transuranium elements would be biologically incorporated, the dose rates of Table VIII would be increased by a

factor of 50 for Pu-239 and a factor of 5 for Am-241. The resultant bone doses attributable to the consumption of milk are given in Table IX.

3.3 Ingestion of Beef

Similarly, Martin and Bloom developed discrimination factors for beef muscle and beef liver and these have been utilized in our calculations of ingestion rates:

Beef Muscle

$$H\ (Pu\text{-}239) = C_s\ ID$$

$$H\ (Pu\text{-}239) = 1.25\ \frac{pCi}{g} \times \frac{273\ g}{day} \times .25 \times \frac{365d}{yr} \times 3.3 \times 10^{-5}$$

$$H\ (Pu\text{-}239) = 1.02\ pCi/yr$$

$$H\ (Am\text{-}241) = .18\ H\ (Pu\text{-}239)$$

$$H\ (Am\text{-}241) = 1.85 \times 10^{-1}\ pCi/yr$$

Beef Liver

$$H\ (Pu\text{-}239) = 1.25\ \frac{pCi}{g} \times \frac{13g}{day} \times .25 \times 365\ \frac{day}{yr} \times 2. \times 10^{-3}$$

$$H\ (Pu\text{-}239) = 2.96\ pCi/yr$$

$$H\ (Am\text{-}241) = .18\ H\ (Pu\text{-}239)$$

$$H\ (Am\text{-}241) = 5.33 \times 10^{-1}\ pCi/yr$$

Assuming that transuranium material is biologically incorporated, the resultant bone dose rates after 70 years of ingestion have been calculated and are included in Table X.

4. Bone Dose Due to Soil Ingestion

4.1 Casual Ingestion

Bloom and Martin (23) have assumed a casual ingestion rate for a desert environment to be approximately 3-4 g/year. Likewise, Rogers (20) has estimated the accidental ingestion rate of soil as a result of hand to mouth transfer to be 3-4 g/yr. Based upon these estimates, one can calculate the plutonium and americium ingestion and resulting dose rates. The ingestion period is assumed to be 70 years and the surface soil concentration of Pu-239 is that developed previously for unplowed, undiluted soil in the vicinity of Indiana Street; i.e., 10 DPM/g (4.5 pCi/g). The americium concentration, also as before, is assumed to be at its maximum contribution of 18% or 0.8 pCi/g. The resulting bone dose have been calculated assuming the transuranic material is in the oxide form and these have been included in Table X.

4.2 Deliberate Ingestion

Healy (27) has addressed the problem of deliberate soil ingestion by children below the age of five. After reviewing the limited available data on the topic, he concluded that a deliberate soil ingestion rate of 20 g/day would be a reasonably severe case. Applying this estimate to the Rocky Flats situation would produce the following ingestion rates for deliberate soil ingestion:

$$H\ (\text{Pu-239}) = C_s\ ID^*$$

$$= 4.5\ \text{pCi/g} \times \frac{20\text{g}}{\text{day}} \times 365\ \frac{\text{days}}{\text{yr}}$$

$$H\ (\text{Pu-239}) = 3.24 \times 10^4\ \text{pCi/yr}$$

---

* D is equal to 1.0

$$H\ (Am\text{-}241) = 0.18\ (Pu\text{-}239)$$

$$H\ (Am\text{-}241) = 5.84 \times 10^{3}\ pCi/yr$$

Since this condition of excessive soil ingestion would occur over a relatively few years, the resultant dose rates were calculated assuming the period of ingestion to be 5 years and are included in Table X.

5. Conclusions

From the results presented in Table X, one can conclude that, even for the unlikely case where the calculated doses for all pathways are additive, the doses received by ingestion would be well below the EPA guideline of 3 mrad/yr to bone. In reality, an individual in the vicinity of Rocky Flats would receive much lower doses than those calculated. It is deemed very unlikely that one could identify other possible ingestion pathways of such magnitude that they would result in bone doses exceeding 3 mrads in any year.

Table 1*

SURFACE AIR PU-239 CONCENTRATION AT ROCKY FLATS
ATTOCURIES/CUBIC METER

		JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.
SITE #1													
	1970	--	--	--	--	--	1990.00	1250.00	790.00	850.00	693.00	2260.00	962.00
	1971	1960.00	--	7140.00	9730.00	4920.00	3800.00	2980.00	3530.00	4040.00	5770.00	5770.00	3160.00
	1972	5430.00	1670.00	4610.00	1460.00	2080.00	6610.00	4720.00	1380.00	--	1620.00	498.00	1860.00
	1973	1160.00	3640.00	2520.00	612.00	1780.00	3040.00	2920.00	3320.00	1050.00	2010.00	1810.00	1690.00
	1974	402.00	802.00	891.00	1810.00	3060.00	5470.00	2670.00	3330.00	1120.00	407.00	580.00	643.00
	1975	1260.00	1360.00	1780.00	2180.00	2190.00	1160.00	567.00	426.00	179.00	--	1220.00	655.00
	1976	680.00	1240.00	864.00	--	--	--	--	--	--	--	--	--
SITE #2													
	1972	--	--	--	--	--	--	98.90	55.50	119.00	609.00	48.50	45.20
	1973	37.80	57.70	55.80	716.00[c]	51.80	57.70	92.10	65.00	152.00	31.50	25.20	76.30
	1974	16.80	23.20	462.00[c]	135.00	176.00	140.00	78.70	58.10	34.20	24.00	29.20	43.70
	1975	141.00	34.70	56.80	39.70	--	--	27.40	14.00	9.98	--	10.60	16.40
	1976	12.20	23.10	14.40	--	--	--	--	--	--	--	--	--
SITE #3													
	1972	--	--	--	--	--	--	--	--	--	21.90	18.50	25.60
	1973	18.40	41.70[a]	24.20	24.00	40.40	42.00	25.80	25.70	38.20	21.50	11.00	16.90
	1974	21.70	39.10	163.00[c]	283.00[c]	--	--	--	--	--	--	--	--
SITE #4													
	1974	--	--	--	--	1460.00	758.00	1430.00	222.00	199.00	395.00	1240.00	710.00
	1975	288.00	399.00	1850.00	254.00	139.00	684.00	118.00	146.00	72.20	189.00	188.00	128.00
	1976	184.00	303.00	72.60	236.00	109.00	319.00	98.20	63.10	--	--	--	--

-- NO DATA
Errors are less than 20% except:
a -error between 20% and 100%
b -error greater than 100%
c -suspect, omitted from average
* Table from reference 1.

Table II*

Plutonium in Three-to Six-Kilometer-(2-to 4-Miles-)Distant Ambient Air

Station	Number of Samples Taken	Less Than Detectable	Volume (cubic meters)	Concentration ($\times 10^{-15}$ µCi/ml)	
				$C_{maximum}$	$C_{average}$[a]
S-31	12	1	461,547.0	0.144	<0.032 ± 96%
S-32	12	1	543,346.0	0.134	<0.035 ± 96%
S-33	12	1	531,886.0	0.097	<0.034 ± 95%
S-34	3	1	118,243.0	0.176	<0.037 ± 550%
S-35	3	0	119,322.0	0.116	0.027 ± 538%
S-36	2	0	57,286.0	0.012	0.012 ± 1734%
S-37	12	0	525,181.0	0.198	0.056 ± 93%
S-38	10	0	460,089.0	0.097	0.027 ± 108%
S-39	12	1	502,129.0	0.102	<0.026 ± 97%
S-40	12	0	486,876.0	0.198	0.054 ± 92%
S-41	12	1	472,698.0	0.136	<0.033 ± 99%
S-42	12	1	416,244.0	0.137	<0.037 ± 96%
S-43	11	1	360,818.0	0.185	<0.056 ± 105%
S-44	12	1	429,709.0	0.094	<0.029 ± 103%
Summary	137	9	5,485,374.0	0.198	-
Volume-Weighted Average					<0.037 ± 29%

a. Volume-weighted average.

* Table from reference 8.

Table III

Annual Dose Rate to Various Lung Compartments from
Chronic Exposure to Plutonium and Americium Aerosols

(Concentration 1 fCi/m^3 and Particle AMAD = 0.05, 1.0, and 5.0 micrometers)

Plutonium-239

Duration of Exposure years	Pulmonary mrad/yr x 10^{-1}			Tracheo bronchial mrad/yr. x 10^{-2}			Nasopharyngeal mrad/yr x 10^{-6}		
	0.05μ	1.0μ	5.0μ	0.05μ	1.0μ	5.0μ	0.05μ	1.0μ	5.0μ
1	3.9	1.5	.7	2.7	1.1	6.1	.04	11.	30.
5	9.1	3.5	1.7	3.7	1.5	7.9	.04	11.	30.
10	9.8	3.8	1.8	3.8	1.6	8.1	.04	11.	30.
70	9.9	3.8	1.8	3.8	1.6	8.1	.04	11.	30.

Americium-241

Duration of Exposure years	Pulmonary mrad/yr x 10^{-1}		
	0.5μ	1.0μ	5.0μ
70	10.	4.2	1.9

Table IV

Annual Dose Rates to Various Organs from Chronic Exposure to Plutonium-239 and Americium-241 Aerosols AMAD=1μ; Concentration 1 fCi/m^3

Duraction of Exposure (years)	Pu-239 (mrad/year)			Am-241 (millirad/year)		
	Liver	Bone	T-B Lymph Nodes	Liver	Bone	T-B Lymph Nodes
1	.001	.0005	.40	.0015	.0005	.39
5	.018	.0065	4.0	.019	.007	4.2
10	.052	.019	7.0	.055	.021	7.4
15	089	.034	8.7	.095	.036	9.1
20	.13	.049	9.8	.13	.052	10
30	.19	.078	12	.20	.082	12
40	.24	.11	14	.26	.11	14
50	.29	.13	15	.30	.14	16
70	.36	.17	19	.37	18	20

Table V

Sample	Size Increment (μm)	Wgt. Fract.	Act. Fract.	g_i	f_i	$\Sigma f_i g_i$
RF 1A	2000-105	.62	.07	.12	-	
	105-10	.18	.40	2.21	.7	
	<10	.20	.53	2.65	.3	2.34
RF 1B	2000-105	.63	.39	.63	-	
	105-10	.17	.06	.34	.7	
	<10	.20	.55	2.74	.3	1.06
RF 1C	2000-105	.64	.43	.68	-	
	105-10	.16	.07	.46	.7	
	<10	.20	.49	2.47	.3	1.06
RF 2A	2000-105	.46	.13	.28	-	
	105-10	.34	.37	1.10	.7	
	<10	.20	.50	2.48	.3	1.51
						av. 1.49

*Sampling and analysis by USEPA, Office of Radiation Programs, Las Vegas Facility.

Table VI*

Plutonium and Americium in Public Water Supplies

Reservoirs	Number of Samples Taken	Plutonium Concentration ($\times 10^{-9}$ µCi/ml) $C_{minimum}$	$C_{maximum}$	$C_{average}$ [b]
Great Western	36	<0.013	0.952	<0.099 ± 58%
Great Western [a]		.046	.214	
Standley Lake	36	<0.013	0.142	<0.036 ± 23%
Summary	72	<0.013	0.952	-
Finished Water				
Arvada	11	<0.005	0.019	<0.006 ± 50%
Boulder	12	<0.005	0.014	<0.007 ± 17%
Broomfield	39	<0.013	0.133	<0.041 ± 26%
Broomfield [a]			.038	
Denver	11	<0.005	0.016	<0.008 ± 29%
Golden	11	<0.005	0.048	<0.009 ± 107%
Lafayette	12	<0.005	0.030	<0.007 ± 67%
Louisville	11	<0.005	0.012	<0.006 ± 21%
Thornton	12	<0.005	0.018	<0.009 ± 32%
Westminster	36	<0.013	0.210	<0.041 ± 31%
Summary	155	<0.005	0.210	-
Average	-	-	-	<0.027 ± 49%

Reservoirs	Number of Samples Taken	Americium Concentration ($\times 10^{-9}$ µCi/ml) $C_{minimum}$	$C_{maximum}$	$C_{average}$ [b]
Great Western	38	0.014	<0.090	<0.033 ± 20%
Standley Lake	37	<0.013	<0.090	<0.027 ± 19%
Summary	75	<0.013	<0.090	-
Finished Water				
Arvada	11	<0.001	0.239	<0.026 ± 180%
Boulder	11	<0.001	0.015	<0.006 ± 180%
Broomfield	37	<0.023	0.150	<0.029 ± 31%
Denver	11	<0.001	0.420	<0.043 ± 196%
Golden	11	<0.001	0.044	<0.009 ± 80%
Lafayette	12	<0.001	0.030	<0.007 ± 67%
Louisville	12	<0.001	0.400	<0.039 ± 185%
Thornton	12	<0.001	0.007	<0.005 ± 3%
Westminster	39	<0.013	0.079	<0.029 ± 18%
Summary	156	<0.001	0.420	-
Average	-	-	-	<0.032 ± 25%

* Table from reference 8.

a. Data of Poet and Martell (1970)

b. Sample-weighted average

Table VII

Fraction of Ingestion Material Transferred to Blood from the Gastrointestinal Tract

Radionuclide	Transfer Fraction non-oxide	oxide	Biologically Incorporated
Plutonium-238	10^{-3}	10^{-3}	$5x10^{-3}$
Plutonium-239	10^{-3}	10^{-4}	$5x10^{-3}$
Plutonium-240	10^{-3}	10^{-4}	$5x10^{-3}$
Plutonium-241	10^{-3}	10^{-3}	$5x10^{-3}$
Americium-241	10^{-3}	10^{-3}	$5x10^{-3}$
Curium-244	10^{-3}	10^{-3}	$5x10^{-3}$

Table VIII

Annual Dose Rate Due to Chronic Ingestion of
Plutonium-239 Oxide, Americium-241, Plutonium-241 and Curium-224
Annual Intake 1000 pCi/Year

Duration of Ingestion Years	Plutonium-239 Oxide (μrad/year)			Americium-241 (μrad/year)		
	Bone	Liver	Whole Body	Bone	Liver	Whole Body
1	0.9	2.4	4.6×10^{-3}	9.2	2.5×10^{1}	4.9×10^{-2}
5	4.3	1.2×10^{1}	2.7×10^{-2}	4.5×10^{1}	1.2×10^{2}	2.4×10^{-1}
10	8.4	2.2×10^{1}	4.5×10^{-2}	8.8×10^{1}	2.3×10^{2}	4.7×10^{-1}
15	1.2×10^{1}	3.2×10^{1}	6.6×10^{-2}	1.3×10^{2}	3.4×10^{2}	6.9×10^{-1}
20	1.6×10^{1}	4.1×10^{1}	8.6×10^{-2}	1.7×10^{2}	4.3×10^{2}	9.0×10^{1}
30	2.4×10^{1}	5.6×10^{1}	1.3×10^{-1}	2.4×10^{2}	5.9×10^{2}	1.3
40	3.0×10^{1}	6.9×10^{1}	1.6×10^{-1}	3.1×10^{2}	7.2×10^{2}	1.7
50	3.7×10^{1}	8.1×10^{1}	1.9×10^{-1}	3.8×10^{2}	8.3×10^{2}	2.0
70	4.8×10^{1}	9.8×10^{1}	2.6×10^{-1}	4.9×10^{2}	9.9×10^{2}	2.6

Table IX

Food Ingestion Rates and Radionuclide Discrimination Ratios

Substance	Ingestion Rate(g/day)	Discrimination Ratio	
Leafy Vegetables	270[b]	Pu(ext.)	$[10^{-1}x10\%]$
		Pu(int.)	10^{-4}
		Am(ext.)	$[10^{-1}x10\%]$
		Am(int.)	$5x10^{-3}$
Other Vegetables	740[b]	Pu(ext.)	$[10^{-1}x1\%]$
		Pu(int.)	10^{-4}
		Am(ext.)	$[10^{-1}x1\%]$
		Am(int.)	$5x10^{-3}$
Cow Milk	436	Pu[a]	$3.17x10^{-8}$
		Am[c]	$3.17x10^{-8}$
Beef Muscle	273	Pu[a]	$3.29x10^{-5}$
		Am[c]	$3.29x10^{-5}$
Beef Liver	13	Pu[a]	$2.0x10^{-3}$
		Am[c]	$2.0x10^{-3}$
Soil (casual)	.01	Pu	1.0
		Am	1.0
Soil (deliberate)	20	Pu	1.0
		Am	1.0

a. from ref. 23
b. assumes vegetation is 70% water
c. assumes retention and transport within cow is the same for Pu and Am

Table X

Ingestion and Resultant Bone Dose Rates

Substance	Radionuclide	Ingestion Rates (pCi/yr)	70^{th} Year Bone Dose Rate (mrad/yr)
Drinking Water	Pu	18	8.8×10^{-3}
	Am	13	6.2×10^{-3}
Leafy Vegetables	Pu (ext.)	297	.014
	Pu (int.)	3	.071
	Am (ext.)	53	.026
	Am (int.)	27	.067
Other Vegetables	Pu (ext.)	82	.004
	Pu (int.)	9	.020
	Am (ext.)	15	.007
	Am (int.)	74	.018
Cow Milk	Pu	1.6×10^{-3}	$.40 \times 10^{-5}$
	Am	$.28 \times 10^{-3}$	$.67 \times 10^{-6}$
Beef Muscle	Pu	1.02	2.5×10^{-3}
	Am	1.85×10^{-1}	2.8×10^{-4}
Beef Liver	Pu	2.96	7.1×10^{-3}
	Am	5.33×10^{-1}	1.28×10^{-3}
Soil (casual)	Pu	18.0	8.6×10^{-4}
	Am	3.2	1.6×10^{-3}
(deliberate)	Pu	3.24×10^{4}	.14
	Am	5.84×10^{3}	.26
		Total	0.653

Reference

1. H. Volchok, M. Schonberg, and L. Toonkel, Pu-239 Concentration in Air Near Rocky Flats, Colorado, HASL-315, Health and Safety Laboratory, USERDA (1977).

2. P. W. Krey and E. P. Hardy, Plutonium in Soil Around the Rocky Flats Plant, HASL-235, Health and Safety Laboratory, USERDA (1970).

3. Task Group on Lung Dynamics, Health Physics, 12, p173 (1966).

4. H. Volchok, R. Knuth, and M. Kleinman, "The Respirable Fraction of Plutonium at Rocky Flats," Health Physics, 23, p395 (1972).

5. G. A. Sehmel, Airborne ^{238}Pu and ^{239}Pu Associated with the Larger than Respirable Resuspended Particles at Rocky Flats During July 1973, BNWL-2119, Battelle Pacific Northwest Laboratories (1976).

6. Description of USEPA PAID Code to be published.

7. P. Krey et al., Plutonium and Americium Contamination in Rocky Flats Soil, 1973, HASL-304, Health and Safety Laboratory, USERDA (1976).

8. Environmental Monitoring at Major USERDA Contractor Sites - Cy 1975, ERDA-76-104, Vol. 1, USERDA, Washington, D.C. (1976).

9. L. R. Anspaugh, L. H. Shinn, P. L. Phelps, and N. C. Kennedy, "Resuspension and Redistribution of Plutonium in Soils," Health Physics, 29, p571 (1975).

10. Proposed Guidance on Dose Limits for Persons Exposed to Transuranium Elements in the General Environment, USEPA, Washington, D.C. (September 1977).

11. L. R. Anspaugh, "The Use of NTS Data and Experience to Predict Air Concentrations of Plutonium Due to Resuspension on the Enewetak Atoll," The Dynamics of Plutonium in Desert Environment, NVO-142, p299 (1974).

12. D. E. Bernhardt, "Resuspension of Plutonium; It's Particle Size Distribution in Soil," in Evaluation of Sampling and Collection Techniques for Environmental Plutonium, ORP/LV-76-5, USEPA (1976).

13. T. Tamura, "Physical and Chemical Characteristics of Plutonium in Existing Contaminated Soils and Sediments," in Proceedings of the International Symposium on Transuranium Nuclides in the Environment (NOV. 1975), IAEA, Vienna.

14. C. J. Johnson, R. R. Tidball and R. C. Severson, "Plutonium Hazard in Respirable Dust on the Surface of Soil," Science, 193, p488 (1976).

15. W. S. Chepil, "Sedimentary Chacteristics of Dust Storms: III Composition of Suspended Dust," AM. J. Sci., 225, p206 (1957).

16. W. G. Slinn, "Dry Deposition and Resuspension of Aerosol Particles - A New Look at Some Old Problems," in Atmospheric-Surface Exchange of Particulate and Gaseous Pollutants, CONF 740-921, ERDA, Washington, D.C. (1974).

17. K. Willeke, K. Whitby, W. Clark, and V. Mayle," Size Distribution of Denver Aerosols - A Comparison of Two Sites," ATM. Env., 8, p609 (1974).

18. J. W. Healy, A Proposed Interim Standard for Plutonium in Soil, LA 5483-MS, Los Alamos Scientific Laboratory (1974).

19. R. C. Milham, J. F. Schubert, J. R. Watts, A. L, Boni, and J. C. Corey, "Measured Plutonium Resuspension and Resulting Dose from Agricultural Operations on an Old Field at the Savannah River Plant in the Southeastern U.S.," in Proceedings of the International Symposium on Transuranium Nuclides in the Environment, (Nov. 1975), IAEA, Vienna.

20. D. R. Rogers, Mound Laboratory Environmental Plutonium Study 1974, MLM-2249, Mound Laboratory (1975).

21. J. S. Jones and S. F. Pond, "Some Experiments to Determine the Resuspension Factor of Plutonium from Various Surfaces," Surface Contamination, B. R. Fish (ed.), Pergamon Press, New York, N.Y. (1964), p83.

22. S. E. Poet and E. A. Martell, "Plutonium-239 and Americium-241 Contamination in the Denver Area," Health Physics, 23, p537 (1972).

23. W. E. Martin and S. G. Bloom, "Plutonium Transport and Dose Estimation Model," in Proceedings of the International Symposium on Transuranium Nuclides in the Environment, (Nov. 1975), IAEA, Vienna.

24. D. E. Bernhardt, and G. G. Eadie, Parameters for Estimating the Uptake of Transuranic Elements by Terrestrial Plants, ORP/LV-76-2, USEPA (1976).

25. R. L. Thomas and J. W. Healy, An Appraisal of Available Information on Uptake by Plants of Transplutonium Elements and Neptunium, LA-6460-MS, Los Alamos Scientific Laboratory (1976).

26. R. A. Bulman, Concentration of Actinides in the Food Chain, NRPB-R44, Harwell (1976).

27. J. W. Healy, An Examination of the Pathways from Soil to Man for Plutonium, LA-6741-MS, Los Alamos Scientific Laboratory (1977).

APPENDIX H

PROPERTY LOSSES, LOST TIME INJURIES, AND REPORTABLE RADIATION EXPOSURES

This appendix identifies all property losses in excess of $5000 that have occurred at Rocky Flats since the Plant became operational in 1952 (see Table H-1). Table H-2 lists lost-time injuries to employees. Injury statistics are presented in Tables H-3 through H-5. Subsequent tables list external radiation exposures to employees (Table H-6), systemic burden estimates of plutonium (Table H-7), and positive body-counter cases (Table H-8).

The personnel safety record compiled by employees at Rocky Flats is among the best of all DOE production facilities. For example, during 1977 only one organization within the DOE Albuquerque Operations Complex established a better safety record than Rocky Flats. Despite an impressively good safety record, lost-time or disabling injuries have occurred at Rocky Flats. These are noted in Table H-2. Occasionally, considerable time passes before an injury is defined as a lost-time injury. For this reason, some entries in Table H-2 appear to be out of sequence. The dates shown are those on which the incidents occurred; however, the overall listing follows the sequence in which the mishaps were designated lost-time injuries.

Prior to January 1975, a lost-time injury (LTI) was defined as any work injury resulting in death, permanent total disability, or permanent partial disability--even if the injured employee returned to work the same day the injury occurred. A work injury resulting in temporary total disability was also considered an LTI, as was any injury, regardless of how minor, that resulted in an employee losing a full day of work after the day of the injury. The severity of an injury was recorded in accordance with a standard time charged in number of days assigned to each part of the body. If, for example, an employee lost the tip of his little finger but returned to work the same day that the injury occurred, the incident was considered an LTI, and 50 days of "lost time" was charged for the injury.

On January 1, 1975, the Occupational Safety and Health Administration (OSHA) recordkeeping and reporting system was adopted as the standard for occupational injury experience. The term LTI was replaced with "Lost Workday Cases Involving Days Away from Work." Under this system the number of actual workdays on which an employee would have worked but could not because of an occupational injury or illness is reported as "Time Charged."

In Tables H-3 through H-5 and Figures H-1 and H-2, comparative injury statistics within Colorado and nationally are presented. Gross numbers of injuries or lost work

days cannot be directly compared from one unit to another. Two considerations are essential for a meaningful comparison. First, the size of the work force should be considered because a larger employer is expected to have more accidents than a small employer. Secondly, the different type of work performed by each employer should be considered because a high-risk operation (e.g., steel erection) is expected to have more accidents than a low-risk operation (e.g., retail store operation).

Work-force size can be equalized by calculating injury rates based on the number of hours worked by each unit during the same comparable period. Until OSHA was established, the nationally recognized method for evaluating injury experience was the calculation of Frequency Rates and Severity Rates as defined by the American National Standards Institute (ANSI), ANSI Z-87.1. The Frequency Rate was based on the number of lost-time injuries; the Severity Rate was based on the time charged (in days). They were calculated as follows:

$$\text{Frequency Rate} = \frac{\text{Number of Lost Time Injuries X } 1{,}000{,}000}{\text{Hours Worked}}$$

$$\text{Severity Rate} = \frac{\text{Time Charged X } 1{,}000{,}000}{\text{Hours Worked}}$$

The OSHA recordkeeping system offers Incidence Rates as follows:

$$\text{Lost Time Injuries (LTI) Incidence Rate} = \frac{\text{Number of Lost Time Injuries X } 200{,}000}{\text{Hours Worked}}$$

$$\text{Lost Work Days (LWD) Incidence Rate} = \frac{\text{Number of Lost Work Days X } 200{,}000}{\text{Hours Worked}}$$

The calculation of injury rates can be used for two purposes: (1) comparison with prior experience and (2) comparison with similar industries or companies. Comparison with prior experience is the most meaningful application of injury rates because an average industry rate does not accurately reflect the hazards and risks associated with one particular company. However, an industry comparison can be used as an approximation to consider the different types of industrial risks.

Table H-3 compares Rocky Flats Plant Severity and Frequency Rates of injuries from 1952 through 1974 with the National Safety Council's "all industry" average rates. This information is shown graphically in Figures H-1 and H-2. Figure H-1 shows that while the "all industry" Frequency Rates are relatively higher and have increased, the Rocky Flats Frequency Rates have remained stable over the years. The Severity Rates in Figure H-2 show that with the exception of 1967, the Rocky Flats Severity Rates have been relatively stable and low.

Because of the change to the OSHA record keeping system after 1974, Frequency and Severity Rates are no longer used. The OSHA incidence rates for LTIs and LWDs are given in Table H-4. Incidence rates for manufacturing, chemical, and metal fabrication industries are also given for comparison, because these three industries most closely represent operations performed at Rocky Flats. Injury incidence rates for these three industries are given for national and Colorado industries. As with Frequency and Severity Rates, incidence rates for LTIs and LWDs for the Rocky Flats Plant are lower than the industry rates.

The data in Table H-5 show 1976 and 1977 gross number statistics by industry within Colorado for fatalities and for LTIs involving four or more lost work days. The Rocky Flats Plant operation is covered within the manufacturing classification. It is emphasized that industry size is not considered in this information.

In summary, injury rate data show that the Rocky Flats Plant Safety program is effective in minimizing occupationally related injuries and illnesses.

TABLE H-1

PLANT PROPERTY LOSSES EXCEEDING $5,000

Date	Dollar Loss	Incident
11-21-52	7,000	Boiler explosion
6-14-57	30,936	Explosion from chemical reaction
9-11-57	818,600	Fire in a manufacturing building
10-25-61	5,000 to 10,000	Boiler explosion
3-16-63	8,200	Sub-station failure and fire
3-19-63	20,000	Failure of engine in building's compressor house
4-23-63	5,662	Contamination from nitric acid spill
6-20-63	8,364	Contamination leak and spill
6-12-64	56,400	Chemical explosion in glove box
4-08-65	8,810	Inspected parts knocked off storage shelving
5-06-65	7,557	Product feed sprayed out of loose flange
10-15-65	17,034	Glove box drain fire
11-09-65	23,253	Glove box fire
11-27-65	59,800	Wind damage to building roof
9-28-67	10,246	Contamination spill resulting from blow-out of temporary pipe plug
1-07-69	23,285	High winds caused damage to windows, doors, and roofs of buildings; a trailer was destroyed, and considerable cleanup and repair work were required

TABLE H-1 (continued)

PLANT PROPERTY LOSSES EXCEEDING $5,000

Date	Dollar Loss	Incident
5-11-69	26,539,000	Glove box fire in plutonium processing area
6-20-69	8,000	Molten metal released into furnace interior
7-30-69	20,000 (estimated)	Fire in tunnel between buildings
4-20-70	15,000	Contamination release by compressed air used in an attempt to clear a plugged drain line
8-15-70	5,870	Power lead short-circuited to bus bar
9-11-70	12,040	Acid leaked from storage tank
4-12-71	5,777	Corrosion caused steam condensate line to leak contamination
4-19-71	13,500	Contamination spread from reduction-furnace gasket failure
8-22-71	60,000	Small container exploded. Contamination was spread by ignited plutonium in the container
9-02-71	15,600	Hole in a barrel liner allowed plutonium oxide to escape into room
1-5,6-72	20,000	Electrical faulting of three main substations because of heavy winds and snow
1-11-72	5,660	Cell shrouding of cooling tower blew away
4-10-72	20,000	Incinerator glove box fire
2-08-72	6,000	Incinerator fire and contamination caused by an aerosol can being punctured in an unsafe manner near a burning incinerator
4- -73	9,973	Tritium released to atmosphere and Plant waste streams during the processing of metal scrap contaminated with tritium
11-30-75	5,912	Trailer blown over by high winds
5-19-76	13,857	R&D experiments caused contamination to equipment and instruments
8-18-76	7,500	Overheating caused coils in induction heat treating furnace to melt
11-18-76	14,334	Source dropped in office area, causing replacement of desks, chairs, vending machines, floor tile, etc., in surrounding area

TABLE H-2

LOST-TIME INJURIES TO EMPLOYEES

Date	Incident	Time Charged
8-22-53	A fireman was hammering on some metal when another fireman walked up. A piece of metal hit the second fireman in the eye.	16 days
2-23-54	A monitor was in a jeep that turned over on Highway 93. He suffered bruises.	5 days
6-23-54	A carpenter caught his left hand in the blade of a table saw. Portions of his first and second fingers were amputated, and the fourth finger was lacerated.	375 days
11-12-54	A chemist slipped and fell, striking her right elbow against a door. Fracture of the elbow required surgery.	11 days
7-16-56	A toolmaker was using pliers in an attempt to remove chips from a revolving cylinder. Severe lacerations of the index finger resulted.	6 days
6-14-57	A chemical operator was struck by particles of glass or metal when a chemical-reaction explosion occurred. He received lacerations on the face and tip of the fifth finger of the right hand, in addition to contamination. The tip of the fifth finger on his right hand was amputated.	50 days
9-16-57	A machinist caught his finger in a piece of tubular metal being turned on a lathe and cut off the tip of the second finger of his left hand.	100 days
7-10-63	An electrician punctured his left index finger with a screwdriver, severing the flexor tendon at the second joint. Surgery was required for partial repair.	22 days
12-22-63	A handyman's feet slipped out from under him while he was walking down a snow-covered sidewalk. He suffered pulled and sprained back muscles.	8 days
3-25-64	A toolmaker had his left upper arm injured when the shank of a grinding tool broke and the tool became imbedded in his arm. Surgery was required to remove the tool, and hospitalization was required when an infection developed.	17 days
6-12-64	A chemical explosion in a glove box resulted in severe damage to a process operator's left hand, necessitating amputation of the left index finger and thumb.	2,100 days
1-05-62	A sheetmetal worker was hooking a portable welder on a pickup, alone, and injured his back. The injury was evaluated at 7.5% permanent partial disability to the whole body unit.	450 days
9-17-59	A 1.5-inch piece of metal became embedded in the tip of a production machinist's left middle finger. The metal was removed by surgery. A nodule, which subsequently formed, was surgically removed on 2-16-65. Plastic repair required removal of 3/16 inch of bone.	75 days

TABLE H-2 (continued)

LOST-TIME INJURIES TO EMPLOYEES

Date	Incident	Time Charged
2-20-65	A production machinist struck his left middle finger against a rotating part in an X-cello tape machine. To properly repair the resulting laceration, plastic surgery (skin graft) was required.	27 days
12-30-66	An instrument repairman fell while walking down a bank, and he broke his right ankle. Hospitalization was required to have the ankle pinned and set.	30 days
2-16-67	A maintenance sheetmetal worker was raising a telescoping scaffolding when a second section, raising improperly, dropped and mashed three fingers of his left hand. The first joint of his ring finger had to be amputated.	1,160 days
11-23-66	A horizontal press was being used to press a gear on a motor shaft. A maintenance machinist foreman, in a squatting position, placed his hand on one of the arms. The arms, which were under pressure, released in a snapping action and caught his right middle and ring fingers. The middle finger, at the second joint, had to be amputated on 3-7-67.	150 days
4-05-67	A service attendant/vehicle driver fractured his hip when he fell from the track of a Caterpiller tractor atop a low-boy trailer. He died April 10, 1967 from post-operative complications.	6,000 days
5-12-67	A laborer was loading large wooden boxes into an open-top trailer. As he was attempting to remove the cable sling, he stepped backward and fell 52 inches to the bed of the truck, then fell another 52 inches to the ground. He suffered fractures of the third and fourth vertebral processus, requiring hospitalization.	23 days
4-08-67	A painter bumped the palm of his right hand while scraping a shower room floor. The soreness in his hand failed to respond to medical treatment and on June 6, 1967, an exploratory operation disclosed a blocked artery in the hand. This was classified as an occupational disease, being a "peripheral neurovascular disorder resulting from prolonged manual use of tools." Approximately 3 inches of artery had to be removed.	16 days
9-11-67	An experimental operator was pouring molten lithium into a mold. He had partially filled the mold when the molten metal was explosively ejected, splattering his face, shoulder, torso, and thighs. He suffered second- and third-degree burns to his body and received one small burn on the cornea of his right eye. Hospitalization was required.	20 days
1-15-68	A laborer was fastening the safety chain on a dock when the hydraulic tailgate latch failed on a truck backed up to the dock. The falling tailgate struck his right foot and broke two bones. Treatment resulted in seven lost days.	7 days
11-06-65	A process operator suffered a puncture wound to his right long finger. Subsequent nodule growth required surgical removal resulting in 6% disability of the distal phalanx of the finger (March 26, 1968).	4 days

TABLE H-2 (continued)

LOST-TIME INJURIES TO EMPLOYEES

Date	Incident	Time Charged
9-05-68	A clerk packer squatted down to clean a shipping container and struck the edge of a waste container behind him. He suffered a ruptured urethra and was hospitalized.	24 days
8-20-71	A painter was applying strippable latex paint to wood studs and sheeting. The work was in a contaminated area and was being done in full face masks. The painter was working from a 12-foot ladder and was standing on the step next to the top when he fell to the floor. Five ribs were fractured when he hit an airlock as he fell.	58 days
9-02-71	A machinist caught his finger between a chuck and tool bit while he was attempting to adjust a coolant line. The tip of his index finger was cut off. He had not shut the machine off during this operation.	100 days
9-13-71	A process operator was standing on a barrel when the lid tipped. He fell and broke his right elbow, resulting in 5% permanent partial disability.	180 days
5-13-69	A process operator lacerated his forefinger, right hand, on a beryllium burr. The injury failed to heal. Surgery was needed to excise the wound, and plastic surgery was necessary to close it.	7 days
4-03-72	A machinist was performing a cutting operation on a lathe. Some chips whipped around, cutting his third finger, left hand.	150 days
4-28-72	A machinist was leaning against a box that was on rollers. The box moved and he fell, striking his knee on the floor and breaking his kneecap.	90 days
6-21-72	A vehicle driver, while backing up a fork lift, failed to stop in time, and the rear of the fork lift collided with a cinder block wall. The operator's left foot was caught between the fork lift platform and the wall. He suffered a severe break in his left ankle and foot.	360 days
12-9-69	A machinist was moving a heavy piece of machinery on two, two-wheel dollies. The load shifted, and his thumb was caught between the dolly handle and the frame of the load. His right thumb was fractured.	240 days
2-02-73	A carpenter was working in the plenum of a manufacturing building. As he was exiting the plenum, he smelled some toxic substance in the breathing air. He passed out from this substance and fell backwards on the stairs, hitting his head and suffering a linear skull fracture.	135 days
8-22-71	An employee received a lung burden of plutonium when a container of metal plutonium exploded and the plutonium caught fire. He later volunteered to have a lung lavage on an experimental basis. He was hospitalized 14 days.	·'ays
4-21-70	A decontamination worker, crawling through overhead pipes while performing his job, twisted and sprained his left knee. His knee was reinjured on 7-14-72, requiring surgery and hospitalization.	45 days
1-09-75	While walking between buildings, an employee slipped on ice, fell, and received a hairline fracture of his 8th rib.	7 days

TABLE H-2 (continued)

LOST-TIME INJURIES TO EMPLOYEES

Date	Incident	Time Charged
2-25-75	An employee slipped on ice. He did not fall, but did pull some muscles. A doctor advised him to stay home several days.	5 days
5-24-75	A security guard fell against a door. His hand went through the glass in the door, resulting in tendons being cut.	5 days
4-18-75	An employee was working on a machine when the lead hammer being used slipped and hit his finger. Surgery was required later to repair tendon damage.	100 days
7-22-75	An electric technician, while working on a current limiter, struck his left elbow on the open door of a tool cart. The elbow later required surgery.	9 days
11-8-75	A utilities employee slipped on a wet surface outdoors and fell, fracturing his left hip. Surgery was necessary to pin the fracture.	158 days
1-23-76	A sheetmetal worker tripped over his shoe covering and fell. He fractured his lower right leg.	108 days
3-08-76	A process operator strained his back while lifting a filter housing.	24 days
5-20-76	An employee was caught between his parked vehicle and a moving plant protection car driven by a security guard. The employee suffered compound fractures of both ankles and other injuries resulting in a permanent disabling injury.	154 days
5-28-76	A chemist strained his back while lifting 50-pound drums. Bed-rest was advised by a doctor.	3 days
2-3-76	Sheetmetal worker had surgery on shoulder which was injured while using a wrench (surgery 11-76).	92 days
10-14-77	Air filter technician slipped on wet/damp floor while moving a ladder. Cracked knee cap.	52 days

TABLE H-3

FREQUENCY AND SEVERITY RATE COMPARISON[1]

YEAR	FREQUENCY RATE		SEVERITY RATE	
	Rocky Flats Plant	National Safety Council Statistics*	Rocky Flats Plant	National Safety Council Statistics*
1952	0	8.40	0	880
1953	0.52	7.44	8.4	830
1954	1.39	7.22	181	800
1955	0	6.96	0	815
1956	0.38	6.38	2.3	733
1957	0.64	6.27	48.2	740
1958	0	6.17	0	744
1959	0.27	6.47	20.0	754
1960	0	6.04	0	729
1961	0	5.99	0	666
1962	0.20	6.19	90.3	694
1963	0.34	6.12	5.1	682
1964	0.30	6.45	319.4	693
1965	0.32	6.53	4.9	695
1966	0.31	6.91	28.1	689
1967	0.78	7.22	1,127	672
1968	0.29	7.35	4.5	665
1969	0.27	8.08	33.7	640
1970	0.14	8.87	6.2	667
1971	0.50	9.37	43.9	611
1972	0.39	10.17	77.2	655
1973	0.14	10.55	19.3	654
1974	0	10.20	0	614

*National Safety Council statistics are those for the "all industries" average, as reported by member companies. The National Safety Council asserts that from 1965 to 1970 manufacturing member companies had Frequency Rates 70 percent lower and Severity Rates 40 percent lower than nonmember companies.

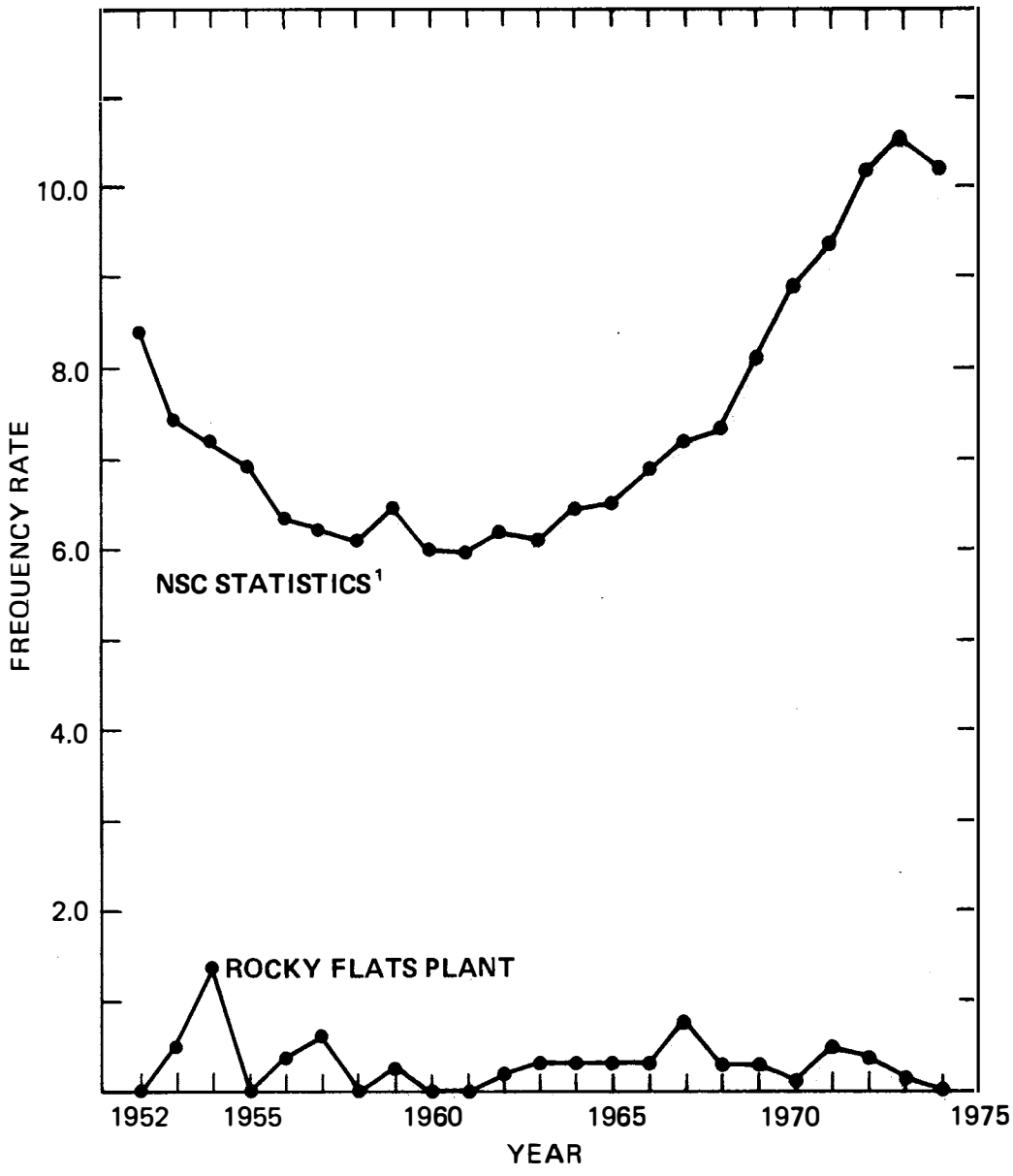


Figure H-1. Frequency Rate Comparison

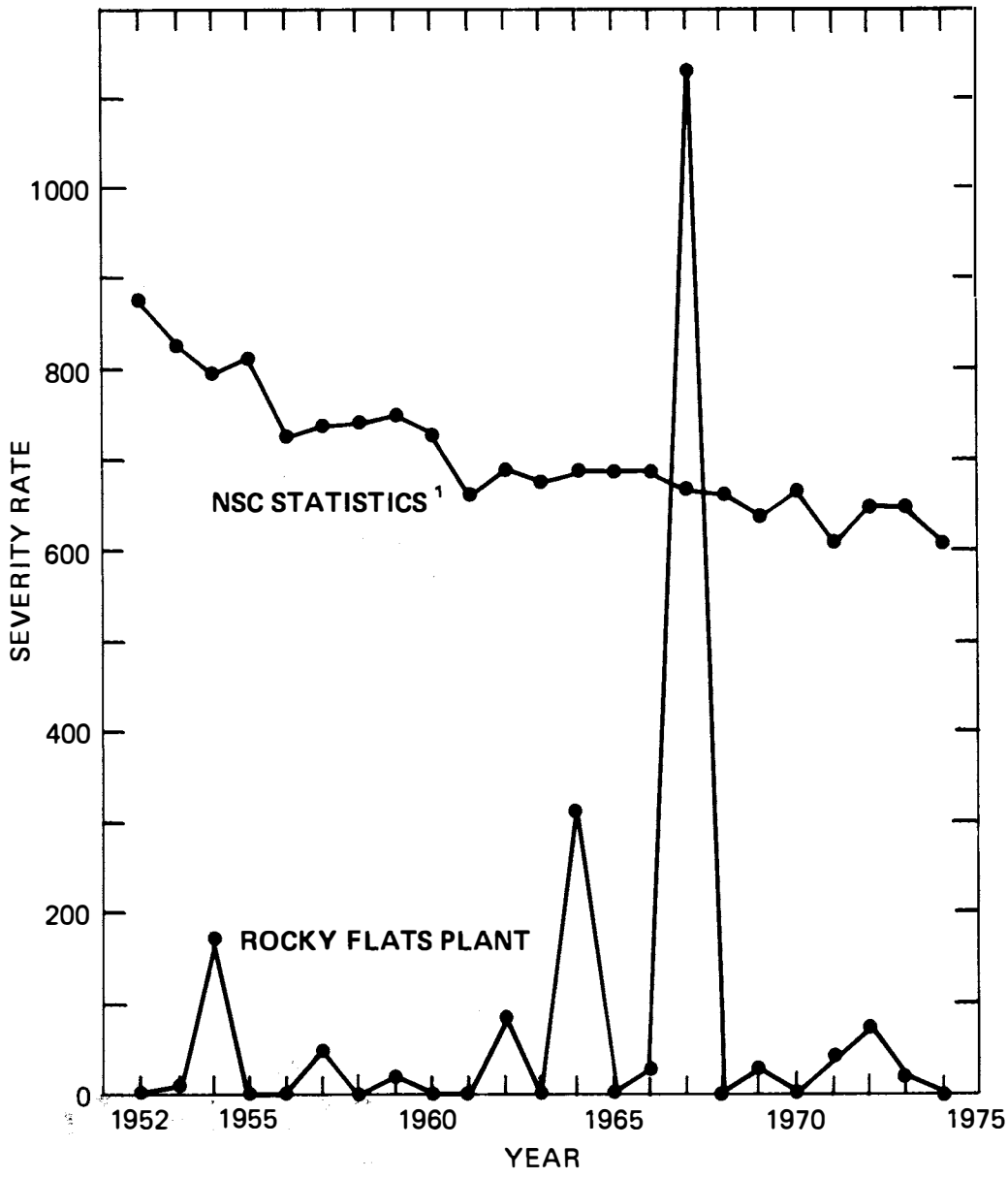


Figure H-2. Severity Rate Comparison

TABLE H-4

INJURY INCIDENCE RATE COMPARISON[2,3]

YEAR	INCIDENCE RATE*OF LOST-TIME INJURIES						
	Rocky Flats	Manufacturing		Chemical		Metal Fabrication	
		Colorado	National	Colorado	National	Colorado	National
1975	0.20	5.5	4.3	2.6	2.6	6.1	6.4
1976	0.19	6.2	4.6	1.8	2.9	7.1	6.6
1977	0.04	NA**	4.9	NA	2.9	NA	7.0

YEAR	INCIDENCE RATE*OF LOST WORK DAYS						
	Rocky Flats	Manufacturing		Chemical		Metal Fabrication	
		Colorado	National	Colorado	National	Colorado	National
1975	9.4	76.1	72.9	24.8	46.1	75.4	101.4
1976	14.3	83.8	76.7	30.9	48.0	96.4	106.5
1977	1.9	NA	79.3	NA	48.0	NA	106.3

*Colorado and National Incidence Rates include restricted activity cases and days at work. The Rocky Flats statistics do not reflect this information; however, according to the Department of Labor, nearly 95 percent of all lost-time cases involve time away from the job. For this reason, these is no significant discrepancy between National, Colorado, and Rocky Flats data.

**NA - not available at printing time.

TABLE H-5

LOST TIME INJURIES AND FATALITIES BY INDUSTRY IN COLORADO[4]

COLORADO INDUSTRY	# CASES INVOLVING 4 OR MORE LOST WORK DAYS		# FATALITIES	
	1976	1977	1976	1977
Agriculture, Forestry, Fisheries	646	914	5	4
Mining	1,176	1,432	9	10
Construction	3,894	5,126	14	19
Manufacturing	6,415	7,337	11	2
(Rocky Flats Plant)	(4)	(1)	(0)	(0)
Transportation and Public Utilities	1,905	2,389	6	10
Wholesale and Retail Trade	5,649	7,004	8	7
Finance, Insurance and Real Estate	394	560	2	1
Services	4,670	5,800	15	5
Government	2,589	3,145	7	6
Unclassified	479	524	0	0
Colorado Total	27,817	34,231	77*	64

*Additional fatalities have been subsequently confirmed as work related. The 1976 total as of 7-1-78 was 86.

Employee radiation exposure can occur from external and internal sources. Programs are maintained at Rocky Flats that detect, measure, and record such occurrences. External radiation is detected and measured by a radiation-sensitive badge worn on the upper front portion of the body. A radiation-sensitive badge is worn by every employee. These badges are calibrated for various types of radiation, and results are reported in units called rem. As defined in NCRP Report No. 39, "Basic Radiation Protection Criteria," National Council on Radiation Protection and Measurements, Washington, DC, 1971, the maximum permissible level of 5(N-18) rem, where N equals the employee's age, has never been exceeded by an external exposure experienced at Rocky Flats. In 1967, Plant personnel initiated a more stringent, self-imposed limit of five rem per year. That limit was later adopted by what is now known as the DOE and has not been exceeded by any subsequent, external exposure. Table H-6 shows external radiation exposures at Rocky Flats since 1953.

TABLE H-6

EXTERNAL RADIATION EXPOSURE TO EMPLOYEES

CY	Employees Badged	Dose Range (rem) 0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	>12
1953	262	213	29	10	4	3	2	1	0	0	0	0	0	0
1954	341	283	31	12	4	2	3	3	1	0	0	2	0	0
1955	512	422	45	17	9	6	6	4	1	0	0	1	1	0
1956	719	692	16	8	3	0	0	0	0	0	0	0	0	0
1957	868	781	51	30	4	1	0	0	0	0	0	0	1	0
1958	1046	874	66	46	33	17	9	1	0	0	0	0	0	0
1959	1090	877	67	54	51	27	9	2	3	0	1	0	0	0
1960	1362	1171	93	66	30	2	0	0	0	0	0	0	0	0
1961	1602	1256	162	99	74	11	0	0	0	0	0	0	0	0
1962	2147	1738	222	73	42	38	34	0	0	0	0	0	0	0
1963	1798	1315	224	126	58	36	37	1	1	0	0	0	0	0
1964	3005	2629	240	108	25	3	0	0	0	0	0	0	0	0
1965	3018	2479	331	131	67	6	4	0	0	0	0	0	0	0
1966	3175	2287	425	190	104	82	54	23	8	1	1	0	0	0
1967	3221	2593	251	151	92	46	26	24	20	13	4	1	0	0
1968	3115	2657	248	127	70	13	0	0	0	0	0	0	0	0
1969	3850	3554	163	73	54	6	0	0	0	0	0	0	0	0
1970	3811	3467	213	101	27	3	0	0	0	0	0	0	0	0
1971	3959	3633	154	60	69	43	0	0	0	0	0	0	0	0
1972	3777	3442	213	97	23	2	0	0	0	0	0	0	0	0
1973	3514	3233	215	58	7	1	0	0	0	0	0	0	0	0
1974	3151	2827	221	72	29	2	0	0	0	0	0	0	0	0
1975	2956	2770	161	22	3	0	0	0	0	0	0	0	0	0
1976	2908	2848	59	1	0	0	0	0	0	0	0	0	0	0
1977	3114	3073	39	2	0	0	0	0	0	0	0	0	0	0

Internal exposure is determined by a urine bioassay program and by a body-counting program. Urine bioassay determines an employee's systemic burden by measuring the amount of plutonium remaining in the employee's system. Measurements of plutonium have been made possible by a time-dependent formula based on work by Dr. W. Langham at the Los Alamos Scientific Laboratory in New Mexico. Each urine sample from an individual is used in conjunction with all of the person's previous samples. A systemic burden is then calculated in terms of percent of the maximum permissible systemic burden (MPSB). For plutonium, the MPSB is 0.04 μCi with bone being considered as the critical organ.[5] The systemic burden represents the total, accumulated, internal exposure since an almost negligible quantity is excreted.

The number of active and former employees in each major category of exposure, according to systemic burdens, is shown in Table H-7. Autopsy data to date indicate that the results of systemic burden calculations are conservative.[6]

TABLE H-7

SYSTEMIC BURDEN ESTIMATES OF PLUTONIUM

(as of January 1978)

	Maximum Permissible Systemic Burden			
Employees	10-25%	25-50%	50-100%	>100%
Active	223	37	9	6
Terminated	125	20	2	8

The body-counting program began in 1964 and is complementary to urine bioassay. The equipment used measures gamma rays coming from within the chest region. Gamma rays from plutonium are insufficient for measurements within the sensitivity desired; consequently, measurements are made of americium that may be present. Americium is associated with plutonium at Rocky Flats, and emits gamma rays of higher energy and abundance than plutonium. Upon determining the ratio of americium to plutonium in the material to which an employee was exposed, arithmetic calculations can be used to determine the amount of plutonium that is present. With this technique, body counting can measure, directly or indirectly, plutonium or other radioactive material in the chest region (assumed to be lungs). The autopsies performed for cases in which there was sufficient lung deposition to measure with the body counter showed less than 10% difference between the body counter measurement and the radiochemical analysis of the lung tissue. The amount of material in the lungs, which is called the lung burden, will decrease with time.

Table H-8 shows year-end, body-counting results at Rocky Flats since 1964. Included in the Table are the numbers of employees who have positive (measurable) amounts of americium-241 but for whom no estimate of the amount of plutonium was made.

TABLE H-8

POSITIVE BODY COUNTER CASES

CY	>100% MPLB[a]		50-100% MPLB		<50% MPLB		Positive Count[b]		Total	
	Employed	Term[c]	Employed	Term	Employed	Term	Employed	Term	Employed	Term
1964	1								1	
1965	18		4	NT[d]			NT		22	NT
1966	13	1	4	NT	7	NT	NT		24	NT
1967	8	2	2	NT	6	NT	NT		16	NT
1968	8	3	4	NT	5	NT	NT		17	NT
1969	11	3	9	NT	16	NT	32	NT	68	NT
1970	9	4	12	NT	14	NT	34	NT	69	NT
1971	12	6	13	5	11	8	48	11	84	30
1972	13	5	14	5	30	8	62	11	119	29
1973	9	6	16	5	28	13	64	18	117	42
1974	9	6	17	5	29	14	74	20	129	45
1974[e]	13[f]	6	31[f]	5	85[f]	14	0[f]	20[g]	129	45
1975	11	8	33	5	112	15			156	48
1976	10	8	27	6	183	18			220	52
1977	10	8	16	6	295	29			320	63

a. MPLB - Maximum Permissible Lung Burden. (ICRP Publication 2, 0.016 μCi or alpha-emitting plutonium, averaged annually)

b. Positive body count, but exposure conditions of plutonium burden not estimated prior to 1974.

c. Term - cumulative number of employees that have terminated their employment at Rocky Flats and had that lung burden during the termination year.

d. NT - Not tabulated. Summaries kept only on individuals who had exceeded the MPLB until 1971 when totals since 1964 were determined for each category.

e. Prior to 1974, plutonium burden was not estimated. Beginning in 1974, analysis of counting data has been done to estimate content of plutonium for active employees.

f. As noted in the above numbers for 1974, there were 74 employees with positive body counts but with unknown exposure condition or plutonium burden. Estimates of their burdens were made and the number of individuals was added in each column, as appropriate, to the number of employees known to belong in these columns.

g. Best estimate of the plutonium burden was not made for terminated employees.

An increased incidence of chromosome aberrations in lymphocyte culture is a very sensitive indicator of radiation exposure. A cytogenetic study was undertaken in 1972 of the chromosomes of cultured peripheral blood lymphocytes from workers at Rocky Flats.[7-13] To date over 1,400 samples from more than 1,050 persons have been studied. These participants include all cooperating workers having more than 0.002 μCi systemic burden (5% MPSB) and/or 0.0016 μCi lung burden (10% MPLB) of plutonium as determined by urine analysis and body counter data, respectively. Some of these individuals had burdens obtained in incidents dating back approximately 20 years.

Control populations were (1) 49 employees having no known work history around plutonium, (2) 19 Denver area residents, and (3) over 50 employees having work histories in plutonium production areas with varying measured doses of penetrating radiation exposures but no measured internal deposition of plutonium. A medical and work history questionnaire was completed for each individual regarding their history of smoking, exposure to potentially cytotoxic materials, exposure to medical X rays, hereditary genetic histories, health and medication records, and work areas while employed at Rocky Flats. For the past two years, baseline samples from new employees have been obtained.

The purpose of the study was to explore chromosome aberrations in peripheral lymphocytes as an in vivo biological dosimeter for effects from internally deposited plutonium. An increased incidence of chromosome aberrations has been observed in plutonium-exposed Rocky Flats employees,[7-13] with the data showing a linear dose-response relationship between the burdens of plutonium and the aberration rate in peripheral lymphocyte chromosomes.[13] The occurrence of these chromosome aberrations is not known to relate to biological effects influencing survival (see Appendix G).

REFERENCES

1. National Safety Council. Accident Facts. Chicago. 1977.

2. Colorado Division of Labor, ADP/Statistics Section, Administrative Services. Unpublished data from Bureau of Labor statistics.

3. U.S. Department of Labor, Bureau of Labor Statistics. OSHA 103 Survey.

4. Colorado Division of Labor, ADP/Statistics Section, Administrative Services. Colorado Work Related Accidents and Illnesses. July 1, 1978.

5. ICRP Publication 2. "Recommendations of the International Commission on Radiological Protection," Pergamon Press. Oxford. 1959.

6. C.R. Lagerquist, S.E. Hammond, D.L. Bokowski, and D.B. Hylton. "Distribution of Plutonium and Americium in Occupationally Exposed Humans as Found From Autopsy Samples." Health Physics Journal. 25:581, 1973.

7. W.F. Brandom, R.W. Bistline, A.D. Bloom, and P.G. Archer. "Preliminary Findings: Chromosomes of Plutonium Workers." 21st Annual Meeting of the Radiation Research Society, April 29 - May 3, 1973 and 1st International Conference on Environmental Mutagens, Asilomar, Pacific Grove, California, August 29 - September 1, 1973.

8. W.F. Brandom, R.W. Bistline, A.D. Bloom and P.G. Archer. "Somatic Cell Chromosome Changes in Humans Exposed to ^{239}Pu." Radiation Research. 59:206, 1974.

9. W.F. Brandom, Geno Saccomanno, A.D. Bloom, P.G. Archer, V.E. Archer, R.W. Bistline, and A. Lilienfeld. "Somatic Cell Chromosome and Sputum Cell Cytology Changes in Humans Exposed to ^{222}Radon and ^{239}Plutonium." Research Proposal to ACE-DBER, 1974.

10. W.F. Brandom, Geno Saccomanno, A.D. Bloom, P.G. Archer, R.W. Bistline, and A. Lilienfeld. "Somatic Cell Chromosome Changes in Human Exposures to ^{239}Pu: An Updating Report." Workshop on the Biological Effects and Toxicity of ^{239}Pu and ^{226}Ra. October 6-9, 1975. Sun Valley, Idaho.

11. W.F. Brandom, A.D. Bloom, P.G. Archer, V.E. Archer, R.W. Bistline, and A. Lilienfeld. "Radiation Cytogenetic of Plutonium Workers." Joint Annual Meetings of Health Physics Society and Radiation Research Society. June 27 -July 2, 1976. San Francisco, California.

12. W.F. Brandom, A.D. Bloom, Geno Saccomanno, P.G. Archer, V.E. Archer, R.W. Bistline, and A. Lilienfeld. "Somatic Cell Chromosome Changes in Humans Exposed to 239-Plutonium and 222-Radon." Progress Report - Contract Period July 1, 1976 through September 30, 1977.

13. W.F. Brandom, A.D. Bloom, P.G. Archer, V.E. Archer, R.W. Bistline, and G. Saccomanno. Somatic Cell Genetics of Uranium Miners and Plutonium Workers: A Biological Dose-Response Indicator. IAEA-SM-224/310 IAEA Symposium March 13-17, 1978, Vienna, Austria.

APPENDIX I

FINAL REPORT

DETERMINATION OF SAMPLING EFFECTIVENESS OF ROCKY FLATS HI-VOLUME SAMPLER AND FILTRATION EFFICIENCY OF MICROSORBAN-98 FIBER FILTER

Submitted to:

Dr. Marilyn Werkema
Dr. Douglas Hunt
Mr. John Hurley
Atomic International Division
Rockwell International
Box 464
Rocky Flats Laboratory
Golden, Colorado 80401

Prepared by:

Dr. James B. Wedding
Associate Professor
Civil Engineering Department

Mr. T. C. Carney
Research Associate
Civil Engineering Department

Engineering Research Center
Colorado State University
Fort Collins, Colorado 80523

June, 1978

Abstract

Recently completed tests of the collection effectiveness of the Rocky Flats Hi-Volume Sampler are compared to previously completed tests of the Standard Hi-Volume Sampler for a variety of field realistic conditions. Collection effectiveness is defined as the ratio of the aerosol collected on the collection substrates of the sampler to that collected by an isokinetic sampling system.

The collection effectiveness of the Rocky Flats Hi-Volume Sampler was determined as a function of particle size (1 μm-34 μm), wind speed (1.52-12.19 m/sec) and sampler orientation to the mean flow (0°, 45°, 180°). The results show the sampler, with an inlet flow rate of 880 ℓ/min, has an inlet effectiveness that was a slight function of orientation angle for particles 1-10 μm with a larger effect seen for 20-34 μm; a strong effect of velocity was seen up to 5 m/sec where a further increase showed only a slight decrease in effectiveness. At the 0° orientation and 6-12 m/sec approach flow speeds, the effectiveness ranges from 75 percent at 10 μm to 15 percent at 34 μm. The results compare quite favorably with the Standard EPA Hi-Volume Sampler.

The Microsorban-98 filter that was used in the sampler was also tested for efficiency over the size range of particles from 0.01-1 μm and with three different face velocities using the sampler flow rates of 600, 800, and 1000 ℓ/min corresponding to pressure drops of 20-24 inches of water (3.74-4.49 cm Hg). The filter paper, which was of the fiber type, was found to be greater than 99.9 percent efficient over the range of particle sizes and pressure drops tested.

AMBIENT AEROSOL SAMPLERS

Introduction

Inlet Effectiveness

The capability of commercially available ambient aerosol samplers to successfully ingest particles greater than 5 μm has become of increasing interest in the last few years. The purpose of this paper is to evaluate the Rocky Flats Hi-Volume Sampler for effective collection of particles in the size range 1 to 34 μm. As attempts continue to further exploit natural resources in search of alternate sources of energy, an increase in potential deleterious environmental impact is possible due to aerosolized particles arising from such operations as mining oil shale, coal gasification and fuel transportation and utilization. The burning of high sulfur content fuels necessitating the use of scrubbers may increase the presence of larger sulfate carrying droplets which could cause property damage. Wind aerosolized dusts exist from such anthropogenic activities as accidental or purposeful weapons explosions, radioactive wastes, agricultural operations, construction, strip mining, demolitions, and aerial pesticide disseminations to mention some.

Characterization of the concentration of suspended particles in the ambient atmosphere is primarily accomplished through the use of several thousand Standard Hi-Vol Samplers (1971) spread across the United States. These samplers have an efficiency approaching 100 percent for particles for which the gravitational and inertial forces are small (less than approximately 5 μm); however, for larger-sized particles the efficiency is quite variable and depends upon particle size, wind speed, sampler orientation to the mean wind direction (Wedding, 1977), and to a lesser degree upon air sampling rate. To enable evaluation of

Hi-Vol data, it is desirable to acquire additional knowledge of inlet particle collection effectiveness of the system. The resulting data may be judiciously used for future judgments in aerosol sampler selection. For example, Hi-Volume samplers have been used extensively for sampling in situations in which large wind-blown dust particles are present. The efficiency with which these larger particles are drawn into the samplers has only recently been published (Wedding, 1977).

To provide the basis for understanding of the effectiveness of various ambient air samplers so as to suggest areas for which fruitful design improvements may be made, it is of necessity that the performance of these samplers be examined under controlled, simulated field conditions. This goal can best be accomplished through use of wind tunnel facilities which are appropriately equipped to obtain uniform profiles of monodisperse aerosol in a realistic fluid flow situation. The facility must be large enough such that flow blockage is precluded--meaning fluid and particle streamlines around the sampler are not altered by the presence of the sampler. Such facilities are available at Colorado State University through the Aerosol Science Laboratory in the Fluid Mechanics and Wind Engineering Program, Civil Engineering Department.

Key results of prior tests conducted by Wedding (1977) will be presented for comparison purposes along with the study just completed on the Rocky Flats Hi-Volume Sampler.

Efficiency of the Microsorban-98 Membrane Filter

While numerous papers appear in the literature on the subject of filtration efficiency, most of them were concerned with mathematically modeling the capture mechanism and few have detailed experimental tests on the filtration efficiency of fiber or membrane filters over a wide

range of particle sizes and pressure drops*. An experimental evaluation of the efficiency of this filter was performed. The microsorban filter had been tested previously (USNRL, 1964) but it is doubtful that the 1964 version was the same filter. As some of the particles present in the atmosphere may be of submicron size, the question of filtration efficiency must be addressed. Microsorban-98 is used as the filter medium in the Rocky Flats Hi-Volume air sampler.

Experimental Procedure

Wind Tunnel Tests

The test results on the Rocky Flats sampler were based upon studies conducted in the Environmental Wind Tunnel facility at Colorado State University shown schematically in Figure 1. The tunnel has a 3.65 m wide test section with a roof that can be adjusted up to 2.44 m in height--a feature which allows the tests to be conducted with a zero pressure gradient in the direction of flow. The present series of tests was performed with a 1.83 m ceiling height sufficient to preclude blockage effects which require less than 5 percent obstruction in the tunnel cross sectional area (Maskell, 1965). Previous tests involving the Standard Hi-Volume Sampler (Wedding, 1977) and the recent study of the Rocky Flats Hi-Volume Sampler were compared for a variety of field realistic conditions using monodisperse aerosol (5-50 μm for the previous tests and 1-34 μm for the Rocky Flats tests), variable flow velocities and at different inlet orientations to the mean flow. Referring to Figure 1, the aerosol was generated using the vibrating orifice type atomizer (Wedding, 1975, 1978) operating in an inverted manner. The

*There is at present a study underway at the University of Minnesota under the direction of Dr. B. Y. H. Liu aimed at developing a handbook on filtration efficiency.

particles were injected into the tunnel through two 15 cm diameter tubes positioned in the roof of the tunnel.

The consistency of the aerosol concentration was determined prior to and subsequent to each test using two isokinetic sampling manifolds positioned in two parallel horizontal planes, six inches apart vertically and spanning the sampler inlet. Each manifold was approximately 90 cm in width with the six isokinetic sampling nozzles and filters spaced at equal intervals (~15 cm) on the same plane. The sampling effectiveness of the two instruments was then determined by comparing the quantity of aerosol deposited on the collection substrates of a particular sampler to that detected by the isokinetic sampling system with appropriate corrections for differences in sampling volumes.

Figure 2 reveals the Rocky Flats sampler tested and the Standard Hi-Volume sampler with inlet flow rates, dimensions, and angle orientation conventions noted. The Rocky Flats samplers are attached to power poles in the field, so the sampling effectiveness of this sampler was determined with the pole in place in the wind tunnel.

Sample Analysis

The particles used in the studies were formed from the atomization of an oleic acid solution tagged with uranine dye, the latter used for increasing mass sensitivity through fluoroscopic analysis. Analysis was performed by washing the collection substrates (filters) from the particular sampler being tested in pure ethanol. The resulting solution was diluted 1:1 with distilled water. One drop of 1 N NaOH was added to a 4 ml aliquot of each sample solution to stabilize and maximize fluorescence. These aliquots were quantified in terms of fluorescent content with the aid of a calibrated Turner Model 111 fluorometer.

Filtration Efficiency Tests

In the absence of electrostatic effects, filtration efficiency of filters varies with particles size and flow rate. For a given particle size and flow rate, efficiency is defined as the ratio of the number of particles retained by the filter after passage of a known volume of gas to the original number of particles in the same volume of gas before passage through the filter. Efficiency is defined as one minus the ratio of the downstream to upstream number concentration of the particle size of interest.

The filtration efficiency of the Microsorban-98 filter was determined by means of the experimental setup shown in Figure 3. Measurements were made at flow rates of 15.6, 20.7, and 25.9 ℓ/min through a filter section held in a commercial 47 mm filter holder. These flow rates resulted in filter face velocities of 27, 36 and 45 cm/sec, equivalent to those occurring at flow rates of 600, 800, and 1000 ℓ/min respectively, in the Rocky Flats Hi-Volume sampler. The experimental apparatus consisted of a submicron atomizer (Liu, 1975), a charge neutralization and drying chamber, a filter holder in parallel with a bypass line, a vacuum pump and flow metering equipment, and an Electrical Aerosol Analyzer (Thermo-Systems Inc., Model 3030). The Electrical Aerosol Analyzer (EAA) utilized has the ability to accurately resolve a size distribution consisting of particles between 0.01 and 1 microns into 8 logarithmically equal increments. This resolution was sufficient for the scope of this study.

The filtration efficiency of the Microsorban-98 filter was determined as follows: a polydisperse aerosol was formed by atomization of a NaCl solution in the syringe pump atomizer. The atomizer was operated at a

pressure of 50.8 N/cm^2 (35 psig), resulting in an aerosol flow rate of 4.61 ℓ/min. Excess electrical charge on the aerosol, a consequence of the atomization process, was neutralized with the aid of the 10 millicurie KR-85 source, and the aerosol was dried in a 12.7 cm (5 in), 61 cm (24 in) long diameter tube containing silica gel. The upstream number concentration (particles/cm^3) was measured by closing valve 2, opening valve 1, and with the EAA flow rate set, adjusting valve 3 until the flowmeter indicated the difference between the desired flow rate and the aerosol flow rate. After a time sufficient for the drying-and-charge-neutralization chamber to reach a steady state concentration, the EAA output was recorded at the internally programmed nine high voltage settings. The overall operation and theory of the instrument is given by Liu (1975). The instrument's reproducibility and reliability have been well documented. The size distribution downstream of the filter was determined in like manner with valve 2 opened and valve 1 closed. The pressure drop across the filter was monitored during measurement of the downstream number concentration. For the pressure drops encountered in this experiment, direct use was made of the data without a need to correct for volume expansion across the filter as the correction was less than 6%. The filter efficiency of each size range increment was determined by ratioing the corresponding values of the downstream to the upstream number concentration measurements and subtracting this number from 1.

Results and Discussion

Sampler Effectiveness

The reduced data for the Standard Hi-Volume sampler and the ocky Flats sampler are presented in Table 1 for comparison purposes.

The sampler effectiveness was determined at four different particle sizes (1, 10, 20, and 34 μm), three different approach flow orientations and velocities from 1.52-12.2 m/sec. Presented in Table 1 is data at ∿5 m/sec along with the Standard Hi-Volume Sampler which was tested previously (Wedding, 1977) at particle sizes ranging from 5-50 μm, and orientation angles of 0° and 45°. Note that the inlet flow rates of the two samplers differ appreciably (1415 and 880 ℓ/min for the Standard Hi-Volume and the Rocky Flats Sampler, respectively).

Considering the Rocky Flats sampler, orientation angle is not important for particles $\leqq$ 10 μm and the 45° orientation is more efficient than 0° for the larger particles. The 180° orientation places the power-support pole directly upstream so initially one may presuppose that the 180° position would have a lower effectiveness than the 0°. This doesn't prove to be the case as the 180° direction is more effective than the 0° direction, the latter orientation acting more as a pure impaction surface. The effect of the pole is seen to increase the inlet velocity somewhat (15-20 percent determined by hot wire anemometer velocity measurements of the entire inlet) as well as create a negative pressure region that serves to cause the 20 μm particles to enter the inlet more effectively than at 0°. At the 34 μm particle size, the effectiveness is about the same at 20-23 percent. The 45° direction proves to be the most effective overall inlet orientation.

The Standard Hi-Volume is even more efficient at 45° than the Rocky Flats but proves to be more sensitive to orientation. The flow around the Standard Hi-Volume inlet is extremely unsound aerodynamically with the sharp corners causing the separated flow pattern to deviate greatly with angle. Note also that the inlet flow rate is substantially

greater so that the flow area effectively altered by the inlet velocity is greater than the Rocky Flats sampler and thus one may expect a greater capability to alter the trajectories of large particles.

These Hi-Volume samplers tested have a separation flow region whose effect on particle trajectories is complicated more so by the presence of the power pole in the case of the Rocky Flats sampler. The particle trajectories are altered by the presence of the free shear layer that accompanies separated regions. In the lower particle size ranges ($\leq$ 10 μm) more diffusion controlled behavior tends to cause the cloud concentration to become more homogeneous throughout the separated region around the sampler enabling relatively efficient particle entrance into the sampler (with more particles probably entering the inlet from the downstream side). As the particle behavior becomes more inertially governed, the particles are deflected less around the sampler and begin to penetrate closer to the sampler body itself. There will tend to be more losses by impaction on the sampler exterior and fewer particles will successfully negotiate the two sharp turns required to enter the inlet. Thus, as particle size increases, a tradeoff on the inlet effectiveness is seen to exist between increased inertial losses versus the increased penetration of the particles to that area near the inlet where there is sufficient aerodynamic force created by the inlet velocity to alter the particle trajectory to allow initial entry into the inlet. To conclude, only the upstream portion at a 0° orientation of a prismatic-like bluff body will serve more nearly like an impaction surface so that one cannot expect the inlet effectiveness curves to be directly predictable by inertial mechanism alone (i.e., proportional to the square of the particle size). One may even see a tendency for the

effectiveness to increase for a time for certain flow geometries as the particle size increases due to the greater ability of the particle to cross the fluid streamlines. This trend is noticeable in Figures 5 and 7 where the effectiveness curves tend to have an upward lifting or flattening out tail on them at the larger particle sizes.

Figure 4 is a reproduction of part of a figure that appeared in Wedding (1977) with the present data from the Rocky Flats Hi-Volume added in for comparison purposes.

Figures 5, 6, and 7 reveal the effect of particle size on the sampling effectiveness of the Rockwell International Sampler at the three orientation angles of 0°, 45° and 180°, respectively, and at three representative test velocities of 1.52, 6.09 and 12.19 m/sec. The aforementioned tradeoff in inertial effects is seen as the plots do not, in general, decay proportional to the square of the particle size. Note at the 0° and 45° orientations the larger particles (34 μm) penetrate through the free shear layer closer to the sampler than the 20 μm particles thus realizing nearly the same sampling effectiveness. This effect is not seen at the 180 angle as the flow around the sampler behaves less like a bluff body due to the presence of the power pole. Assuredly the effectiveness would decrease with further increase in particle size but the argument for the 20 and 34 μm particles being sampled with near equivalent effectiveness is as explained earlier.

Figures 8, 9, 10 are plots of sampling effectiveness versus velocity at three different orientations of 0°, 45°, and 180°, respectively for the four different particle sizes of 1, 10, 20, and 34 μm. Two interesting effects are evident from these plots. First, at the lower velocities, near impaction efficiency form of the plot results at the 0° orientations

for the 10 and 20 μm sizes and at 180° for the 20 and 34 μm data. The fluid flow effects discussed earlier are lessened and one sees a decay rate approaching the square of the particle size ratio. Secondly, one sees that increasing velocity past ∿5 m/sec has relatively little effect on sampling effectiveness except at 180° where the upstream position of the pole tends to cause some impaction losses at the higher velocity of 12.19 m/sec.

In previous tests of this type (Wedding, 1977) a turbulence generating biplane grid was placed in the wind tunnel upstream of the sampler test location to note the effect of approach flow turbulence on sampling effectiveness. None was found. Thus, the present tests on the Rocky Flats Sampler were conducted without the grid at a tunnel background condition of $\leq$ 1% relative turbulence intensity (ratio of the root mean square of the fluctuating component of velocity to the local mean velocity, longitudinal direction) as no effect of turbulence on sampling effectiveness was anticipated.

Note that in experimental studies involving the behavior of particles in turbulent flow regions, there will exist scatter in the data. For example, Figure 5 has values for sampling effectiveness of 17, 21 and 32 percent for a 34 μm particle at the 12.19 m/sec velocity for an average value of percent and a standard deviation of 7.8 percent. It is common for a researcher to encounter such variability in even these tests where all test parameters of velocity, particle size, sampler orientation and sampler flow rate* were strictly controlled. These have been discussed in great detail with colleagues at other institutions to include

*The Hi-Volume Sampler flow was not recalibrated during wind tunnel testing but operated at the calibration condition as provided by Rocky Flats personnel.

BNWL, University of Minnesota, University of Illinois, Battelle Columbus, Texas A & M University and University of California at Davis. All have realized similar problems in exactly reproducing test data points. In earlier work (Wedding, 1977) specific points were rerun as many as 8 times to prove a value. Relying on personal past experience as well as opinions of fellow researchers, we have the utmost faith in the accuracy of published data and recommend the curve averages as presented in the figures are adequate representations of data values and trends.

Filter Efficiency

Table 2 contains data for a representative test of the filtration efficiency results of the Microsorban-98 Fiber filter. Particle sizes from 0.01 - 1 μm were tested at a pressure drop of ∿4.5 cm Hg. Upstream concentrations (particles/cm^3) are given for the indicated size increments and a cumulative percent by number calculation is shown. Note that while the cumulative percentages in column 3 reach values near 100 for the larger size increments used, there are still sufficient particles present to conduct meaningful tests. There were no particles detected downstream of the Microsorban-98 Filter for any of the three face velocity conditions noted earlier. The limit of detectability for particle size of the instrument ultimately is 0.0032 μm and 0.01 μm was used in these tests. The minimum detectable concentration is also given in Table 2. The minimum penetration is determined by ratioing column 5 to column 2 and the maximum filtration efficiency is presented in column 6. Column 4 indicates that no particles were detected passing through the filter for any size ranges. The minimum detectable concentration presented in column 5 is based upon the background noise of the instrument. Thus, the collection efficiencies as shown in column 6 are

conservative estimates and will be higher in most cases. Note that the figure of 99.8% in column 6 for the 0.562 - 1.00 μm particle size does not indicate that the efficiency is anticipated to be lower for these larger particles but merely reflects the lower upstream concentration of 1.236×10^3 particles/cm^3 approaching the filter.

References

R. E. Houman and R. J. Sherwood (1965), J. Am. Ind. Hyg. Assoc., 26, 122.

B. Y. H. Liu and K. W. Lee (1975), "An Aerosol Generator of High Stability," J. Am. Ind. Hyg. Assoc., December, pp. 861-865.

B. Y. H. Liu, D. Y. H. Pui (1975), "On the Performance of the Electrical Aerosol Analyzer," Journal Aerosol Science, 6, 1.249-264.

E. G. Maskell (1965), "A Theory of the Blockage Effects on Bluff Bodies and Stalled Wings in a Closed Wind Tunnel," REM No. 2400, Aeronautical Research Council, London.

A. R. McFarland, J. B. Wedding and J. E. Cermak (1977), "Wind Tunnel Evaluation of a Modified Andersen Impactor and an All Weather Sampler Inlet," Env. Sci. and Technol., 11, pp. 535-539.

R. Spirtas and H. J. Levin (1970), "Characteristics of Particulate Patterns," AP-61, U.S. Department of Health, Education, and Welfare, Public Health Service, National Air Pollution Control Administration.

U.S. Environmental Protection Agency (1971), National Primary and Secondary Ambient Air Quality Standards, Fed. Regist., 36 (84), 8186, April 30.

USNRL 6054 (1964), Characteristics of Air Filter Media Used for Monitoring Airborne Radioactivity, Lock, Anderson & Patterson.

J. B. Wedding, A. R. McFarland and J. E. Cermak (1977), "Large Particle Collection Characteristics of Ambient Aerosol Samples," Env. Sci. and Technol., 11, pp. 387-390.

J. B. Wedding (1975), "Operational Characteristics of the Vibrating Orifice Aerosol Generator," Env. Sci. and Technol., 9, pp. 637-674.

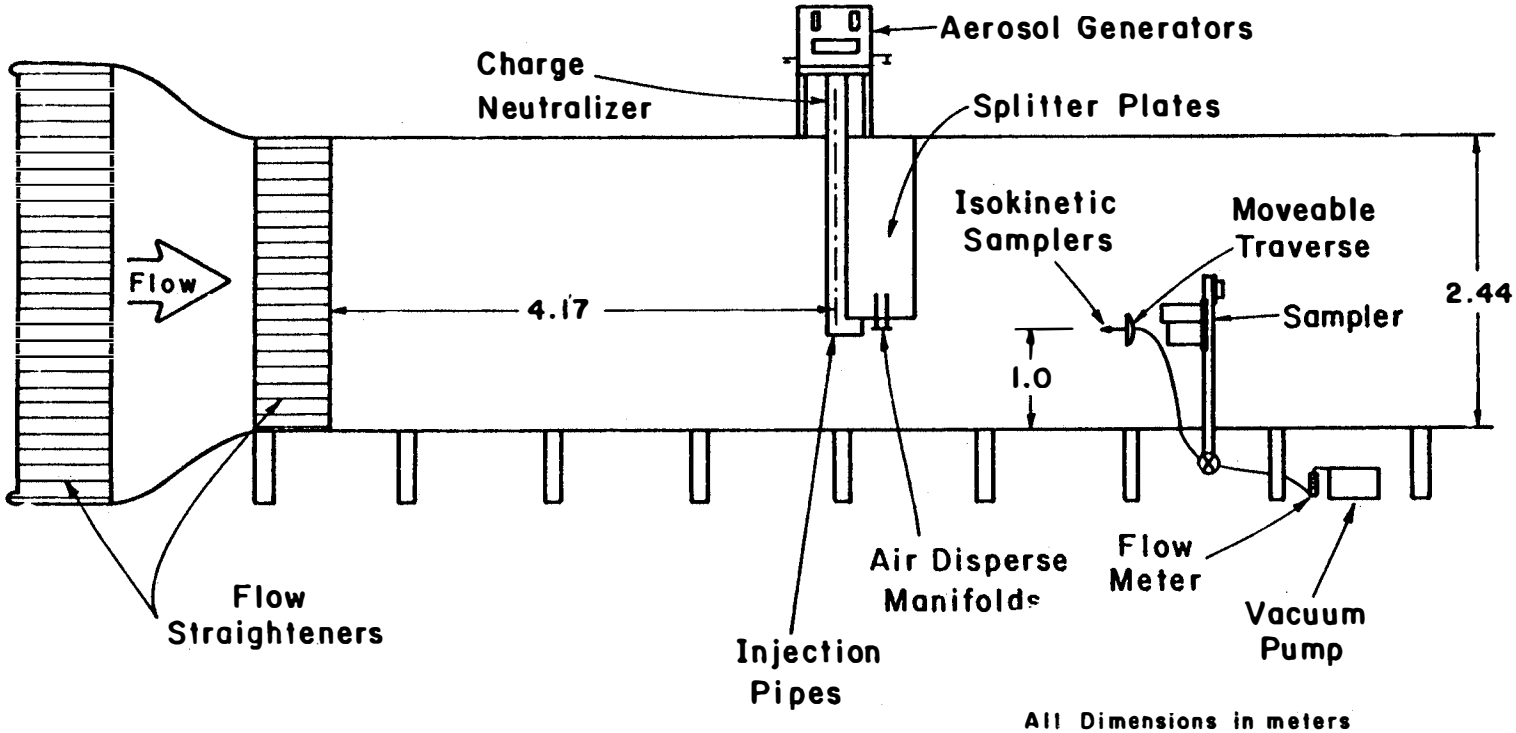
J. B. Wedding, T. C. Carney and M. E. Montgomery (1978), "Vibrating Orifice Aerosol Generator: Extending the Capability to 200 Micron Diameter Particles," to be submitted to Env. Sci. and Technol., September, 1978.

K. T. Whitby, R. B. Husar and B. Y. H. Liu (1972), J. Colloid Interface Sci., 39, pp. 177.

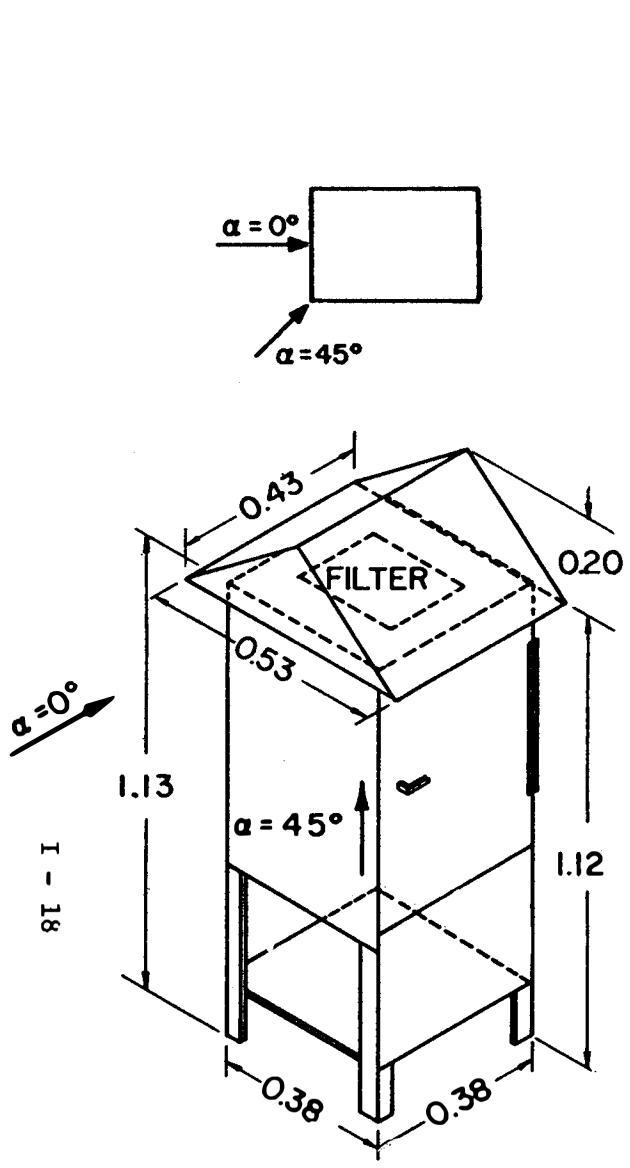
LIST OF FIGURES AND TABLES

Figure

Table

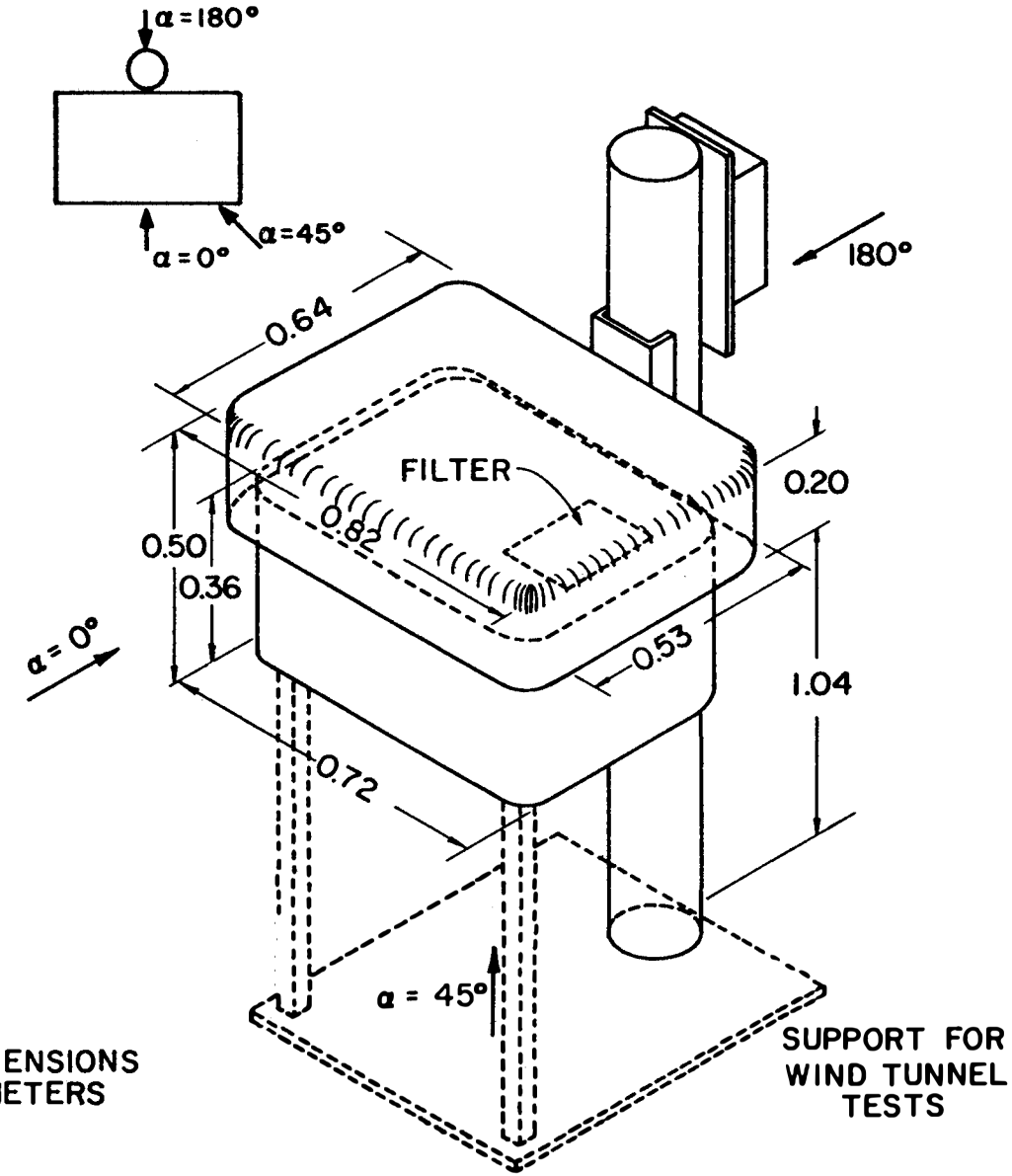

Aerosol Generators
Charge
Neutralizer
Splitter Plates
Isokinetic
Samplers
Moveable
Traverse
Flow
4.17
2.44
Sampler
1.0
Flow
Straighteners
Injection
Pipes
Air Disperse
Manifolds
Flow
Meter
Vacuum
Pump
All Dimensions in meters

Side View

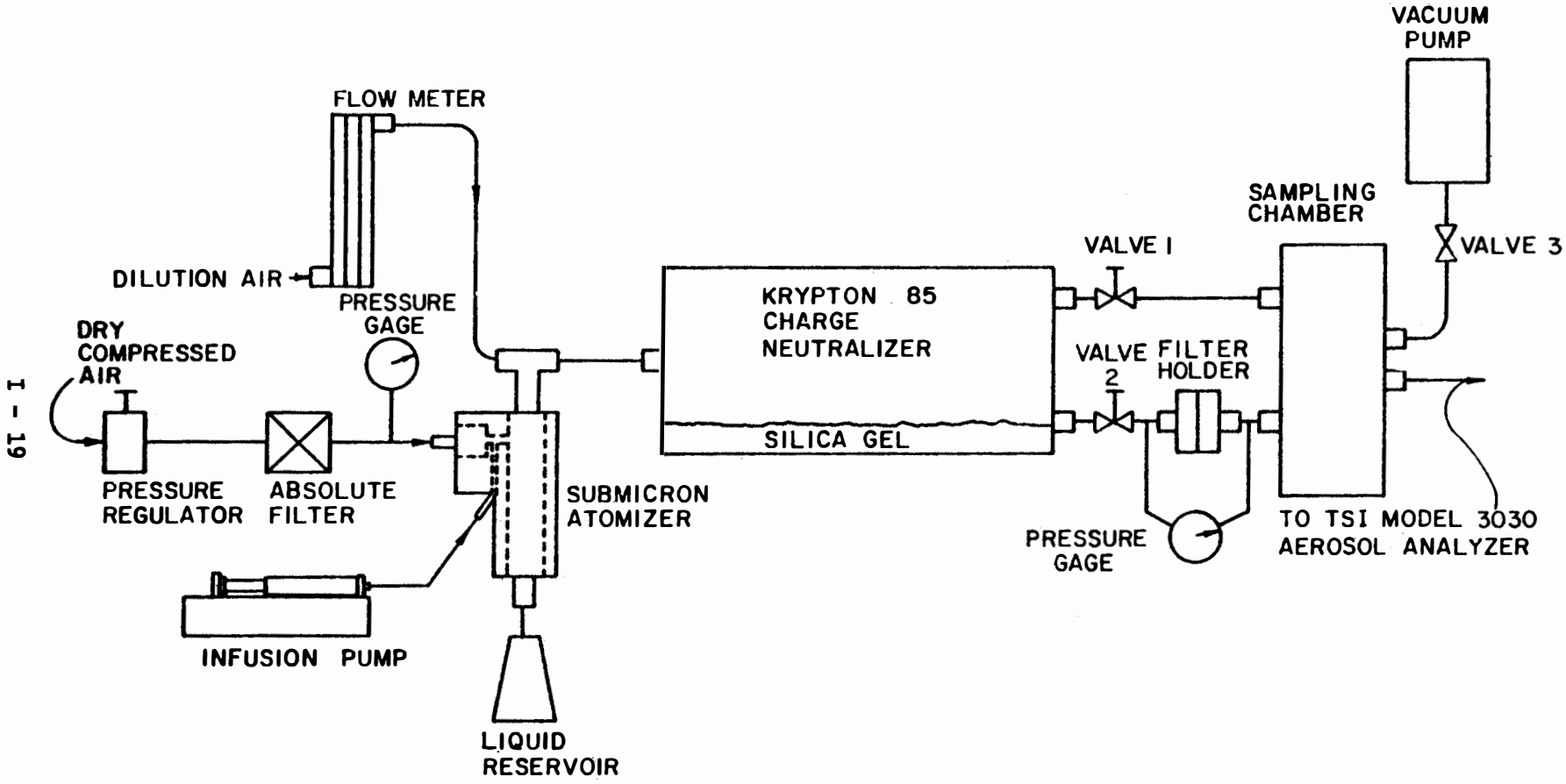


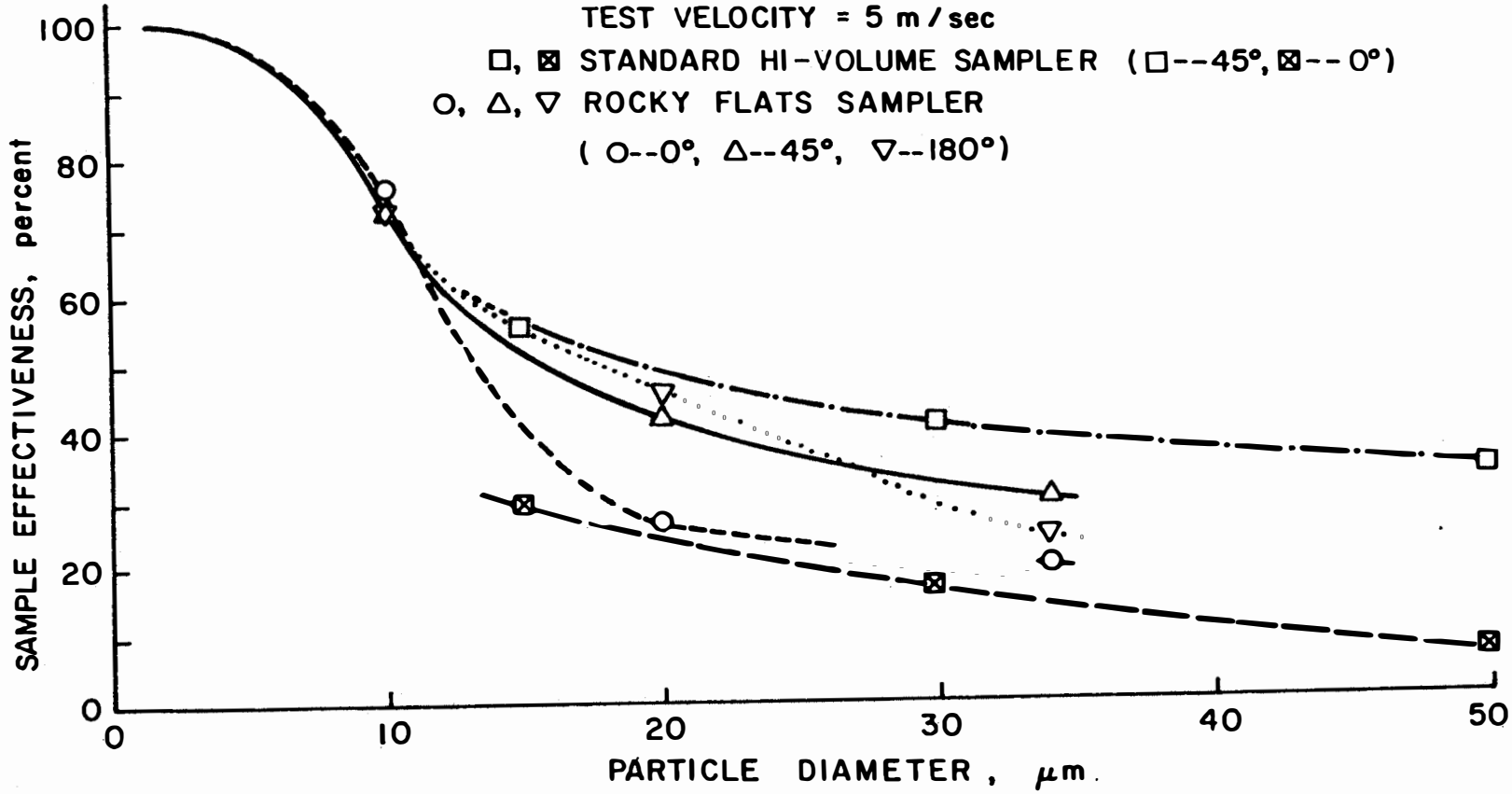
HIGH VOLUME SAMPLER
SAMPLING RATE = 1414 ℓpm

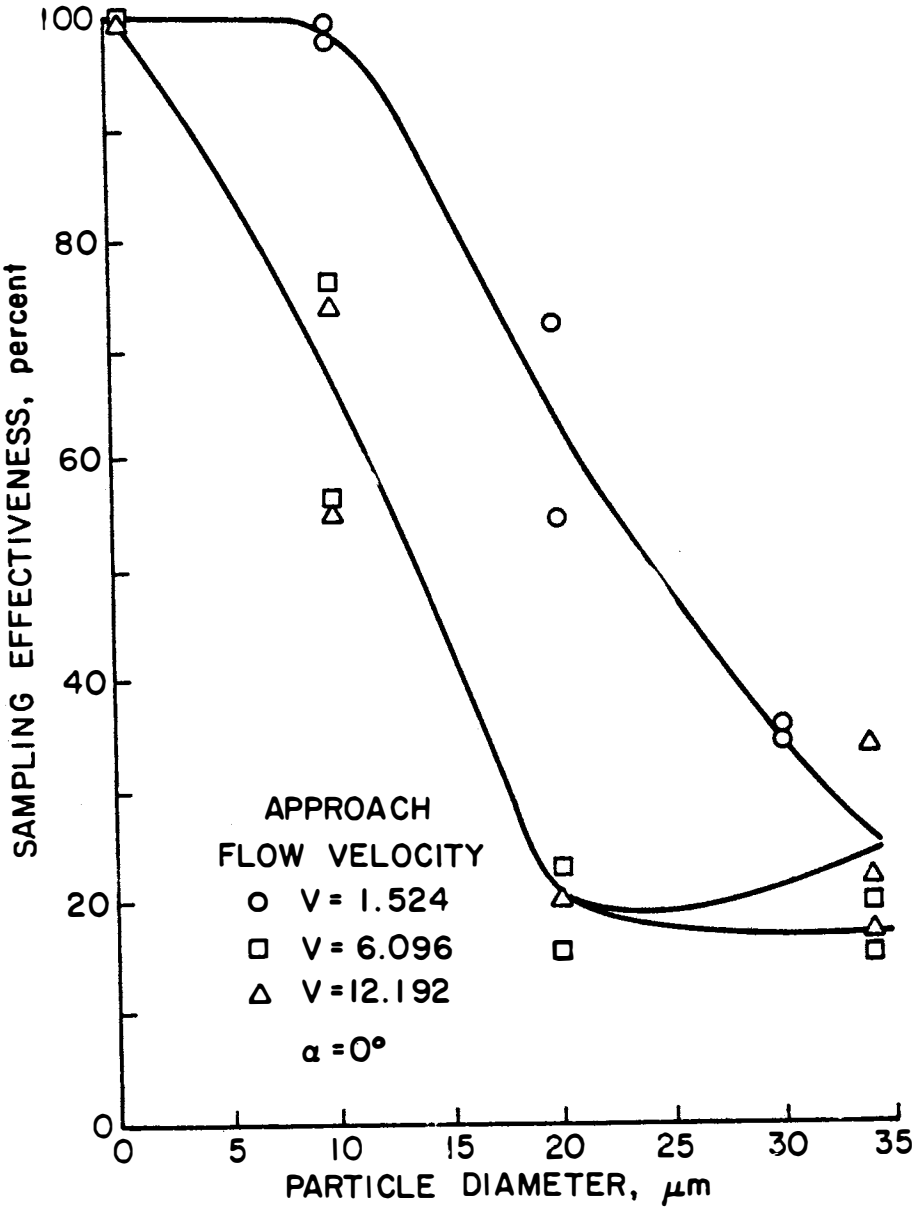
ALL DIMENSIONS
IN METERS

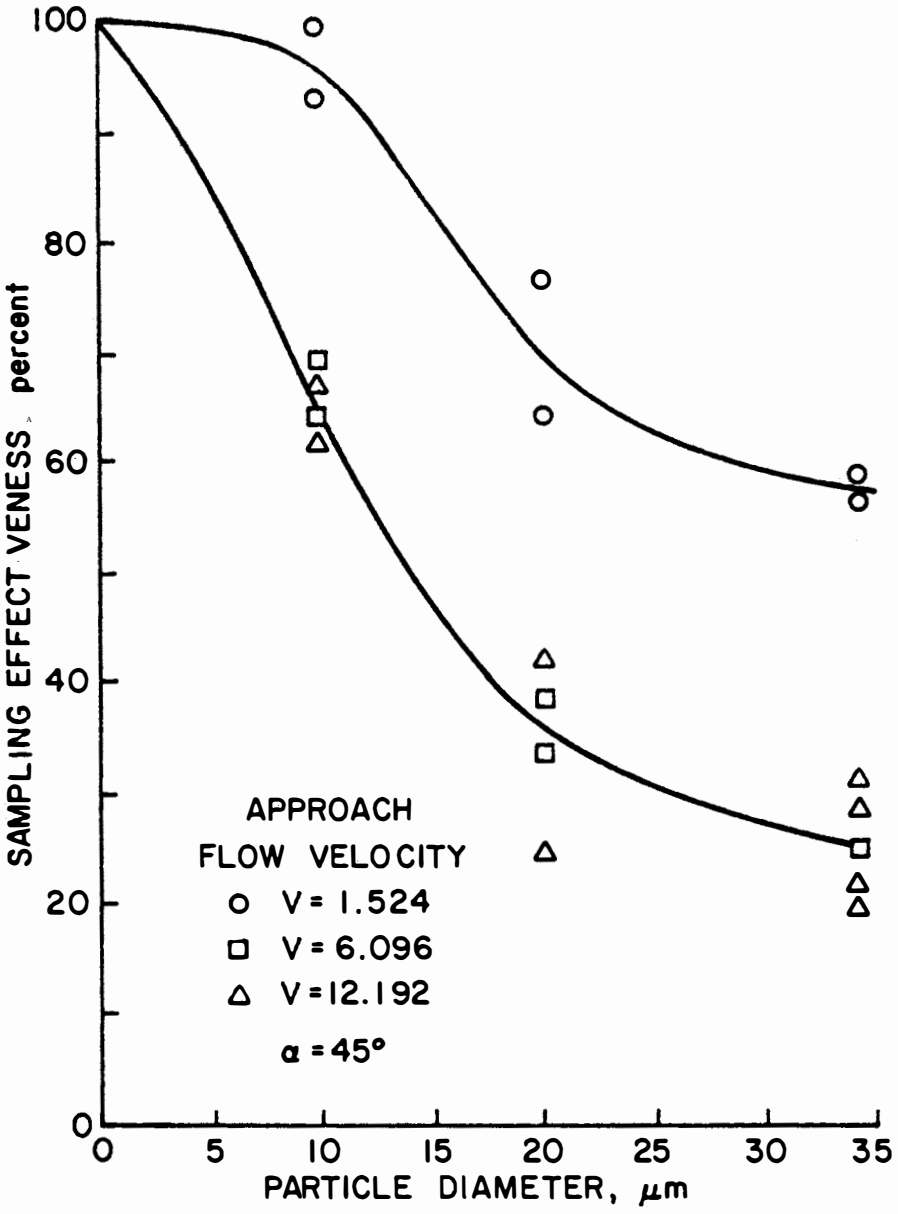


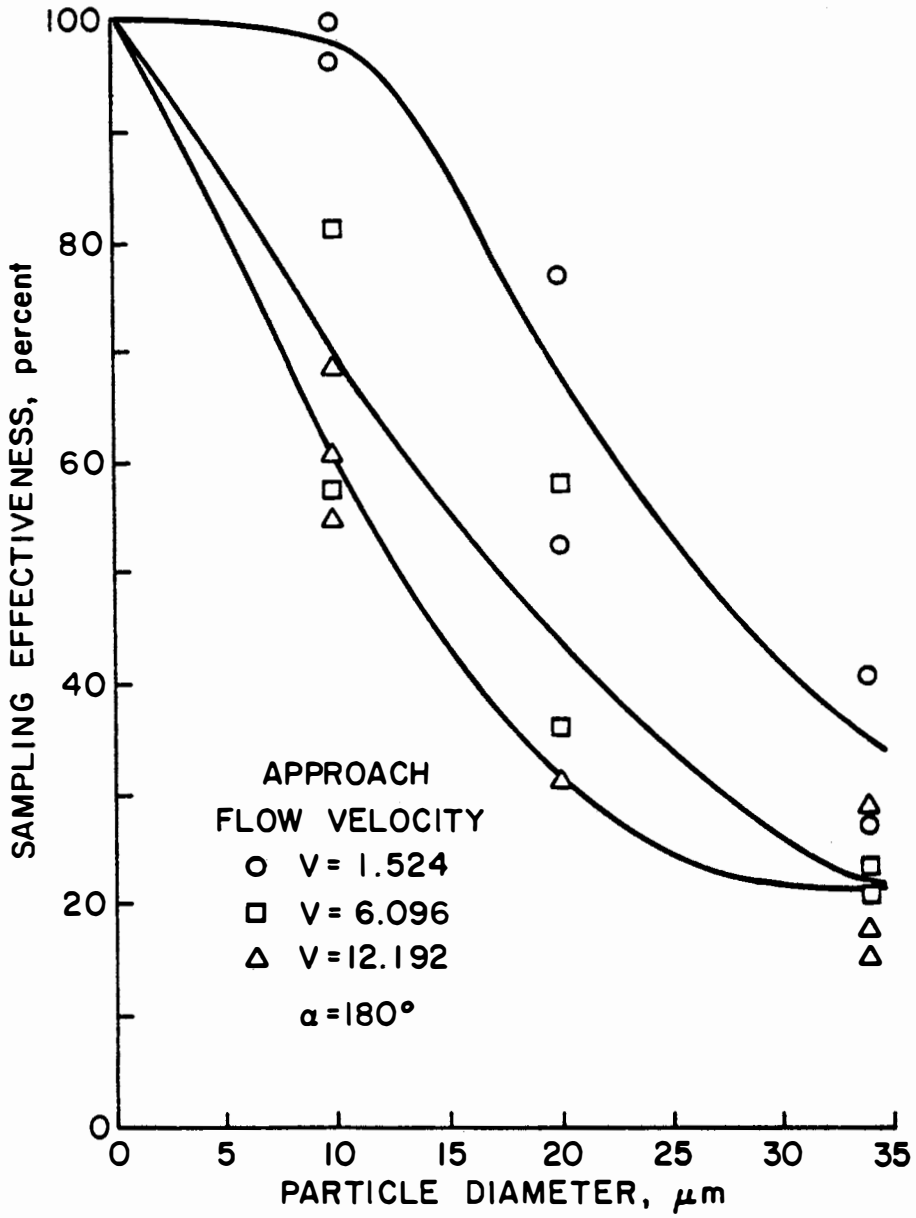
ROCKY FLATS SAMPLER
SAMPLING RATE = 880 ℓpm

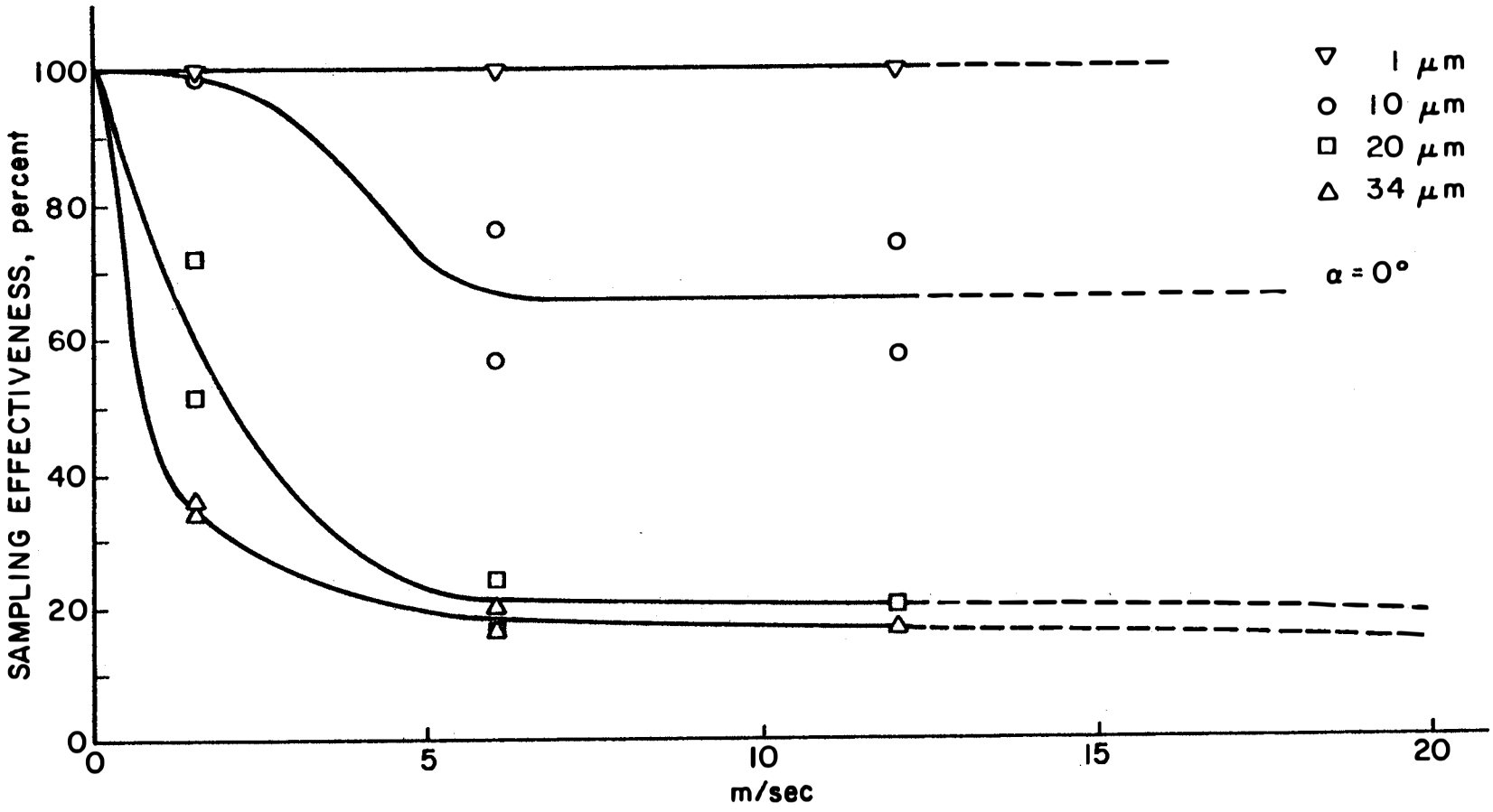

VACUUM PUMP
FLOW METER
SAMPLING CHAMBER
VALVE 3
VALVE 1
DILUTION AIR
PRESSURE GAGE
KRYPTON 85 CHARGE NEUTRALIZER
DRY COMPRESSED AIR
VALVE 2
FILTER HOLDER
SILICA GEL
PRESSURE REGULATOR
ABSOLUTE FILTER
SUBMICRON ATOMIZER
PRESSURE GAGE
TO TSI MODEL 3030 AEROSOL ANALYZER
INFUSION PUMP
LIQUID RESERVOIR

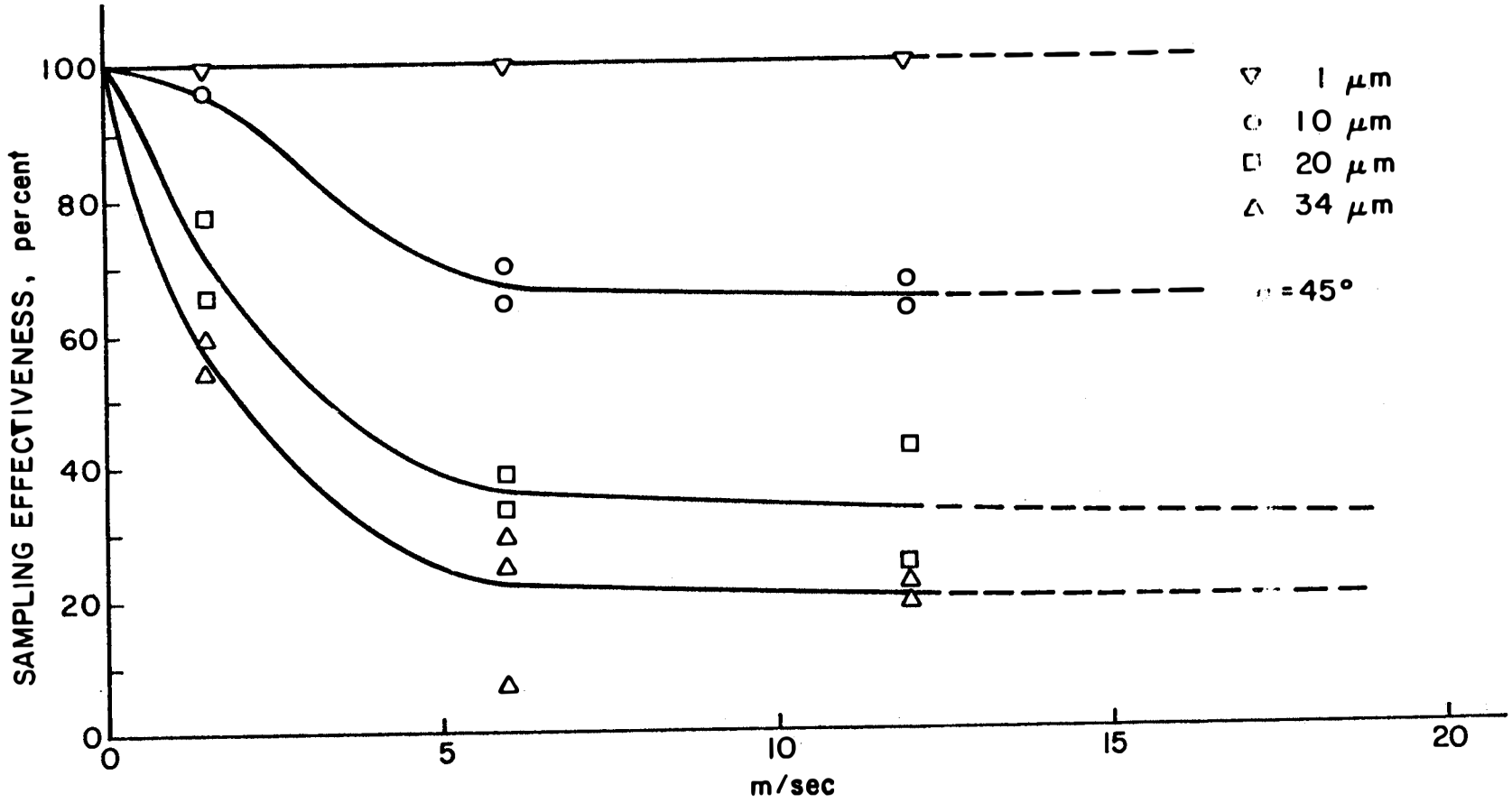

TEST VELOCITY = 5 m / sec
□, ⊠ STANDARD HI-VOLUME SAMPLER (□--45°, ⊠--0°)
○, △, ▽ ROCKY FLATS SAMPLER
(○--0°, △--45°, ▽--180°)
SAMPLE EFFECTIVENESS, percent
100
80
60
40
20
0
0
10
20
30
40
50
PARTICLE DIAMETER, μm.


SAMPLING EFFECTIVENESS, percent
100
80
60
40
20
0
0
5
10
15
20
25
30
35
PARTICLE DIAMETER, μm
APPROACH
FLOW VELOCITY
V = 1.524
V = 6.096
V = 12.192
α = 0°


100
80
60
40
20
0
SAMPLING EFFECT VENESS, percent
0
5
10
15
20
25
30
35
PARTICLE DIAMETER, μm
APPROACH
FLOW VELOCITY
V = 1.524
V = 6.096
V = 12.192
α = 45°


SAMPLING EFFECTIVENESS, percent
100
80
60
40
20
0
0
5
10
15
20
25
30
35
PARTICLE DIAMETER, μm
APPROACH
FLOW VELOCITY
V = 1.524
V = 6.096
V = 12.192
α = 180°


SAMPLING EFFECTIVENESS, percent
100
80
60
40
20
0
0
5
10
15
20
m/sec
1 μm
10 μm
20 μm
34 μm
α = 0°


SAMPLING EFFECTIVENESS, percent
100
80
60
40
20
0
0
5
10
15
20
m/sec
1 μm
10 μm
20 μm
34 μm
θ=45°

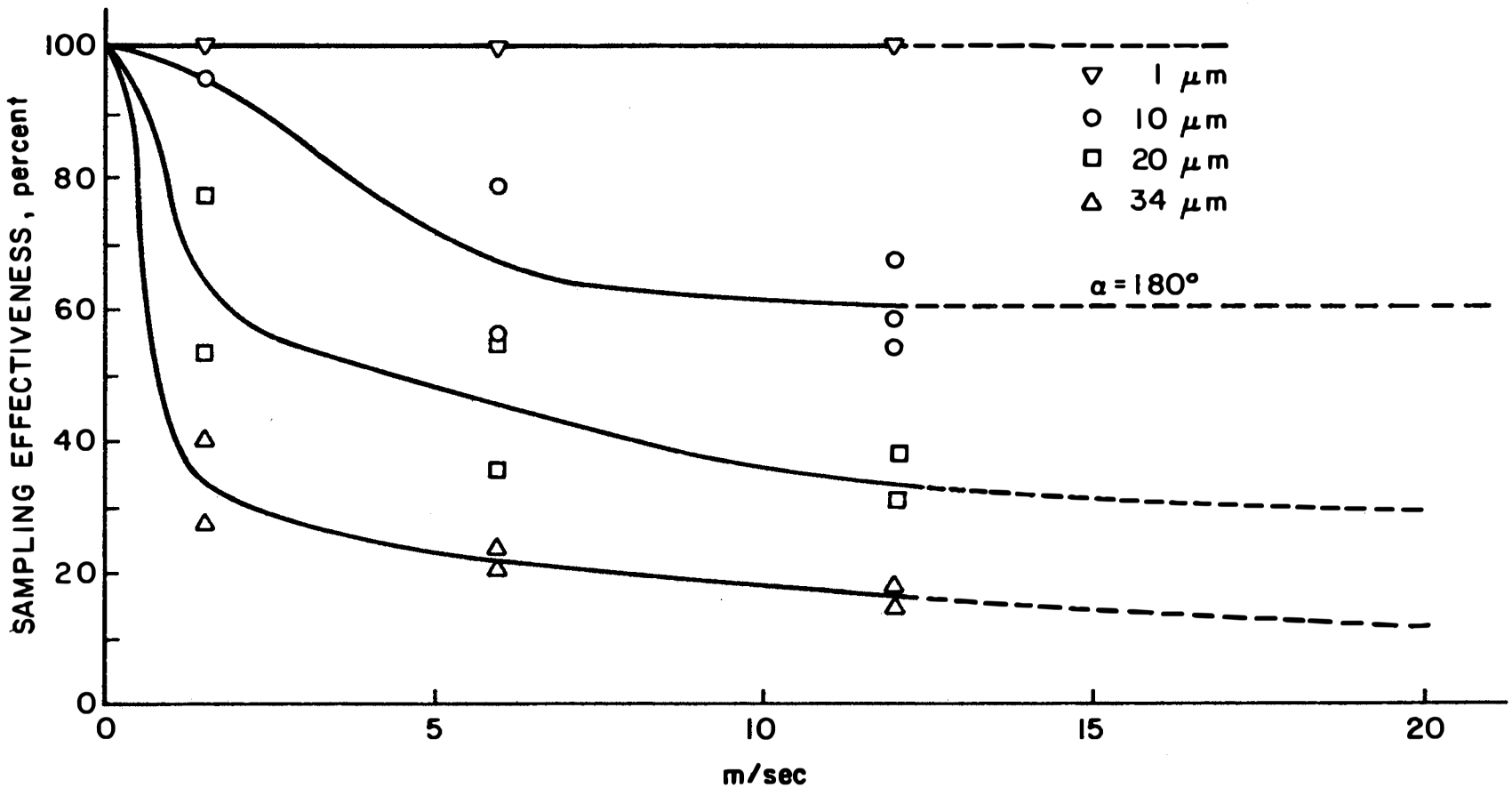

SAMPLING EFFECTIVENESS, percent
100
80
60
40
20
0
0
5
10
15
20
m/sec
1 μm
10 μm
20 μm
34 μm
α = 180°

Table 1. Comparison of the Sampling Effectiveness (%) of the Rocky Flats Hi-Volume Sampler and the Standard Hi-Volume Sampler at ∿5 m/sec for various particle sizes.
1: Standard Hi-Volume
2: Rocky Flats Hi-Volume

	Particle Diameter (μm)														
	1^2-5^1			10^2			15^1-20^2			30^1-34^2			50^1		
	Sampler Orientation														
Sampler	0	45	180	0	45	180	0	45	180	0	45	180	0	45	180
1	97	100	-	-	-	-	35	55	-	18	41	-	7	34	-
2	100	100	100	75	72	72	27	42	47	20	30	23	-	-	-

Sampling rates { 1 = 1415 ℓ/min
2 = 880 ℓ/min

Table 2. Typical Set of Data Showing Particle Sizes Employed and Concentrations Measured During the Efficiency Tests of the Microsorban-98 Fiber Filter Tested at 4.5 cm Hg Pressure Drop.

1	2	3	4	5	6
Particle Sizes (μm)	Number Concentration Upstream of the Filter (particles/cm^3)	Cumulative Percent Less Than Stated Size	Number Concentration Downstream of the Filter (particles/cm^3)	Minimum Detectable Concentration particles/cm^3*	Maximum Detectable Filtration Efficiency (%)
0.0100					
	9.740×10^5		-	417	99.9
0.0178		25.97			
	1.597×10^6		-	164	99.9
0.0316		68.54			
	4.538×10^5		-	87	99.9
0.0562		80.64			
	4.275×10^5		-	45	99.9
0.100		92.04			
	2.262×10^5		-	24	99.9
0.1780		98.06			
	6.238×10^4		-	12	99.9
0.3160		99.73			
	8.965×10^3		-	6	99.9
0.562		99.97			
	1.23×10^3		-	3	99.8
1.000		100.00			

*This number is derived from the background noise of the device. Also this instrument detects an average concentration and does not count single particles.

APPENDIX J

LIST OF PREPARERS

The principal preparers of the RF EIS are listed alphabetically, with a brief tabulation of their qualifications, in the list that follows:

APPENDIX J
LIST OF PREPARERS

The principal preparers of the RFP EIS (Vol. 1) are listed alphabetically, with a brief description of their qualifications, in the list that follows:

Earl W. Bean, B.S., Registered Professional Nuclear Engineer, 17 years experience in nuclear technology

Robert W. Bistline, Ph.D., 13 years experience in health physics and radiation biology

Meryln R. Boss, B.A., 17 years experience in health physics, nuclear safety, air pollution control, radiation dosimetry and standards engineering

Bert L. Crist, M.S., 10 years experience in health physics

Loren M. Crow, Ph.D., 37 years experience in meteorology

Duane A. Dunn, M.S., 26 years experience in nuclear materials control

Roger B. Falk, M.S., 13 years experience in internal and external dosimetry

John A. Geer, M.S., 30 years experience in chemical engineering and utilities administration

John A. Hayden, B.S., 23 years experience in chemical research, soil science, and particle resuspension

John C. Hayden, A.B., 15 years experience in security management, nuclear safeguards and emergency preparedness

Margaret F. Hickey, M.S., 11 years experience in nuclear physics, chemistry, environmental research and land management

Daryl D. Hornbacher, M.S., 11 years experience in chemistry, physics, engineering, and environmental monitoring

Robert D. Howerton, A.B., 21 years experience in communications, public affairs, and technical editing

Douglas C. Hunt, Ph.D., Registered Professional Environmental Engineer, 16 years experience in nuclear safety and environmental science research

R. Theodore Hurr, M.E., 16 years experience in geology and groundwater hydrology

Charles T. Illsley, M.S., 24 years experience in geology, geochemistry, radiochemistry, and soil science

Charles W. Jacoby, M.B.A., 21 years experience in chemical research, engineering, auditing, and industrial safety

Delores M. Krieg, 27 years experience in transportation management

James M. Langsted, M.S., 3 years experience in internal dosimetry

Maurice E. Maas, 27 years experience in radioactive waste processing

Raymond L. Miller, B.S., 26 years experience in health physics and environmental protection

Deanne Pecora, Ph.D., 11 years experience in criticality safety

Edward A. Putzier, B.A., Certified Health Physicist, 28 years experience in health physics

James E. Randall, D. J., 16 years experience in nuclear weapons engineering and government law

William B. Sayer, M.S., Certified Health Physicist, 18 years experience in health physics, engineering, and meteorology

Judith Selvidge, D.B.A., 10 years experience in decision and risk analysis and statistics

Jerome D. Shaykin, B.S., Certified Public Health Sanitarian, 40 years experience in public health sanitation and environmental health

Kenneth E. Shirk, B.S., 13 years experience in engineering design and utilities operation

TERA Corporation, a diversified consulting firm in environmental science and nuclear engineering, was responsible for preparing the preliminary draft environmental impact statement

Milton A. Thompson, Ph.D., 22 years experience in chemistry research and development, nuclear waste management, environmental research, and applied environmental science

Marilyn V. Werkema, Ph.D., 14 years experience in chemistry, crystallography, metallurgy, and environmental science

Terrol F. Winsor, Ph.D, 7 years experience in terrestrial ecology and radioecology

Woodward-Clyde Consultants, a consulting firm in earth sciences, geotechnical engineering and environmental sciences, was responsible for preparing sections on geology, hydrology, and seismology

Robert E. Yoder, Sc.D., Certified Health Physicist, 25 years experience in health physics, safety engineering, and environmental sciences

Edward R. Young, B.S., 20 years experience in product engineering, production control, warehousing, and security and safeguards

Volume II preparers are identified with their respective contributions.

APPENDIX K

HISTORIC PLACES WITHIN 50-MILE RADIUS OF

THE ROCKY FLATS PLANT SITE

EXTRACTED FROM

DEPARTMENT OF THE INTERIOR

HERITAGE CONSERVATION AND RECREATION SERVICE

NATIONAL REGISTER OF HISTORIC PLACES

ANNUAL LISTING OF HISTORIC PROPERTIES

FEDERAL REGISTER

FEBRUARY 6, 1979

BOOK 2: PAGES 7415-7649

COLORADO

arapahoe county

Strasburg vicinity, COMANCHE CROSSING OF THE KANSAS PACIFIC RAILROAD, On Union Pacific Railroad tracks E of the Strasburg depot, (8-10-70) PH0066109

boulder county

Boulder, CHAUTAUQUA AUDITORIUM, Chautauqua Park, (1-21-74) PH0066125

Boulder, COLORADO CHAUTAUQUA, Chautauqua Park, (3-21-78)

Boulder, HIGHLAND SCHOOL, 885 Arapahoe Avenue, (12-18-78)

Boulder, SQUIRES-TOURTELLOT, quires-Tourtellot, co Ocf Oi09 1019 Spruce Street, (8-10-78)

Longmont. ST. STEPHEN'S EPISCOPAL CHURCH, 1881, 470 Main Street, (2-24-75)

Lyons. FIRST CONGREGATIONAL CHURCH OF LYONS, High and 4th Streets, (12-12-76)

Lyons. LYONS RAILROAD DEPOT, 400 block of Broadway, (12-2-74) PH0066133

Ward vicinity. MODOC MILL, N of Ward, (12-27-78)

clear creek county

Georgetown. ALPINE HOSE COMPANY NO. 2, 507 5th Street, (1-25-73) PH0066176

Georgetown. GRACE EPISCOPAL CHURCH, Taos Street, between 4th and 5th Streets, (8-14-73) PH0066206

Georgetown. HAMILL HOUSE, Argentine and 3rd Streets, (5-31-72) PH0066214G.

Georgetown. HOTEL DE PARIS, Alpine Street, (4-28-70) PH0066222G.

Georgetown. MCCLELLAN HOUSE, 919 Taos Street, (12-5-72) PH0066257

Georgetown. TOLL HOUSE (JULIUS G. POHLE HOUSE), S side of Georgetown adjacent to I 70, (12-18-70) PH0066281G.

Georgetown-Silver Plume vicinity. GEORGETOWN-SILVER PLUME HISTORIC DISTRICT, (11-13-66) PH0066192NHL;G.

Georgetown vicinity. ORE PROCESSING MILL AND DAM, 1 mi. SW of Georgetown off I 70, (5-6-71) PH0066265G.

Idaho Springs. ARGO TUNNEL AND MILL, 2517 Riverside Drive, (1-31-78)

Silver Plume. SILVER PLUME DEPOT, off I 70, (5-6-71) PH0066273

Silver Plume vicinity. LEBANON AND EVERETT MINE TUNNELS, NE of Silver Plume adjacent to I 70 right-of-way, (10-7-71) PH0066231 G.

denver county

Denver. ALL SAINTS EPISCOPAL CHURCH, 2222 W. 32nd Avenue, (6-23-78)

Denver. AURARIA 9TH STREET HISTORIC DISTRICT, (3-26-73), PH0066320G.

Denver. BAILEY HOUSE, 1600 Ogden Street, (9-18-78)

Denver. BELCARO (PHIPPS HOUSE), 3400 Belcaro Drive, (2-10-75) HABS.

Denver. BOSTON BUILDING, 828 17th Street, (9-18-78) HABS.

Denver. BRINKER COLLEGIATE INSTITUTE, 1725-1727 Tremont Place, (10-28-77)

Denver. BROWN, MOLLY, HOUSE, 1340 Pennsylvania Street, (2-1-72) PH0066346G.

Denver. BROWN PALACE HOTEL, 17th Street and Tremont Place, (4-28-70) PH0066354

Denver. BYERS-EVANS HOUSE, 1310 Bannock Street, (8-25-70) PH0066362

Denver. CATHEDRAL OF THE IMMACULATE CONCEPTION, NE corner of Colfaz Avenue and Logan Street, (3-3-75)

Denver. CENTRAL PRESBYTERIAN CHURCH, 1660 Sherman Street, (11-21-74) PH0066389HABS.

Denver. CHRIST METHODIST EPISCOPAL CHURCH, 2201 Ogden Street, (11-7-76)

Denver. CIVIC CENTER, Between Grant and Delaware Streets, S of 13th Avenue, (2-27-74) PH0066397 HABS.

Denver. COLORADO GOVERNOR'S MANSION, 400 E. 8th Avenue, (12-3-69) PH0066516

Denver. CONSTITUTION HALL (FIRST NATIONAL BANK BUILDING), 1507 Blake Street, (8-25-70) PH0066401

Denver. CORNWALL APARTMENTS, 1317 Ogden Street, 912 E. 13th Avenue, (10-8-76)

Denver. CRESWELL MANSION, 1244 Grant Street, (11-25-77)

Denver. CROKE-PATTERSON-CAMPBELL MANSION, 428-430 E. 11th Avenue, (9-19-73) PH0066419HABS.

Denver. CURRY-CHUCOVICH HOUSE, 1439 Court Place, (6-9-78)

Denver. CURTIS-CHAMPA STREETS DISTRICT, Roughly bounded by Arapahoe, 30th, California, and 24th Streets, (4-1-75)

Denver. DANIELS AND FISHER TOWER, 1101 16th Street, (12-3-69) PH0066427

Denver. DENVER DRY GOODS COMPANY BUILDING, 16th and California Streets, (1-9-78)

Denver. DENVER MINT, W. Colfax Avenue and Delaware Street, (2-1-72) PH0066435

Denver. ELITCH THEATRE, W. 38th Avenue and Tennyson Street, (3-31-78)

Denver. EMMANUAL SHEARITH ISRAEL CHAPEL (EMMANUEL EPSICOPAL CHAPEL) 1201 10th Street, (12-1-69) PH0066443

Denver. EQUITABLE BUILDING, 730 17th Street, (1-9-78)

Denver. EVANS MEMORIAL CHAPEL, University of Denver campus, (12-27-74) PH0066451

Denver. FIELD, EUGENE, HOUSE, 715 S. Franklin Street, (11-1-74), PH0066460HABS.

Denver. FISHER, WILLIAM G., HOUSE, 1600 Logan Street, (11-20-74) PH0066478HABS

Denver. FITZROY PLACE, 2160 S. Cook Street, (2-20-75)

Denver. FORD, BARNEY L., BUILDING, 1514 BLAKE Street, (6-24-76)

Denver. FOSTER, A. C., BUILDING, 912 16th Street, (1-9-78)

Denver. FOUR-MILE HOUE, 715 S. Forest Street, (12-3-69) PH0066494HABS.

Denver. GHOST BUILDING, 500-518 15th Street, (1-9-78)

Denver. GRANT-HUMPHREY'S MANSION, 770 Pennsylvania Street, (9-30-70) PH0066508 HABS.

Denver. HUMBOLDT STREET HISTORIC DISTRICT, Humboldt Street between E. 10th and E. 12th Streets, (12-29-78)

Denver. IDEAL BUILDING, 821 17th Street, (6-9-77)

Denver. KITTREDGE BUILDING, 511 16th Street, (12-2-77)

Denver. LARIMER SQUARE, 1400 block of Larimer Street, (5-7-73) PH0066524

Denver. LEFEVRE, OWEN E., HOUSE, 1311 York Street, (8-13-76)

Denver. LORETTO HEIGHTS ACADEMY, 3001 S. Federal Boulevard, (9-18-75)

Denver. MARNE, THE, 1572 Race Street, (11-21-74) PH0066532

Denver. MASONIC TEMPLE BUILDING, 1614 Welton Street, (11-22-77)

Denver. MOFFAT STATION, 2105 15th Street, (10-22-76)

Denver. MOORE, DORA, ELEMENTARY SCHOOL, E. 9th Avenue and Corona Street, (6-9-78)

Denver. PEARCE-MCALLISTER COTTAGE, 1880 Gaylord Street, (6-20-72) PH0088765G.

Denver. PUBLIC SERVICE BUILDING, 910 15th Street, (7-20-78)

Denver. RICHTHOFEN CASTLE, 7020 E. 12th Avenue, (4-21-75)

Denver. SCHLEIER, GEORGE, MANSION, 1665 Grant Street, (11-17-77)

Denver. SCHMIDT, GEORGE, HOUSE, 2345 7th Street, (10-29-76)

Denver. SMITH'S IRRIGATION DITCH, Washington Park, (10-8-76)

Denver. ST. ANDREWS EPISCOPAL CHURCH, 2015 Glenarm Place, (3-18-75)

Denver. ST. ELIZABETH'S CHURCH, 1062 11th Street, (12-1-69) PH0066541

Denver. ST. ELIZABETH'S RETREAT CHAPEL (CATHOLIC), 2825 W. 32nd Avenue, (5-24-76)

Denver. ST. JOHN'S CATHEDRAL, 14th and Washington Streets, (8-1-75)

Denver. ST. MARK'S PARISH CHURCH, 1160 Lincoln Street, (9-18-75)

Denver. SUGAR BUILDING, 1530 16th Street, (2-17-78)

Denver. TEARS-MCFARLANE HOUSE, 1200 Williams Street, (1-11-76)

Denver. TEMPLE EMANUEL, 24 Curtis Street, (10-10-78)

Denver. THOMAS H. H., HOUSE, 2104 Glenarm Place, (5-30-75)

Denver. TIVOLI BREWERY COMPANY, 1320-1348 10th Street, (4-11-73) PH0066583HAER

Denver. TRAMWAY BUILDING, 1100 14th Street, (1-5-78)

Denver. TREAT HALL, E. 18th Avenue and Pontiac Street, (8-10-78)

Denver. TRINITY UNITED METHODIST CHURCH, E. 18th Avenue and Broadway, (7-28-70) PH0066559

Denver. U.S. POST OFFICE AND FEDERAL BUILDING, 18th and Stout Streets, (3-20-73) HABS.

Denver. UNION STATION, 17th Street at Wynkoop, (11-20-74) PH0066567

Denver. VINE STREET HOUSES, 1415, 1429, 1435, 1441, 1452 Vine Street, (12-16-74) PH0066591

Denver. WESTSIDE NEIGHBORHOOD, 1311-1466 Lipan Street, 1305-1370 Kalamath Street, 931-1126 W. 14th Avenue, 1312-1438 on E side of Maraposa Street, and 1008-1118 on N side of W. 13th Avenue, (4-17-75)

Denver. WOOD-MORRIS-BONFILS HOUSE, 707 Washington Street, (12-4-74) PH0066605

Denver. ZANG, ADOLPH, MANSION, 709 Clarkson Street, (11-23-77)

douglas county

Castle Rock. CASTLE ROCK DEPOT, 420 Elbert Street, (10-11-74) PH0066621

Castle Rock. DOUGLAS COUNTY COURTHOUSE, 301 Wilcox Street, (12-12-76)

Denver vicinity. BEAR CANON AGRICULTURAL DISTRICT, S of Denver on both sides of CO 105 from CO 67 S to Jarre Creek, (10-29-75)

Larkspur vicinity. SPRING VALLEY SCHOOL, E of Larkspur at Spring Valley and Lorraine Roads, (12-18-78)

Palmer Lake vicinity. GLEN GROVE SCHOOL, N of Palmer Lake off Perry Park Road, (11-5-74) PH0066648

Palmer Lake vicinity. QUICK, BEN, RANCH AND FORT, 6695 W. Plum Creek Road, (10-1-74) PH0066664

Sedalia vicinity. CHURCH OF ST. PHILIP-IN-THE-FIELD AND BEAR CANON CEMETERY, 5 mi. S of Sedalia on CO 105, (4-11-73) PH0066630

Sedalia vicinity. INDIAN PARK SCHOOL, 10 mi. (16 km) W of Sedalia on CO 67, (2-8-78)

Sedalia vicinity. KINNER, JOHN, HOUSE, 6694 Perry Park Road, (10-11-74) PH0066656

gilpin county

Central City. CENTRAL CITY HISTORIC DISTRICT, (10-15-66) PH0086975 NHL;HABS;G.

Central City. CENTRAL CITY OPERA HOUSE, Eureka Street, (1-18-73) PH0086983

Central City. TELLER HOUSE, Eureka Street, (1-18-73) PH0086991

jefferson county

Arvada. ARVADA FLOUR MILL, 5580 Wadsworth Boulevard, (4-24-75)G.

Buffalo Creek. BLUE JAY INN, Highway 126, (10-1-74) PH0087041

Buffalo Creek. LA HACIENDA (JOHN L. JEROME SUMMER ESTATE), on SR off U.S. 285, (7-20-73) PH0087092

Buffalo Creek vicinity. GREEN MERCANTILE STORE, NW of Buffalo Creek, (10-1-74)

Buffalo Creek vicinity. GREEN MOUNTAIN RANCH, S of Buffalo Creek on Highway 126, (10-1-74) PH0087068

Evergreen. HIWAN HOMESTEAD, Meadow Drive, (4-9-74) PH0087076

Evergreen. HUMPHREY HOUSE, 620 S. Soda Creek Road, (12-31-74) PH0087084

Golden. ASTOR HOUSE HOTEL (LAKE HOUSE, CASTLE ROCK HOUSE), 822 12th Street, (3-1-73) PH0087033

Golden. COLORADO NATIONAL GUARD ARMORY, 1301 Arapahoe Street, (12-18-78)

Golden vicinity. MOUNT VERNON HOUSE (ROBERT W. STEELE HOUSE), about 1 mile S of Golden city limits at jct. of I 70, CO 26, and Mount Vernon Canyon Road, (11-20-70) PH0087114HABS.

Golden vicinity. ROONEY RANCH, S of Golden, jct. of Rooney Road and Alameda Parkway, (2-13-75)

Lakewood vicinity. STONE HOUSE, S of Lakewood off of S. Wadsworth Boulevard, (5-1-75)

Littleton vicinity. HILDEBRANDE RANCH, 7 miles SW of Littleton off Deer Creek Canyon Road, (3-13-75)

Morrison. MORRISON HISTORIC DISTRICT, CO 8, (9-28-76)

Morrison. MORRISON SCHOOLHOUSE, 226 Spring Street, (9-4-74) PH0087106

Pine and South Platte. NORTH FORK HISTORIC DISTRICT, both sides of South Platte River from Pine to South Platte, in Pike National Forest, (10-9-74) PH0087122

Wheat Ridge. PIONEER SOD HOUSE, 4610 Robb Street, (3-14-73) PH0087149

Wheat Ridge. RICHARDS MANSION, 5349 W. 27th Avenue, (9-15-77)

larimer county

Estes Park. ELKHORN LODGE, 530 W. Elkhorn Avenue, (12-27-78)

Estes Park. STANLEY HOTEL, 333 Wonder View Avenue, (5-26-77)

Estes Park vicinity. LEIFFER HOUSE, S of Estes Park off CO 7, (8-2-78)

Estes Park vicinity. MILLS, ENOS, HOMESTEAD CABIN, S of Estes Park off CO 7, (5-11-73) PH0087238

Estes Park vicinity. MORAINE LODGE, W of Estes Park off U.S. 36 on Bear Lake Road, (10-8-76)

Estes Park vicinity. WHITE, WILLIAM ALLEN, CABINS, W of Estes Park at Moraine Park Visitor Center in Rocky Mountain National Park, (10-25-73) PH0087254

Fort Collins. AMMONS HALL, Colorado State University campus, (6-15-78)

Fort Collins. ANDREWS HOUSE, 324 E. Oak Street, (12-15-78)

Fort Collins. AVERY HOUSE, 328 W. Mountain Avenue, (6-24-72) PH0087220G.

Fort Collins. BAKER HOUSE, 304-304 1/2 E. Mulberry Street, (7-20-78)

Fort Collins. BOTANICAL AND HORTICULTURAL LABORATORY, Colorado State University campus

Fort Collins. BOUTON, JAY H., HOUSE, 113 N. Sherwood Street, (12-18-78)

Fort Collins. FORT COLLINS POST OFFICE, 201 S. College Avenue, (1-30-78)

Fort Collins. FULLER, MONTEZUMA, HOUSE, 226 W. Magnolia Street, (12-15-78)

Fort collins. MCHUGH-ANDREWS HOUSE, 202 Remington Street, (12-27-78)

Fort Collins. OLD TOWN FORT COLLINS, Roughly bounded by College Avenue, Mountain, Pine, Willow, and Walnut Streets, (8-2-78)

Fort Collins. SPRUCE HALL, Colorado State University campus, (1-9-77)

Fort Collins vicinity. LINDENMEIER SITE, 28 miles N. of Fort Collins, 1.75 miles S. of Wyoming state line, (10-15-66) PH0087246NHL.

Loveland vicinity. CHASTEEN'S GROVE, W of Loveland off U.S. 34, (9-6-78)

park county

Fairplay. SOUTH PARK COMMUNITY CHURCH, 6th and Hathaway Streets, (11-22-77)
Fairplay. SOUTH PARK LAGER BEER BREWERY, 3rd and Front Streets, (6-25-74) PH0087378
Fairplay. SUMMER SALOON, 3rd and Front Streets, (5-8-74) PH0087386

weld county

Greeley. MEEKER MEMORIAL MUSEUM, 1324 9th Avenue, (2-26-70) PH0087491
Greeley. WELD COUNTY COURTHOUSE, 9th Street and 9th Avenue, (1-9-78)
Platteville vicinity. FORT VASQUEZ SITE, on U.S. 85, (10-30-70) PH0087483G.

The following properties have been determined to be eligible for inclusion in the National Register.

boulder county

Longmont. HOVER MANSION DISTRICT, 1309 Hover Road

denver county

Denver. 31st STREET OVERFLOW STRUCTURE, 31st Street and Atkins Court (63.3)

douglas county

KEYSTONE RAILROAD BRIDGE, Pike National Forest
South Platte Canyon. DEANSBURRY BRIDGE, Foothills Project 7.7 miles (12.3 km) W from gate at Kassler Treatment Plant along access road, (also in Jefferson County)

garfield county

HAVEMEYER-WILCOX CANAL SYSTEM

jefferson county

South Platte vicinity. DENVER AND RIO GRANDE ROCKWORK AND RAILROADS, Foothills Project.

larimer county

Buckeye vicinity. SITES 5-LR-257 AND 5-LR-263, Boxelder Watershed Project.
Estes Park. BEAVER MEADOWS MAINTENANCE AREA, Rocky Mountain National Park Utility Area

United States
Department of Energy
Washington, DC 20545

Postage and Fees Paid
U.S. Department of Energy
DOE-350

Official Business
Penalty for Private Use, $300