40 CFR Part 192, Subpart D
Standards for Management of Uranium
Byproduct Materials

EPA 402-D-93-001

TECHNICAL SUPPORT FOR

AMENDING STANDARDS FOR

MANAGEMENT OF URANIUM

BYPRODUCT MATERIALS

DRAFT

BACKGROUND INFORMATION DOCUMENT

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
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PREFACE

The Environmental Protection Agency (EPA) is proposing to amend 40 CFR 192, Subpart D, dealing with disposal of uranium mill tailings at nonoperational sites licensed by the Nuclear Regulatory Commission (NRC) or an Agreement State pursuant to the Uranium Mill Tailings Radiation Control Act (UMTRCA) of 1978 (42 U.S.C. 2022, 7901-7942).

This Background Information Document (BID) has been prepared in support of the rulemaking proceedings for EPA's action. This BID only considers long-term disposal of tailings at facilities licensed by the NRC or an Agreement State, and designated as Title II facilities in the UMTRCA. Currently, the tailings at these facilities are subject to the disposal and long-term stabilization regulations developed under the UMTRCA by the EPA and the NRC and set forth in 40 CFR 192, Subpart D. In addition, the standards at 40 CFR Part 61, Subpart T (National Emission Standard for Hazardous Air Pollutants) which would otherwise apply to these sites, are currently stayed until EPA takes final action on its proposal to rescind Subpart T or until June 30, 1994, whichever occurs first.

Copies of this BID, in whole or in part, are available to all interested persons. An announcement of the availability appears in the Federal Register. For additional information, contact Eleanor Thornton at (202) 233-9773 or write to:

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CHAPTER 1

BACKGROUND INFORMATION

1.1 STATEMENT OF PURPOSE

Uranium mill tailings refer to the wastes that result from the processing of ores to recover uranium. Since commercially-processed uranium ores in the United States typically contain 0.05 to 0.2 percent uranium, virtually the entire ore throughput of milling becomes tailings waste. Historically, uranium mill tailings have been stored in large surface impoundments, or piles, in quantities ranging from less than one million tons to over 30 million tons. These impoundments cover areas from seven to over three hundred acres.

Tailings emit radon gas, a radioactive decay product of uranium. Since tailings impoundments often have large unprotected surface areas, the exposure to radon-222 is a health concern. Under the authority of the Uranium Mill Tailings Radiation Control Act (UMTRCA) and the Clean Air Act (CAA), the U.S. Environmental Protection Agency (EPA), the Department of Energy (DOE), and the Nuclear Regulatory Commission (NRC) have devised and implemented controls to limit risks from the milling of uranium ores during both the active period of operations and the closure/disposal phase, when active milling of ore has ceased.

This Background Information Document (BID) only considers long-term disposal of tailings at facilities licensed by the NRC or an Agreement State, and designated as Title II facilities in the UMTRCA. Currently, the tailings at these facilities are subject to the disposal and long-term stabilization regulations developed under the UMTRCA by the EPA and the NRC and set forth in 40 CFR 192, Subpart D.

As discussed in the sections that follow, the EPA initially promulgated regulations in 1983 under the UMTRCA that established generally applicable environmental standards for both radiological and non-radiological contaminants. The NRC subsequently developed specific licensing and design criteria to implement the EPA's standards for Title II sites. In 1989, under the authority of the CAA, the EPA promulgated National Emission Standards for Hazardous Air Pollutants (NESHAPs), 40 CFR 61, Subpart T, which address only the emission of radon-222 from the disposal of tailings. Subpart T requires that a radon barrier capable of limiting emissions to an average of 20 pCi/m^2-s be installed within two years of the promulgation date of the NESHAPs or two years from cessation of operations, which ever is later. Subpart T also requires that a one-time emission test be performed to assure that the design objective of 20 pCi/m^2-s for the radon barrier has been achieved. In promul-

gating Subpart T, the EPA found that the regulations established under UMTRCA did not set specific deadlines for disposal; therefore a NESHAPs was required to achieve radon-222 emissions at levels consistent with protection of the public's health with an ample margin of safety.

In its review of the EPA's Subpart T NESHAPs, the NRC expressed concerns regarding the duplication of the UMTRCA requirements. In response to the concerns regarding duplication, Congress amended the CAA prior to its reauthorization in 1990. This amendment gives the EPA the authority to amend the CAA to avoid duplicative regulation while still protecting public health with an ample margin of safety. Under the authority of this amendment, and after consultations with the NRC and affected Agreement States, the Administrator has undertaken the following actions:

- Stayed the NESHAPs (40 CFR 61, Subpart T) as it applies to the Title II uranium mill tailings (NRC- or Agreement State-licensed) until the date on which the rulemakings discussed below have been completed (or June 30, 1994, whichever occurs first)

- Proposed to rescind 40 CFR 61 Subpart T as it applies to Title II facilities

- Published an Advanced Notice of Proposed Rulemaking to amend its UMTRCA regulations (40 CFR 192, Subpart D) to require emplacement of radon control barriers at currently non-operational impoundments by specified dates and at operational impoundment within seven years of cessation of operations, and to require one-time testing of the radon barriers to assure that the design flux has been attained.

This Background Information Document provides information in support of these rulemakings. This chapter provides a historical summary of mill tailings regulations under the UMTRCA and CAA, details of the possible rescission of 40 CFR 61, Subpart T, and the amendment of 40 CFR 192, Subpart D. Chapter 2 of this BID provides a profile of the uranium milling industry and an assessment of its economic status. Past operational information and the current status of the non-operational impoundments are presented in Chapter 3. Radon sources, environmental transport, and risk coefficients are developed in Chapter 4. Chapter 5 summarizes the exposures and health risks to nearby populations from non-operational tailings impoundments. Chapters 6 and 7 discuss radon control techniques and provide cost estimates for the emplacement of an earthen cover that will reduce radon emissions to regulatory standards.

1.2 REGULATION OF URANIUM MILL TAILINGS

1.2.1 UMTRCA Authorities

The Atomic Energy Act of 1954 gave the Atomic Energy Commission (AEC) authority to license and regulate source material (uranium and thorium) processed at uranium mills. However, once a mill stopped operating, the AEC had no authority to regulate the tailings piles that remained. One result was that some tailings were used in the 1960s as fill around foundations of houses, causing high indoor radon concentrations. The 1976 Resource Conservation and Recovery Act (RCRA) gave EPA the authority to place controls on mill tailings, if EPA considered them hazardous. However, in 1978 Congress passed UMTRCA (P.L. 95-604, 42 USC 2022, 7901-7942), which gave the EPA the authority to regulate mill tailings for the purpose of protecting the public from radon and other exposure pathways.

UMTRCA set up two programs to protect public health and the environment from mill tailings hazards. Both programs required EPA to set standards for disposal of tailings; the other agencies involved were required to implement those standards. The "Title I" program directed the Department of Energy (DOE) to remediate the tailings at inactive (generally abandoned) uranium mill sites that did not have an effective AEC or NRC license as of January 1, 1978. The "Title II" program was for "active" sites licensed by the NRC or an Agreement State. EPA standards for these sites were to cover final disposal of the tailings, including radon control after the mill closed, and to be consistent with standards for wastes promulgated under the RCRA. UMTRCA directed EPA to set standards for Title I sites within one year and standards for Title II sites within 18 months of enactment.

1.2.2 EPA's UMTRCA Rulemakings

On April 22, 1980, EPA proposed cleanup standards for Title I sites, covering open lands and buildings contaminated with residual radioactive materials from uranium processing (to be codified in 40 CFR 192, Subpart A). These were made immediately effective as interim standards pending public review and promulgation of final standards (45 FR 27370 and 27366). On January 9, 1981, EPA proposed disposal standards for Title I sites (46 FR 2556), and on January 5, 1983, EPA promulgated final rules for the disposal and cleanup of the Title I sites (48 FR 605).

About this time Congress amended UMTRCA. PL 97-415, passed in January 1983, included a provision that would strip EPA of its standard-setting authority if EPA did not set standards for Title II sites by September 30 of that year. In response, EPA proposed general environmental standards for Title II uranium and thorium mill tailings sites on April 29, 1983 (48 FR 19584) and promul-

gated final rules on September 30 (48 FR 45926, codified in 40 CFR 192, Subparts D and E).

Both the UMTRCA Title I and Title II standards were challenged in the Tenth Circuit Court of Appeals by several parties in thirteen separate suits filed in 1983 and 1984 (56 FR 67570 lists the case numbers of these suits). In September of 1985, the court upheld all provisions of the standards, as promulgated, except those dealing with groundwater protection at Title I sites. The court directed EPA to promulgate groundwater standards for Title I sites similar to those for Title II sites. EPA proposed new ground water regulations to replace those set aside on September 24, 1987 (52 FR 36000). Promulgation of the final standards is awaiting the Office of Management and Budget's review. Groundwater protection standards are not the focus of these proposed rulemakings.

For Title II sites, the EPA's UMTRCA standards require, in part, that management of byproduct materials (tailings) during operations and prior to the end of the closure period be consistent with the standards set forth in 40 CFR 190. However, 40 CFR 190 does not address the doses caused by radon and its decay products, nor does it establish a numerical limit for radon emissions from the tailings piles. Instead, it requires that radon emissions be kept as far below Federal Radiation Protection Guides as is practicable.

EPA's UMTRCA standards established a limit on radon emissions from the tailings piles that have been closed, requiring that they not exceed an average of 20 pCi/m^2-s, and that the radon barrier be effective for 1000 years.

1.2.3 NRC's UMTRCA Rulemakings

UMTRCA placed requirements on NRC as well as on EPA. To prevent existing uranium milling operations licensed by NRC as well as by Agreement States from violating the Atomic Energy Act as amended by UMTRCA, NRC proposed rules relating to uranium mill tailings and construction of major plants on August 24, 1979 (44 FR 50015). On the same date, NRC also promulgated final regulations (with request for public comments) for uranium mill tailings licensing (44 FR 50012). On October 3, 1980, NRC promulgated final rules that specified licensing requirements for uranium and thorium milling (45 FR 65521).

The January 1983 Congressional amendments to UMTRCA that required EPA to issue regulations for Title II sites, in turn, caused the NRC to suspend, on May 26, 1983, portions of their rules (48 FR 23649). NRC licensees could have incurred significant costs to implement the NRC standards, had the NRC not modified its standards to conform with those issued by EPA, as UMTRCA

required. On November 26, 1984, NRC proposed rules that would conform its requirements to EPA's standards (49 FR 46418). Since these proposed rules excluded EPA groundwater protection standards, the NRC also issued, on the same date, a notice of proposed rulemaking to incorporate the groundwater and other provisions of EPA's 40 CFR 192, Subpart D standards into NRC standards (49 FR 46425). In various other actions in 1985, 1986, and 1987, NRC proposed and promulgated rules that incorporated all EPA standards for UMTRCA Title II mill tailings sites (50 FR 41852, 51 FR 24679, and 52 FR 43562). Thus, by November of 1987, the NRC's standards under UMTRCA were fully compatible with those promulgated by the EPA.

1.2.4 Clean Air Act Rulemakings

When Congress amended the Clean Air Act in 1977, it specifically addressed emissions of radioactive materials. Before that time, emissions of radionuclides either were regulated under the Atomic Energy Act or were not regulated at all. Section 112 of the Clean Air Act required the EPA Administrator to determine, after public notice and opportunity for public hearings (44 FR 21704, April 11, 1979), whether emissions of radionuclides cause or contribute to air pollution that may reasonably be expected to endanger public health. In December of 1979, the EPA published a notice in the Federal Register listing radionuclides as hazardous air pollutants under Section 112 of the Clean Air Act (44 FR 76738, December 27, 1979). This determination was supported by a technical report issued by the EPA detailing emission levels, applicable effluent controls, and the radiological impacts caused by airborne radioactive effluents released by various source categories of facilities (EPA79).

In June of 1981, the Sierra Club filed a suit alleging that the Clean Air Act required the EPA to propose standards for radionuclides within 180 days of listing them as hazardous pollutants under Section 112. The court agreed with the Sierra Club and in September of 1982 ordered the EPA to publish proposed emissions standards for radionuclides, with notice of public hearing within 180 days of that order.

In April of 1983, the EPA proposed radionuclides emission standards for four source categories: DOE facilities; NRC-licensed and non-DOE Federal facilities; underground uranium mines; and elemental phosphorus plants. The Agency also determined that emissions from several other source categories did not require regulations: coal-fired boilers; the phosphate industry; other mineral extraction industries; uranium fuel cycle facilities; uranium mill tailings; high-level radioactive waste facilities; and low energy accelerators (48 FR 15077, April 6, 1983). The Agency prepared a draft background information document in support of these decisions (EPA83).

After several extended comment periods and two public hearings, the Sierra Club again filed suit in February of 1984 to compel the EPA either to make the standards final or to determine that radionuclides are not hazardous air pollutants and "delist" them. In August of that year, the court ordered the Agency to take final action by October 23, 1984. In response to that order, the EPA withdrew the proposed standards for elemental phosphorus plants, DOE facilities, and NRC licensees, finding the control practices used for these source categories already protective of public health. The proposed standard for underground uranium mines was also withdrawn, but with the intent to set a different standard. The Agency also announced its intention to regulate radon-222 emissions from licensed uranium mills and reaffirmed its decision not to regulate emissions from coal-fired boilers, the phosphate industry, other extraction industries, uranium fuel cycle facilities, and high-level radioactive waste. Phosphogypsum stacks would be studied to determine whether a standard was needed.

In December 1984, the court ordered the EPA either to issue final standards for the original four source categories or delist radionuclides. The Agency then promulgated NESHAPs for elemental phosphorus plants, DOE facilities, and NRC-licensed facilities (50 FR 7280, February 6, 1985). Two other NESHAPs established work practice standards to control radon emissions from underground uranium mines (50 FR 15385, April 17, 1985) and licensed uranium mill tailings (51 FR 34056, September 24, 1986). These standards were again challenged in court.

While these suits were being adjudicated, the U.S. Court of Appeals for the D.C. Circuit found that the EPA's NESHAPs for vinyl chloride was defective because the Agency had considered costs and technological feasibility without first making a determination based only on health risk. The court proposed a two-step process as one means for the Administrator to establish NESHAPs that met the Congressional intent of safe with an ample margin of safety. As a first step, a level that would be deemed acceptable is established based solely on consideration of the health risks imposed by that level. Once an acceptable level of emissions is determined, the ample margin of safety is addressed by evaluating all relevant factors including technical feasibility of controls, cost of controls, etc.

The court also ordered the EPA to examine the effect of the vinyl chloride decision on other standards. Concluding that costs had been considered in many of the radionuclide rulemakings, the Agency asked the court to let those NESHAPs remain in place while it reconsidered them and all other issues raised in the lawsuits.

In early December 1987, the court accepted the EPA's proposal to reconsider all the NESHAPs using this two-step approach and established a time schedule requiring the Agency to propose decisions for all radionuclide source categories within 180 days and make final decisions within 360 days. This schedule was later modified to require proposed regulatory decisions by February 28, 1989, and final action by August 31, 1989.

On March 7, 1989, the EPA published proposed NESHAPs that described four possible policy approaches for regulating emissions of radionuclides (54 FR 9612). Public hearings were held in April. On July 14, 1989, the court extended the deadline for final action until October 31, 1989. The NESHAPs were made final on that date and most, including Subpart T, became effective on December 15, 1989, when they were published in the Federal Register (54 FR 51654).

In establishing the final radionuclide NESHAPs for each source category, the EPA adopted three risk criteria as central to the determination of acceptable levels of emissions and in its determination of the ample margin of safety:

- Maximum Individual Risk (MIR) - the maximum additional risk of any individual member of the public contracting fatal cancer from exposure to radioactive materials released to the air from any facility that is part of the source category. In evaluating the MIR, the EPA calculates a 70-year lifetime risk to an individual assuming that the level of emissions is constant throughout the persons entire life. The EPA considers that a risk to the maximum exposed individual of approximately one in ten thousand (1E-4) is presumptively acceptable.

- Risk Distribution - an estimate of how many persons exposed to the airborne effluents from the facilities that comprise a given source category are at a given level of individual risk. In evaluating the risk distribution, the EPA assesses the doses to all individuals within 80 kilometers of any facility in the source category. The Agency's goal is to assure that as many persons as possible are at a lifetime risk of less than one in one million (1E-6).

- Incidence - an estimate of the health impact on the entire population within a given area from exposure to a facility's emissions. The EPA considers no more than approximately 1 fatal cancer per year caused by all facilities in the source category to be acceptable.

These criteria are not absolute, but serve as guidelines that the EPA considers along with other factors which may be unique to each source category.

In establishing the NESHAPs for disposal of uranium mill tailings (40 CFR 61, Subpart T), the Administrator found that emissions of radon-222 which meet the UMTRCA design criteria of 20 pCi/m^2-s averaged over the entire disposal area represent a level that is safe with an ample margin of safety. By promulgating the NESHAPs, the Administrator assured that final disposal would be achieved as expeditiously as possible and the monitoring of emissions would be made prior to final stabilization to assure that the design objective of 20 pCi/m^2-s was indeed achieved by the radon barrier.

1.3 THE 1989 CAA NESHAP STANDARDS AND THE CLEAN AIR ACT AMENDMENTS OF 1990

On December 15, 1989, the Environmental Protection Agency (EPA) promulgated National Emission Standards for Hazardous Air Pollutants (NESHAPs) under Section 112 of the Clean Air Act (CAA). These standards regulated radionuclide emissions to the ambient air from several source categories, inclusive of non-operational uranium mill tailings sites. These sites are also regulated under the Uranium Mill Tailings Radiation Control Act (UMTRCA). The UMTRCA separated these sites into (1) inactive and abandoned sites controlled by the DOE (Title I sites) and (2) tailings sites licensed and regulated by the Nuclear Regulatory Commission (NRC) or an Agreement State (Title II sites).

The NESHAPs for licensed, but non-operational uranium mill tailings sites, Subpart T of 40 CFR 61, specifies that once a uranium mill tailings pile or impoundment ceases to be operational, it must be disposed of and brought into compliance with the radon emission standard (not greater than 20 pCi/m^2-s) within two years. For impoundments that were non-operational at the time of rulemaking, this meant emplacement of an earthen cover had to be completed by December 15, 1991 to meet the standard. In addition to specifying a time for closure and emission limits, Subpart T also requires specific monitoring and record keeping.

The UMTRCA regulations, as implemented by the NRC, specify a design flux that must be met for 1000 years. This flux is identical to the emission standard in Subpart T, but UMTRCA currently establishes no time limits for disposal of the piles. The UMTRCA standards also do not require monitoring to confirm that the design flux limits have been achieved.

Although the NESHAPs and UMTRCA complement each other, they create dual regulatory oversight, including independent procedural requirements seeking to ensure compliance with the common 20

pCi/m^2-s flux standard. Concern over the duplication and complication created by the two regulations resulted in petitions by the NRC and the American Mining Congress, which urged the EPA to reconsider its position.

Congress, in response to its own concerns over the dual authority established by the UMTRCA and CAA regulations, substantially amended the CAA in 1990. As part of that enactment, section 112(d)(9) was added to the statute. It states the following:

> "No standard for radionuclide emissions from any category or subcategory of facilities licensed by the Nuclear Regulatory Commission (or an Agreement State) is required to be promulgated under this section if the Administrator determines, by rule, and after consultation with the Nuclear Regulatory Commission, that the regulatory program established by the Nuclear Regulatory Commission pursuant to the Atomic Energy Act for such category or subcategory provides an ample margin of safety to protect the public health."

This provision strives to eliminate duplicative regulations by the EPA and the NRC and preserve governmental resources.

Moreover, Congress expressed sensitivity to the special compliance problems of uranium mill tailings sites through new section 112(i)(3). This section provides an additional three-year extension to mining waste operations (e.g., uranium mill tailings) if the four years allowed (including a one-year extension) for compliance with standards promulgated under the amended section 112 is insufficient to dry and cover the mining waste.

The result is that the EPA, NRC, and affected Agreement States have consulted and drafted a Memorandum of Understanding (MOU). The primary purpose of the MOU is to ensure that the nineteen non-operational uranium mill tailings piles licensed by the NRC or the affected Agreement States achieve compliance through an effective installation of an earthen cover that limits radon emissions to the 20 pCi/m^2-s flux standard as defined in 40 CFR 192.32(b)(1). A second objective of the MOU was to ensure that compliance proceeds as expeditiously as practicable considering technological feasibility. Target dates for the nineteen non-operational uranium mill tailings piles were established for meeting the radon emission standard; the target dates are based on a guiding objective that disposal occur by the end of 1997 or within seven years of when the existing operating and standby sites enter disposal status.

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CHAPTER 2

INDUSTRY PROFILE

The U.S. uranium milling industry is an integral part of a domestic uranium production industry that includes companies engaged in uranium exploration, mining, milling, and downstream activities leading to the production of fuel for nuclear power plants. The product of uranium milling is uranium concentrate, also referred to as uranium oxide, yellowcake, or U_3O_8.

2.1 DEMAND AND USES

Domestic producers of uranium concentrate have two markets: the U.S. nuclear power industry and exports. The nuclear power industry is by far the more important of the two. Military uses, once the only source of demand for uranium, have been supplied solely by government stockpiles since 1970 (DOE87a).

Demand for domestically produced uranium reached its highest level in 1979 when utilities delivered 30.9 million pounds of U_3O_8 to DOE for enrichment, but has fallen since then. By 1990 less than 15 million pounds of domestic U_3O_8 were sent to DOE for enrichment. Domestic production reached its highest level in 1980 and has steadily declined since then. Exports also have declined substantially. Exports of uranium by domestic suppliers in 1990 totaled 2.0 million pounds, slightly less than the 2.1 million pounds in 1989 and less than one-third of total exports in 1978, the year of highest exports (DOE91b).

A number of negative forces have combined to cause the current depressed state of the industry. The boom of the 1970's along with high expectations for the 1980's, encouraged large scale domestic and foreign exploration. The discovery of low cost foreign reserves, coupled with relaxed restrictions on imports effectively priced the domestic sources out of the market. Expectations are that a growing portion of utility requirements will be supplied by foreign-origin uranium during the second half of this decade. Further exacerbating the downturn in domestic production is the slow growth in overall demand for electrical power and the slower than anticipated expansion of nuclear energy as power source for generating electricity. Growth also has been hindered by delays in completing construction of new plants and by the cancellation of projected construction (DOE91a).

Also contributing to the depressed state in the domestic uranium industry are the large inventories of yellowcake, enriched uranium and fabricated fuel being held by both producers and utilities. These inventories accumulated because utilities, anticipating a growing need for uranium a decade or more ago, entered into long-term contracts to purchase large amounts of

domestically produced uranium. As actual needs fell short of expected needs due to nuclear power plant construction delays and cancellations, large inventories accumulated. These inventory supplies were once estimated to cover four to five years of utility requirements, and they adversely affected suppliers in two ways: Primarily, they served to extend the downturn in uranium demand for a number of years by decreasing the need for utilities to enter into new contracts. In addition, high interest rates increased inventory holding costs, leading some utilities to contribute to current excess supply by offering inventory stocks for sale on the spot market (EPA86). By 1990, utilities had reduced their inventories to three years of forward coverage (DOE91a).

Provided below is a brief description of the historical uses and demand for uranium in the United States.

2.1.1 Military Applications

In the early 1950's, the U.S. government's need for uranium for defense uses far exceeded the world's production capability. A Federally funded production incentives program was then instituted. The incentives program was so effective that the government phased it out in the 1960's and terminated its purchase program in 1970. The government still has sufficient stockpiles to meet military requirements well into the future.

2.1.2 Nuclear Power Plants

Since 1971, utilities, which use uranium as fuel for nuclear power plants, have been virtually the only source of demand for current uranium production. Commercial generation of nuclear powered electricity began in 1957 with the operation of the first central station reactor at Shippingport, Pennsylvania. By the end of 1990, 111 nuclear reactors were licensed to operate in the United States, with 99.6 gigawatts of net generating capacity (DOE91c).

Demand for uranium by utilities may be directly linked to the fuel requirements of currently operating or planned nuclear power plants. The status of U.S. nuclear power plants as of December 31, 1990 is shown in Table 2-1. Because of the long lead times associated with the ordering, construction and permitting of nuclear power plants, it is extremely unlikely that any additional orders for new nuclear plants will result in operable capacity before 1998 (DOE87c). Historical consumption data for utilities are not available. However, information on contract commitments between suppliers and utilities, which constitutes a share of total utility uranium consumption, is available. Commitments for deliveries from 1990 to 2000 are listed in Table 2-2. In 1990, utilities signed 49 uranium procurement contracts with domestic suppliers equal to 27 million pounds of uranium. Thirty-eight contracts were based on spot-market purchases and 11 were long-term contracts. Although

these contracts are with domestic suppliers, not all of the uranium delivered will be domestic in origin. Domestic suppliers import a significant share of uranium which they deliver to utilities. The origin of committed uranium for the years 1990 through 2000 are given in Table 2-3. In 1990, domestic suppliers delivered a total of 20.5 million pounds of uranium to utilities, 30 percent of these deliveries were foreign in origin. Utilities and suppliers accounted for roughly equal shares of 1990 imports. The quantity of deliveries from domestic suppliers is projected to decline markedly between now and 2000. By the end of 1990, market commitments for delivery in 1991 and beyond from domestic suppliers totaled 87.9 million pounds. Just more than 50 percent of that uranium has been specified as being of domestic origin (DOE91b). Over the same period, commitments from foreign suppliers for the same period totaled 137.3 million pounds. For years beyond 1990, the data show that utility commitments account for 84% of the total quantity under contract as of December 31, 1990.

Table 2-1. Status of U.S. Nuclear Power Plants as of December 31, 1990

Status	Number of Reactors	Net Summer Capability (GWe)
Operable*		
In Commercial Operation**	111	99.6
In Power Ascension	0	0
Total	111	99.6
In Construction		
In Low-Power Testing	0	0
Under Construction	3	3.4
Indefinitely Deferred***	5	6.1
Total	8	9.6
Total	119	109.2

Notes:

* Operable units or reactors are those that have been issued a full power license by the Nuclear Regulatory Commission. Retired units are not included. Shoreham received a possession-only license in June, 1991. Since the unit is not currently scheduled to operate, it is not included in the total for units in the construction pipeline or operable units.

** Three Mile Island 2, Hanford-N, Fort St. Vrain, and Rancho Seco are not included.

*** Includes Bellafonte 1 and 2, Perry 2, WNP1 and WNP3.

Source: (DOE91c)

Table 2-2. Commitments for Delivery of Uranium from Domestic Suppliers to U.S. Utilities: 1990 to 2000 and Later, (Million Pounds U_3O_8)

	As of December 31, 1989				As of December 31, 1990				Change in Total From December 31, 1990	
Delivery	Firm	Optional	Total	Cumulative	Firm	Optional	Total	Cumulative	Total	Cumulative
1990*	13.1	1.1	14.2	14.2	20.5	0.0	20.5	20.5	6.3	6.3
1991	11.2	3.1	14.3	28.5	18.9	1.0	19.9	40.4	5.6	11.9
1992	9.5	3.2	12.7	41.2	9.7	3.4	13.0	53.4	0.3	12.2
1993	8.3	4.5	12.8	54.0	10.3	3.5	13.8	67.2	1.0	13.2
1994	6.1	3.7	9.8	63.8	6.6	3.5	10.1	77.3	0.3	13.5
1995	6.3	4.3	10.6	74.4	6.5	4.4	10.9	88.2	0.3	13.8
1996	4.5	3.9	8.4	82.8	3.6	3.9	7.5	95.7	-0.9	12.9
1997	2.5	2.8	5.3	88.2	2.6	2.4	4.9	100.7	-0.4	12.5
1998	2.0	2.3	4.3	92.5	0.9	2.3	3.2	103.9	-1.1	11.4
1999	1.6	1.8	3.4	95.9	0.6	1.7	2.3	106.2	-1.1	10.3
2000 and Later	1.4	3.5	4.8	100.7	0.2	2.0	2.2	108.4	-2.6	7.7
TOTAL	66.5	34.1	100.7	--	80.3	28.1	108.4	--	--	--

Notes:

* Actual deliveries

-- Not applicable

Source: (DOE91b)

Table 2-3. Origin of Uranium Committed for Delivery to U.S. Utilities from Domestic Suppliers: 1990 to 2000 and Later, as of December 31, 1990 (Million Pounds U_3O_8)

	Origin of Committed Uranium			
Year of Delivery	Domestic	Unspecified	Foreign	Total
1990*	14.3	0.0	6.2	20.5
1991	6.7	12.4	0.8	19.9
1992	6.4	6.0	0.6	13.0
1993	6.4	6.8	0.6	13.8
1994	6.4	3.1	0.6	10.1
1995	6.3	4.0	0.6	10.9
1996	5.3	2.2	0.0	7.5
1997	3.5	1.4	0.0	4.9
1998	2.4	0.8	0.0	3.2
1999	1.7	0.6	0.0	2.3
2000 & Later	1.8	0.4	0.0	2.2
TOTAL	61.3	37.7	9.4	108.4

Notes:

* Actual deliveries

Source: (DOE91b)

2.1.3 Exports

Exports of uranium by producers have generally declined since 1979. In 1987, they were at their lowest level since 1975, but have grown slightly since 1987. For 1990, exports of uranium concentrate totaled 2 million pounds. As of December 31, 1990, contracts were in place for exports of an additional 17.5 million pounds for 1991-2000 (DOE91b). Exports of uranium by utilities and domestic suppliers for 1977-1990, as well as commitments for 1991 through 2000 are shown in Table 2-4. Since 1967, U.S. companies have exported a total of 69.4 million pounds of uranium concentrate equivalent.

Table 2-4. Exports of Uranium by Utilities and Domestic Suppliers 1967 to 2000 and Later, as of December 31, 1990 (Million Pounds U_3O_8)

Year of Delivery	Annual	Cumulative
Actual Deliveries:		
1967	1.4	1.4
1968	1.6	3.0
1969	1.0	4.0
1970	4.2	8.2
1971	0.4	8.6
1972	0.2	8.8
1973	1.2	10.0
1974	3.0	13.0
1975	1.0	14.0
1976	1.2	15.2
1977	4.0	19.2
1978	6.8	26.0
1979	6.2	32.2
1980	5.8	38.0
1981	4.4	42.4
1982	6.2	48.6
1983	3.3	51.9
1984	2.2	54.1
1985	5.3	59.4
1986	1.6	61.0
1987	1.0	62.0
1988	3.3	65.3
1989	2.1	67.4
1990	2.0	69.4
Subtotal	69.4	--
Commitments:		
1991	2.0	71.4
1992	2.5	73.9
1993	2.6	76.5
1994	2.6	79.1
1995	2.3	81.4
1996	2.0	83.4
1997	1.3	84.7
1998	1.1	85.8
1999	1.1	86.9
2000	0.0	86.9
Subtotal	17.5	--
TOTAL	86.9	--

Notes:
Figures for 1967-1981 represent exports by uranium producers only.
Source: (DOE91b)

2.2 SUPPLY

2.2.1 Sources of Supply

The uranium used to fuel nuclear reactors is supplied by domestic and foreign producers and inventories held by utilities. The role of each is described in the following sections.

Domestic Production

Table 2-5 shows trends in domestic production of uranium concentrate from 1953 to 1990, by state. Total production was relatively constant at 10,500 to 12,500 tons per year until 1977, when it began an increase that peaked in 1980 at 21,852 tons. Production has declined almost every year since, reaching only 5,657 tons in 1985 and falling to 4,443 tons in 1990 (DOE91b).

Coinciding with the overall decline in the domestic production industry is a decline in the share of production represented by conventional mills. Historically, conventional milling accounted for approximately 70 percent of U.S. production. However, by 1985, the conventional share of production had fallen to 54 percent. It rose to 66 percent in 1986, but then declined again (DOE87b). By 1990 conventional milling accounted for 52 percent of total production (DOE91b).

Although non-conventional methods of production are limited in the quantity of uranium concentrate they can produce, they produce it cheaply. DOE has estimated that by the middle of 1991, nearly two-thirds of domestic uranium was produced from two non-conventional methods, in-situ leaching and by-product recovery. This shift has occurred because these non-conventional methods can produce low quantities of uranium cheaply. The trend towards non-conventional methods is expected to continue in the near term, and is expected to account for nearly all production by 1993.

The decline in domestic production by conventional methods has resulted in severe over capacity and mill shutdowns. Milling capacity, which almost doubled between 1975 and 1980 when the price of uranium was high and optimistic demand forecasts stimulated investment in milling facilities, once enjoyed a utilization rate of 94 percent (EPA86). In December 1986, capacity utilization was about 32 percent at operating mills, and only 9 percent of the total industry potential. By December of 1990 conventional mills were operating at a mere 7 percent of total available industry capacity. The number of operating mills has also declined dramatically, from 20 in 1981 to a low of two in June 1985. NUEXCO indicates that six mills operated in 1987, but the number was only two by the end of December 1990 (DOE91b). In terms of nonconventional milling, at the end of 1990 there

TABLE 2-5. Production of Uranium Concentrate by Conventional Mills and Other Sources: 1953 through 1990 (Tons U_3O_8)

Year	New Mexico	Wyoming	Texas	Utah	Colorado	Others	Total
1953	--	--	--	214	940	9	1,163
1954	--	--	--	180	1,239	181	1,600
1955	847	--	--	454	1,483	--	2,784
1956	2,891	--	--	1,222	1,726	119	5,958
1957	2,534	--	--	3,291	1,966	691	8,482
1958	3,604	1,247	--	3,822	2,917	847	12,437
1959	6,772	1,675	--	3,535	3,278	979	16,239
1960	7,760	2,770	--	3,034	3,117	956	17,637
1961	7,750	2,823	--	2,954	2,951	870	17,348
1962	7,293	3,055	--	3,188	2,652	820	17,008
1963	5,512	2,566	--	3,080	2,134	925	14,217
1964	4,747	2,216	--	2,063	1,800	1,020	11,846
1965	4,591	2,097	--	1,510	1,290	954	10,442
1966	5,076	2,248	--	*	1,423	1,842	10,589
1967	5,933	2,667	--	*	1,340	1,313	11,253
1968	6,192	2,873	--	*	1,614	1,689	12,368
1969	5,993	3,063	--	*	1,678	925	11,659
1970	5,771	3,654	--	*	*	3,480	12,905
1971	5,305	3,487	--	*	*	3,481	12,273
1972	5,464	4,216	--	*	*	3,220	12,900
1973	4,634	5,159	--	*	*	3,442	13,235
1974	4,951	3,767	--	*	*	2,810	11,528
1975	5,191	3,447	*	*	*	2,962	11,600
1976	6,059	4,046	*	*	*	2,642	12,747
1977	6,779	4,990	*	*	*	3,170	14,939
1978	8,539	5,329	*	*	*	4,618	18,486
1979	7,423	5,452	2,651	*	*	3,210	18,736
1980	7,751	6,036	3,408	*	*	4,657	21,852
1981	6,206	4,355	3,141	*	*	5,535	19,237
1982	3,906	2,521	2,131	*	*	4,876	13,434
1983	2,550	2,630	1,650	*	*	3,750	10,580
1984	1,458	1,560	1,310	*	*	3,113	7,441
1985	692	1,214	1,084	*	*	2,667	5,657
1986	926	317	1,293	*	*	4,768	7,304
1987	1,166	284	1,358	*	*	4,504	7,312
1988	1,130	1,004	1,403	*	*	4,159	7,696
1989	1,152	804	1,470	*	--	3,343	6,769
1990	306	684	916	*	--	2,537	4,443

Notes:
-- No production
* Individual state production aggregated with "others".

Source: Personal Communication, Mining and Mineral Division, New Mexico Energy, Mineral and Natural Resources Department.

U.S. and comparative New Mexico data from U.S. Department of Energy, 1979-1982;
New Mexico data from Mining and Minerals Division, New Mexico Energy, Minerals and Natural Resource Department for 1983-1990;
Non-New Mexico data from Energy Information Administration for 1983-1990;
Texas recovery for 1986-1987 included unspecified quantity of U_3O_8 milled from New Mexico ore.

were 3 phosphate and 2 in-situ mills in operation. They produced 4.2 million pounds of uranium concentrate, 1.4 million pounds less than in 1989. Uranium mill capacities and utilization levels are listed in Table 2-6.

TABLE 2-6. Uranium Mill Capacity
(Tons of Ore per Day)

Year	Total Capacity	Operating Capacity	Operating Capacity Utilization Rate	Total Capacity Utilization Rate
1981	54,050	49,800	83%	77%
1982	55,050	33,650	74%	45%
1983	51,650	29,250	58%	33%
1984	48,450	19,250	64%	25%
1985	47,250	6,550	78%	11%
1986	42,650	11,650	32%	9%
1987	34,650	13,250	31%	12%
1988	30,600	7,900	44%	11%
1989	30,600	7,900	45%	12%
1990	30,600	4,300	48%	7%

Source: (DOE91a)

Imports

A second source of uranium is the import market. Until 1975, foreign uranium was effectively banned from U.S. markets by a Federal law prohibiting the enrichment of imports for domestic use. This restriction was lifted gradually after 1975, and was eliminated completely in 1984. From 1975 through 1977, imports amounted to a small portion of total domestic requirements, and U.S. exports actually exceeded imports in each year from 1978 through 1980. By 1986, however, imports supplied 44 percent of U.S. requirements. Total imports in 1990 have grown 54 percent since 1986 to a total of 23.7 million pounds of uranium concentrate, surpassing domestic supply. This is a marked increase from the 13.1 million in imports reported in 1989. Table 2-7 lists U.S. imports from 1975 through 1990, as well as import commitments through the year 2000 (DOE87a, DOE91b).

TABLE 2-7. Imports of Uranium for Commercial Uses, 1975 - 1990
(Million Pounds, U_3O_8)

Year of Delivery	Annual	Cumulative
Actual Deliveries:		
1975	1.4	1.4
1976	3.6	5.0
1977	5.6	10.6
1978	5.2	15.8
1979	3.0	18.8
1980	3.6	22.4
1981	6.6	29.0
1982	17.1	46.1
1983	8.2	54.3
1984	12.5	66.8
1985	11.7	78.5
1986	13.5	92.0
1987	15.1	107.1
1988	15.8	122.9
1989	13.1	136.0
1990	23.7	159.7
Subtotal	159.7	--
Commitments:		
1991	20.2	179.9
1992	16.2	196.1
1993	18.7	214.8
1994	15.6	230.4
1995	15.6	246.0
1996	14.1	260.1
1997	13.2	273.3
1998	7.5	280.8
1999	8.3	289.1
2000	14.7	303.8
Subtotal	144.1	--
TOTAL	303.8	--

Source: (DOE91b)

Utilities and suppliers purchased roughly equal shares of 1990 imports. For delivery commitments beyond 1990, utilities account for 84% of the total quantity of imports under contract as of December 31, 1990 (DOE91b).

The primary sources of U.S. uranium imports have been Canada, South Africa and Australia. In 1990, 43 percent of U.S. uranium imports were from Canada, 32 percent were from Australia, and 25 percent were from various other countries. The United States has not imported uranium from South Africa since the 1986 ban which was called for in the Comprehensive Anti-Apartheid Act. However, on July 11, 1991 the U.S. eliminated restrictions against South Africa, and uranium imports have been permitted to resume.

Forecasts of import penetration call for the import share to grow through the 1990's. The Department of Energy projects that without government intervention, imports will rise from 52 percent in 1991 to 83 percent by the year 2003. Many factors will affect the amount of uranium imported in the near future, including: the extent to which the U.S. resumes trade with Namibia and South Africa, whether Germany sells its unwanted inventories, whether Australia lifts regulations restricting certain drilling and whether the former Soviet Republics are able to produce and sell uranium on a large scale (DOE91a).

Inventories

Utilities hold uranium inventories in order to meet changes in the scheduling of various stages of the fuel cycle, such as minor delays in deliveries of uranium feed. Uranium inventories also protect the utilities against disruption of nuclear fuel supplies.

Table 2-8 lists inventories of commercially owned natural and enriched uranium held in the United States as of December 31, 1988, 1989, and 1990. DOE-owned inventories are not included in this table. The uranium inventory owned by utilities alone at the end of 1984 represented almost four years of forward coverage. Forward coverage dropped to 3 years by the end of 1990. In 1990 total commercial inventories decreased by 5.9 million pounds from 138.1 million pounds in December of 1989 to 132.2 million pounds in December of 1990. Utility inventories decreased from 115.8 million pounds in 1989 to 102 million pounds in 1990 - a reduction of 13.8 million pounds. Government held inventories of uranium concentrate decreased from 77.5 million pounds in 1989 to 59.8 million pounds in 1990. Finally, in 1990, the amount of enriched uranium held in inventory by the Government increased from 24.7 million pounds to 32.8 million pounds (DOE91b).

TABLE 2-8. U.S. Commercially-Owned Uranium Inventories as of December 31, 1988, 1989 and 1990 (Million Pounds, U_3O_8 Equivalent)

	1988		1989		1990	
Owner Category	Natural	Enriched	Natural	Enriched	Natural	Enriche
Utilities	80.2	45.3*	R67.3	R48.5*	61.4	40.6*
Suppliers	18.2	1.1	R21.2	1.0	25.8	4.4
TOTAL	98.4	46.4	R88.6	R49.5	87.2	45.0

Notes:
* Includes fabricated fuels (23.7 million pounds U_3O_8 in 1988, 22.8 million pounds in 1989 and 19.5 million pounds in 1990).

R = Revised from data published DOE90a

Source: (DOE91a)

2.3 INDUSTRY STRUCTURE AND PERFORMANCE

The number of firms participating in the domestic uranium milling industry declined between 1977 and 1983, and again after 1987. In 1977, 26 companies owned active uranium mills. By June 1985, there were only two (DOE87b). In 1987, six companies operated six mills (industry sources). However, by 1990 only two mills were operational and by the middle of 1992 the remaining two mills plan to shut down and begin reclamation (industry sources). The contraction of the industry can also be seen in trends in employment and capital expenditures (Table 2-9). Capital expenditures in 1986 were only $1 million, compared to $72 million in 1981 (1986 dollars) (DOE87a, DOE87b). By 1990 capitol expenditures for conventional milling were so small that the DOE no longer published the figure independently of other processing methods. Employment in 1984 was 513 person-years, compared to 2,367 person-years in 1981. In 1990, employment had dropped to 304 person years (DOE87a, DOE91a, DOE91b). The overall level of employment in the raw materials industry reported in 1990, 1,335 person-years, was approximately 6% of the level of 21,251 person-years reported in the peak year 1979 (DOE91b).

A wide variety of companies have been represented within the uranium industry. In the industry's early years, holdings were dominated by independent mining and exploration companies. Since then, mergers, acquisitions, and the entry of conglomerates have considerably altered industry structure. During the 1970's, the oil embargo and optimistic forecasts of future nuclear power capacity made entry into the uranium market attractive to oil

companies and utilities. However, by 1990 depressed market conditions prompted multinational domestic oil companies to leave the uranium industry.

TABLE 2-9. Capital Expenditures, Employment, and Active Mills: Conventional Uranium Milling Industry

Year	Capital Expenditures* (Million Constant 1990 $)	Employment (Person-Years)	Number of Active Mills At Year-End
1987	0.3	432	6
1988	7.3	572	6
1989	4.6	367	3
1990	0.6	304	2
1991**	0.5	--	--
1992***	NA	NA	0

Notes:

* Capital Expenditures figures include processing activities/unconventional mines. Expenditures for conventional mines fall every year. They constitute a negligible percentage of the figures given above.

** Capital Expenditures for 1991 are projected. Other data for the same year are not available.

*** The two remaining active mills are expected to decommission be the end of 1992.

Source: (DOE91a, DOE91b)

Currently, uranium milling and mining has experienced an increased level of industry concentration. Nine firms account for almost all domestic uranium output, both conventional and non-conventional. Four firms account for almost 80 percent of all domestic production. The DOE projects that the industry will become even more concentrated in the near term. The sale and production of uranium is only a small segment of the firms' principal activities for nearly all of the firms remaining in the industry. Among the four largest uranium firms in 1990; two were foreign-based energy firms, one was controlled by a foreign-based uranium firm, and one was a wholly owned subsidiary of a domestic utility (DOE91a).

These ownership characteristics influence the financial viability of the industry. The desire of the parent companies to weather a downturn in the uranium market and to retain an interest in producing properties is a function of how necessary their involvement is to their main business activity. Most firms are continuing to withdraw from an extremely soft market. Foreign

owned firms appear to have adopted a longer term viewpoint than have some of their domestic counterparts. It is certain that the industry will continue to undergo structural change. This change will depend on the regulatory environment, domestic and foreign demand, costs of production, and the industry's ability to compete with lower-priced imports (DOE87a, DOE91a).

2.4 ECONOMIC AND FINANCIAL CHARACTERISTICS

In March 1992, the departments of mining or natural resources in the states with uranium mills were contacted to provide their assessments of the status of the uranium industry. This assessment disclosed that due to protracted low prices no licensed mill will be active beyond the spring of this year. Only two mills are currently operational, and both plan to shut down, one will begin decommissioning.

In New Mexico, the two milling facilities together employ 61 people, although neither facility is operational. The laborers at those mills are engaged in reclamation work and the leaching of small quantities of uranium. The State estimates that a total of 87 workers are employed in both the milling and mining industry, down from 318 the year before. Grants, New Mexico, the location of the two remaining licensed facilities in the state, has been in steady economic decline. The Rio Algom Mill in Grants, which once employed between 1,300 and 1,600 people, now employs only 37. Most of their former employees have left the state, some work for a new prison facility and a few others now are employed by a local coal mine (NM92).

Wyoming still has one mill in operation, the Pathfinder Mill in Shirley Basin. The Pathfinder Mill is operating significantly below capacity, and plans to close in spring 1992. However, it will remain on standby status. State figures on employment in the industry remain unchanged since 1984, at 454 people. Employment is expected to drop after the mill closes (WY92).

The uranium industry in the state of Washington has been inactive since 1985, and no indication has been shown that this will change. No new industries have entered the regions where mining took place. The workers who were not part of the Indian community have left the area (WA92).

Texas, like Wyoming, has one mill which is still operating. This mill is scheduled to shut down and will begin decommissioning in April of 1992. The mill, recently bought from Chevron by General Atoms, currently employs 60 people. Most of the workers are currently engaged in dismantling the mill. The area around the mill is economically depressed, however most of the labor hopes to find work in the larger economy of San Antonio. All other mills in Texas have been permanently closed, although the

former Conquista Project, once owned by Conoco, now by DuPont, still employs several people (TX92).

Colorado and Utah experienced some activity in the late 1980's, but more recently have had no milling production. Both states have a skeletal labor force in the uranium industry. The Cotter Mill in Canon City, Colorado is in danger of decommissioning, causing a permanent loss of between 100 and 150 jobs. These jobs translate into a $5 to $7.5 million per year pay-roll loss to the local economy. The situation in Utah is similar. The Umetco Minerals Mill in Blanding has been opened recently, and is currently on stand-by status (CO92, UT92).

2.5 INDUSTRY FORECAST AND OUTLOOK

This section presents projections of total U.S. utility market requirements, domestic uranium production and net imports. Developed for a fifteen year period (1991-2005), these projections are considered "near term." A basic assumption of the near term projections is that current conditions, as defined by the Department of Energy's Energy Information Administration (DOE, EIA), will continue unchanged through the end of this century. This section is based on the reference case projections in EIA's *Domestic Uranium Mining and Milling Industry: 1990 Viability Assessment* (DOE91a).

2.5.1 Projections of Domestic Production

The EIA's Reference case[1] forecasts for 1991-2005 in five year intervals are based on the output of two EIA economic models; the Uranium Market Model (UMM) which projects demand, and the Uranium Supply Analysis System which projects supply. The methodology of these models is beyond the scope of this study; it is fully described in Appendix D of the *1990 Viability Assessment*. The EIA examines future developments in the domestic uranium industry and in the domestic and international uranium markets under current market conditions and under certain hypothetical supply disruption scenarios.[2] The current market conditions are generally the same as those presented in Sections 2.1 -

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[1] The EIA publishes three projection cases, an upper, lower and no new order case. However, in the near term no significant difference exists among any of these cases.

[2] These scenarios, the "current disruption status" scenario and the "projected disruption status" scenario, are used to test the viability of the U.S. uranium industry, to examine the ability of this industry to respond to an abrogation of various fractions of contracts for uranium imports intended for domestic end use. Both of these bear only tangentially to this study and will not be discussed further here.

2.4 of this study and are based on historical trends in the domestic uranium industry as outlined by the *Viability Assessment* and the EIA's *Uranium Industry Annual 1990*. In addition to the uranium prices, production and imports, exploration expenditures, capital expenditures, and employment data developed for inclusion as "current market conditions," the EIA identifies several international political uncertainties which could affect the uranium industry. Also taken into account by DOE are assumptions on future electricity generation, fuel burnup levels, enrichment in tails assay, and inventory drawdowns.

2.5.2 Near-Term Projections

The reference case projections for uranium concentrate requirements, domestic production and net imports through the year 2005 is shown in tabular form in Table 2-10, along with comparisons to previous DOE and independent projections. Aggregate domestic production from 1991 though the year 2000 is projected to be 82.8 million pounds, about the same as total domestic production in the years 1980 and 1981. Production is expected to remain low through 2005 (DOE91a).

Using the same models, the Department of Energy has forecast industry-wide employment through the year 2005. The DOE projects that employment will remain steady at approximately 1,200 person-years per year in mining, milling, and processing past the turn of the century. However, the DOE does not predict how that labor will be dispersed throughout the industry (DOE91a). Both historical and projected employment are presented in tabular form in Table 2-11.

In the immediate future, very little of the domestic production of uranium can be expected to come from conventional milling methods. As of the winter of 1992 many mills have filed for decommissioning status. The remaining mills will remain on standby status for a short period to evaluate changing market conditions. If conditions remain unchanged, the last facilities will likely shut down as well.

Whereas low prices have forced conventional domestic milling out of the market, they have less of an affect on processing methods such as by-product recovery and in-situ leaching. Thesenon-conventional methods of production have a lower marginal cost of production than do conventional producers, and therefore are less affected by the fluctuations in uranium market prices. However, the non-conventional methods have a relatively low capacity and will not be able to respond to large increases in demand (DOE92).

TABLE 2-10. Comparison of Uranium Projections: U.S. Uranium Requirements, Domestic Production, and Net Imports (Million Pounds U_3O_8)

Source	Projection Period 1991-1995	1996-2000	2001-2005	Total, 1991-2000	Total, 1991-20
	Uranium Requirements				
1990 Viability Assessment	209.2	213.1	203.3	422.3	625.6
1989 Viability Assessment	195.1	198.2	193.8	393.5	587.3
1988 Viability Assessment	189.6	181.8	176.0	371.4	547.4
1987 Viability Assessment	168.8	173.2	--	342.0	--
Nuexco, Reference Case	218.3	208.5	205.0	426.8	631.8
Energy Resources International, Inc., Low Case	196.1	188.4	182.6	384.5	569.1
	Domestic Production				
1990 Viability Assessment	44.3	38.5	31.6	82.8	114.4
1989 Viability Assessment	45.8	46.4	68.5	92.2	160.7
1988 Viability Assessment	47.1	49.9	74.7	97.0	171.7
1987 Viability Assessment	41.3	69.3	--	110.6	--
Nuexco, Reference Case	35.8	65.3	72.3	88.4	127.0
	Net Imports				
1990 Viability Assessment	129.7	156.7	161.4	286.4	447.8
1989 Viability Assessment	117.8	128.6	110.5	246.4	356.9
1988 Viability Assessment	113.2	112.8	92.6	226.0	318.6
1987 Viability Assessment	106.1	92.1	--	198.2	--

Source: (DOE91a)

The Reference case EIA projections of domestic U_3O_8 production through the year 2000 are based on a unit by unit review of nuclear power plants that are new, operating, under construction, or units for which orders have been placed and for which licenses are currently being processed. Under EIA's Reference case, nuclear generating capacity is expected to increase from 99.6 GWe in 1991 to 106.5 GWe in 2005 (Table 2-12).

2.6 EVALUATION OF FORECASTS AND URANIUM MARKET DEMAND

This section compares our scenario, as developed from DOE forecasts, for total domestic production of U_3O_8 to total domestic uranium resources.

TABLE 2-11. Employment in the U.S. Uranium Industry Under Current Market Conditions: 1975 TO 2005 (Person-Years)

Year	Exploration	Mining, Milling and Processing**	Total
Historical:			
1975	2,049	7,623	9,672
1976	2,793	10,330	13,123
1977	4,140	13,901	18,041
1978	4,449	16,391	20,840
1979	4,066	17,455 R	21,521 R
1980	3,370	16,549	19,919
1981	2,300	11,376	13,676
1982	769	8,338 *	9,107
1983	374	5,241	5,615
1984	235	3,362	3,597
1985	163	2,283	2,446
1986	162	1,957	2,119
1987	183	1,819	2,002
1988	144	1,997	2,141
1989	86	1,497	1,583
1990	73	1,262	1,335
Projected:			
1991	60	1,200	1,260
1992	60	1,300	1,360
1993	60	1,300	1,360
1994	60	1,300	1,360
1995	60	1,300	1,360
1996	60	1,200	1,260
1997	60	1,200	1,260
1998	60	1,200	1,260
1999	70	1,100	1,170
2000	70	1,000	1,070
2001	70	800	870
2002	70	800	870
2003	60	800	860
2004	60	1,000	1,060
2005	60	1,100	1,160

Notes:
* Includes 140 contract truckers
** Includes employment in byproduct and in-situ processing.

R Revised from data published in the 1989 viability assessment report (DOE89a).

Source: (DOE91a)

2.6.1 Domestic Uranium Resources

The most recent projections of domestic U_3O_8 production shown in Table 2-10 indicate that slightly over 114 million pounds of U_3O_8 will be produced domestically between the years 1991 and 2005. By-product recovery and in-situ leaching are expected to account for much of this production. Historically, these methods have processed between 3.7 and 6.5 million pounds of uranium per year. Moreover, non-conventional production at this level is not greatly impacted by market forces. The marginal cost of processing small quantities of uranium from by-product recovery of minerals such as copper and phosphate is negligible. In-situ leaching also can produce small quantities of uranium at low costs. However, the capacity for production from these two methods at costs below current market prices is limited.

If these methods produce at their historical maximum capacity and process 6.5 million pounds of uranium each year between the years 1991 and 2005, 97.5 million pounds of U_3O_8 will be generated by non-conventional methods. On the other hand, if the non-conventional methods operate at a minimal capacity and process only 3.7 million pounds, then over the fifteen years only 55.5 million pounds will be generated. Therefore, non-conventional methods can be expected to produce somewhere between 55.5 million pounds and 97.5 million pounds accounting for between 48 and 85 percent of total projected domestic production. Since domestic production is expected to decline over the projected years, while domestic non-conventional production could remain steady, non-conventional production could easily account for all of the 31.6 million pounds projected between the year 2000 and 2005. Thus, conventional milling should account for the remaining 16.9 million pounds to 58.9 million pounds of the 114.4 million forecast for this period. Most of this production should be expected in the earlier projection years.

2.6.2 Conventional Milling Domestic Resources

DOE also estimates the total "endowment" of domestic U_3O_8 resources. The "endowment" is defined as all U_3O_8 in deposits containing at least 0.01 percent (100 ppm) of U_3O_8. Resources are grouped according to resource categories, as defined below. The three resource categories used by DOE are also those used by the International Atomic Energy Commission and the OECD Nuclear Power Agency:

- Reasonably Assured Resources (RAR) refers to uranium in known mineral deposits which could be recovered within given cost ranges, and using currently proven technology. This corresponds to DOE's Reserves Category;

TABLE 2-12. Projected U.S. Nuclear Power Capacity and Uranium Requirements
(Million Pounds, U_3O_8)

Year	Net Design Capacity* (GWe)	Uranium Requirements** (Million Pounds, U_3O_8)	Optimal Variable Tails Assays***	Utility Contract Commitments (Million Pounds, U_3O_8)	Utility Unfilled Requirements and Inventory Drawdowns**** (Million Pounds, U_3O_8)
1991	99.6	41.8	0.30	33.5	8.2
1992	100.8	41.8	0.30	26.5	15.3
1993	101.9	40.8	0.30	28.8	12.1
1994	101.9	42.4	0.30	23.8	18.6
1995	103.1	42.4	0.30	24.6	17.9
1996	103.1	43.5	0.30	19.9	23.6
1997	103.1	43.5	0.30	16.2	27.3
1998	104.3	42.4	0.30	9.3	33.1
1999	104.3	42.4	0.30	9.2	33.2
2000	105.4	41.3	0.30	6.2	35.1
2001	105.4	41.3	0.29	3.6	37.7
2002	105.4	42.7	0.28	NA	NA
2003	106.6	39.9	0.27	NA	NA
2004	106.6	39.9	0.26	NA	NA
2005	106.5	39.5	0.25	NA	NA

Notes:

* Capacity in operation at the end of the year

** These projections have been smoothed to reduce the magnitude of yearly variations due to reactor fueling schedules; smoothing, however, does not affect the overall trend of the projections.

*** Percent U-235 transaction enrichment tails assay.

**** Uranium requirements minus contact commitments equals unfilled requirements and inventory drawdowns.

Source: (DOE91a)

- Estimated Additional Resources (EAR) refers to uranium in addition to RAR that is expected to occur, mostly on the basis of direct geological evidence in extension of well explored deposits, little explored deposits, and undiscovered deposits believed to exist along well defined geological trends with known deposits, such that the uranium can be recovered within the given cost estimates. This corresponds to DOE's Provable Potential Category;

- Speculative Resources (SR) refers to uranium in addition to EAR and RAR which is thought to exist, mostly on the basis of indirect evidence and geological extrapolations. This corresponds to DOE's Possible Potential Resource Category.

The "forward cost of recovery" of uranium resources represents estimates of most future costs of mining, processing, and marketing U_3O_8, exclusive of return to capital. These estimates include the costs of transportation, environment and waste management, construction of new operating units and maintenance of all operating units, and future exploration and development costs. Also, appropriate indirect costs such as those for office overhead, taxes and royalties are included. Table 2-15 presents estimates of all reasonably assured U_3O_8 resources having a "forward cost of recovery" of no more than $50/lb (DOE91a). In addition to the reasonably assured resources, the DOE expects 2,200 million pounds of estimated available resources as well as 1,300 million pounds of speculative resources, both at a forward cost of recovery of less than $30 per pound. At a forward cost of recovery of up to $50 per pound, expectations rise to 3,400 million pounds and 2,200 million pounds, respectively.

Using only Reasonably Assured Resources, Table 2-13 suggests that the United States currently has about 265 million pounds of U_3O_8 with a forward cost of recovery of no more than $30 per pound (DOE91a). Assuming an average U_3O_8 recovery rate of about 90 percent, domestic mills have enough resources in this category to cover all of the projected domestic production through 2005 even without the expected contribution of non-conventional methods.

The determination of conventional milling output over the fifteen year period is not only dependent on the accuracy of the DOE forecasts, but also on the assumption that no technology is introduced to expand the capabilities of non-conventional processing. Although the introduction of such technology is not anticipated under current market conditions, some possibilities remain open. These possibilities include: increased by-product recovery in the processing of bauxite and beryllium ores, and by extraction of uranium from copper waste dumps (DOE80). Studies are also being conducted to remove uranium from seawater. Scien-

tists are capable of accessing the large quantities of uranium found in seawater but the economical viability of such technology is questionable (Ca79, Ro79).

TABLE 2-13. U.S. Reasonably Assured Resources (RAR) by State by Mining Method, as of December 31, 1990 (Million Pounds U_3O_8)

Origin	Forward-Cost Category (Nominal $) $30 Per Pound U_3O_8	 $50 Per Pound U_3O_8
State		
New Mexico	85	351
Wyoming	71	330
Texas	23	47
Arizona, Colorado, & Utah	43	125
Other*	43	73
Total**	265	926
Mining Method		
Underground	141	468
Open Pit	39	277
In Situ	84	163
Other***	1	18
Total**	265	926

Notes:

* Includes California, Idaho, Nebraska, Nevada, North Dakota, Oregon, South Dakota and Washington

** Uranium resources that could be recovered as a byproduct of phosphate and copper mining are not included, but may amount to 37 million pounds U_3O_8.

*** Includes heap leaching, mine water and low grade stockpile.

Reasonably Assured Resources (RAR) in forward-cost categories are cumulative; i.e. the quantity listed at $50/lb U_3O_8 includes all RAR at $30/lb.

Source: (DOE91a)

CHAPTER 3

BACKGROUND INFORMATION FOR LICENSED NON-OPERATING URANIUM MILL TAILINGS IMPOUNDMENTS

3.1 OVERVIEW

Uranium mills process ore for the purpose of recovering and concentrating uranium to an intermediate, semi-refined product called yellowcake. There are two basic conventional processes for extracting uranium from the ore: the acid-leach process and the alkaline-leach process. The leaching process removes the uranium from the crushed ore, with sulfuric acid as the leaching agent in the acid-leach process; a mixed sodium carbonate sodium bicarbonate solution is the leaching agent in the alkaline-leach process (NRC80).

Both milling processes involve a series of operations, including ore handling and preparation (crushing and grinding), extraction, concentration and precipitation, product preparation, and tailings disposal (EPA86). Although each of these milling activities has the potential to release radon, essentially all the radon-222 emissions associated with the uranium mill process come from the tailings disposal area. Previous evaluations have shown that radon releases from other milling operations are insignificant (NRC80; EPA83b; EPA85). Therefore, the reduction of radon-222 emissions at licensed uranium mill sites is accomplished most effectively by reducing the emission from the tailings disposal area.

The tailings represent the bulk of the wastes originating from the uranium mill and contain (1) all the contaminants present in the original ore, (2) about 10 percent of the uranium not recovered in the milling process, and (3) a variety of chemicals and additives, inclusive of water, used in the extraction processes. Both the acid-leach and alkaline-leach extraction processes create waste with concentrated levels of thorium and radium. In the acid-leach process, approximately 95 percent of the thorium in the original ore remains in the solid tailings waste. Less than one percent of the radium is dissolved in the liquids. Even greater amounts of thorium and radium remain in the solid waste from the alkaline-leach process (EPA83b). These concentrated levels of thorium and radium in the tailings waste are the source of radon-222 emissions.

This Section provides a historical overview of the licensed non-operating uranium mills identified in the Memorandum of Understanding (MOU) between the EPA and the NRC and the current status of the associated tailings impoundments. Impoundment characteristics and surface area status are summarized in Table 3-1. It should be noted that seven of the twenty tailings impoundments listed in Table 3-1 contain evaporation ponds within the tailings

disposal area. Evaporation ponds are used for dewatering of the piles and for long-term maintenance of ground water. Since the use of the evaporation ponds is an integral part of the remediation process, it is not the EPA's intent to require the final radon cover to include these ponds, even when located on the tailings pile, by the target dates specified in the MOU. Therefore, the acreage associated with the evaporation ponds has not been included in the total surface areas of the tailings impoundments.

Data were compiled using NRC dockets and EPA documents written in support of previous rulemakings associated with the UMTRCA and the CAA. An updated status of the tailings surface configuration, obtained from mill facility licensees, was provided by the NRC's Uranium Recovery Field Office and cognizant individuals from affected Agreement States.

Table 3-1. 1992 STATUS OF NON-OPERATIONAL TAILING IMPOUNDMENTS IDENTIFIED IN THE MEMORANDUM OF UNDERSTANDING

FACILITY	TAILINGS SURFACE AREA (Acres)					MOU Target Date
	Total	Ponded	Wet	Dry	Interim Cover	
ANC, Gas Hill, WY	110	0	0	0	110	1995
ARCO Coal, Bluewater, NM	300	0	0	150	150	1995
Atlas, Moab, UT	128	0	10	118	0	1996
Conoco, Conquista, TX	250	0	100	0	150	1996
Ford-Dawn Mining, Ford, WA	123	0	28	0	95	2010
Hecla Mining, Durita, CO	35	0	0	0	35	1997
Homestake, NM (large impoundment)	170	0	18	152	0	1996
Homestake, NM (small impoundment)	13	0	0	7	6	1997
Pathfinder-Lucky Mc, GH, WY	203	9	6	0	188	1998
Petrotomics, Shirley Basin, WY	114	0	0	0	114	1995
Quivera, Ambrosia Lake, NM	368	0	0	36	332	1997
Rio Algom, Lisbon, UT	100	0	0	0	100	1996
Sohio-L-Bar, NM	80	0	0	0	80	1992
UMETCO, Gas Hills, WY	192	0	0	0	192	1995
UMETCO, Maybell, CO	50	0	0	15	35	1997
UMETCO, Uravan, CO	70	0	0	0	70	1997
UNC, Church Rock, NM	103	0	0	0	103	1997
Union Pacific, Bear Creek, WY	178	0	0	0	178	1996
WNI, Sherwood, WA	94	0	44	50	0	1996
WNI, Split Rock, WY	223	0	0	0	223	1995

3.2 FACILITY-SPECIFIC CHARACTERISTICS

3.2.1 ANC, Gas Hills (also known as FAP)

In 1959, Federal-American Partners (FAP) began operation of a uranium mill located in the Gas Hills Mining District of Wyoming. FAP was originally a partnership consisting of two corporations, Federal Resources Corporation and American Nuclear Corporation (ANC). Tennessee Valley Authority (TVA) was the leaseholder.

The ANC Gas Hills mill was licensed to process 860 metric tons per day. The mill used acid leach-solvent extraction process to recover uranium oxide from the ore. Waste tailings were deposited in a dam impoundment (Tailings Pond No. 2) as a slurry and the liquid was decanted into Tailings Pond No.1, which served as a solar evaporation pond. The total tailings area encompasses approximately 110 acres.

During the operation period of 1959 through 1981, approximately 5.4 million metric tons of tailings waste was generated. In February 1981, TVA instructed FAP to suspend their mining operation. Milling of stockpiled ores continued until October 1981, when the mill was shutdown.

Currently, reclamation activities at the site include decommissioning of the mill and reshaping and regrading of both tailings impoundments. A six-inch interim soil cover has been placed over the 110-acre tailings area. The MOU target date for completion of a final earthen cover over the tailings impoundments to reduce radon levels to the UMTRCA standard is 1995.

3.2.2 ARCO Coal, Bluewater Mill

The Bluewater Uranium Mill is owned by the Anaconda Minerals Company, a unit of ARCO Coal Company, a Division of Atlantic Richfield Company. The mill is located about ten miles northwest of Grants, New Mexico. The mill operated between 1953 and February 1982.

Originally, Bluewater Mill was designed to process 300 tons of ore per day using a carbonate leaching operation to extract uranium. In 1959, the mill was upgraded to handle 6000 to 7000 tons of sandstone ore, and the carbonate process was replaced by an acid leach method.

The mill site has three tailings impoundments. Tailings from the carbonate leach process were initially stored in an above-ground area covering about 47 acres (Impoundment No. 2) north of the mill. After the process changed to acid leach, slurring of the materials began, and the tailings were deposited in the main tailings impoundment (No. 1), which is a natural basin enhanced and enlarged through earthen dikes and embankment to encompass roughly

230 acres. A third tailings impoundment, the north area acid pile, is situated immediately northwest of the main pile and covers 23 acres.

From 1982 until 1985, ARCO dewatered the main tailings impoundment and removed the dissolved uranium from the liquid by solvent extraction. The waste from this recycling process, or barren raffinate, was pumped to the tailings pile until the end of 1983. Thereafter, the barren raffinate was pumped directly to the evaporation ponds. Approximately 25 million tons of tailings materials, generated during operating and recycling activities, have been deposited in the main tailings impoundment.

Reclamation activities are currently underway at the site. These activities include removal of tailings material in four evaporation ponds to the tailings slime area, regrading of tailings embankments, and pickup of windblown tailings and placement into impoundment. Approximately 150 acres of the 300-acre tailings area has been covered with an average of 2.5 feet of native soil. According to the Memorandum of Understanding, it is projected that the radon cover will be in place by 1995.

3.2.3 Atlas, Moab Mill

The Moab uranium recovery facility, located in Moab, Utah, is owned by Atlas Minerals Corporation. Milling operations began in October 1956. The ore processing circuits underwent several design changes over the years. The mill's initial design consisted of two alkaline leach circuits. A copper circuit was added in 1965 and operated until December 1970. In 1965, one of the alkaline leach circuits was converted to an acid leach and a uranium and vanadium solvent extraction unit was installed. A fire in 1968 temporarily suspended operations. The alkaline leach circuit was restarted in 1969 and ran until January 1982. The acid leach and solvent extraction circuits operated until the mill was put on a standby status in March 1984.

Waste tailings were disposed in a single tailings impoundment consisting of five embankments formed by sand tailings dikes. Approximately 10.6 million tons of waste were deposited as a slurry in the tailings impoundment. The tailings disposal area covers approximately 128 acres.

Presently, site reclamation activities are proceeding. The tailings pile is currently being dewatered, with 118 acres dry and the remaining 10 acres wet. The MOU target date for completion of an earthen cover, which meets the UMTRCA emission standards, is 1996.

3.2.4 Conoco, Conquista Mill

The Conquista Mill is located in Falls City, Texas, an Agreement State. The owner, Conoco, Inc., operated the mill between 1972 through the early 1980's. The mill was licensed to process a maximum of 3100 metric tons of ore per day.

Approximately 8 million metric tons of tailings waste was produced during the mill's operating life. The tailings were deposited in an above-grade tailings impoundment constructed of natural clay. This single impoundment encompasses approximately 250 acres.

Currently, reclamation of the Conquista site is underway. Mill decommissioning has been completed. A permanent radon cover, which meets the UMTRCA emission standard of 20 pCi/m^2-s, has been placed over approximately 150 acres of the tailings impoundment. The remaining tailings area (100 acres) is wet. In accordance with the MOU, the entire tailings disposal area will have a final radon cover by 1996.

3.2.5 Ford-Dawn Mill

The Dawn Mill is located in Ford, Washington, an Agreement State. Dawn Mining Company operated the mill from 1957 until 1964 under government contract. The mill was shut down and rehabilitated between 1965 to 1969. The mill resumed operations in 1969 processing uranium ore under commercial contracts until 1982, when it was placed in a standby mode for economic reasons.

During operations, production capacity of the mill was 600 tons of ore per day resulting in the generation of approximately 2.9 million tons of tailings waste. These tailings were deposited in three unlined, above-grade impoundments, constructed behind earthen dams, and one lined, below-grade disposal area. The three above-grade impoundments encompass an area of 95 acres. The below-grade disposal area covers 28 acres.

Presently, the three above-grade impoundments have been blanketed with a five-foot interim earthen cover. There have been no reclamation activities performed on the lined, below-grade disposal area. A target date of 1996 has been established for completion of a final radon cover over the entire impoundment areas, as stated in the Memorandum of Understanding.

3.2.6 Hecla Mining, Durita Project

The Durita site was constructed and operated as a secondary-extraction heap leach facility that recovered uranium and vanadium from mill tailings originally processed through the Naturita Mill. The Durita Site occupies 160 acres in Montrose County, Colorado, (an Agreement State), about three miles southwest of the town of Naturita. The operation is managed by Hecla Mining Company.

The site contains an ore preparation facility, a plant for leachate recovery, three leach tanks (piles), and six evaporation ponds. The three small heap leach piles encompass approximately 35 acres and contain 600,000 tons of tailings. The leach areas were constructed of earthen dikes, underlain by a clay liner.

The Durita site is in the process of reclamation. An interim soil cover of approximately 2 feet of compacted sandy clay soil has been placed over the three heap leach piles. Based on the MOU, a final radon cover, which satisfies the emissions standard of 20 pCi/m^2-s, will be in place by 1997.

3.2.7 Homestake Mill

The Homestake Uranium Mill is located in Grants, New Mexico. Homestake's milling facilities were constructed and originally operated as two distinct partnerships, with Homestake Mining Company acting as the managing partner for both.

The smaller of the two mills was organized as Homestake-New Mexico Partners. The mill operated between February 1958 and January 1962 at a nominal capacity of 750 tons per day. An alkaline leach-caustic precipitation extraction process was used to recover uranium.

The larger mill, organized under Homestake-Sapin Partners, began operations in May 1958 at a capacity of 1750 tons of ore per day. The mill was designed as an alkaline leach extraction facility. In April 1968, through a change in the distribution of ownership, Homestake-Sapin Partners became United Nuclear-Homestake Partners. In March 1981, Homestake purchased United Nuclear Corporation's interest and operated the mill as Homestake Mining Company-Grants until February 1990.

A separate tailings impoundment area was constructed for each of the two mills. The first and smaller tailings impoundment (associated with the Homestake-New Mexico Partners facility) was constructed of earthen embankments. Approximately 1.22 million tons of tailings were deposited in the approximately 13-acre impoundment area. This impoundment is designated as Homestake's "small impoundment" in Table 3-1.

The second tailings disposal area, associated with Homestake-Sapin Partners, was constructed of compacted coarse tailings embankments and is divided into two cells. The impoundment encompasses approximately 170 acres and contains over 22 million tons of tailings. This impoundment area is designated as Homestake's "large impoundment" in Table 3-1.

Reclamation activities have commenced at the sites which include mill decommissioning and tailings impoundment dewatering.

A lined evaporation pond has been constructed to aid in the dewatering process. Currently, the configuration of the large tailings pile consists of 152 acres that are dry, with no soil cover, and 18 acres wet. Seven acres of the total 13-acre small tailings pile currently exists in a dry, uncovered state. The remaining 7 acres have been blanketed with an interim soil cover.

The EPA and NRC have decided to treat the reclamation of the two Homestake tailings disposal areas separately. Therefore, in accordance with the Memorandum of Understanding, a 1997 target date for completion of a final earthen cover has been set for the large tailings impoundment; and a date of 2001 has been established for the small impoundment.

3.2.8 Pathfinder-Lucky Mc Mill

The Lucky Mc Mill, located in Gas Hills, Wyoming, is owned by Pathfinder Mines Corporation. The mill commenced operations in 1958 with an ore-processing capacity of 935 tons per day. Subsequently, the capacity was expanded to about 2800 tons of ore per day. An acid leach process is used to recover uranium from the ore.

The tailings retention system consists of four unlined, earthen dam impoundments having a surface area of roughly 87, 63, 38, and 15 acres. Approximately 10.7 million tons of tailings have been disposed of in the 203-acre impoundment areas.

Currently, an interim soil cover has been placed over 188 acres of the tailings disposal areas. The remaining impoundment areas consist of 9 acres which are covered with free standing water (ponded) and 6 acres that are wet. As specified by the MOU, an earthen cover reducing radon emanation to 20 pCi/m^2-s will be in place by 1998.

3.2.9 Petrotomics, Shirley Basin Mill

The Shirley Basin Mill is owned by Petrotomics Company, a subsidiary of Texaco. The mill is located in Shirley Basin, Wyoming. Petrotomics operated the mill from 1962 until 1985. An acid leach-solvent extraction process was used to extract uranium oxide from ore. The mill operated at a maximum ore processing capacity of 1400 tons per day.

During operations, about 6.4 million tons of tailings waste was generated and deposited in a single above-grade, earthen dam constructed impoundment. The tailings impoundment area encompasses approximately 114 acres.

Petrotomics is proceeding with reclamation activities at the site. To date, these activities include completion of the mill

decommission, drying of the tailings area, and placement of an interim stabilization soil cover over the entire tailings pile. Based on the MOU, a target date of 1995 has been set for completion of a final radon attenuation cover over the impoundment area.

3.2.10 Quivera, Ambrosia Lake

The Ambrosia Lake Mill, located in Ambrosia Lake, New Mexico, is owned by Quivera Mining Company. Milling operations began in 1958 under the ownership of Kerr-McGee at a design capacity of 3630 tons of sandstone ore per day. The capacity was subsequently expanded to 7000 tons per day. In 1985, the mines and mill were placed in standby status. The mill utilized a conventional sulfuric acid leach and solvent extraction recovery process. Ion exchange units were also used to extract uranium from mine water discharged during dewatering of the Quivera mines.

Approximately 33 million tons of process solids were deposited on-site in two main tailings impoundments (Nos. 1 and 2a) and two ancillary impoundments (No. 2b and 2c). The disposal areas are enclosed by dams (embankments) constructed with sand tailings. Impoundment No. 1 encompasses approximately 229 acres and was used almost exclusively during operations; Impoundment No. 2a, 2b, and 2c covers approximately 139 acres. Liquid tails were decanted as clear solutions and pumped to lined ponds for evaporation. Solids from the evaporation ponds will be returned to the tailings pile.

Interim site reclamation activities are currently underway. Tailings pile No. 1 has been regraded and recontoured to convey precipitation off the top and covered with an interim cover consisting of one-foot of alluvium material. Approximately 85 acres of Impoundment No. 2a, 2b, and 2c have also been dried and blanketed with a one-foot interim soil cover. In accordance with the Memorandum of Understanding between the EPA and NRC, the target date for completing emplacement of a final earthen cover to limit radon emissions to a flux of 20 $pCi/m^2/s$ or less is 1997.

3.2.11 Rio Algom Mill

The Rio Algom Mill owned by Rio Algom Mining Corporation is located in Lisbon, Utah. Rio Algom operated the mill from May 1972 until October 1988, when it was shut down due to declining ore reserves.

The mill's designed throughput was 750 tons of ore per day. The ore was processed by alkaline leaching and ion exchange. During operations, tailings were deposited in two above-grade, earthen dam constructed impoundments. The impoundments are unlined but dug into natural clay. The total tailings disposal area encompasses an estimated 100 acres with approximately 3.3 million tons of tailings.

Reclamation activities, to date, include completion of a three-foot interim radon attenuating cover of clay and clay silt over both tailings impoundments. Based on the MOU, a final radon cover will be in place over the entire impoundment area by 1996.

3.2.12 Sohio-L-Bar Mill

The L-Bar Uranium Mill is located in Seboyeta, New Mexico. Mining and milling operations were managed by Kennecott Corporation, a subsidiary of BP America, from 1977 until cessation of operations in May 1981. The source materials license was transferred to Sohio Western Mining Company in 1990.

The L-Bar mill utilized an acid leach process for extracting uranium from the ore. An estimated 1.6 million tons of tailings waste, consisting of about 38 percent solids mixed with water, acid, and a variety of spent process chemicals, was generated during the operating period. These tailings were pumped into an above-grade tailings impoundment. The impoundment dam was constructed from a starter dam of weathered Mancos Shale, with a bottom lining of salt-treated shale (to promote clay swelling). The tailings disposal area encompasses approximately 80 acres.

Reclamation activities at the site are nearing completion. A final earthen cover, which meets the radon emission limit of 20 pCi/m^2-s, has been placed over the entire impoundment area. Rock erosion protection is in place over the embankment slopes and spillways, and vegetation is beginning to grow on the pile top. The MOU target date for the L-Bar site has been set for 1992.

3.2.13 UMETCO, Gas Hills Mill

Umetco Minerals Corporation, a wholly owned subsidiary of Union Carbide Corporation, began operations of the Gas Hill Mill, located in East Gas Hills, Wyoming, in 1960. The mill's initial throughput capacity of 1100 tons of ore per day was increased to 1400 tons per day in 1980. An acid leach process was used to extract the uranium from the start of operations in 1960 until late 1984. Heap leach operations at the mill were introduced in March 1980. The heap was extended in November 1982 and leaching operations continued until shut down in December 1984. The facility remained in a standby status from 1985 until 1987 awaiting improved market conditions. Operations resumed in May 1987 and shut down permanently on January 1, 1988.

The mill site encompasses a total of 235 acres which includes the uranium mill, two tailings impoundments (one above-grade tailings area and the A-9 below-grade tailings pit), heap leach operations, and evaporation ponds. The 147-acre above-grade tailings disposal area was used between 1960 and 1980 and contains

approximately 5.8 million tons of tailings. The 24-acre A-9 pit (a clay-lined, depleted open pit mine) received approximately 1.4 million tons of tailings between 1980 and 1984. In addition, the A-9 pit has received 2.3 million tons of tailings from the Riverton site (Title I). The total tailings area (two impoundments and the heap leach pile) encompasses approximately 192 acres.

Reclamation activities have begun at the Umetco Gas Hill site. Currently, a four-foot interim soil cover has been placed over the 192-acre tailings impoundment area. According to the MOU, all tailings areas will have a final cover, which meets the UMTRCA emission standards, by 1995.

3.2.14 UMETCO, Maybell Site

The Maybell, located northeast of Maybell Colorado (an Agreement State) is a heap leach facility. Umetco Minerals Corporation operated the facility between 1975 and 1982.

At the Maybell site, low grade uranium ore was placed on a clay liner in piles (heaps) from 35 to 50 foot high. The heap leach process consisted of ponding a dilute solution of sulfuric acid in cells on top of heaps of low grade uranium ore. The acid percolated through the ore producing uranium-laden fluids (leachate). The leachate was collected by a drain system, constructed above the clay liner, and piped to an adjacent plant for concentration.

The heaps cover an area of approximately 50 acres. A thick containment berm constructed of mine overburden surrounds the perimeter of the leach piles.

Reclamation activities, to date, include dewatering of the heaps and placement of a six-inch interim soil cover over approximately 35 acres. The remaining 15 acres are currently dry and uncovered. In accordance with the MOU, a target date of 1997 has been set for completion of an earthen cover, which meets the radon emanation limit of 20 pCi/m^2-s.

3.2.15 UMETCO, Uravan Mill

The Uravan Mill is located in Uravan, Colorado (an Agreement State). Umetco Mineral Corporation, a subsidiary of Union Carbide Corporation, owns the mill. The mill began processing uranium, vanadium, and radium in 1915 using a two-stage acid leach operation to recover uranium and vanadium. The mill operated at a maximum licensed capacity of 1400 tons of ore per day. In November 1984, the mill was placed on standby. In 1987, the license was amended to maintain the mill on standby and to permit reclamation of the existing tailings.

An estimated 12 million tons of tailings was produced during operations. This waste was disposed of in three tailings impoundments situated on mesas. Impoundments 1 and 2 are adjacent and overlapping and actually constitute one impoundment, which combined cover approximately 39 acres. The outward face of the impoundment is constructed behind dikes of coarse tailings and the inward side is contained by the native terrain. Impoundment 3 is also constructed behind embankments of course tailings and encompasses about 19 acres. In addition, the site contains a 12-acre sludge pile.

Reclamation activities, to date, include placement of a ten-foot soil cover over approximately 90% of the impoundment area. The remaining 10% (about 7 acres) contains a one-foot interim soil cover. The MOU specifies a target date of 2002. However, a CERCLA Consent Decree requires final cover over the tailings by 1997 with the exception of a small portion of the impoundment (roughly 1%), which may remain open to receive residues from groundwater restoration activities. For the purposes of this analysis, 1997 will be used as the target date.

3.2.16 UNC, Church Rock Mill

United Nuclear Corporation's (UNC) Church Rock Uranium Mill facility is located about 17 miles northeast of Gallup, New Mexico. The mill operated from 1977 until May 1982, when activities were stopped due to the poor uranium market.

The mill normally processed approximately 3500 tons of ore per day using an acid leaching process to extract the uranium. The resulting acid solution and tailings were stored in a series of three unlined tailings impoundments, each of earthen dam construction. In July 1979, there was a breach in the earthen retaining dam of one of the ponds spilling approximately 94 million gallons of acidified effluent and about 1100 tons of tailings slurry. Following the dam failure, UNC dug two pits (Borrow Pits 1 and 2) for disposal of mill solutions and tailings. The total tailings disposal area covers about 103 acres.

Currently, the Church Rock Mill is in the process of being decommissioned. Other reclamation activities are in progress at the site including the completion of a one-foot interim soil cover over the entire tailings impoundment. A final earthen cover, which meets the UMTRCA emission standards, will be in place by 1997.

3.2.17 Union Pacific, Bear Creek Mill

Bear Creek Uranium Company, owned by Rocky Mountain Energy (a subsidiary of Union Pacific Corporation) operated the Bear Creek Mill located in Powder River Basin, Wyoming. The mill was operated from September 1977 through January 1986, when it was shut down due to unfavorable uranium market conditions.

The mill utilized a conventional sulfuric acid leach-solvent extraction process for extracting uranium oxide. The original mill throughput capacity of 1000 tons per day was expanded to 2000 tons per day in 1979. Tailings were disposed in an earth-filled dam constructed from mine overburden. With the increased mill throughput, it was recognized that the original design capacity of the tailings area would be inadequate. Therefore, the mined out B-3 pit was used as a second tailings disposal impoundment. The coarse, dewatered solids (sands) were deposited in the B-3 pit and the fine tailings solids (slimes) and solution were disposed in the originally designed tailings impoundment area. The total tailings disposal surface area occupies approximately 178 acres.

Bear Creek Uranium Company has begun reclamation activities at the site. Mill decommissioning has been completed. Currently, the tailings surface is protected with an average one-foot thick interim cover of clay soil. The projected target date for completion of the final earthen cover is 1996 in accordance with the Memorandum of Understanding.

3.2.18 WNI, Sherwood Mill

The Sherwood Mill is located on the Spokane Indian Reservation in Washington, an agreement state. Western Nuclear, Inc. (WNI) operated the mill from 1978 through 1984. In 1984 the mill was maintained in a "hot" standby mode between 1984 and 1988. In 1988, the boilers were shut down and the mill was considered to be in "cold" standby.

A conventional acid leach-solvent extraction circuit was used for the recovery of uranium oxide from ore. The mill was designed to process 2000 tons of ore per day. Resultant tailings waste (approximately 2.3 million tons) was disposed in a single above-grade tailings impoundment constructed with earthen embankments. This tailings area encompasses about 94 acres and at the cessation of operations was filled to approximately 70% of full capacity.

Decommissioning of the mill commenced in January 1990. Western Nuclear, Inc. is currently in the process of dewatering the tailings impoundment area. To date, approximately 50 acres are dry and 44 acres are wet. In accordance with the MOU, the target date of 1996 has been set for completion of a radon attenuation cover over the tailings area.

3.2.19 WNI, Split Rock Mill

Between the years of 1957 and 1981, Western Nuclear Inc. (WNI) operated the Split Rock Uranium Mill and adjacent tailings disposal areas, located in Jeffery City, Wyoming. The mill was placed on standby status during the period of 1981 through 1986. In 1986, the license was amended to terminate use of the tailings pond for tailings disposal. During operations, the mill was licensed to process 1700 tons of ore per day using an acid leach-solvent extraction method.

The original tailings disposal area, constructed with an earthen starter dike and a tailings sand embankment, was utilized from 1958 to 1977. In 1977, the tailings liquid breached the extreme northern section of the embankment. Following the breach, the embankment was repaired and the impoundment area was enlarged by constructing a new compacted tailings dam upstream of the existing embankment. The entire 223 acre disposal area contains approximately 7.7 million tons of tailings waste.

To date, WNI has completed decommissioning activities at the site. Reclamation operations, inclusive of an interim cover over the entire impoundment area, are underway. As specified in the MOU, a target date of 1995 has been set for completion of an earthen cover which reduces radon levels to 20 pCi/m^2-s or less.

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CHAPTER 4

RADON-222 SOURCES, ENVIRONMENTAL TRANSPORT, AND RISK COEFFICIENTS

This chapter presents the physical and chemical properties of radon-222, where and how it is emitted from the uranium tailings, and the mechanism by which it is transported through the environment. Also presented are the methods used to model the atmospheric dispersion of the radon-222 and a description of how the health risks associated with these emissions are estimated.

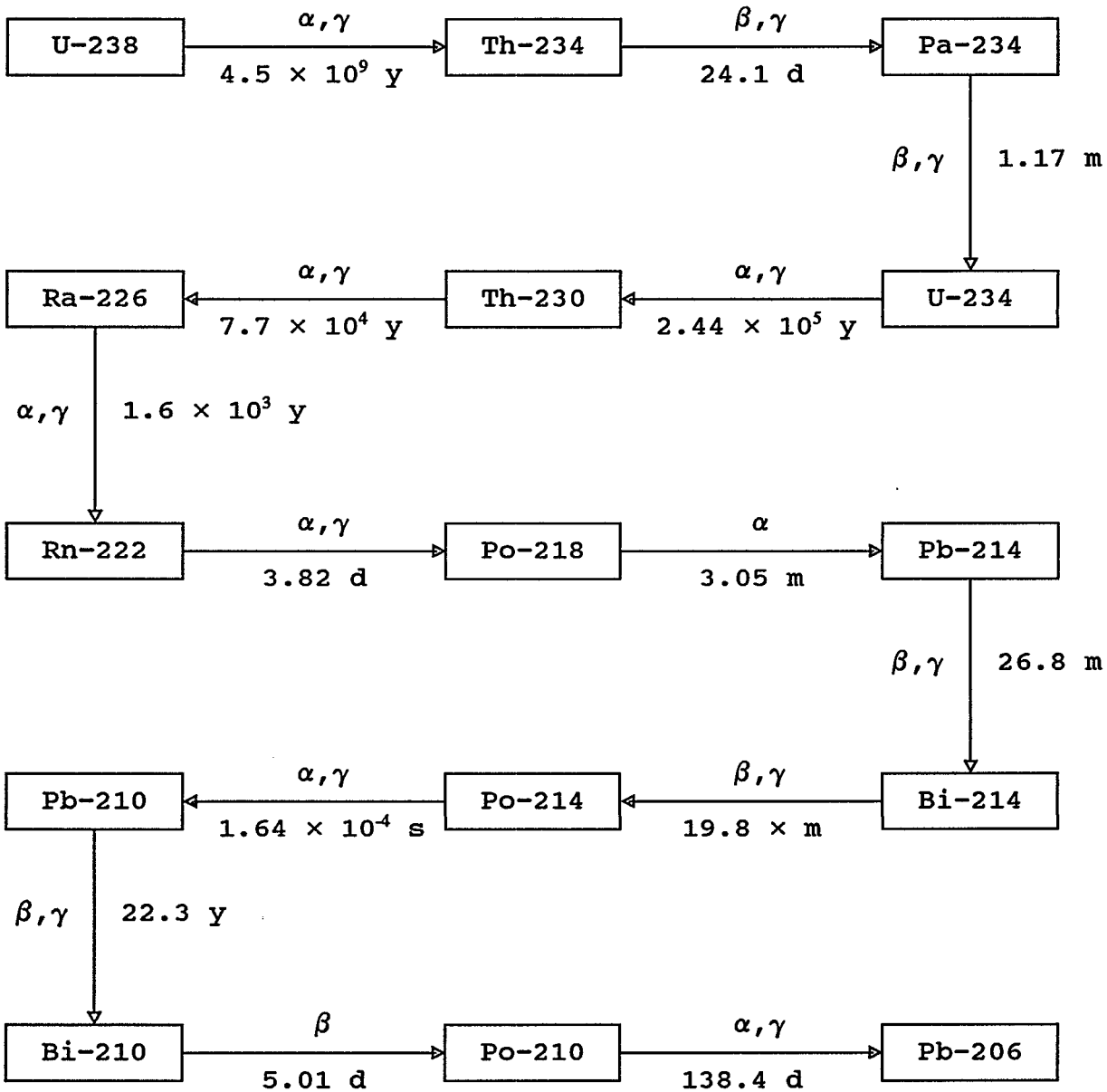
Uranium ore contains both uranium and its decay products, including significant concentrations of radium-226. Radon-222 is a naturally occurring radioactive gaseous element that is formed by the radioactive decay of radium-226. Radium-226 is a long-lived (1620 year half-life) decay product of the uranium-238 series. In nature, uranium is about 99.3 percent uranium-238; thus, it is the decay products of uranium-238 (Figure 4-1) that govern the radioactive content of the ore.

4.1 MILL TAILINGS: ENVIRONMENTAL SOURCE TERMS FOR RADON-222

Uranium ore that is processed in mills to concentrate uranium to an intermediate semi-refined product called yellowcake, yields a waste material with significant concentrations of radium. About ten percent of the starting concentrations of the uranium-238 and virtually all of the decay products in the ore inclusive of radium-226 are contained in the tailings. Radium-226 undergoes further radioactive decay to produce radon-222 gas. The half-life of radon-222 is 3.8 days. Therefore, when radon is released to the atmosphere, the released atoms can travel large distances before they decay. Tailings represent the largest and longest lasting source of radon-222 emissions from licensed uranium mills because of the large exposed area and the residual concentrations of radium.

Radon-220, a decay product of thorium-232, is also contained in tailings. Because of its short half-life of only 55 seconds, it has a limited time to be released into the atmosphere and reach a potential target population. Radon-220 is regarded to have an insignificant impact on human health when released from uranium mill tailings piles and will, therefore, not be considered in this report.

Radon, as an inert gas, is chemically unreactive with most materials and is free to travel through the small spaces between particles which constitute a tailings pile. The fine slime fraction contains the majority of radium-226 in the tailings (NRC80). The sand fraction contains radium-226 in concentrations ranging from 26 to 100 pCi per gram (NRC80), and the tailings liquid (raffinate) contains 1.7 to 35,000 pCi per liter of radium-226 (EPA83b).



y - years
d - days
m - minutes
s - seconds

Figure 4-1. Uranium-238 Decay Chain and Half-Lives of Principal Radionuclides

Not all the radon produced within the pile will be released to the pore spaces between particles. Some of radon produced will remain trapped within the physical structure of the particles or through recoil become "impacted" in adjoining particles and will, therefore, be unable to enter the pore spaces (Figure 4-2). Because radon is moderately soluble in water, the single most important variable is moisture content of the piles. However, a limited amount of water is thought to enhance the apparent emission of radon because it reduces the radon atom's recoil range and may prevent radon atoms from lodging in adjacent grains. The radon atom can then diffuse into the pore air space where it is available to migrate through the pile. If the pore spaces are totally saturated, as is the case when piles are wetted or in ponded areas, the radon atom has a low probability of emanating from the pile. This is due to the fact that water hinders radon's migration by lowering the diffusion coefficient and by absorbing radon atoms (Ta86). Radon solubility depends on the water temperature; the colder the water, the greater the radon's solubility. A measure of gas solubility is given by the solubility coefficient. The radon solubility coefficient is defined as the ratio of the radon concentration in water to that in air (Co86). The warmer the water temperature, the more radon is released; and, therefore, the lower the solubility coefficient. The maximum solubility coefficient of radon is about 0.5 at water temperatures approaching 0°C. Solubility decreases exponentially with a rise in temperature and is reduced to about 0.25 at 20°C and 0.1 at 90°C.

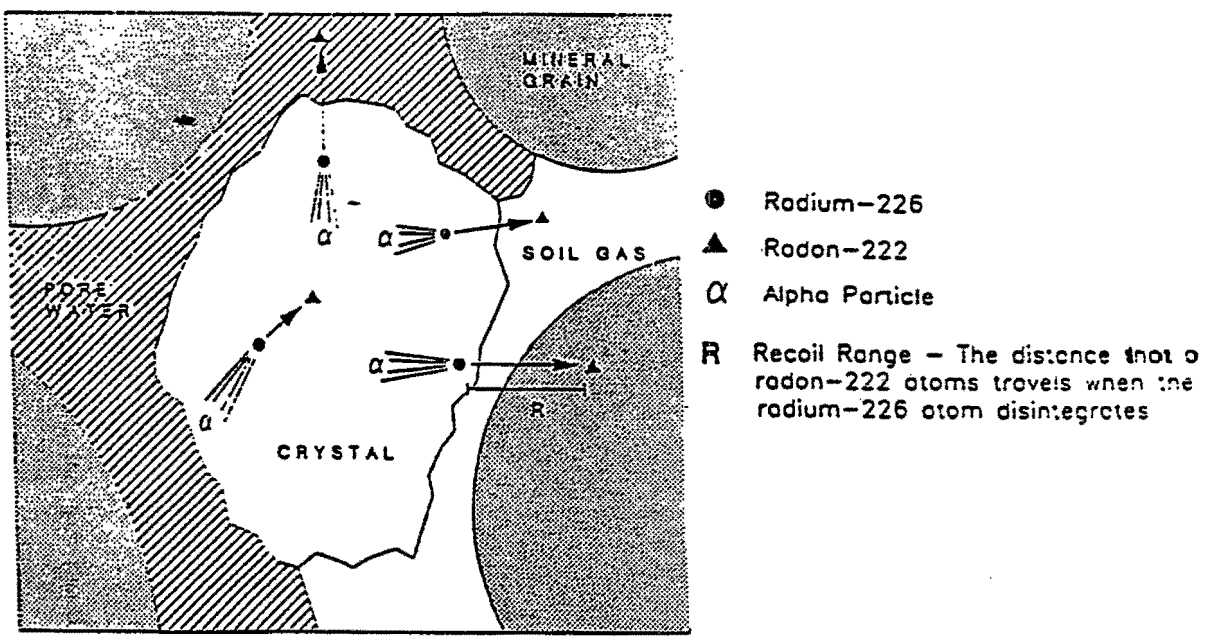


Figure 4-2. Radon Emanation Process

4.1.1 Estimating Radon Emissions from Tailings Impoundments

In addition to moisture content, the amount of radon-222 emitted from tailings impoundments depends on a number of highly variable factors, such as ore grade, grain size, porosity, temperature, and barometric pressure. These factors, in turn, vary between sites, between locations on the same site, and with time (PEI85). For these reasons, mathematical models typically have been used to estimate average radon-222 emissions on a theoretical basis. Considerable research has been conducted to develop and refine ways of calculating average radon-222 flux from infinitely thick or deep sources (i.e., at least 1 meter deep). This work has largely been carried out in support of the Uranium Mill Tailings Remedial Action Program (UMTRAP) and pertains to inactive mill tailings piles. Empirical measurements have been made of radon-222 emissions from licensed uranium mills and tailings piles, and studies have demonstrated good agreement between actual measurements and estimates based on mathematical models (EPA83b).

A one-dimensional, steady-state, radon-222 diffusion equation has been developed for sources (e.g., ore piles and tailings) that are more than several meters thick (Ni84, Fr84). Equation 4-1 defines the radon flux at the surface as follows:

$$J_t = 10^4 \, R\rho E \, (\gamma D)^{1/2} \qquad \text{(Eq. 4-1)}$$

where J_t is the radon-222 flux at the surface of the source (pCi/m^2-s); R is the specific activity of radium-226 in ore or tailings equal to 2812 x (uranium ore grade in percent), pCi/g; ρ is the bulk dry density of the source (g/cm^3); E is the radon-222 emanating fraction of source, dimensionless; γ is the radon-222 decay constant (2.1×10^{-6}/s); D is the effective diffusion coefficient for radon-222, equal to bulk radon diffusion coefficient/ porosity De/p (cm^2/s); and p is the porosity, equal to 1-(bulk density/ specific gravity).

For piles that are less than a few meters thick, Equation 4-1 should be multiplied by a hyperbolic tangent function that varies with depth or thickness (T), as shown in Figure 4-3. With the exception of the radon-222 decay constant, these parameters can vary significantly from location to location within the source, both horizontally and with depth, in a given ore pile or tailings impoundment. Except for the decay constant and bulk density, these parameters are difficult to measure. They are based on the physical characteristics of the source materials, which vary (1) over time (e.g., radium-226 content may decrease over the life of the mill as ore grade declines), (2) seasonally, and (3) with changing mill operation. Given the complexity and variability of parameters affecting radon emission and the scarcity of site-specific measurements, the EPA has adopted the following generic correlation between radon emissions and radium concentration (EPA83b):

Radon emanation estimates in this report are based on the average radium concentration of a pile using the simplified relationship of 1 pCi Ra-222/m^2-s per pCi Ra-226 per gram of tailings. This emanation rate is applied to all areas of a pile that are free of significant moisture. Wetted or ponded areas of a pile are assumed to emit no significant levels of radon.

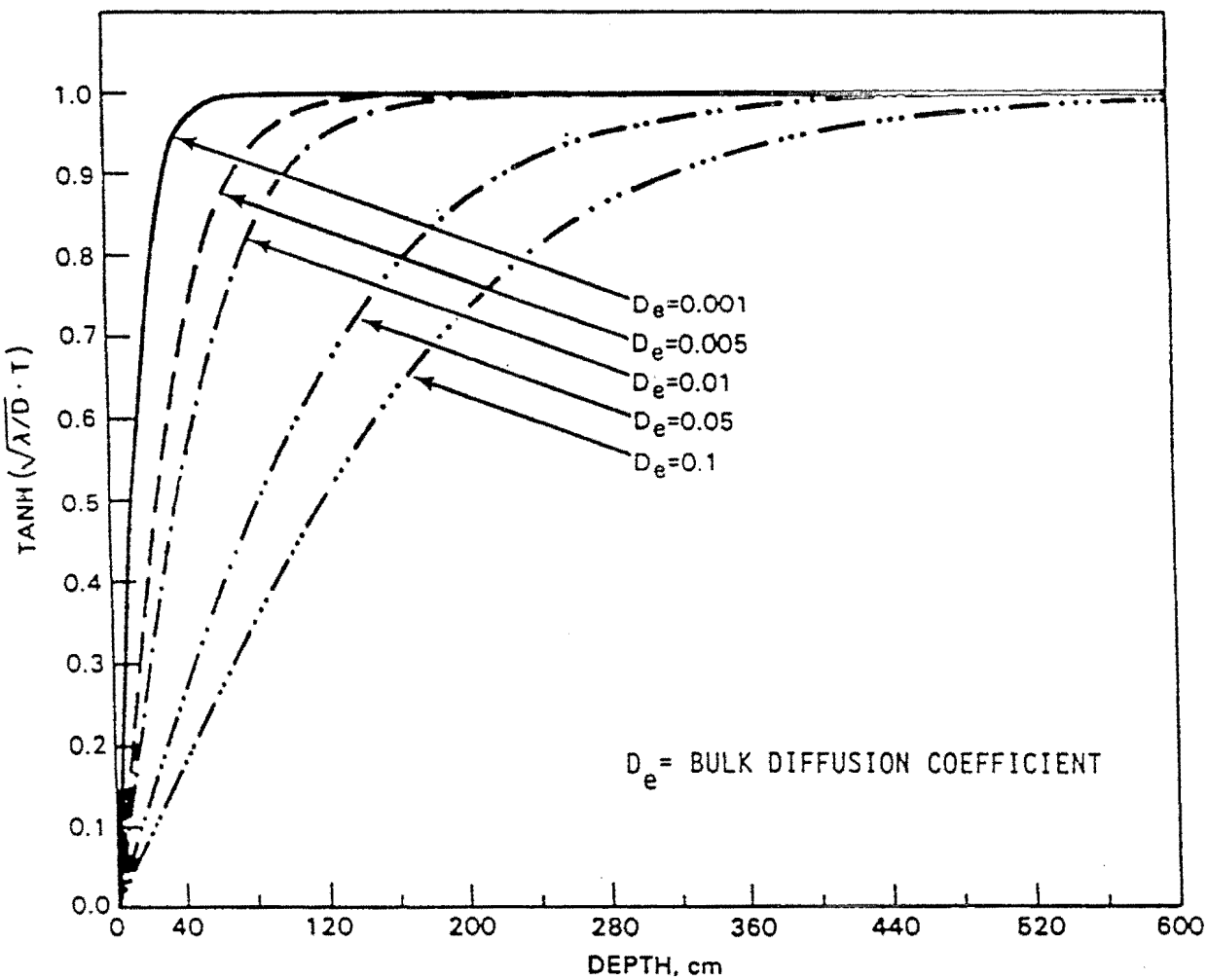


Figure 4-3. Effect of Pile Depth on Hyperbolic Tangent Term in Radon-222 Flux Equation (Ha85).

4.1.2 Ingrowth of Radon-222 Decay Products

At the point where radon-222 diffuses out of the tailings pile surface, the concentrations of associated radon-222 decay products are zero, because those decay products generated prior to diffusion from the surface are retained in the tailings. As soon as radon-222 is airborne, ingrowth of decay products commences. The quantitative relationship between radon and radon decay products depends on the extent to which radioactive equilibrium is reached. If the rate of formation and disintegration of the decay products suspended in air is exactly equal, a condition of secular equilibrium is reached. Although secular equilibrium is a theoretical upper limit, in reality it is not achievable due to plume depletion of radon daughters by dry and wet deposition and precipitation scavenging.

Human exposure to radon-222 progeny from tailings piles is based on an indoor/outdoor exposure model. The model assumes that the average individual spends about 75 percent of the time indoors and 25 percent outdoors (Mo76; Oa72). Radon-222 and its decay products may enter a structure that is downwind and enhance the normal indoor air concentration.

The specific activity of radon or individual decay product isotopes is commonly quantified in picocuries per liter (pCi/l). However, the specific activity of short-lived radon decay products collectively is also measured in units called working levels (WL). One working level is any concentration of short-life radon-222 progeny having 1.3×10^5 MeV per liter of potential alpha energy (FRC67). The relationship between the working level concentration of decay products and the picocurie per liter concentration of radon depends on the degree of equilibrium between radon and radon daughters. At secular equilibrium, one WL is equal to 100 pCi/l of radon-222.

Equation 4-2 defines the relationship between WL and pCi/l in terms of the equilibrium fraction:

$$Equilibrium\ Fraction = \frac{[WL] \times 100}{[pCi/l]} \qquad \text{(Eq. 4-2)}$$

The exposure to radon-222 progeny at a site of interest is based on the calculated radon-222 concentration and the calculated radon-222 progeny equilibrium fraction:

(Eq. 4-3)

Radon progeny concentration (WL)	=	Radon concentration (pCi/l)	x	Radon progeny equil. fraction (f_e^{eff})	x	1.0×10^{-2} (WL/pCi/l)

Calculations of radon-222 progeny equilibrium fractions are based on distance from a source and the time required to reach the exposure site. By using the ingrowth model of Evans (Ev69) and the potential alpha energy data of United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR77), the outdoor equilibrium fraction can be calculated by the expression:

$$f_e^{out} = 1.0 - 0.0479e^{-t/4.39} - 2.1963e^{-t/38.6} + 1.2442e^{-t/28.4} \qquad \text{(Eq. 4-4)}$$

where t is the travel time in minutes (distance/transport velocity).

The indoor equilibrium fraction presumes that those decay products associated with the radon-222 release also enter the building and that a ventilation rate of 1 hour^{-1} (one air change per hour) in combination with indoor removal processes (e.g., deposition onto room surfaces) produces an indoor equilibrium fraction of 0.35 when there are no decay products in the ventilation air and 0.70 when the decay products are in equilibrium with the radon-222 in the ventilation air (EPA83b). A simple linear interpolation is used to obtain the indoor equilibrium fraction:

$$f_e^{in} = 0.35\ (1 + f_e^{out}) \qquad \text{(Eq. 4-5)}$$

If one further assumes that a person spends 75 percent of his or her time indoors and the remaining 25 percent outdoors at the same location, the effective equilibrium fraction is given by:

$$f_e^{eff} = 0.75\ f_e^{in} + 0.25\ f_e^{out} = 0.2625 + 0.5125\ f_e^{out} \qquad \text{(Eq. 4-5)}$$

To calculate air exposure concentrations for specific members of the public and regional populations, EPA uses the computer model CAP-88 EPA 1991 (EPA 520/6-91/022, December 1991, "User's Guide for CAP88-PC"). CAP-88, which stands for Clean Air Act Assessment Package - 1988, is a set of computer programs, databases, and associated utility programs for estimating dose and risk from a variety of radionuclide emissions to air inclusive of radon from large area sources. Large area sources are modeled in CAP88-PC using a method described by Mills and Reeves, as modified by Christopher Nelson, EPA, and implemented by Culkowski and Patterson (Mo79). The method transforms the original area source into an annular segment with the same area. The transformation is dependent on the distance between the centroid of the area source and the receptor. At large distances (where the distance/diameter ratio is 2.5), the area source is modeled as a point source; at close distances it becomes a circular source centered at the receptor. A point source model is also used if the area source is 10 meters in diameter or less.

CAP-88 uses a modified Gaussian plume equation along with proximal meteorological data. Annual average meteorological data sets include frequencies for several windspeed categories for each wind direction and Pasquill atmospheric stability category. CAP-88 uses reciprocal-averaged wind speeds in the atmospheric dispersion equations, which permit a single calculation for each wind speed category.

The principle of reciprocity is used to calculate the effective chi/Q. The problem is equivalent to interchanging source and receptor and calculating the mean chi/Q from a point source to one or more sector segments according to the angular width of the transformed source. The mean value of chi/Q for each sector segment is estimated by determining chi/Q at the distance which would provide the exact value of the mean if the variation in chi/Q were proportional to $r^{-1.5}$ for distances from the point source to location within the sector segment. The chi/Q for the entire transformed source is the sum of the chi/Q values for each sector weighted by the portion of the total annular source contained in that sector.

Table 4-1 provides a sample set of values for a 3.5 m/s windspeed and various distances from an 80 hectare source. Removal processes outdoors were assumed to limit the equilibrium fraction to 0.85, which corresponds to an indoor equilibrium fraction of 0.65 and an effective fraction of 0.70. Table 4-1 shows that this limit is reached at a distance of 19,550 meters.

Table 4-1. Radon-222 Decay Product Equilibrium Fraction at Selected Distances from the Center of a 80 Hectare Tailings Impoundment[1]

Distance (m)	f_e^{out}	f_e^{in}	f_e^{eff}
150	0.013	0.355	0.267
200	0.020	0.357	0.273
250	0.026	0.359	0.276
300	0.031	0.361	0.278
400	0.041	0.364	0.284
500	0.051	0.368	0.289
600	0.060	0.371	0.293
800	0.078	0.377	0.302
1,000	0.094	0.383	0.311
1,500	0.133	0.397	0.331
2,000	0.168	0.409	0.349
2,500	0.201	0.421	0.366
3,000	0.234	0.435	0.382
4,000	0.295	0.453	0.414
5,000	0.353	0.473	0.443
6,000	0.407	0.493	0.471
8,000	0.507	0.527	0.522
10,000	0.593	0.558	0.566
15,000	0.755	0.614	0.650
19,551	0.850	0.648	0.698

[1] Calculations (tabulated to 3 decimal places to facilitate comparisons) presume: a 3.5 m/s windspeed for the outdoor equilibrium fraction; an indoor equilibrium fraction of 0.35 for no radon-222 decay products in the ventilation air and 0.70 for ventilation air with 100 percent equilibrium between radon-222 and its decay products; and an effective equilibrium fraction based on 75 percent of time indoors and 25 percent of time outdoors.

4.2 RADON-222 EXPOSURE PATHWAYS AND RISKS TO HUMAN HEALTH

Radon-222 has a half-life of 3.8 days and follows a decay process that involves seven principal decay products* before ending as stable non-radioactive lead (see Figure 4-1). The dominant decay products are those with very short half-lives and include polonium-218, lead-214, bismuth-214, and polonium-214. It is generally believed that it is radon decay products, rather than radon itself, that may induce lung cancer among exposed individuals. The quantitative relationship between radon and radon decay products depends on the extent to which radioactive equilibrium is reached. Polonium-218, the first decay product, has a half-life of just over three minutes. This, however, is long enough for most of these electrically charged and chemically reactive atoms to attach themselves to microscopic airborne dust particles. The total radon daughter products (attached and unattached) that remain suspended in air is reduced by several processes so that secular equilibrium is never reached. Removal processes are affected by the concentration of airborne dust particles, the size of dust particles, surface to volume ratio, surface texture, air flow, etc. Based on simultaneous measurements of radon and radon decay products, it has been found that the indoor equilibrium fraction ranges from 0.3 to 0.7 with an average of about 0.5 (Ge85).

When inhaled, attached radon decay products with particle sizes in the micron range are deposited on the moist epithelial lining of the larger bronchi of the lung. Unattached radon decay products when inhaled penetrate smaller regions of the lung where they may be deposited. Although most particles are eventually removed from the larger bronchi and upper respiratory tract by natural mechanisms, radioactive decay occurs in time to expose lung cells to ionizing radiation. Two of the short-lived decay products, polonium-218 and polonium-214, emit alpha particles during the decay process, which exposes proximal cells to radiation with high linear energy transfer (high-LET).

High-LET radiations have a larger biological effect per unit dose (rad) than low-LET radiations. How much greater depends on the particular biological endpoint under consideration. For cell killing and other readily discernable endpoints, the relative biological effectiveness (RBE) of high-LET alpha radiation may be 10 or even 20 times greater than low-LET radiation. The RBE value is also influenced by the dose level; for example, if linear and linear-quadratic dose response functions are demonstrated for high- and low-LET irradiations, respectively, the RBE must be assumed to decrease with increasing dose for the high-LET radiation.

For purposes of calculating dose equivalent, each type of radiation emission is assigned a quality factor (Q) to account for

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* Radon decay products are also referred to as radon daughters.

its relative efficiency in producing biological damage. The dose equivalent (in rems) is the absorbed dose (in rad) times the appropriate quality factor (Q) for a specified kind of radiation. Unlike an RBE value, which is usually defined in terms of a specific target cell, biological endpoint, and dose-level, a quality factor represents a generic assessment by radiation experts of the potential harm of a given radiation relative to X- or gamma-rays. In 1977, the International Commission on Radiological Protection (ICRP) assigned a quality factor of 20 to alpha particle irradiation from internal emitters (ICRP77). The ICRP also found evidence that for very low dose rates such as in occupational settings, the biological risks were lower by a factor of 2.5 than the same exposure received over a short period of time. Implicit in ICRP's risk estimates for low dose/low dose rate is a dose reduction factor (DREF) of about 2.5. The EPA risk model does not employ DREF; therefore, in order to avoid an artificial inflation in high-LET risk estimates, EPA has assumed a RBE of 8 (i.e., 20/2.5 = 8) for calculating the risks from internal alpha particles.

In the case of alpha irradiation of the lung by radon decay products, an assessment of risk is not only limited by uncertainties regarding RBE values but also by the non-uniformity of radionuclide distribution and dose distribution among and within individual target cells. Adequate characterization cannot be made of the exact doses delivered to cells that eventually become cancerous. In uranium miners, and the general population, the majority of lung cancers arise from the epithelium of bronchial airways. In this tissue, both secretory and basal cells are considered to be targets for lung cancer development (NRC91). Knowledge of the deposition pattern of the radioactive particles and non-attached decay products and the geometric spacing of decay progeny to cells that are susceptible can only be ascertained by theoretical models. (Ha82, Ja80, Ja81, Mc78, Mc83). Fortunately, there are human epidemiological data that allow direct estimates of risks per unit of exposure that do not use a dosimetric approach. The Agency's estimates of risk of lung cancer due to inhaled radon progeny is based on the epidemiological approach adopted by the National Academy of Science, in which risk estimates are based on observed excess lung cancers among groups exposed to varying time-integrated air concentrations of radon progeny. In effect, EPA's estimates of lung cancer risks are based on the amount of inhaled radon-222 decay products to which people are exposed rather than on the dose absorbed by specific target cells of the lung.

4.2.1 Characterizing Exposures and Risks to the General Population Vis-a-Vis Underground Miners

Epidemiological investigations of uranium and other underground miners have provided valuable data on the quantitative risks of lung cancer associated with exposure to radon progeny in underground mines. The principal occupational groups that constitute

the epidemiological database for the risk estimates include: (1) U.S. uranium miners, (2) Czechoslovakian uranium miners, (3) Ontario uranium miners, (4) Malmberget iron miners, and (5) Eldorado uranium miners.

As discussed above, exposure to radon-222 decay products under working conditions is commonly reported in the unit of working level (WL). The WL unit was developed because the concentration of specific radon progeny depends on ventilation rates and other factors. A working level month (WLM) is the unit used to characterize a miner's exposure to one working level of radon progeny for a working month of about 170 hours. Because the results of epidemiological studies are expressed in units of WL and WLM, the following outlines how they can be interpreted for members of the general population exposed to radon progeny.

The EPA assumes that a mine worker inhales 30 liters per minute (averaged over a work day). This average corresponds to about 4 hours of light activity and 4 hours of moderately heavy work per day (ICRP75). The new ICRP radon-222 model, however, assumes an inhalation rate of 20 liters per minute for mine workers, which corresponds to 8 hours of light activity per day (ICRP81). This may be appropriate for nuclear workers; however, studies of the metabolic rate of mine workers clearly show that they are not engaged in light activity only (Sp56; ICRP75; NASA73). Therefore, 30 liters appears to be a more realistic estimate of the average per minute volume for this group. Based on this per minute volume, a mine worker inhales 3.6×10^3 cubic meters in a working year of 2000 hours (ICRP79). One working level of radon-222 progeny is equivalent to 2.08×10^{-5} joules per cubic meter (1.3×10^5 MeV per liter); therefore, in a working year, the potential alpha energy inhaled by a mine worker exposed to one working level is 7.5×10^{-2} joules.

There are age- and sex-specific respiratory rate and volume differences, as well as differences in duration of exposure, in a general population as compared to a mining population. According to the ICRP Task Group Report on Reference Man (ICRP75), an inhaled air volume of 2.3×10^4 liters per day is assumed for adult males, 2.1×10^4 liters per day for adult females of the general population. Reduced volumes of air are respired by children. However, the smaller bronchial area of children, as compared with that of adults, more than offsets their lower per minute volume.

For a given concentration of radon-222 progeny, the amount of potential alpha energy a member of the general population inhales in a month is more than the amount a mine worker receives in a working month. Although members of the general population are exposed longer (up to 24 hours per day, 7 days a week), the average amount of air inhaled per minute (minute volume) is less in this group than that for a mine worker when periods of sleeping and

resting are taken into account (EPA79; Th82). The radon-222 progeny exposure of a mine worker can be compared with that of a member of the general population by considering the amount of potential alpha energy each inhales per year (Ev69). That radon daughter deposition (and dose) in the conducting airways of the lung is proportional to ventilation rate (quantity inhaled) has also been recommended by other investigators (Ra 85; Ho 82).

In earlier reports, EPA used an "exposure equivalent," a modified WLM in which adjustments were made for age-specific differences in airway dimensions and surface area, respiratory frequency, and minute volume. These factors were expected to influence aerosol deposition and, therefore, radiation dose from radon daughters. This approach to quantifying exposure, correcting for differences in these factors, was recommended by Evans (Ev69) and is consistent with the original derivation of the working level (Ho57).

The BEIR IV Committee, however, concluded that the tracheo-bronchial "dose per WLM in homes, as compared to that in mines, differs by less than a factor of 2," and, at the time the BEIR IV Report was issued, advised that the dose and risk per WLM exposure in residences and in mines should be considered to be identical until better dosimetric estimates are developed (NAS88). The BEIR IV Report, however, also stated the need for further research and analysis on uncertainties in applying lung cancer risks characterized for underground miners to people in their homes. Because of the importance to the public of the risks of radon exposure in homes and schools, the EPA asked the National Research Council to initiate a study of the dosimetric considerations affecting the applications of risk estimates, based on studies of miners to the general population. The EPA asked that a panel be assembled to investigate the differences between underground miners and members of the general public in the doses they receive per unit exposure due to inhaled radon progeny. In 1991, the NRC published a companion report to the BEIR IV Report entitled "Comparative Dosimetry of Radon in Mines and Homes," (NRC91).

On the basis of this publication and review of other current information, the EPA, in 1992, with approval of its Science Advisory Board, adopted a risk coefficient of 2.24×10^{-4} lung cancer deaths per person-WLM.

This risk coefficient applies to residential radon exposure received by the general public and is based on a modified BEIR IV model using a standard life table calculation with 1980 U.S. vital statistics. Modifications to the BEIR IV model include the K factor value of 0.7 and an adjustment to account for background radon exposure. The K factor is defined and discussed in Section 4.2.4 below.

The following provides a historical account of the EPA risk model and derives the current risk coefficient of 2.24×10^{-4} lung cancer deaths per person-WLM.

4.2.2 The History and Derivation of EPA's Radon Risk Coefficients

The Early EPA Model. The initial EPA method for calculating radon risks has been described in detail (EPA79, E179). As new data were reported, the EPA revised its model to reflect changes, as contained in consecutive reports (EPA79, EPA82, EPA83a, EPA83b, EPA84, EPA85, and EPA86). The Agency initially projected radon lung cancer deaths for both absolute and relative risk models, but since 1978, EPA has based risk estimates due to inhaled radon-222 progeny on a linear dose response function, a relative risk projection model, and a minimum cancer induction period of 10 years. A life table analysis has been used to project this risk over a full life span. Lifetime risks were initially projected on the assumption that an effective exposure of 1 WLM increased the age-specific risk of lung cancer by 3 percent over the age-specific rate in the U.S. population as a whole (EPA79). In the most recent documents, lifetime risks were calculated for a range of risk coefficients from 1 percent to 4 percent per WLM (EPA86).

Comparison of Earlier Risk Estimates. Several estimates of the risk due to radon progeny have been published since the original EPA model was developed. These risk estimates were reviewed in a number of EPA reports (EPA84, EPA85, and EPA86).

Previous EPA risk estimates for lifetime exposure to a general population, along with Atomic Energy Control Board (AECB), National Academy of Sciences (NAS), UNSCEAR, ICRP, and National Council on Radiation Protection and Measurements (NCRP) estimates of the risk of lung cancer resulting from inhaled radon progeny, are listed in Table 4-2. The AECB estimate for lifetime exposure to Canadian males is 830 fatalities per million person-WLM (Th82). In Table 4-2, this estimate has been adjusted for the U.S. 1970 male and female population.

Table 4-2. Past Risk Estimate for Exposures to Radon Progeny

Organization	Model	Fatalities per 10^6 person-WLM	Exposure Period	Expression Period
EPA	Rel.	760 (460)[a]	Lifetime	Lifetime
NAS*	A-S Abs.	730 (440)[a]	Lifetime	Lifetime
AECB[b]	Rel.	600 (300)[a]	Lifetime	Lifetime
ICRP	---	150-450	Working Lifetime	30 years
UNSCEAR	---	200-450	Lifetime	40 years
NCRP[c]	Dec. Abs.	130	Lifetime	Lifetime

*BEIR III

[a] EPA and AECB based their estimates of risk for the general population on an exposure equivalent, corrected for breathing rate (and other factors). For comparison purposes, the values in parentheses express the risk in more customary units, in which a continuous annual exposure to 1 WL corresponds to 51.6 WLM.

[b] Adjusted for U.S. General Population: see text.

[c] NCRP84: Table 10.2; assumes risk diminishes exponentially with a 20-year halftime, and no lung cancer risk is expressed before age 40.

Sources: EPA83b; NAS80; Th82; ICRP81; EPA86; UNSCEAR77; NCRP84; USRPC80.

Models: Rel. - Relative Risk Projection
A-S Abs. - Age-Specific Absolute Risk Projection
Dec. Abs. - Decaying Absolute Risk Projection

The National Institute for Occupational Safety and Health reviewed published data on miner studies used as a basis for estimated risk coefficients and pointed out some of the strengths and limitations of selected studies (NIOSH87).

The occupational exposure groups that constitute the epidemiological database for the risk estimates are as follows:

1. U.S. Uranium Miners (NIOSH87)

   (a) Strengths: A large, clearly defined, well-traced cohort with some smoking histories and exposure records on the same persons. Standard sampling techniques were used to make measurements.

   (b) Limitations: There were few measurements in small mines, work histories were self-reported, exposures were high, and potential error due to excursions in exposure levels is high.

   (c) Follow-up: 19 years in 1977.

2. Czechoslovakian Uranium Miners (NIOSH87)

   (a) Strengths: Extensive exposure data with a large number of low level exposures and limited exposure to other underground mining. Many possible confounding factors have been investigated and eliminated.

   (b) Limitations: Exposure estimates prior to 1960 based on radon gas measurements. Person years at risk not determined in standard manner. Smoking effect neglected. Elevated levels of arsenic in ore.

   (c) Follow-up: 26 years in 1975.

3. Ontario Uranium Miners (NIOSH87)

   (a) Strengths: Miners received low mean cumulative exposures. Prior mining experience was carefully traced. Exposures prior to 1967 may be disputed.

   (b) Limitations: Median age of the cohort was 39 years in 1977. Thoron and gamma exposures may have been high but not accounted for. Smoking history is limited.

   (c) Follow-up: 18 years in 1977.

4. Malmberget Iron Miners (NIOSH87)

   (a) Strengths: Low exposure levels, long follow-up and stability of work force. Complete ascertainment of

vital status and confirmation of diagnosis. Risk from confounders was examined and ruled out.

(b) Limitations: Relatively small cohort with limited exposure data and an unclear cohort definition.

(c) Follow-up: 44 years in 1976

5. Eldorado - Uranium Miners (NAS88)

(a) Strengths: Very low exposure rates, miners screened for prior mining experience, roughly equal groups of surface only and underground only miners, Silica and diesel exhaust exposures low. Potential confounders investigated.

(b) Limitations: Exposure estimates are disputed. Sixteen percent of the miners excluded for incorrect or missing data. Average age in 1980 was 43 years.

(c) Follow-up: 14 years in 1980.

BEIR IV Risk Estimates. In early 1988, the National Academy of Sciences released the BEIR IV Committee report, which comprehensively examined information on the risks from radon and other alpha-emitting radionuclides (NAS88). With the cooperation of the principal investigators, BEIR IV reviewed in detail the mortality experience of four cohorts of underground miners (the U.S., Ontario, and Eldorado uranium miners and the Malmberget iron miners) and how the mortality related to radon daughter exposure. The Committee calculated the relationship of age-specific relative risk to exposure level and time-since-exposure (TSE) in two analyses. The first used internal cohort comparisons and was a grouped-data analog of a Cox relative-risk regression (NAS88). The second analysis compared the cohorts with external rates and was a generalization of common standard mortality ratio (SMR) methods. Separate parallel analyses were carried out to establish a single combined value for each parameter.

The mathematical form of the Committee's preferred TSE model for the radon related age-specific mortality rate at age (a) is

$$r(a) = r_o(a)\,[1 + 0.025\,\gamma(a)\,(W_1 + 0.5W_2)] \qquad (4\text{-}7)$$

where:
r(a) is the lung cancer mortality at attained age (a) due to all causes,

$r_o(a)$ is the age-specific baseline rate of lung cancer death in the absence of any excess radon exposure over low background levels,

$\gamma(a)$ is the age-specific adjustment to the relative risk coefficient for radon with

$$\gamma(a) = \begin{cases} 1.2 & \text{when } a < 55 \text{ years} \\ 1.0 & \text{when } a \text{ is } 55\text{-}64 \text{ years} \\ 0.4 & \text{when } a \geq 65 \text{ years} \end{cases}$$

The $\gamma(a)$ adjustment decreases the radon-induced lung cancer risk with age. This incorporates the Committee's finding that excess relative risk in the miners decreased with age at risk.

$(W_1 + 0.5W_2)$ represents cumulative lifetime exposure up to age (a) modified as follows:

W_1 = cumulative exposure occurring from 5-15 years before age (a), and

W_2 = cumulative exposure up to age a-15 years.

Since W_2 is reduced by 50 percent, the model gives less weight to exposures more distant in time since exposure. This reflects the Committee's conclusion that risk decreases with time since exposure as modeled for the four cohort studies of miners. Hence, the relative risk coefficient (ß = 0.025) effectively varies from 0.5 percent per WLM to 3.0 percent per WLM, depending upon age at risk and time since exposure (Pu89). Therefore, $r_o(a)(0.025)(\gamma_a)(W_1 + 0.5W_2)$ represents the rate of excess lung cancer due to radon.

The Committee model is, therefore, an age-specific, relative-risk projection model with a 5-year latent period prior to expression of risk.

In its analysis, the BEIR IV Committee identified two major areas of uncertainty affecting its conclusions: (1) uncertainty related to the Committee's analysis of cohort data and (2) uncertainty related to projection of the risk to other groups. The Committee's TSE model uses risk coefficients derived from analysis of data from four miner cohorts. Random or systematic errors, particularly systematic errors, could bias the conclusions. Sources of error in addition to basic sampling variation include: (1) errors in exposure estimates, particularly since the magnitude of error may differ among the studies; (2) errors of misclassification of cause of death; (3) errors in smoking status

of individual miners, and (4) modeling uncertainty--i.e., does the model properly address all parameters that are determinants of risk?

Having developed the TSE model for miners, the Committee anticipated the following sources of uncertainty in projecting the model across other groups: (1) effect of gender (miner data are for males); (2) effect of age (miner data contain no information on exposures before about age 20); (3) effect of smoking (miner data contain poor information on smoking status); (4) temporal expression of risk (not enough miners have died to establish accurately the pattern of lifetime risk from radon exposure), and (5) extrapolation from mining to indoor environments (what are significant differences in the air in mines compared to air indoors?). After reviewing the various sources of uncertainty, the BEIR IV Committee concluded [p42], " ...The imprecision that results from sampling variation can be readily quantified, but other sources of variation cannot be estimated in a quantitative fashion." Therefore, the Committee chose not to combine the various uncertainties into a single numerical value" (NAS88).

The question of errors in exposure estimates is particularly interesting since the modeling is strongly influenced by the U.S. uranium miner data. In fact, the model risk estimates would be 33 percent higher if the U.S. cohort was removed. Exposure in the U.S. cohort is poorly known: cumulative WLM (CWLM) are calculated from measured radon levels for only 10.3 percent of the miners, estimates are used for about 36.1 percent of the miners, and "guesstimates" are employed for about 53.6 percent of the miners (NAS88, Lu71). Only 26.1 percent of the U.S. uranium miner exposure data are based on measured values (Lu71).

The Ontario cohort exposure estimates also are not well founded. Upper and lower estimates were developed: the lower from measured values, the upper based on engineering judgment (NAS88). Eldorado cohort estimates of CWLM were based almost entirely on measured values, while Malmberget cohort estimates were based on a reconstruction of past ventilation conditions (NAS88). Of the four cohorts, the United States has one of the poorest bases for CWLM estimates. One serious problem is the potential error due to large excursions in radon daughter concentrations (NIOSH87). The uncertainties in exposure estimates are particularly significant in view of the rather large impact the U.S. cohort has on the form of the model.

When the BEIR IV model is run with the 1980 lifetable and vital statistics at an exposure level of 0.001 WLM per year, the reference risk can be calculated (Table 4-3).

Table 4-3. BEIR IV Risk Model - Lifetime Exposure and Lifetime Risk.

Group	Risk (10^{-6}/WLM)
Male	530
Female	185
Combined	350

ICRP 50. The International Commission on Radiological Protection, in its Publication 50, addressed the question of lung cancer risk from indoor radon daughter exposures. The ICRP Task Group took a direction quite different from the BEIR Committee. The Task Group reviewed published data on three miner cohorts: U.S., Ontario, and Czech uranium miners. The estimated risk coefficients by cohort are presented in Table 4-4.

Table 4-4. Estimated Lung Cancer Risk Coefficients from Radon Progeny Exposure for Three Miner Cohorts.

Cohort	Follow-up	Relative model	Absolute model
U.S.	1950-1977	0.3%-1.0%	2-8 cases/10^6 PWLMY
Czech	1948-1975	1.0%-2.0%	10-25 cases/10^6 PWLMY
Ontario	1958-1981	0.5%-1.3%	3-7 cases/10^6 PWLMY
Average		1%	10 cases/10^6 PWLMY

Source: ICRP87.

The relative risk model then developed for a constant exposure rate is:

$$\lambda(t) = \lambda_o(t)\left[1 + \int_0^{t-\tau} r(t_e)\ \dot{E}(t_e)\ dt_e\right] \qquad (4\text{-}8)$$

= the mortality rate at age t

where:

$\lambda_o(t)$ = the age-specific lung cancer rate at age t

$r(t_e)$ = risk coefficient at age of exposure t_e

$\dot{E}(t_e)$ = age-dependent exposure rate

τ = time lag (minimal latency) = 10 years

In the case of a constant exposure rate or constant annual exposure, the equation collapses to:

$$\lambda(t) = \lambda_o(t)[1 + \bar{r}\, E(t - \tau)] \qquad (4\text{-}9)$$

where:

$\bar{r}$ = age-averaged relative risk coefficient

$E(t - \tau) = \dot{E}\,[t - \tau]$

= cumulative exposure to radon daughters to age $t-\tau$

Since ICRP recommends the use of the relative risk model, the ICRP 50 absolute risk model will not be addressed further in this document.

To adapt the relative risk model derived from studies of underground miners for the general population, the ICRP Task Group introduced several adjustments. The first was to correct for co-carcinogenic influences in mines. To account for unidentified, unproven carcinogens that might be present in mine environments but not elsewhere, only 80 percent of the risk was attributed to radon. The second adjustment was for dosimetric corrections. The dose to bronchial epithelium used by the Task Group for persons indoors was estimated to be only 80 percent as large as that for persons in mines; therefore, the risk to the public from radon was considered to be 80 percent of the risk of miners.

Adjusting the average relative risk coefficient of 1 percent per WLM by these two factors gives a risk coefficient of 0.64 percent per WLM:

$$1.0\% \times 0.8 \times 0.8 = 0.64\%. \qquad (4\text{-}10)$$

The third adjustment made by the Task Group is related to age. Since reports of Japanese A-bomb survivors and some other radiation-exposed groups support an elevated estimate of risk in children compared to adults, the Task Group increased the risk coefficient of persons between birth and age 20 by a factor of 3.

The final relative risk coefficients in the ICRP 50 model are: 1.9 percent per WLM if the age at time of exposure is between birth and 20 years, and 0.64 percent per WLM if age at time of exposure exceeds 20 years.

When the ICRP 50 relative risk model is run with 1980 U.S. lifetable and vital statistics at an exposure level of 0.001 WLM per year, the reference risk calculated is:

Group	Risk (10^{-6}/WLM)
Male	610
Female	205
Combined	420

EPA's Selection of Risk Coefficients in Earlier Documents. To estimate the range of reasonable risks from exposure to radon-222 progeny for use in the Background Information Document for Underground Uranium Mines (EPA85), EPA averaged the estimates of BEIR III, the EPA model, and the AECB to establish an upper bound of the range. The lower bound of the range was established by averaging the UNSCEAR and ICRP estimates. The Agency chose not to include the NCRP estimate in its determination of the lower bound because this estimate was believed to be outside the lower bound. With this procedure, the EPA arrived at relative risk coefficients of 1.2 percent to 2.8 percent per WLM exposure equivalent (300 to 700 fatalities per million person-WLM exposure equivalent) as estimates of the possible range of effects from inhaling radon-222 progeny for a full lifetime. Although these risk estimates did not encompass the full range of uncertainty, they seemed to illustrate the breadth of much of scientific opinion at that time.

The lower limit of the range of 1985 EPA relative risk coefficients, 1.2 percent per effective WLM, was similar to that derived by the Ad Hoc Working Group to Develop Radioepidemiological Tables, which also used 1.2 percent per WLM (NIH85). However, some other estimates based only on U.S. and Czech miner data averaged 1 percent per WLM (Ja85) or 1.1 percent per WLM (St85). On the other hand, three studies - two on miners (Ra84, Ho87) and one on residential exposure (Ed83; Ed84) - indicated a relative risk coefficient greater than 3 percent per WLM, perhaps as large as 3.6 percent.

The EPA, therefore, increased the upper limit of its estimated range of relative risk coefficients. To estimate the risk due to radon-222 progeny, the EPA used the range of relative risk coefficients of 1 to 4 percent per WLM. (See EPA86 for a more detailed discussion.) Based on 1980 vital statistics, this yielded, for members of the general public, a range of lifetime risks from 380 to 1,520 fatal cases per 10^6 WLM (expressed in exposure equivalents). In standard exposure units, uncorrected for breathing rate and age, this corresponds to 230 to 920 cases per 10^6 WLM. Coincidentally, the geometric mean estimate obtained in this way with 1980 vital statistics, 4.6×10^{-4}/WLM in standard units of exposure, is numerically the same as that

obtained using a 3 percent relative risk coefficient and 1970 vital statistics.

In response to the consensus-based reports, BEIR IV and ICRP 50, and a recent report on the Czech miner groups (Se88), the Agency subsequently reviewed its basis for radon risk estimation. Comparable relative risk coefficients for miners (age-constant relative risk) yielded a coefficient of around 1 percent in ICRP 50, 1.34 percent in BEIR IV, and 1.5 percent in the Czechs. This suggested that the range, 1 percent to 4 percent, previously used by EPA, may have been too wide.

The BEIR IV Committee noted and modeled a drop in relative risk with increasing time of exposure and a decreasing relative risk with increasing age after exposure (NAS88). The Czech miners show a similar response pattern (Se88). Though the Committee did note a dose rate effect in the U.S. uranium miner cohort, i.e., a decrease in risk per unit exposure at high dose rates, it was not included in the model (NAS88). The possibility of a similar dose-rate effect was found recently in a study on Port Radium uranium miners (Ho87).

The ICRP 50 Task Group worked from a different database and developed a simpler model with fewer age- and time-dependent parameters. The Task Group provided a 3 times higher risk for exposure between birth and 20 years of age than after 20 years of age (ICRP87). The finding in the recent Czech report that risk prior to age 30 is 2 to 2.5 times greater than after age 30 lends some support to the ICRP conclusions (Se88).

Both BEIR IV and ICRP 50 models treat radon and smoking risks as multiplicative. This conclusion is based primarily on data from the U.S. uranium miner cohort. Although apparently based on weaker evidence, the report on Malmberget miners and the recent report on Czech miners both concluded that the interaction of smoking and radon exposure is small (Ra84, Se88). The attributable risk per unit exposure in smokers and non-smokers was essentially the same (Se88). The true interaction of radon and cigarette smoking is controversial. Both antagonistic (Lu79) and multiplicative (Lu69, Wh83) interactions have been reported in man, and animal studies can be found to justify either position (Ch81, Ch85). In prior calculations, EPA has always treated the interaction between radon daughters and cigarette smoke as multiplicative. EPA continues to treat the radon daughter-smoke interaction as multiplicative at this time.

At the advice of the Radiation Advisory Committee of EPA's Science Advisory Board, EPA continued to use relative risk models but included both BEIR IV and ICRP 50 model calculations to illustrate the difference in results from the two models. The ICRP 50 model was slightly modified. To compensate for differences in dosimetry, the risk reduction factor of 0.8 was elimi-

nated to place the ICRP 50 model and BEIR IV model on a comparative basis. Calculations in the ICRP 50 model were made using risk coefficients of 2.4 percent per WLM from birth to age 20 and 0.8 percent per WLM for ages greater than 20 years, yielding estimates listed in Table 4-5.

Table 4-5 also summarizes previous risk estimates based on the BEIR IV and the ICRP 50 model, modified as described above. Both models were adjusted for the effect of background radon exposure (see section below).

Table 4-5. Lifetime Risks from Radon Daughter Exposure of Lung Cancer Death (per 10^6 WLM).

	Model	
Group	BEIR IV	ICRP 50
Men	530	760
Women	185	255
Combined Population	350	500
(Range)	-	(170-840)

The ICRP Task Group concluded that, all things considered, the range of variation of the mean relative risk coefficient is from about 0.3 up to 2 times the value stated (ICRP87). The range of risk cited in Table 4-5 for the ICRP model reflects this uncertainty in the risk coefficient. Since the BEIR IV Committee did not provide a numerical range of uncertainty, no range is given for that model.

4.2.3 Correction of Radon Risk Estimates for the Effect of Background Exposure

A relative risk model for radon-induced lung cancer generally assumes the excess risk, λ_r, from a given exposure, is proportional to the observed baseline risk of lung cancer in the population, λ_o. Thus, for a constant exposure rate, w, the excess risk at age, a, attributable to previous exposure can be written:

$$\lambda_r(w,a) = \lambda_o(a)\ \beta(a) f(w,a) \qquad (4\text{-}11)$$

For example, in the case of an age-constant relative risk model with a 10-yr minimum latency:

$$\beta(a) = \beta = \text{constant} \tag{4-12}$$

$$f(w,a) = (a-10)w \tag{4-13}$$

Although λ_r is commonly assumed to be proportional to λ_o, a more consistent (and biologically plausible) way to formulate a relative risk model is to assume that the radon risk, λ_r, is proportional to λ_o', the lung cancer rate that would prevail in the absence of any radon exposure (Pu88):

$$\lambda_r(w,a) = \lambda_o'(a)\beta(a)f(w,a) \tag{4-14}$$

Presuming that the risk model can be used to relate $\lambda_o(a)$ to $\lambda_o'(a)$, then

$$\lambda_o(a) = \lambda_o'(a)\ [1 + \beta(a)f(\bar{w},a)] \tag{4-15}$$

where $\bar{w}$ is the <u>average</u> exposure rate in the population. It follows from the previous equation that

$$\lambda_o'(a) = \lambda_o(a)/[1 + \beta(a)f(\bar{w},a)] \tag{4-16}$$

The inferred baseline rate without radon exposure depends, of course, on both the risk model and the presumed average background exposure rate. The excess risk associated with an arbitrary exposure situation can be calculated using standard life-table methodology.

The ICRP 50 committee did correct the baseline rate in this way in calculating lifetime population risks, assuming an average exposure rate of 0.2 WLM/yr. The BEIR IV Committee did not incorporate the correction, noting that it would be small (see NAS88, p. 53). In arriving at a final estimate based on the ICRP 50 and BEIR IV models (Table 4-6), EPA has incorporated a model-specific baseline correction, calculated on the assumption of a 0.25 WLM/yr average radon exposure rate (Pu88). As seen from Table 4-5, this correction results in roughly a 15 percent reduction in each of the estimates of lifetime risk for the general population.

Table 4-6. Lifetime Risk from Excess Radon Daughter Exposure (Adjusted for a Background Exposure of 0.25 WLM/yr).

	Risk of Excess Lung Cancer Deaths per 10^6 WLM		
Group	BEIR IV	ICRP 50	Average
Men	460	640	550
Women	160	215	190
Population Combined	305	420	360
(Range)		(140-720)	(140-720)

Consistent with the recommendations of the Agency's Radiation Advisory Committee, EPA averaged the risk estimates derived from the BEIR IV and ICRP 50 models. These estimates are based on 1980 U.S. vital statistics and are adjusted for an assumed background exposure of 0.25 WLM/yr. Thus, as shown in Table 4-6, the excess lifetime risk in the general population due to a constant, low-level, lifetime exposure was estimated by the EPA to be 360 excess lung cancer deaths per 10^6 WLM, with a range of 140 to 720 excess lung cancer deaths per 10^6 WLM. The EPA used the risk coefficient of 3.6×10^{-4} fatal lung cancer per WLM in its risk assessment involving NESHAPs radionuclides (EPA89).

4.2.4 EPA's Current Risk Projection Approach - Adjusted BEIR IV Model

In 1991, the Office of Radiation Programs requested that the SAB review proposed revisions to EPA's radon risk assessment methodology. The SAB recommended that the Agency use only the BEIR IV model for assessment of risk from residential exposure to radon. The recommendation to use only the BEIR IV model and discontinue use of the ICRP 50 model was based on several new pieces of information. The first was evidence from epidemiological studies of a decrease in lung cancer risk with time since exposure, which had been incorporated into the BEIR IV model, but not the ICRP 50 model. The second was the publication of the BEIR V report (NAS90) and a study of Chinese miners exposed to radon gas (Lu90). These publications found no evidence of dependence on age at exposure for lung cancer. This was not consistent with the increased risk to children assumed in the ICRP 50 model. Finally, the BEIR IV model was based on the most updated information, was well documented, and represented the consensus of a body of established and qualified scientists (EPA92).

EPA has made two adjustments to the BEIR IV model in estimating radon risks. The first modification, previously described, was an adjustment of the age-specific baseline rate of

lung cancer from all causes by eliminating death due to average background exposure. This reduced the lifetime risk estimates by about 15 percent. The second modification was based on findings cited by the National Research Council in a report completed under a grant from EPA (Comparative Dosimetry of Radon in Mines and Homes, NRC91).

The National Research Council in a companion publication to its earlier BEIR IV report, compared radon exposures in mines to those of typical homes. This comparative study identified physical and biological parameters which uniquely apply to miners in a mining environment and the general population in a home environment. Parameter values considered to be significantly different include age- and sex-dependent respiration rate and volume, breathing route, age at exposure, aerosol size distribution, unattached fraction, cigarette smoking, and effects of environmental contaminants other than radon. The committee also explored the consequences of various underlying model assumptions for the efficiency of nasal deposition, the efficiency of bronchial deposition, the solubility of progeny in mucus, and the growth of aerosols in the respiratory tract. Using the terminology of the BEIR IV report (NAS88), if exposure is expressed in the commonly used unit working level month (WLM), the risk per unit exposure in the home, $(Risk)_h/(WLM)_h$, can be related to that in mines, $(Risk)_m/(WLM)_m$, by a dimensionless factor K.

where:

$$K = \frac{(Risk)_h/(WLM)_h}{(Risk)_m/(WLM)_m} \qquad \text{(Eq. 4-17)}$$

Thus, if the K factor exceeds unity, the risk per unit of exposure is greater in the home; if it is less than unity, the risk per unit of exposure is less in the home.

Across a wide range of exposure scenarios considered by the Committee, most values of K were less than unity. Because uncertainty remained after the committee's review concerning the cells of origin of lung cancer, the Committee performed the calculation separately for basal and secretory cells in the respiratory epithelium. The K factors for normal people without respiratory illness are summarized in Table 4-7. The Committee concluded that the risk per unit exposure to target cells in the respiratory tract tends to be lower for the home environment by about 30 percent for adults and by 20 percent or less for infants and children. Thus, when exposure is chronic (i.e., lifetime), direct extrapolation of risk estimates from the mining to the home environment is likely to overestimate the number of radon-caused lung cancer by about 30 percent.

Table 4-7. Summary of K Factors for Bronchial Dose Calculated for Normal People in the General Environment Relative to Healthy Underground Miners

Subject Category	K Factor for the Following Target Cells: Secretory	Basal
Infant, age 1 mo	0.74	0.64
Child, age 1 yr	1.00	0.87
Child, age 5-10 yr	0.83	0.72
Female	0.72	0.62
Male	0.76	0.69

Using the K value of 0.7 for both sexes and all ages, the adjusted BEIR IV model can be written as:

$$r(a) = r_0(a)\,[1 + 0.0175\,\gamma(a)\,(W_1) + 0.5W_2)] \qquad \text{(Eq. 4-18)}$$

where, the parameters are those described previously in equation 4-7 with the difference that ß = 0.0175 as a result of the adjustment for the factor K = 0.7.

The modified BEIR IV model, when used in a standard life table calculation in conjunction with U.S. 1980 vital statistics, yields a risk factor of 2.24×10^{-4} lung cancer deaths per person WLM.

The assessment of radon risk from uranium mill tailings impoundments in this report uses the current EPA risk value of 2.24×10^{-4} lung cancer deaths per person-WLM.

CHAPTER 5

70-YEAR RADON EMISSIONS FROM NON-OPERATIONAL TAILINGS IMPOUNDMENTS AND HEALTH RISKS TO NEARBY POPULATIONS

This chapter provides a quantitative assessment of radon emissions and risks to nearby populations for the nineteen non-operational tailings impoundments scheduled for covering as defined in the Memorandum of Understanding between the EPA and the NRC. Emission and risk estimates are based on a lifetime exposure of 70 years, beginning December 15, 1991 and ending December 15, 2061.

5.1 THE 70-YEAR ASSESSMENT PERIOD

The Clean Air Act (CAA), 40 CFR 61, Subpart T, specifies that once a uranium mill tailings pile or impoundment ceases to be operational, it must be disposed of and brought into compliance with the emission rate not to exceed 20 pCi/m^2-s within two years. For the nineteen impoundments which had been non-operational at the time of rulemaking, enforcement of Subpart T of 40 CFR 61 would have meant emplacement of an earthen cover to meet compliance with the UMTRCA emission standard as early as December 15, 1991. This objective, however, was not met, which led the EPA to seek a revised closure date as defined in the Memorandum of Understanding. The selection of December 15, 1991 as a start date for the 70-year assessment period provides a basis for comparing radon emissions and risks for tailings impoundments under the MOU disposal dates and the original date specified by 40 CFR 61, Subpart T. Emissions and risk estimates corresponding to the original December 15, 1991 disposal date represent "baseline values."

A 70-year assessment period of projected radon emissions corresponds to the total number of years to which an individual may be at risk from uranium mill tailings emissions. Radon emissions for the 70-year period may involve three discrete time intervals:

(1) The first interval corresponds to the standby phase which reflects the current configuration of the tailings impoundment.

(2) The second interval encompasses the time needed to dewater, dry, and cover tailings piles.

(3) The third and final interval is the post-disposal portion of the 70-year period, when all tailings piles for a given impoundment have been covered and all tailings piles meet regulatory emission standards.

The duration of the three phases is partly linked to the MOU target date and the need to dewater and dry currently ponded and wetted tailings before heavy equipment can be used to emplace a final earthen cover. Previous estimates assumed a five-year period for the disposal phase (EPA86).

In estimating the duration for each of these three phases within the 70-year time span starting December 15, 1991 and ending December 15, 2061 for the nineteen non-operational impoundments, the following protocol was used:

(1) Disposal period is defined by the five-year period which precedes the MOU target date. For impoundments with MOU target dates prior to January 31, 1996, the disposal period is obviously less than five years and is defined by the time interval between December 15, 1991 and the MOU target date.

(2) Standby period is defined by that period between December 15, 1991 and the MOU target date minus five years. In order for a standby period to exist, the MOU target date must be later than 1996.

(3) The post-disposal period is the balance of time remaining and is equal to 70 years minus the disposal and standby periods.

Table 5-1 identifies the nineteen facilities, their MOU target disposal dates, and the corresponding time periods for standby, disposal, and post-disposal.

Table 5-1. Assessment Period for Non-Operational Tailings Impoundments

Facility Name/Location	MOU Target Date	70 Year Assessment Period (12/15/1991 - 12/15/2061)		
		Standby (Yrs)	Disposal (Yrs)	Post-Disposal (Yrs)
ANC (FAP)/Gas Hills, WY	1995	none	4	66
ARCO Coal, Bluewater, NM	1995	none	4	66
Atlas, Moab, UT	1996	none	5	65
Conoco, Conquista, TX	1996	none	5	65
Ford-Dawn Mining, Ford, WA	2010	14	5	51
Helca Mining, Durita, CO	1997	1	5	64
Homestake, NM: large impound.	1996	none	5	65
Homestake, NM: small impound.	2001	5	5	60
Pathfinder-Lucky Mc, GH, WY	1998	2	5	63
Petrotomics, Shirley Basin, WY	1995	none	4	66
Quivera, Ambrosia Lake, NM	1997	1	5	64
Rio Algom, Lisbon, UT	1996	none	5	65
Sohio-L-Bar, Cebolleta, NM	1992	none	none	70
UMETCO, Gas Hills, WY	1995	none	4	66
UMETCO, Maybell, CO	1997	1	5	64
UMETCO, Uravan, CO	1997	1	5	64
UNC, Church Rock, NM	1997	1	5	64
Union Pacific, Bear Creek, WY	1996	none	5	65
WNI, Sherwood, WA	1996	none	5	65
WNI, Split Rock, WY	1995	none	4	66

5.2 PROTOCOL FOR ESTIMATING RADON EMISSIONS

Radon emission rates for each of the nineteen non-operational tailings facilities are estimated on the basis of (1) the tailings status, (2) areas of the tailings, (3) radium-226 concentrations, and (4) the duration, in years, for the three phases which make up the 70-year assessment period.

The current status of the nineteen facilities was obtained from the NRC's Uranium Recovery Field Office and cognizant officials representing Agreement States. Information included tailings surface areas, interim cover data, and average radium-226 concentrations. The data are summarized in Table 5-2.

Estimated radon emissions from dry tailings are based on the generic emission relationship of 1 pCi Radon-222/m^2-s per pCi Radium-226/g of tailings. Emissions from tailings with a permanent cover are either assessed at the design flux levels or the UMTRCA limit of 20 pCi/m^2-s. Emissions from tailings that are currently wet or ponded (i.e., sprayed to mitigate dust and radon emissions) are assumed to emit no significant levels of radon.

5.2.1 Emissions From Wet and Ponded Areas During Disposal Period

During the five-year disposal phase, however, wet and ponded areas undergo a thorough drying before heavy equipment can be used to install a permanent earthen cover. For the five-year disposal phase, a drying period of four years is assumed with a one-year period for the installation of a permanent cover. During the four-year drying-out period, emissions are assumed to linearly increase from zero to a maximum value defined by the generic relationship of 1 pCi Radon-222/m^2-s per 1 pCi Radium-226/g of tailings. In the fifth and final year of the disposal phase, covering of all dried areas (i.e., recently dried and previously dried areas) commences and progresses throughout the year at a constant rate. During the fifth and final year of disposal, radon emissions are assumed to linearly decrease from the maximum dry level to 20 pCi/m^2-s, the final emission rate assumed for all impoundments that do not now have a permanent cover.

For impoundments whose MOU target dates do not allow for a full five-year disposal period, the start date for drying out of wet or ponded areas is assumed to have begun prior to December 15, 1991 so that a five-year disposal period is achieved. For example, an impoundment with a MOU target date of 1995 will be assumed to have started the dewatering and drying process in 1990, or one year prior to the start of the 70- year assessment period. Starting emission rates from tailings areas, which have had one year of drying as of December 15, 1991, are assumed to be 25 percent of their maximum dry state (i.e., (0.25) x (1 pci Radon-222/m^2-s per 1 pCi Radium-226/g)).

Table 5-2. 1992 Status of Non-Operational Tailings Impoundments

FACILITY	TAILINGS SURFACE AREA (m^2 x 1000)					INTERIM COVER INFORMATION		Average Radium-226 (pCi/g)
	Total	Ponded	Wet	Dry	Interim Cover	Depth (cm)	Earthen Type	
ANC, Gas Hill, WY	445	0	0	0	445	15	unknown	420
ARCO Coal, Bluewater, NM	1214	0	0	607	607	75	unknown	620
Atlas, Moab, UT	518	0	40	478	0	N/A	N/A	540
Conoco, Conquista, TX	1012	0	405	0	607	(see footnote [1])		224
Ford-Dawn Mining, Ford, WA	497	0	113	0	384	150	unknown	240
Hecla Mining, Durita, CO	142	0	0	0	142	60	E-clay	428
Homestake, NM (large impoundment)	688	0	73	615	0	N/A	N/A	300
Homestake, NM (small impoundment)	52	0	0	28	24	unknown	unknown	300
Pathfinder-Lucky Mc, Gas Hills, WY	821	36	24	0	761	unknown	unknown	220
Petrotomics, Shirley Basin, WY	461	0	0	0	461	unknown	unknown	570
Quivera, Ambrosia Lake, NM	1490	0	0	146	1344	30	B-soil	237
Rio Algom, Lisbon, UT	405	0	0	0	405	90	E-clay	420
Sohio-L-Bar, NM	324	0	0	0	324	(see footnote [1])		500
UMETCO, Gas Hills, WY	777	0	0	0	777	120	unknown	310
UMETCO, Maybell, CO	202	0	0	61	141	15	unknown	128
UMETCO, Uravan, CO	283	0	0	0	255/28[2]	300/30[2]	unknown	480
UNC, Church Rock, NM	417	0	0	0	417	30	unknown	290
Union Pacific, Bear Creek, WY	720	0	0	0	720	30	E-clay	420
WNI, Sherwood, WA	380	0	178	202	0	N/A	N/A	200
WNI, Split Rock, WY	902	0	0	0	902	300	unknown	430

[1] Tailings impoundment has a final cover which meets the UMTRCA emission standard.
[2] Represents two discrete areas of 255,000 m^2 and 28,000 m^2 covered with soil thickness of 300 cm and 30 cm, respectively.

5.2.2 Interim Covered Areas

Tailings with an interim cover are assumed to remain status quo during the standby phase and the first four years of the disposal phase. The installment of a permanent cover is assumed to coincide with those of recently and previously dried tailings in the fifth and final year of disposal.

Of the twenty impoundments, all but three have interim covers over portions of their tailings. An interim cover significantly reduces radon as well as particulate emission. Its effectiveness depends mainly on moisture content, porosity, and cover depth (EPA86). The relationship between the flux from an interim covered surface to the flux from a bare dry tailings surface is described by equation 5-1:

$$F_{IC} = F_{DT}\, e^{-bx} \qquad \text{(Eq. 5-1)}$$

where:

F_{IC} is the flux through interim cover (pCi/m^2-s)

F_{DT} is the flux through dry tailings (pCi/m^2-s)

b is a coefficient dependent upon the moisture content, bulk density, specific gravity and porosity of the soil used

x is the cover thickness in cm

Table 5-3 provides representative values for b for specific earth types and moisture content.

Table 5-3. Coefficient b Values for Select Soil Types and Moisture Content[1]

Earth Type	% Moisture	Coefficient b
A Sandy Soil	3.4	0.00699
B Soil	7.5	0.00937
C Soil	12.6	0.01350
D Compacted Moist Soil	17.0	0.01850
E-Clay	21.5	0.02553

[1] Reference: EPA89

The approximate effectiveness of these various types of earth covers in reducing radon-222 emissions is graphically depicted in Figure 5-1. The application of almost any type of earth will initially affect a rapid decrease in radon emission. For example, an interim cover of 0.5 meter (1.6 feet) or 1 meter (3.3 feet), which consists of type B soil with a moisture content of 7.5%, would result in reductions of radon-222 emissions of 37 and 60 percent, respectively. Installed interim covers commonly consist of local native soil, which can be assumed to represent B soil with a 7.5 percent moisture content. When the depth of the interim cover is known, radon-222 emission rates are calculated using equation 5-1 with the appropriate b coefficient value. When earth type is not known, the interim cover is assumed to consist of B-soil with 7.5 percent moisture content having a b-coefficient value of 0.00937.

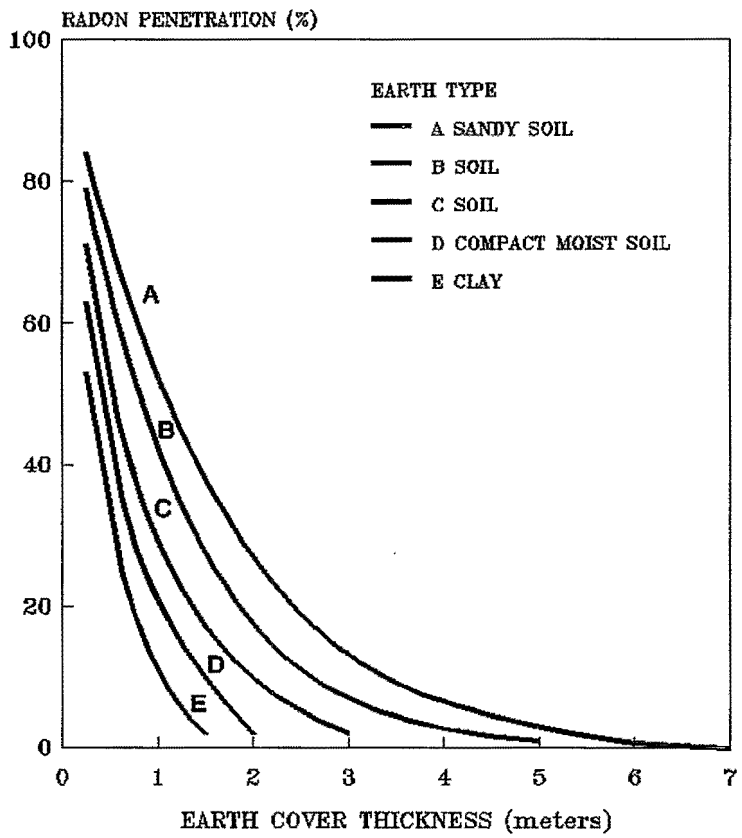


Figure 5-1. Changes in Radon-222 Penetration with Earth Cover Thickness (adapted from EPA89).

For impoundments with tailings where the thickness of the interim cover was not available, emanation rates are assumed to be 50 percent of their maximum value (i.e., $F_{IC}/F_{DT} = 0.5$).

5.2.4 Sample Calculation

A sample calculation, which estimates radon emissions, is provided below and serves to illustrate the methodology used to calculate radon emissions for the nineteen non-operational tailings facilities:

Problem: Calculate the radon-222 emissions for Pathfinder-Lucky Mc for (1) the 70-year assessment period (12/15/1991 - 12/15/2061) under the revised UMTRCA regulations/MOU target date and (2) 70-year baseline emissions.

Given:

- MOU target date 1998
- Current tailings characteristics

- Wet	=	24,000 m^2
- Ponded	=	36,000 m^2
- Dry	=	0 m^2
- Interim Cover	=	761,000 m^2
Total:	=	821,000 m^2

- No information was available about the interim cover with regard to earth type and depth of cover.
- Average radium-226 concentration in tailings is 220 pCi/g.

Solution: Emissions must be calculated separately for wet, ponded, and covered areas and for each of the three time periods.

1. Standby Period: During the standby period of two years, the wet and ponded areas are assumed to be non-fluxing. The interim covered area of 761,000 m^2 can be assessed by the equation:

$$F_{IC} = F_{DT}\, e^{-bx} \qquad \text{(see equation 5-1)}$$

Since no information about earth type and cover depth was available, it will be assumed that $F_{IC}/F_{DT} = 0.5$. This implies that the radon flux from the interim covered tailings will be

one-half of the maximum flux for dry uncovered tailings of 220 pCi/m^2-s.

Radon emissions for the two-year standby period for interim covered tailings are:

$$\text{Rn-222 Emission}_{\text{Standby}} = (220\ pCi/m^2\text{-s})\,(0.5)\,(3.1536 \times 10^7 s/y)\,(761{,}000\ m^2)\,(2y)$$

$$\text{Rn-222 Emission}_{\text{Standby}} = 5280\ Ci$$

2. Disposal Period: During the five-year disposal period, wet and ponded areas will be dewatered and dried for the first four years. In the fifth and final year, a permanent earthen cover is installed that meets the UMTRCA emission standard of 20 pCi/m^2-s.

During the first four years, emissions are assumed to linearly increase from 0 to a maximum of 220 pCi/m^2-s with an average value of 110 pCi/m^2-s. During the final (fifth) year, emis sions are assumed to decrease from 220 pCi/m^2-s to 20 pCi/m^2-s with an average value of 120 pCi/m^2-s.

During the disposal period, tailings with interim cover are conservatively assumed to remain unchanged for the first four years. A permanent cover is assumed to be installed during the fifth and final year of the disposal period and coincides with the permanent cover installation of the previously wet and ponded areas.

a. Radon emissions from interim covered tailings (i.e., $F_{IC}/F_{DT} = 0.5$):

$$\text{Rn-222}_{IC} = [(220\ pCi/m^2\text{-s})\,(0.5)\,(3.1536\text{x}10^7\ s/y)\,(4y) + \left(\frac{110\ pCi/m^2\text{-s} + 20\ pCi/m^2\text{-s}}{2}\right)(3.1536\text{x}10^7 s/y)\,(1y)]\ 761{,}000 m^2$$

$$\text{Rn-222}_{IC} = 12{,}120\ Ci$$

b. Radon emissions from wet and ponded tailings:

$$\text{Rn-222}_{W/P} = [(110\ pCi/m^2\text{-s})\,(3.1536\text{x}10^7 s/y)\,(4y) + (120\ pCi/m^2\text{-s})\,(3.1536\text{x}10^7 s/y)\,(1y)]\ 60{,}000 m^2$$

$$\text{Rn-222}_{W/P} = 1059\ Ci$$

c. Radon emission for the five-year disposal period from all tailings:

$$\text{Rn-222}_{\text{Disposal}} = \text{Rn-222}_{IC} + \text{Rn-222}_{W/P}$$

$$\text{Rn-222}_{\text{Disposal}} = 12{,}120\ Ci + 1059\ Ci$$

$$\text{Rn-222}_{\text{Disposal}} = 13{,}179\ Ci$$

3. Post-Disposal Period: During the post-disposal period of 63 years, all permanently covered tailings are assumed to be fluxing at the UMTRCA emission limit of 20 pCi/m^2-s.

Radon emissions for the post-disposal period:

$$Rn\text{-}222_{PD} = (20\ pCi/m^2\text{-}s)(3.1536 \times 10^7 s/y)(63y)(821{,}000\ m^2)$$

$$Rn\text{-}222_{PD} = 32{,}634\ Ci$$

Table 5-4 summarizes emissions for the Pathfinder-Lucky Mc Facility.

Table 5-4. Summary of Emissions for the Pathfinder-Lucky Mc Facility

Period	Covered (761,000m^2)	Wet (24,000m^2)	Ponded (36,000m^2)	Dry (0m^2)	Total (821,000m^2)
Standby (2 years)	5280 Ci	0	0	0	5280 Ci
Disposal (5 years)	12,120 Ci	424 Ci	635 Ci	0	13,179 Ci
Post-Disposal (63 years)	30,249 Ci	954 Ci	1431 Ci	0	32,634 Ci
				Total Emission$_{70y}$ =	51,093 Ci

Emissions for the baseline condition involves estimating radon releases for the 70-year period (i.e., 12/15/1991 - 12/15/2061) if the tailings had been covered as of 12/15/1991, as required in 40 CFR 61, Subpart T. For baseline conditions, radon emission is estimated at a constant rate of 20 pCi/m^2-s for the full duration of 70 years.

$$Rn\text{-}222_{Baseline} = (20\ pCi/m^2\text{-}s)(3.1536 \times 10^7 s/y)(70y)(821{,}000\ m^2)$$

$$Rn\text{-}222_{Baseline} = 36{,}260\ Ci$$

5.3 RADON EMISSIONS FROM NON-OPERATIONAL TAILINGS IMPOUNDMENTS

Estimates of radon emissions for each of the non-operational impoundments cited in the MOU are provided in Table 5-5. Emissions are provided where applicable for the standby period, disposal period, and post-disposal period. Emissions, when summed, provide an estimate of the cumulative radon that is released over the 70-year assessment period.

Table 5-5. Radon Emissions for Non-Operational Tailings Impoundments

FACILITY	MOU Target Date	Emissions: Revised UMTRCA Regulations					Baseline Emissions	
		Standby (Ci)	Disposal (Ci)	Post-Disposal (Ci)	70 Year Total (Ci)	Average Annual Ci/Year	70 Year Total (Ci)	Average Annual Ci/Year
ANC, Gas Hill, WY	1995	N/A	18,067	18,546	36,613	523	19,670	281
ARCO Coal, Bluewater, NM	1995	N/A	62,507	50,556	113,063	1615	53,620	766
Atlas, Moab, UT	1996	N/A	38,498	21,255	59,753	854	22,890	327
Conoco, Conquista, TX	1996	N/A	9193	41,470	50,663	724	44,660	638
Ford-Dawn Mining, Ford, WA	2010	9996	5515	15,963	31,474	450	21,910	313
Hecla Mining, Durita, CO	1997	416	1919	5760	8095	116	6300	90
Homestake, NM (large impoundment)	1996	N/A	28,123	28,210	56,333	805	30,380	434
Homestake, NM (small impoundment)	1997	1895	1721	1980	5596	80	2310	33
Pathfinder-Lucky Mc, Gas Hills, WY	1998	5280	13,179	32,634	51,093	730	36,260	518
Petrotomics, Shirley Basin, WY	1995	N/A	14,653	19,206	33,859	484	20,370	291
Quivera, Ambrosia Lake, NM	1997	8678	39,521	60,160	108,359	1548	65,800	940
Rio Algom, Lisbon, UT	1996	N/A	2605	16,575	19,180	274	17,850	255
Sohio-L-Bar, NM	1992	N/A	N/A	14,280	14,280	204	14,280	204
UMETCO, Gas Hills, WY	1995	N/A	8920	32,340	41,260	589	34,300	490
UMETCO, Maybell, CO	1997	740	3395	8128	12,263	175	8890	127
UMETCO, Uravan, CO	1997	553	2582	11,392	14,527	208	12,460	178
UNC, Church Rock, NM	1997	2880	13,098	16,832	32,810	469	18,410	263
Union Pacific, Bear Creek, WY	1996	N/A	20,367	29,510	49,877	713	31,780	454
WNI, Sherwood, WA	1996	N/A	8658	15,600	24,258	347	16,800	240
WNI, Split Rock, WY	1995	N/A	10,753	37,554	48,307	690	39,830	569
TOTALS		30,438	303,274	477,951	811,663	---	518,770	---

Table 5-5 also provides 70-year baseline emissions, which represent the hypothetical releases that would have been expected if impoundment facilities had been able to meet the original target date of December 15, 1991 for permanent disposal, as defined by Subpart T of 40 CFR 61.

An assessment of these two disposal schedules reveals that the collective 70-year emissions corresponding to the MOU disposal schedule of about 810,000 Ci exceeds the collective 70-year baseline emissions of about 520,000 Ci by 290,000 Ci. Correspondingly, this difference in cumulative emissions yields annual average facility emission rates that differ by a factor of about 1.6 (i.e., average annual facility emissions of 610 Ci/y versus 390 Ci/y).

Based on radium-226 concentrations, the emplacement of a permanent cover is expected to reduce radon emissions by one to two orders of magnitude from the maximum emission rate of dry tailings. Nevertheless, post-disposal releases appear relatively significant. In fact, for eleven impoundments, the largest cumulative release occurs during the post-disposal period when a permanent cover has been installed. This seeming paradox, however, is resolved by noting that the average post-disposal period represents 64.7 years or 92.4 percent of the 70-year assessment period. For the same reason, the average annual emission rate for the 70-year assessment period is low since this value is also dominated by the lengthy post-disposal period.

Variations in emission rates over the 70-year assessment period are quantitatively and graphically depicted in the illustration provided below for Pathfinder's Lucky Mc facility. During the two-year standby phase, emissions are estimated at 2640 Ci/y. Emission rates increase linearly during the first four years of the disposal phase, reaching a maximum value of 3056 Ci/y. During the fifth and final year of the disposal phase, the emplacement of the permanent earthen cover steadily reduces emissions to the final level of 518 Ci/y. The emission rate of 518 Ci/y meets the UMTRCA standard and is assumed to remain constant for the full duration of the 63 year post-disposal phase ending in the year 2061.

ILLUSTRATION: 70-YEAR EMISSION PROFILE FOR LUCKY MC

Data Elements:

1. MOU target disposal date 1998
2. Average Radium-226 Concentration: 220 pCi/g
3. 70-year Assessment Period:
   Standby = 2 yrs; Disposal = 5 yrs; Post-Disposal = 63 yrs
4. Current Tailing Surface Area ($m^2 \times 10^3$):
   Ponded = 36; Wet = 24; Dry = 0; Interim Cover = 761; Total = 821

Emission Rates:

E_1 = Current/Standby Emission Rate
= (Interim Covered Area)(Flux)
= (7.61E+5 m^2)(110 pCi/m^2-s) = 2640 Ci/y

E_2 = Maximum Emission Rate - (Maximum emission rate is the combined emission of areas with interim cover and those from dried areas (i.e., currently wet and ponded).
= (7.61E+5 m^2)(110 pCi/m^2-s) + (6.00E+4 m^2)(220 pCi/m^2-s)
= 2640 Ci/y + 416 Ci/y = 3056 Ci/y

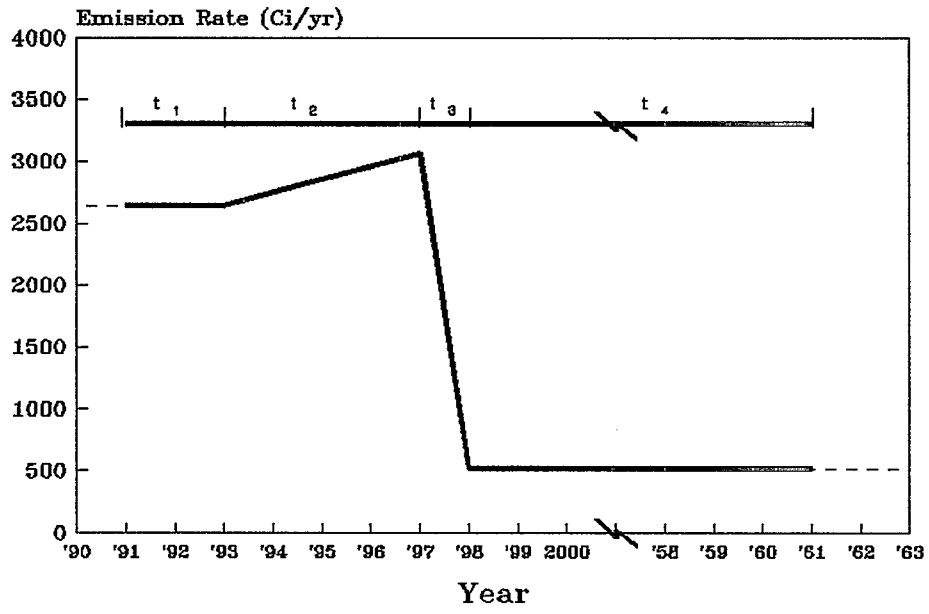
E_3 = Post-Disposal Emission Rate
= (Total Area)(UMTRCA Emission Flux)
= (8.21E+5 m^2)(20 pCi/m^2-s) = 518 Ci/y

$$Total\ Emission_{70y} = t_1(E_1) + t_2\left(\frac{E_1 + E_2}{2}\right) + t_3\left(\frac{E_2 + E_3}{2}\right) + t_4(E_3)$$

where: t_1 = 2 yrs; t_2 = 4 yrs; t_3 = 1 yr; t_4 = 63 yrs

$$Total\ Emission_{70y} = 2x2640 + (4)\left(\frac{2640+3056}{2}\right) + (1)\left(\frac{3056+518}{2}\right) + 63x518$$

Total Emission$_{(1991\text{-}2061)}$ = 51,093 Ci *Average Emission Rate* = 730 Ci/y



5.4 POPULATION EXPOSURES AND HEALTH RISKS

The previously described CAP88-PC model was used to estimate the down-wind radon exposures from tailings emissions (see Appendix A). When public exposure is assessed, the two parameters of concern are: (1) the lifetime fatal cancer risk to the individual(s) experiencing the maximum risk (MIR) and (2) the annual collective risk to near-field residents. Exposure estimates are based on historical site-specific meteorological conditions and empirical population data which identify residents by distance and sector.

Due to the prevailing winds, which favor some sectors over others, the maximum individual risks are not necessarily experienced by the residents closest to the sites. Prevailing winds also influence the dose distribution and affect the cumulative population exposures to individuals residing within the 0-80 km radii of the impoundment facilities. All exposures conservatively assume that individuals spend 100 percent of their time at their residential location (i.e., 75 percent indoors and 25 percent outdoors).

Table 5-6 provides summary data for each facility based on the MOU disposal schedule. The values are derived as follows and are illustrated by using the Pathfinder-Lucky Mc facility as an example:

- Average Radon Emission (Column #1). This value represents the yearly average radon emissions (Ci/y) for the 70-year assessment period starting December 15, 1991 and ending in 2061.

  For the Lucky-Mc facility, the 70-year assessment period includes a 2-year standby, a 5-year disposal, and a 63-year post-disposal period (see Table 5-1). For the 70-year periods, it was estimated that a total of 51,093 Ci would be released yielding an average annual value of 730 Ci (see Table 5-5).

- MIR Radon Concentration (Column #2). The tailings enhanced average radon-222 concentrations for the MIR is a site-specific value which is defined by meteorologic and population data.

  Appendix B provides a computer generated Synopsis Report for the Lucky-Mc facility. Based on prevailing wind and air dispersion, the maximally exposed individual is located 25,000 meters north of the tailings where the radon concentration is 8.77E-4 pCi/l above prevailing background.

- MIR Decay Product Concentration (Column #3). Radon concentrations in Column #2 are converted to concentration levels of radon-222 progeny by means of an appropriate equilibrium fraction. Values for the indoor/ outdoor equilibrium fraction vary with radon plume travel time and, therefore, distance from tailings.

To determine the decay product concentration for the Lucky Mc's MIR, which is to an individual that is located at 25,000 meters, the effective equilibrium fraction of 0.698 is used (see Table 4-1):

Decay Prod. Conc.(WL) = (Radon Conc.)(Equil. Fraction)
= (8.77E-4 pCi/l)(0.698)(1WL/100 pCi/l)
= 6.12E-6 WL

- MIR Lifetime Fatal Cancer risk (Column #4). Risk values are derived by: (1) integrating the exposure to radon progeny over the 70-year exposure duration, which yields exposure in the conventional time-integrated unit of WLM, and (2) multiplying the derived WLM value times the EPA risk coefficient.

  For the Lucky Mc MIR, the lifetime fatal risk of cancer is derived as follows:

  $Risk_{cancer}$ = (70 y exposure)(Cancer Risk Coefficient)

  $$= (6.12E\text{-}6\ WL)\frac{(24h/d \times 365d/y \times 70y)}{170\ hr/m}(2.24E\text{-}4\ cancer/WLM)$$

  $Risk_{cancer}$ = 4.95E-06 (lifetime)

- Population Decay Product Concentration (Column #5). This value represents the collective air concentrations of radon progeny for all residents residing within 80 km of the facility.

  The computer-generated collective exposure of 2.29E-2 WL for the Lucky Mc population is not readily derived manually, and represents the sum of population weighted air-concentrations at residential locations defined by sector and distance (see Table 1 of Appendix B).

- Population Annual Fatal Cancer Risk (Column #6). The annual risk to the 0-80 km population is derived by integrating population exposures to radon progeny over a one year period and multiplying the derived person-WLM/y times the EPA's risk coefficient.

  The annual fatal cancer risk to the 0-80 km population for the Lucky-Mc facility is derived as follows:

  $$Risk_{cancer} = (2.29E\text{-}2\ person\text{-}WL)\frac{(24\ h/d \times 365\ d/y)}{170\ h/m}(2.24E\text{-}4\ cancer/WLM)$$

  $Risk_{cancer}$ = 2.64E-04 cancers/y

Table 5-6. Radon-222 Exposures and Associated Risks For MOU Disposal Schedule

Facility	Average Radon Emission (Ci/y)	Maximum Individual at Risk: Radon Conc. (pCi/l)	Maximum Individual at Risk: Decay Product Conc. (WL)	Maximum Individual at Risk: Lifetime Fatal Cancer Risk	Population (0-80 km): Person-Decay Prod. Conc. (Person-WL)	Population (0-80 km): Population Fatal Cancer Risk (deaths/y)
ANC, Gas Hills, WY	523	7.21E-4	4.69E-6	3.79E-6	1.76E-2	2.03E-4
ARCO Coal, Bluewater, NM	1615	2.29E-2	9.12E-5	7.37E-5	4.67E-1	5.39E-3
Atlas, Moab, UT	854	3.60E-2	1.32E-4	1.07E-4	1.53E-1	1.77E-3
Conoco, Conquista, TX	724	1.39E-2	4.59E-5	3.71E-5	1.04E+0	1.20E-2
Ford-Dawn Mining, Ford, WA	450	3.47E-2	1.04E-4	8.40E-5	1.94E-1	2.24E-3
Hecla Mining, Durita, CO	116	1.21E-1	3.34E-4	2.70E-4	1.04E-2	1.19E-4
Homestake, NM*	885	4.77E-2	1.57E-4	1.27E-4	3.19E-1	3.68E-3
Pathfinder-Lucky Mc, Gas Hills, WY	730	8.77E-4	6.12E-6	4.95E-6	2.29E-2	2.64E-4
Petrotomics, Shirley Basin, WY	484	5.27E-3	2.10E-5	1.70E-5	3.15E-2	3.64E-4
Quivera, Ambrosia Lake, NM	1548	3.82E-3	1.95E-5	1.57E-5	2.31E-1	2.67E-3
Rio Algom, Lisbon, UT	274	1.52E-3	6.52E-6	5.27E-6	1.50E-2	1.73E-4
Sohio-L-Bar, NM	204	3.78E-3	1.51E-5	1.22E-5	1.35E-1	1.56E-3
UMETCO, Gas Hills, WY	589	7.13E-4	4.98E-6	4.02E-6	1.82E-2	2.10E-4
UMETCO, Maybell, CO	175	2.13E-3	1.39E-5	1.12E-5	1.28E-2	1.47E-4
UMETCO, Uravan, CO	208	1.44E-3	7.31E-6	5.89E-6	2.52E-2	2.91E-4
UNC, Church Rock, NM	469	2.20E-2	7.29E-5	5.89E-5	1.40E-1	1.61E-3
Union Pacific, Bear Creek, WY	713	8.72E-4	5.66E-6	4.57E-6	4.53E-2	5.23E-4
WNI, Sherwood, WA	347	3.24E-3	1.29E-5	1.04E-5	1.04E-1	1.20E-3
WNI, Split Rock, WY	690	1.47E-2	5.37E-5	4.34E-5	2.92E-2	3.37E-4
					Total =	3.48E-2

* These values represent the combined releases from both the large and small impoundments.

Variations in exposures and risks among facilities differ by two to three orders of magnitude. For lifetime fatal risks to the maximally exposed individuals, values range from a low probability of 3.79E-6 (ANC, Gas Hills) to a high of 2.70E-4 (Hecla Mining) among the nineteen facilities under the MOU disposal schedule (see Table 5-6). Variations in the risks to the MIR primarily reflect radon emission rates and distances from the impoundment facilities. The collective annual fatal cancer risks to the 0-80 km population show a similar variation. The low annual population cancer risk of 1.19E-4 (Hecla Mining, Durita) is two orders of magnitude lower than the highest value of 1.20E-2 cancer death per year corresponding to Conoco's Conquista facility. In addition to radon emission rates, the principal factors affecting variations in population risks are population size and distribution within the 80 km radii.

The annual population fatal cancer risks for all nineteen facilities combined are 3.48E-2 deaths per year with an average value of 1.8E-3 deaths/year. Based on these probabilities, a single fatal cancer is estimated for the cumulative exposures from all facilities over a 29 year period. For a single facility, the average probability of one fatal cancer over the 70-year assessment period is about 0.13.

For comparison, baseline radon-222 exposures and associated risks are provided in Table 5-7. Fatal cancer deaths for all nineteen facilities is 2.26E-2, with an average of 1.19E-3 deaths per year. The reduced radon emissions and risks representing baseline values are those that would have been expected had all nineteen non-operational facilities been able to meet the original CAA disposal date of December 15, 1991. A comparison of values from Table 5-6 and 5-7 show that the baseline emissions and risks are nearly a factor of two lower than those corresponding to the MOU disposal schedule.

5.5 MEASURED RADON EMISSION LEVELS

There has been relatively little experience with measurements determining the effectiveness actually achieved by the radon covers placed on uranium mill tailings piles. This is because few Title II piles have been covered under Subpart T and because testing the effectiveness of covers was not required for Title II piles under UMTRCA. The available evidence, some of it from Title I piles that are being reclaimed by the Department of Energy, indicates that the actual level of emissions through the radon covers is considerably lower than the 20 pCi/m^2-s flux standards in Subpart T and UMTRCA, generally lower by a factor of two to ten. The probable reason is that clay and soil with high clay content have proven to be more readily available at the mill tailings sites than was assumed in the cost analyses performed for the UMTRCA and the 1989 Subpart T rulemakings. The superiority of clay as a cover material can be seen in Figure 5-1; it is considerably more effective for a given depth of cover than are other cover materials.

Table 5-7. Radon-222 Exposures and Associated Risks For Baseline Emissions

Facility	Average Radon Emission (Ci/y)	Maximum Individual at Risk: Radon Conc. (pCi/l)	Maximum Individual at Risk: Decay Product Conc. (WL)	Maximum Individual at Risk: Lifetime Fatal Cancer Risk	Population (0-80 km): Person-Decay Prod. Conc. (Person-WL)	Population (0-80 km): Population Fatal Cancer Risk (deaths/y)
ANC, Gas Hills, WY	281	3.88E-4	2.52E-6	2.04E-6	9.44E-3	1.09E-4
ARCO Coal, Bluewater, NM	766	1.09E-2	4.32E-5	3.50E-5	2.22E-1	2.56E-3
Atlas, Moab, UT	327	1.38E-2	5.04E-5	4.07E-5	5.85E-2	6.75E-4
Conoco, Conquista, TX	638	1.22E-2	4.05E-5	3.27E-5	9.15E-1	1.06E-2
Ford-Dawn Mining, Ford, WA	313	2.41E-2	7.22E-5	5.83E-5	1.35E-1	1.56E-3
Hecla Mining, Durita, CO	90	9.37E-2	2.59E-4	2.09E-4	8.04E-3	9.28E-5
Homestake, NM*	467	2.51E-2	8.31E-5	6.71E-5	1.68E-1	1.94E-3
Pathfinder-Lucky Mc, Gas Hills, WY	518	6.23E-4	4.35E-6	3.51E-6	1.62E-2	1.87E-4
Petrotomics, Shirley Basin, WY	291	3.17E-3	1.26E-5	1.02E-5	1.89E-2	2.18E-4
Quivera, Ambrosia Lake, NM	940	2.32E-3	1.18E-5	9.53E-6	1.40E-1	1.62E-3
Rio Algom, Lisbon, UT	255	1.42E-3	6.07E-6	4.90E-6	1.40E-2	1.62E-4
Sohio-L-Bar, NM	204	3.78E-3	1.51E-5	1.22E-5	2.57E-3	2.97E-5
UMETCO, Gas Hills, WY	490	5.93E-4	4.14E-6	3.35E-6	1.52E-2	1.75E-4
UMETCO, Maybell, CO	127	1.54E-3	1.01E-5	8.13E-6	9.26E-3	1.06E-4
UMETCO, Uravan, CO	178	1.24E-3	6.27E-6	5.06E-6	2.16E-2	2.49E-4
UNC, Church Rock, NM	263	1.23E-2	4.09E-5	3.30E-5	7.82E-2	9.03E-4
Union Pacific, Bear Creek, WY	454	5.55E-4	3.61E-6	2.92E-6	2.88E-2	3.32E-4
WNI, Sherwood, WA	240	2.24E-3	8.92E-6	7.21E-6	7.16E-2	8.26E-4
WNI, Split Rock, WY	569	1.21E-2	4.43E-5	3.58E-5	2.41E-2	2.78E-4
						Total = 2.26E-2

* These values represent the combined releases from both the large and small impoundments.

CHAPTER 6

RADON-222 CONTROL TECHNIQUES

This chapter provides a brief discussion of specific techniques employed for interim and long-term control of radon emissions from the tailings piles. Also discussed are methods used to dewater and dry the tailings impoundment areas before a permanent cover can be installed.

6.1 INTERIM RADON CONTROL TECHNIQUES

6.1.1 Water Spraying

Saturating tailings with a water sprinkling system effectively reduces radon-222 emissions to nominal levels. The degree of radon-222 control increases slightly with the depth of the water. Factors affecting the effectiveness of this practice include the mill water recirculation rate (if any), evaporation and precipitation rates, impoundment construction and slope, phreatic levels, ground water contamination potential, and dike or dam stability. Some above-grade tailings impoundments minimize the depth of the water to reduce seepage and possible ground water contamination through the use of overflow pipes, which direct water to separate evaporation ponds. (Strict ground water contamination standards, as specified in 40 CFR Subpart D 192.32, will frequently determine the degree of water cover maintained in an active area.)

6.1.2 Interim Soil Cover

An application of an interim earthen cover on dry portions of a tailings impoundment reduces radon-222 emissions prior to final reclamation. The effectiveness of the interim cover in reducing radon emissions is determined by the earth-type used and the thickness of the cover (see Chapter 5, Figure 5-2). For example, a 0.3 meter (1 foot) or a 1 meter (3.3 foot) thick soil cover having 8 percent moisture content would theoretically reduce radon-222 emissions by about 25 and 62 percent, respectively.

Site characteristics that control or prohibit the applicability of interim cover include impoundment design and construction; dam height; stability; phreatic level; permeability; site water balance; evaporation rates; presence and availability of suitable earth cover material. Operating factors such as expected uranium production rate, length and number of standby periods, impoundment capacity, and expected mill life must also be considered in determining applicability of interim covers.

6.2 DEWATERING OF TAILINGS PILES IN PREPARATION FOR PERMANENT COVER

During operational and standby phases of uranium milling, a water cover over the tailings piles is commonly used as a radon reduction technique. Prior to final reclamation, the tailings disposal area, however, must be dewatered and dried in order to permit the use of heavy equipment for permanent cover installation. Past and current uranium tailings disposal methods have relied exclusively upon exposure of the surface of the impounded tailings to sunlight and winds for drying. Rates of evaporation vary considerably with climate, but are generally very high in those states which produce most of the uranium.

The time required to dewater a tailings pile can vary considerably, based on many factors such as size of the tailings disposal area, the uranium recovery process utilized, the disposal management system employed, the method used for dewatering, etc. As mentioned above, the most commonly used method for dewatering the tailings piles is natural evaporation. Although evaporation rates are greatly dependent on climate, the majority of uranium mill sites are located in semi-arid, dry areas of the country.

In order to expedite site reclamation and consolidation of the tailings pile, it is common for the owners of the mill to employ the use of an enhanced evaporation system. The evaporation process is greatly enhanced through the use of a pumping and spraying distribution system.

In addition, tailings embankments are generally recontoured and surface water diversion systems are constructed for the purpose of directing rain and snow runoff away from the tailings area.

Based on the above consideration and industry/DOE experience to date, the NRC, in the Final Generic Environmental Impact Statement On Uranium Milling (NUREG-0706), utilized a five-year disposal period for the tailings pile in their assessment of the "model" mill, which was considered to be representative of the milling industry. This five-year disposal period has been commonly adopted in other uranium mill environmental assessments (NRC80).

Processes that reduce the liquid content of impounded tailings also reduce the potential for seepage problems, by reducing the source of and driving head for seepage. In addition, tailings with a low moisture content will consolidate more rapidly and add to the stability of the tailings mass, thus reducing problems associated with final impoundment drying and reclamation.

The most common engineered method of reducing the water content in the tailings is in-situ dewatering. This is accomplished by permitting gravity draining of liquids to a tailing low point (sump pit) from which clear decanted liquid is withdrawn and

recycled and/or transported to an evaporation pond. An underdrain system, generally consisting of a network of slotted PVC piping covered by a blanket of sand and/or gravel and supported by the low-permeability impoundment bottom, is used to withdraw free liquid from the tailings. Water, which collects in the sump pit, can then be pumped back to the mill for reuse or directed to an evaporation pond. This not only reduces the phreatic surface of the liquids in the tailings (the driving force for seepage), but also increases the stability of the tailings mass.

6.3 LONG-TERM RADON CONTROL TECHNIQUES

6.3.1 Earth Cover

Covering the dried tailings with soil is a proven effective method for reducing radon-222 emissions (Ro84). The depth of soil required for a given amount of control varies with the type of earth and radon-222 exhalation rate.

Earth covers decrease radon-222 emissions by retaining the radon-222 released from the tailings long enough so that a major portion will decay in the cover. A large decrease in radon-222 emissions is achieved by applying almost any type of earth. Radon-222 diffusion through earth is a complex phenomenon affected by processes such as molecular diffusion, described mathematically by Fick's law. These complex parameters have been evaluated by Rogers and Nielson (Ro81) and were described in Chapter 4. Diffusion depends greatly on the porosity and moisture content of the medium through which it occurs. Therefore, high-moisture content soils, such as clay, provide greater radon-222 emission reduction because of their smaller diffusion coefficients.

In practice, earthen cover designs must take into account uncertainties in the measured values of the specific cover materials used, the tailings to be covered, and predicted long-term values of equilibrium moisture content for the specific location. The uncertainty in predicting reductions in radon-222 flux increases rapidly as the radon-222 emission limit is reduced.

6.3.2 Asphalt Covers

Asphalt cover systems have been proposed as a radon-222 control technique because such systems exhibit very low radon-222 diffusion coefficients. The Pacific Northwest Laboratory (PNL) has investigated controlling the release of radon-222 through use of asphalt emulsion covers for DOE's Uranium Mill Tailings Remedial Action Project (UMTRAP). Results have shown asphalt emulsion cover systems to be effective at substantially reducing radon-222 emissions, and field tests indicate that such systems have the properties necessary for long-term effectiveness and stability. Of the various types of asphalt cover systems that were researched, an

asphalt emulsion admix seal was found to be the most effective (Ha84; Ba84).

Based on cost estimates for application of a full-scale asphalt cover (Ba84), asphalt cover systems could prove to be economically competitive with earthen covers at some existing sites. These cost estimates are applicable to relatively flat sites, which may require regrading before these techniques could be applied. Long-term cover protection, in the form of gravel or vegetation above an earthen cover applied over the asphalt radon-222 barrier, may also have to be considered.

6.3.3 Soil Cement Covers

A mixture of soil and Portland cement, called soil cement, is widely used for stabilizing and conditioning soils (Pc79). The aggregate sizes of tailings appear suitable for soil cement, which is relatively tough, withstands freeze/thaw cycles, and has a compressive strength of 300 to 800 psi. When combined in a disposal system with a 1-meter earth cover, soil (tailings) cement would likely provide reasonable resistance to erosion and intrusion, substantially reduce radon releases, and shield against penetrating radiation. A previous study (EPA82) has estimated that soil cement covers would control emissions to approximately the same levels as a 2-meter earth cover. Costs are expected to be comparable to those of thick earth covers. The long-term performance of soil cement is unknown, especially as tailings piles shift or subside with age. When placed over large surface areas, soil cement typically cracks at various intervals. The importance of this cracking on the effectiveness of soil cement has not been evaluated, but is expected to be small.

6.3.4 Other Radon Control Techniques

A number of other radon control techniques have been proposed and subjected to preliminary evaluations for applicability. Several of these techniques are summarized below.

Synthetic Covers and Chemical Sprays. Synthetic material such as a polyethylene sheet can reduce radon-222 emissions if carefully placed and sealed on dry tailings. The overall effectiveness of synthetic covers is not known since leaks occur around the edges and at seams and breaks. Synthetic covers also have a limited life, especially in dry, sunny, windy areas, and will not provide a long-term barrier to radon-222. Such a barrier would aid, at least temporarily, in the control of radon-222 if a soil cover material were subsequently applied.

Chemical stabilization sprays that form coatings on the dry tailings are effective for controlling dust, but are not effective in controlling radon-222 since an impermeable cover is not obtained.

The lack of long-term stability of synthetic covers and the ineffectiveness of chemical sprays make these options unsuitable for long-term passive control.

Thermal Stabilization. Thermal stabilization is a process in which tailings are sintered at high temperatures. The Los Alamos National Laboratory has conducted a series of tests on tailings from four different inactive mill sites (Dr81). The results show that thermal stabilization is effective in preventing the release (emanation) of radon from tailings. However, before thermal stabilization can be considered as a practical disposal method, information is needed on the following: (1) the long-term stability of the sintered material; (2) the interactions of the tailings and the refractory materials lining the kiln; (3) the gaseous and particulate emissions produced during sintering of tailings; and (4) revised engineering and economic analysis as more information is developed.

Since gamma radiation is still present, protection against the misuse of sintered tailings is required. While the potential health risk from external gamma radiation is not as great as that from the radon decay products, it can produce unacceptably high exposure levels in and around occupied buildings. Also, the potential for groundwater contamination may require the use of liners in a disposal area.

Chemical Processing. The Los Alamos National Laboratory has also studied various chemical processes such as nitric acid leaching to extract thorium-230 and radium-226 from the tailings, along with other materials (Wm81). After removal from the tailings, the thorium and radium can be concentrated and fixed in a matrix such as asphalt or concrete. This greatly reduces the volume of these hazardous materials and allows disposal with a higher degree of isolation than economically achievable with unextracted tailings.

The major question regarding chemical extraction is whether it reduces the thorium and radium values in the stripped tailings to safe levels. If processing efficiencies of 80 to 90 percent were attained, radium concentrations in tailings would still be in the 30 to 60 pCi/g range. Thus, careful disposal of the stripped tailings would still be required to prevent misuse. Another disadvantage of chemical processing is the cost, although some of the costs might be recovered from the sale of other minerals recovered in the processing (Th81).

Deep-Mine Disposal. Disposal of tailings in worked-out deep mines offers several advantages to surface disposal options. The probability of intrusion into and misuse of tailings in a deep mine is much less than in the case of surface disposal. Radon releases to the atmosphere would be eliminated, for practical purposes, as would erosion and external radiation. The major disadvantage of deep mine disposal is the potential contamination of groundwater

resulting from leaching of radionuclides and other toxic chemicals from the tailings. Overall, while this method can provide a relatively high level of protection against exposure to radon and misuse of tailings, it has a high potential for causing serious groundwater contamination which is very costly to control.

Caliche Cover. Caliche (calcium deposits that form within or on top of soil in arid or semi-arid regions) cover material for mill tailings piles has been suggested as a control method (Br81). This material may be effective in precluding excessive mobilization of certain radionuclides and toxic elements. However, the effectiveness and long-term performance of such covers have not been adequately assessed.

6.4 COMPARISON OF EARTH COVERS TO OTHER CONTROL TECHNIQUES

In comparison to other control technologies, earth covers have been shown to be the most cost effective (NRC 80). Apart from cost considerations, earth covers as a method to control radon-222 emissions also offer several other benefits. For example, synthetic covers, such as plastic sheets, do not reduce gamma radiations. However, earth covers that are thick enough to reduce radon-222 emissions will reduce gamma radiation to insignificant levels. Further, chemical and physical stresses over a substantial period of time destabilize synthetic covers; earth covers are stable over the long term, provided the erosion caused by rain and wind is contained with vegetation or rock covers, and appropriate precautions are taken against natural catastrophes, e.g., floods and earthquakes.

Earth covers also reduce the likelihood of groundwater contamination resulting from either storing radioactive materials in underground mines (typically located under the water table) or from using the leaching process to extract radioactive and nonradioactive contaminants from mill tailings. Moreover, although underground mine disposal is an effective method to protect against degradation and intrusion by man, it nevertheless incurs a social cost. For example, storing tailings in underground mines eliminates the future development of the mines' residual resources. Again, earth covers with proper vegetation and rock covers can protect against human intrusion, without incurring such social costs.

Finally, earth covers provide more effective long-term stabilization than either water or soil cement covers. Inasmuch as soil cement covers are comparable to earth covers in terms of cost effectiveness, their long-term performance is as yet unknown. Water covers, on the other hand, depend upon long term institutional oversight. Institutional controls cannot be relied upon over time periods as long as 1000 years or more. Moreover, earth covers are more practical than water covers in arid regions.

The standards established for long-term control of residual radioactive materials from inactive uranium processing sites under UMTRCA (40 CFR 192, Subpart A) require the following:

> ". . . Control shall be designed to: (a) Be effective for up to one thousand years, to the extent reasonably achievable, and, in any case, for at least 200 years, and, (b) Provide reasonable assurance that releases of radon-222 from residual radioactive material to the atmosphere will not: (1) Exceed an average release rate of 20 picocuries per square meter per second, or (2) Increase the annual average concentration of radon-222 in air at or above any location outside the disposal site by more than one-half picocurie per liter."

It has been decided that the earth cover will serve as the radon control technique (specified by 10 CFR 40, Appendix A) which currently provides the most cost effective means of satisfying the UMTRCA control standards.

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CHAPTER 7

COSTS AND BENEFITS

The perspective from which the costs and benefits of this rulemaking are assessed is addressed in the first section of this chapter. The costs of covering the piles and the financial burden this imposes on the mill tailings industry are discussed in Sections 7.2 through 7.4, and in Section 7.6. Costs and benefits are compared in Section 7.5. The regulatory flexibility analysis is in the last section of this chapter.

7.1 THE COSTS AND BENEFITS OF RADON COVER IN PERSPECTIVE

The 20 pCi/m^2-s radon emissions limit used throughout this analysis was established in the 1983 UMTRCA rulemaking. That rulemaking found that the costs of achieving a 20 pCi/m^2-s limit were justified by the reduction in radon induced fatal cancers. The 1989 CAA rulemaking reaffirmed the 20 pCi/m^2-s limit, finding that it was safe with an ample margin of safety. The rulemaking discussed in this BID does not alter those decisions, nor does it reconsider the results of those rulemakings. The costs and benefits of covering the uranium mill tailings piles in order to control radon emissions are not changed.

However, there are other costs and benefits specifically associated with the rulemaking addressed in this BID. They are separate from the costs and benefits discussed in the paragraph above and are dealt with separately. These costs and benefits are evaluated from the perspective of the situation as it existed at the end of 1991, after the MOU between EPA, NRC and the Agreement States on Subpart T had been signed. The mill tailings piles subject to the MOU did not have completed radon covers at that time. Under provisions of Subpart T as enacted, they were to have had permanent radon covers by December, 1991. The MOU postponed the time for achieving final cover; effectively reducing the costs to the mill operators of meeting the cover requirements because it delays the time when the expenditures were to have been made. The MOU also allowed an increase in the overall fatal cancers caused by emissions from the piles by allowing emissions to continue past the end of 1991. From this perspective, the cost to society of this rulemaking becomes the increased fatal cancers caused by the extended period of radon emissions and the benefit to society becomes the reduction in costs due to the delay in covering the piles.

The increased fatal cancers resulting from this rulemaking are presented in Chapter 5 and the cost savings are presented in the next three sections of this chapter.

7.2 COSTS OF COVERING THE PILES

The costs of covering the piles subject to the MOU are developed in this section. Earthen covers placed on the tops and sides of uranium mill tailings piles have been demonstrated to be a cost-effective means of providing long-term control of radon emissions. This chapter presents cost estimates for the placement of earthen covers which meet the 20 pCi/m^2-s emissions limit for the currently non-operational tailings impoundments.

The cost of earthen cover varies with the geographic location of the tailings impoundment, its layout, the topography of the disposal site and its surroundings, and the thickness of the cover required to achieve the emission standard. The cost also varies with the availability of cover material, the distance it must be hauled, and the ease of its excavation. If the necessary materials, such as gravel, dirt, and clay, are not available locally, they must be purchased and/or hauled, thereby significantly increasing costs. In general, the more difficult the excavation the more elaborate and expensive the equipment needed will be, and the higher the cost will be.

The date of covering the piles affects the present valuation of the cost of cover. Therefore, the length of the delay, as well as site specific characteristics of the piles themselves, must be taken into account in determining the costs of the covers.

Table 7-1 provides estimates of the radon emissions release rates and cover thickness required on each pile to meet the 20 pCi/m^2-s emissions limit. It also gives the pile areas and information on any interim cover that may be on the pile. Estimates of the total volume of earth needed for permanently covering each pile can be calculated from the information in this table by subtracting the volume of the interim cover from the volume needed to cover the entire pile.

The installation of the permanent cover is assumed to take one year, as is also assumed for calculating estimated radon emissions in Chapter 5. The permanent cover is assumed to be completed at the end of the year of the MOU target disposal date.

Cost estimates are generated using the same methods as were used in estimating the costs for covering the tailings at licensed mill tailings facilities for the NESHAPs promulgated in 1989. The methodology is described in detail in Appendix B of the Risk Assessments Appendixes (Appendix to Volume 2), and the costs are summarized in Chapter 4 of the Economic Assessment (Volume 3), of the Background Information Document for those NESHAPs (EPA89c, EPA89d). The unit costs for individual cover activities were updated to 1991 dollars for this analysis. The revised costs were

Table 7-1. Facility-Specific Release Rates, Cover Depths, and Areas

Facility	Release Rate (pCi/m^2-s)	Cover Depth Required to Meet Standard (m)	Current Interim Cover Depth (m)	Area Covered by Interim Cover (m^2)	Total Area to be Covered (m^2)
ANC, Gas Hill, WY	420	3.25	0.15	445,000	445,000
ARCO Coal, Bluewater, NM	620	3.66	0.75	607,000	1,241,000
Atlas, Moab, UT	540	3.52	N/A	0	518,000
Conoco, Conquista, TX	224	2.58	2.58	607,000	1,012,000
Ford-Dawn Mining, Ford, WA	240	2.65	1.50	384,000	497,000
Hecla Mining, Durita, CO	428	3.27	0.60	142,000	142,000
Homestake, NM (large impoundment)	300	2.89	N/A	0	688,000
Homestake, NM (small impoundment)	300	2.89	0.75	24,000	52,000
Pathfinder-Lucky Mc, GH, WY	220	2.56	0.75	761,000	821,000
Petrotomics, Shirley Basin, WY	570	3.58	0.75	461,000	461,000
Quivera, Ambrosia Lake, NM	237	2.64	0.30	1,344,000	1,490,000
Rio Algom, Lisbon, UT	420	3.25	0.90	405,000	405,000
Sohio-L-Bar, NM	500	3.43	3.43	324,000	324,000
UMETCO, Gas Hills, WY	310	2.92	1.20	777,000	777,000
UMETCO, Maybell, CO	128	1.98	2.73	141,000	202,000
UMETCO, Uravan, CO	480	3.39	2.73	283,000	283,000
UNC, Church Rock, NM	290	2.85	0.30	417,000	417,000
Union Pacific, Bear Creek, WY	420	3.25	0.30	720,000	720,000
WNI, Sherwood, WA	200	2.46	N/A	0	380,000
WNI, Split Rock, WY	430	3.27	3.00	902,000	902,000
TOTALS				8,744,000	11,777,000

taken from recent versions of the same sources used for the unit costs in Appendix B (ME91a, ME91b). The updated unit costs are:

- Hauling — $3.88 per cubic meter,
- Excavating — $1.23 per cubic meter,
- Grading — $2.04 per cubic meter,
- Compacting — $1.63 per cubic meter.

The total cost of covering each tailings pile is estimated based on these unit costs and the volumes of earth cover calculated from information in Table 7-1. Excavating and grading costs are applied for regrading of slopes of each pile and for the reclama-

tion of the borrow pits. Table 7-2 presents the costs for each pile for the specific cover activities required to construct earth covers. A standard overhead cost is applied to arrive at the total 1991 cost to cover each pile to achieve a radon emission rate of 20 pCi/m^2-s.

Table 7-2 also shows the present value, or discounted, costs of covering these piles on the MOU target dates. The present value costs shown are based on discount rates of 2, 5 and 7 percent.

7.3 COST OF VERIFYING RADON EMISSIONS

Testing the covered piles for radon emissions is a relatively minor cost. After completing construction of the radon cover, the owner or operator of each uranium mill tailings pile is required to measure the radon flux through the permanent radon barrier to verify the effectiveness of the design of the barrier in ensuring that the 20 pCi/m^2-s standard is not exceeded. The flux is to be determined after the radon barrier is in place, but before the placement of gravel and riprap, which are measures for achieving long-term stabilization of the pile. The necessary measurements are to be performed in accordance with the procedures described in 40 CFR part 61, Appendix B, Method 115 or any other method proposed by a licensee and approved by NRC or an affected Agreement State as being at least as effective as EPA method 115 in demonstrating the effectiveness of the permanent barrier in achieving compliance with the standard. Method 115 specifies that the flux be determined from the mean of a minimum of 100 radon flux measurements made from the adsorption of radon on activated charcoal in large-area collectors placed at regularly spaced intervals on the surface of the pile. Radon is to be collected for a 24-hour period. The radon collected is measured by gamma-ray spectroscopy.

The typical cost of verifying that a covered pile meets the 20 pCi/m^2-s limit is in the range of $5,000 to $6,000, but it may be as high as $10,000. This is the cost to the pile owner or operator if the task is performed by a firm specializing in this type of measurement. It covers transportation to and from the pile site, all labor associated with placing and recovering the large-area collectors and measuring the radon adsorbed on the charcoal, the cost of the activated charcoal used in the collectors, and the capital cost of the canisters and instruments used.

Assuming that it costs $10,000 to test each pile, the total cost of verifying the emissions for the approximately 34 piles at the 19 sites is expected to be about $340,000 disregarding discounting. These costs would be added to the costs shown in Table 7-2, but they increase overall costs insignificantly.

Table 7-2. Costs of Achieving the Regulatory Emission Standards
(1991 $, Million)

Mill Name	Regrade Slopes	Dirt Cover	Reclaim Borrow Pit	Total	Total Including O&P @ 7%	MOU Target Date	Present Value Costs			
							At Zero Percent Real Interest Rate	At 2 Percent Real Interest Rate	At 5 Percent Real Interest Rate	At 7 Percent Real Interest Rate
ANC, Gas Hill, WY	1.2	12.2	0.6	14.0	15.0	1995	15.0	13.9	12.4	11.4
ARCO Coal, Bluewater, NM	4.1	35.4	1.8	41.2	44.1	1995	44.1	40.7	36.3	33.6
Atlas, Moab, UT	1.5	16.1	0.8	18.5	19.7	1996	19.7	17.8	15.5	14.0
Conoco, Conquista, TX	4.1	9.3	0.5	13.8	14.8	1996	14.8	13.4	11.6	10.6
Ford-Dawn Mining, Ford, WA	1.1	6.6	0.3	8.0	8.6	2010	8.6	5.9	3.4	2.4
Hecla Mining, Durita, CO	0.2	3.4	0.2	3.7	4.0	1997	4.0	3.6	3.0	2.7
Homestake, NM (large impoundment)	2.3	17.6	0.9	20.8	22.3	1996	22.3	20.2	17.5	15.9
Homestake, NM (small impoundment)	0.0	1.2	0.1	1.3	1.4	2001	1.4	1.1	0.8	0.7
Pathfinder-Lucky Mc, Gas Hills, WY	1.7	13.6	0.7	15.9	17.0	1998	17.0	14.9	12.1	10.6
Petrotomics, Shirley Basin, WY	1.3	11.5	0.6	13.4	14.3	1995	14.3	13.2	11.8	10.9
Quivera, Ambrosia Lake, NM	4.8	31.3	1.6	37.6	40.2	1997	40.2	35.7	30.0	26.8
Rio Algom, Lisbon, UT	0.7	8.4	0.4	9.6	10.3	1996	10.3	9.3	8.0	7.3
Sohio-L-Bar, NM	0.0	0.0	0.0	0.0	0.0	1992	0.0	0.0	0.0	0.0
UMETCO, Gas Hills, WY	2.1	11.9	0.6	14.5	15.6	1995	15.6	14.4	12.8	11.9
UMETCO, Maybell, CO	0.4	0.1	0.0	0.5	0.5	1997	0.5	0.4	0.4	0.3
UMETCO, Uravan, CO	0.4	1.7	0.1	2.1	2.3	2001	2.3	1.9	1.4	1.2
UNC, Church Rock, NM	1.1	9.4	0.5	11.0	11.8	1997	11.8	10.5	8.8	7.9
Union Pacific, Bear Creek, WY	2.5	18.8	0.9	22.2	23.8	1996	23.8	21.6	18.6	17.0
WNI, Sherwood, WA	0.9	8.3	0.4	9.6	10.3	1996	10.3	9.3	8.1	7.3
WNI, Split Rock, WY	3.5	2.2	0.1	5.7	6.2	1995	6.2	5.7	5.1	4.7
Total	33.9	218.9	10.9	263.7	282.2		282.2	253.5	217.5	197.3

7.4 COST SAVINGS DUE TO POSTPONING THE TIME OF COVER

Under provisions of the CAA, 40 CFR 61, Subpart T, all non-operational piles were to have been permanently covered by December 15, 1991. The MOU agreement between the EPA, the NRC, and the affected Agreement States postponed the dates for requiring final cover; providing specific dates for covering each pile. The dates were deferred from one to nineteen years. This delay is a savings to the uranium milling industry and to society as a whole. The savings, shown in the last column of Table 7-3, are the differences between the 1991 cost of covering the piles and the discounted costs of covering the piles on the dates specified in the MOU. The 1991 cost of increasing the cover to the required depth for all impoundments would have been somewhat less than $300 million. Postponing covering the piles reduces this cost by about $29, $65, or $85 million, at 2, 5, or 7 percent discount rates, respectively. This savings would be increased if the time for covering any of the piles were delayed beyond the MOU cover dates. The savings would be reduced if any of the final covers were completed before the dates established by the MOU, or if additional interim covers were placed on the piles before the MOU dates.

Table 7-3. Present Value Costs to Cover by MOU Target Dates (Millions of 1991 Dollars)

	Baseline Cost to Cover in 1991	Present Value Cost to Cover by MOU Target Date	Cost Savings From 1991 Baseline
0% Real Interest Rate	282.2	282.2	0.0
2% Real Interest Rate	282.2	253.5	28.7
5% Real Interest Rate	282.2	217.5	64.6
7% Real Interest Rate	282.2	197.3	84.9

7.5 COST SAVINGS AND RISK INCREASES COMPARED

Table 5-7 shows that 2.26E-2 fatal cancers were expected to have occurred over the 70 year assessment period used for evaluating risk, had all the piles listed in the MOU been covered by the end of 1991. The expected number of fatal cancers increases to 3.48E-2 as a result of delaying placement of radon covers until the dates agreed to in the MOU. The increased number of fatal cancers resulting from this rulemaking is 1.22E-2 over the 70 year assessment period. This increase in fatal cancers can be compared to the reduced costs shown in Table 7-3.

7.6 FINANCIAL BURDEN ON INDUSTRY

A variety of costs are borne by the uranium milling industry in keeping piles on standby or inactive status rather than taking them to final closure. They include the costs of keeping personnel at the pile sites to carry out the variety of duties associated with the maintenance, upkeep and guarding of the piles, and the costs associated with management oversight. In addition, there are various fees associated with maintaining NRC or Agreement State licenses as long as the piles are on standby or inactive status. The licensees are also financially liable for the piles as long as they retain title to them.

All of these costs cease when the piles have been covered and stabilized in accordance with the provisions of UMTRCA, so that permanent responsibility for their care passes to the Federal Government. The cessation of these costs is an incentive for the licensees to close the piles.

There are, however, substantial costs associated with covering these piles, as shown in Tables 7-2 and 7-3. Further expenditures are necessary to meet the ground water and stability provisions of UMTRCA in order to finally close these piles. The costs of these other provisions are not addressed in this rulemaking because they do not contribute to the reduction in radon emissions.

EPA has assumed in its previous rulemakings that the piles could be closed five years after milling operations ended. Five years is the approximate time it takes to dry out a thoroughly wet pile and to complete construction of the radon cover. The MOU between NRC, the affected Agreement States, and EPA was negotiated in Oct. 1991, before this rulemaking was undertaken. The target dates in the MOU were established expressly so that the licensees would achieve control of radon emissions as expeditiously as practicable considering technological feasibility.

The postponement in the dates for requiring cover, past the December 1991 deadline established by Subpart T, represents a reduction in the costs of covering the piles. This, in itself, reduces the cost burden to the pile owners.

The NRC and the affected Agreement States agreed to ensure that the schedules and conditions for affecting final closure are flexible enough to consider technological feasibility. A number of licensees were allowed more than five years from the signing of the MOU to complete construction of radon covers. Therefore, it is reasonable to assume that the licensees will be able to meet the MOU dates without incurring unreasonable costs.

7.7 REGULATORY FLEXIBILITY ANALYSIS

The Regulatory Flexibility Act (RFA) requires regulators to determine whether proposed regulations would have significant economic impact on a substantial number of small businesses or other small entities. If so, regulators are required to consider specific regulatory alternatives that minimize the impacts on these small entities without compromising the objective of the statute under which the rule is enacted. Alternatives for consideration by the RFA are tiering regulations, performance rather than design standards, and small firm exemptions.

Most firms that own uranium mills are divisions or subsidiaries of major U.S. and international corporations. Many of these uranium milling operations are a part of larger diversified mining firms which are engaged in a number of raw materials industries; uranium milling represents only a small portion of their overall operations.. Others are owned by major oil companies and electric utilities which were engaged in horizontal and vertical integration, respectively, during the industry's growth phase in the 1960s and 1970s. In 1977 there were 26 companies operating uranium mills in the U.S. Presently there are approximately three, and these operate only part time. Future projections for the industry are bleak; it is unlikely that more than a very few mills will operate at any one time in the future. The high financial risk and the large capital requirement needed to enter or to remain viable in the industry means that the industry will be restricted to large diversified firms and large electric utilities.

This rulemaking reduces the economic cost to the mill owners for covering the uranium mill tailings piles subject to the Subpart T regulation promulgated in 1989 because it effectively postpones the required expenditures to later dates. It was found in the 1989 rulemaking that there was no significant impact on small business entities. There has been no change in this, no new tailings piles have been constructed since 1989.

The result is that no significant impact on small business entities is expected if this rulemaking is promulgated.

APPENDIX A

CAP88-PC INFORMATION SHEETS

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CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Baseline Emissions Page 1 of 1

Facility: Federal American Location: Riverton, Wyoming

X Population Run Input File Name: FED AMER BASE Output File Prefix: AAO
____ Array Attached Pop. File Name: FEDAMERI
Latitude: 42 ° 47 ' 59 " Longitude: 107 ° 38 ' 00 "

Distances: (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	40,000	60,000	80,000

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

____ Individual Run Input File Name: Output File Prefix:

Distances: (meters)											

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: ____ Array Attached STAR File Name: LND1100
Location: LANDER WBAN: 24021 HDR: 1100 CODE: LN LND SET#: STAR05

Temperature: 6.0 °C Lid Height: 608 m Rainfall: 25.4 cm/yr

____ Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:

Circular Area (m^2):	445,000					

Plume Rise:

___ Buoyant (cal/s):							
___ Momentum (m/s):							
___ Entered (m):							
Pasquill Stability	A	B	C	D	E	F	G

Nuclide Class AMAD Release Rates (Ci/yr)

Rn-222			281					

____ Additional Source Term Attached
Comments:

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Baseline Emissions Page 1 of 1

Facility: Anaconda (ARCO Coal) Location: Bluewater, N.M.

X Population Run Input File Name: ANACONDA BASE Output File Prefix: AAB
____ Array Attached Pop. File Name: BLUEWATE
Latitude: 35 ° 16 ' 12 " Longitude: 107 ° 56 ' 44 "

Distances: (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	40,000	60,000	80,000

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

____ Individual Run Input File Name: Output File Prefix:

Distances: (meters)										

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: ____ Array Attached STAR File Name: STARANHM
Location: AMBROSIA LAKE WBAN: HDR: CODE: SET#:

Temperature: 13.4 °C Lid Height: 767 m Rainfall: 20.6 cm/yr

____ Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:

Circular Area (m^2):	1,214,000					

Plume Rise:

___ Buoyant (cal/s):						
___ Momentum (m/s):						
___ Entered (m):						

Pasquill Stability	A	B	C	D	E	F	G

Nuclide Class AMAD Release Rates (Ci/yr)

Rn-222			766					

____ Additional Source Term Attached
Comments:

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Baseline Emissions Page 1 of 1

Facility: Moab Location: Moab, Utah

X Population Run Input File Name: MOAB BASELINE Output File Prefix: AAC
_____ Array Attached Pop. File Name: MOABATLA
Latitude: 38 ° 35 ' 59 " Longitude: 109 ° 35 ' 44 "

Distances: (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	40,000	60,000	80,000

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

_____ Individual Run Input File Name: Output File Prefix:

Distances: (meters)											

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: _____ Array Attached STAR File Name: GJT0476
Location: GRAND JUNCTION WBAN: 23066 HDR: 0476 CODE: GJT SET#: STAR03

Temperature: 13.7 °C Lid Height: 538 m Rainfall: 20.3 cm/yr

_____ Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:
Circular Area (m^2): 518,000

Plume Rise:

___ Buoyant (cal/s):						
___ Momentum (m/s):						
___ Entered (m):						

Pasquill Stability	A	B	C	D	E	F	G

Nuclide Class AMAD Release Rates (Ci/yr)

Rn-222			327				

_____ Additional Source Term Attached
Comments:

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Baseline Emissions Page 1 of 1

Facility: Conquista Location: Falls City, Texas

X Population Run Input File Name: CONQUISTA BASE Output File Prefix: AAD
Array Attached Pop. File Name: CONQUIST
Latitude: 28 ° 54 ' 03 " Longitude: 98 ° 05 ' 40 "

Distances: (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	40,000	60,000	80,000

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

Individual Run Input File Name: Output File Prefix:

Distances: (meters)										

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: Array Attached STAR File Name: SAT0064
Location: SAN ANTONIO WBAN: 12921 HDR: 0064 CODE: SAT SET#: STAR01

Temperature: 20.4 °C Lid Height: 873 m Rainfall: 68.6 cm/yr

Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:

Circular Area (m^2):	1,012,000					

Plume Rise:

Buoyant (cal/s):							
Momentum (m/s):							
Entered (m):							
Pasquill Stability	A	B	C	D	E	F	G

Nuclide Class AMAD Release Rates (Ci/yr)

Rn-222			638					

Additional Source Term Attached

Comments:

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Baseline Emissions Page 1 of 1

Facility: Dawn Location: Ford, Washington

X Population Run Input File Name: DAWN BASELINE Output File Prefix: AAE
Array Attached Pop. File Name: DAWNMILL
Latitude: 47 ° 54 ' 06 " Longitude: 117 ° 49 ' 58 "

Distances: (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	40,000	60,000	80,000

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

Individual Run Input File Name: Output File Prefix:

Distances: (meters)										

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: Array Attached STAR File Name: GEG0360
Location: SPOKANE WBAN: 24157 HDR: 0360 CODE: GEG SET#: STAR03

Temperature: 8.4 °C Lid Height: 640 m Rainfall: 42.4 cm/yr

Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:

Circular Area (m^2):	497,000					

Plume Rise:

Buoyant (cal/s):						
Momentum (m/s):						
Entered (m):						

Pasquill Stability	A	B	C	D	E	F	G

Nuclide Class AMAD Release Rates (Ci/yr)

Rn-222			313					

Additional Source Term Attached

Comments:

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Baseline Emissions Page 1 of 1

Facility: Naturita Location: Naturita, CO

X Population Run Input File Name: NATURITA BASE Output File Prefix: AAF
X Array Attached Pop. File Name: NATURITA
Latitude: 38 ° 12 ' 00 " Longitude: 108 ° 37 ' 00 "

Distances: (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	30,000	40,000
	50,000	60,000	80,000							

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

Individual Run Input File Name: Output File Prefix:

Distances: (meters)										

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: Array Attached STAR File Name: GJT0476
Location: Grand Junction WBAN: 23066 HDR: 0476 CODE: GJT SET#: STAR03

Temperature: 11.5 °C Lid Height: 538 m Rainfall: 20.3 cm/yr

Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:

Circular Area (m^2):	142,000					

Plume Rise:

Buoyant (cal/s):						
Momentum (m/s):						
Entered (m):						

Pasquill Stability	A	B	C	D	E	F	G

Nuclide	Class	AMAD	Release Rates (Ci/yr)					
Rn-222		9						

Additional Source Term Attached
Comments:

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Baseline Emissions Page 1 of 1

Facility: Homestake (large impoundment) Location: Grants, N.M.

X Population Run Input File Name: LHOMESTAKE BASE Output File Prefix: AAI
Array Attached Pop. File Name: HOMESTAK
Latitude: 35 ° 14 ' 31 " Longitude: 107 ° 51 ' 46 "

Distances: (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	40,000	60,000	80,000

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

Individual Run Input File Name: Output File Prefix:

Distances: (meters)											

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: Array Attached STAR File Name: STARANHM
Location: AMBROSIA LAKE WBAN: HDR: CODE: SET#:

Temperature: 13.4 °C Lid Height: 767 m Rainfall: 20.6 cm/yr

Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:

Circular Area (m^2):	688,000					

Plume Rise:

Buoyant (cal/s):						
Momentum (m/s):						
Entered (m):						

Pasquill Stability	A	B	C	D	E	F	G

Nuclide Class AMAD Release Rates (Ci/yr)

Rn-222			434					

Additional Source Term Attached

Comments:

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Baseline Emissions Page 1 of 1

Facility: Homestake (small impoundment) Location: Grants, N.M.

X Population Run Input File Name: SHOMESTAKE BASE Output File Prefix: AAJ
Array Attached Pop. File Name: HOMESTAK
Latitude: 35 ° 14 ' 31 " Longitude: 107 ° 51 ' 46 "

Distances: (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	40,000	60,000	80,000

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

Individual Run Input File Name: Output File Prefix:

Distances: (meters)											

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: Array Attached STAR File Name: STARANHM
Location: AMBROSIA LAKE WBAN: HDR: CODE: SET#:

Temperature: 13.4 °C Lid Height: 767 m Rainfall: 20.6 cm/yr

Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:
Circular Area (m^2): 52,000

Plume Rise:

Buoyant (cal/s):							
Momentum (m/s):							
Entered (m):							
Pasquill Stability	A	B	C	D	E	F	G

Nuclide Class AMAD Release Rates (Ci/yr)

Rn-222			33					

Additional Source Term Attached
Comments:

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Baseline Emissions Page 1 of 1

Facility: Lucky Mc Location: Riverton, Wyoming

X Population Run Input File Name: LUCKY MN BASE Output File Prefix: AAK
Array Attached Pop. File Name: GASLUCKY
Latitude: 42 ° 49 ' 55 " Longitude: 107 ° 37 ' 00 "

Distances: (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	40,000	60,000	80,000

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

Individual Run Input File Name: Output File Prefix:

Distances: (meters)										

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: Array Attached STAR File Name: LND1100
Location: LANDER WBAN: 24021 HDR: 1100 CODE: LND SET#: STAR05

Temperature: 6.0 °C Lid Height: 608 m Rainfall: 22.9 cm/yr

Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:

Circular Area (m^2):	821,000					

Plume Rise:

Buoyant (cal/s):						
Momentum (m/s):						
Entered (m):						

Pasquill Stability	A	B	C	D	E	F	G

Nuclide	Class	AMAD	Release Rates (Ci/yr)					
Rn-222			518					

Additional Source Term Attached

Comments:

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Baseline Emissions Page 1 of 1

Facility: Petrotomics Location: Medicine Bow, Wyoming

X Population Run Input File Name: PETROTOMICS BASE Output File Prefix: AAL
Array Attached Pop. File Name: PETROTOM
Latitude: 42 ° 20 ' 04 " Longitude: 106 ° 11 ' 49 "

Distances: (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	40,000	60,000	80,000

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

Individual Run Input File Name: Output File Prefix:

Distances: (meters)										

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivitvity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: Array Attached STAR File Name: CPR1564
Location: CASPER WBAN: 24089 HDR: 1564 CODE: CPR SET#: STAR07

Temperature: 5.3 °C Lid Height: 533 m Rainfall: 30.5 cm/yr

Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:
Circular Area (m^2): 461,000

Plume Rise:
Buoyant (cal/s):
Momentum (m/s):
Entered (m):

Pasquill Stability	A	B	C	D	E	F	G

Nuclide Class AMAD Release Rates (Ci/yr)

Rn-222			291					

Additional Source Term Attached
Comments:

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Baseline Emissions Page 1 of 1

Facility: Kerr-McGee (Quivera) Location: Ambrosia Lake, N.M.

X Population Run Input File Name: KERR-MCGEE BASE Output File Prefix: AAM
Array Attached Pop. File Name: AMBROSIA
Latitude: 35 ° 23 ' 39 " Longitude: 107 ° 49 ' 47 "

Distances: (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	40,000	60,000	80,000

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

Individual Run Input File Name: Output File Prefix:

Distances: (meters)											

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: Array Attached STAR File Name: STARANHM
Location: AMBROSIA LAKE WBAN: HDR: CODE: SET#:

Temperature: 13.4 °C Lid Height: 767 m Rainfall: 20.6 cm/yr

Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:

Circular Area (m^2):	1,490,000					

Plume Rise:

Buoyant (cal/s):							
Momentum (m/s):							
Entered (m):							
Pasquill Stability	A	B	C	D	E	F	G

Nuclide Class AMAD Release Rates (Ci/yr)

Rn-222			940					

Additional Source Term Attached

Comments:

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Baseline Emissions Page 1 of 1

Facility: Rio Algom Location: La Sal, Utah

X Population Run Input File Name: RIO ALGOM BASE Output File Prefix: AAN
Array Attached Pop. File Name: LASALRIO
Latitude: 38 ° 15 ' 00 " Longitude: 109 ° 16 ' 30 "

Distances: (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	40,000	60,000	80,000

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

Individual Run Input File Name: Output File Prefix:

Distances: (meters)											

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: Array Attached STAR File Name: GJT0476
Location: GRAND JUNCTION WBAN: 23066 HDR: 0476 CODE: GJT SET#: STAR03

Temperature: 13.7 °C Lid Height: 538 m Rainfall: 20.3 cm/yr

Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:

Circular Area (m^2):	405,000					

Plume Rise:

Buoyant (cal/s):						
Momentum (m/s):						
Entered (m):						

Pasquill Stability	A	B	C	D	E	F	G

Nuclide Class AMAD Release Rates (Ci/yr)

Rn-222			255						

Additional Source Term Attached

Comments:
area changed per comments; 0-5 km demography updated.

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Baseline Emissions Page 1 of 1

Facility: L-Bar Location: Seyboyeta, N.M.

X Population Run Input File Name: L BAR BASELINE Output File Prefix: AAV
_____ Array Attached Pop. File Name: LBARSOHI
Latitude: 35 ° 11 ' 09 " Longitude: 107 ° 20 ' 09 "

Distances (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	40,000	60,000	80,000

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

_____ Individual Run Input File Name: _____ Output File Prefix: _____

Distances (meters)											

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: _____ Array Attached STAR File Name: ABQ0282
Location: ALBUQUERQUE WBAN: 23050 HDR: 0282 CODE: ABQ SET#: STAR03

Temperature: 13.4 °C Lid Height: 767 m Rainfall: 20.6 cm/yr

Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:
Circular Area (m^2): 324,000

Plume Rise:

___ Buoyant (cal/s):							
___ Momentum (m/s):							
___ Entered (m):							
Pasquill Stability	A	B	C	D	E	F	G

Nuclide	Class	AMAD	Release Rates (Ci/yr)					
Rn-222			204					

_____ Additional Source Term Attached
Comments: _____

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Baseline Emissions Page 1 of 1

Facility: Umetco Gas Hills Location: Riverton, Wyoming

X Population Run Input File Name: GAS HILLS BASE Output File Prefix: AAA
_____ Array Attached Pop. File Name: UCCGASHI
Latitude: 42 ° 49 ' 45 " Longitude: 107 ° 29 ' 34 "

Distances: (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	40,000	60,000	80,000

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

_____ Individual Run Input File Name: _____ Output File Prefix: _____

Distances: (meters)										

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: _____ Array Attached STAR File Name: LND1100
Location: LANDER WBAN: 24021 HDR: 1100 CODE: LND SET#: STAR05

Temperature: 6.0 °C Lid Height: 608 m Rainfall: 25.4 cm/yr

_____ Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:

Circular Area (m^2):	777,000					

Plume Rise:

___ Buoyant (cal/s):						
___ Momentum (m/s):						
___ Entered (m):						

Pasquill Stability	A	B	C	D	E	F	G

Nuclide Class AMAD Release Rates (Ci/yr)

Rn-222			490					

_____ Additional Source Term Attached
Comments: _____

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Baseline Emissions Page 1 of 1

Facility: Maybell Location: Maybell, CO

X Population Run Input File Name: MAYBELL BASELINE Output File Prefix: AAP
_____ Array Attached Pop. File Name: MAYBELL
Latitude: 40 ° 32 ' 36 " Longitude: 107 ° 59 ' 36 "

Distances: (meters)										
	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	30,000	40,000
	50,000	60,000	80,000							

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

_____ Individual Run Input File Name: _____ Output File Prefix: _____

Distances: (meters)										

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: _____ Array Attached STAR File Name: EEE1420
Location: Eagle County WBAN: _____ HDR: 1420 CODE: EEE SET#: _____

Temperature: 5.8 °C Lid Height: 538 m Rainfall: 33.8 cm/yr

_____ Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:

Circular Area (m^2):	202,000					

Plume Rise:

___ Buoyant (cal/s):						
___ Momentum (m/s):						
___ Entered (m):						

Pasquill Stability	A	B	C	D	E	F	G

Nuclide Class AMAD Release Rates (Ci/yr)

Rn-222			13					

_____ Additional Source Term Attached
Comments: _____

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Baseline Emissions Page 1 of 1

Facility: Uravan Location: Uravan, Colorado

X Population Run Input File Name: URAVAN BASELINE Output File Prefix: AAQ
____ Array Attached Pop. File Name: URAVANUN
Latitude: 38 ° 22 ' 00 " Longitude: 108 ° 45 ' 00 "

Distances: (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	40,000	60,000
	80,000									

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

____ Individual Run Input File Name: Output File Prefix:

Distances: (meters)										

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: ____ Array Attached STAR File Name: GJT0476
Location: GRAND JUNCTION WBAN: 23066 HDR: 0476 CODE: GJT SET#: STAR03

Temperature: 9.4 °C Lid Height: 538 m Rainfall: 29.4 cm/yr

____ Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:

Circular Area (m^2):	283,000					

Plume Rise:

___ Buoyant (cal/s):						
___ Momentum (m/s):						
___ Entered (m):						

Pasquill Stability	A	B	C	D	E	F	G

Nuclide Class AMAD Release Rates (Ci/yr)

Rn-222			18					

____ Additional Source Term Attached
Comments:

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Baseline Emissions Page 1 of 1

Facility: Church Rock Location: Church Rock, N.M.

X Population Run Input File Name: CHURCH ROCK BASE Output File Prefix: AAR
Array Attached Pop. File Name: CHURCHRO
Latitude: 35 ° 38 ' 47 " Longitude: 108 ° 30 ' 08 "

Distances: (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	40,000	60,000	80,000

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

Individual Run Input File Name: Output File Prefix:

Distances: (meters)											

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: Array Attached STAR File Name: GUP1167
Location: GALLUP/SEN WBAN: 23081 HDR: 1167 CODE: GUP SET#: STAR03

Temperature: 10.3 °C Lid Height: 767 m Rainfall: 30.3 cm/yr

Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:
Circular Area (m^2): 417,000

Plume Rise:

Buoyant (cal/s):							
Momentum (m/s):							
Entered (m):							
Pasquill Stability	A	B	C	D	E	F	G

Nuclide Class AMAD Release Rates (Ci/yr)

Rn-222			263					

Additional Source Term Attached
Comments:

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Baseline Emissions Page 1 of 1

Facility: Bear Creek Location: Douglas, Wyoming

X Population Run Input File Name: BEAR CREEK BASE Output File Prefix: AAS
Array Attached Pop. File Name: BEARCREK
Latitude: 43 ° 16 ' 11 " Longitude: 105 ° 37 ' 46 "

Distances: (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	40,000	60,000	80,000

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

Individual Run Input File Name: Output File Prefix:

Distances: (meters)											

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: Array Attached STAR File Name: CPR1564
Location: CASPER WBAN: 24089 HDR: 1564 CODE: CPR SET#: STAR07

Temperature: 7.3 °C Lid Height: 533 m Rainfall: 30.5 cm/yr

Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:

Circular Area (m^2):	720,000					

Plume Rise:

Buoyant (cal/s):						
Momentum (m/s):						
Entered (m):						

Pasquill Stability	A	B	C	D	E	F	G

Nuclide Class AMAD Release Rates (Ci/yr)

Rn-222			454					

Additional Source Term Attached

Comments:

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Baseline Emissions Page 1 of 1

Facility: Sherwood Location: Wellpinit, Washington

X Population Run Input File Name: SHERWOOD BASE Output File Prefix: AAT
_____ Array Attached Pop. File Name: WELLPINI
Latitude: 47 ° 52 ' 27 " Longitude: 118 ° 07 ' 00 "

Distances: (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	40,000	60,000
	80,000									

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

_____ Individual Run Input File Name: _____ Output File Prefix: _____

Distances: (meters)										

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: _____ Array Attached STAR File Name: GEG0360
Location: SPOKANE WBAN: 24157 HDR: 0360 CODE: GEG SET#: STAR03

Temperature: 8.4 °C Lid Height: 640 m Rainfall: 31.7 cm/yr

_____ Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:

Circular Area (m^2):	380,000					

Plume Rise:

___ Buoyant (cal/s):						
___ Momentum (m/s):						
___ Entered (m):						

Pasquill Stability	A	B	C	D	E	F	G

Nuclide Class AMAD Release Rates (Ci/yr)

Rn-222			240					

_____ Additional Source Term Attached
Comments: _____

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Baseline Emissions Page 1 of 1

Facility: Split Rock Location: Jeffrey City, Wyoming

X Population Run Input File Name: SPLIT ROCK BASE Output File Prefix: AAU
____ Array Attached Pop. File Name: JEFFREYC
Latitude: 42 ° 30 ' 32 " Longitude: 107 ° 47 ' 14 "

Distances: (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	40,000	60,000	80,000

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

____ Individual Run Input File Name: Output File Prefix:

Distances: (meters)										

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: ____ Array Attached STAR File Name: LND1100
Location: LANDER WBAN: 24021 HDR: 1100 CODE: LND SET#: STAR05

Temperature: 6.9 °C Lid Height: 608 m Rainfall: 25.4 cm/yr

____ Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:

Circular Area (m^2):	902,000					

Plume Rise:

___ Buoyant (cal/s):						
___ Momentum (m/s):						
___ Entered (m):						

Pasquill Stability	A	B	C	D	E	F	G

Nuclide Class AMAD Release Rates (Ci/yr)

Rn-222			569					

____ Additional Source Term Attached
Comments:

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Revised UMTRCA Regulations Page 1 of 1

Facility: Federal American Location: Riverton, Wyoming

X Population Run Input File Name: FEDERAL AMERICA Output File Prefix: AG
____ Array Attached Pop. File Name: FEDAMERI
Latitude: 42 ° 47 ' 59 " Longitude: 107 ° 38 ' 00 "

Distances: (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	40,000	60,000	80,000

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

____ Individual Run Input File Name: Output File Prefix:

Distances: (meters)										

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: ____ Array Attached STAR File Name: LND1100
Location: LANDER WBAN: 24021 HDR: 1100 CODE: LN LND SET#: STAR05

Temperature: 6.0 °C Lid Height: 608 m Rainfall: 25.4 cm/yr

____ Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:

Circular Area (m^2):	445,000					

Plume Rise:

___ Buoyant (cal/s):						
___ Momentum (m/s):						
___ Entered (m):						

Pasquill Stability	A	B	C	D	E	F	G

Nuclide	Class	AMAD	Release Rates (Ci/yr)					
Rn-222			523					

____ Additional Source Term Attached
Comments:

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Revised UMTRCA Regulations Page 1 of 1

Facility: Anaconda (ARCO Coal) Location: Bluewater, N.M.

X Population Run Input File Name: ANACONDA Output File Prefix: AS
_____ Array Attached Pop. File Name: BLUEWATE
Latitude: 35 ° 16 ' 12 " Longitude: 107 ° 56 ' 44 "

Distances: (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	40,000	60,000	80,000

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

_____ Individual Run Input File Name: _____ Output File Prefix: _____

Distances: (meters)											

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: _____ Array Attached STAR File Name: STARANHM
Location: AMBROSIA LAKE WBAN: _____ HDR: _____ CODE: _____ SET#: _____

Temperature: 13.4 °C Lid Height: 767 m Rainfall: 20.6 cm/yr

_____ Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:
Circular Area (m^2): 1,214,000

Plume Rise:
___ Buoyant (cal/s):
___ Momentum (m/s):
___ Entered (m):

Pasquill Stability	A	B	C	D	E	F	G

Nuclide Class AMAD Release Rates (Ci/yr)

Rn-222			1,615					

_____ Additional Source Term Attached

Comments: _____

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Revised UMTRCA Regulations Page 1 of 1

Facility: Moab Location: Moab, Utah

X Population Run Input File Name: MOAB Output File Prefix: AP
_____ Array Attached Pop. File Name: MOABATLA
Latitude: 38 ° 35 ' 59 " Longitude: 109 ° 35 ' 44 "

Distances: (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	40,000	60,000	80,000

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

_____ Individual Run Input File Name: Output File Prefix:

Distances: (meters)										

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: _____ Array Attached STAR File Name: GJT0476
Location: GRAND JUNCTION WBAN: 23066 HDR: 0476 CODE: GJT SET#: STAR03

Temperature: 13.7 °C Lid Height: 538 m Rainfall: 20.3 cm/yr

_____ Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:

Circular Area (m^2):	518,000					

Plume Rise:

___Buoyant (cal/s):						
___Momentum (m/s):						
___Entered (m):						

Pasquill Stability	A	B	C	D	E	F	G

Nuclide Class AMAD Release Rates (Ci/yr)

Rn-222			854					

_____ Additional Source Term Attached
Comments:

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Revised UMTRCA Regulations Page 1 of 1

Facility: Conquista Location: Falls City, Texas

X Population Run Input File Name: CONQUISTA Output File Prefix: AF
____ Array Attached Pop. File Name: CONQUIST
Latitude: 28 ° 54 ' 03 " Longitude: 98 ° 05 ' 40 "

Distances: (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	40,000	60,000	80,000

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

____ Individual Run Input File Name: Output File Prefix:

Distances: (meters)										

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: ____ Array Attached STAR File Name: SAT0064
Location: SAN ANTONIO WBAN: 12921 HDR: 0064 CODE: SAT SET#: STAR01

Temperature: 20.4 °C Lid Height: 873 m Rainfall: 68.6 cm/yr

____ Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:

Circular Area (m^2):	1,012,000					

Plume Rise:

___ Buoyant (cal/s):						
___ Momentum (m/s):						
___ Entered (m):						

Pasquill Stability	A	B	C	D	E	F	G

Nuclide	Class	AMAD	Release Rates (Ci/yr)					
Rn-222			724					

____ Additional Source Term Attached

Comments:

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Revised UMTRCA Regulations Page 1 of 1

Facility: Dawn Location: Ford, Washington

X Population Run Input File Name: DAWN Output File Prefix: AT
Array Attached Pop. File Name: DAWNMILL
Latitude: 47 ° 54 ' 06 " Longitude: 117 ° 49 ' 58 "

Distances: (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	40,000	60,000	80,000

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

Individual Run Input File Name: Output File Prefix:

Distances: (meters)											

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: Array Attached STAR File Name: GEG0360
Location: SPOKANE WBAN: 24157 HDR: 0360 CODE: GEG SET#: STAR03

Temperature: 8.4 °C Lid Height: 640 m Rainfall: 42.4 cm/yr

Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:

Circular Area (m^2):	497,000					

Plume Rise:

Buoyant (cal/s):							
Momentum (m/s):							
Entered (m):							
Pasquill Stability	A	B	C	D	E	F	G

Nuclide Class AMAD Release Rates (Ci/yr)

Rn-222			450					

Additional Source Term Attached
Comments:

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Revised UMTRCA Regulations Page 1 of 1

Facility: Naturita Location: Naturita, CO

X Population Run Input File Name: NATURITA Output File Prefix: AD
X Array Attached Pop. File Name: NATURITA
Latitude: 38 ° 12 ' 00 " Longitude: 108 ° 37 ' 00 "

Distances: (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	30,000	40,000
	50,000	60,000	80,000							

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

Individual Run Input File Name: Output File Prefix:

Distances: (meters)										

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: Array Attached STAR File Name: GJT0476
Location: Grand Junction WBAN: 23066 HDR: 0476 CODE: GJT SET#: STAR03

Temperature: 11.5 °C Lid Height: 538 m Rainfall: 20.3 cm/yr

Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:

Circular Area (m^2):	142,000					

Plume Rise:

Buoyant (cal/s):						
Momentum (m/s):						
Entered (m):						

Pasquill Stability	A	B	C	D	E	F	G

Nuclide Class AMAD Release Rates (Ci/yr)

Rn-222			41					

Additional Source Term Attached
Comments:

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Revised UMTRCA Regulations Page 1 of 1

Facility: Homestake (large impoundment) Location: Grants, N.M.

X Population Run Input File Name: HOMESTAKE LARGE Output File Prefix: AAG
_____ Array Attached Pop. File Name: HOMESTAK
Latitude: 35 ° 14 ' 31 " Longitude: 107 ° 51 ' 46 "

Distances (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	40,000	60,000
	80,000									

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

_____ Individual Run Input File Name: _____ Output File Prefix: _____

Distances (meters)										

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: _____ Array Attached STAR File Name: STARANHM
Location: AMBROSIA LAKE WBAN: _____ HDR: _____ CODE: _____ SET#: _____

Temperature: 13.4 °C Lid Height: 767 m Rainfall: 20.6 cm/yr

_____ Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:
Circular Area (m^2): 688,000

Plume Rise:

___ Buoyant (cal/s):							
___ Momentum (m/s):							
___ Entered (m):							
Pasquill Stability	A	B	C	D	E	F	G

Nuclide	Class	AMAD	Release Rates (Ci/yr)					
Rn-222			918					

_____ Additional Source Term Attached
Comments: _____

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Revised UMTRCA Regulations Page 1 of 1

Facility: Homestake (small impoundment) Location: Grants, N.M.

X Population Run Input File Name: HOMESTAKE SMALL Output File Prefix: AAH
Array Attached Pop. File Name: HOMESTAK
Latitude: 35 ° 14 ' 31 " Longitude: 107 ° 51 ' 46 "

Distances: (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	40,000	60,000	80,000

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

Individual Run Input File Name: Output File Prefix:

Distances: (meters)										

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: Array Attached STAR File Name: STARANHM
Location: AMBROSIA LAKE WBAN: HDR: CODE: SET#:

Temperature: 13.4 °C Lid Height: 767 m Rainfall: 20.6 cm/yr

Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:
Circular Area (m^2): 52,000

Plume Rise:
Buoyant (cal/s):
Momentum (m/s):
Entered (m):

Pasquill Stability	A	B	C	D	E	F	G

Nuclide Class AMAD Release Rates (Ci/yr)

Rn-222			94					

Additional Source Term Attached
Comments:

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Revised UMTRCA Regulations Page 1 of 1

Facility: Lucky Mc Location: Riverton, Wyoming

X Population Run Input File Name: LUCKY MC Output File Prefix: AU
_____ Array Attached Pop. File Name: GASLUCKY
Latitude: 42 ° 49 ' 55 " Longitude: 107 ° 37 ' 00 "

Distances: (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	40,000	60,000
	80,000									

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

_____ Individual Run Input File Name: Output File Prefix:

Distances: (meters)										

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: _____ Array Attached STAR File Name: LND1100
Location: LANDER WBAN: 24021 HDR: 1100 CODE: LND SET#: STAR05

Temperature: 6.0 °C Lid Height: 608 m Rainfall: 22.9 cm/yr

_____ Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:

Circular Area (m^2):	821,000					

Plume Rise:

___ Buoyant (cal/s):						
___ Momentum (m/s):						
___ Entered (m):						

Pasquill Stability	A	B	C	D	E	F	G

Nuclide Class AMAD Release Rates (Ci/yr)

Rn-222			730					

_____ Additional Source Term Attached
Comments:

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Revised UMTRCA Regulations Page 1 of 1

Facility: Petrotomics Location: Medicine Bow, Wyoming

X Population Run Input File Name: PETROTOMICS Output File Prefix: AH
____ Array Attached Pop. File Name: PETROTOM
Latitude: 42 ° 20 ' 04 " Longitude: 106 ° 11 ' 49 "

Distances: (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	40,000	60,000	80,000

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

____ Individual Run Input File Name: Output File Prefix:

Distances: (meters)											

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivitvity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: ____ Array Attached STAR File Name: CPR1564
Location: CASPER WBAN: 24089 HDR: 1564 CODE: CPR SET#: STAR07

Temperature: 5.3 °C Lid Height: 533 m Rainfall: 30.5 cm/yr

____ Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:

Circular Area (m^2):	461,000					

Plume Rise:

___ Buoyant (cal/s):						
___ Momentum (m/s):						
___ Entered (m):						

Pasquill Stability	A	B	C	D	E	F	G

Nuclide Class AMAD Release Rates (Ci/yr)

Rn-222			484					

____ Additional Source Term Attached
Comments:

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Revised UMTRCA Regulations Page 1 of 1

Facility: Kerr-McGee (Quivera) Location: Ambrosia Lake, N.M.

X Population Run Input File Name: KERR-MCGEE Output File Prefix: AJ
_____ Array Attached Pop. File Name: AMBROSIA
Latitude: 35 ° 23 ' 39 " Longitude: 107 ° 49 ' 47 "

Distances: (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	40,000	60,000	80,000

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

_____ Individual Run Input File Name: Output File Prefix:

Distances: (meters)										

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: _____ Array Attached STAR File Name: STARANHM
Location: AMBROSIA LAKE WBAN: HDR: CODE: SET#:

Temperature: 13.4 °C Lid Height: 767 m Rainfall: 20.6 cm/yr

_____ Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:

Circular Area (m^2):	1,490,000					

Plume Rise:

___ Buoyant (cal/s):							
___ Momentum (m/s):							
___ Entered (m):							
Pasquill Stability	A	B	C	D	E	F	G

Nuclide Class AMAD Release Rates (Ci/yr)

Rn-222			1,548					

_____ Additional Source Term Attached
Comments:

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Revised UMTRCA Regulations Page 1 of 1

Facility: Rio Algom Location: La Sal, Utah

X Population Run Input File Name: RIO ALGOM Output File Prefix: AN
_____ Array Attached Pop. File Name: LASALRIO
Latitude: 38 ° 15 ' 00 " Longitude: 109 ° 16 ' 30 "

Distances: (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	40,000	60,000	80,000

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

_____ Individual Run Input File Name: Output File Prefix:

Distances: (meters)										

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: _____ Array Attached STAR File Name: GJT0476
Location: GRAND JUNCTION WBAN: 23066 HDR: 0476 CODE: GJT SET#: STAR03

Temperature: 13.7 °C Lid Height: 538 m Rainfall: 20.3 cm/yr

_____ Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:
Circular Area (m^2): 405,000

Plume Rise:
___ Buoyant (cal/s):
___ Momentum (m/s):
___ Entered (m):

Pasquill Stability	A	B	C	D	E	F	G

Nuclide Class AMAD Release Rates (Ci/yr)

Rn-222			274						

_____ Additional Source Term Attached
Comments:

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Revised UMTRCA Regulations Page 1 of 1

Facility: L-Bar Location: Seyboyeta, N.M.

X Population Run Input File Name: L BAR Output File Prefix: AM
Array Attached Pop. File Name: LBARSOHI
Latitude: 35 ° 11 ' 09 " Longitude: 107 ° 20 ' 09 "

Distances: (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	40,000	60,000	80,000

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

Individual Run Input File Name: Output File Prefix:

Distances: (meters)											

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: Array Attached STAR File Name: ABQ0282
Location: ALBUQUERQUE WBAN: 23050 HDR: 0282 CODE: ABQ SET#: STAR03

Temperature: 13.4 °C Lid Height: 767 m Rainfall: 20.6 cm/yr

Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:
Circular Area (m^2): 324,000

Plume Rise:

Buoyant (cal/s):						
Momentum (m/s):						
Entered (m):						

Pasquill Stability	A	B	C	D	E	F	G

Nuclide Class AMAD Release Rates (Ci/yr)

Rn-222			204					

Additional Source Term Attached
Comments:

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Revised UMTRCA Regulations Page 1 of 1

Facility: Umetco Gas Hills Location: Riverton, Wyoming

X Population Run Input File Name: UMETCO GAS HILLS Output File Prefix: AI
____ Array Attached Pop. File Name: UCCGASHI
Latitude: 42 ° 49 ' 45 " Longitude: 107 ° 29 ' 34 "

Distances: (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	40,000	60,000
	80,000									

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

____ Individual Run Input File Name: Output File Prefix:

Distances: (meters)										

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: ____ Array Attached STAR File Name: LND1100
Location: LANDER WBAN: 24021 HDR: 1100 CODE: LND SET#: STAR05

Temperature: 6.0 °C Lid Height: 608 m Rainfall: 25.4 cm/yr

____ Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:

Circular Area (m^2):	777,000					

Plume Rise:

___ Buoyant (cal/s):						
___ Momentum (m/s):						
___ Entered (m):						

Pasquill Stability	A	B	C	D	E	F	G

Nuclide Class AMAD Release Rates (Ci/yr)

Rn-222			589					

____ Additional Source Term Attached
Comments:

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Revised UMTRCA Regulations Page 1 of 1

Facility: Maybell Location: Maybell, CO

X Population Run Input File Name: MAYBELL Output File Prefix: AC
_____ Array Attached Pop. File Name: MAYBELL
Latitude: 40 ° 32 ' 36 " Longitude: 107 ° 59 ' 36 "

Distances: (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	30,000	40,000
	50,000	60,000	80,000							

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

_____ Individual Run Input File Name: _____ Output File Prefix: _____

Distances: (meters)										

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: _____ Array Attached STAR File Name: EEE1420
Location: Eagle County WBAN: _____ HDR: 1420 CODE: EEE SET#: _____

Temperature: 5.8 °C Lid Height: 538 m Rainfall: 33.8 cm/yr

_____ Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:

Circular Area (m^2):	202,000					

Plume Rise:

___ Buoyant (cal/s):						
___ Momentum (m/s):						
___ Entered (m):						

Pasquill Stability	A	B	C	D	E	F	G

Nuclide Class AMAD Release Rates (Ci/yr)

Rn-222			70					

_____ Additional Source Term Attached
Comments: _____

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Revised UMTRCA Regulations Page 1 of 1

Facility: Uravan Location: Uravan, Colorado

X Population Run Input File Name: URAVAN Output File Prefix: AL
Array Attached Pop. File Name: URAVANUN
Latitude: 38 ° 22 ' 00 " Longitude: 108 ° 45 ' 00 "

Distances: (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	40,000	60,000	80,000

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

Individual Run Input File Name: Output File Prefix:

Distances: (meters)										

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: Array Attached STAR File Name: GJT0476
Location: GRAND JUNCTION WBAN: 23066 HDR: 0476 CODE: GJT SET#: STAR03

Temperature: 9.4 °C Lid Height: 538 m Rainfall: 29.4 cm/yr

Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:

Circular Area (m^2):	283,000					

Plume Rise:

Buoyant (cal/s):							
Momentum (m/s):							
Entered (m):							
Pasquill Stability	A	B	C	D	E	F	G

Nuclide Class AMAD Release Rates (Ci/yr)

Rn-222			60					

Additional Source Term Attached

Comments:

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Revised UMTRCA Regulations Page 1 of 1

Facility: Church Rock Location: Church Rock, N.M.

X Population Run Input File Name: CHURCH ROCK Output File Prefix: AR
____ Array Attached Pop. File Name: CHURCHRO
Latitude: 35 ° 38 ' 47 " Longitude: 108 ° 30 ' 08 "

Distances: (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	40,000	60,000	80,000

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

____ Individual Run Input File Name: Output File Prefix:

Distances: (meters)										

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: ____ Array Attached STAR File Name: GUP1167
Location: GALLUP/SEN WBAN: 23081 HDR: 1167 CODE: GUP SET#: STAR03

Temperature: 10.3 °C Lid Height: 767 m Rainfall: 30.3 cm/yr

____ Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:

Circular Area (m^2):	417,000					

Plume Rise:

___ Buoyant (cal/s):						
___ Momentum (m/s):						
___ Entered (m):						

Pasquill Stability	A	B	C	D	E	F	G

Nuclide	Class	AMAD	Release Rates (Ci/yr)					
Rn-222			469					

____ Additional Source Term Attached
Comments:

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Revised UMTRCA Regulations Page 1 of 1

Facility: Bear Creek Location: Douglas, Wyoming

X Population Run Input File Name: BEAR CREEK Output File Prefix: AO
Array Attached Pop. File Name: BEARCREK
Latitude: 43 ° 16 ' 11 " Longitude: 105 ° 37 ' 46 "

Distances: (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	40,000	60,000	80,000

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

Individual Run Input File Name: Output File Prefix:

Distances: (meters)										

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: Array Attached STAR File Name: CPR1564
Location: CASPER WBAN: 24089 HDR: 1564 CODE: CPR SET#: STAR07

Temperature: 7.3 °C Lid Height: 533 m Rainfall: 30.5 cm/yr

Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:

Circular Area (m^2):	720,000					

Plume Rise:

Buoyant (cal/s):							
Momentum (m/s):							
Entered (m):							
Pasquill Stability	A	B	C	D	E	F	G

Nuclide Class AMAD Release Rates (Ci/yr)

Rn-222			713					

Additional Source Term Attached

Comments:

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Revised UMTRCA Regulations Page 1 of 1

Facility: Sherwood Location: Wellpinit, Washington

X Population Run Input File Name: SHERWOOD Output File Prefix: AQ
____ Array Attached Pop. File Name: WELLPINI
Latitude: 47 ° 52 ' 27 " Longitude: 118 ° 07 ' 00 "

Distances (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	40,000	60,000	80,000

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

____ Individual Run Input File Name: Output File Prefix:

Distances (meters)											

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: ____ Array Attached STAR File Name: GEG0360
Location: SPOKANE WBAN: 24157 HDR: 0360 CODE: GEG SET#: STAR03

Temperature: 8.4 °C Lid Height: 640 m Rainfall: 31.7 cm/yr

____ Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:
Circular Area (m^2): 380,000

Plume Rise:
___ Buoyant (cal/s):
___ Momentum (m/s):
___ Entered (m):

Pasquill Stability	A	B	C	D	E	F	G

Nuclide	Class	AMAD	Release Rates (Ci/yr)					
Rn-222			347					

____ Additional Source Term Attached
Comments:

CAP88PC INFORMATION SHEET

Date: April 1992 Source Category: Revised UMTRCA Regulations Page 1 of 1

Facility: Split Rock Location: Jeffrey City, Wyoming

X Population Run Input File Name: SPLIT ROCK Output File Prefix: AK
Array Attached Pop. File Name: JEFFREYC
Latitude: 42 ° 30 ' 32 " Longitude: 107 ° 47 ' 14 "

Distances: (meters)	500	1,000	2,000	3,000	4,000	5,000	10,000	20,000	40,000	60,000	80,000

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					X
Vegetables:					

Individual Run Input File Name: Output File Prefix:

Distances: (meters)											

Food Fractions:	F1-Grown at Home	F2-Grown Regionally	F3-Imported	Urban/Low Productivity	Rural
Meat:					
Milk:					
Vegetables:					

Meteorological (STAR) Data: Array Attached STAR File Name: LND1100
Location: LANDER WBAN: 24021 HDR: 1100 CODE: LND SET#: STAR05

Temperature: 6.9 °C Lid Height: 608 m Rainfall: 25.4 cm/yr

Stack Source:	1	2	3	4	5	6
Height (m):						
Diameter (m):						

X Area Source:

Circular Area (m^2):	902,000					

Plume Rise:

Buoyant (cal/s):						
Momentum (m/s):						
Entered (m):						

Pasquill Stability	A	B	C	D	E	F	G

Nuclide Class AMAD Release Rates (Ci/yr)

Rn-222			690					

Additional Source Term Attached

Comments:

Appendix B

C A P 8 8 - P C

Version 1.00

Clean Air Act Assessment Package - 1988

S Y N O P S I S R E P O R T

Radon Population Assessment

Facility: LUCKY MC
City: RIVERTON
State: WY

LUCKY MC SYNOPSIS

Effective Dose Equivalent (mrem/year)
2.49E-02

At This Location:	25000 Meters North
Source Category:	INACTIVE TAILINGS
Source Type:	Area
Emission Year:	730 Ci/y

Dataset Name:	LUCKY MC
Dataset Date:	Mar 30, 1992 10:00 pm
Wind File:	WNDFILES\LND1100.WND
Population File:	POPFILES\GASLUCKY.POP

SITE INFORMATION

Temperature:	6 degrees C
Precipitation:	23 cm/y
Mixing Height:	608 m

SOURCE INFORMATION

Source Number:	1
Source Height (m):	1.00
Area (sq m):	8.21E+05
Plume Rise Bouyancy (cal/s): (Release Rate)	0.00E+00

LUCKY MC SYNOPSIS

RN-222 MAXIMALLY EXPOSED INDIVIDUAL

Location Of The Individual:	25000 Meters North
Radon Concentration (pCi/l):	8.77E-04
Decay Product Concentration (WL):	6.12E-06
Lifetime Fatal Cancer Risk:	4.95E-06

TABLE 1
FREQUENCY DISTRIBUTION OF LIFETIME FATAL CANCER RISKS

Risk Range	Number of People	Number of People In This Risk Range Or Higher	Deaths/Year In This Risk Range	Deaths/Year In This Risk Range Or Higher
1.0E+00 TO 1.0E-01	0	0	0.00E+00	0.00E+00
1.0E-01 TO 1.0E-02	0	0	0.00E+00	0.00E+00
1.0E-02 TO 1.0E-03	0	0	0.00E+00	0.00E+00
1.0E-03 TO 1.0E-04	0	0	0.00E+00	0.00E+00
1.0E-04 TO 1.0E-05	37	37	5.70E-06	5.70E-06
1.0E-05 TO 1.0E-06	21420	21457	5.67E-04	5.72E-04
LESS THAN 1.0E-06	402	21859	4.60E-06	5.77E-04

Collective Exposure (Person Working Levels): 2.29E-02

RADIONUCLIDE EMISSIONS DURING THE YEAR

Nuclide	Class	Size	Source #1 Ci/y	TOTAL Ci/y
RN-222	*	0.00	7.3E+02	7.3E+02

TABLE 2
POPULATION DATA

Direction	Distance (m)						
	250	750	1500	2500	3500	4500	7500
N	0	0	0	0	0	0	0
NNW	0	0	0	0	0	0	0
NW	0	0	0	0	0	0	0
WNW	0	0	0	0	0	0	0
W	0	0	0	0	0	0	0
WSW	0	0	0	0	0	0	0
SW	0	0	0	0	0	0	0
SSW	0	0	0	0	0	0	0
S	0	0	0	0	0	0	0
SSE	0	0	0	0	0	0	0
SE	0	0	0	0	0	0	0
ESE	0	0	0	0	0	0	0
E	0	0	0	0	0	0	0
ENE	0	0	0	0	0	0	0
NE	0	0	0	0	0	0	0
NNE	0	0	0	0	0	0	0

Direction	Distance (m)					
	15000	25000	35000	45000	55000	70000
N	0	13	0	0	112	0
NNW	0	0	0	92	0	140
NW	0	0	1	0	0	1364
WNW	0	0	34	0	0	14704
W	0	0	0	0	0	1362
WSW	451	0	0	0	355	36
SW	0	0	0	50	22	9
SSW	0	0	0	1882	0	11
S	0	82	0	0	489	215
SSE	0	0	0	0	0	51
SE	0	11	0	0	0	35
ESE	0	0	0	40	0	0
E	0	0	0	0	59	36
ENE	0	0	24	0	0	100
NE	0	0	0	66	0	0
NNE	0	0	0	0	0	13

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