NUREG/CR-4964
ANL/EES-TM-332

Update of Table S-3 Nonradiological Environmental Parameters for a Reference Light-Water Reactor

Uranium Mining, Milling, and Enrichment

Prepared by L. J. Habegger, D. D. Carstea, J. H. Opelka

Argonne National Laboratory

Prepared for
U.S. Nuclear Regulatory Commission

NUREG/CR-4964
ANL/EES-TM-332

Update of Table S-3 Nonradiological Environmental Parameters for a Reference Light-Water Reactor

Uranium Mining, Milling, and Enrichment

Manuscript Completed: March 1986
Date Published: June 1987

Prepared by
L. J. Habegger, D. D. Carstea, J. H. Opelka

Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439

Prepared for
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, DC 20555
NRC FIN A2330

ABSTRACT

In 1974, Table S-3 of the report *Environmental Survey of the Uranium Fuel Cycle* was published as a technical basis for consideration of the environmental effects of the uranium fuel cycle supporting operation of light-water reactors. A reference reactor cooled with light, or ordinary, water was established to reduce the burden on the Nuclear Regulatory Commission (NRC) staff, reactor license applicants, and other interested persons by removing the necessity to relitigate the environmental effects attributable to the fuel cycle, effects that are not within an applicant's control, in every individual reactor licensing proceeding. In a 1984 evaluation of a license application, it was demonstrated that the Table S-3 estimate of annual effluent of coal particulates is larger, possibly by as much as a factor of 100, than actual current values. Partially as a result of this evaluation, the NRC initiated a study to update all of the major nonradiological values in Table S-3. The results of the study are documented in this update. The report evaluates only the mining, milling, and isotopic-enrichment components of the fuel cycle's environmental parameters since these are the areas in which the greatest changes from the original study could be anticipated.

NRC FIN No. A23305
NRC FIN Title: Update of Table S-3 Nonradiological
Environmental Parameters for a Reference
Light-Water Reactor: Uranium Mining,
Milling, and Enrichment

CONTENTS

CONTENTS (Cont'd)

TABLES

TABLES (Cont'd)

FIGURES

FOREWORD

In 1974, Table S-3 of the report *Environmental Survey of the Uranium Fuel Cycle* (WASH-1248) was codified in 10 CFR Part 51 to establish a technical basis for consideration of the environmental effects of the uranium fuel cycle supporting operation of light-water reactors (LWRs). A reference reactor cooled with light, or ordinary, water was established to reduce the burden on the Nuclear Regulatory Commission (NRC) staff, reactor license applicants, and other interested persons by removing the necessity to relitigate the environmental effects attributable to the fuel cycle, effects that are not within an applicant's control, in every individual reactor licensing proceeding.

In 1984, a contention was admitted by the Atomic Safety and Licensing Board (ASLB) that the draft Environmental Impact Statement for the Shearon Harris Nuclear Power Plant did not analyze or give sufficient weight to the health effects of the coal particulates listed in Table S-3. In an ASLB hearing on this matter, it was demonstrated that the Table S-3 estimate of annual effluent of coal particulates is larger, possibly by as much as a factor of 100, than actual current values. Partially as a result of this evaluation conducted for the Shearon Harris ASLB hearing, the NRC initiated a study to update all of the major nonradiological values in Table S-3. The results of that study are documented in this report.

FOCUS OF THIS UPDATE

The Table S-3 estimates of fuel-cycle environmental parameters include the effects of uranium mining and milling, production of uranium hexafluoride (UF_6), isotopic enrichment, fuel fabrication, radioactive waste management, fuel reprocessing, and transportation. In this update, only the mining, milling, and isotopic-enrichment components were evaluated since these are the areas in which the greatest changes from the original study could be anticipated. The changes in mining and milling are largely the result of a downward trend, from about 0.2% to 0.1%, in the uranium concentration of ores being mined, resulting in approximately twice the ore needing to be mined and processed to produce a given quantity of fuel. Also, there is an increased dominance of underground mining for ore production because of the depletion of near-surface resources. The original Table S-3 assumed all uranium extraction was from surface mines on the basis of the dominance of this type of mining at the time the original study was conducted.

Since the original publication of Table S-3, the isotopic-enrichment processes have undergone considerable development to upgrade uranium performance and efficiency. This upgrading has included the development of the gaseous centrifuge process, although this process has only replaced a limited amount of capacity of the older gaseous diffusion process. Although focusing on the diffusion process, this report includes an evaluation of the centrifuge process for purposes of comparison.

A reevaluation was also conducted of the environmental parameters associated with electrical generation to supply the energy requirements of the enrichment process.

This reevaluation was considered essential because, for one thing, the level of pollutants emitted by power plants has changed significantly, primarily because of introduction of environmental regulations. Also included in this study is the development of environmental factors associated with the mining and preparation of coal to supply both the electrical generation and the on-site boiler at the enrichment plant. The production of coal was not considered in the previous studies related to the Table S-3.

OVERVIEW OF FINDINGS

The results of these updated environmental evaluations are summarized in Table F-1. (For comparison, the Table S-3 values, as they are given in 10 CFR Part 51, are included in Table F-1). There was no attempt to relate the nonradiological environmental values to any actual impacts on human health or the environment. However, the emissions to air and water and solid wastes generated by the various facilities are regulated by various provisions of environmental statutes that are intended to protect human health and the environment. Inherent in the approach to this study is the assumption that all fuel-cycle activities comply with relevant regulations currently in effect.

TABLE F-1 Summary of Nonra
Uranium Fuel-Cycle Requireme

Resource Requirements and Effluents
RESOURCE REQUIREMENT
Land (acres)[a]
Temporarily committed
Disturbed land use
Undisturbed land use
Permanently committed
Water (10^6 gal/yr)
Discharged to air
Discharged to water bodies, ground
Total
Energy
Electricity (10^3 MWh/yr)
Coal (cleaned) (10^3 tons/yr)
Gasoline/diesel fuel (10^3 gal/yr)
EFFLUENT
Air Emissions (tons/yr)
Particulates
Sulfur dioxide (SO_2)
Nitrogen oxides (NO_x)
Hydrocarbons (HC)
Carbon monoxide (CO)
Hydrogen fluoride (HF)
Fugitive dust
Liquid Effluents (tons/yr)
Total suspended solids (TSS)
Total dissolved solids (TDS)
Chlorides (Cl^-)
Sulfates (SO_4^{-2})
Arsenic (As)
Cadmium (Cd)
Chromium (Cr)
Copper (Cu)
Iron (Fe)
Lead (Pb)
Manganese (Mn)
Mercury (Hg)
Magnesium (Mg)
Selenium (Se)
Zinc (Zn)
Nitrates (NO_3^-)
Fluoride (F^-)
Solid Wastes (10^3 tons/yr)
Uranium tailings/sub-ore
Coal ash
Misc. (chem. process, refuse, waste rock not backfilled)
Thermal discharge (10^9 Btu/yr)

[a]Land-use values assume a 30-year lif
apportioned annually.

[b]Assumes mechanical draft cooling tow
electrostatic precipitators, no flue

[c]Assumes Appalachian coal with acid m
preparation effluents treated with t

[d]Based on 60% underground uranium min
gaseous diffusion enrichment; coal e
coal, 60% from underground mines, 40

TI
APERTURE
CARD

Also Available On
Aperture Card

diological Environmental Values Associated with
nts for a 1000-MWe Light-Water Reactor

Uranium Mining		Uranium	Gaseous Enrichment		Coal for	Coal Mining/Preparation			
Surface	Underground	Milling	Diffusion	Centrifuge	Electrical Generation[b]	Underground[c]	Surface[c]	Total[d]	Table S-3[e]
284	5.3	44	13.5	9.9	16	0.6	93.7	284	100
			5.5	5.1					
			8	4.8					
23	35	90	0.25	0.25	15	4.7	12	141	13
63	288	16	83.3	5.3	131	-[f]	-	g	160
567	2520	22	12.4	6.7	69	-	-	g	
630	2808	38	95.7	12	200	4.25	3.1	g	11,200
0.25	-	5.4	262	12	-	6.1	1.7	272	323
-	-	-	0.7	0.85	115.5	-	-	116	130
-	-	1000	2.39	2.5	-	5.9	470	1190	-
5	0.36	-	0.34	0.47	104	0.074	5.2	110	1270
12	0.75	2.7	21.4	9.6	7970	0.092	7.3	8005	4850
150	10	0.6	0.08	7.7	1280	0.97	99	1410	1310
15	1	84	0.2	0.08	17.3	0.074	6.5	114	15
92	6.2	-	-	0.15	57.8	0.26	21	124	33
-	-	-	0.04	0.0007	-	-	-	0.04	0.74[h]
1180	99	130	-	-	-	-	-	994	-
55	325		0.88	-	-	-	-	164	-
-	-	-	29.2	-	99	743	898	933	-
-	-	-	0.011	-	2.48	-	-	2.49	9.4
460	1360	610	29.6	-	55	270	355	1820	10.9
0.013	0.14	-	0.0005	-	0.021	0.009	0.011	0.095	-
0.011	0.082	-	0.00024	-	0.003	0.0071	0.0091	0.051	-
-	-	-	0.0014	0.0002	0.007	0.024	0.029	0.034	-
-	-	-	0.0012	-	0.014	0.011	0.012	0.027	-
-	-	3	0.0033	-	0.97	1.11	1.32	5.17	0.44
-	-	-	0.0008	-	0.013	0.086	0.11	0.11	-
-	-	1.5	0.02	-	0.061	1.22	1.45	2.89	-
-	-	-	0.00008	-	0.0002	-	-	0.0003	-
-	-	-	-	-	-	0.0005	0.0007	0.0006	-
-	0.89	9.7	-	-	0.028	0.015	0.018	10.1	-
0.19	0.5	-	0.004	0.0002	0.064	0.043	0.051	0.43	-
-	-	-	0.278	0.998	-	-	-	0.28	28.4
-	-	-	0.0214	-	-	-	-	0.021	14.2
100	100	215	0.223	0.223	-	-	-	315	-
-	-	-	0.056	0.068	9.21	-	-	9.27	-
-	22	-	0.091	0.001					
-	-	-	900	45	1660	-	-	2560	-

etime for a mine; values are not

ers, particulate control with
-gas desulfurization, and fly-ash pond.

ine drainage; mine drainage; and coal-
he best practical technology (BPT).

ing and 40% surface mining; 100%
lectrical generation; and Appalachian
% from surface mines, and 100% cleaned.

[e]From Table S-3, 10 CFR 51.

[f](-) indicates estimates not available.

[g]Uranium mining water estimates include water discharged from the mines, while coal mining estimates do not include this discharge. Because of the inconsistency, values are not totaled.

[h]As elemental fluorine.

8707010655-01

UPDATE OF TABLE S-3 NONRADIOLOGICAL ENVIRONMENTAL PARAMETERS FOR A REFERENCE LIGHT-WATER REACTOR: URANIUM MINING, MILLING, AND ENRICHMENT

by

L.J. Habegger, D.D. Carstea, and J.H. Opelka

1 INTRODUCTION

1.1 BACKGROUND

In 1974, a document entitled *Environmental Survey of the Uranium Fuel Cycle*[1] was published by the Atomic Energy Commission (AEC) to establish a technical basis for consideration of the environmental effects of the uranium fuel cycle supporting operation of light-water reactors (LWRs). One of the summary tables from that report, Table S-3, "Table of Uranium Fuel Cycle Environmental Data," was codified in 10 CFR Part 51. In developing this report and subsequent proceedings, the AEC determined that the environmental impacts of the uranium fuel cycle, as summarized in Table S-3, need not be reconsidered in each individual reactor licensing proceeding. The result of this determination was a reduced burden on the Nuclear Regulatory Commission staff (NRC, an AEC successor), reactor license applicants, and other interested parties by removing the necessity to relitigate environmental effects attributable to the fuel cycle, effects that are not within an applicant's control, in every individual reactor licensing proceeding.

Subsequently, the NRC amended the Table S-3 environmental impacts associated with reprocessing spent fuel and radioactive waste management (44 FR 45362, Aug. 2, 1979). In the notice promulgating this amendment, the NRC announced it would publish an explanatory narrative that would describe the bases for the values of releases summarized in Table S-3 and would convey their significance with respect to the risks they impose on the total population of the United States. This explanatory narrative was published for public comments in March 1981 (46 FR 15154) as a proposed Appendix to 10 CFR Part 51, but at the current time it has not been promulgated in final form.

The current version of the Table S-3, as it appears in 10 CFR part 51, is shown in Fig. 1.1.

The various challenges and related amendments to Table S-3 have primarily been directed toward the uranium fuel-cycle radiological releases and impacts. A notable exception was the contention that the draft Environmental Impact Statement for the Shearon Harris Nuclear Power Plant did not analyze or give sufficient weight to the health effects of the 1154 metric tons (t) of coal particulates listed in Table S-3 as one of the annual emissions of uranium fuel-cycle activities supporting the annual operation of a 1000-MWe LWR. This contention was admitted for further consideration in a hearing before the Atomic Safety and Licensing Board (ASLB).[2] In this hearing it was demonstrated that the estimated annual effluent of 1154 t is possibly as much as a factor

TABLE S-3—TABLE OF URANIUM FUEL CYCLE ENVIRONMENTAL DATA [1]

[Normalized to model LWR annual fuel requirement [WASH-1248] or reference reactor year (NUREG-0116)]

[See footnotes at end of the table]

Environmental considerations	Total	Maximum effect per annual fuel requirement or reference reactor year of model 1,000 MWe LWR
NATURAL RESOURCE USE		
Land (acres):		
Temporarily committed [2]	100	
Undisturbed area	79	
Disturbed area	22	Equivalent to a 110 MWe coal-fired power plant.
Permanently committed	13	
Overburden moved (millions of MT)	2.8	Equivalent to 95 MWe coal-fired power plant.
Water (millions of gallons):		
Discharged to air	160	=2 percent of model 1,000 MWe LWR with cooling tower.
Discharged to water bodies	11,090	
Discharged to ground	127	
Total	11,377	<4 percent of model 1,000 MWe LWR with once-through cooling.
Fossil fuel:		
Electrical energy (thousands of MW-hour)	323	<5 percent of model 1,000 MWe LWR output.
Equivalent coal (thousands of MT)	118	Equivalent to the consumption of a 45 MWe coal-fired power plant.
Natural gas (millions of scf)	135	<0.4 percent of model 1,000 MWe energy output.
EFFLUENTS—CHEMICAL (MT)		
Gases (including entrainment): [3]		
SO_x	4,400	
NO_x [4]	1,190	Equivalent to emissions from 45 MWe coal-fired plant for a year.
Hydrocarbons	14	
CO	28.8	
Particulates	1,154	
Other gases:		
F	.67	Principally from UF_6 production, enrichment, and reprocessing. Concentration within range of state standards—below level that has effects on human health.
HCl	.014	
Liquids:		
SO^-_4	9.9	From enrichment, fuel fabrication, and reprocessing steps. Components that constitute a potential for adverse environmental effect are present in dilute concentrations and receive additional dilution by receiving bodies of water to levels below permissible standards. The constituents that require dilution and the flow of dilution water are: NH_3—600 cfs., NO_3—20 cfs., Fluoride—70 cfs.
NO^-_3	25.8	
Fluoride	12.9	
Ca^{++}	5.4	
Cl^-	8.5	
Na^+	12.1	
NH_3	10.0	
Fe	.4	
Tailings solutions (thousands of MT)	240	From mills only—no significant effluents to environment.
Solids	91,000	Principally from mills—no significant effluents to environment.
Effluents—Radiological (curies)		
Gases (including entrainment):		
Rn-222		Presently under reconsideration by the Commission.
Ra-226	.02	
Th-230	.02	
Uranium	.034	
Tritium (thousands)	18.1	
C-14	24	
Kr-85 (thousands)	400	
Ru-106	.14	Principally from fuel reprocessing plants.
I-129	1.3	
I-131	.83	
Tc-99		Presently under consideration by the Commission.
Fission products and transuranics	.203	

FIGURE 1.1 Current Version of Table S-3, as It Appears in 10 CFR Part 51

TABLE S-3—TABLE OF URANIUM FUEL CYCLE ENVIRONMENTAL DATA [1]—Continued

[Normalized to model LWR annual fuel requirement [WASH-1248] or reference reactor year [NUREG-0116]]

[See footnotes at end of this table]

Environmental considerations	Total	Maximum effect per annual fuel requirement or reference reactor year of model 1,000 MWe LWR
Liquids:		
Uranium and daughters	2.1	Principally from milling—included tailings liquor and returned to ground—no effluents; therefore, no effect on environment.
Ra-226	.0034	From UF_6 production.
Th-230	.0015	
Th-234	.01	From fuel fabrication plants—concentration 10 percent of 10 CFR 20 for total processing 26 annual fuel requirements for model LWR.
Fission and activation products	5.9×10^{-6}	
Solids (buried on site):		
Other than high level (shallow)	11,300	9,100 Ci comes from low level reactor wastes and 1,500 Ci comes from reactor decontamination and decommissioning—buried at land burial facilities. 600 Ci comes from mills—included in tailings returned to ground. Approximately 60 Ci comes from conversion and spent fuel storage. No significant effluent to the environment.
TRU and HLW (deep)	^{11} 1.1 × 10	Buried at Federal Repository.
Effluents—thermal (billions of British thermal units)	4,063	<5 percent of model 1,000 MWe LWR.
Transportation (person-rem):		
Exposure of workers and general public	2.5	
Occupational exposure (person-rem)	22.6	From reprocessing and waste management.

[1] In some cases where no entry appears it is clear from the background documents that the matter was addressed and that, in effect, the Table should be read as if a specific zero entry had been made. However, there are other areas that are not addressed at all in the Table. Table S-3 does not include health effects from the effluents described in the Table, or estimates of releases of Radon-222 from the uranium fuel cycle or estimates of Technetium-99 released from waste management or reprocessing activities. These issues may be the subject of litigation in the individual licensing proceedings.

Data supporting this table are given in the "Environmental Survey of the Uranium Fuel Cycle," WASH-1248, April 1974; the "Environmental Survey of the Reprocessing and Waste Management Portion of the LWR Fuel Cycle," NUREG-0116 (Supp.1 to WASH-1248); the "Public Comments and Task Force Responses Regarding the Environmental Survey of the Reprocessing and Waste Management Portions of the LWR Fuel Cycle," NUREG-0216 (Supp. 2 to WASH-1248); and in the record of the final rulemaking pertaining to Uranium Fuel Cycle Impacts from Spent Fuel Reprocessing and Radioactive Waste Management, Docket RM-50-3. The contributions from reprocessing, waste management and transportation of wastes are maximized for either of the two fuel cycles (uranium only and no recycle). The contribution from transportation excludes transportation of cold fuel to a reactor and of irradiated fuel and radioactive wastes from a reactor which are considered in Table S-4 of § 51.20(g). The contributions from the other steps of the fuel cycle are given in columns A-E of Table S-3A of WASH-1248.

[2] The contributions to temporarily committed land from reprocessing are not prorated over 30 years, since the complete temporary impact accrues regardless of whether the plant services one reactor for one year or 57 reactors for 30 years.

[3] Estimated effluents based upon combustion of equivalent coal for power generation.

[4] 1.2 percent from natural gas use and process.

FIGURE 1.1 Cont'd

of 100 too large (although the testimony before the ASLB was restricted to using the larger value of 1154 t since it was codified in 10 CFR Part 51 as part of the current Table S-3).

Partially as a result of the evaluation conducted for the Shearon Harris ASLB hearing, the NRC initiated a study to update all of the major nonradiological values in Table S-3. The results of that study are documented in this report.

1.2 SCOPE AND APPROACH

The Table S-3 estimates of fuel-cycle environmental parameters include the effects of uranium mining and milling, production of uranium hexafluoride (UF_6), isotopic enrichment, fuel fabrication, radioactive waste management, fuel reprocessing, and transportation (see Fig. 1.2). In this update, only the mining, milling, and isotopic enrichment components were evaluated since these are the areas in which the greatest changes from the original study could be anticipated.

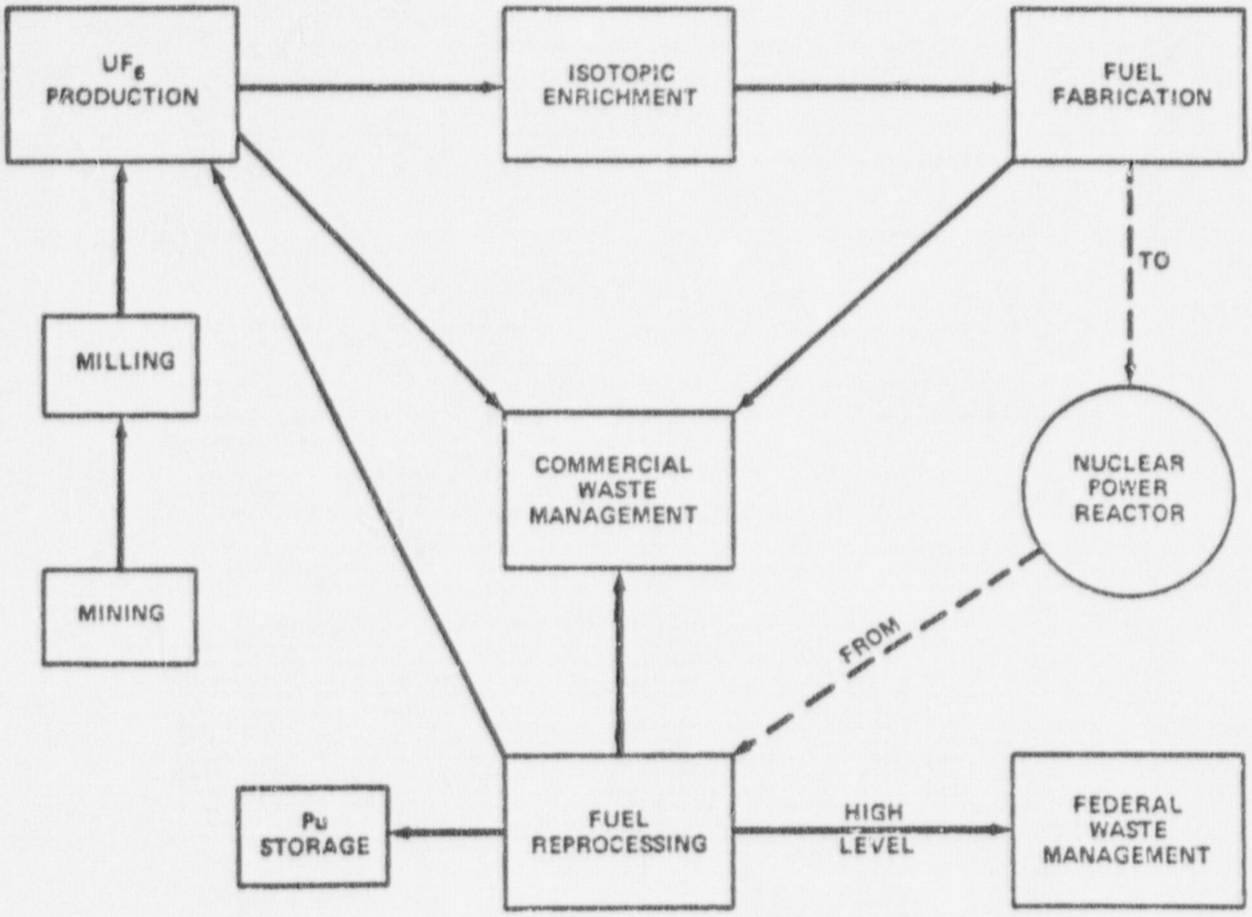

FIGURE 1.2 Uranium Fuel Cycle for Light-Water Reactors

The changes in mining and milling are largely the result of a downward trend, from about 0.2% to 0.1%, in the uranium concentration of ores currently being mined. Compared to the original estimates, approximately twice as much ore must now be mined and processed to produce a given quantity of fuel. Also, there is an increased dominance of underground mining for ore production because of the depletion of near-surface resources. The original Table S-3 assumed all uranium extraction was from surface mines on the basis of the dominance of this type of mining at the time the original study was conducted. Also, considering only surface mines tends to be conservative since, on the basis of many factors, this kind of mine gives larger environmental impacts. A combination of surface and underground mines is assumed for this study. The evaluation of mining and milling of uranium is presented in Secs. 2 and 3, respectively.

Since the original publication of Table S-3, the isotopic-enrichment processes have undergone considerable development to upgrade uranium performance and efficiency. This upgrading has included development of the gaseous centrifuge process, although this process has only replaced a limited amount of capacity of the older gaseous diffusion process. Although focusing on the diffusion process (Sec. 4.1), this report includes an evaluation of the centrifuge process for purposes of comparison (Sec. 4.2).

A reevaluation was also conducted of the environmental parameters associated with electrical generation to supply the energy requirements of the enrichment process (Sec. 4.3). This reevaluation was considered essential for three reasons: (1) the large amounts of electrical energy required to supply the enrichment process, (2) the assumption that generation is from coal-fired power plants, which emit significant levels of pollutants, and (3) a significant change in the level of pollutants emitted from electrical generation because of introduction of environmental regulations.

Also included in this study is the development of environmental factors associated with the mining and production of coal to supply both the electrical generation and the on-site boiler at the enrichment plant (Sec. 4.4). The production of coal was not considered in the previous studies related to Table S-3.

The major assumptions for the factors driving the level of activity in the uranium fuel cycle, including the operating and design characteristics of the model LWR, are given in Table 1.1. These assumptions are basically the same as the ones used to develop the original Table S-3;[1] the major exception, discussed above, is that the ore requirement is based on a concentration of 0.1% instead of 0.2%.

The parameters considered in this study are similar to those given in the original Table S-3. The list of liquid effluents has been extended to include additional constituents. The land use is listed in terms of total commitment for a 30-yr lifetime since the land in many instances is not uniformly committed on a yearly basis. Other parameters are related to fuel-cycle activities to support the reference reactor year (RRY) defined in Table 1.1.

The results of these evaluations are given in terms of quantities of resources required and quantities of nonradiological releases. There was no attempt to relate these quantities to any actual impacts on human health or the environment. However, the emissions to air and water, and the solid wastes generated by the various facilities, are regulated by various provisions of environmental statutes that are intended to protect human health and the environment. Inherent in the approach to this study is the assumption that all fuel-cycle activities comply with relevant regulations currently in effect.

Engineering units are generally used throughout this report. Table 1.2 lists factors used to convert engineering units to metric units.

1.3 REFERENCES

1. *Environmental Survey of the Uranium Fuel Cycle*, U.S. Atomic Energy Commission, WASH-1248 (1974).

2. U.S. Nuclear Regulatory Commission staff testimony of Dr. Loren Habegger, Dr. A. Haluk Ozkaynak, and Mr. Ronald L. Ballard regarding Eddleman Contention 8F(1) (Health Effects of Coal Particulates at the Table S-3 Level), hearing before the Atomic Safety and Licensing Board, Raleigh, N.C. (1984).

TABLE 1.1 Characteristics of Model LWR (1000-MWe) and Their Maximum Annual Average Fuel-Cycle Requirements

Characteristic	Requirement
Irradiation level (MWth/ton U)	30,000
Fresh fuel assay (wt % U-235)	3.2
Spent fuel assay (wt % U-235)	0.84
Ore supply (tons)	200,000
Yellowcake supply (tons U_3O_8)	200
Natural UF_6 (tons)	297
Separative work units[a] (tons)	114
Enriched UF_6 (tons)	35
Enriched UO_3 (tons)	44
Fuel loading (tons U)	38.5
Reactor plant load factor (%)	80
Enrichment tails assay (wt % U-235)	0.25

[a]A separative work unit (SWU) applies to the process of increasing the percentage of uranium for fuel used in a model LWR. (See also Sec. 4.) Separative work is usually expressed in kilograms, with the model LWR annually requiring about 116,000 kg SWU.

Source: Adapted from Ref. 1.

TABLE 1.2 Conversion Factors

Multiply	By	To Obtain
Acres	4046	Square meters
Btu	1055	Joules
Btu/hr	0.2929	Watts
Cubic yards	0.7646	Cubic meters
Feet	0.3048	Meters
Gallons	0.003785	Cubic meters
Tons	0.9072	Metric tons

2 URANIUM MINING

After a uranium deposit has been delineated, a mining method that is physically, economically, and environmentally acceptable to the recovery of ore must be adopted. There are two basic types of mining techniques used by the uranium industry, surface mining and underground mining.

Surface, or open pit, mining is used to excavate ore from near-surface deposits. This method is best suited to ore bodies of substantial horizontal dimensions, which permit high rates of production. Surface mining until recent times accounted for more than half the uranium ore mined annually. Typically, more ore is produced per mine in above-ground mining than in underground mining.

Underground mining is used where the depth of the deposit makes removal of the overburden too costly. Generally, underground mining is used for ore bodies at depths greater than 400 feet.[1,2] Underground uranium mining techniques are significantly different from underground coal mining techniques. Large-capacity air pumps and special exhaust shafts are required at underground uranium mines to provide adequate removal of the radon gas that emanates from the uranium decay process.

In WASH-1248, surface mining was selected as the basis for the S-3 Table because of its highly visible effects on the local environment, including large land-use impacts.[3] Also, surface mining was the dominant means of extraction in the early 1970s. At present, however, underground mining has become the dominant means of extraction as near-surface veins of ore have become exhausted. In 1982, 46% of the uranium ore came from underground mining, 29% from open surface mining, and the remaining 25% from in-situ mining and other processes.[4] In light of this change in the dominant means of extraction -- coupled with the fact that radon gas is an issue for underground mines and not for above-ground mines[5,6] -- this report presents the mining impacts of the fuel cycle, per reference reactor year (RRY), based on both surface and underground mining.

To obtain the cumulative fuel-cycle impacts given in the foreword of this report, the emission values for an RRY represent the weighted average of the values selected in this study for surface and underground mines, based on the 1982 ratio of underground to surface mining, about 3:2. Other mining techniques are not included; however, since the impacts of these other techniques are less than those of either surface or underground mining, this omission will produce a realistic, conservative set of estimates.

The historical trend in the grade of ore has been consistently downward since 1966. In 1966, the grade of U_3O_8 in mined ore was 0.229%; in 1973, it was 0.208%; by 1983, the grade of ore was only 0.126%.[4] Therefore, for this report, the uranium ore content has been revised downward to 0.1%, whereas 0.2% was used in WASH-1248. As a result, 200,000 tons (180,000 t) of ore are required per reference reactor year compared to 100,000 tons (91,000 t) presented in Table S-3 of WASH-1248.

Several different reports on uranium mining have reviewed existing mine operation and have developed representative model surface and underground mines.[7-9]

No single reference appears to be authoritative. Therefore, for some environmental issues, results from each of these reports were reviewed.

2.1 RESOURCE REQUIREMENTS

2.1.1 Land

The land required for uranium mining, both for surface and underground mines, largely consists of land used for long-term storage of overburden and waste rock, and, during operation, of land used for storage of sub-ore (containing a smaller percentage of uranium than ore) and the ore itself.

Land requirements for the mining activities are dependent on the particular mining techniques utilized and resource characteristics. For surface mining, the area of the resource is based on the "model mine" ore thickness of 40 ft.[7] Production of 200,000 tons of ore per year for the RRY would thus require mining an area of approximately 60 acres over a 30-yr lifetime. This land would be recovered by backfilling after the mining is completed.

Assuming that the overburden-to-ore ratio is about 50:1 and that backfilling is done concurrently with mining, Ref. 7 estimates that, for a typical-size surface mine (based on the average of 63 mines in the United States in 1978), 0.65 acres per 1000 tons annual ore production are required to store the overburden at any time over the lifetime of the mine if the overburden piles are about 100 ft high. For the RRY ore production of 200,000 tons/yr, these assumptions imply an ongoing commitment of 130 acres during the lifetime of the mine. This value is assumed in the current report. Using other assumptions for surface mining operations,[7] the range is from 40 to 450 acres. This is a temporary land commitment since the overburden is backfilled into the surface mine after closure.

Ore is stockpiled at the mine. Assuming a typical 41-day ore stockpile, the surface area of the stockpile is in the range of 0.0030 to 0.0064 acres per 1000 tons annual production.[7] Using the higher value, 200,000 tons/yr annual production, for the RRY gives a land commitment of 1.3 acres for ore stockpiling over the lifetime of the mine. This is also a temporary commitment extending only through the lifetime of the mine.

Sub-ore is stored until it is economic to mill, and thus the storage period and associated land requirements is quite variable. Assuming that the quantity of sub-ore produced is equal to that of the ore produced,[7] and that only one-half the sub-ore is eventually used, the production of 200,000 tons of ore for the RRY results in a sub-ore storage area of 23 acres after 30 years. It is conservatively assumed that this quantity of sub-ore remains uneconomical to recover and that the land commitment is permanent.

The land area for haul roads, settling ponds, shop, and other associated surface mine facilities is estimated at 93 acres.[8]

For underground mines, the amount of waste rock produced is much less than the overburden produced at surface mines. The amount of waste rock is, in fact, less than the amount of ore produced, with an estimated average ore-to-waste rock ratio of 9.1:1.[7] Based on data for the average underground "model mine" described in Ref. 7, for an annual RRY ore production of 200,000 tons the land requirements for a mine extended to a 30-yr lifetime are 1.2 acres for waste rock storage, 1.3 acres for 41-day ore storage, and 23 acres for sub-ore storage. Land for other facilities at the underground mine is estimated at 4 acres.[8] It is assumed that the land commitments for sub-ore storage are permanent, as they are in surface mining. Also, the waste rock is assumed not to be backfilled, and thus the land for its storage is permanently committed.

The land-use requirements are summarized in Table 2.1.

2.1.2 Water

One of the major impacts associated with mining is the withdrawal of groundwater to prevent flooding of the mine. Declining water levels in the tapped aquifers, and possibly adjacent formations, are immediately noticed.[7] Lowering of the water table may also affect the flora and fauna, especially in the West, where many of the plants are dependent on subsurface water. Water levels in the aquifers generally return to premining conditions after the mining operations cease.[9]

The discharge of water pumped away from the mining area and into the neighboring environment is one of the major impacts of uranium mining. This water is often released to the environment without processing or being allowed to reside in a settlement pond prior to release. The discharge of mine water may transform dry washes

TABLE 2.1 Land-Use Requirements (acres) for Surface and Underground Uranium Mines in Support of a Reference Reactor[a]

	Surface		Underground	
Requirement	Temp.	Perm.	Temp.	Perm.
Mined surface area	60	-	-	-
Overburden, waste rock storage	130	-	-	12
Ore storage	1.3	-	1.3	-
Sub-ore storage	-	23	-	23
Associated facilities	93	-	4	-
Total	284	23	5.3	35

[a]Land-use estimates are values extended over the 30-yr lifetime of the mine.

Sources: Refs. 7, 8.

and ephemeral streams into perennial streams. The relative amounts of water that evaporate and go to surface and ground water sources vary with the climate and the topography. The mine water is also used to control fugitive dust in surface mines.

Based on the nine-model averages from Ref. 7, the water discharged is 630 x 10^6 gal/yr for a surface mine and 2800 x 10^6 gal/yr for an underground mine for 200,000 tons/yr of ore production for the RRY.

For water discharged from mines, the final disposition to air (evaporation), to groundwater, and to surface water bodies is less clear than in the case of uranium milling. The water discharged from a mine is generally pumped into alluvial stream beds -- how far it proceeds through above-ground streams and rivers is highly dependent on the specific location, hydrology, topography, and climate of the mine. A sufficient number of mines has not been characterized to make a definitive judgment. In Ref. 7, it is suggested that, for the surface mines, about 90% of the water goes to ground and 10% goes to surface water. However, inherent in this analysis is the assumption that the area of the mines is extremely dry. For the same type of analysis of underground mines, no data are provided on the relative amounts discharged to air and to ground and surface water, but it is indicated that a substantial fraction of the water will be deposited in the Rio Grande River.[7] In light of the information provided in Ref. 7, it is assumed that 40% goes to surface water, 50% to ground water, and 10% to the air.

2.1.3 Energy

After an extensive review of the literature, we have determined that the energy consumption cited in WASH-1248 remains reasonable. This determination is supported by the environmental reviews done by the Department of Energy.[10] It is likely that energy consumption (electrical) has increased at underground mines as increased ventilation of the mines has become common practice. However, lacking better information, it is assumed that these energy increases would be offset by decreases in the natural gas and fuel oil requirements of today's energy-efficient engines.

2.2 CHEMICAL EFFLUENTS

2.2.1 Air Emissions

Most of the emissions to air result from the combustion of hydrocarbons in the heavy-duty diesel-powered equipment used in mining operations. These emissions are primarily NO_x, SO_x, and hydrocarbons. Surface mine operations result in more pollutants being emitted because more overburden must be removed to get to the ore body.

Surface mining also generates larger quantities of fugitive dust, again because of the movement of larger quantities of overburden. The dust emitted to the atmosphere is primarily silica, with small amounts of uranium, thorium, sulfates, and trace elements from the soil overburden.

Table 2.2 is a summary of the emissions to air based on the models for surface and underground mines provided in Ref. 7. That is the most recent reference and takes into account current developments in land reclamation and stabilization of the spoil surfaces at mine sites.

2.2.2 Liquid Effluents

The estimated contaminants in the water discharged from uranium mines, presented in Table 2.3, are based on average model mines described in Ref. 7 and discharge volumes given in Sec. 2.1.2. The contaminants can be transported to other geographic areas by stream migration in perennial or ephemeral streams. As the water evaporates from ephemeral streams, it also leaves behind its dissolved and suspended materials, which can subsequently percolate into the groundwater.

2.2.3 Solid Waste

The amount of residual solid material at uranium mines is determined by the amount of overburden and waste rock that is not backfilled and the sub-ore that is not processed. For both surface and underground mines it is assumed that the sub-ore produced is equal in quantity to the ore produced (200,000 tons per RRY) and that one-half (100,000 tons per RRY) remains unused (see Sec. 2.1.1). For surface mines, all the overburden and waste rock is assumed to be backfilled. For underground mines, the waste rock is assumed not to be backfilled, also assuming an ore-to-waste rock ratio of 9.1:1.[7] The quantity of residual waste rock is thus estimated at 22,000 tons per RRY.

TABLE 2.2 Air Emissions from Uranium Mines

	Surface Mines		Underground Mines	
Type of Emission	tons/yr[a]	tons/RRY	tons/yr[b]	tons/RRY
Particulates	3.3	5	0.035	0.36
SO_x	7.7	12	0.074	0.75
CO	61	92	0.62	6.2
NO_x	100	150	1.0	10
Hydrocarbons	9.9	15	0.10	1.0
Fugitive dust	780	1180	9.8	99

[a]Based on Ref. 7, a surface mine with emissions of 1.32×10^5 tons/yr.

[b]Based on Ref. 7, an underground mine with emissions of 1.98×10^4 tons/yr.

TABLE 2.3 Estimate of Effluents Contained in Water Discharges from Uranium Mines for an RRY (tons/yr)[a]

Constituent	Surface Mine	Underground Mine
Total suspended solids	55	325
Sulfate	460	1360
Arsenic	0.013	0.14
Cadmium	0.011	0.082
Selenium	-	0.89
Zinc	0.19	0.50

[a]Based on average model mine given in Ref. 7 and discharge volumes of 630 x 10^6 gal/yr for surface mines and 2800 x 10^6 gal/yr for underground mines.

2.3 REFERENCES

1. *Environmental Considerations in Future Energy Growth*, Battelle-Columbus Division and Pacific Northwest Laboratory (1973).

2. Kelmenic, John, *Examples of Overall Economics in a Future Cycle of Uranium Concentrate Production for Assumed Open Pit and Underground Mining Operation*, U.S. Atomic Energy Commission, TID-26294 (1972).

3. *Environmental Survey of the Uranium Fuel Cycle*, U.S. Atomic Energy Commission, WASH-1248 (1974).

4. *Statistical Data of the Uranium Industry*, U.S. Department of Energy, Grand Junction Office, Col., GJO-100(83) (Jan. 1, 1983).

5. *Standard for Radon-222 Emissions from Underground Mines*, U.S. Environmental Protection Agency, EPA 520/1-85-010 (April 10, 1985).

6. *Radionuclides Background Information Document for Final Rules*, U.S. Environmental Protection Agency, EPA/1-84-022.2 (Oct. 22, 1984).

7. *Potential Health and Environmental Hazards of Uranium Mine Wastes*, U.S. Environmental Protection Agency, EPA/1520-83-007 (June 1983).

8. *Energy from the West: Energy Resource Development Systems Report, Vol IV: Uranium*, U.S. Environmental Protection Agency, EPA-600/7-79-060d (March 1979).

9. Reed, A.K., H.C. Meeks, S.E. Pomeroy, and V.Q. Hale, *Assessment of Environmental Aspects of Uranium Mining and Milling*, EPA-600/7-76-036 (Dec. 1976).

10. *Technology Characterizations, Environmental Information Handbook*, U.S. Department of Energy, DOE/EV-0072 (June 1980).

3 URANIUM MILLING

In the uranium milling process, uranium is extracted from the mined crude ore and concentrated into a semirefined product called "yellowcake." After the ore is pulverized and has gone through a process of wet grinding, it goes through an acid or alkaline leach process. The resultant slurry is then decanted to remove the suspended solids, and the uranium is removed from the decanted liquid by solvent extraction. The residual liquids from the solvent extraction and the decanted solids, washed and resuspended, are sent to the mill tailings pond for disposal.

Since the issuance of WASH-1248, the NRC has performed a major study of the environmental impacts of uranium milling.[1] Also, the EPA prepared an environmental impact statement in support of its consideration of standards for the uranium ore processing industry.[2] In both of these studies, two major changes since the issuance of WASH-1248 were factored. First, the estimated average uranium content of ore processed at a mill was reduced from 0.2%, used in WASH-1248, to 0.1%. Second, both of the newer studies took into account improvements in the lining of mill tailings ponds (to prevent groundwater seepage) and in mill tailings management in general; these improvements came in response to regulatory requirements.

After 1976, the NRC made a concerted effort to bring uranium mill tailings under control. Performance objectives were issued in 1977,[3] providing location criteria, requiring the elimination of wind-blown tailings, and requiring the reduction of post-reclamation radiation exposures on off-site areas to essentially background levels. The same NRC guidance discouraged the use of upstream dam construction and specified the use of clay or artificial liners in tailings ponds to minimize seepage. The EPA promulgated a requirement in 1983 that radon emissions be limited to 20 pCi per m^2/s.[2] In the same regulatory action, the EPA incorporated the Solid Waste Disposal Act standards (40 CFR 264) into the existing standards for operating mills (40 CFR 190, 40 CFR 440, 25 FR 4402) in order to protect groundwater quality.

Both the EPA and NRC environmental analyses[1,2] are based on the same model mill, which has an ore processing capacity of 1980 tons per day, with a yellowcake production rate of 570 tons per year. The model mill chosen by both the NRC and EPA utilizes the acid leach process, since about 80% of milling in the U.S. utilizes this process.[2] The major impacts of the alkaline leach process are expected to be about the same as those of the acid leach process.[2] The NRC and EPA environmental analyses represent the most recent and thorough reviews of the environmental impacts of the domestic uranium milling industry. Therefore, the acid leach model mill developed in the NRC and EPA environmental analyses has been chosen to determine the impacts for this updating of Table S-3.

Historically, about 90% of the yellowcake utilized by the U.S. commercial reactor industry has been produced by conventional mills operating primarily in the United States.[2] However, in the future, imports are projected to increase, as well as yellowcake from unconventional sources as in-situ solution mining and by-product recovery. It is estimated by the Department of Energy that, by 1990, only about 64% of the yellowcake used in the United States will be produced by conventional mills whose feed ore comes from conventional underground and surface uranium mines.[5] However, for purposes of this review of Table S-3, it will be conservatively assumed that 100% of the yellowcake required for a reference reactor year comes from acid leach mills operating in the United States. The WASH-1248 analysis used 200 tons of yellowcake per year for the RRY, a value analyzed during this review and still considered reasonable. In order to produce this amount of yellowcake, approximately 200,000 tons per year of uranium ore with the 0.1% assumed concentration will have to be mined and milled. (The actual quantity of ore processed may actually be slightly larger because less than 100% of the uranium is extracted; however, this is within the accuracy of this generic study.) Since the model mill produces yellowcake at a rate of 570 tons per year, the values developed for environmental impacts from the model mill must be multiplied by 0.35 to obtain the impacts per reference reactor year.

3.1 RESOURCE REQUIREMENTS

3.1.1 Land

For a model mill with a 15-yr lifetime, about 250 acres will be permanently committed to the mill disposal area (pond). This entire area could be committed to tailings initially or in several stages during the lifetime of the mill. In addition, about 25 acres could become contaminated by wind-blown tailings (i.e., greater than 5 pCi/g of radium). To adjust for a 30-yr operating period, these permanent land commitments must be doubled. During operation, about 125 acres would be devoted to the milling process and allied activities. This is a temporary land commitment independent of mill lifetime.

Adjusting these values for a 30-yr lifetime and the capacity requirement for the RRY, the permanent land commitment is 90 acres and the temporary land commitment is 44 acres. These values do not include additional land requirements during construction.

3.1.2 Water

Each day the model mill processes 1980 tons of ore, resulting in nearly equal daily quantities of dry tailings and nearly equal daily water weights for slurrying the tailings. On the average, 30% of the tailings liquid is recycled, so that the net consumption of water is 1390 tons (3.5×10^5 gal) per day. This water typically comes from deep wells or possibly from supplies available from nearby mining operations. When discharged from the mill, the slurried tailings materials are pumped in pipes to a tailings pond. (Water consumption for alkali-leach mills is about one fourth as large as it is for acid-leach systems.)[4] A well is normally drilled for potable water, but potable water requirements are small compared with those for the milling itself.

The use of wells to supply process water results in a decrease in the amount of water available in aquifers for other uses, but the quantities withdrawn are not expected to have major long-term effects on regional water supplies.[4] The use of water from mining operations for process water at the mill reduces the need for process water wells and also reduces the volume of mine water discharged to the environment.

The amount of seepage to groundwater from the tailings pond, which serves as an evaporation-percolator pond, varies from as much as 85% to as little as 7% in properly engineered clay-lined ponds.[4] There are generally no routine releases to surface water from uranium mills, if the tailings pile is properly sited and minimal engineering controls are used.[2] In the unlikely event that excess liquids exist in the ponds (precipitation and influx from the mill exceeds seepage and evaporation), these liquids would be discharged, after treatment, to steams or underground wells. Standing water in adjacent intermittent streams has been found with elevated concentration of toxic materials. Also, contaminated groundwater can conceivably find its way to nearby surface streams and lakes.

At equilibrium operating conditions, a seepage rate of 0.24 million tons of water per year for the model mill has been estimated. It was further estimated that after the mill is shut down, about 5% of this amount will continue to percolate annually. The remainder of the water will evaporate. Table 3.1 summarizes the use and disposition of water for the model mill and adjustments for the RRY based on these values.

3.1.3 Energy

Electrical energy and natural gas consumption have apparently not been reviewed since the issuance of WASH-1248; because the milling process is essentially unchanged, the assumption that Table S-3 entries for electricity and natural gas per unit of ore throughput remain unchanged seems reasonable. However, to account for a doubling in ore throughput, based on an average uranium concentration that has been cut in half in recent years, it is conservatively assumed that the energy requirements will double. With these assumptions, the energy requirements for the mill supporting the RRY are 5400 MWh/yr and 137 x 10^9 Btu/yr from natural gas and/or fuel oil.

TABLE 3.1 Annual Water Use and Disposition for the Model Mill and for a Mill Adjusted for the Reference Reactor Year (10^6 gal/yr)

Use or Other Disposition	Model Mill[a]	Mill for RRY
Use	107	38
Discharge to air	47	16
Discharge to surface water bodies	0	0
Discharge to groundwater bodies	60	22

[a]Source: Ref. 1.

3.2 CHEMICAL EFFLUENTS

3.2.1 Air Emissions

Gaseous emissions from milling come from fuel combustion and the chemicals used in the acid- or alkali-leach procedure. The use of fuels such as natural gas or fuel oil results in the emission of hydrocarbons, SO_x, NO_x, CO, and CO_2. The primary effluents given off to the atmosphere from the chemical processes at the mill are SO_2, kerosene, ammonia, and amines.[6,7] Also, vapors of organic chemicals enter the atmosphere from evaporation from the tailings ponds.

The published emissions to the air from the 570 ton/yr model mill[1] were used in Table 3.2 to estimate the air emissions associated with a mill supporting the RRY.

3.2.2 Liquid Effluents

When discharged from the mill, the slurried tailings material is pumped through pipes to the tailings pond. The slurried tailings at the model mill contain equal parts by weight of the uranium-depleted ore and waters. Therefore, about 1390 tons/day of slurry are released to the tailings pond for the mill supporting the RRY. In addition to the radiological residue in the tailings pond (which gives rise to the most serious problem of radon gas emissions), chemicals are released both from the ore and from the chemicals used in the acid-leach process. The composition of the slurry generated at the model mill is quantified in Table 3.3.

TABLE 3.2 Emissions to the Air for a Model Mill and for a Mill Supporting the Reference Reactor Year (tons/yr)

Air Emission	Model Mill[a]	Mill for RRY
Ore dust plus tailings dust	370	130
Hydrocarbons - organic solvent (92% kerosene)	240	84
Fuel oil burning		
SO_x	7.5	2.6
NO_x	1.7	0.6
SO_2 (acid leach tank vent)	0.34	0.12

[a]Source: Ref. 1.

Seepage from groundwaters will contain principally iron, manganese, sulfate, and selenium as the nonradioactive constituents. About 40% of water in the tailings slurry, or about 2×10^5 gal (790 tons) of water per day for the mill supporting the RRY, will seep through to the groundwater each year during operation. Estimates of the concentrations and quantities of constituents in this seepage at the base of the tailings pond are given in Table 3.4.

3.2.3 Solid Wastes

Solid wastes from the model mill are generated at a rate of 690 tons per day, or 215,000 tons per year, for a mill supporting an RRY. In regions, where mills are generally found, the mill tailings slurry will tend to dry out and form a solid waste deposit. This material can be stabilized by vegetation or alternative methods.

TABLE 3.3 Composition of the Tailings Slurry Generated at the Model Mill

Chemical Element	Model Mill (mg/L)
Aluminum	2000
Arsenic	0.2
Chloride	300
Copper	50
Fluoride	5
Iron	1000
Lead	7
Manganese	500
Mercury	0.07
Selenium	20
Sulfate	30,000
Zinc 56	80

Source: Ref. 1.

TABLE 3.4 Estimated Concentration and Quantities of Major Contaminants in Tailing Pond Seepage for a Mill Supporting an RRY

Constituent	Concentration (mg/L)[a]	Quantity (tons/yr)[b]
Iron	10	3.0
Manganese	5	1.5
Sulfate	2000	610
Selenium	32	9.7

[a]Source: Ref. 1.

[b]Based on 2×10^5 gal/day seepage.

3.3 REFERENCES

1. *Final Generic Environmental Impact Statement on Uranium Milling*, Project M-25, U.S. Nuclear Regulatory Commission, NUREG-0706 (Sept. 1980).

2. *Final Environmental Impact Statement for Standards for the Control of By-product Materials from Uranium Ore Processing* (40 CRF 192), U.S. Environmental Protection Agency, EPA 520/1-83-008-1 (Sept. 1983).

3. *Design, Construction and Inspection of Embankment Retention Systems for Uranium Mills*, U.S. Nuclear Regulatory Commission, Regulatory Guide 3.11, Washington, D.C. (1977).

4. Reed, A.K., H.C. Meeks, S.E. Pomeroy, V.Q. Hale, *Assessment of Environmental Aspects of Uranium Mining and Milling*, Battelle Columbus Division, EPA-600/7-76-036 (Dec. 1976)

5. *United States Uranium Mining and Milling Industry: A Comprehensive Review*, U.S. Department of Energy, DOE/S-0028 (May 1984).

6. *Environmental Impact Statement on the Highland Uranium Mill*, Atomic Energy Commission Report to Exxon Co. (March 1973).

7. *Supplemental Environmental Report*, Operating License Stage, Rio Algom Corp. (Nov. 1977).

4 URANIUM ENRICHMENT

Uranium enrichment is an important phase in the uranium fuel cycle (Fig. 4.1). The enrichment process consists of a series of steps designed to increase the percentage in the fuel of the desired fissile material, uranium-235 (U-235). Natural uranium contains approximately 0.7% of this fissile material, and nearly all of the remainder is nonfissile uranium-238 (U-238). Light-water reactors require uranium fuel containing from 2 to 4% U-235.

The effort expended by the facility to separate a quantity of uranium of a given concentration into two components, one having a higher percentage of U-235 than the other, is known as a "separative work unit" (SWU). The production resulting from separative work is generally expressed in kilograms (kg). The SWU quantifies an enrichment effort by weighting the importance of plant flows and their respective assays. For example, 3.4 kg SWU are needed to produce a 1-kg mass of 4% U-235 under typical conditions.[1] About 116,000 kg/yr SWU are required to support a reference reactor year (RRY), i.e., the annual fuel requirement of the selected Model 1000-MWe LWR.[2]

The gaseous diffusion process (GDP) is currently used by the United States to enrich uranium. The three gaseous diffusion plants owned by the U.S. Department of Energy and operated by private industry under contract are located at Oak Ridge, Tenn.; Portsmouth, Ohio; and Paducah, Ky. The gas centrifuge technology has been developed and has reached an operational stage; a gas centrifuge plant has been under construction for several years at Portsmouth, Ohio. This planned centrifuge facility would add approximatel [illegible]% to the enrichment capacity existing in 1980.[3] The resources required (land, water, and energy) and the chemical environmental residuals associated with both gas diffusion and gas centrifuge technologies are discussed in Secs. 4.1 and 4.2, respectively; discussions are based on model enrichment plants appropriately normalized to support the model 1000-MWe LWR.

The enrichment activities require large amounts of electrical energy; major potential resource and environmental impacts are therefore associated with supporting an RRY. These impacts come from electrical generation and, assuming the generation is from a coal-fired plant, production of necessary coal, discussed in Secs. 4.3 and 4.4, respectively.

4.1 GAS DIFFUSION ENRICHMENT PROCESS

The principles of the gaseous diffusion technology are described in Refs. 1 through 7.

Basically, uranium hexafluoride gas (UF_6) is compressed by high-pressure pumps and forced to flow along the inside of a porous barrier tube. The mechanism for U-235 and U-238 separation is based upon the differences in the mass and kinetic energy during the flow of these isotopes through the barrier materials. The lighter U-235 molecules are moving faster through the porous barrier than the heavier U-238. The UF_6 gas can

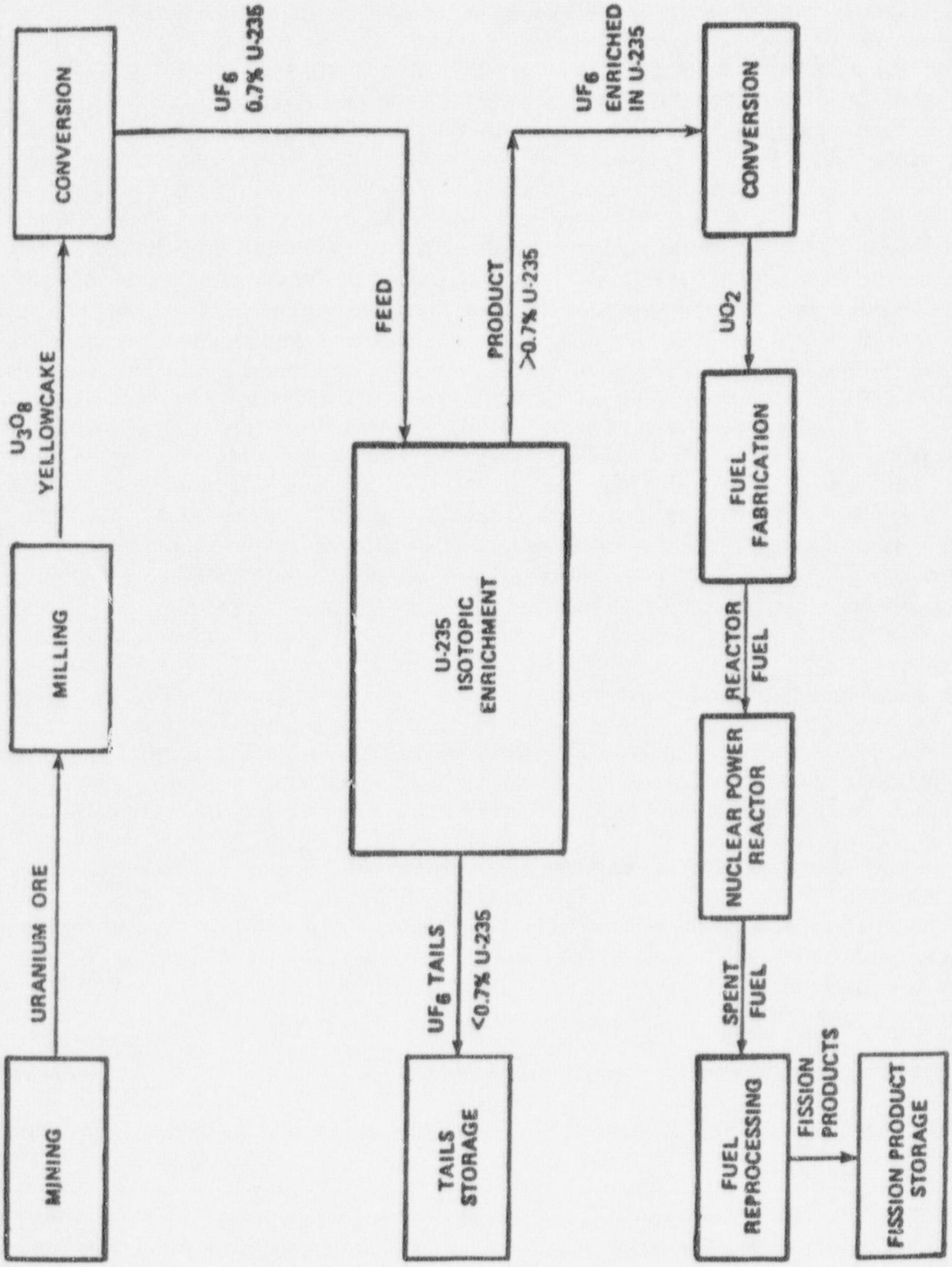

FIGURE 4.1 Processing Scheme for Nuclear Power Reactor Fuel

be further enriched by a combination of a series of stages. A large number of separation stages is required to attain the necessary enrichment because the difference between the light and heavy molecules of uranium is small. For example, about 1700 stages are needed to produce UF_6 that contains 4% U-235.

Each enrichment stage produces two outgoing streams of UF_6: the enriched product, which has a higher percentage of U-235 than the input feed; and the tails, which have a lower percentage of U-235 than the input feed. The assay of the final-stage tails averages about 0.25% U-235. The depleted product, in solid uranium hexafluoride form, is stored in cylinders on-site for possible future use (i.e., recycling). A more economical balance between feed and separative work is achieved by the operation of gaseous diffusion plants with a tails assay ranging between 0.20 and 0.255% U-235 than with one ranging between 0.29 and 0.37% U-235. Tails with assays in the vicinity of 0.25% U-235 reduce the requirement for uranium feed and thus conserve the uranium resources; tails of this grade consequently would reduce the environmental impacts associated with uranium mining and milling.

The U.S. gaseous diffusion plant (GDP) enrichment capacity was recently expanded from 17.2 x 10^6/yr SWU to 27.3 x 10^6/yr SWU during the Cascade Improvement Program (CIP) and Cascade Upgrading Program (CUP). The CIP involves process equipment modification and expansion of production support facilities at the three gaseous diffusion plants, and this program resulted in a significant increase of separative work production. The CUP involved the upgrading and modification of process utility systems and process equipment, which resulted in a more efficient use of electric power.

4.1.1 Resource Requirements

Several technical reports describing the existing and the planned expansion of the gaseous diffusion enrichment industry in the United States were prepared since the publication of Table S-3 in the 10 CFR Part 51.51.[1,3-7] These documents were reviewed in detail in the current study, and the annual resources required by the gaseous diffusion plant in support of a Model 1000-MWe LWR were estimated primarily from these sources.

The estimated proportions of GDP requirements for land, water, and energy to support the model LWR are shown in Table 4.1. The basis for these estimates from the literature is also described in Table 4.1.

4.1.1.1 Land

The land requirement, as estimated in the literature (Table 4.1), varies considerably, and a pattern of land use is not readily apparent. The 1974 data[2] cited actual land area of about 1500 acres for the three plants. In recent years, during the upgrading and improvement programs, the capacities of these plants have more than doubled, while their areas remained the same or increased slightly. Therefore, the smaller surface area exhibited by the Oak Ridge and Paducah GDPs are most likely a reflection of the improvement program.

TABLE 4.1 Estimated Land, Water, and Energy Requirements for a Gaseous Diffusion Plant with an Equivalent Capacity of 116×10^3 kg/yr SWU

Resource Requirement	This Study[a]	Ref. 2 (1974)	Ref. 1 (1976)	Ref. 4 (1977)	Ref. 5 (1979)	Ref. 3 (1980)	Ref. 6 (1983)	Ref. 7 (1982)
Land (acres)[a]								
Temporarily committed[b]								
Disturbed land use	5.5	4.7	5.3	8.0	-	4.2	-	-
Undisturbed	8.0	11.8	4.7	2.7	-	12.6	-	-
Permanently committed	0.25[c]	-	-	-		-	-	-
Water (10^6 gal/yr)								
Discharged to air	83.3	84	82.7	90.5	79.9	84	75.3	87
Discharged to water bodies	12.4	6	22.1	16.0	26.6	6	5.5	4.7
Energy								
Electricity (10^3 MWh/yr)	262[d]	314	279	313	221	315	276	260
Coal, cleaned (tons/yr)	700[e]							
Gasoline and diesel fuel (gal/yr)	2390[e]							

[a]Based on averages from references cited except as noted.

[b]Disturbed land is occupied by structures or dedicated to a specific use for the lifetime of the plant; undisturbed land is unoccupied buffer zones and lands available for future expansion. Values given are for the plant lifetime and are not apportioned to yearly production.

[c]Based on 30-yr collection of ash, process wastes, and miscellaneous refuse and trash quantities given in Table 4.2 and 18,000 tons/acre ash disposal for power plants (Sec. 4.3).

[d]30-MWe average generation. Assuming plant upgrading has reduced energy requirements, higher values from Refs. 2-4 were not included in the averaging.

[e]Source: Ref. 1.

Some of the documents examined provide a definition of disturbed and undisturbed land, while others do not. The undisturbed land cited in some documents has undergone disturbance to a certain degree when compared to the pristine state. The proximity to the plant in itself constitutes a disturbance, even for land in the buffer zone. Disturbed land, as defined in this study, is the land occupied by various structures or dedicated to specific use (e.g., roads) for the lifetime of the plant. The available land for buffer zones and future expansion is considered to be undisturbed. The plant can be decommissioned and the land used for other human activities, or land no longer used can be allowed to return to a more natural state.

The annual allocation of annual land use to enrichment production is ambiguous since the plant and auxiliary structures commit the land once, at the beginning of operation, and not every year. Expansions and modernizations of plants that are periodically made to the basic structures further invalidate a meaningful estimate of land use per annual enrichment production. The approach thus taken here is to list land use per unit of enrichment production capacity, based on available data.

The proportion of GDP land area in support of a model 1000-MWe LWR is relatively small (about 14 acres) when compared to a coal-fired power plant (25-35 acres), discussed below, which supplies the electricity needed for uranium enrichment. This GDP land includes the area needed for the disposal of uranium-contaminated and nonuranium waste at the facility. Only the nonuranium waste disposal areas are assumed to be permanently committed; the uranium tailings are typically stored in cylinders as solid UF_6 and can be recovered.

4.1.1.2 Water

Gaseous diffusion plants must be provided with cooling systems to remove the heat generated during the compression of gas and by other auxiliary processes. Approximately 90% of the electrical energy consumed at the site is converted to heat in the enrichment process.

The water requirement shown in Table 4.1. is for makeup water; some of the water is lost to the air from the cooling towers by evaporation and drift; other water is discharged to water bodies as blowdown water. The term "drift" is applied to the entrainment of water droplets by wind. The drift is the smallest component of water loss from cooling towers (e.g., about 0.05% for cooling towers at the Paducah GDP). The blowdown is the amount of water continuously discharged from the cooling water inventory and replaced by a fresh supply of water. This discharge is necessary in order to limit the concentration of dissolved solids in the cooling water as a result of continuous evaporative losses.

On the average, the fraction of a gaseous diffusion plant complex with a capacity equivalent to 116×10^3 kg/yr of SWU, and which includes the fraction of the steam plant that provides steam for process and space heating, discharges about 83×10^6 gal of water to air and 12×10^6 gal to water bodies. In contrast, the coal-fired plant that produces electricity for this enrichment capacity consumes about 1.2×10^8 gal of water lost to air by evaporation, 0.11×10^8 gal lost as drift, and about 0.5×10^8 gal discharged to water.

4.1.1.3 Energy

The gaseous diffusion plant with a capacity equivalent to 116 x 10^3 kg/yr SWU needs about 262 x 10^3 MWh/yr (30 MWe-average generation) -- see Table 4.1. Approximately 96 to 98% of the electrical energy consumed in the entire fuel cycle is used in the enrichment operations. The electricity requirements cited in the literature for enrichment plants exhibit a relatively wide variation (Table 4.1). The lower electricity requirements reported following the publication of Table S-3 in 10 CFR Part 51 are certainly a result of upgrading and improvement efforts undertaken during the intervening period.

Additional annual energy requirements by the diffusion plant supporting a capacity of 116 x 10^3 kg/yr SWU include about 700 tons of coal consumed by the on-site steam plant and about 2390 gal of gasoline and diesel fuel.[1]

4.1.2 Chemical Effluents

The air emissions, liquid effluents, solid waste, and thermal discharges of a GDP are shown in Table 4.2 and described below.

4.1.2.1 Air Emissions

The enrichment plant complex emits airborne residuals from the process and auxiliary systems, including the steam plant. The air emissions contain hydrogen fluoride, nitrogen oxides, sulfur dioxide, particulates, hydrocarbons, and carbon monoxide.

There are no federal New Source Performance Standards (NSPS) for the on-site GDP boilers, since their capacity is less than 73 MW, or less than the 250 x 10^6 Btu/hr heat input cut-off for boiler NSPS. Boilers are subject to state emission limits, which vary from state to state and reflect local conditions and requirements for achieving and maintaining national ambient air quality standards (NAAQS).

4.1.2.2 Liquid Effluents

The liquid effluent pollutant discharges in Table 4.2 are based on the Oak Ridge GDP.[5] The data from other references are at best inconclusive and incomplete. The data from Oak Ridge GDP is thus assumed to be representative of the chemical effluents from the gaseous diffusion plants. The sources of the liquid effluents are primarily from:

- Liquid wastes from process cleanup operations,
- Blowdown water from the process cooling system,
- Condensate and blowdown from the on-site steam plant, and
- Liquid wastes from auxiliary production facilities.

TABLE 4.2 Estimated Annual Effluents for a Gaseous Diffusion Enrichment Plant with an Equivalent Capacity of 116 x 10^3 kg/yr SWU

Type of Effluent	Amount Released
Gaseous emissions (tons/yr)[a]	
Particulates	0.34
Sulfur dioxide (SO_2)	21.4
Nitrogen oxides (NO_x)	0.08
Hydrocarbons (HC)	0.2
Hydrogen fluoride (HF)	0.04
Liquid effluents (tons/yr)[a]	
Total suspended solids (TSS)	0.88
Total dissolved solids (TDS)	29.2
Sulfates (SO_4^{-2})	29.6
Arsenic (As)	0.0005
Cadmium (Cd)	0.00024
Chromium (Cr)	0.0014
Copper (Cu)	0.0012
Iron (Fe)	0.0033
Lead (Pb)	0.0008
Manganese (Mn)	0.020
Mercury (Mg)	0.00008
Zinc (Zn)	0.004
Chloride	0.011
Nitrate	0.278
Fluoride	0.0214
Solid waste (tons/yr)	
Enrichment tailings	223
Coal ash	55.7
Chemical process wastes	1
Misc. trash and refuse	90
Thermal discharges (10^9 Btu)	
Gaseous diffusion plant (without steam plant)	896
Steam plant	4.6

[a]Source: Oak Ridge GDP data[5] scaled to 116 x 10^3 kg/yr SWU.

The data in Table 4.2 are derived from permits and associated standards, monitoring, and reporting requirements under the National Pollutant Discharge Elimination System (NPDES) for the Oak Ridge GDP.[5] As expected, the mass discharges of sulfates and total dissolved solids are the largest quantities among the chemical effluents associated with a gaseous diffusion plant.

4.1.2.3 Solid Waste

The data regarding the amount of solid waste generated by the gaseous diffusion plants are sparse and inconsistent.

Four types of solid wastes generated at the gaseous diffusion plants were considered in this study, namely, spent uranium tailings, ash from the coal plant, chemical process wastes, and trash and refuse. The estimated uranium tailings resulting from the annual enrichment of fuel for the RRY are obtained from the mass balance equations:

$$U_i\,(0.72) = U_t\,(a) + U_f\,(b),$$

$$U_i = U_t + U_f$$

where U_i is the natural uranium mass input, which has a U-235 concentration of 0.72%; U_t is the mass of uranium in the tailings with a U-235 concentration of (a)%; and U_f is the fuel mass with a U-235 concentration of (b)%. Assuming "a" is 0.25%, "b" is 3.2%, and U_f is 38.5 tons/yr, then U_t is 203 tons/yr, or 223 tons/yr as UF_6.

Assuming that the on-site boilers burn about 700 tons of coal with 8% ash, about 11 tons of bottom ash (20% of total ash) and 45 tons of fly ash will be generated at the plant. If the steam plant atmospheric particulate emissions are well controlled (>99%), as assumed in Table 4.2, nearly 56 tons of bottom and fly ash would be generated as solid waste by the steam plant, and about 0.34 tons of fly ash will be released. For comparison, if the plant is equipped with particulate control technology with an 80% removal efficiency, then about 47 tons of ash would need to be disposed of at the gaseous diffusion plant.

The solid chemical waste includes various liquid effluents collected and treated in the holding ponds. The annual amount of such waste generated by the gaseous diffusion plant in support of the RRY is about 1 ton.[2,3] The add-on gaseous diffusion plant at Portsmouth, Ohio, with a capacity of 8.75×10^6 kg/yr SWU, was expected to generate annual trash and refuse that included about 12,600 ft^3 of cafeteria wastes (estimated for this study at 150 tons), 0.9 tons of sludge from the sewage treatment plant, and 6400 tons of miscellaneous material. By applying the normalization factor of 75.4 plant equivalents to the estimates for Paducah, the model plant with a capacity of 116×10^3 kg/yr SWU considered in this study would annually generate about 90 tons of trash and refuse materials.

4.1.2.4 Thermal Discharges

It has been already established that the gaseous diffusion plant in support of the RRY requires about 262 x 10^3 MWh/yr, or 896 x 10^9 Btu/yr.

This energy is dissipated as heat and rejected to the atmosphere. About 10% of the heat is rejected to the atmosphere through the blowdown steam, and the remainder of the heat passes to the atmosphere via cooling towers by evaporation of water.

The second source of thermal discharges is the steam plant that produces process steam and space heating. About 4.6 x 10^9 Btu/yr of heat are rejected by a steam plant needed to support a gaseous diffusion plant with an equivalent capacity of 116 x 10^3 kg/yr SWU.[1]

4.2 CAS CENTRIFUGE ENRICHMENT PROCESS

The theoretical principles underlying gas centrifuge process (GCP) enrichment are described in detail in Refs. 1, 3, and 4. The GCP is characterized by many centrifuge machines operating in a cascade. Pressure diffusion is used to accomplish the separation of gas mixtures in the centrifuge. The mass difference of the isotopes, rotor length, and speed of rotation determine the degree of enrichment from a single centrifuge machine. A relatively high degree of gas-centrifuge enrichment, which may be many times larger than diffusion enrichment, can be obtained by using high-speed centrifuges. UF_6 gas is fed into a rotor, which rotates inside an evacuated casing. The heavier U-238 molecules move closer to the wall of the rotor because of the centrifugal force, thus producing partial separation of U-235 and U-238 isotopes. An axial counter-current flow of gas within the centrifuge increases the separative effect. The product streams containing enriched and depleted UF_6 are withdrawn near the ends of the rotor. The machines have large overall separation factors, but they have small throughput rates. Therefore, a large number of machines must be joined in parallel to form a single stage and to meet the needs of adequate interstage flow in a gas centrifuge cascade.

The equivalent annual capacity of a GCP in support of the RRY is 116 x 10^3 kg/yr SWU, as with the gaseous diffusion process.

Several technical reports describing the gas centrifuge plant under construction at Portsmouth, Ohio, were prepared since the publication of Table S-3 in 10 CFR Part 51.51.[1,4] In fact, Table S-3 did not assume or discuss use of the gas centrifuge process.

The estimates regarding the resource requirements and associated chemical effluents are primarily derived from scaling values in the above-mentioned references, which are based on a GCP with capacity of 8.75 x 10^6/yr SWU. The estimated land, water, and energy resource requirements of a gas centrifuge plant with an annual capacity of 116 x 10^3 kg SWU are shown in Table 4.3.

The gas centrifuge plant requires about 4.6% of the electricity required by the gaseous diffusion plant for equal enrichment capacity. Additionally, the gas centrifuge plant annually requires about 850 tons of coal and 2500 gal of gasoline and diesel fuel.[1]

TABLE 4.3 Estimated Annual Land, Water, and Energy Requirements for Gaseous Centrifuge Plant with an Equivalent Capacity of 116×10^3 kg/yr SWU

Resource Requirement	Amount
Land (acres)[a]	
Temporarily committed[b]	
Disturbed	5.1
Undisturbed	4.8
Permanently Committed	-
Water (10^6 gal/yr)[c]	
Discharged to air	5.3
Discharged to water bodies	6.7
Energy	
Electricity (10^3 MWh/yr)[d]	12.0
Coal (tons/yr)[e]	850
Gasoline and diesel fuel (gal/yr)[e]	2500

[a]Source: Ref. 1

[b]See Table 4.1, note b, for definitions of disturbed and undisturbed land.

[c]Source: Ref. 4.

[d]Source: Ref.4. Equivalent to 1.4 MWe average generation. A larger value of 29.9 MWe/hr is obtained from Ref. 1.

[e]Source: Ref. 1.

The air emissions, solid waste, and thermal discharges for a GCP are shown in Table 4.4. Except for HF, which comes from process leaks, nearly all of the air emissions from a gas centrifuge plant are from the on-site steam generation plant.

The gas centrifuge enrichment plant also generates uranium tailings, coal ash, chemical process wastes, and miscellaneous ash and refuse. The estimate in Sec. 4.1.2.3 for tailings in a GDP is generally applicable to the gas centrifuge plants.

TABLE 4.4 Estimated Annual Gaseous, Solid, and Thermal Effluents for a Gaseous Centrifuge Plant with an Equivalent Capacity of 116 x 10^3 kg/yr SWU

Type of Effluent	Amount Released
Gaseous emissions (tons/yr)[a]	
Particulates	0.47
Sulfur dioxide (SO_2)	9.6
Nitrogen oxides (NO_x)	7.7
Hydrocarbons (HC)	0.08
Carbon monoxide (CO)	0.15
Hydrogen fluoride (HF)	0.007
Solid waste (tons/yr)	
Enrichment tailings	223
Ash (bottom and fly ash)	68
Thermal discharges (10^9 Btu/yr)	
Gas centrifuge plant (without steam plant)	40
Steam plant	4.6

[a]Source: Ref. 1.

Assuming that about 850 tons/yr of coal with 8% ash are burned on-site in boilers, about 14 tons of bottom ash and 54 tons of fly ash will be generated. If the steam plant is also subject to stringent particulate emissions limitations (>99% control), nearly 60 tons/yr of bottom and fly ash would be collected as solid waste and only 0.47 tons/yr of fly ash will be released into the atmosphere (see Table 4.4); the installation of particulate control technology with an 80% removal efficiency would result in about 68 tons of solid waste (fly ash and bottom ash). The data in Table 4.4. reflect a high degree (>99%) of particulate control efficiency.

No estimates were available for chemical process wastes and for miscellaneous trash and refuse.

As discussed above, the gas centrifuge enrichment plant in support of a Model 1000-MWe LWR requires about 12 x 10^3 MWh/yr, or 40 x 10^9 Btu/yr. This energy is dissipated as heat and is rejected to the atmosphere. The second source of thermal discharge is the steam plant, which produces process steam and space heating. About 4.6 x 10^9 Btu are rejected by the steam plant.[1]

The estimated annual mass discharges of various water constituents received by and discharged from the primary holding pond of a stand-alone gas centrifuge enrichment plant with an annual equivalent capacity of 116 x 10^3 kg/yr SWU are shown in Table 4.5.

4.3 COAL-FIRED POWER PLANT

Electrical energy for the existing gaseous diffusion plants is drawn primarily from the grids of four utilities: the Oak Ridge GDP is supplied by the Tennessee Valley Authority (TVA); the Paducah GDP is supplied by the TVA and by the Electric Energy Incorporated System; and the Portsmouth GDP is supplied by the Ohio Valley Electric Corporation and the Indiana-Kentucky Electric Corporation system.[8] The electric power for these grids is supplied by coal-fired power plants, gas turbine units, hydroelectric units, and nuclear plants.

Because of the interconnections within utility grids, it is not possible to completely associate with any specific individual or group of power plants the electrical generation required to produce the 116 x 10^3 kg/yr SWU required for the model LWR. A possible approach is to allocate the incremental generation to specific plants in the grids according to utility dispatching practices. This approach would not only be extremely difficult, however, but it would also not necessarily be justified for future fuel-cycle analyses because of changing utility dispatching practices.

The alternate approach used in this study is to define a generic coal-fired power plant that provides the incremental electrical generation requirements to support the GDP activity for the model 1000-MWe LWR. This approach, which is consistent with the basis for Table S-3 in 10 CFR Part 51, is conservative in that it results in larger estimated coal-fired electrical generation; therefore, impacts related to combustion, and certain other impacts of coal mining and fuel preparation for the electrical generation, are somewhat larger than actual.

The assumption that the electrical supply is from coal-fired power plants also has basis in the fact that much of the electrical energy comes from three coal plants that were constructed primarily to supply electrical energy to the GDPs. These dedicated plants include the Joppa plant, which has 735 MWe of its 1100 MWe capacity dedicated to the Paducah GDP; and the Clifty Creek plant, with 1304 MWe capacity, and Kyger Creek plant, with 1086 MWe capacity, both of which are dedicated to the Portsmouth GDP.[8]

As shown in Table 4.1, the equivalent of 30 MWe of generation is required to support GDP production of enriched uranium needed to fuel a model 1000-MWe LWR. The assumed characteristics of the model coal-fired electrical generation facility to provide this generation capacity are given in Table 4.6. No separate analysis is provided for the impacts of electrical generation required to supply the alternative gaseous centrifuge enrichment. The energy requirements for the GCP are about 4.6% of those for the GDP, and it can be assumed that the impacts could be scaled equivalently.

The subsequent discussion will describe the estimated resources and chemical effluents associated with this generation.

TABLE 4.5 Estimated Annual Mass Flows to and from a Primary Holding Pond of a Gas Centrifuge Enrichment Plant with an Equivalent Capacity of 116×10^3 kg/yr SWU

Constituent and Flow	Decontamination and Uranium Recovery	Cooling Tower Blowdown	Water Treatment Backwash	Steam Plant	Discharge to Receiving Waters
Constituent (tons/yr)					
Suspended solids	a	a	a	0.192	a
Dissolved solids	a	a	a	1.23	a
Sulfate	-	a	a	0.343	a
Chloride	-	a	a	0.151	a
Nitrate	0.014	-	-	-	0.998
Phosphate	-	0.005	-	0.02	0.02
Chromium	-	2.4×10^{-6}	-	-	0.0002
Zinc	-	2.4×10^{-5}	-	-	0.0002
Flow (10^3 L/yr)	45,000	8,907	1,467	2,480	13,900

[a]Not reported; it is assumed, however, that federal, state, and local guidelines for effluents and receiving waters will be met.

Source: Based on Ref. 1 data.

TABLE 4.6 Assumed Parameters for Coal-Fired Power Generation in Support of Gaseous Diffusion Enrichment That Provides Fuel for a Model 1000-MWe LWR

Parameter	Value or Description
Average generation (MWe)	30
Peak capacity (MWe)	37.5
Annual capacity factor (%)	80
Efficiency (%)	35
Heat rate (Btu/hr per kW)	9,751
Heat value of coal (Btu/lb)[a]	11,085
Cooling method	mechanical-draft cooling towers
Coal use rate (tons/hr)	13.27
Type of firing	pulverized coal
Sulfur content of coal (%)	2
Ash content of coal (%)	8
Total amount, cleaned coal (tons/yr)[b]	115,500
Particulate control	electrostatic precipitator

[a]Eastern bituminous coal from Appalachia coal region.

[b]The run-of-mine coal mined is 154,000 tons with 25% loss during coal preparation.

4.3.1 Resource Requirements

The estimated land, water, and energy requirements for an annual average of 30 MWe of generation are shown in Table 4.7.

Based on values in Ref. 6, the 30 MWe of coal-fired electrical generation would require about 30 acres of total land over the plant lifetime. This total includes land for the power plant and the needed waste disposal area. The literature indicates that there is only a weak correlation between power-plant capacity and land requirements. The land required by a large (e.g., 1000-MWe) power plant varies with the type of facilities used, such as water storage ponds and wet scrubber sludge ponds, and with the type of cooling system used (Table 4.8).

Coal-fired power plants are seen to require relatively large amounts of water for cooling systems. The water requirements and consumption do not vary substantially between the evaporative systems.[9] The annual evaporative water losses for the

TABLE 4.7 Estimated Land, Water and Energy Requirements Associated with 30-MWe Coal-Fired Electrical Generation in Support of Gaseous Diffusion Enrichment That Provides Fuel for a Model 1000-MWe LWR

Resource Requirements	Amount
Land (acres)[a]	
Power plant (temporarily committed)	16
Waste storage (permanently committed)	15
Water (10^8 gal/yr)	
Cooling towers (mechanical draft)	
Discharged to air (evaporation)	1.21
Discharged to air (drift)	0.11
Discharged to water (blowdown)	0.51
Ash removal (sluicing)[b]	0.18
Energy (10^3 tons/yr)	
Cleaned bituminous coal	115.5

[a]Land area values are apportioned to capacity and not annual generation.

[b]This is the average depending upon the method used; the water requirements range between 0.07×10^8 and 0.29×10^8 gal.

TABLE 4.8 Typical Land Requirements for a 1000-MWe Coal-Fired Power Plant and Cooling Alternatives

Facility	Acres Required[a]
Coal storage area	20
Water storage surge pond	0-100
Generating unit	10
Switchyard	50
Ash ponds	100-200
Wet-scrubber sludge pond	250
Cooling Alternatives	
Cooling pond	1100
Spray pond	55
Evaporative natural-draft tower	5
Evaporative mechanical-draft tower	3.5
Dry natural-draft tower	20
Dry mechanical-draft tower	10

[a]These values are primarily applicable to western plants with an 80% capacity factor.

Source: Ref. 9.

equivalent 30-MWe coal-fired electrical generation amount to about 1.21 x 10^8 gal; 0.11 x 10^8 gal are discharged as drift, and 0.51 x 10^8 gal are discharged as blowdown. Additionally, the handling of ash by wet methods requires between 0.07 and 0.29 x 10^8 gal/yr of water, depending on methods used.[10]

Additional water would be required for wet lime and limestone scrubbing for sulfur dioxide control. The amount of water consumed by scrubbing for 30-MWe generation is about 240 acre-ft per year (78 x 10^6 gal).[10]

The 30-MWe coal-fired electrical generation requires about 154,066 tons of run-of-mine bituminous coal. Following the cleaning, about 115,550 tons of cleaned coal with an assumed heating value of 11,085 Btu/lb are needed to fuel a power plant with a 35% conversion efficiency to produce about 30 MWe needed for the operation of the gaseous diffusion plant with a capacity of 116 x 10^3 kg/yr SWU.

4.3.2 Chemical Effluents

4.3.2.1 Air Emissions

Typical coal-fired power plants, if uncontrolled, emit significant large quantities of particulates (especially fly ash entrained in the hot flue gases) and other gases such as sulfur oxides (SO_x), nitrogen oxides (NO_x), carbon monoxide (CO), and hydrocarbons (HC). Smaller quantities of trace inorganic elements and radionuclides, which are often adsorbed on the surface of the ash particles, are also emitted. These pollutants may be transformed in the atmosphere by chemical reactions, and they are transported and deposited under a variety of meteorological conditions.

Emissions of particulates, SO_x, and NO_x can be reduced by existing technologies: during precombustion by coal cleaning, during combustion by controlling the temperature and pressure, and after combustion by removing these pollutants from flue gases.

Air pollution from coal combustion is regulated under the Clean Air Act, which establishes air quality standards. The federal New source Performance Standards (NSPS) for the emission of particulate material, sulfur oxides, and nitrogen oxides from large (> 250×10^6 Btu/hr heat input) were initially established under the authority of the Clean Air Act in 1971. Table 4.9 presents the NSPS standards for particulates, nitrogen oxides, and sulfur oxides, as revised in 1979 and applicable for new units constructed after that date. There are currently no federal standards for coal-fired steam generators with capacities less than 250×10^6 Btu/hr heat input. The assumed coal-fired power plant

TABLE 4.9 New Source Performance Standards for Specified Pollutants for Coal-Fired Steam Generators Larger than 250×10^6 Btu/hr Heat Input

PARTICULATES

0.03 lb of particulates/10^6 Btu heat input

NITROGEN OXIDES

0.6 lb $NO_x/10^6$ Btu heat input for bituminous coal
0.5 lb $NO_x/10^6$ Btu heat input for subbituminous coal

SULFUR OXIDES

Uncontrolled emissions (lb $SO_2/10^6$ Btu input)	% Reduction	Controlled emissions (lb $SO_2/10^6$ Btu input)
>12	>90	1.2 Maximum
12 to 6	90	1.2 to 0.6
6 to 2	90 to 70	0.6
<2	70	<0.6

Source: Ref. 6. Boilers with capabilities less than 73-MW thermal input are subject to state emission limits, which vary from state to state.

characteristics listed in Table 4.6 show that the input heat rate for the 30-MWe coal-fired electrical generation needed to produce electricity for the gaseous diffusion enrichment plant is 292.5 x 10^6 Btu/hr. Therefore, the NSPS listed in Table 4.9 would be applicable to the 30-MWe coal-fired generation, if this generation were to be supplied by a separate new power plant. Assuming the generation to be provided by a new coal-fired electrical generation facility would give a lower bound to the emission estimate.

However, the more conservative approach, giving higher emission estimates, used in this study assumes generation is from existing plants for which the NSPS do not apply. The emissions from these existing plants are regulated under the Clean Air Act by state implementation plans (SIPs), which are specified by state agencies, with U.S. EPA approval, such that NAAQS are achieved and maintained in areas impacted by the emissions.

The SIP emission limits for SO_2 are given in Table 4.10 for the Joppa, Clifty Creek, and Kyger Creek plants dedicated to the Paducah and Portsmouth GDP electrical supplies and also for the major coal-fired plants in the TVA system, which supplies the Oak Ridge GDP. As discussed previously, the generation to supply the 30-MWe generation for the GDP enrichment for the model 1000-MWe LWR cannot be associated completely with any single plant or group of plants. In lieu of this association, the approach used here assumes an SO_2 emission limit of 6.22 lb $SO_2/10^6$ Btu input, which is the weighted average SIP limit for the three dedicated plants (Joppa, Clifty Creek, and Kyger Creek) shown in Table 4.10. (For the Joppa plant, only the 735 MWe of the total electrical capacity was considered dedicated and was therefore used to obtain the weighted average.) For comparison, the weighted average for the TVA plants is 2.81 lb $SO_2/10^6$ Btu input. Using this emission limit and the 35% efficiency given in Table 4.6, the SO_2 emissions is 7970 tons/yr for the 30-MWe electrical generation of a GDP enriching the fuel for a model 1000-MWe LWR.

It is assumed that 80% of the ash in the coal leaves the combustion chamber entrained in the combustion gases as fly-ash particulate materials. The remaining 20% of ash is collected in hoppers located beneath the boiler, as bottom ash. The total amount of ash resulting from burning 115,500 tons of cleaned coal with 8% ash is 9244 tons. About 7400 tons end up as fly-ash. Table 4.11 indicates that the Joppa, Clifty Creek, and Kyger Creek design collection efficiencies using an electrostatic precipitator (ESP) for fly ash range from 98 to 99.4%, with a weighted average of 98.6%. (For the Joppa plant, again, only the 735 MWe of dedicated capacity were used to obtain the weighted average.) The data given for actual tests indicate an even higher collection efficiency. Assuming the 98.6% collection efficiency, the 30-MWe generation to support GDP fuel enrichment for the model 1000-MWe LWR results in 104 tons/yr particulate emissions. Using the heat rate parameters in Table 4.6, this is equivalent to an emission rate of 0.08 lb particulates/10^6 Btu input. For comparison, the NSPS emission rate is 0.03 lb particulates/10^6 Btu input. Hydrocarbon and carbon monoxide levels of emissions are largely a function of the completeness of combustion independent of the coal quality and they are related to the amount of coal burned. The emission factors assumed for hydrocarbon and carbon monoxide are 0.3 pound per ton and 1.0 pound per ton of coal, respectively.[6]

TABLE 4.10 SIP Emission Limits for SO_2 for Major Coal-Fired Plants Supplying Electrical Energy to GDPs

Plant	State	Coal-Fired Capacity (MWe)	SIP SO_2 Emission Limit (lb/10^6 Btu Input)
Non-TVA Plants			
Joppa	Illinois	1100[a]	3.61
Clifty Creek	Indiana	1304	6.00
Kyger Creek	Ohio	1086	8.20
TVA System Plants			
Colbert	Alabama	1286	4.00
Widows Creek	Alabama	1826	0.73
Paradise	Kentucky	2377	2.84
Shawnee	Kentucky	1530	1.20
Allen	Tennessee	876	4.00
Bull Run	Tennessee	903	4.00
Cumberland	Tennessee	2550	2.78
Gallatin	Tennessee	1090	5.00
Sevier	Tennessee	800	4.00
Johnsonville	Tennessee	1342	2.09
Kingston	Tennessee	1580	2.80
Watts Bar	Tennessee	224	4.00

[a]735 MWe dedicated to Paducah GDP electrical energy supply.

Source: Ref. 11.

Nitrogen oxides, which contain primarily nitric oxide (NO) and nitrogen dioxide (NO_2), originate from nitrogen in the fuel, as well as from the nitrogen in the combustion air. The emission factors for NO_x vary from 0.6 to 1.4 lb $NO_x/10^6$ Btu heat input, with the smaller value being equal to the NSPS limit when subbituminous coal is used. An average of 1.0 lb/10^6 Btu is assumed in this study.

A summary of estimated air emissions from the 30-MWe generation is given in Table 4.12. Trace elements are found in the raw coals of the United States in varying concentrations, as shown in Table 4.13.

Mercury, fluorine, and bromine are the most prone to release, with mercury here in the vapor phase. Lead, arsenic, cadmium, and their compounds exhibit a less marked tendency to escape from the stack. Manganese, beryllium, nickel, vanadium, and zinc are generally trapped before reaching the stack. Emission estimates for these pollutants related to the 30-MWe generation are not included because of their variability in both coal and percentage of emission.

TABLE 4.11 Fly-Ash Collection Efficiencies for Major Coal-Fired Plants Supplying Electrical Energy to GDPs

Plant	State	Coal-Fired Capacity (MWe)	Fly-Ash Collection Efficiency (%) Design	Test
Joppa	Illinois	1100[a]	98.6	b
Clifty Creek	Indiana	1304	98.0	99.84
Kyger Creek	Ohio	1086	99.4	99.8

[a]735 MWe dedicated to Paducah GDP electrical energy supply.

[b]Not available.

Source: Ref. 12.

TABLE 4.12 Estimated Annual Air Emissions from 30-MWe Coal-Fired Power Plant Generation in Support of Gaseous Diffusion Enrichment to Support the Model 1000-MWe LWR

Constituent	Emissions (tons/yr)
Sulfur Dioxide (SO_2)	7970
Nitrogen Oxides (NO_x)	1280
Particulates	104
Hydrocarbon (HC)	17.3
Carbon Monoxide (CO)	57.8

4.3.2.2 Liquid Effluents

The major wastewater streams for coal-fired power plants are briefly defined below.

- *Cooling tower blowdown* is a continuous effluent stream from the evaporative cooling processes to limit the concentration of dissolved solids such as chromium, zinc, and phosphate from corrosion inhibitors. These pollutants have a tendency to concentrate in the recirculating cooling tower. The makeup water replenishes the evaporation and blowdown volume, thus preventing increase of pollutant levels in the cooling water recirculating system.

TABLE 4.13 Typical Concentrations of Trace Elements in U.S. Raw Coal

Element	Concentration (ppm) Mean	Range
Arsenic (As)	14.0	0.5 - 93.0
Beryllium (Be)	1.6	0.2 - 4.0
Cadmium (Cd)	2.5	0.1 - 65.0
Chromium (Cr)	13.8	4.0 - 54.0
Cobalt (Co)	9.6	1.0 - 43.0
Iron (Fe)	1.9	0.3 - 4.3
Lead (Pb)	34.8	4.0 - 218.0
Nickel (Ni)	21.1	3.0 - 80.0

Source: Ref. 9.

- *Once-through cooling water*, for power plants with this cooling option, is the water constantly withdrawn from a river, lake, or ocean for circulation through the condenser and discharge to the body of water.

- *Boiler blowdown* is a continuous or periodic effluent, which is associated with the elimination of accumulated scaling compounds on the boiler tube surfaces.

- *Metal cleaning waste* contains pollutants, such as suspended solids, copper, zinc, nickel, iron, phosphate, and ammonia, resulting from cleaning of the boiler tubes, condenser, and air preheaters.

- *Low-volume wastes* are intermittent flows generated by floor and yard drains -- and sanitary and laboratory sources that have wide variation in pollutant levels -- and containing mostly oil, grease, and suspended and dissolved solids.

- *Ash-handling wastewaters* are the result of quenching and sluicing of fly ash and bottom ash produced during the combustion of coal.

- *Coal-pile runoff*, with suspended and dissolved solids and other leachates, originates from rainfall and snowmelt, which percolate through the coal stockpile.

The existing and proposed effluent limitations, as well as the NSPS for steam-electric power plant effluents listed above, are shown in Table 4.14.

TABLE 4.14 Effluent Limitation Guidelines and New Source Performance Standards for Steam-Electric Power Plants

		Effluent Concentration (mg/L)							
		BPT Standard		BAT Standard		Proposed BCT Standard		NSPS	
Wastewater Source	Waste Constituent	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Once-through cooling water systems	Free available chlorine[a]	0.2	0.5	-	-[b]	-	-	-	-[b]
	Total residual chlorine[a]	-	-	-	0.2	-	-	-	0.2
Cooling-tower blowdown	Free available chlorine[a]	0.2	0.5	0.2	0.5	-	-	0.2	0.5
	Total residual chlorine[a]	-	-	-	0.14	-	-	-	0.14
	Maintenance chemicals	-	-	No discharge[c]		-	-	No discharge[c]	
Fly-ash transport water	Total suspended solids	30	100	-	-	30	100	No discharge[d]	
	Oil and grease	15	20	-	-	15	20	No discharge[d]	
Bottom-ash transport water	Total suspended solids	30	100	-	-	30	100	30	100
	Oil and grease	15	20	-	-	15	20	15	20
Low-volume wastes[e]	Total suspended solids	30	100	-	-	30	100	30	100
	Oil and grease	15	20	-	-	15	20	15	20
Metal-cleaning wastes	Total suspended solids	30	100	-	-	30	100	30	100
	Oil and grease	15	20	-	-	15	20	15	20
	Cu (total)	1.0	1.0	1.0	1.0	-	-	1.0	1.0
	Fe (total)	1.0	1.0	1.0	1.0	-	-		
Coal-pile runoff	TSS	-	50[f]	-	-	-	50[f]		50[f]
All waste streams	PCB	No discharge		No discharge		No discharge			
All waste streams except once-through cooling water	pH (range)	6-9		6-9					

[a]Neither free available nor total residual chlorine may be discharged from any unit for more than two hours in any one day and not more than one unit in any plant may discharge free available or total residual chlorine at one time unless a variance is obtained.

[b]For any plant with a total rated capacity greater than 25 MW. For plants with capacity less than 25 MW, the maximum is 0.5 and the average is 0.2.

[c]No discharge of cooling-tower maintenance chemicals that contain any of the 129 priority pollutants.

[d]No discharge of fly-ash water.

[e]Flue-gas-desulfurization blowdown is now regulated under the subcategory of low-volume waste on an interim basis.

[f]This limitation is not applied to the untreated overflow from facilities designed, constructed, and operated to treat the volume of coal-pile runoff from a 10-yr, 24-hr maximum rainfall event.

Source: *Effluent Limitations Guidelines, Pretreatment Standards and New Source Performance Standards Under Clean Water Act*; Steam Electric Power Generating Point Source Category, Final Rule, FR Vol. 47, No. 224, Nov. 19, 1982, for BPT, BAT, NSPS; Proposed Rule, FR Vol. 45, No. 68, Oct. 14, 1980, for BCT. Average daily value is computed for 30 consecutive days, and the maximum value is for any one day. With the exception of coal-pile runoff, limitations as actually expressed as "shall not exceed quantity determined by multiplying the flow [of the waste stream] times the concentration" given.

Table 4.15 shows annual mass discharge per unit of installed capacity of specific constituents by individual effluent streams (in kg/yr per MW of installed capacity) based on Table 4.14 and other values in Ref. 13. Using these values, Table 4.15 presents the estimated annual mass discharges by a 30-MWe coal-fired generation in support of a gaseous diffusion enrichment plant that produces uranium to fuel a Model 1000-MWe LWR. The values in Table 4.16 were derived by multiplying the values from Table 4.15 by 30 MWe. Four combinations, representing alternatives of plants with and without flue-gas desulfurization systems and with and without fly-ash pond effluents, were computed.

The discharge of ash transport water is controlled under the National Pollutant Discharge Elimination System (NPDES) of the Clean Water Act. Under the proposed NSPS, no discharge is allowed from the fly-ash pond effluent (Table 4.15). The power plant selected for this study in support of the gaseous diffusion plant was assumed not subject to the NSPS of zero discharge from the fly-ash pond. The coal-fired plant is also assumed not to have a flue-gas desulfurization (FGD) system. For the purpose of this study, the values from column 3 of Table 4.16 were thus considered representative for the selected power plant; they are used in Table F-1 of this report.

4.3.2.3 Solid Wastes

The main sources of solid waste associated with the 30-MWe coal-fired power plant generation are bottom ash and fly ash. (FGD sludge would also be a major source of solid wastes, but the assumed model plant does not include FGD.) The estimated amounts of the solid wastes are presented in Table 4.17. The bottom ash and fly ash generation and collection were discussed above in Sec. 4.1.2.3.

Wet scrubber sludges from power plants that utilize lime or limestone FGD methods constitute a major source of solid waste and are included for comparison in Table 4.17. The quantity of sludge produced typically exceeds the quantity of wet ash. The composition and amounts of sludge depend upon the composition of coal, alkali added, alkali utilization, efficiency, and process operation characteristics of the scrubber. For example, power plants using 3% sulfur coal result in 0.8 tons/yr of sludge per kW of installed capacity.[9]

The ash solid waste is regulated by the Resource Conservation and Recovery Act (RCRA). Ash and FGD wastes generated by the coal-fired utilities are not hazardous under the RCRA regulations (40 CFR 261.4[b]4).[6] Section 4004 of RCRA governs the nonhazardous waste disposal management techniques.

4.3.2.4 Thermal Discharges

The net heat rate of the 30-MWe coal fired plant generation is 9751 Btu/kWh, assuming a thermal efficiency of 35%. The heat rejection thus amounts to about 1.66×10^{12} Btu/yr. Cooling water discharges are regulated by Secs. 301, 306, and 316 of the Clean Water Act. The federal thermal discharge standards promulgated by EPA are listed in Table 4.18. The states that were granted authority to conduct a

TABLE 4.15 Annual Mass Discharge (kg/yr) per Unit of Installed Capacity (MW)[a]

	Constituents												
Effluent Stream	TDS	Cl	SO_4^{-2}	As	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Se	Zn
Fly-ash-pond overflow[b]	2,400	66	1,300	0.19	0.061	0.97	0.16	10	0.16	0.82	0.003	0.026	1.3
Bottom-ash-pond overflow	3.5	8.2	310	0.088	0.04	0.07	0.14	19	0.12	0.88	0.004	0.03	0.53
Low-volume wastes	3.5	-	-	c	c	0.0014	0.029	0.11	0.01	c	c	c	0.006
Boiler blowdown	3.5	-	-	c	c	0.0014	0.029	0.026	0.01	c	c	c	0.006
Metal-cleaning wastes	69	0.79	2.8	c	c	0.033	0.026[d]	0.026[d]	0.087	0.13	c	c	0.092
Flue-gas desulfurization	14,000	2,600	4,200	0.022	0.036	0.036	0.23	0.29	0.14	0.84	0.001	0.16	0.20
Coal-pile runoff[e]	72	0.048	55	0.35	0.001	0.001	0.042	0.29	0.009	0.017	c	0.78	0.0096

[a]Estimates assume operation at full capacity.

[b]No discharge allowed under NSPS.

[c]Negligible -- <0.001 kg/yr per MW.

[d]Annual mass discharge under BPT, BAT/BCT, and NSPS.

[e]Based on 75 cm/yr precipitation and untreated coal-pile runoff concentrations given in Ref. 13.

Source: Ref. 13

TABLE 4.16 Estimated Annual Mass Discharge (kg/yr) by Various Effluent Streams from 30-MWe Coal-Fired Power Plant Generation in Support of Gaseous Diffusion Enrichment

Constituent	Without Fly-Ash Pond Overflow and No FGD	Without Fly-Ash Pond Overflow but with FGD	With Fly-Ash Pond Overflow but No FGD	With Fly Ash Pond Overflow and with FGD
Total dissolved solids	20	482	99	561
Chlorides (Cl^-)	0.30	86.10	2.48	88.28
Sulfates (SO_4^{-2})	12	151	55	194
Arsenic (As)	0.014	0.015	0.021	0.021
Cadmium (Cd)	0.001	0.003	0.003	0.005
Chromium (Cr)	0.004	0.007	0.007	0.010
Copper (Cu)	0.009	0.016	0.014	0.022
Iron (Fe)	0.64	0.65	0.97	0.98
Lead (Pb)	0.008	0.012	0.013	0.018
Manganese (Mn)	0.034	0.062	0.061	0.089
Mercury (Mg)	0.0001	0.0002	0.0002	0.0003
Selenium (Se)	0.027	0.032	0.028	0.033
Zinc (Zn)	0.021	0.028	0.064	0.071

Source: Ref. 13.

TABLE 4.17 Estimated Solid Waste Generated Annually by 30-MWe Coal-Fired Power Plant Generation

Type of Waste	30-MWe Coal-Fired Power Plant (tons/yr)
Bottom ash (dry)	1,850
Fly ash (dry)	7,360
FGD sludge[a]	13,200

[a]For comparison only based on a lime/limestone throw-away system. The assumed power plant does not include FGD.

Source: Ref. 14. The assumed power plant does not include FGD.

TABLE 4.18 Standards for Power Plant Thermal Discharges into Water Bodies

Type of Water Body	Max. Temp. Increment above Ambient	
	°F	°C
Streams and rivers	5.0	2.8
Lakes	5.0	1.7
Estuaries and marine coastal waters		
Winter (September-May)	4.0	2.2
Summer (June-August)	1.5	0.8

Source: Ref. 6.

discharge-permitting program also have authority to establish similar limits. Several impact categories must be considered before exemptions are granted. The model plant is assumed to have evaporative cooling towers, and thus the standards in Table 4.18 are not a major constraint.

4.4 COAL MINING AND PREPARATION

For the modeled 30-MWe coal-fired power plant generation needed to support gaseous diffusion enrichment for the RRY, 115,500 tons of cleaned coal (154,000 tons/yr of run-of-mine coal) with a heating value of 11,085 Btu/lb are required. Additionally, 700 tons of cleaned coal (933 tons run-of-mine coal) are needed for the steam plant at the gaseous diffusion complex, for a total cleaned coal requirement of 116,200 tons/yr (155,000 tons/yr of run-of-mine coal).

In order for this document to be more useful in the preparation and evaluation of appropriate generic environmental impact assessments and still be beneficial for the preparation of site-specific environmental documents, underground and surface mining were analyzed separately to estimate the respective resource requirements and environmental pollutant loadings. No separate analysis was conducted for gaseous centrifuge enrichment, which requires only 6200 tons/yr cleaned coal (5300 tons/yr for the electrical generation and 850 tons/yr for the on-site steam plant). As an approximation, it can be assumed that the coal mining and preparation resource requirements and pollutant loadings for the GCP enrichment are proportional to coal use, that is, 5.3% of those given in the following for GDP enrichment.

Approximately 60% of national coal production comes from surface mining, and this proportion will remain somewhat constant in the future (Table 4.19). However, there are regional variations with respect to surface and underground mining. For example, in Appalachia, about 60% of coal production comes from underground mining, while surface coal mining is predominant in the coal regions of the West. The Appalachia and Interior underground mines produced an estimated 91% of the coal from underground mines in 1985, while the western surface mines produced an estimated 39% of the underground coal in the United States for that year.

Table 4.20 presents some characteristics of representative regional coals. In general, eastern coals have higher heating values than western coals. However, the percentage of sulfur in western coal is generally lower than that in eastern coal.

Coal preparation is normally performed to upgrade the characteristics of run-of-mine coal. Crushing and sizing of coal by mechanical means is almost universally used. Physical cleaning of coal is widely used in the eastern United States to increase the heating value of coal by removing shale, clay, pyritic sulfur, and other impurities. Physical cleaning is used for approximately 60% of underground mined coal, and about 25% of surface-mined coal is cleaned.[15]

Chemical cleaning procedures use chemicals to remove ash, sodium, organic sulfur, and other impurities chemically bound to the coal. The estimated costs for chemical cleaning are significantly higher than those for physical cleaning, but the former method is also more effective.

TABLE 4.19 Projected U.S. Coal Production (10^6 tons), by Region and Type of Mining

Type of Mining	1975	1985	2000
	Production Year		
	Appalachia		
Surface	165	187	127
Deep	219	237	423
	Interior		
Surface	93	79	45
Deep	58	123	349
	Gulf		
Surface	93	49	72
Deep	-	-	-
	West		
Surface	76	200	904
Deep	12	27	80
	Total U.S.		
Surface, all regions	427	515	1148
Deep, all regions	289	387	852
Total, Surface and Deep Mining Combined	716	902	2000

Source: Ref. 15.

TABLE 4.20 Representative Characteristics of Regional Coals in the United States

Region	Type of Coal	Moisture (%)	Ash (%)	Sulfur (%)	Heat Value (Btu/lb)
Northern Appalachia	Bituminous	3	10	1.7	13,000
Central Appalachia	Bituminous	3	8	2.2	13,400
Southern Appalachia	Bituminous	3	9	1.1	13,400
Eastern Interior	Bituminous	11	a	2.8	11,400
Western Interior	Bituminous	10	13	4.2	11,200
Texas Gulf	Lignite	28	9	0.8	8,000
Powder River	Subbituminous	12	9	0.5	10,200
First Union	Lignite	35	7	0.4	7,000
Green River	Bituminous	12	8	0.6	11,300
Four Corners	Bituminous	7	10	0.7	11,900

[a]Data not provided.

Source: Ref. 16.

The information in this section was primarily obtained from Ref. 6, which describes actual typical underground and surface coal mines with coal preparation plants in the East. The information was then adapted to the quantities of coal needed to support the gaseous diffusion plant in support of the model 1000-MWe LWR.

4.4.1 Resource Requirements

4.4.1.1 Land

The land requirements for both eastern underground and surface coal mining and associated coal preparation plants are shown in Table 4.21. The total area required is dependent upon the lifetime of the operation.

For the eastern underground coal mine and preparation plant, about 0.6 acre of land is needed for facilities such as a water treatment plant, power substations, maintenance and ventilation equipment buildings, and the preparation plant. This is fixed land used for the 30-yr lifetime of the mine. A variable land area of about 0.16 acres/yr is needed for the storage of solid waste. The variable area amounts to about 4.7 acres over the lifetime of the mine. Therefore, about 5.3 acres of land are needed to support the operations of coal mining and preparation for the model 1000-MWe LWR.

TABLE 4.21 Estimated Land, Water, and Energy Requirements for Mining and Preparation of 155,000 tons/yr Raw Coal in Support of Gaseous Diffusion Enrichment for a 1000-MWe LWR

Resource Requirement	Eastern Underground Coal Mining (with Preparation Plant)	Eastern Surface Coal Mining (with Preparation Plant)
Land (acres)[a]		
Temporarily committed		
Surface construction	0.6	0.7
Strip mining	-	93
Permanently committed (coal preparation waste storage)	4.7	12
Total	5.3	105.7
Water (10^6 gal/yr)		
Dust control (used)	11.5	-
Dust control (consumed)	1.15	-
Coal preparation (consumed)	3.1	3.1
Total (consumed)	4.25	3.1
Energy		
Diesel fuel (10^3 gal/yr)	5.9	470
Electricity (10^3 MWh/yr)		
Mine equipment	5.4	1.0
Coal preparation	0.7	0.7

[a]Total over assumed 30-year lifetime.

Source: Ref. 6.

The total land needed for an eastern surface coal mine and preparation plant is about 106 acres, of which 93 acres are needed for strip mining. The yearly land area for waste storage is about 0.4 acres, or about 12 acres for the lifetime of the mine. An estimated 0.7 acre of land is needed for the coal preparation plant.

4.4.1.2 Water

The annual water requirements for mining and preparation of 116,200 tons/yr of cleaned coal by eastern underground and surface mining are also shown in Table 4.21.

There are three main activities associated with underground mining that require the use of water: (1) suppression of dust during the construction of mains, (2) dust suppression during construction of a longwall system, and (3) dust control during extraction operations. The total amount of water required by the above operations is about 11.5×10^6 gal/yr. About 10% of this water is lost to evaporation or is absorbed by the coal and needs to be made up. In addition, the coal preparation plant requires about 3.1×10^6 gal/yr of water. Therefore, the amount of water consumed annually is about 4.25×10^6 gal.

For the eastern surface mining and coal preparation, the makeup water is approximately 3.1×10^6 gal, or approximately 20 gal/yr per ton of coal mined and cleaned.

4.4.1.3 Energy

The yearly energy needs for coal mining and preparation plants for eastern underground and surface mining are also shown in Table 4.21.

For eastern underground mining, about 5.9×10^3 gal of diesel fuel are used during the exploration and resource assessment and for the mine and associated facility construction. Electrical power needed for the mine equipment is about 3.5 kWh/ton of coal. About 4.3 kWh/ton of coal are required by the coal preparation plant. Applying these values to the 155,000 tons of run-of-mine coal needed, the total amount of electrical power needed by both mining and cleaning coal operations is about 6.07×10^6 kWh. For eastern surface coal mining, about 470×10^3 gal of diesel fuel are needed for the following activities: topsoil removal, overburden removal, coal removal, backfilling, and topsoiling. An electrically powered dragline is used to remove the overburden material. The consumption of electrical power for the dragline is about 1815 kWh under load and 615 kWh under no-load conditions. The electrical power used to mine 155,000 tons of run-of-mine coal is 1.7×10^6 kWh.

4.4.2 Chemical Effluents

4.4.2.1 Air Emissions

The estimated annual air emissions generated by eastern underground and surface coal mining and preparation of 155,000 tons of run-of-mine coal are shown in Table 4.22. The emissions for both the underground and surface coal mining were derived from those estimated in Ref. 6 by applying the appropriate proportionality factor to account for mine size.

The yearly pollutant load associated with underground mining is considerably less than for surface mining because of the significantly lower energy requirements to mine underground coal. The estimated emissions are primarily from diesel fuel use to drive mining equipment.

TABLE 4.22 Estimated Annual Air Emissions from Mining and Preparation of 155,000 tons/yr Raw Coal in Support of Gaseous Diffusion Enrichment for a 1000-MWe LWR (tons/yr)[a]

Air Emission	Eastern Underground Coal Mining (with Preparation Plant)	Eastern Surface Coal Mining (with Preparation Plant)
Particulates	0.074	5.2
Sulfur dioxides (SO_2)	0.092	7.3
Nitrogen oxides (NO_x)	0.97	99
Hydrocarbons (HC)	0.074	6.5
Carbon monoxide (CO)	0.26	
Fugitive dust	Negligible or unquantified	290[b]

[a]Source: Ref. 6, except as noted.

[b]Based on estimates for a well controlled Illinois surface coal mine. Controls assumed were paved access roads (99% control), watered unpaved haul roads (50% control), and enclosed coal dump with baghouse (85% control). Without these controls, the fugitive dust emissions are estimated at 470 tons/yr. Source: Ref. 17.

Fugitive dust from surface mining operations are the primary source of air emissions, and this results from unpaved haul roads, material handling, and wind erosion of barren land areas. A 38% reduction in uncontrolled fugitive dust emissions is assumed in Table 4.22.

4.4.2.2 Liquid Effluents

Coal mine drainage results from both surface and underground mining. This drainage is composed of precipitation and associated surface runoff, as well as groundwater flow from the intercepted aquifers. Depending on the natural environments of the mine, the drainage can be acid or alkaline and may contain quantities of pollutants that need to be controlled. Additional discharge results from coal cleaning operations, especially from those using wet cleaning. A permit is required to discharge effluents from coal mines and preparation plants.

The existing and proposed effluent limitation guidelines and the proposed NSPS for coal mining category are shown in Table 4.23. Total suspended solids, iron (total)

TABLE 4.23 Effluent Limitation Guidelines and New Source Performance Standards for the Coal Mining Point-Source Category

		Effluent Concentration (mg/L, except for settleable solids)							
		BPT Standard		BAT Standard		Proposed BCT Standard		NSPS	
Wastewater Source	Pollutant	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Coal preparation plants and associated areas									
Acid discharge	Total Fe	3.5	7.0	3.5	7.0	-	-	3.0[a]	6.0[a]
	Total Mn	2.0	4.0	2.0	4.0	-	-	2.0[a]	4.0[a]
	Total suspended solids	35	70	-	-	35	70	35[a]	70[a]
Alkaline discharge	Total Fe	3.5	7.0	3.5	7.0	-	-	3.0[a]	6.0[a]
	Total Mn	-	-	-	-	-	-	2.0[a]	4.0[a]
	Total suspended solids	35	70	-	-	35	70	35[a]	70[a]
Acid mine drainage	Total Fe	3.5	7.0	3.5	7.0	-	-	3.0	6.0
	Total Mn	2.0	4.0	2.0	4.0	-	-	2.0	4.0
	Total suspended solids	35	70	-	-	35	70	35	70
Alkaline mine drainage	Total Fe	3.5	7.0	3.5	7.0	-	-	3.0	6.0
	Total suspended solids	35	70	-	-	35	70	35	70
Post-mining areas[b]									
Reclamation areas	Settleable solids[c]	-	0.5	-	0.5	-	-	-	0.5
Underground mine drainage									
Acid mines	Total Fe	3.5	7.0	3.5	7.0	-	-	3.0	6.0
	Total Mn	2.0	4.0	2.0	4.0	-	-	2.0	4.0
	Total suspended solids	35	70	-	-	35	70	35	70
Alkaline mines	Total Fe	3.5	7.0	3.5	7.0	-	-	3.0	6.0
	Total suspended solids	35	70	-	-	35	70	35	70
All sources	pH	------ Within the range 6.0 to 9.0 at all times ------							

[a]Only for areas associated with coal preparation plants; discharge of plant process water is not allowed.

[b]Limits apply until performance bond has been released. Limit for BPT is proposed.

[c]Settleable solids are measured in mL/L.

Source: *Coal Mining Point Source Category: Effluent Limitations Guidelines for Existing Sources, Standards of Performance for New Sources and Pretreatment Standards*, Final Rule, Vol. 50, No. 196, Oct. 9, 1985, for BPT, BAT, NSPS; Proposed Rule, Vol. 46, No. 3, Jan. 15, 1981, for BCT. Average daily value is computed for 30 consecutive days, and the maximum value is for any one day.

manganese (total), and pH parameters are regulated. No discharge of process water from new coal preparation plants is allowed under the NSPS.

The estimated average pollutant concentrations in untreated and treated wastewater for an acid coal mine and associated coal preparation plant[13] are shown in Table 4.24. At the national level, flow cannot be directly related to coal production and type of mine drainage (e.g., acid or alkaline) or type of mining (e.g., surface or underground). A relationship between flow and production of mines does exist, however, at the regional level, and this is estimated in Table 4.25. Assuming coal from mines in Appalachia with acid mine drainage, the estimated annual pollutant loadings in treated wastewater from surface and underground mines and their respective coal preparation plants are estimated in Table 4.26.

4.4.2.3 Solid Waste

During the underground mine construction, about 0.05 tons of overburden per ton of mined coal are generated. Therefore, for the 155,000 tons of coal needed to support the gaseous diffusion enrichment plant, approximately 7700 tons of overburden are generated.[6] The second source of solid waste is from the ventilation shaft construction. For each ton of coal mined, about 0.015 tons of overburden are generated per year.[6] Therefore, for 155,000 tons of mined coal, the amount of over burden is 2300 tons.

The coal preparation plant is by far the largest producer of solid waste. This waste consists of shale, pyrites, coal fines, and impurities. On the average, about 25% of raw coal that is cleaned ends up as solid waste. Applying this percentage to the 155,000 tons of coal needed, the amount of solid waste is about 39,000 tons.

The value of 39,000 tons is also used for solid wastes from preparation of coal from surface mines. Surface mines also generate large amounts of material from overburden removal; however, it is assumed that this material is returned during the mine area reclamation, with no net solid waste generation.

The fraction of coal that results in solid waste during cleaning and preparation has increased over the years for two reasons. One reason for this increase is that the mining equipment digs less selectively than the previous manual-mining methods. The second reason is that coal seams currently being mined tend to contain more impurities.

4.5 REFERENCES

1. *Final Environmental Statement, Expansion of U.S. Uranium Enrichment Capacity*, U.S. Energy Research and Development Administration, ERDA-1543 (April 1976).

2. *Environmental Survey of the Uranium Fuel Cycle*, U.S. Atomic Energy Commission, WASH-1248 (1974).

TABLE 4.24 Average Pollutant Concentrations in Untreated and Treated Wastewater from Acid Coal Mine Drainage and Associated Coal Preparation Plant (mg/L)[a]

			Coal Preparation Plant			
	Acid Mine Drainage		Associated Areas		Process Water	
Constituent	Untreated	Treated[a]	Untreated	Treated[a]	Untreated	Treated[a,b]
TDS	50	1200	2000	1700	1400	1000
Cl^-	-	-	-	-	-	-
SO_4^{-2}	710	630	310	170	-	-
As	0.089	0.016	0.35	0.003	1.1	0.01
Cd	0.040	0.015	0.025	0.016	0.10	0.003
Cr	0.13	0.039	0.24	0.030	1.3	0.031
Cu	0.13	0.014	0.23	0.016	2.1	0.02
Fe	200	1.6	1200	1.8	830	1.9
Pb	0.15	0.17	0.27	0.003	1.5	0.062
Mn	8.3	2.1	17	1.8	8.3	1.4
Mg	0.0017	0.0011	0.0011	0.0018	0.018	0.0003
Se	0.025	0.025	0.14	0.005	0.14	0.02
Zn	0.93	0.063	4.3	0.056	4.6	0.07

[a]Treatment at the BPT level.

[b]Discharge of process water is not permitted under NSPS.

Source: Ref. 13.

TABLE 4.25 Estimated Average Flow Rates for Effluent Streams by Coal Supply Region (L/ton coal)[a]

Region	Type of Drainage	Underground Mine	Surface Mine	Refuse Pile Runoff	Plant Process Discharge[b]
Northern Appalachia	Acid	2500	3300	30	1,300
Central Appalachia	Acid	2500	3300	45	1,300
Southern Appalachia	50% acid	2500	3300	40	1,300
Interior Midwest[c]	50% acid	1700	1100	30	1,300
Interior Center West[d]	50% acid	1700	1100	30	1,300
Fort Union[e]	Alkaline	530	30	10	0[g]
Northwest Great Plains[f]	Alkaline	530	30	10	0[g]

[a]Adapted from Ref. 14.

[b]No discharge is allowed under provisions of NSPS.

[c]Illinois, Indiana, and western Kentucky.

[d]Iowa, Kansas, Missouri, and Oklahoma.

[e]North Dakota, South Dakota, and eastern Montana.

[f]Western Montana, Wyoming, and northeastern Colorado.

[g]Assumes existing coal-preparation plants in these regions operate on a 100% recycle basis. Very little coal cleaning occurs in these regions.

TABLE 4.26 Estimated Annual Pollutant Loading in Treated Acid Mine Drainage and Coal Preparation Plant Wastewater from Production of 155,000 tons/yr of Coal in the Appalachian Coal Region (tons/yr)[a]

	Acid Mine Drainage		Coal Preparation	
Constituent	Underground	Surface	Area Runoff	Process Water[b]
TDS	512	676	8.7	222
SO_4	269	355	0.87	-
As	0.0068	0.0090	-	0.0022
Cd	0.0064	0.0084	0.0001	0.0007
Cr	0.017	0.022	0.0002	0.0069
Cu	0.0060	0.0079	0.0001	0.0044
Fe	0.68	0.90	0.0092	0.42
Pb	0.073	0.096	-	0.014
Mn	0.90	1.2	0.0092	0.31
Mg	0.0005	0.0006	-	0.0044
Se	0.011	0.014	-	0.0044
Zn	0.027	0.035	0.0003	0.016

[a]Source: Flow rates from Table 4.25; concentrations in treated effluents from Table 4.24.

[b]No discharge is permitted under NSPS.

3. *Environmental Data Energy Technology Characterizations, Nuclear Fuel Cycle*, Vol. 2, U.S. Department of Energy, DOE/EV-006/2 (Jan. 1980).

4. *Final Environmental Statement, Portsmouth Gaseous Diffusion Plant Expansion, Piketon, Ohio*, Vol. 1, U.S. Energy Research and Development Administration, ERDA-1549 (Sept. 1977).

5. *Environmental Assessment of the Oak Ridge Gaseous Diffusion Plant Site*, U.S. Department of Energy, DOE/EA-0106 (Dec. 1979).

6. *Energy Technology Characterizations Handbook, Environmental Pollution and Control Factors*, U.S. Department of Energy, DOE/EP-0093 (March 1983).

7. *Final Environmental Impact Assessment of the Paducah Gaseous Diffusion Plant Site*, U.S. Department of Energy, DOE/EA-0155 (DE 83001211) (Aug. 1982).

8. Nuclear Regulatory Commission staff testimony of Dr. L.J. Habegger, Dr. A.H. Ozkaynak, and Mr. R.L. Ballard regarding Eddleman Contention 8F(1) (Health Effects of Coal Particulates at the Table S-3 Level), Docket NOS 50-400 OL, 50-401 OL (Shearon Harris Nuclear Power Plant, Units 1 and 2) (July 1984).

9. Bisselle, A., et al., *Resource and Land Investigations (RALI) Program: An Approach to Environmental Assessment with Application to Western Coal Development*, the MITRE Corp., MTR-6988 (Aug. 1975).

10. Bhutani, J., et al., *An Analysis of Constraints on Increased Coal Production*, the MITRE Corp., MTR-6830 (Jan. 1975).

11. Garvey, D.B., S.B. Moser, and D.G. Streets, *In Pursuit of Clean Air: A Data Book of Problems and Strategies at the State Level, 1982 Update*, Argonne National Laboratory, ANL/EES-TM-212 (Aug. 1982).

12. Form 67, *Steam Electric Plant Air and Water Quality Control Data*, U.S. Federal Power Commission, Joppa Electric Station (1980).

13. Davis, M.J., and R.D. Doctor, *The Water Quality Significance of Zero-Discharge Requirements for Energy Industry*, Argonne National Laboratory, ANL/EES-TM-234 (March 1982).

14. Chiu, S-Y, et al., *Problems Associated with Solid Wastes from Energy Systems*, Argonne National Laboratory, ANL/EES-TM-113 (Sept. 1980).

15. *Energy Technologies and the Environment*, *Environmental Information Handbook*, the Aerospace Corp., DOE/EP-0026 (June 1981).

16. *Draft Environmental Impact Statement*, Coal Research and Demonstration Program, Energy Research and Development Administration, ERDA 1557-D (Aug. 1977).

17. *Assessment of Impacts on the Surface Coal Mine Industry Resulting from Possible Changes to PSD and Ambient Air Quality Standard*, Pedco Environmental, Inc., report to DOE (June 1984).

*U.S. GOVERNMENT PRINTING OFFICE:1987-181-682:60139

NRC FORM 335 (2-84) NRCM 1102, 3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

SEE INSTRUCTIONS ON THE REVERSE

1. REPORT NUMBER (Assigned by TIDC, add Vol. No., if any)
NUREG/CR-4964
ANL/EES-TM-332

2. TITLE AND SUBTITLE
Update of Table S-3 Nonradiological Environmental Parameters for a Reference Light-Water Reactor: Uranium Mining, Milling, and Enrichment

3. LEAVE BLANK

4. DATE REPORT COMPLETED

MONTH	YEAR
March	1986

5. AUTHOR(S)
L.J. Habegger, D.D. Carstea, and J.H. Opelka

6. DATE REPORT ISSUED

MONTH	YEAR
June	1987

7. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439

8. PROJECT/TASK/WORK UNIT NUMBER

9. FIN OR GRANT NUMBER
A2330

10. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, DC 20555

11a. TYPE OF REPORT

b. PERIOD COVERED (Inclusive dates)
July 1984 - March 1986

12. SUPPLEMENTARY NOTES

13. ABSTRACT (200 words or less)

In 1974, Table S-3 of the report "Environmental Survey of the Uranium Fuel Cycle" was published as a technical basis for consideration of the environmental effects of the uranium fuel cycle supporting operation of light-water reactors. A reference reactor cooled with light, or ordinary, water was established to reduce the burden on the Nuclear Regulatory Commission (NRC) staff, reactor license applicants, and other interested persons by removing the necessity to relitigate the environmental effects attributable to the fuel cycle, effects that are not within an applicant's control, in every individual reactor licensing proceeding. In a 1984 evaluation of a license application, it was demonstrated that the Table S-3 estimate of annual effluent of coal particulates is larger, possibly by as much as a factor of 100, than actual current values. Partially as a result of this evaluation, the NRC initiated a study to update all of the major nonradiological values in Table S-3. The results of the study are documented in this update. The report evaluates only the mining, milling, and isotopic-enrichment components of the fuel cycle's environmental parameters since these are the areas in which the greatest changes from the original study could be anticipated.

14. DOCUMENT ANALYSIS - a. KEYWORDS/DESCRIPTORS
fuel cycle environmental parameters
light-water reactors

b. IDENTIFIERS/OPEN-ENDED TERMS

15. AVAILABILITY STATEMENT
Unlimited

16. SECURITY CLASSIFICATION
(This page)
Unclassified
(This report)
Unclassified

17. NUMBER OF PAGES

18. PRICE

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

SPECIAL FOURTH-CLASS RATE
POSTAGE & FEES PAID
USNRC
WASH. D.C.
PERMIT No. G-67

120555078877 1 1AN1RE
US NRC-OARM-ADM
DIV OF PUB SVCS
POLICY & PUB MGT BR-PDR NUREG
W-537
WASHINGTON DC 20555

NUREG/CR-4964 • UPDATE OF TABLE S-3 NONRADIOLOGICAL ENVIRONMENTAL PARAMETERS FOR A REFERENCE LIGHT-WATER REACTOR JUNE 1987