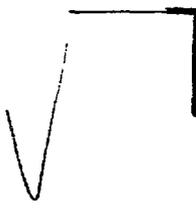


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**DISPOSAL OF WASTES FROM URANIUM CONVERSION
AND ENRICHMENT PROCESSES**

by

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Abstract

The majority of Australian uranium exports will be used to generate nuclear power in Light Water Reactors. Crude uranium ore concentrates will be refined and converted into pure natural uranium hexafluoride. This will be enriched in the uranium-235 isotope and used to manufacture enriched uranium dioxide fuel. The production of enriched uranium hexafluoride for export is a topical Australian interest in the nuclear fuel cycle.

These upgrading operations give rise to solid, liquid and gaseous wastes for disposal. The wastes include chemical effluents containing small quantities of naturally occurring radioactivity, and non-radiological effluents including used cooling water streams.

This paper reviews the general principles and objectives in radioactive waste management, and shows how these are applied in options for management and disposal of wastes from uranium upgrading operations. Some estimates of radiological dose commitments and health effects from LWR nuclear power and its fuel cycle have been made for US conditions. Doses from the upgrading processes of hexafluoride manufacture and enrichment were about 0.007% of the total body dose received by the US population from natural radiation background sources.

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1. INTRODUCTION

At 30 June 1981, 243 nuclear power reactors greater than 30 MWe were in operation in the world, and a further 229 were under construction (AAEC 1981). 379 of these reactors were either pressurised or boiling light water reactors (LWRs); these use fuel containing enriched uranium.

Australia has about 17% of the western world's reasonably assured low cost uranium resources. Three Australian mines are expected to be in operation by the end of 1981, producing a total of more than 4,500 t U per year in the form of natural uranium oxide (yellowcake) for export. (A production rate of 9,000 t U per year could be reached by 1990). The majority of this uranium will eventually be enriched.

Enrichment processes require the uranium in the crude yellowcake to be refined from impurities and converted into pure natural uranium hexafluoride (UF_6), a uranium compound which is readily converted into a gas. In commercial enrichment plants the UF_6 vapour is subjected to gas centrifugation or gaseous diffusion, resulting in the percentage of the light isotope ^{235}U being increased from 0.71% to about 3%. The domestic upgrading of uranium prior to its export is a topical subject in Australia and has been reviewed by George (1981). A group comprising the Broken Hill Associated Smelters Pty Ltd, British Nuclear Fuels Ltd, Roxby Management Services Pty Ltd and the South Australian Government are conducting a joint venture to study the feasibility of converting uranium ore concentrates into uranium hexafluoride in South Australia.

The South Australian Enrichment Committee is conducting a feasibility study on siting of a uranium enrichment plant in Australia. The Uranium Enrichment Group of Australia, comprising the Broken Hill Pty Co Ltd, CSR Ltd, Peko-Wallsend Operations Ltd and Western Mining Corporation, is independently studying the establishment of hexafluoride and enrichment facilities in Australia.

These upgrading processes give rise to solid, liquid and gaseous wastes requiring treatment and disposal. The wastes include chemical effluents containing small quantities of naturally occurring radioactivity from uranium and its decay products, together with non-radiological wastes including used cooling water streams and materials arising from maintenance of plant and equipment.

This paper describes the upgrading processes, outlines the nature and amounts of wastes generated, and reviews options for their management and disposal. A perspective is also placed on the radiological hazards of uranium upgrading.

2. OBJECTIVES AND PRINCIPLES OF DISPOSAL OF WASTES FROM UPGRADING PROCESSES.

The principal objective in disposal of any waste material is the protection of man and the environment from potentially harmful effects. In the case of wastes from uranium upgrading processes, this includes consideration of their chemical and radioactive toxicities. In practice, protection involves the achievement of a sufficient degree of isolation or dilution of the wastes so that any return to the biosphere is at a rate and/or concentration sufficiently low that there is no unacceptable biological hazard.

Radioactive waste disposal involves the use of three basic principles:

- . dilution and dispersion of short-lived or very dilute wastes;
- . concentration and confinement of long-lived and/or very radioactive wastes; and
- . storage of very short-lived radioactive wastes to permit their decay into non-radioactive species.

These principles are applied separately or in combination, depending on the nature and concentration of radioactive elements in the wastes. Practical options may be summarised as follows

(OECD/NEA 1977):

Solids:	above ground retention system; shallow land burial; deep geologic burial; ocean dumping.
Liquids:	discharge to waterways, estuaries and coastal waters; evaporation.
Gases & airborne particulates:	atmospheric discharge; partial retention

3. MANUFACTURE OF URANIUM HEXAFLUORIDE:

Uranium hexafluoride (UF_6) is manufactured commercially by two so-called 'wet processes' and a 'dry' process. These processes are outlined schematically in Fig. 1. The wet processes are similar in that they both purify the uranium feed at the commencement of the process; in the dry process, complete purification is not achieved until after the uranium hexafluoride has been produced. The technology of these processes has been reviewed by Alfredson (1972); all could be technically suitable for a commercial Australian plant.

In the wet processes, yellowcake is dissolved in nitric acid and uranium purified by solvent extraction. The pure solution of uranium nitrate is either treated with ammonia to precipitate uranium diuranate (process A), which is filtered, dried and calcined into uranium trioxide (UO_3) or it is concentrated and thermally decomposed into UO_3 (process B). The UO_3 is then reduced in both processes with hydrogen to uranium dioxide (UO_2), which is treated with hydrofluoric acid to form uranium tetrafluoride (UF_4) and finally with fluorine to produce pure UF_6 .

In dry process C, yellowcake is treated initially to size the material, make it suitable for fluidised bed operation, and possibly to remove some contained sodium. It is then reduced with hydrogen to form UO_2 , converted into UF_4 with hydrofluoric acid, and reacted with fluorine to produce crude UF_6 , which is purified by fractional distillation.

Wet process A is used by COMURHEX at its Malvesi Plant in France, and was formerly used by the first plant in the UK to produce UF_4 . Wet process B is used in the British Nuclear Fuels Ltd. plant at Springfields, UK, in the Eldorado Nuclear Ltd. refinery at Port Hope, Ontario, Canada, and in the Kerr McGee Nuclear Corporation plant at Sequoyah, Oklahoma, USA. Dry process C is used in the Allied Chemical Corporation plant at Metropolis, Illinois, USA.

More information has been published on processes B and C than on process A. Process B was the subject of an environmental impact statement for a commercial plant (USNRC, 1975), and processes B and C have been reviewed in generic impact studies (USEPA, 1973; USAEC, 1974; ERDA, 1975). Improvements to waste treatment in the dry process C have been reviewed by Sears et al. (1977).

3.1 Wastes from Manufacture of Uranium Hexafluoride

The sources of wastes from wet process B and their treatment processes are illustrated in Figures 2 and 3 respectively. Wastes from dry process C are illustrated in Fig. 4. Estimates of radiological wastes are based on a yellowcake feed from an acid-leach, solvent extraction uranium milling process (Table 1). This feed contains about 30% of the radioactivity originally present with the uranium in an ore body at secular equilibrium. Radioactive constituents of yellowcake are ^{238}U and near equilibrium quantities of its decay products ^{234}Th and ^{234}mPa ; ^{234}U and ^{235}U ; and

traces of ^{230}Th and ^{226}Ra not removed in the uranium milling process, which have been assumed here to comprise 2.0% and 0.2% respectively of that in the ore. Quantities of gaseous, liquid and solid wastes arising from these processes on a scale of 5,000 tonnes uranium per year, which is thought to be the minimum economic production capacity, are listed in Table 2.

The processes give rise to a range of gaseous wastes which can include hydrofluoric acid vapour, fluorine, oxides of nitrogen, hydrogen sulphide, ammonia and entrained solids, together with combustion products from generation of process heat. Potential effluents are filtered and scrubbed with caustic solutions before being released to atmosphere through a stack of suitable height to achieve a dispersion which meets appropriate standards of concentration at ground level.

Both wet and dry processes use substantial amounts of cooling water which is evaporated and discharged. Other effluents from the wet process (Figure 2) include:

- . nitrate solution waste from uranium purification by solvent extraction, which contains most of the radiological and mineralogical impurities entering with the yellowcake;
- . dilute caustic solutions from recovery of nitric acid, hydrogen fluoride and general treatment of off-gas streams; and
- . solid wastes, consisting mainly of calcium fluoride sludges, resulting from treatment of off-gases, maintenance of fluorine cells and some fluorination operations.

The liquid nitrate waste from solvent extraction, about 5 m³ per tonne of uranium (USNRC, 1975), may contain dissolved solids, radium-226, thorium-230 and -234, and about 0.2 per cent of the uranium processed.

This stream is neutralized and the resultant slurry impounded in storage ponds. In one commercial wet process, the sludge is allowed to settle and the supernatant liquid discharged to a tidal river (Anderson, 1979).

The disposal of this impounded waste from the wet process has been reviewed recently in the US (USNRC, 1975, ERDA, 1975). Possibilities include evaporation of the liquid and shallow surface burial of the nitrate sludge, or its transfer to a uranium mill retention system (ERDA, 1975). The alternative wet process A also produces other nitrate waste solutions from precipitation of ammonium diuranate.

Fluoride wastes from the wet process B are neutralised with lime and the calcium fluoride sludge allowed to settle in an impoundment pond. The neutral clarified waste is decanted, mixed with used cooling water and discharged to local rivers. Fluoride sludges may be removed for shallow surface burial (USNRC, 1975). Fig. 3 is a schematic illustration of management procedures for disposal of wastes from the wet process.

Most of the chemical solid waste from the dry process (Figure 4) occurs as non-volatile ash containing iron, calcium, magnesium, copper and other fluorides. This residue can amount to about 0.1 tonne per tonne of product UF_6 (USAEC, 1974); it is reacted with fresh fluorine to recover uranium and the final residue packaged and buried as low activity solid waste. Scrubber solutions arising from treatment of the hydrofluorination off-gas stream are treated similarly to those in the wet process, and discharged after dilution with the cooling water stream (Sears et al., 1977).

Management schemes for liquid wastes from the production of uranium hexafluoride largely depend on the location of the plant and options available for the disposal of the waste, eg. to a river, estuary or the open sea. Liquid wastes arising from all of the processes could probably be discharged without further treatment through a submarine pipeline into the open sea where dilution and dispersion could be assured. All processes may therefore be acceptable in Australia if the plant were located on an open coastal site.

4. URANIUM ENRICHMENT

Light water reactors use uranium enriched to 2-4 per cent in uranium -235. Commercial enrichment technologies (ERDA, 1976) are based on either gaseous diffusion or gas centrifugation of uranium isotopes in the form of UF_6 vapour. The principles of commercial enrichment processes are shown in Figure 5.

In the diffusion process, gaseous UF_6 is compressed and passed over a porous membrane. Molecules of UF_6 containing the lighter isotope, uranium -235, diffuse through the membrane more rapidly than those with the heavier uranium -238 isotope; consequently, the UF_6 passing the membrane has a slightly greater proportion of molecules containing uranium -235. The degree of enrichment for one membrane is very small and over a thousand successive diffusion stages are necessary to raise the proportion of uranium -235 from the naturally occurring level of 0.71 per cent to the 2-4 per cent required in the product stream, and about 0.25 per cent in the depleted 'tails' stream.

In enrichment by gas centrifugation, molecules of UF_6 containing the heavier isotope uranium -238 migrate preferentially to the wall of a rapidly rotating cylinder. There is a consequent enrichment in the lighter uranium -235 isotope in the gas near the tube axis. The separation factor

is greater than in the diffusion process, and the two streams removed from the tube axis and wall require only tens of stages arranged in a cascade to produce the required percentages of uranium -235 in the product and the reject tails. High centrifugal stresses limit the size of the equipment and many parallel cascades involving hundreds of thousands of centrifuges are required to achieve the separation capacity of a commercial enrichment plant.

The separation capacity of enrichment plants is measured in separative work units (SWU). A separative work unit is a measure of the effort expended to separate a quantity of uranium of a given assay into two components, one having a higher percentage of uranium -235 and one having a lower percentage (USAEC, 1974). Separative work has units of mass and is generally expressed in kilograms, but should not be confused with quantities of uranium processed.

Gaseous diffusion plants are being operated by the US Department of Energy and by COGEMA in France, and have been highly successful for more than 25 years. Gas centrifuge technology is being demonstrated in European plants operated by URENCO-CENTEC, an organisation set up under a tripartite agreement between the UK, the Federal Republic of Germany and the Netherlands. US centrifuge technology is understood to involve a smaller number of large centrifuges for a given output than required by European technology and has been adopted for construction of new enrichment plant in the USA.

The minimum economic capacity for a gaseous diffusion plant is at least 6 million SWU per year, requiring an electrical power supply of about 1500 MWe. By contrast, it is estimated that centrifuge technology is economic at plant capacities as low as 1 million SWU/year, requiring a substantially lower power input of about 25 MWe.

4.1 Wastes from Uranium Enrichment

Table 3 contains estimates of wastes from the annual operation of a gaseous diffusion and a gas centrifuge plant operated at minimum economic separating capacities assumed to be 6 million and 1 million SWU per year respectively. Gaseous wastes from supporting electrical generating stations are also listed. The data have been based on US technology (ERDA, 1976; ERDA, 1977), and it should be noted that the data on solid wastes from the gas centrifuge plant are unlikely to be representative of URENCO-CENTEC technology, which is known to have a different approach to maintenance of centrifuges. Wastes produced during fabrication of replacement gas centrifuge rotors and manufacture of other components for maintenance are not included in Table 3.

The primary source of environmental impact associated with the enrichment of uranium by gaseous diffusion is the emission of particulates and oxides of nitrogen and sulphur from the generation of electrical energy through fossil fuel combustion. Enrichment plants themselves generate small quantities of airborne fluorides and oxides of nitrogen and sulphur & liquid wastes from cooling systems process clean-up operations, on-site steam plant and auxiliary production facilities. These may contain low concentrations of sulphate, chloride, fluoride and nitrate, and metallic ions such as sodium, calcium, chromium and iron. Uranium losses in the wastes are very low - typically about 0.005 per cent of throughput. Effluents are disposed of by discharge and dilution. Some sludges arising from clean-up operations are buried at the site. Fig. 6 is a schematic illustration of management procedures for disposal of wastes from a gas centrifuge process.

Both types of enrichment plant also produce tails of depleted uranium hexafluoride. For tails containing 0.2% Uranium -235, either technology would produce annually about 1500 tonnes of depleted UF_6 for each million SWU utilised. These tails are generally stored as UF_6 in cylinders although a proportion is being converted for storage as UF_4 . In either case, the uranium content of the tails is an energy resource which can be used in fast breeder reactors and the tails are not regarded as waste material.

5. RADIOLOGICAL DOSE COMMITMENTS FROM THE LWR FUEL CYCLE

Estimates of radiological dose commitments and health effects for a nuclear power and fuel cycle industry assumed to grow to about 500 GWe by the year 2000 have been made for US conditions (USNRC, 1976). These estimates include dose commitments to occupational workers in the nuclear industry and to the US population at large.

Fig. 7 illustrates percentage estimates of radiological dose commitments over a 25-year period deduced from the USNRC study. The majority of radiological dose commitments were derived from uranium mining and milling (55%), nuclear reactor operation (30%) and spent fuel transportation, reprocessing and waste disposal (14%). The upgrading processes of uranium hexafluoride and enrichment accounted for less than 1 per cent of the total dose commitment from the fuel cycle, or about 0.007 per cent of that due to natural background radiation.

6. CONCLUSION

Wastes from uranium hexafluoride manufacture and uranium enrichment contain small quantities of naturally occurring radioactive elements. These wastes are managed by well established treatment processes and should prove no obstacle in the introduction of uranium upgrading processes to Australia.

REFERENCES

- AAEC (1981) - Australian Atomic Energy Commission News Release No. 164
September.
- Alfredson, P.G. (1972) - Review of Methods and Technology for the Production
of Uranium Hexafluoride, AAEC/E238, Paper VIII. AAEC Symposium
on Uranium Processing, Lucas Heights, 20-21 July.
- Anderson, A.R. (1979) - The manufacture of Nuclear Fuel, J. Inst. Nuc. Eng.,
Vol. 20, No. 4, pp. 115 - 123.
- ERDA (1975) - Draft Environmental Statement, Light Water Breeder Reactor
Program, ERDA 1541, July.
- ERDA (1976) - Final Environmental Statement, Expansion of US Uranium
Enrichment Capacity, US Energy Research and Development
Administration, ERDA - 1543, April.
- ERDA (1977) - Final Environmental Impact Statement, Portsmouth Gaseous
Diffusion Plant Site, Piketon, Ohio, ERDA - 1555, May.
- George D. (1981). The case for enrichment of uranium in Australia. Invited
Paper to 51st ANZAAS Congress, Brisbane, 11 May.
- OECD/NEA (1977) - Objectives, Concepts and Strategies for the Management
of Radioactive Waste arising from Nuclear Power Programs, NEA
Experts' Report, September.
- OECD/NEA (1979) - Uranium Resources, Production and Demand, OECD, Paris.
- Sears, M.B., Blanco, R.E., Finney, B.C., Hill, G.S., Moore, R.E. and
Witherspoon, J.F. - Correlation of Radioactive Waste
Treatment Costs and the Environmental Impact of Waste Effluents in
the Nuclear Fuel Cycle Conversion of Yellowcake to Uranium
Hexafluoride, Part 1, the Fluorination - Fractionation Process,
ORNL/NUREG/TM-7, September 1977.
- USAEC (1974) - Environmental Survey of the Uranium Fuel Cycle, US Atomic
Energy Commission, WASH-1248, April.
- USEPA (1973) - Environmental Analysis of the Uranium Fuel Cycle. Part 1 -
Fuel Supply, US Environment Protection Agency, EPA-520/9-73-003-B,
October.
- USNRC (1975) - Final Environmental Statement related to the Sequoyah Uranium
Hexafluoride Plant, Kerr McGee Nuclear Corporation, NUREG-75/007,
February.
- USNRC (1976) - Final Generic Environmental Statement on the use of Recycle
Plutonium in Mixed Oxide Fuel in Light Water Reactors, US Nuclear
Regulatory Commission, NUREG-0002, August.

TABLE 1.

MAJOR RADIOACTIVE CONSTITUENTS OF YELLOWCAKE

ISOTOPE	RADIATION	HALF LIFE	CONCENTRATION	
			GBq.t ⁻¹ U	(Ci.t ⁻¹ U)
²³⁸ ₉₂ U	α γ	4.5 x 10 ⁹ yr	12.2	0.33
²³⁵ ₉₂ U	α γ	7.1 x 10 ⁸ yr	0.5	0.015
²³⁴ ₉₀ Th	β γ	24.1d	12.2	0.33
²³⁴ ₉₁ Pa	β γ	1.14 min	12.2	0.33
²³⁴ ₉₂ U	α γ	2.5 x 10 ⁵ yr	12.2	0.33
²³⁰ * ₉₀ Th	α γ	80,000 yr	0.24	6.6 x 10 ⁻³
²²⁶ * ₈₈ Ra	α γ	1620 yr	2.4 x 10 ⁻²	6.6 x 10 ⁻⁴
²²² * ₈₆ Rn	α	3.83 d	2.4 x 10 ⁻²	6.6 x 10 ⁻⁴

* 0.2% of ²²⁶Ra and 2.0% of ²³⁰Th originally present in uranium ore at secular equilibrium have been assumed.

TABLE 2. ANNUAL EFFLUENTS FROM URANIUM HEXAFLUORIDE
PRODUCTION PLANTS - CAPACITY 5000 tU/YEAR

<u>PROCESS TYPE</u>	<u>DRY</u>	<u>WET</u>
<u>Chemical Effluents tonnes/year</u>		
<u>Gaseous and Particulate (to atmosphere)</u>		
SO _x	<1	15
NO _x	98	102 - 180
F	1.2	1.4
NH ₃	1.4	-
H ₂ S	26	-
Hydrocarbons	10	87
Water	2.4 x 10 ⁵	3.2 x 10 ⁴
N ₂ + O ₂	n.a.	2.6 x 10 ⁵
Particulates	4	n.a.
U natural	<125 kg	55 kg
<u>Liquid (discharged)</u>		
F ⁻	481	3
SO ₄ ⁻⁻ + S ⁻	225	21
Na ⁺⁺ + K ⁺	179	66
NH ₄ ⁺	86	-
Cl ⁻	9	93
Fe	2	0.3
U natural	0.4	2.4 - 4.2
Water	9.7 x 10 ⁵	1.9 x 10 ⁶
<u>Liquid and Sludge (impounded)</u>		
Raffinate (m ³)	-	2.5 x 10 ⁴
U natural	-	3.2
<u>Fluoride Sludges (impounded)</u>		
CaF ₂	800	300
U natural	0.2	0.06
<u>Solids (burial)</u>		
U natural	600	~600
	2.8	0.2

TABLE 2 (cont'd)

<u>PROCESS TYPE</u>	<u>DRY</u>	<u>WET</u>
<u>Radiological, GBq/year (mCi/year)</u>		
<u>Gaseous or Particulate (to atmosphere)</u>		
U natural	<3.3 (90)	} Similar to dry process
²³⁴ Th + ²³⁴ mPa	<3.3 (90)	
²³⁰ Th	40 MBq (1.1)	
²²⁶ Ra	4 MBq (0.1)	
²²² Ra	560 (15.1 Ci)	
<u>Liquid (discharged)</u>		
U natural	11 (280)	<110 (3.0 Ci)
²³⁴ Th + ²³⁴ mPa	4 (100)	50 (1.3 Ci)
²³⁰ Th	7 MBq (0.2)	4 MBq (0.1)
²²⁶ Ra	140 MBq (3.8)	37 MBq (1.0)
<u>Sludges from U purification (impounded)</u>		
U natural	-	80 (2.3 Ci)
²³⁴ Th + ²³⁴ mPa	-	80 (2.3 Ci)
²³⁰ Th	-	~1.2 TBq (33 Ci)
²²⁶ Ra	-	~120 (3.3 Ci)
<u>Fluoride Sludges (impounded)</u>		
U natural	5 (140)	1.5 (40)
²³⁴ Th + ²³⁴ mPa	5 (140)	1.5 (40)
²³⁰ Th	1 MBq (0.03)	-
²²⁶ Ra	0.8 MBq (0.02)	70 kBq (20 µCi)
<u>Solid (burial)</u>		
U natural	70 (2.0 Ci)	5 (140)
²³⁴ Th + ²³⁴ mPa	70 (2.0 Ci)	5 (140)
²³⁰ Th	~1.2 TBq (33 Ci)	} very low.
²²⁶ Ra	~122 (3.3 Ci)	
<u>Thermal Effluent, kWh/year</u>		
to air	1.7 x 10 ⁸	1.7 x 10 ⁸
to water course	2.9 x 10 ⁵	6.6 x 10 ⁶
Basis of Estimate :	0.2% of ²²⁶ Ra in ore enters with yellowcake.	
	2.0% of ²³⁰ Th in ore enters with yellowcake.	

TABLE 3: ANNUAL EFFLUENTS FROM ENRICHMENT PLANTS

<u>ENRICHMENT PROCESS</u>	<u>GAS CENTRIFUGATION</u>	<u>GASEOUS DIFFUSION</u>		
Plant capacity, SWU/year	10 ⁶	6 x 10 ⁶		
<u>Chemical Effluents</u>				
<u>Gaseous (to atmosphere), tonnes/year</u>				
(a) From Enrichment Plant and associated steam plant	SO _x	18	108	
	NO _x	60	360	
	CO	1	7	
	Particulates	9	56	
	Hydrocarbon	1	4	
	HF	0.06	2	
	Ethanol	1	-	
	U (kg)	2	12	
	(b) From supporting electrical power station	SO _x	1000	6 x 10 ⁴
		NO _x	860	5.2 x 10 ⁴
Particulates		2200	1.4 x 10 ⁵	
CO		22	1.3 x 10 ³	
Hydrocarbons		1	570	
Aldehydes		<1	13	
<u>Liquid Effluents (Discharged) tonnes/year</u>				
Flow (m ³)	1.3 x 10 ⁵	4.1 x 10 ⁶		
SO ₄ ⁻⁻⁻	n.a.	n.a.		
NO ₃	14.8	21.5		
Cl	n.a.	1.2		
F ⁻	0.1	0.3		
PO ₄ ⁻⁻⁻⁻	0.4	2.8		
Nitric acid	9.5	21.1		
Al(NO ₃) ₃	0.9	1.1		
Cr	0.003	0.2		
Zn	0.004	0.05		
U (kg)	0.7	4		
TBP Solvent	0.02	0.04		
Other organic materials	0.03	0.1		

Table 3 (Cont'd.)

	<u>GAS CENTRIFUGATION</u>	<u>GASEOUS DIFFUSION</u>
<u>Liquid Wastes (reclamation or burial), tonnes/year</u>		
Diffusion pump oil	0.4	n.a.
Damping oil	1.9	n.a.
Lubricating oil	2.8	n.a.
<u>Solid Wastes (reclamation or burial), tonnes/year</u>		
Steel	150	} 43 m ³ of metal scrap
Aluminium	102	
Iron	0.4	
Brass	1.8	
Other alloys	5.2	
Plastics	0.8	
Rotor material	240	
Alumina	29	~20
U	0.2	0.2
<u>Radiological Wastes</u> *		
<u>Particulate (to atmosphere), GBq (mCi)/year</u>		
$^{234}\text{U} + ^{235}\text{U} + ^{238}\text{U}$	0.2 (5.4)	1.2 (32.4)
<u>Liquid (discharged), MBq (mCi)/year</u>		
$^{234}\text{U} + ^{235}\text{U} + ^{238}\text{U}$	22 (0.6)	67 (1.8)
<u>Solid (burial), GBq (mCi)/year</u>		
$^{234}\text{U} + ^{235}\text{U} + ^{238}\text{U}$	4 (120)	~3.8 (104)

* Excludes an approximately equal amount of $^{234}\text{Th} + ^{234}\text{mPa}$ which will be produced over about 100 days through decay of ^{238}U .

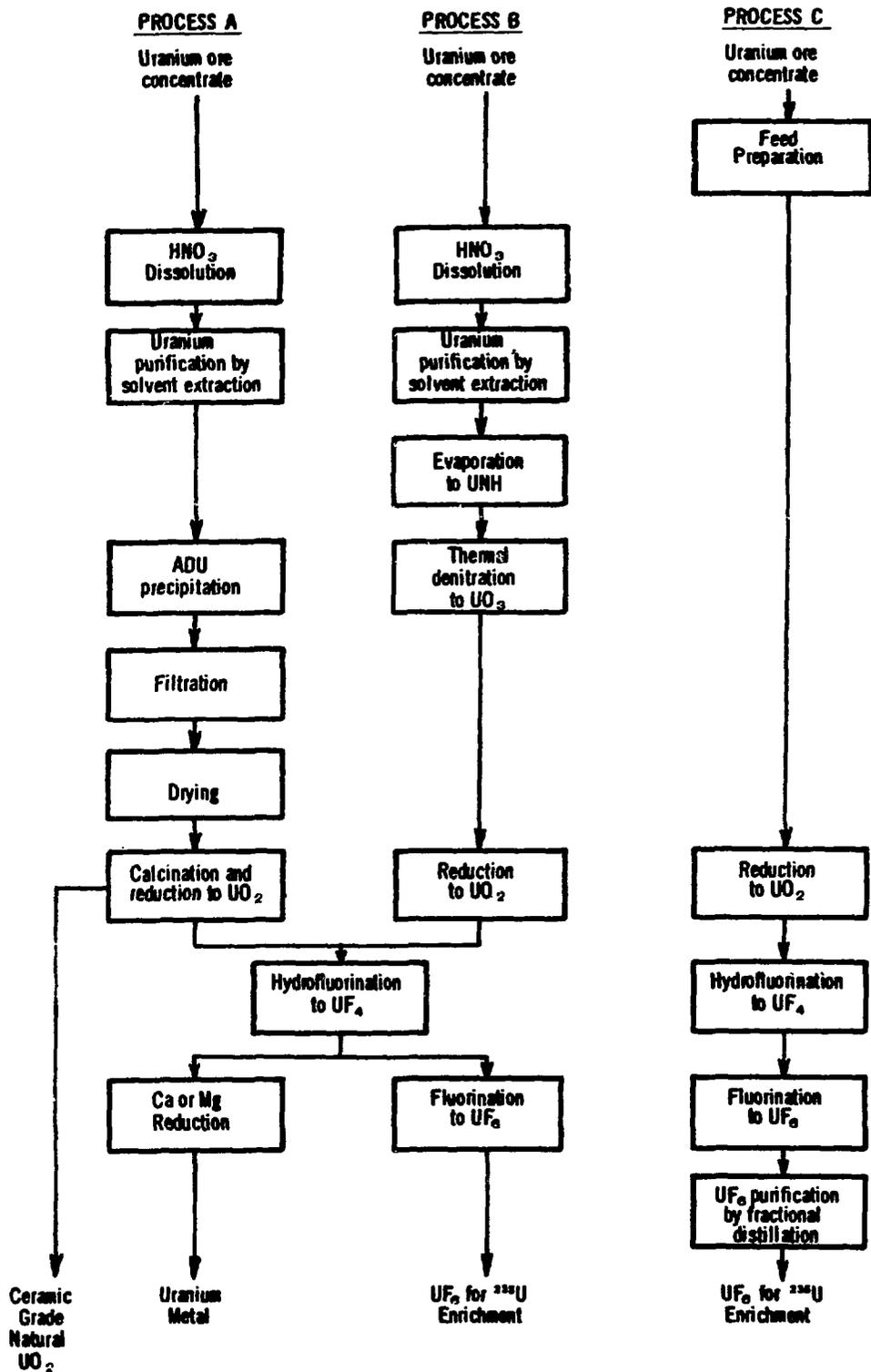


FIGURE 1. PROCESSES FOR PRODUCTION OF NUCLEAR GRADE URANIUM MATERIALS FROM ORE CONCENTRATES

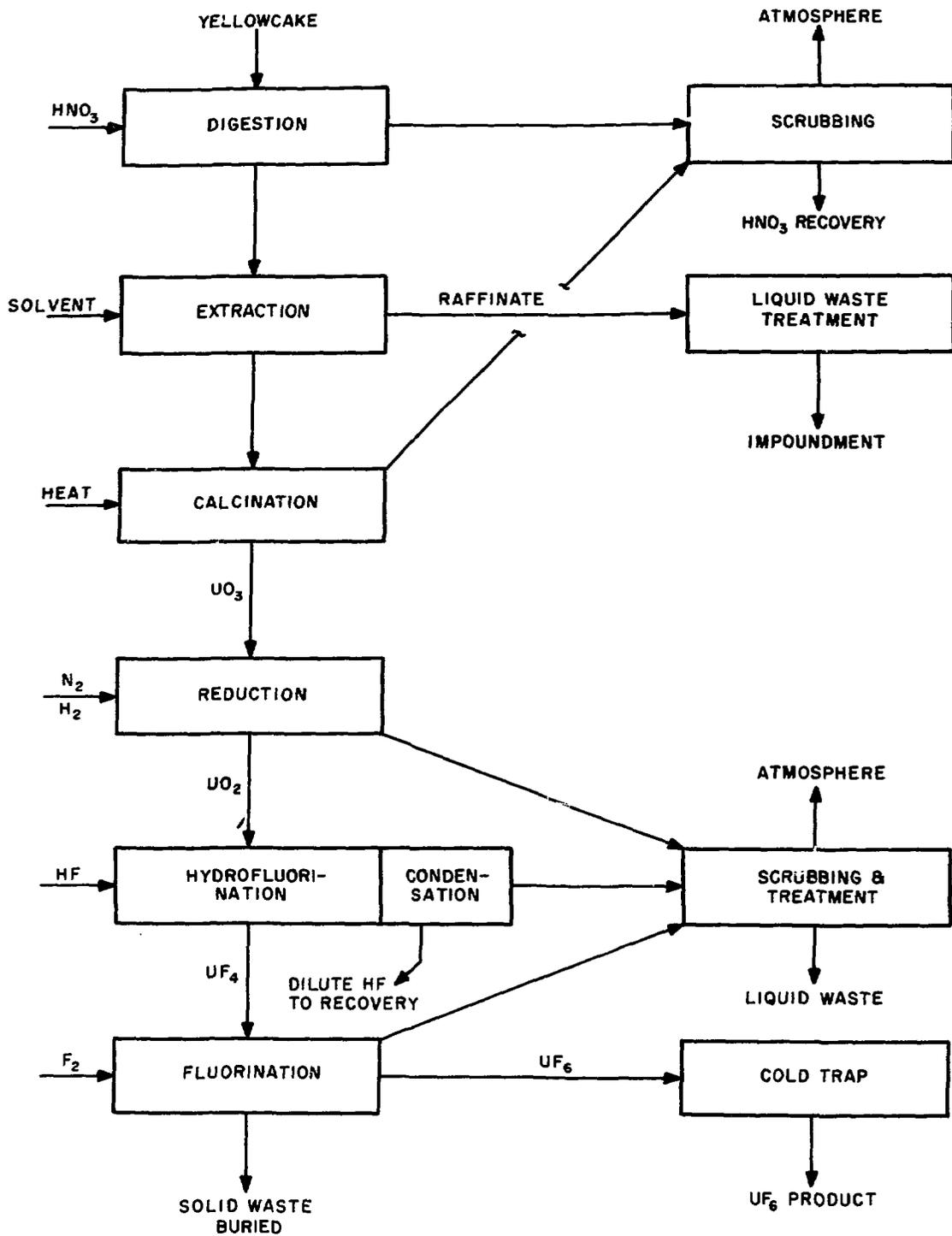


FIGURE 2. SCHEMATIC DIAGRAM OF WET PROCESS FOR URANIUM HEXAFLUORIDE PRODUCTION

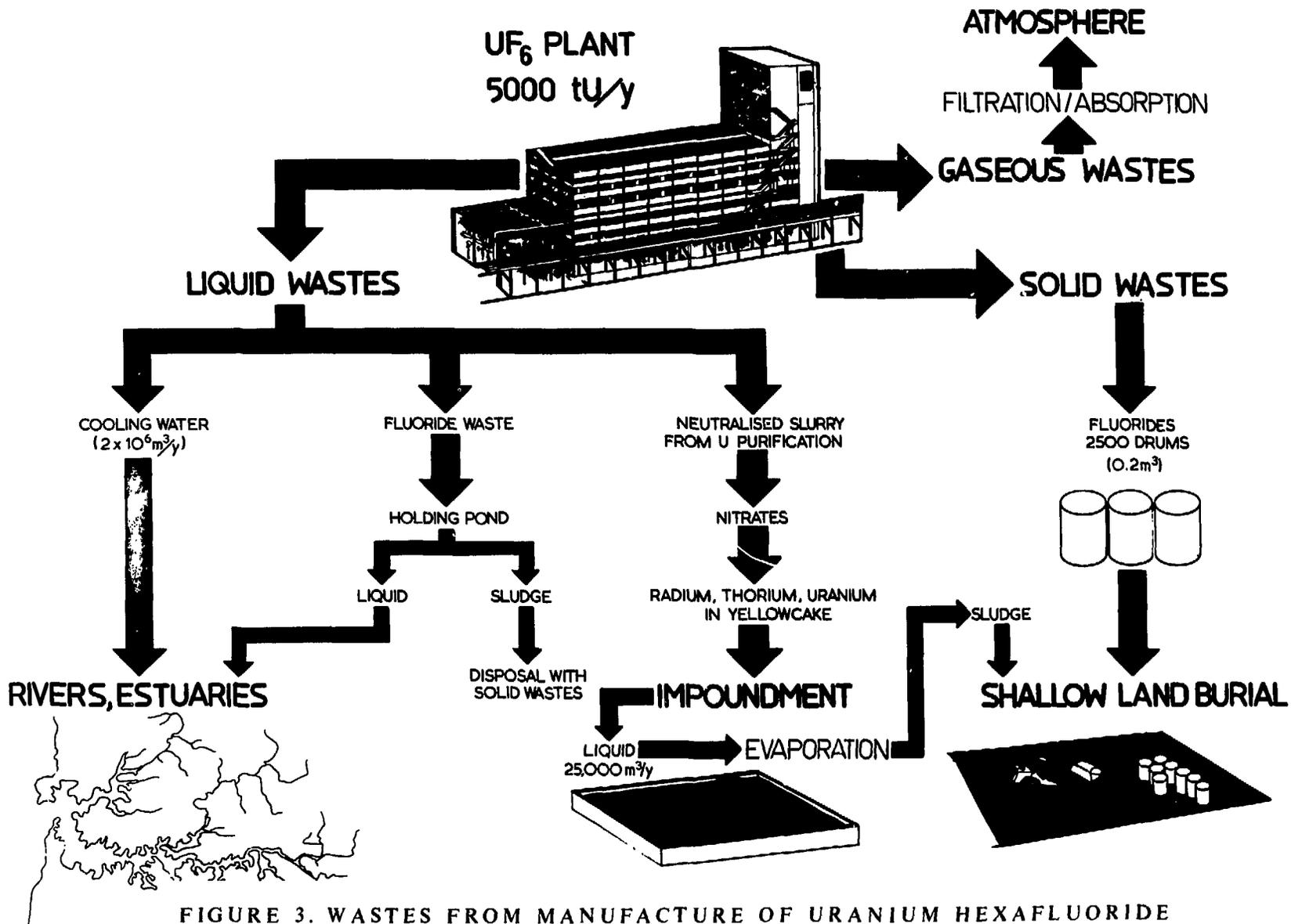


FIGURE 3. WASTES FROM MANUFACTURE OF URANIUM HEXAFLUORIDE

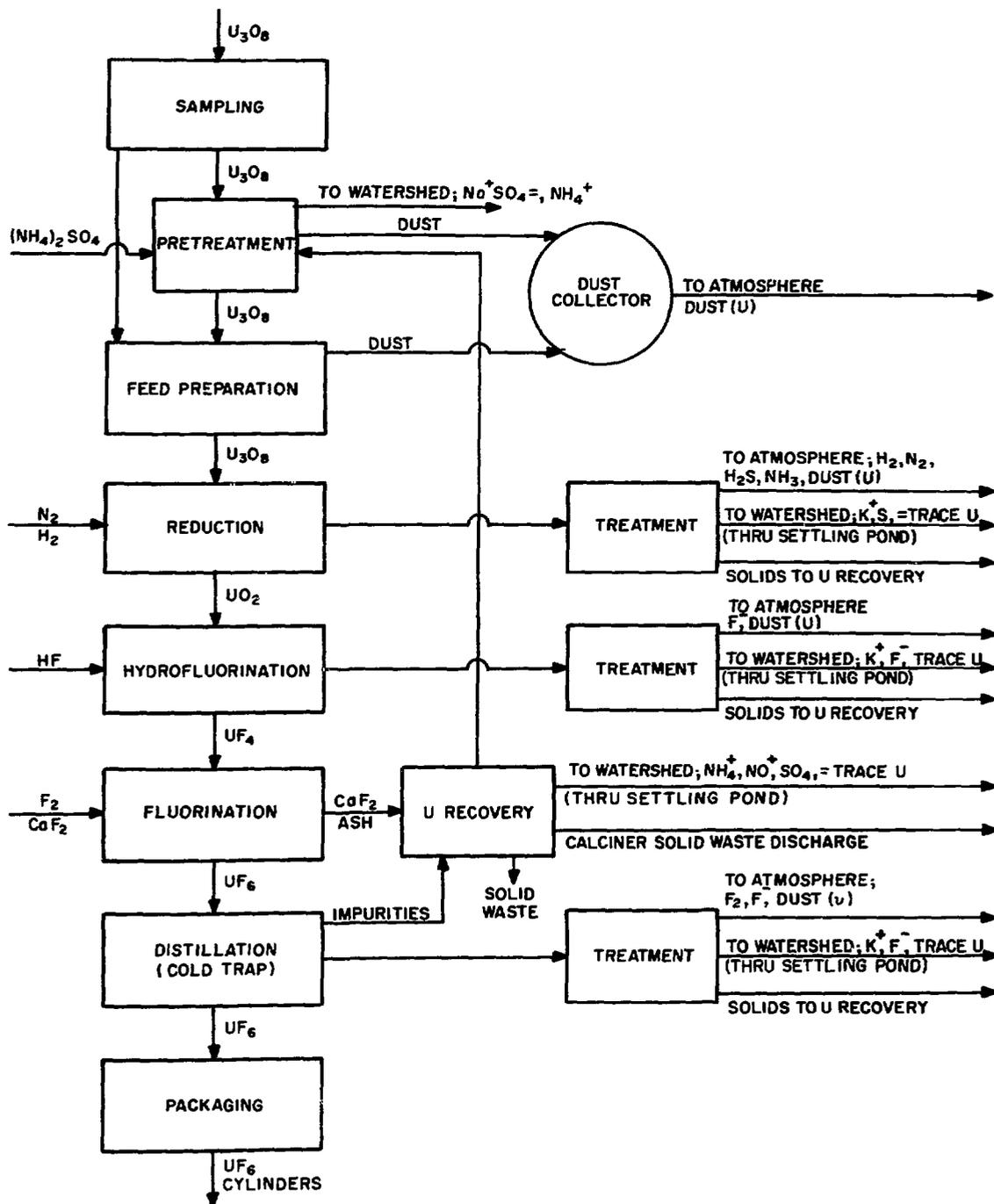


FIGURE 4. SCHEMATIC DIAGRAM OF HYDROFLUOR PROCESS FOR URANIUM HEXAFLUORIDE PRODUCTION

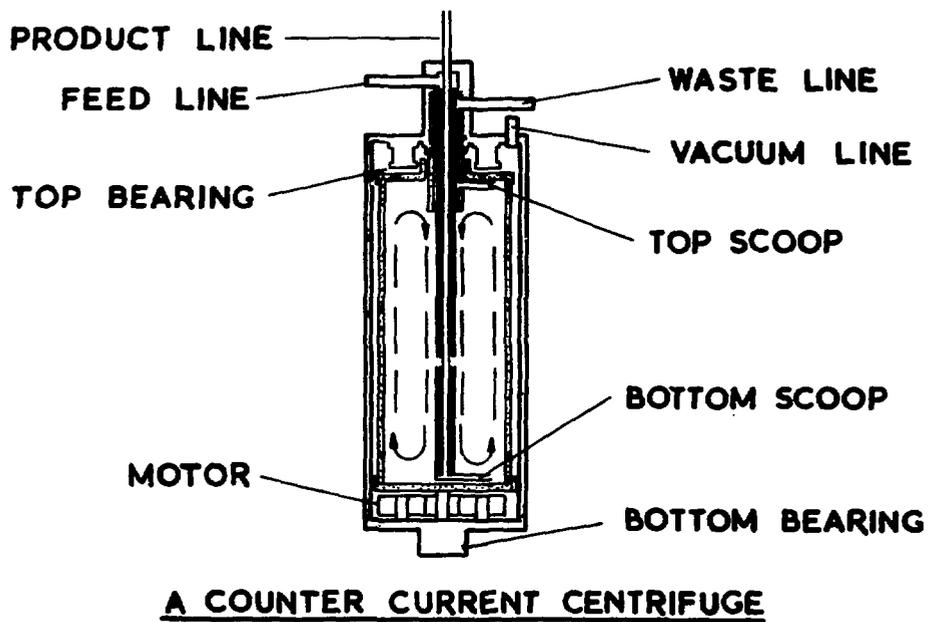
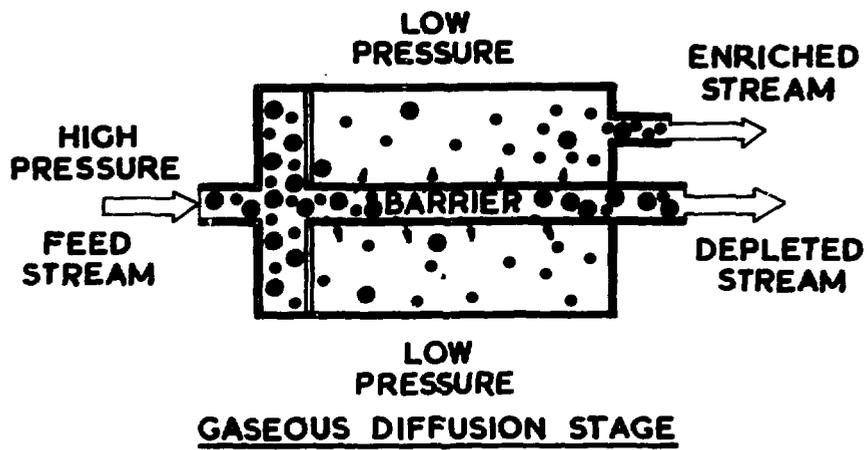


FIGURE 5. COMMERCIAL ENRICHMENT PROCESSES

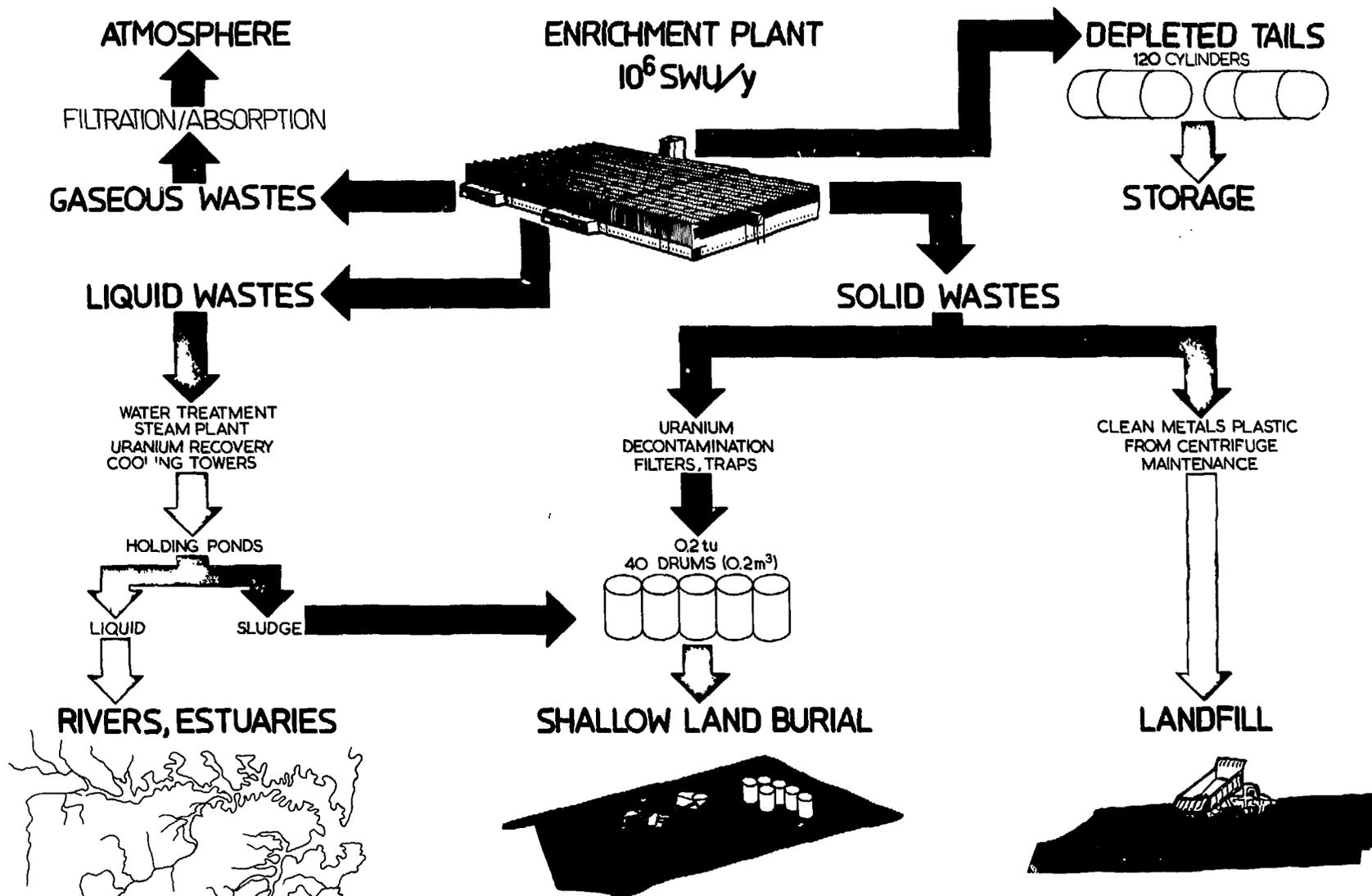


FIGURE 6. ANNUAL WASTES FROM URANIUM ENRICHMENT

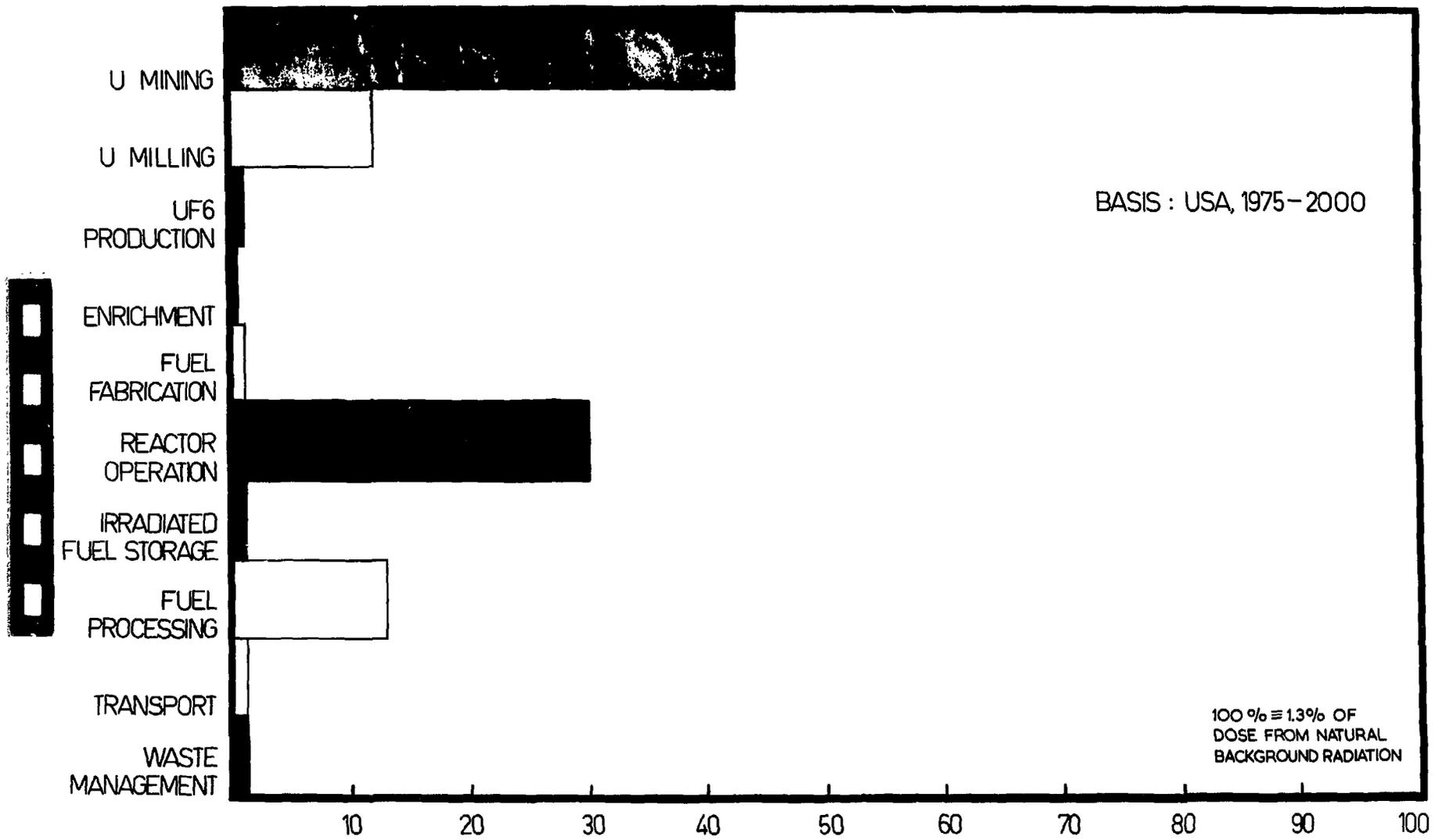


FIGURE 7. %DOSE COMMITMENTS FROM STAGES OF THE LWR FUEL CYCLE