Summary of National and International Radioactive Waste Management Programs (Excluding United States)

by
K. M. Harmon

March 1978

Pacific Northwest Laboratory
Richland, Washington 99352
Operated for the
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K. M. Harmon, Manager
International Program Review

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ACRONYMS AND ABBREVIATIONS

AECL	Atomic Energy of Canada, Ltd.
AERE	Atomic Energy Research Establishment (United Kingdom)
AKUT	West German Process for decontamination of HTGR fuel burner off-gas
AVM	Waste vitrification plant at Marcoule, France
BARC	Bhabha Atomic Research Center, Trombay, Bombay, India
BNFL	British Nuclear Fuels, Ltd., United Kingdom fuel cycle company
BWR	Boiling water reactor
CANDU	Canadian deuterium-uranium reactor
CEA	Atomic Energy Commission (France)
CEC	Commission of the European Communities
CEN/SCK	Belgian Nuclear Energy Research Center (Mol, Belgium)
CMEA	Council for Mutual Economic Assistance (Soviet-bloc countries)
COGEMA	French fuel cycle company
COREDIF	International consortium for commercial uranium enrichment
DERE	Dounreay Experimental Reactor Establishment (United Kingdom)
EIR	Federal Institute for Reactor Research, Switzerland
EUROBITUM	Eurochemic bituminization process
EURODIF	International consortium for commercial uranium enrichment
FBR	Fast breeder reactor
FINGAL/HARVEST	British waste vitrification process
FIPS	West German process for vitrifying high-level waste, developed at Juelich
FRG	Federal Republic of Germany
GCR	Gas-cooled reactor
GWe	Gigawatts electrical
GWK	Gesellschaft zur Wiederaufarbeitung von Kernbrennstoffen, German fuel reprocessing company which operates the WAK pilot plant
HEWC	High-enriched waste concentrate (Eurochemic high-level waste)
HLLW	High-level liquid waste
HLW	High-level waste
HMI	Hahn-Meitner Nuclear Research Institute, Berlin
HTGR	High-temperature gas-cooled reactor
HTR	High-temperature reactor
JAERI	Japan Atomic Energy Research Institute
IGS	Institute of Geological Sciences (United Kingdom)
INFCE	International Nuclear Fuel Cycle Evaluation
JRC	Joint Research Centers (CEC)
KBS	Swedish Nuclear Fuel Safety Project

KFA	Kernforschungsanlage Juelich, Juelich Nuclear Research Center (West Germany)
KfK	Kernforschungszentrum Karlsruhe, Karlsruhe Nuclear Research Center (West Germany)
KRYOSEP	Facility for removing krypton-85 from fuel reprocessing pilot plant at Juelich Research Center
LEWC	Low-enriched waste concentrate (Eurochemic high-level waste)
LMFBR	Liquid metal fast breeder reactor
LOTES	Low temperature solidification (waste calcination) process developed by Eurochemic
LWCHW	Light water cooled, heavy water moderated reactor
LWR	Light water reactor
MOX	Mixed (plutonium-uranium) oxide
MTR	Materials test reactor
NEA	Nuclear Energy Agency of the OECD
NEZ	Nukleares Entsorgungszentrum, West Germany fuel element disposal center
OECD	Organization for Economic Cooperation and Development
PAMELA	West German and Eurochemic process for converting high-level waste to glass beads and embedding them in a metal alloy
PFR	Prototype fast reactor (UK)
PHWR	Pressurized heavy water reactor
PIVER	Pilot Verres, French HLLW vitrification process
PNC	Power Reactor and Nuclear Fuel Development Corporation (Japan)
RWMC	Radioactive Waste Management Committee of the NEA
THTR	Thorium high-temperature reactor
TRU	Transuranic
UKAEA	United Kingdom Atomic Energy Authority
VERA	West German process for vitrifying high-level waste, developed at Karlsruhe
WAK	Fuel reprocessing pilot plant near Karlsruhe

SURVEY OF NATIONAL AND INTERNATIONAL RADIOACTIVE WASTE MANAGEMENT PROGRAMS

INTRODUCTION

Many nations and international agencies are working to develop improved technology and industrial capability for nuclear fuel cycle and waste management operations. The effort in some countries is limited to research in university laboratories on treating low-level waste from reactor plant operations. In other countries, national nuclear research institutes are engaged in major programs in all phases of the fuel cycle and waste management, and there is a national effort to commercialize fuel cycle operations.

Since late 1976, staff members of Pacific Northwest Laboratory have been working under USERDA/DOE sponsorship to assemble and consolidate openly-available information on foreign and international nuclear waste management programs and technology. This report summarizes the information collected on the status of fuel cycle and waste management programs in selected countries making major efforts in these fields. This compilation attempts to provide current information as of the end of February 1978. The situation in many countries is changing rapidly, however, and the data presented may be outdated.

This report is divided into two parts. The first section summarizes in tabular form various national fuel cycle and waste management programs. The rest of the report gives a nation-by-nation overview of fuel cycle and waste management technologies. Included in this section are brief summaries on the activities of several international organizations:

TABLE SUMMARIES**NUCLEAR POWER PROJECTIONS**

The mid-February 1978 issue of Nuclear News⁽¹⁾ lists 34 nations as having committed nuclear power stations (30 MWe or greater).^(a) Table 1 lists nuclear power projections for these and six other countries planning for future nuclear commitment.

TABLE 1. Nuclear Power Projections

GWe			GWe		
Country	Committed (a)	Projected (Year)	Country	Committed (a)	Projected (Year)
Argentina	0.9 (PHWR)	9 (2000)	Japan	18 (LWR)	40 (1985)
Austria	0.7 (LWR)			0.3 (LMFBR)	90 (1990)
Belgium	5.5 (LWR)			0.2 (GCR)	
Brazil	3.1 (LWR)	10 (1990)		0.2 (LWCHW)	
		70 (2000)	Korea (So.)	1.2 (LWR)	4 (1986)
Bulgaria	1.8 (LWR)	7.7 (1990)		0.6 (PHWR)	40-46 plants (2000)
Canada	11.9 (PHWR)	75 (2000)	Kuwait		6 + desalination capacity (2000)
Chile		0.6 (1988)			
Cuba	1.7 (LWR)	Several reactors (1990)	Luxembourg	1.3 (LWR)	
Czechoslovakia	1.8 (LWR)	12 (1990)	Mexico	1.3 (LWR)	10 (1990)
	0.1 (GCHWR)		Netherlands	0.5 (LWR)	3.5 (?)
Egypt	0.6 (LWR)	7 (2000)	New Zealand		1.2 (?)
Finland	2.2 (LWR)	6 (1985)	Pakistan	0.1 (PHWR)	4.8 (1990)
France	37.2 (LWR)	40 (1985)			16 (2000)
	2.2 (GCR)		Philippines	1.2 (LWR)	3.9 (2000)
	0.07 (GCHWR)		Poland	0.4 (LWR)	8 (1990)
	1.4 (LMFBR)		Rumania	0.4 (LWR)	+16 PHWR (2000)
Germany (East)	2.7 (LWR)		South Africa	1.8 (LWR)	12 (2000)
Germany (West)	26.3 (LWR)	30 (1985-6)	Spain	15.6 (LWR)	
	0.3 (LMFBR)			0.5 (GCR)	
	0.3 (THTR)		Sweden	9.4 (LWR)	
	0.05 (PHWR)		Switzerland	5.9 (LWR)	
Hungary	1.8 (LWR)	5.7 (1990)	Taiwan	4.9 (LWR)	
		12 (2000)	Turkey		4.4 (1990)
India	0.4 (LWR)	6 (1990)	United Kingdom	11.4 (GCR)	100 (2000)
	1.3 (PHWR)	20 (2000)		0.1 (HMLWR)	
Iran	4.2 (LWR)	22 (1992)		0.3 (LMFBR)	
		34 (2000)	United States	197	
Israel		0.6 (with desalination capacity)	U.S.S.R.	5.0 (LWR)	26 (?)
Italy	5.1 (LWR)	9-13 (1985)		14.9 (LGR)	
	0.2 (GCR)			1.0 (LMFBR)	
	0.04 (LWCHW)		Yugoslavia	0.6 (LWR)	0.6 (1987)

(a) Operable, under construction or on order.

NUCLEAR FUEL CYCLE PROGRAMS IN SELECTED COUNTRIES

Table 2 lists countries with significant R&D effort in one or more fuel cycle and/or waste management areas and indicates the areas in which each country is working.

TABLE 2. Nuclear Fuel Cycle Programs in Selected HLLW Countries

Country	Page No.	Power Generation	U Enrichment	Fuel Fabrication	Fuel Reprocessing	HLLW	Non-HLLW	TRU	Hulls	Solid Wastes	Volatile Radio-nuclides	Waste Isolation	Safety Assessment
Argentina	14	PHWR		X			X						
Australia	14		Gas Cent.				X						
Austria	15	LWR				X	X					Geol.	X
Belgium	16	LWR LMFBR		U U-Pu	LWR		X	X		X	X	Geol.	X
Brazil	17	LWR	Becker Nozzle	X	LWR								
Canada	17	PHWR		U U-Pu	X	X	X			X	X	Geol.	X
Denmark												Geol.	
Eurochemic	39					X	X		X	X			
European Community (CEC)						X	X	X				X	X
Finland		LWR					X			X		Shallow Burial	X
France	19	LWR LMFBR GCR	Diff. Chem. Exch.	U U-Pu	U Metal LWR FBR	X	X	X	X	X	X	Geol.	X
Germany, East (Dem. Rep.)		LWR										Geol.	
Germany, West (Fed. Rep.)	22	LWR LMFBR	Gas Cent. Becker	U U-Pu	LWR	X	X	X	X	X	X	Geol.	X
India	26	PHWR LWR FBR		X	LWR	X	X	X	X			Geol.	X
Iran	27	LWR											
Italy	27	LWR GCR LMFBR		U U-Th-Pu	LWR MTR	X	X	X		X		Geol.	X
Japan	29	LWR LMFBR GCR	Gas Cent.	U U-Pu	LWR	X	X	X		X	X	Geol. Seabed	X
Mexico		LWR		U U-Pu	LWR								
Netherlands		LWR LMFBR	Gas Cent.				X			X		Geol.	X
Pakistan		PHWR			X								
South Africa		LWR	Vortex Tube										
Spain	30	LWR GCR		X	X	X	X			X		Geol.	
Sweden	31	LWR				X		X		X		Geol.	X
Switzerland	32	LWR										Geol.	X
United Kingdom	32	GCR LMFBR	Diff. Gas Cent.	U U-Pu	LWR LMFBR	X	X	X	X	X	X	Geol. Seabed	X
United States		LWR HTGR LMFBR	Diff. G.C. Laser	U U-Pu	X	X	X	X	X	X	X	Geol. Seabed	X
USSR	35	LWR LWGR LMFBR	X	X	X	X	X	X		X		Geol.	X

URANIUM ENRICHMENT

Table 3 identifies nations with active uranium enrichment production and/or development programs. There is a strong trend away from the gaseous diffusion process in the construction of new plants. The URENCO-CENTEC consortium (United Kingdom, Netherlands, Federal Republic of Germany) has recently started up gas centrifuge plants in England and Holland, and other nations are developing gas centrifuge capability. German (FRG) scientists have developed the Becker "Nozzle" process, which is to be demonstrated in a Brazilian pilot plant currently planned as a Brazil-FRG joint venture. France has announced plans for a small plant to demonstrate a chemical exchange process, and South Africa's vortex tube process is in the pilot plant stage.

TABLE 3. Uranium Enrichment

Nation	Process	Status
Australia	Gas Centrifuge	R&D at Lucas Heights; negotiations with Urenco and Japan to purchase technology
Brazil	Becker Nozzle Process	Planning to build pilot plant in partnership with West Germany
France	Gaseous Diffusion	Partnership in Eurodif and Coredif consortia for commercial enrichment
	Chemical Exchange	R&D; planning to build demonstration-scale plant
Germany (FRG)	Gas Centrifuge	R&D; member of Urenco
	Becker Nozzle Process	R&D; supplying technology to Brazil for Becker pilot plant
Japan	Gas Centrifuge	R&D; planning to build pilot plant
Netherlands	Gas Centrifuge	Partnership in Urenco; plant at Almelo
South Africa	Vortex Tube	R&D; pilot plant
United Kingdom	Gaseous Diffusion	Plant at Capenhurst
	Gas Centrifuge	Partnership in Urenco, plant at Capenhurst
United States	Gaseous Diffusion	Production plants in operation
	Gas Centrifuge	Planning commercial plant
	Laser	R&D
USSR	Gaseous Diffusion	Production plants in operation
Belgium, Iran, Italy, Spain	Gaseous Diffusion	Partners with France in Eurodif and Coredif

FUEL FABRICATION

In nations with private-enterprise economic systems, uranium fuels for power stations are generally fabricated by private industry, and manufacturing capability is widespread. A number of nations are also working toward plutonium recycle, to fuel LWRs and/or fast breeders. Plutonium-uranium mixed oxide (MOX) fuel fabrication is generally handled by government plants.

FUEL REPROCESSING

Nations with spent fuel reprocessing R&D programs, reprocessing capability, or current aspirations to develop these programs are identified in Table 4. Some countries (e.g., France and England) are planning to handle spent fuel for other nations, some are striving to become or remain self-sufficient, and a few plan to buy reprocessing services elsewhere. A number of the smaller countries, which would not find it economical to build and operate their own plants, would welcome partnership in a regional fuel cycle center or in an international fuel reprocessing consortium.

TABLE 4. Fuel Reprocessing

Nation	Plant	Status	Major Milestones
Belgium	Eurochemic (Mol. international sponsorship)	60 tonne/yr. Shut down by Eurochemic in 1974. Takeover by Belgium planned.	Startup by Belgium--1982-1983
	Belgoprocess (Mol)	1500 kg/day plant is under consideration	
Brazil	Pilot plant	10 kg U/day. Conceptual study done by KEWA/Uhde.	
France	SAP (Marcoule)	25 kg/day operational pilot plant--used for R&D.	
	UP ₁ (Marcoule)	900-1200 tonne/yr, operational, used for U metal fuels.	
	AT-1 (La Hague)	200 kg/yr operational pilot plant (MOX fuel). Reprocessing breeder fuels.	
	UP ₂ (La Hague)	1000 tonne/yr, operational, used to reprocess gas reactor fuels; now has a 400 tonne/yr head end for LWR fuels.	
	UP ₃ (La Hague)	Dual-line reprocessing plant for LWR fuels. First line (800 tonne/yr) is to service foreign customers.	
Germany (West)	WAK (Leopoldshafen)	40 tonne/yr operational pilot plant for R&D.	Startup of first line--1985 Startup of second line--1987
	KEWA (Gorleben)	1400 tonne/yr commercial plant for LWR fuels.	
India	JUPITER (Jülich)	2 kg/day pilot plant for HTGR fuel	Startup--1980
	Trombay	60 tonne/yr operational pilot plant for U metal or oxide fuels.	
	Tarapur	100 tonne/yr, oxide fuels	
	Kalpakkam	Planned--to handle CANDU and thorium FBR fuels.	
Italy	EUREX (Saluggia)	30 kg/day, operational, MTR and oxide fuels.	
	ITREC (Trisaia)	15 kg/day, operational, ²³³ U-Th and Pu-U fuels.	
Japan	Commercial	1000-1500 tonne/yr.	Startup--late 1990s
	Tokai	210 tonne/yr, operational, oxide fuels.	
	Commercial (2 plants)	Plants are planned.	
Pakistan	Commercial	Capacity--100 tonne/yr range	Commercial plant--late 1990s
Spain		Lab-scale, 2000 kg/yr--in design stage.	
United Kingdom	Windscale	1500-2500 tonne/yr, GCR fuels; the plant has a new 400 tonne/yr head end for oxide fuels.	Startup--mid 1980s
	THORP (Windscale)	1200 tonne/yr, for oxide fuels. In planning stages.	
	Dounreay	10 tonne/yr operational pilot plant, FBR (MOX) fuels.	
United States	NFS (West Valley, NY)	300 tonne/yr oxide fuels; shut down (operated 1956-1972).	
	MFRP (Morris, IL)	300 tonne/yr oxide fuels. Inoperable--providing fuel storage.	
	AGNS (Barnwell, SC)	1500 tonne/yr, oxide fuels. Plant constructed, awaiting decision concerning U.S. reprocessing.	
USSR	Klopov Radium Institute	Experimental (several kg/day) reprocessing facility.	Startup--about 1980
		5 tonne/day plant for oxide fuels is reportedly under construction.	

HLLW SOLIDIFICATION

National and international programs to develop HLLW solidification technology are listed in Table 5. Several countries have processes in advanced stages of development and are working toward achieving full-scale process demonstration in the late 1970s and 1980s. France is striving for international acceptance of their AVM (Marcoule) vitrification process and has succeeded to the extent that AVM is to be used to solidify most of the existing Eurochemic HLLW. Also, FRG plans to use AVM as the reference process for pending vitrification plant licensing applications in Germany.

TABLE 5. HLLW Solidification

Nation	Process	Status/Major Milestones
Canada (Whiteshell)	Conversion of thorium-CANDU fuel cycle wastes to glass or ceramic.	Laboratory studies in progress.
Eurochemic (Mol, Belgium)	LOTES process: stirred-fluidized bed (continuous), process $AlPO_4$ -waste granules (can handle high Al-high Na feeds). Vitrimet process: incorporates waste granules or glass beads into lead alloy matrix.	All-steel test unit (10 t/hr feed) is operable. Demonstrated with radioactive glass beads from FRG PAMELA vitrification process.
France (Marcoule)	PIVER pilot plant (batch): pot calciner-melter, drained through a freeze-valve. Produces borosilicate glass. Maximum capacity: 4 kg glass/hr per unit.	Extensive process demonstration with Marcoule HLLW. Pilot plant now used for special work, e.g., FBR waste treatment.
France (La Hague)	AVM demonstration plant (continuous): rotating tube calciner; Inconel melter drained through freeze valve. (AVM plant to be built at Mol to solidify Eurochemic HLLW.)	Capacity--40 t/hr feed (150 m ³ /yr); 20 kg/hr glass. Startup--1978.
FRG (Karlsruhe)	AVH production plant (continuous); AVM process.	Startup--1982-1983.
FRG (Jülich)	VERA pilot plant (nonradioactive) 1. Steam-heated spray calciner coupled to a metallic melter; bottom drain produces borosilicate glass. 2. Liquid- or spray-fed ceramic melter (continuously). Produces borosilicate glass. Capacity--30 t feed/hr. FIPS hot cell unit (semicontinuous): drum dryer coupled to rising-level, in-pot melter. Designed to convert HTGR fuel reprocessing waste to borosilicate glass or ceramic capacity--1 kg glass/hr. FIPS pilot plant. Capacity--10 kg glass/hr.	Extensive cold process demonstration; hot-cell tests completed. No further work planned. Cold testing under way. Process demonstration conducted with ERROCHEMIC HLLW. To handle waste from JUPITER HTGR fuel reprocessing pilot plant.
FRG (Gelsenberg A.G.)	PAMELA process pilot plant (continuous): ceramic calciner-melter coupled with a glass bead-maker. Produces phosphate glass beads which can be incorporated in a metal matrix to form a "vitrimet."	Process development: Bead making--Jülich Vitrimet process--Eurochemic Process pilot plant to be built at Mol. Capacity--30-40 t/hr HLLW. Startup--1983.
India (Trombay and Tarapur)	Tarapur vitrification plant (semicontinuous): pot calcine and melt; drain to waste canister. Capacity--25 t/hr HLLW.	Startup--1979-1980. (Process developed by BARC at Trombay).
Italy (CNEN--Casaccia and JRC--Ispra)	ESTER bench-scale unit (batch): (Inconel pot). Capacity--2 kg glass/run.	Hot-cell tests at Ispra; scaleup planned.
Japan (PNC)	Fluidized-bed calcination, followed by vitrification or hot-pressing.	Demonstration facility planned. Startup--1986.
Japan (JAERI)	Calcination and vitrification of waste-loaded zeolites.	Lab-scale work.
Spain (Juan Vigon)	HLLW solidification.	Laboratory studies.
Sweden (ASEA-Atom)	Hot isostatic pressing to encapsulate fuel or convert calcine to ceramics.	Laboratory studies.
Sweden (Royal Inst. of Tech.)	Fission product absorption into titanate ion exchange resins.	Laboratory studies.
United Kingdom (Harwell)	FINGAL/HARVEST (semicontinuous): rising-level, in-canister calcination and vitrification. Product--borosilicate glass cylinders.	Hot demonstration with Windscale HLLW achieved in FINGAL pilot plant. Process studies under way in cold HARVEST pilot plant.
United Kingdom (Windscale)	FINGAL/HARVEST process (semicontinuous): Windscale hot pilot plant (1 t/hr feed) Windscale demonstration plant Windscale production plant	Startup--1979. Startup--1986. Startup--1990.
United Kingdom (Dounreay)	Vitrification plant for HLLW from FBR fuels (process not selected). Required capacity: 30 t/hr (HLLW).	Startup--late 1980s.
United States (ICPP, Idaho Falls)	Fluidized bed calcination with in-bed combustion.	In service.
United States (PNL, Richland)	ORNL pot calcination process: calcination in the storage canister. ORNL rising-level glass process. BNL phosphate glass process: platinum calciner-melter. Spray calciner/in-can melter. Capacity--50 kg/hr glass.	Developed at ORNL; tested in WSEP at PNL. Developed at ORNL; tested in WSEP. Developed at Brookhaven; tested in WSEP.
United States (PNL, Richland)	Fluidized bed calciner with in-bed combustion. Joule-heated ceramic melter: Engineering-scale unit Full-scale development unit Direct liquid-fed ceramic melter: Engineering-scale unit Full-scale developmental unit (100 t/hr feed)	Full-scale cold testing started. Active pilot plant startup: 1978; development complete by end of 1980. Process development in pilot-scale unit completed; testing of scaled-up unit started. Operated from January 1975 (Capacity--60 kg/hr). Startup--1977. Cold tests run. Capacity--30 t/hr HLLW. Startup--1977.
USSR	Single-stage phosphate glass process (continuous): simultaneous evaporation, calcination and vitrification in ceramic-lined metal box. Two-stage fluidized bed process (semicontinuous): calcine in fluidized bed; melt and store in concrete refractory crucible.	Cold pilot plant has operated several years. Cold pilot plant tests. Capacity--20 kg/hr glass.

GEOLOGIC WASTE ISOLATION

Plans for geologic storage and/or isolation of spent fuel elements and solidified waste of various activity levels are being made by many countries, including nations which are contracting with France and the United Kingdom for fuel reprocessing services. These contracts require return of solidified high-level wastes to the country of origin.

A few nations are also investigating the feasibility of seabed disposal of high- and non-high-level wastes.

National and international geologic waste isolation development programs are summarized in Table 6.

TABLE 6. Geologic Waste Isolation

Nation	Waste Type	Formations of Interest	Current Studies	Milestones
Austria	Spent fuels; Misc. Wastes	Hard rock	Site evaluation Granite properties Safety assessment	
Belgium	HLW Non-HLW	Clay beds	Site evaluation Clay-bed properties In situ studies--tunnel	Pilot repository at Mol for alpha and non- HLW--1981
Canada	Spent fuels HLW Non-HLW	Bedded salt Plutonic rocks	Site evaluation In situ studies-- Granite test site	Commercial repository: Site selection--1981 Demonstration--1986 Startup--2000
Denmark	Non-HLW		Geologic survey	
France	Alpha wastes	Rock salt Crystalline rocks	Geologic survey Safety assessment Oklo Phenomenon	Pilot plant repository (alpha wastes)--1985
Germany (East)	Non-HLLW	Salt	Repository development at Bartensleben	
Germany (West)	Spent HTGR fuels; Non- HLLW; HLLW	Salt	Salt Mine operation--Asse mine Safety assessment Engineering for spent fuel and HLW storage	Commercial repository at Gorleben--late 1980s
India	HLW Non-HLW	Igneous rock Sediments	Site evaluation; proper- ties of rocks	
Iran			UKAEA evaluation of dis- posal in Iran	
Ireland	Non-HLW		Geologic survey	
Italy	HLW	Clay Salt	Geologic survey; In situ studies in clay beds	Pilot plant repository-- mid 1980s
Japan	HLW	Varied rock	Geologic survey; safety assessment	
Netherlands	Non-HLW	Salt	Geologic survey; safety assessment	
Spain	HLW Non-HLW	Shale Clay Salt	Non-HLW going into old uranium mines; site evaluation	Pilot plant repository-- late 1980s
Sweden	Spent fuels HLW Non-HLW	Hard rock (granite)	Field tests--Stripa mine; Safety assessment	Pilot plant repository-- mid 1980s
Switzerland	HLW Non-HLW	Anhydrite; Clay	Site evaluation; safety assessment; development of test site for HLW	
United Kingdom		Clay Crystalline rock	Geologic survey; safety assessment; site evalua- tion	Commercial repository- 2000
United States	Spent fuels HLW Non-HLW	Salt Shale Igneous rock	Site evaluation; safety assessment; repository engineering	Pilot plant repositories-- mid 1980s
USSR	Non-HLW	Varied	Direct injection under- ground	
CEC	HLW		Catalog of potential sites in member countries; support work in Belgium (clay), FRG (salt), UK and France (crystalline rock)	

NATIONAL AND INTERNATIONAL PROGRAM OVERVIEWS

Brief overviews of fuel cycle and waste management activities are provided for the following nations and international organizations.

Argentina	Spain
Australia	Sweden
Austria	Switzerland
Belgium	United Kingdom
Canada	USSR
France	IAEA
Germany, Federal Republic of (FRG)	European Communities (including JRC-Ispra)
India	OECD/NEA
Iran	Eurochemic
Italy	CMEA
Japan	

ARGENTINA

Nuclear Power

Committed: 0.9 GWe (PHWR)

Projected: 9 GWe (PHWR) by the year 2000

Note: Argentina has chosen the Canadian CANDU reactor system and depends heavily upon Canada for technical assistance.

Fuel Cycle

Argentina plans to become self-sufficient in uranium fuel and heavy water production by 1985. Their schedule calls for the following facilities to be operational by the dates shown below:

- fuel fabrication plant, 1979
- zirconium sponge pilot plant, 1978; a Zircaloy tubes plant, 1983
- heavy-water pilot plant, 1980; a production plant, 1984.

Waste Handling

In 1985, work is to be completed on the first stage of an experimental plant for solidifying "high-activity liquid waste," presumably from reactor operations.

AUSTRALIA

Nuclear Power

None planned for Australia

Fuel Cycle

Australia possesses tremendous uranium reserves, and is developing a uranium mining, milling, and ore processing industry to exploit them. Uranium enrichment is also under consideration.

- Gas centrifuge R&D is under way at the Lucas Heights (New South Wales) Research Establishment. The AEC has gas centrifuges operating in cascade.
- Australia is negotiating with other nations regarding the establishment of a uranium enrichment plant in Australia.

Waste Management

Waste handling R&D activities are primarily directed toward uranium ore processing wastes.

AUSTRIA

Nuclear Power

Committed: A 730 MWe BWR at Tullnerfeld, near Vienna, which is nearly ready for its first fuel load

Note: The government has decided that until the waste disposal problem has been properly settled, the Tullnerfeld reactor will not be loaded with fuel and no other reactors will be ordered. Two additional reactors had been planned.

Fuel Reprocessing

France's COGEMA and Austria's GKT utility have initiated a contract for the La Hague reprocessing plant to reprocess Austrian spent fuel. Austria will take back the vitrified waste and the recovered uranium. Recovered plutonium will be Austrian property, but will remain at La Hague.

HLLW Solidification, R&D

Seibersdorf Research Centre: Vapor deposition techniques for coating HLW calcine granules with pyrolytic carbon in a fluidized bed are being developed.

Waste Isolation, R&D

Seibersdorf:

- survey of potential disposal sites
- tests of granite behavior when heated and irradiated
- safety assessment.

Waste Isolation

National Planning: At Iran's invitation, Austria and Iran are negotiating for disposal of Austria's wastes in the Iranian desert.

Waste Treatment - Other, R&D

Seibersdorf:

- thermoanalytic characterization of bitumen-salt mixtures
- conditioning and bituminization processes for low-level wastes.

BELGIUMNuclear Power

Committed: 6 GWe (LWR) by 1983

Projected: In mid-1977, Belgian utilities projected 8 to 10 GWe nuclear power capacity by 1990. Present plans are very uncertain.

R&D: Participation with West Germany and Holland in the 300 MW Kalkar FBR station (SNR) and with OECD in the Dragon HTR project.

Fuel Fabrication

Two companies located in Dessel manufacture nuclear fuel:

- Franco-Belge de Fabrication de Combustibles (FBFC), owned jointly by French and Belgian interests, manufactures uranium fuels
- Belgonucléaire fabricates uranium-plutonium fuels for LWRs and FBRs.

Fuel Reprocessing

Belgoprocess, owned jointly by the state and by Synatom (a utilities organization), plans to take over and operate the 60 tonne/yr Eurochemic reprocessing plant. Decontamination of the plant, shut down since 1974, is nearly completed. Startup under Belgoprocess ownership is anticipated in 1982-1983. Construction of a second plant at the Mol site, rated at 1500 kg/day, is also under consideration.

Waste Isolation

Belgium is working to develop and demonstrate technology for waste isolation in the claybeds beneath the Mol site. R&D (CEN/SCK and the Geologic Service) includes:

- safety assessment and supporting studies
- in-situ tests (nonradioactive) in an existing tunnel near Antwerp
- development of plans for a pilot repository at Mol, to be operable in 1980-1981.

Solid Waste Handling (Including TRU), R&D

Nuclear Energy Research Centre, Mol-CEN/SCK: A high-temperature incinerator with a 150 kg/hr capacity has given good results in cold tests and is being modified to handle TRU wastes. The incinerator operates at a temperature high enough to convert the ashes to a basalt-like slag.

Non-HLLW Treatment

SCK/CEN operates a stirred-evaporator, batch bituminization plant for low-level wastes.

Eurochemic Activities

See the EUROCHEMIC summary, p. 39

BRAZILNuclear Power

Committed: 3.1 GWe (LWR) by 1984

Projected: 10 GWe by 1990; 70 GWe by the year 2000

R&D: Brazil plans FBR research and development.

Note: Brazil has a national goal to achieve nuclear plant and fuel cycle independence by 1992.

Fuel Cycle

Nuclebrás, the state-owned nuclear holding company, has become a partner with the Federal Republic of Germany (FRG) in a number of jointly-owned subsidiaries. One of these subsidiaries is to build and operate in Brazil a demonstration plant for the Becker "nozzle" (uranium enrichment) process, developed in Germany. Nuclebrás also plans to set up a 50 tonne/yr oxide fuel fabrication plant and a 10 kg U/day pilot reprocessing plant.

The developmental facilities are to be located at a new technology center near Santa Cruz.

CANADANuclear Power

Committed: 12 GWe (PHWR) 0.25 GWe (LWR)

Projected: 75 GWe by the year 2000

R&D: conversion to thorium-burning CANDU system

Fuel Cycle

It has been past Canadian policy to store their spent CANDU fuels in water-filled bays at the power generating sites, meanwhile deferring any serious work on reprocessing on the grounds that recycle was neither necessary nor economic. Current plans are to transfer spent fuels from the reactor fuel basins to a centralized interim storage facility at a Federal "Fuel Cycle Center."

Long-term Canadian Policy, however, assumes the eventual need to recover plutonium and uranium from spent reactor fuels. Hence it is assumed that the Fuel Cycle Center would include Federally-owned reprocessing, refabrication and waste treatment facilities. In order to acquire Pu-handling experience, work

was initiated recently at Whiteshell on reprocessing and Pu fuel fabrication. This effort was ordered stopped by the Canadian Government in October 1977, pending the results of the INFCE study.

HLLW Solidification

Canadian policy also assumes the eventual need for geologic disposal of either solidified HLLW (probably as glass) or unprocessed spent fuel elements. Workers at Whiteshell are studying the incorporation of spent fuel wastes from the thorium fuel cycle into glasses and crystalline ceramic materials. The studies include development of solidification equipment and determination of the leaching and stability characteristics of solidified waste.

Spent Fuel and HLLW Storage/Isolation

Spent CANDU fuels have been stored at Chalk River in concrete-lined holes in the ground, and studies of spent fuel storage in surface concrete canisters are under way at Whiteshell.

Whiteshell is coordinating a Canadian program to demonstrate the use of a mined cavity for retrievable storage and, ultimately, disposal of solidified HLLW and/or spent fuel. The program calls for laboratory and field studies on hard rock and salt formations.

Geological and geophysical studies are concentrated in three branches of the Department of Energy, Mines and Resources: the Geological Survey of Canada, Can Met and the Earth Physics Branch. AECL also has contracts with the University of Quebec at Montreal for studies on serpentinite and with a mining consultant, Acres Consulting Services, for the preliminary conceptual design of the repository.

A test site has been established in a small granitic body (White Lake) approximately 110 km northwest of Ottawa to test equipment and theoretical concepts being developed for the hard rock repository concept.

The schedule for providing a licensed repository calls for site selection by 1981, construction of the demonstration facility by 1986, and commissioning of the repository by the year 2000.

Non-High-Level Waste Treatment, R&D

Chalk River: concentration of liquid wastes using reverse osmosis.

Solid Waste Treatment, R&D

Ontario Hydro: development of a waste compactor and a "starved air dual-chamber" incinerator. These facilities are now operational in their Radioactive Waste Volume Reduction Facility at Bruce.

Volatile Radionuclides, R&D

Whiteshell:

- recovery of volatile radionuclides from fuel reprocessing operations
- incorporation of noble gases in solids (e.g., krypton in zeolites).

FRANCENuclear Power

Committed: 37 GWe (mainly LWR, also LMFBFR, GCR)

Projected: 40 GWe by 1985, 5 GWe/yr increments beyond 1985

Major R&D: LMFBFR (Rapsodie, Phenix, Super Phenix)

Fuel Cycle

Through the CEA and the state-owned company, COGEMA, France is making extensive efforts to commercialize all steps of the fuel cycle, including its AVM waste vitrification process. Activities include:

- Uranium Enrichment. COGEMA operates gaseous diffusion production plants and has a lead role in the projects for two new multinational enrichment facilities, EURODIF and COREDIF. The CEA has also developed a chemical exchange enrichment process which is to be the basis for a proposed demonstration plant.
- Fuel Fabrication. LWR fuels are produced commercially. The CEA's Cadarache Nuclear Research Centre has responsibility for development and fabrication of MOX fuels for FBRs and future LWR recycle.
- Fuel Reprocessing. COGEMA operates the UP₁ (Marcoule) and UP₂ (La Hague) reprocessing plants which were constructed to handle natural uranium metal fuels. A 400 tonne/yr head-end for commercial LWR fuels has been added to the La Hague plant, and reprocessing of high-burnup oxide fuels has been started there. Work is also under way on design and construction of a new UP₃ plant at La Hague for commercial LWR fuel reprocessing. UP₃ is to have two parallel lines, each rated at 800 tonne/yr. The first UP₃ line which is to be operational about 1985 is to be used for foreign customers. Marcoule and La Hague each have a small pilot reprocessing plant. The La Hague AT-1 plant handles FBR fuels.

HLLW Solidification

Two major processes have been developed at Marcoule.

- PIVER is a pot vitrification process in which HLLW and chemicals are added to the pot and calcined, the temperature is raised and the mixture melted, and the glass is drained into a waste canister. PIVER has been tested on full-level Marcoule waste in the PIVER pilot plant, producing 12 tonnes of glass with a maximum activity of 3000 Ci/l. The PIVER plant is still used for special projects, e.g., process tests with LMFBFR HLLW.
- The Marcoule continuous vitrification process uses a rotary calciner coupled to a melting furnace. Product glass drains (batchwise) into the waste canisters (Figure 1). The Marcoule process has been tested in a cold pilot plant with a throughput of 20 kg glass/hr. The AVM, a hot

FIGURE 1. Simplified Flowsheet of Vitrification Plant at Marcoule (AVM)(2)

demonstration plant to be used for solidification of Marcoule HLLW, is undergoing startup tests. Hot operation is scheduled for 1978 with a capacity of 40 ℓ /hr feed ($150 \text{ m}^3/\text{yr}$) and 20 kg/hr glass. Calciner dimensions are 27 cm diameter by 3.6 m. Melter dimensions are 35 cm diameter by 1 m high.

Since French (COGEMA) contracts to reprocess spent fuel for other nations require return of the HLLW in solid form, France is endeavoring to secure international acceptance of the Marcoule vitrification process and waste glass product. To this end, France has secured Eurochemic agreement to install the Marcoule process at Mol for vitrification of existing Eurochemic high-level wastes.

TRU Waste Treatment, R&D

Fontenay-aux-Roses: partitioning and transmutation of alpha wastes.

Marcoule:

- vitrification of TRU wastes
- characterization of glasses doped with alpha emitters. (A new hot cell for leach-testing and strength measurements on glasses doped with ^{242}Cm is planned.)

Waste Isolation

The planned disposal method for alpha-bearing wastes is emplacement in deep geological formations. For fission products, either geologic disposal or long-term storage in engineered facilities is a possible solution. The formations presently being studied for geologic disposal are rock salt and crystalline rocks. The reconnaissance of salt formations in France has indicated the existence of several promising areas. However, present plans are to devote a significantly greater effort to crystalline rocks.

The possibility of disposal in granite has been evaluated for the site of La Hague, and plans are under way for a large program that will evaluate many other crystalline-rock formations. This program will be partially financed by the Commission of European Communities. The target date for the first pilot-plant repository (alpha-bearing waste only) is 1985.

Marcoule has an air-cooled underground facility for interim storage of AVM waste glass. Cadarache is testing "capillary barrier" techniques for shallow land burial.

Non-HLLW

- Bituminization: R&D is being conducted at Cadarache (thin-film evaporator dehydration of the waste-bitumen emulsion, twin-screw extruder plant), Marcoule (screw-extruder), and Saclay (commercial turbulent-film-evaporator process).
- Incorporation in Thermo-Setting Resins: Pilot-plant tests are now being performed at Grenoble. Construction of demonstration plant was started in 1977.
- Incorporation in Concrete: Production operations at Saclay immobilize non-HLLW in concrete.

Cladding Hulls, R&D

Marcoule: meltdown of zirconium cladding hulls for consolidation and decontamination.

Solid Wastes

- Cadarache has built a pilot plant (operational in 1977) for crushing solid alpha-contaminated wastes at liquid air temperatures.
- Marcoule operates two incinerators (up to 60 to 70 kg/hr feed) for burning solid contaminated wastes.

Volatile Radionuclides, R&D

Fontenay-aux-Roses: A noble-gas cryogenic separation unit has been built. Tests with this unit are to be followed by pilot-scale tests at Marcoule or La Hague.

GERMANY, FEDERAL REPUBLIC OF (FRG)Nuclear Power

Committed: 28 GWe (mainly LWR; also LMFBR, THTR, PHWR)

Projected: 30 GWe by 1985/1986

R&D: HTGR and LMFBR systems

Uranium Enrichment

The FRG firm CENTEC has partnership with British and Dutch companies in the URENCO consortium, which operates centrifuge enrichment plants at Capenhurst, England and Almelo, Holland. CENTEC also plans to construct a centrifuge plant in FRG.

KfK is working on the development of Becker "nozzle process" technology. FRG and Brazil are cooperating in the construction of a Brazilian pilot plant based on the Becker process.

Fuel Fabrication

Development and fabrication of MOX fuels for FBRs and recycle to LWRs are handled by ALKEM at Hanau. HTGR fuel fabrication and development (uranium oxides and carbides; thorium oxides) are the responsibility of KFA at Jülich.

Fuel-Cycle: Back-End

The Federal government, nuclear power producing utilities, and other private enterprises are deeply involved in the back-end of the nuclear fuel cycle. Major effort is going into development of the Nukleares Entsorgungs Zentrum (NEZ), the proposed spent fuel element disposal centre that is to be built at Gorleben. NEZ has been divided into the seven areas of activity shown below.

<u>Activity</u>	<u>Target Date for Operation</u>
Fuel reception and storage	1986-1st 1990-2nd
Reprocessing	1990
Uranium storage and conversion	1990
Plutonium storage, conversion and MOX fabrication	1990
Waste management	1986-1990
Waste disposal	1996
Infrastructure	1982

Fuel Reprocessing

The following R&D is being done:

- KfK, Karlsruhe: Large-scale, cold testing of process operations and equipment in the "TEKO Hall" facility
- GWK: WAK pilot plant (40 tonne/yr capacity)

- KFA, Jülich: JUPITER pilot plant (2 kg/day) for reprocessing HTGR fuels; Startup: 1980.

A 1400 tonne/yr reprocessing plant is planned for the NEZ at Gorleben. In the interim, the German utilities plan to have their spent fuels reprocessed by COGEMA at the La Hague plant in France.

HLLW Solidification

Extensive effort has gone into development of the following solidification processes.

- VERA Process (KfK, Karlsruhe) for Purex-type wastes: For several years, development work was centered on a spray-calcliner/metallic melter process which produces a borosilicate glass. These operations were tested extensively in the VERA pilot plant (cold) and in hot-cell runs.

In 1977, work on the spray-calcliner/metallic melter process was dropped in favor of calcination and melting in a ceramic melter unit. The HLLW is sprayed or dropped into the melter at melting temperature, and the waste glass produced is drained into waste canisters (Figure 2). The pilot-scale melter has been tested extensively at feed rates up to 30 l/hr HLLW with nonradioactive feed.

FIGURE 2. Simplified Flowsheet and Illustration of Compact Ceramic Unit (VERA)(3)

Future plans for VERA are uncertain since the French AVM process has been chosen by German authorities as the reference vitrification process in their licensing applications for the WAK vitrification facility and the new fuel cycle center.

- FIPS Process (KFA, Jülich) for thorium-containing HTGR wastes: FIPS uses a drum dryer and rising-level in-pot melting to produce a borosilicate glass. The process has been tested cold and in a hot-cell facility (1 kg/hr glass). A pilot plant (10 kg/hr glass) is planned.
- PAMELA Process (Gelsenberg A. G., Jülich and Mol, and EUROCHEMIC, Mol): PAMELA involves phosphate glass production in a ceramic melter, drainage of the glass through a bead maker, and incorporation of the beads in a metallic (lead alloy) matrix. The vitrification and bead-making operations (Figure 3) were developed by Gelsenberg in KFA facilities at Jülich. The technology for making the glass-metal matrix was developed by Eurochemic. The process has been tested cold and with Eurochemic HLLW.

FIGURE 3. Simplified Flowsheet of the PAMELA Process⁽²⁾

Gelsenberg, with Federal government support, now plans to construct a small PAMELA pilot plant in Eurochemic space at Mol. Startup of the 30-40 t/hr HLLW pilot plant is scheduled for 1982-1983. Other projects in progress include:

- a thermite process to produce a ceramic (KfK),
- formation of glass-ceramics by devitrification (KfK and HMI), and

- fixation in concrete (KfK).

Studies of high-level waste form properties are conducted at KfK, KFA, and HMI.

TRU Waste Treatment, R&D

KfK:

- partitioning of TRU wastes
- characterization of waste glasses containing alpha-emitters
- design of a TRU-waste incinerator.

Waste Isolation

FRG is well advanced in developing a salt-mine geologic repository for radioactive wastes, with the following activities:

- operation of the Asse salt mine as a repository for non-high-level wastes
- evaluation of salt mine storage of solidified high-level wastes and spent fuel elements from the AVR pebble-bed reactor
- evaluation of the Konrad iron mine for waste isolation
- planning for the installation of a waste isolation facility in the salt beds below the proposed national waste management center at Gorleben
- safety assessment.

Non-High-Level Waste Treatment, R&D

KfK Karlsruhe: development of waste forms that can be pumped into a salt cavern and allowed to solidify in place.

Cladding Hulls, R&D

KfK:

- properties of hulls (e.g., heat generation, tritium release)
- immobilization of hulls in concrete.

Solid Wastes, R&D

KfK: wet oxidation and mechanical compaction studies.

Volatile Radionuclides, R&D

KfK:

- iodine and tritium control in a separations plant
- recovery and separation of Kr and Xe (cold pilot plant, 50 m³/hr capacity, for ⁸⁵Kr recovery)
- ⁸⁵Kr storage in a metal matrix.

KFA:

- AKUT process for I₂, Kr, Xe removal from plant off-gas
- separation of ⁸⁵Kr by fractional distillation (KRYOSEP facility for ⁸⁵Kr removal from JUPITER pilot reprocessing plant).

INDIA

Nuclear Power

Committed: 0.4 GWe (LWR); 1.3 GWe (PHWR); LMFBR prototype

Projected: 6 GWe by 1990; 20 GWe by 2000 including 5-7 GWe in FBRs

R&D: LMFBR; thorium fuel cycle.

Fuel Cycle

National objectives are to

- develop nuclear fuel cycle self-sufficiency, with full capacity to meet the country's needs for heavy water, fuel reprocessing and waste immobilization
- develop a ²³³U-Th nuclear power system.

The high population density and limited transport facilities of India have led to a national policy of setting up small-capacity fuel reprocessing/waste solidification/interim waste storage complexes at several locations, rather than to establish a centralized, large-capacity plant.

Fuel Reprocessing

Two plants are operable:

- The Trombay pilot plant, 60 tonne/yr, is designed to handle either metal or mixed oxide fuels.
- The Tarapur plant is designed to handle 100 tonne/yr of oxide fuels
- A third plant at Kalpakkam is planned. It is to be designed for CANDU and thorium FBR fuels from the Madras power station.

HLLW Solidification

A waste immobilization plant is under construction at Tarapur, scheduled for startup in 1979-1980. It is based on a semicontinuous pot process developed at Trombay. The HLLW feed is preconcentrated, then calcined in the calciner-melter pot. When the pot is 75% full of calcine, the waste is melted and drained into a waste canister.

TRU Waste Treatment, R&D

BARC, Trombay:

- partitioning of TRU wastes
- conversion of TRU wastes into insoluble alumino-silicates by a hydro-thermal process.

Waste Isolation

India has started a geologic waste isolation program, with a survey of potential sites and characterization of preferred formations. Igneous rock and sedimentary deposits appear to hold the most promise.

Non-High-Level Wastes, R&D

BARC, Trombay:

- chemical decontamination processes for low-level wastes
- bituminization.

Cladding Hulls

Tarapur is developing techniques for interim storage of Zircaloy cladding hulls in cylindrical tile holes in the ground.

IRANNuclear Power

Committed: 4 GWe (LWR)

Projected: 22 GWe by 1992; 34 GWe by the year 2000

Note: Iran depends on UK for technical assistance and R&D.

Fuel Cycle

Iran has a share of the proposed multinational Eurodif and Coredif gaseous diffusion plants and plans to develop complete fuel cycle capability.

Waste Management

UKAEA has been employed by Iran to evaluate the problems associated with the storage and management of spent fuel and radioactive waste from Iran's nuclear power plants. Options considered for spent fuel handling will include extended pool storage after recanning, reprocessing either in Iran or abroad, and vitrification and geologic isolation of high-level wastes. Second-stage spent fuel facilities are required by 1984, when it will be necessary to remove fuel elements from the storage pond at Bushehr.

In response to an Iranian invitation, Austria and Iran are negotiating on a proposal to store Austria's nuclear wastes in the Iranian desert.

ITALYNuclear Power

Committed: 5 GWe (LWR); 0.2 GWe (other)

Projected: 9 GWe by 1990; 11 GWe by the year 2000

R&D: Italy is participating in LMFBR demonstration plants in France and West Germany.

Fuel Cycle

Italy hopes to become independent of other countries for nuclear fuel supplies by developing a strong breeder reactor industry. Activities include enrichment (participation in Eurodif), fabrication (U and recycled U-Th-Pu fuels), and reprocessing.

Fuel Reprocessing

Italy has two operational reprocessing pilot plants:

- The EUREX plant at Saluggia in northern Italy is designed to reprocess 30 kg/day of MTR fuels. It has been modified to handle oxide fuels.
- The ITREC pilot plant at the Trisaia Center near Rotondello in Southern Italy is designed for ^{233}U -Th and U-Pu fuels with a 15 kg/day capacity.

A new 1200 tonne/yr reprocessing plant is planned as part of a spent fuel storage, reprocessing and waste treatment center. Startup is scheduled for the late 1990s.

HLLW Solidification

ESTER, developed at CSN-Casaccia, is a multistage pot calcination vitrification process that may produce either a phosphate or a borosilicate glass. It has been tested in hot-cell runs at Ispra. The French Marcoule vitrification process is under consideration for installation at the proposed reprocessing and waste treatment center.

TRU Waste Treatment, R&D

CSN-Casaccia:

- actinide partitioning
- transmutation for TRU disposal.

AGIP Nucleare:

- combination of TRU wastes in molten salts.

Waste Isolation

Italy is studying geologic waste isolation. Present plans are to evaluate plastic argillaceous sediments in the Trisaia area as possible sites, with coring studies, in situ tests, engineering work, and safety analysis. A pilot plant repository is planned, to be operating by the mid-1980s.

Non-HLLW Treatment, R&D

CSN-Casaccia: use of polymer-impregnated cement for nuclear wastes.

Solid Wastes, R&D

AGIP Nucleare: combustion of solid wastes in molten salts.

JAPANNuclear Power

Committed: 18 GWe (LWR); 0.3 GWe (LMFBR); 0.3 GWe (other)

Projected: 40 GWe by 1985; 90 GWe by 1990

R&D: FBR technology; fusion

Fuel Cycle

Japan is endeavoring to become independent of other nations in the nuclear fuel cycle field. The Japanese program is directed toward these objectives:

- direct participation in overseas uranium mining projects
- development of plutonium recycle to conserve uranium
- development of uranium enrichment capability (A gas centrifuge pilot plant is planned. In the interim, Japan will buy enriched uranium from outside suppliers.)
- operation of the Tokai fuel reprocessing plant (210 tonne/yr) and construction of one or two 1500 tonne/yr reprocessing plants, the first in the late 1980s. (Japan will rely on reprocessing by English and French plants until their own plants can handle the load.)

Japan relies on private industry for fabrication of LWR uranium fuels and on PNC for development and fabrication of plutonium fuels.

HLLW Solidification, R&D

PNC: fluidized bed calcination of high-sodium HLLW, calcine converted to glass or ceramic

JAERI-Tokai: rotary kiln calcination and vitrification of waste-loaded zeolite ion exchangers

Government Research Institute, Osaka: sintering or hot-pressing (with Pyrex glass and Cu powder additives) of calcined wastes; devitrification of waste glasses; waste solidification facility to be built for startup in 1981; a demonstration waste solidification facility for PNC wastes to start up in 1986.

TRU Waste Treatment, R&D

JAERI-Tokai: evaluate TRU partitioning scheme.

PNC: test incinerator for TRU-contaminated combustible solids.

Waste Isolation

The Science and Technology Agency is sponsoring an extensive program to develop geologic disposal sites in Japan for high-level wastes. JAERI is to conduct the safety studies. Under subcontract with JAERI, Mitsubishi Metals

Corporation is making a survey of Japan for potential sites. Its preliminary report, issued in 1977, identifies geological bodies of granite and zeolite rock as attractive possibilities, and suggests further consideration of limestone, diatomite and shale formations. Preliminary concepts of geological disposal systems have also been developed.

Various agencies are involved in studies of deep-sea disposal of low-level wastes. These studies include tests of the mechanical behavior of packages under hydrostatic pressures, and leaching.

Non-High-Level Waste Treatment, R&D

JAERI:

- installation of a batchwise bituminization unit at OARAI
- use of polyethylene to immobilize spent ion exchange resins
- use of plastic-impregnated concrete containers for waste disposal.

Volatile Radionuclides

Under PNC sponsorship, several groups are studying the recovery and storage of ^{85}Kr , with emphasis on cryogenic distillation, selective membranes for krypton recovery from cover gases, cryogenic absorption-desorption, and thermal diffusion for krypton-argon separation.

SPAIN

Nuclear Power

Committed: 16 GWe (LWR); 0.5 GWe (GCR) by 1987

Projected: Plans beyond 1987 are uncertain.

Fuel Cycle

Spain is working for extensive fuel cycle capability:

- Uranium Enrichment: Spain has partnership in EURODIFF.
- Fuel Fabrication: Plans to develop MOX fuel fabrication capability are reported.
- Fuel Reprocessing: Between 1967 and 1971, Spain operated a small pilot plant in Madrid to reprocess spent MTR fuels. A new laboratory-scale reprocessing facility (2000 kg/yr) is being designed.

HLLW Solidification

Laboratory-scale studies of several techniques to solidify wastes from MTR fuel reprocessing (denitration, calcination, sintering, and vitrification) have been conducted at the Juan Vigon Nuclear Energy Centre, Madrid.

Waste Isolation

Spain is presently disposing of low- and intermediate-level wastes in abandoned uranium mines located in the Sierra Morena. The country is also

being surveyed for other potential sites. Promising formations include crystalline rocks, shales, rock salt, tertiary clays and gypsum. A pilot plant repository, to start up in the late 1980s, is planned.

Non-High-Level Waste Treatment, R&D

- volume reduction and chemical decontamination of non-high-level wastes
- incorporation of solids in cement.

SWEDEN

Nuclear Power

Committed: 9.4 GWe (LWR) by 1985

Projected: The Swedish utilities have planned on major nuclear power increases, but the present political climate in Sweden is such that no projections can be made.

Fuel Cycle

The Swedish Government Committee on Radioactive Waste (AKA Committee) recommended in 1976 that Sweden develop reprocessing and waste management capability. Subsequently, a law was passed requiring that safe disposal of nuclear wastes be assured before any new reactors be loaded with fuel and commence operation. In response, the Swedish utilities have sponsored a crash effort to develop a plan for geologic disposal of either spent fuel elements or solidified high-level waste, and have contracted with COGEMA (France) for reprocessing of Swedish spent fuel at La Hague.

HLLW Solidification

Swedish technical groups are conducting the following R&D programs:

- ASEA-Atom is developing hot isostatic pressing techniques for encapsulating spent fuels, preparing high-density waste ceramics from mixtures of waste calcine with materials such as Al_2O_3 , and converting fission-product-loaded, inorganic-ion-exchange resins into dense ceramic bodies.
- The Royal Institute of Technology in Stockholm is working on absorption of fission products from HLLW onto titanate ion exchange resins, which can then be converted to dense ceramic bodies.

TRU Wastes, R&D

Chalmers University: TRU partitioning.

Waste Isolation

The Swedish Nuclear Fuel Safety Project (KBS), established in early 1977 by four nuclear power utilities, has issued the draft of a report recommending the following HLLW management scheme:

- interim storage of spent fuels in a central storage facility
- reprocessing at La Hague in France and return of vitrified wastes to Sweden
- thirty-year storage in air, in an underground rock formation
- application of a lead plus titanium overpack and emplacement in granite formations 500 m underground.

Research and development is under way in the following areas:

- design of underground spent-fuel storage pools
- preparation to commission a pilot waste repository
- supporting studies (field tests in the Stripa mine, design and testing of equipment, ground water movement measurements, and safety assessment).

SWITZERLAND

Nuclear Power

Committed: 5.8 GWe (LWR) by 1982

Projected: another 3 GWe

Fuel Cycle

Switzerland currently depends on other countries for fuel cycle services and has a contract with COGEMA for reprocessing through 1989. For the future, the utilities plan to build central facilities for interim spent fuel storage and hope to participate with other countries in the construction of new reprocessing plants and related receiving ponds.

Waste Disposal, R&D

EIR, Würenlingen: Evaluation of geologic disposal in rock formations in the Swiss Alps and in anhydrite formations elsewhere.

UNITED KINGDOM

Nuclear Power

Committed: 11 GWe (mainly GCR; 250 MWe LMFBR)

Projected: Up to 100 GWe (total) by the year 2000; 33 GWe (LMFBR) by 2010

R&D: LMFBR, with emphasis on complete FBR fuel cycle.

Fuel Cycle

The United Kingdom has extensive nuclear fuel cycle capability and programs.

- Uranium Enrichment: UK operates gaseous diffusion plants at Capenhurst and has partnership in URENCO, with a gas centrifuge plant at Capenhurst.

- Fuel Fabrication: Extensive plutonium fuel fabrication R&D is conducted at Windscale, and work on MOX fuel recycle for FBRs is conducted at Dounreay.
- Fuel Reprocessing: BNFL operates a 1500-2500 tonne/yr reprocessing plant at Windscale, designed for Magnox-clad uranium metal fuels. The Windscale plant has been equipped with an oxide fuel headend rated at 400 tonne/yr. BNFL also plans to build a 1200 tonne/yr plant (THORP) for commercial LWR fuels and intends to offer reprocessing service to other nations.

The Dounreay site has a 10 tonne/yr reprocessing pilot plant which was recently decontaminated and equipped to handle MOX spent fuel from the prototype LMFBR at Dounreay, the PFR.

HLLW Solidification

The UK has concentrated on developing the FINGAL/HARVEST process, which produces a borosilicate waste glass by the rising-level process (Figure 4). HLLW and glass formers are slowly added to a pot maintained at about 1050°C. Evaporation, calcination and vitrification occur simultaneously. Studies have been conducted at Harwell in:

- the FINGAL pilot plant, which was shut down in 1966 after process demonstration with actual HLLW from Windscale
- the Harwell nonradioactive, full-scale pilot plant which started operation in 1975; in runs through 1976, the glass batch size was maintained at 240 kg.

FIGURE 4. Simplified Flowsheet of FINGAL Process⁽⁴⁾

These major facilities are planned for Windscale:

- an active pilot plant at Windscale for making Kg-scale glass blocks from Windscale HLLW (capacity = 1 t/hr HLLW; startup in 1979)

- a hot cell facility for glass examination (startup in 1978)
- a full-scale prototype of the first production-scale demonstration plant, for nonradioactive testing (startup in 1980)
- an industrial-scale demonstration plant (startup in 1986; full-level operation with Windscale wastes in 1988); this plant is to use cylindrical vessels up to 61 cm in diameter by 2.74 m high which will contain 1.26 tonne of glass
- a full-scale production plant (startup in 1990).

With national emphasis on developing technology for the complete LMFBR fuel cycle, the UKAEA has started a project to build a waste vitrification plant at Dounreay. Criteria for the plant are that it have a 30 t/hr feed capacity and be operational by the late 1980s. UKAEA and BNFL personnel are evaluating a number of vitrification processes for this application.

TRU Waste Handling, R&D

Harwell:

- properties of vitrified TRU wastes
- transmutation of actinides.

Waste Isolation

The Institute of Geological Sciences (IGS) has recently completed a desk survey of the UK to identify where rock formations occur that might meet the criteria for geologic disposal. In the UK it seems likely that there are two options: clay formations and crystalline rocks. This study is to be followed by a 5-yr program aimed at identifying areas for more detailed geological study (structural, hydrogeological, seismic, etc.) so that sites can be selected for trial boreholes. Supporting studies of the effect of heat on selected rock formations, compatibility of containers and rocks, development of any new borehole logging technique needed, and methods for measuring the "age" of groundwater would be included.

Non-High-Level Wastes, R&D

Harwell: cleanup and disposal of used solvent.

Cladding Hulls

AERE/Harwell: properties, compaction and encapsulation of stainless steel and Zircaloy cladding hulls.

Solid Waste Treatment

AERE/Harwell:

- low-temperature pyrolysis
- acid-digestion

DERE/Dounreay: Pyrolytic distillation of polythene and other plastics from solid wastes

BNFL/Windscale: Incineration of alpha waste and treatment of the ash.
Volatile Radionuclides, R&D

AERE/Harwell:

- tritium separation from non-HLLW
- incorporation of krypton in a metal matrix.

USSR

Nuclear Power

Committed: 21 GWe (mainly LWR and LWGR)
 Additional Planned: 14 GWe
 R&D: LMFBR

Fuel Cycle

The Soviet Union does not have a commercial-scale spent fuel reprocessing plant on line (May 1977), but is reportedly building one with a 5 tonne/day capacity to be operational by about 1980. A vitrification plant, to be located with the reprocessing plant, is also projected. A small experimental (several kg/day) reprocessing facility is operational at the Klopov Radium Institute.

HLLW Solidification

The Soviet Union has reported on development of three waste solidification processes.

- Single-stage Phosphate Glass Process: Evaporation, calcination and vitrification are carried out in a refractory-lined metal box divided vertically into two zones (Figure 5). The waste (up to 100 t/hr) and glass formers are added to the top of the larger zone; the molten glass is poured into a 200-l container from the smaller zone. The nonradioactive unit has been operated for about 3 yr and has produced over 300 tonnes of glass.
- Two-stage Fluidized Bed Phosphate Glass Process: This process uses a fluidized bed calciner (1.4 m in diameter by 4.6 m high) which feeds to an induction-heated concrete refractory melter-canister. Capacity: 20 kg glass/hr; the containers hold 160-180 kg glass.
- Chemo-thermal Process: In this technique waste calcine is reacted with appropriate chemicals in an exothermic process which produces basalt-like materials.

Waste Isolation

Although studies of geologic isolation for HLW have been made, the Russians seem to be emphasizing surface storage for solidified HLW. Guiding principles are that the repository should adjoin the vitrification building, be above the

FIGURE 5. Simplified Flowsheet and an Illustration of Electric Furnace for Russian Single-Stage Process(3)

water table, and be converted section by section to a "tomb" as the waste ages and heat generation decreases. Non-high-level wastes have been pumped through boreholes into quartz, sandstone and clay strata at a depth of 1400-1500 m at a site near Dimitrovgrad.

INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA)

A major IAEA program is in the field of nuclear safety and environmental protection. Its purpose is to ensure the safe operation of nuclear installations and the protection of man and his environment from the harmful effects of nuclear radiation and radioactive or nonradioactive releases from nuclear installations.

In the waste management area, the IAEA provides a multinational focus for investigation and development in problem areas which ultimately may be handled satisfactorily only through international solutions.

The IAEA's waste management activities include:

- development of mutually agreed-upon safety standards and criteria for the management and disposal of radioactive waste arising from all stages of the nuclear fuel cycle
- promotion of information exchanges in the radioactive waste management area via international conferences and symposia, technical committees and advisory groups for selected areas of technology, and specialized training courses and seminars
- coordination of research programs in specific technical areas

- issuance of publications in the field of waste management including the annual "Waste Management Research Abstracts."

Limited IAEA funds (generally \$150,000-\$200,000 annually) are provided for research and development in selected areas of radioactive waste management and environmental assessment, usually for coordinated research programs involving participation by member states.

COMMISSION OF THE EUROPEAN COMMUNITIES (CEC)

CEC sponsors and funds nuclear R&D at the research establishments of the CEC (formerly Euratom) Joint Research Centre and in the laboratories of the Member States. Funds for the national laboratories of the Member States are generally provided on a matching basis. In 1975, CEC budgeted \$26M for a 5-yr radioactive waste management program, with about \$16M devoted to geologic disposal. Sponsored activities reported in the First Annual Report, for CY-1976, are listed in Table 7.

A summary for JRC-Ispra is provided below.

Member States of CEC are:

Belgium	Italy
Denmark	Luxembourg
France	The Netherlands
West Germany (FRG)	United Kingdom
Ireland	

CEC: Joint Research Centre (Ispra)

HLLW Solidification

Ispra conducted hot-cell tests of the Italian ESTER waste vitrification process.

TRU Waste Treatment, R&D

- TRU partitioning
- long-term stability of bituminized alpha wastes.

Waste Isolation

The Ispra laboratory is participating in CEC studies of geologic waste isolation. Activities are directed toward the evaluation of long-term hazards of waste disposal and include:

- hazard analysis
- studies of long-term stability of conditioned wastes
- measurements of the interactions of actinides with the environment
- development of instruments to monitor the actinide content of solid wastes.

TABLE 7. Commission of the European Communities (CEC)

Activity	Objective/Scope	Program Duration	Assigned Country
1. Treatment of Low- and Medium-Level Waste			
1.1 Mobile pilot plants for resin imbedding of reactor waste	Develop and operate a mobile pilot plant to immobilize non-high-level reactor plant wastes.	-12/79	FRG (STEAG)
1.2 Stationary resin imbedding with the CEA technique	CEC participation in polyester resin imbedding plant at Chooz.	1977-	France (CEA)
2. Decontamination and Decommissioning of Irradiated Fuel Element Cladding			
2.1 Incorporation in low-melting alloys	Develop a method to press-compact cladding hulls and imbed them in an alloy.	11/76-12/79	Belgium (SCK/CEN)
2.2 Incorporation in concrete	Develop a process and build a pilot plant for compacting hulls (by rolling) and incorporating in concrete.	11/76-12/79	FRG
2.3 Decontamination and conditioning in glass	Develop a process and design a plant for incorporating fuel hulls in a glass matrix.	3/77-4/79	France (CEA)
2.4 Characteristics of the radioactivity in different cladding wastes	Identify the nature, location and activity levels of the radioactive components in typical irradiated fuel claddings.	11/76-12/79	UK (UKAEA)
3. Incineration of Plutonium-Contaminated Wastes			
3.1 High temperature incineration	Develop incineration techniques for Pu-contaminated wastes; build and operate small pilot plant (10 kg/hr); adapt FLK 60 plant to Pu use and operate it.		Belgium (SCK/CEN)
3.2 Acid digestion process	Develop, test and optimize a pilot plant for wet oxidation of Pu-contaminated solid wastes.		FRG (NUKEM)
3.3 Incineration in molten salts	Develop a molten salt process for destroying combustibles and dissolving Pu compounds. Build and operate a bench-scale test rig.		Italy (AGIP Nucleare)
4. Properties of Substances Suitable for Immobilizing High-Level Waste	Establish a joint basis for evaluating high-level waste forms by characterization of similar samples of five different types of solidified waste in each country's laboratories.	10/76-12/79	UK (UKAEA) FRG (HMI) France (CEA)
5. Engineered Storage for Solidified High-Level Waste	Evaluate three storage concepts: water-cooled pond, air-cooled storage, mixed system; water-cooled storage initially, then transfer to air-cooled storage.		Belgium (Belgonucléaire) FRG (NUKEM) Italy (AGIP Nucleare)
6. Long Term Storage and Disposal of Solidified High-Level and/or Alpha-Active Waste in Geological Formations			
6.1 Catalog of geological formations suitable for the disposal of radioactive waste	Provide catalog of potential waste isolation sites.	1977-	Belgium Denmark France FRG Italy Ireland Netherlands UK
6.2 Storage in salt dome	Develop and evaluate technology for storage of HLLW glass blocks in salt cavern. Prepare for storage tests at Asse.	-1984	FRG (Karlsruhe)
6.3 Storage in crystalline formations I	Select a site in France; study radionuclide migration and geochemical barriers.	1976-77	France (CEA)
6.4 Storage in crystalline formations II	Identify potential sites; study waste form-host rock compatibility; define engineering requirements for a demonstration; evaluate ground water problems.		UK (UKAEA)
6.5 Storage in clay formations	Place in service an experimental underground cavity in a clay formation at Mol.		Belgium (SCK/CEN)
7. Storage of Gaseous Wastes	Review Member States' programs for storing radioactive krypton, tritium and iodine.		
8. Separation and Transmutation of Actinides	Develop a program for possible CEC funding 1976-1977 to 2000.		UKAEA ECN

OECD NUCLEAR ENERGY AGENCY (NEA)

The NEA is a specialized agency of the OECD, set up to promote international cooperation among the OECD countries for the development and application of nuclear power for peaceful purposes through international research and development projects and exchange of scientific and technical experience and information.

In 1975, at the request of the OECD, and building upon previous efforts of the IEA Working Group on Radioactive Waste Management, the NEA established a Radioactive Waste Management Committee (RWMC). Its purpose is to initiate, encourage and coordinate cooperative R&D activities in the field of radioactive waste management, particularly within NEA member states. RWMC has held a series of meetings and established a number of permanent and ad hoc committees and study groups to deal with specific technical areas.

Current NEA waste management activities are focused on the definition of cooperative programs to develop geologic waste isolation technology.

Member States are:

Australia	Iceland	Portugal
Austria	Ireland	Spain
Belgium	Italy	Sweden
Canada	Japan	Switzerland
Denmark	Luxembourg	Turkey
Finland	The Netherlands	United Kingdom
France	New Zealand*	United States
Germany, Federal Republic of	Norway	Yugoslavia*
Greece		

* Special Status

Eurochemic

Fuel Reprocessing

The Eurochemic Company, sponsored by a number of OECD/NEA countries,* operated the 60 tonne/yr Eurochemic fuel reprocessing plant at Mol from 1968-1974, and is presently negotiating with Belgium for turnover of the plant to a Belgian company for modernization and future operation. Decontamination of the plant by Eurochemic is nearly complete.

* Member States: Austria, Belgium, Denmark, France, FRG, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey.

HLLW Solidification

Eurochemic's spent fuel reprocessing operations produced 873 m³ of high-level liquid waste, which is stored in acid form. There are two types of HLLW: 67 m³ of Low Enriched Waste Concentrate (LEWC), which are typical Purex wastes from reprocessing LWR fuels; and 806 m³ of High Enriched Waste Concentrate (HEWC), high-aluminum wastes from reprocessing MTR fuels. Eurochemic is obligated to convert these wastes to solid forms suitable for interim storage.

To assure that waste solidification technology would be available, Eurochemic has worked on two processes:

- LOTES: This process solidifies waste at low temperatures in a stirred-bed calciner. The phosphate granules produced can be consolidated by melting or can be incorporated in a metal matrix. As of January 1978 process tests were under way in a new, all-steel test unit rated at 10 t/hr feed rate.
- A Technique for Embedding Waste Particles or Glass Beads in a Low-Melting Alloy: This technique has been demonstrated with LOTES product and with glass beads produced by the German PAMELA process (see the FRG summary, p. 22).

In December 1977 the Eurochemic Board decided to use the French AVM (Marcoule) vitrification process (see the Summary for France, p. 19) for solidification of the Eurochemic HLLW. The Board also agreed to permit West Germany to build a pilot-scale PAMELA facility on Eurochemic property, and to make available some Eurochemic HLLW for demonstration purposes.

Current plans are to transfer the Eurochemic waste handling facilities to Belgium after the Eurochemic waste is solidified--probably by June 1982.

Non-High-Level Waste Treatment

- Bituminization: Eurochemic has recently placed in service a continuous, screw extruder-evaporator, "EUROBITUM," for bituminizing decladding and other intermediate-level wastes. Eurobitum capacity is 650 m³/yr.
- Spent Solvent Treatment: Eurochemic is constructing the "Eurowatt" solvent treatment plant (1 m³/day) for conversion of used Purex solvent to forms suitable for disposal.

Cladding Hulls

Eurochemic has developed a process for encapsulating fuel end pieces in a SiO₂-plastic matrix, underwater.

Solid Wastes, R&D

R&D includes studies of acid digestion, pyrolysis and molten-salt combustion for combustible alpha wastes.

COUNCIL FOR MUTUAL ECONOMIC ASSISTANCE (CMEA)

CMEA is the counterpart of OECD for the countries with centrally controlled economies. The organization has a standing commission concerned with the use of atomic energy for peaceful purposes that holds periodic conferences and meetings of national specialists on radioactive waste management technology.

In 1971, CMEA set up a coordinating scientific and technical council concerned with radioactive waste management. The council meets semiannually and has given high priority to the development of safe disposal methods for radioactive wastes.

Member states are:

Bulgaria	Mongolia
Cuba	Poland
Czechoslovakia	Rumania
East Germany	USSR
Hungary	Yugoslavia*

* Special Status

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