PNC TJ9284 88-002

動力炉・核燃料開発事業団殿

欧州における炉建設費及び燃料サイクル費の調査
最終報告書

昭和63年12月

日本エヌ・ユー・エス株式会社

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1	VDEW (西独)	・DM 130/kg U (U_3O_8)	・西独電力会社は、Puを"Free" materialと考えている。	・DM 197-200/kg SWU	・DM 9-13/kg U(F_6) (U_3O_8 →UF_6)	・DM 550-650/kg U		∘Framatome 1300MWe PWR ・全建設費；8.444 billion FF (FF 6500/KWe)		・DM 2000/kg U (装荷燃料)		
				・DM 320/kg SWU	・DM 100/kg U(UF_6)	・DM 700/kg U						
2	KFK−PAE (西独)	・US$ 30/ℓb U_3O_8		・US$ 125/kg SWU	・US$ 6.3/kg U(UF_6) (U_3O_8 →UF_6)	・DM 530/kg U(燃料)	N.U. DM6/kg U		・DM 41/kg HM (西独内プラントから Wackersdorf まで)	・DM 1683/kg U (1990年代の 700t/a プラントを想定)	・調整；DM 554/kg HM ・輸送；DM 66.3/kg HM ・処分；DM 449/kg HM	・再処理サイクル(PWR) FF 0.0462/KWh
				・US$ 129/kg SWU	・US$ 40/kg U(UF_6)	・DM 600/kg U	R.U. DM6/kg				・輸送処分；DM 488/kg HM	・ワンスルーサイクル(PWR) FF0.0458/KWh
3	Cogema (仏)	・FF 468/kg U (U_3O_8)	・FF 100-130/g・Pu (Puf：71%)	・FF 800/kg SWU (US$ 133/kg SWU)	・FF 36/kg U(UF_6) (U_3O_8→UF_6)	・FF 1600/kg U(US$ 267/kg U)		∘Siemens/KWU 1000MWe PWR ・全建設費；1584.4 million DM (DM 1590/KWe)	・FF 250/kg HM (US$ 42kg HM) (仏内プラントから La Hague まで)	・FF 6000/kg HM (US$ 1000/kg HM) (3年間の中間貯蔵のコストを含む)	・40年間中間貯蔵；FF 1100/kg HM ・調整；FF 1100/kg HM ・輸送処分；FF 1500/kg HM	
				・FF 800/kg SWU (US$ 133/kg SWU)	・FF 245/kg U(UF_6) (UNH→UF_6)	・FF 1920/kg U(US$ 320/kg U)					・輸送処分；FF 1500/kg HM	
4	Baumier (CEA、仏)	・FF 650/kg U	・FF 150/g・Pu	・FF 1015/kg SWU	・US$ 5/kg U(UF_6) (U_3O_8 →UF_6)	・FF 1600/kg U	・一般的に1000kmまでの新燃料輸送費は、US$ 1-3/kg U と言われている。		・欧州内での使用済燃料輸送費は一般的にUS$ 40-60/kg HM と言われている。	・FF 6350/kg HM		
5	Schmiedel and Winnik (Siemens、西独)	・US$ 17-30/ℓb U_3O_8		・DM 270/kg SWU		・DM 530/kg U		∘Sizewell B (英) ・全投資額；1.64 billion £				
6	Bairiot and Lebastard (COMMOX、仏)	・US$ 26/ℓb U_3O_8	・FF 88/g・Pu	・FF 800/kg SWU		・FF 1600/kg U				・FF 5400/kg HM (廃棄物調整コストを含む)		
7	Bairiot and Lebastard (COMMOX、仏)	・US$ 510/kg 成形加工燃料 (3.4%濃縮を仮定)	・US$ 2/g・Puf (35t/y の成形加工工場) ・US$ 10/g・Puf (100t/y の成形加工工場)					∘Hinkley C (英) ・全投資額；1.47 billion £ (予想)				
8	C.F.Forsey and J.A.B.Gresley (BNFL/Urenco, 英)		・英国では、Puを"free" materialと考えている。			・N.U.の成形加工の20% 高						・天然ウラン燃料(PWR) US$ 1500/kg U (燃料)
				N.U.の濃縮費より5%高 (US$ 105/kg SWU)	・N.U.の転換費の3倍 (US$ 21/kg U(UF_6))							・回収ウラン燃料(PWR) US$ 1000/kg U (燃料)
9	N.R. Geary (コンサルタント、英)	・US$ 50/kg U (U_3O_8)		・US$ 100/kg SWU U	・US$ 7/kg U(UF_6) (U_3O_8 →UF_6)					・US$ 850/kg HM		・2000年建設 PWR 0.47 P/KWh
												・2020年建設 PWR 0.43 P/KWh
10	H.N.Patak (CH、西独)	・US$ 25/ℓb U_3O_8		・US$ 100/kg SWU	・US$ 3.5/ℓb U (US$ 7/kg U)	・US$ 220/kg U						
					・US$ 5.25/ℓb U (US$ 11/kg U) (US$ 11/kg U)							
11	OECD/NEA	・US$ 32/ℓb U_3O_8		・US$ 130/kg SWU	・US$ 6/kg U(UF_6)	・US$ 190/kg U			・US$ 40/kg HM (欧州内)	・US$ 750/kg HM (但し、再処理費500$ ガラス固化費250$との和)	・調整；US$ 200/kg HM ・処分；US$ 150/kg HM	・再処理サイクル(PWR) US Mill 8.56/KWh
											・処分；US$ 150/kg HM	・ワンスルーサイクル(PWR) US Mill 7.78/KWh
	2000年推定	・US$ 40-45/ℓb U_3O_8	・将来のFBR,プルサーマル等の導入形態による。	・濃縮単価は年々下がりつつある。2000年頃は LISが主となり、仏では LISの単価の目標を現在の1/2 としている。	・現在の施設の容量で2000年までの増加分を処理できると考えられる。	・成形加工単価は将来もほとんど変わらないと考えられる。				・施設運開から10年間は、高い比率（60〜70%)で施設の投資コストが含まれているので、10年以降（2000年頃）は、単価が30〜40% 低くなると考えられる。		

表 2　炉型：プルサーマル（UO_2，MOX燃料）

出典	工程／機関名	天然ウラン価格	プルトニウム価格	濃縮費（N.U.／R.U.）	転換費（N.U.／R.U.）	成形加工費（N.U.／R.U.／MOX）	新燃料輸送費	原子炉建設費	使用済燃料輸送費	再処理費	廃棄物処理（ワンスルーサイクル／再処理サイクル）	燃料サイクル費
1	VDEW（西独）	• DM 130/kg U (U_3O_8)	• 西独電力会社は、Puを "Free" materialと考えている。	• DM 197-200/kg SWU • DM 320/kg SWU	• DM 9-13/kg U(F₆) (U_3O_8 →UF_6) • DM 100/kg U(UF_6)	• DM 550-650/kg U • DM 700/kg U		• Framatome 1300MWe PWR • 全建設費；8.444 billion FF (FF 6500/KWe)		• DM 2000/kg U （装荷燃料）		
2	KFK−PAE（西独）	• US$ 30/ℓb U_3O_8		• US$ 125/kg SWU • US$ 129/kg SWU	• US$ 6.3/kg U(UF_6) (U_3O_8 →UF_6) • US$ 40/kg U(UF_6)	• DM 530/kg U(燃料) • DM 600/kg U • DM 1315/kg HM (1990年代)	N.U. DM6/kg U R.U. DM6/kg MOX DM60/kg HM		• DM 41/kg HM （西独内プラントから Wackersdorf まで）	• DM 1683/kg U 1990年代の 700t/a プラントを想定	• 調　整；DM 554/kg HM • 輸　送；DM 66.3/kg HM • 処　分；DM 449/kg HM • 輸送処分；DM 488/kg HM	• 再処理サイクル(PWR) FF 0.0462/KWh • ワンスルーサイクル(PWR) FF0.0458/KWh
3	Cogema（仏）	• FF 468/kg U (U_3O_8)	• FF 100-130/g・Pu (Puf：71%)	• FF 800/kg SWU (US$ 133/kg SWU) • FF 800/kg SWU (US$ 133/kg SWU)	• FF 36/kg U(UF_6) (U_3O_8→UF_6) • FF 245/kg U(UF_6) (UNH→UF_6)	• FF 1600/kg U(US$ 267/kg U) • FF 1920/kg U(US$ 320/kg U) • FF 8000/kg HM		• Siemens/KWU 1000MWe PWR • 全建設費；1584.4 million DM (DM 1590/KWe)	• FF 250/kg HM (US$ 42kg HM) （仏内プラントから La Hague まで）	• FF 6000/kg HM (US$ 1000/kg HM) （3年間の中間貯蔵のコストを含む）	• 40年間 中間貯蔵；FF 1100/kg HM • 調　整；FF 1100/kg HM • 輸送処分；FF 1500/kg HM • 輸送処分；FF 1500/kg HM	
4	Baumier（CEA、仏）	• FF 650/kg U	• FF 150/g・Pu	• FF 1015/kg SWU	• US$ 5/kg U(UF_6) (U_3O_8 →UF_6)	• FF 1600/kg U • FF 5815/kg HM	• 一般的に1000km までの新燃料輸送費は、US$ 1-3/kg U と言われている。		• 欧州内での使用済燃料輸送費は一般的にUS$ 40-60/kg HM と言われている。	• FF 6350/kg HM		
5	Schmiedel and Winnik（Siemens、西独）	• US$ 17-30/ℓb U_3O_8		• DM 270/kg SWU		• DM 530/kg U • DM 2700-3200/kg HM *1 • DM 1500-1600/kg HM *2		• Sizewell B（英） • 全投資額；1.64 billion £				
6	Bairiot and Lebastard（COMMOX 、仏）	• US$ 26/ℓb U_3O_8	• FF 88/g・Pu	• FF 800/kg SWU		• FF 1600/kg U				• FF 5400/kg HM （廃棄物調整コストを含む）		
7	Bairiot and Lebastard（COMMOX 、仏）	• US$ 510/kg 成形加工燃料（3.4%濃縮を仮定）	• US$ 2/g・Puf（35t/y の成形加工工場） • US$ 10/g・Puf（100t/y の成形加工工場）					• Hinkley C（英） • 全投資額；1.47 billion £（予想）				
8	C.F.Forsey and J.A.B.Gresley（BNFL/Urenco，英）		• 英国では、Puを "free" materialと考えている。	N.U.の濃縮費より5%高 (US$ 105/kg SWU)	• N.U.の転換費の3倍 (US$ 21/kg U(UF_6))	• N.U.の成形加工の20% 高						
9	N.R. Geary（コンサルタント、英）	• US$ 50/kg U (U_3O_8)		• US$ 100/kg SWU	• US$ 7/kg U(UF_6) (U_3O_8 →UF_6)					• US$ 850/kg HM		
10	H.N.Patak（CH 、西独）	• US$ 25/ℓb U_3O_8		• US$ 100/kg SWU	• US$ 3.5/ℓb U (US$ 7/kg U) • US$ 5.25/ℓb U (US$ 11/kg U)	• US$ 220/kg U • US$ 1320/kg HM *1 • US$ 660/kg HM *3						
11	OECD/NEA	• US$ 32/ℓb U_3O_8		• US$ 130/kg SWU	• US$ 6/kg U(UF_6)	• US$ 190/kg U			• US$ 40/kg HM （欧州内）	• US$ 750/kg HM （但し、再処理費500$ ガラス固化費250$との和）	• 調　整；US$ 200/kg HM • 処　分；US$ 150/kg HM • 処　分；US$ 150/kg HM	
	2000年推定	• US$ 40-45/ℓb U_3O_8	• 将来のFBR,プルサーマル等の導入形態による。	• 濃縮単価は年々下がりつつある。2000年頃は LISが主となり、仏では LISの単価の目標を現在の1/2 としている。	• 現在の施設の容量で2000年までの増加分を処理できると考えられる。	• 成形加工単価は将来もほとんど変わらないと考えられる。しかし MOXについては、2000年頃には、施設が大規模となり、単価が 1/2程度になると考えられる。				• 施設運開から10年間は、高い比率（60〜70%）で施設の投資コストが含まれているので、10年以降（2000年頃）は、単価が30〜40% 低くなると考えられる。		

*1．既存の小規模施設　*2．将来の大規模施設（〜1996）
*3．将来の大規模施設

表 3　炉型：高転換軽水炉（全MOX）

出典	工程 / 機関名	天然ウラン価格	プルトニウム価格	転換費	成形加工費	新燃料輸送費	原子炉建設費	使用済燃料輸送費	再処理費	廃棄物処理（ワンスルーサイクル）	廃棄物処理（再処理サイクル）	燃料サイクル費
1	VDEW（西独）	・DM 130/kg U (U_3O_8)	・西独電力会社は、Puを"Free" materialと考えている。									
2	KFK−PAE（西独）	・US$ 30/ℓb U_3O_8			・DM 1315/kg HM 1990年代	DM60/kg HM		・DM 41/kg HM（西独内プラントから Wackersdorf まで）		・調整；DM 554/kg HM ・輸送；DM 66.3/kg HM ・処分；DM 449/kg HM	・輸送処分；DM 488/kg HM	
3	Cogema（仏）	・FF 468/kg U (U_3O_8)	・FF 100-130/g・Pu（Puf：71%）		・FF 8000/kg HM			・FF 250/kg HM（US$ 42kg HM）（仏内プラントから La Hague まで）	・FF 6000/kg HM（US$ 1000/kg HM）（3年間の中間貯蔵のコストを含む）	・40年間中間貯蔵；FF 1100/kg HM ・調整；FF 1100/kg HM ・輸送処分；FF 1500/kg HM	・輸送処分；FF 1500/kg HM	
4	Baumier（CEA、仏）	・FF 650/kg U	・FF 150/g・Pu		・FF 5815/kg HM	・一般的に1000kmまでの新燃料輸送費は、US$ 1-3/kg Uと言われている。		・欧州内での使用済燃料輸送費は一般的にUS$ 40-60/kg HMと言われている。	・FF 6350/kg HM			
5	Schmiedel and Winnik（Siemens、西独）	・US$ 17-30/ℓb U_3O_8			・DM 2700-3200/kg HM *1 ・DM 1500-1600/kg HM *2							
6	Bairiot and Lebastard（COMMOX、仏）	・US$ 26/ℓb U_3O_8	・FF 88/g・Pu						・FF 5400/kg HM（廃棄物調整コストを含む）			
7	Bairiot and Lebastard（COMMOX、仏）	・US$ 510/kg 成形加工燃料（3.4%濃縮を仮定）	・US$ 2/g・Puf（35t/y の成形加工工場） ・US$ 10/g・Puf（100t/y の成形加工工場）									
8	C.F.Forsey and J.A.B.Gresley（BNFL/Urenco、英）		・英国では、Puを"free" materialと考えている。									
9	N.R. Geary（コンサルタント、英）	・US$ 50/kg U (U_3O_8)							・US$ 850/kg HM			
10	H.N.Patak（CH、西独）	・US$ 25/ℓb U_3O_8			・US$ 1320/kg HM *3 ・US$ 660/kg HM *4							
11	OECD/NEA	・US$ 32/ℓb U_3O_8						・US$ 40/kg HM（欧州内）	・US$ 750/kg HM（但し、再処理費500$ ガラス固化費250$との和）	・調整；US$ 200/kg HM ・処分；US$ 150/kg HM	・処分；US$ 150/kg HM	
	2000年推定	・US$ 40-45/ℓb U_3O_8	・将来のFBR,プルサーマル等の導入形態による。	・現在の施設の容量で2000年までの増加分を処理できると考えられる。	・成形加工単価は将来もほとんど変わらないと考えられる。しかし MOXについては、2000年頃には、施設が大規模となり、単価が 1/2程度になると考えられる。				・施設運開から10年間は、高い比率（60～70%）で施設の投資コストが含まれているので、10年以降（2000年頃）は、単価が30～40% 低くなると考えられる。			

*1．既存の小規模施設　*2．将来の大規模施設（～1996）
*3．将来の大規模施設

表 4　炉型：FBR（MOX、ブランケット）

出典	工程 / 機関名	天然ウラン価格	プルトニウム価格	転換費	成形加工費（ブランケット / MOX）	新燃料輸送費	原子炉建設費	使用済燃料輸送費	再処理費	廃棄物処理（ワンスルーサイクル / 再処理サイクル）	燃料サイクル費
1	VDEW（西独）	• DM 130/kg U (U_3O_8)	∘ 西独電力会社は、Puを "Free" materialと考えている。		• DM 550-650/kg U		∘ Dounreay PFR（英） 全投資額： 300 Million ￡ （￡1200/KWe）				
2	KFK-PAE（西独）	• US$ 30/ℓb U_3O_8			• DM 530/kg U(燃料) • DM 1315/kg HM （1990年代）	ブランケット DM6/kg U MOX DM60/kg HM		• DM 41/kg HM （西独内プラントから Wackersdorf まで）		• 調　整；DM 554/kg HM • 輸　送；DM 66.3/kg HM • 処　分；DM 449/kg HM • 輸　送 処　分；DM 488/kg HM	
3	Cogema（仏）	• FF 468/kg U (U_3O_8)	• FF 100-130/g • Pu （Puf：71%）		• FF 1600/kg U(US$ 267/kg U) • FF 8000/kg HM		∘ Super Phenix（仏） 全投資額　16382 Billion FF （FF 13650/KWe）	• FF 250/kg HM （US$ 42kg HM） （仏内プラントから La Hague まで）		• 40年間 中間貯蔵；FF 1100/kg HM • 調　整；FF 1100/kg HM • 輸　送 処　分；FF 1500/kg HM • 輸　送 処　分；FF 1500/kg HM	
4	Baumier（CEA、仏）	• FF 650/kg U	• FF 150/g • Pu		• FF 1600/kg U • FF 5815/kg HM	∘ 一般的に1000kmまでの新燃料輸送費は、US$ 1-3/kg U と言われている。	∘ SNR-300 （西独） 全建設費　6.05 Billion-DM （DM 20000/KWe）	∘ 欧州内での使用済燃料輸送費は一般的にUS$ 40-60/kg HM と言われている。			
5	Schmiedel and Winnik（Siemens、西独）	• US$ 17-30/ℓb U_3O_8			• DM 530/kg U • DM 2700-3200/kg HM *1 • DM 1500-1600/kg HM *2						
6	Bairiot and Lebastard（COMMOX、仏）	• US$ 26/ℓb U_3O_8	• FF 88/g • Pu		• FF 1600/kg U						
7	Bairiot and Lebastard（COMMOX、仏）	• US$ 510/kg 成形加工燃料（3.4%濃縮を仮定）	• US$ 2/g • Puf （35t/y の成形加工工場） • US$ 10/g • Puf （100t/y の成形加工工場）								
8	C.F.Eorsey and J.A.B.Gresley（BNFL/Urenco、英）		∘ 英国では、Puを "free" materialと考えている。								
9	N.R. Geary（コンサルタント、英）	• US$ 50/kg U (U_3O_8)									• 2000年建設 FBR 0.47 P/KWh • 2020年建設 FBR 0.43 P/KWh
10	H.N.Patak（CH、西独）	• US$ 25/ℓb U_3O_8			• US$ 220/kg U • US$ 1320/kg HM *3 • US$ 660/kg HM *4						
11	OECD/NEA	• US$ 32/ℓb U_3O_8			• US$ 190/kg U			• US$ 40/kg HM （欧州内）		• 調　整；US$ 200/kg HM • 処　分；US$ 150/kg HM • 処　分；US$ 150/kg HM	
	2000年推定	• US$ 40-45/ℓb U_3O_8	• 将来のFBR、プルサーマル等の導入形態による。		∘ 成形加工単価は将来もほとんど変わらないと考えられる。しかし MOXについては、2000年頃には、施設が大規模となり、単価が 1/2程度になると考えられる。				• 施設運開から10年間は、高い比率（60～70%）で施設の投資コストが含まれているので、10年以降（2000年頃）は、単価が30～40% 低くなると考えられる。		

*1．既存の小規模施設　*2．将来の大規模施設（～1996）
*3．既存の小規模施設　*4．将来の大規模施設

表 5　炉型：高温ガス炉（全UO_2燃料）

出典	工程 / 機関名	天然ウラン価格	プルトニウム価格	濃縮費 N.U.	濃縮費 R.U.	転換費 N.U.	転換費 R.U.	成形加工費	新燃料輸送費	原子炉建設費	使用済燃料輸送費	再処理費	廃棄物処理	ワンスルーサイクル / 再処理サイクル	燃料サイクル費
1	VDEW（西独）	・DM 130/kg U (U_3O_8)	∘西独電力会社は、Puを "Free" materialと考えている。	・DM 197-200/kg SWU	・DM 320/kg SWU	・DM 9-13/kg U(F_6) (U_3O_8 →UF_6)	・DM 100/kg U(UF_6)			∘THTR-300（西独） ・全建設費：4 billion DM (DM 13500/KWe)					
2	KFK－PAE（西独）	・US$ 30/ℓb U_3O_8		・US$ 125/kg SWU	・US$ 129/kg SWU	・US$ 6.3/kg U(UF_6) (U_3O_8 →UF_6)	・US$ 40/kg U(UF_6)		N.U. DM6/kg U R.U. DM6/kg		・DM 41/kg HM （西独内プラントから Wackersdorf まで）				
3	Cogema（仏）	・FF 468/kg U (U_3O_8)	・FF 100-130/g・Pu (Puf：71%)	・FF 800/kg SWU (US$ 133/kg SWU)	・FF 800/kg SWU (US$ 133/kg SWU)	・FF 36/kg U(UF_6) (U_3O_8→UF_6)	・FF 245/kg U(UF_6) (UNH→UF_6)				・FF 250/kg HM (US$ 42KG HM) （仏内プラントから La Hague まで）				
4	Baumier（CEA、仏）	・FF 650/kg U	・FF 150/g・Pu	・FF 1015/kg SWU		・US$ 5/kg U(UF_6) (U_3O_8 →UF_6)			∘一般的に1000kmまでの新燃料輸送費は、US$ 1-3/kg Uと言われている。		∘欧州内での使用済燃料輸送費は一般的にUS$ 40-60/kg HMと言われている。				
5	Schmiedel and Winnik (Siemens、西独)	・US$ 17-30/ℓb U_3O_8		・DM 270/kg SWU											
6	Bairiot and Lebastard (COMMOX 、仏)	・US$ 26/ℓb U_3O_8	・FF 88/g・Pu	・FF 800/kg SWU											
7	Bairiot and Lebastard (COMMOX 、仏)	・US$ 510/kg 成形加工燃料（3.4%濃縮を仮定）	・US$ 2/g・Puf（35t/y の成形加工工場） ・US$ 10/g・Puf（100t/y の成形加工工場）												
8	C.F.Forsey and J.A.B.Gresley (BNFL/Urenco，英)		∘英国では、Puを "free" materialと考えている。		・N.U.の濃縮費より5%高 (US$ 105/kg SWU)		・N.U.の転換費の３倍 (US$ 21/kg U(UF_6))								
9	N.R. Geary（コンサルタント 、英）	・US$ 50/kg U (U_3O_8)		・US$ 100/kg SWU		・US$ 7/kg U(UF_6) (U_3O_8 →UF_6)									
10	H.N.Patak（CH 、西独）	・US$ 25/ℓb U_3O_8		・US$ 100/kg SWU		・US$ 3.5/ℓb U (US$ 7/kg U)	・US$ 5.25/ℓb U (US$ 11/kg U)								
11	OECD/NEA	・US$ 32/ℓb U_3O_8		・US$ 130/kg SWU		・US$ 6/kg U(UF_6)					・US$ 40/kg HM（欧州内）				
	2000年推定	・US$ 40-45/ℓb U_3O_8	・将来のFBR,プルサーマル等の導入形態による。	・濃縮単価は年々下がりつつある。2000年頃は LISが主となり、仏では LISの単価の目標を現在の1/2 としている。		・現在の施設の容量で2000年までの増加分を処理できると考えられる。									

0. Introduction

This survey has been prepared for Japan NUS Co., Ltd., within the framework of a contract on behalf of the Power Reactor and Nuclear Fuel Development Corp. (PNC) of Japan.

Nuclear fuel has to pass through quite a number of treatment and fabrication stages, not only from ore mining to its loading as fuel assemblies into a reactor, but also after its discharge following the end of its useful life. Very much has been published and discussed worldwide on processes, equipment and techniques developed and applied for the various activities of the nuclear fuel cycle. In contrast, very little is being released about the related costs and prices. In the front-end of the nuclear fuel cycle of presently used nuclear power plants, competent industries have been established and overcapacity exists in nearly all fields of these front end activities. As a result, considerations of competition have led to silence or even secrecy about costs and prices.

In the back-end of the nuclear fuel cycle with reprocessing, refabrication and waste conditioning as the main parts, the stage of industrialization has not yet been reached, despite the fact that proven technologies have already been developed. Lacking industrial experience, the real costs are not yet known with sufficient precision, so that there is a widespread reluctance to quote figures.

With the present report, the attempt was made to collect cost and price data, which have been quoted or published for fuel cycle costs in France, the FRG and Great Britain. To draw as consistent a picture as possible, only recent publications have been used and much of the information provided was collected through personal contacts.

In the framework of this report only rather general information could have been provided. More indicative information would require an in-depth analysis of each individual case.

1. General Remarks

In reporting on nuclear fuel cycle costs in the following eleven chapters, corresponding to the various activities in the cycle, emphasis was put on submitting cost figures, quoted by competent organizations or people. Such quotations are in most cases rather global figures, which summarize and average the cost situation in a special field. Prices for relevant services may differ from case to case and so may costs for individual facilities. However, most of the figures presented in the following chapters are reliable indications of present costs and future cost trends, as they are used by important groups and organizations for their own calculations. This especially applies for the cost data of the Association of German Utilities, VDEW, (reference 1) and Cogéma (reference 3). As the respective figures are not published, it is recommended to use such figures only for internal purposes.

Facts and ideas on costs are developing constantly. To present a consistent picture of the present cost/price situation in the nuclear fuel cycle, only recent quotations are being presented, whereever possible. The OECD/NEA estimates (reference 11) date back to 1985 and are presented for reason of comparison only.

Figures on costs or prices in the subsequent chapters are presented in terms of the currency in which they are quoted by the respective informant. It was regarded inopportune to convert the values into a reference currency, for example the US $. Differences in the evaluation of exchange rates suggest leaving the interpretation and comparison to those who may use the information provided.

Each of the subsequent chapters contains a short outline on the present situation with respect to facilities, capacities and services as well as on outlook on future development. According to the purpose of this report, such outlines can only be very general. For fully grasping the industrial and economic situation in the various fields of nuclear fuel cycle activities, detailed analysis for individual cases would be necessary.

2. Uranium Price

The price of natural uranium in the form of U_3O_8 is dependent on the market forces. Although production of uranium in recent years was slightly below consumption, the situation at present is that of a buyer's market. Reduced production was the result of larger consumption of existing large stockpiles. Due to lower than forecasted growth of nuclear energy, production capacity at present exceeds the requirements. As a consequence, uranium prices are comparatively low and - even more indicative for the present situation - there is a wide gap between long-term contract prices and the prices on the spot market.

In the spot market, prices are quoted which are even below US $ 15.- per lb U_3O_8 but the quantities of uranium contracted in the spot market are rather limited. For longer term supply contracts prices are in the range of US $ 30.- to 35.- per lb U_3O_8. As can be seen from the price indications listed below, such a range corresponds with the price quotation made by competent European organizations and companies. It is also the range of figures which is used for fuel cycle calculations. It is generally assumed that this range of prices will continue to prevail during the coming years.

Much more uncertainty exists with respect to the medium-term price development. By around 1995 production capabilities from existing and committed centres would be insufficient to cover the expected reactor requirements. However, such requirements would be met even until the end of the century with the addition of production from planned new centres, if there is enough incentive for establishing such new centres. It is therefore generally agreed that the price for uranium will harden in about five to ten years from now but with rather modest price increase. There will be a compensating effect with respect to growing demand in natural uranium and consequent price increase due to technical developments. The beginning of large-scale reprocessing in the early 90s in Europe with the resulting recycling of recovered uranium and plutonium will reduce the demand in natural uranium to an important extent. Further reduction in such demand will result from further improved use of uranium through higher burnup of the fuel.

European estimates for uranium prices around the year 2000 show a range of US $ 40.- to 45.- per lb U_3O_8.

The following prices for uranium have recently been published or have been quoted in personal contacts in France, the FRG or Great Britain:

2.1 Association of German Utilities (VDEW) <1>

DM 130.- per kg U in the form of U_3O_8
Cost range for 1 kg fuel under the following assumptions:
enrichment: 3.5% U-235
tails: 0.2 - 0.25 U-235
natural uranium requirement: 6.4 - 7.1 kg U nat
Uranium price: DM 840.- to 920.- per kg fuel

2.2 KfK - PAE on behalf of the FRG Government <2>

US $ 30.- per lb U_3O_8

2.3 Cogéma <3>

FF 468.- per kg U in the form of U_3O_8
(corresponding to US $ 30.- per lb U_3O_8)

2.4 Baumier (CEA) <4>

FF 650.- per kg U

2.5 Schmiedel and Winnik (Siemens) <5>

US $ 17.- to 30.- per lb U_3O_8

2.6 Bairiot and Lebastard (Commox) <6>

US $ 26.- per lb U_3O_8

2.7 Bairiot and Lebastard (Commox) <7>

US $ 510.- per kg fabricated fuel
Assumption:
Enrichment: 3.4% U-235

2.8 N.R. Geary (UK) <9>

US $ 50.- per kg U in the form of U_3O_8

2.9 H.N. Patak (CH) <10>

US $ 25.- per lb U_3O_8

2.10 OECD/NEA <11>

US $ 32.- per lb U_3O_8

3. Plutonium Value

Whatever figures are quoted, any value for plutonium is artificial and depending on the scenario into which it is introduced. In a self-contained system, provided all direct costs and charges are included and appropriate adjustments are made to fissile material flows, there is no need to attribute a cash value for recovered plutonium. The important figure is the overall cost of the system and how this is affected by different fuel cycle options. Plutonium value would only enter into the calculation if it had to be bought or if surplus could be sold.

However, where individual fuel cycles are considered in isolation, distortion can occur when comparing alternative fuel cycles if appropriate values are not attached to plutonium recovered by reprocessing. For example, plutonium is often regarded as a "free" material because reprocessing has already been paid for under the previous fuel cycle. Thus, if plutonium is given zero value, mixed oxide fuel is cheap at the expense of the precursor. That is the approach at present taken by German utilities.

In other cases, such as in France, a national value for plutonium is being derived which is related to its future use. The value may vary, depending on how the plutonium is used, in fast breeder reactors or light water reactors, and on whether it can be used immediately or has to undergo extended interim storage. A national value reflects separative work and feed uranium savings less the extra cost of mixed oxide fuel fabrication. Other things being equal one can attribute a value to plutonium, the so-called indifference value, by equalizing the costs of comparable uranium and mixed oxid fuel cycles.

The French figures quoted below are such indifference values. The figures presented under item 3.4 show the possible variation with respect to varying fabrication costs.

Except for some long-term fast breeder reactor calculations, it is assumed in Great Britain that plutonium is available as a "free-issue". It is probable that this accountancy convention, coupled with a technical argument regarding the suitability of Advanced Gas-Cooled Reactors for operation with plutonium, generates the lack of interest in thermal recycling of plutonium shown by the British industry.

The following values for plutonium have recently been published or have been quoted in personal contacts:

3.1 **Cogéma <3>**

Range of value
FF 100.- to 130.- per gram Pu
Assumption:
Pu (total) content in used fuel: 0.94% of initial U
Pu (fissile) content: 71.00% of Pu (total)

3.2 **Baumier (CEA) <4>**

FF 150.- per gram Pu
referred to a price of natural uranium of
FF 650.- per kg U

3.3 **Bairiot and Lebastard (Commox) <6>**

FF 88.- per gram Pu

3.4 Bairiot and Lebastard (Commox) <7>

Values related to size of MOX fabrication plant
US $ 2.- per gram Pu fissile in a 35t/a plant
US $ 10.- per gram Pu fissile in a 100t/a plant

4. Enrichment Cost

Enrichment of natural uranium is a well established industry in Europe. Both techniques are employed, the gaseous diffusion by Cogéma in its George Besse-plant at Pierrelatte and the gas ultracentrifugation by the three Urenco partners British Nuclear Fuels plc, Ultra-Centrifuge Nederland NV and Uranit GmbH in their plants at Capenhurst, Almelo and Gronau. Both enterprises are selling in a highly competitive market with production capacities far beyond the present needs of utilities. Despite the problem of properly converting currency values at present, it can be stated that the range of enrichment prices or costs lies between US $ 100.- and 130.- per kg SWU. It can not be said whether such figures really correspond with costs, whether there is a sufficient margin for profits or whether enrichment is sold at a loss.

The figures which have been published recently or have been quoted in personal contacts are listed below. Figures under item 4.1 refer to the enrichment of fresh natural uranium, whereas item 4.2 is presenting the respective figures for reprocessed uranium.

Re-enrichment of reprocessed uranium is attracting much attention. The currently available processes on an industrial scale are gaseous diffusion and gas-centrifugation. Both types of plants can be used for the re-enrichment of reprocessed uranium, as has already been demonstrated, although both have the disadvantage of also enriching the minor uranium isotopes. The two enrichment technologies lead to two different products. Because of the small module size of centrifuge plants, specially designed units can be used for reprocessed uranium feed, thus leading to pure enriched reprocessed uranium. Dedicated facilities are not possible in case of large gaseous diffusion plants. Therefore a certain mixing of reprocessed uranium with fresh uranium cannot be avoided, even when working in special campaigns.

A feed ratio of one part reprocessed uranium to five parts natural uranium, resulting in a diluted reprocessed uranium product, is therefore being considered.

The most exciting programme in research and development for uranium recycling is the work on laser isotope separation, performed in France as well as by the British/Dutch/German Urenco partners. The high selectivity in isotope separation throughout laser enrichment is of utmost importance for the re-use of reprocessed uranium, as it may enable the overcoming of difficulties resulting from the existence of minor isotopes of uranium especially uranium-232 and uranium-236 and to a lesser extent uranium-234. However, the further development of laser isotope separation for uranium enrichment will take quite a while and it is not expected that industrial scale plants will be available before the turn of the century. Thus, existing technologies and plants will and can be used for the recycling of reprocessed uranium during the next decade. The need for additional measures, especially in radiation protection at plants handling reprocessed uranium brings with it some additional costs. They are more than compensated for, however, by the uranium and separative work value of reprocessed uranium.

However, there is only rather limited experience with the re-enrichment of uranium recovered from reprocessing high water reactor fuel. This explains the relatively large differences between the German 1 , French 3 and British 8 quotations.

Enrichment costs and prices are assumed to decrease further, in the medium term in a modest way but more drastically in the long term with the eventual introduction of laser isotope separation (LIS).

A clear economic target has been set for the French policy in the field of uranium enrichment in general and in the industrial application of LIS in particular. The policy aims at using existing plants with absolute preference as long as this is technically feasible. By the turn of the century - the time when AVLIS technology might be available on an industrial scale - the existing Eurodif gaseous diffusion plant will be amortized but still in perfect condition to operate. At that time, it will therefore be possible to deliver SWU at a price well below the present Eurodif cost. The French goal with respect to AVLIS enrichment, therefore, is to cut the SWU cost at least by a factor of 2 which would be consistent with the marginal cost of gaseous diffusion.

4.1 Enrichment of Fresh Uranium

4.1.1 Association of German Utilities (VDEW) <1>

DM 197.- to 200.- per kg SWU
Cost range for 1 kg fuel under the following assumptions:
enrichment to 3.5% U-235
tails 0,2 - 0.25% U-235
natural uranium requirement: 6.4 - 7.1 kg U nat
enrichment: DM 970.- to 1100.- per kg fuel

4.1.2 KfK - PAE on behalf of the FRG Government <2>

US $ 125.- per kg SWU

4.1.3 Cogéma <3>

FF 800.- per kg SWU
(corresponding to US $ 133.- per kg SWU)
Assumption: enrichment to 3.25% U-235

4.1.4 Baumier (CEA)

FF 1015.- per kg SWU

4.1.5 Schmiedel and Winnik (Siemens) <5>
DM 270.- per kg SWU

4.1.6 Bairiot and Lebastard (Commox) <6>
FF 800.- per kg SWU

4.1.7 N.R. Geary (UK) <9>
US $ 100.- per kg SWU

4.1.8 H.N. Patak (CH) <10>
US $ 100.- per kg SWU

4.1.9 OECD/NEA <11>
US $ 130.- per kg SWU

4.2 Enrichment of Reprocessed Uranium

4.2.1 Association of German Utilities (VDEW) <1>
DM 320.- per kg SWU (tails 0.3% U-235)
Cost per 1 kg fuel (with reprocessed U) under the following assumptions:
residual enrichment: 1.0% U-235
new enrichment: 3.8% U-235
Enichment: DM 1140.- per kg fuel

4.2.2 KfK - PAE on behalf of the FRG Government <2>
US $ 129.- per kg SWU

4.2.3 Cogéma <3>
FF 800.- per kg SWU
(corresponding to US $ 133.- per kg SWU

4.2.4 Forsey and Gresley (BNFL + Urenco) 8)
Price for natural uranium enrichment - 5%
(this would correspond to about
US $ 105.- per kg SWU)

5. Conversion Cost

- Worldwide capacity for converting fresh natural uranium oxide into uranium hexafluoride of about 55 000 tonnes uranium per year exceed by far the present requirement and are sufficient to serve the growing needs beyond the year 2000. European conversion capacity corresponds to about 43% of the total capacity in the western world. Two companies are engaged in uranium conversion, Comurhex in France (14000 tonnes per year) and British Nuclear Fuels plc (9500 tonnes per year).

New projects in the field of uranium hexafluoride conversion concern the recycling of reprocessed uranium. There is already broad experience in the recycling of uranium from reprocessed metallic fuel.

More than 15000 tonnes of uranium recovered from metallic fuel has been re-enriched by British Nuclear Fuels plc. for use in the fabrication of fuel for the British AGR stations. More than 1400 tonnes of the 1 900 tonnes uranium of AGR fuel fabricated so far has used recycled uranium. Similarly, Cogéma has recycled already some 5000 tonnes of uranium recovered through reprocessing of used fuel from the French gas/graphite reactors. As far as uranium from reprocessed light water reactor fuel is concerned, the conversion to UF_6 is currently performed by Comurhex in a demonstration plant at Pierrelatte in France. This plant started up in 1976, since when its capacity has been gradually raised from 30t/Uy to 350tU/y in order to keep pace with reprocessing activities. Cumulative production of the Pierrelatte plant to date has been 1500 tU as UF_6. Most of this has been sent to the US Department of Energy for enrichment.

Conversion of reprocessed uranium to the oxide is carried out by Cogéma in its TU2-facility, also located at Pierrelatte. This facility has a capacity of 400 tU/y when producing U_3O_8 for long-term storage; or 100 tU/y when producing sinterable UO_2 powder.

In May 1986, the French companies Cogéma and Comurhex announced the creation of Urep, a joint venture marketing a range of services in the field of reprocessed uranium.

British Nuclear Fuels plc. is planning a recycle uranium hexafluoride conversion plant, called "Echo", to be on-line in the early 1990s with flexible capacity dependent on the demand. BNFL is further arranging for the 1990s a commercial service for the manufacture of fuel assemblies containing reenriched, reprocessed uranium.

Cost figures which have been published recently or have been quoted in personal contacts are listed below. Figures under item 5.1 refer to the conversion of fresh natural uranium, whereas item 5.2. is presenting the respective figures for reprocessed uranium.

5.1 Conversion of Fresh Uranium

5.1.1 Association of German Utilities (VDEW) <1>

$U_3O_8 \rightarrow UF_6$ DM 9.- to 13.- per kg U in UF_6

Cost range for 1 kg fuel under the following assumptions:
enrichment: 3.5% U-235
tails 0.2 - 0.25% U-235
natural uranium requirement: 6.4 - 7.1 kg U nat.
Conversion: DM 60.- to 90.- per kg fuel

5.1.2 KfK - PAE on behalf of the FRG Government <2>

US \$ 6.30 per kg U in UF_6

5.1.3 Cogéma <3>

$U_3O_8 \rightarrow UF_6$
FF 36.- per kg U in UF_6
(corresponding to US \$ 6. per kg U)
Assumption: enrichment to 3.25% U-235
conversion loss 0.50%

5.1.4 Baumier (CEA)

$U_3O_8 \rightarrow UF_6$
FF 47.- per kg U in UF_6

5.1.5 Schmiedel and Winnik (Siemens) <5>

$U_3O_8 \rightarrow UF_6$
US \$ 5.- per kg U in UF_6

5.1.6 N.R. Geary (UK) <9>

$U_3O_8 \rightarrow UF_6$
US \$ 7.- per kg U in UF_6
(upper limit)

5.1.7 H.N. Patak (CH) <10>

US $ 3.50 per lb U
(corresponding to about US $ 7.- per kg U)

5.1.8 OECD/NEA <11>

US $ 6.- per kg U in UF_6

5.2 Conversion of Reprocessed Uranium

5.2.1 Association of German Utilities (VDEW) <1>

DM 100.- per kg U in UF_6

Cost for 1 kg fuel (with reprocessed U) under the following assumptions:
residual enrichment: 1.0% U-235
new enrichment: 3.8% U-235
Conversion: DM 500.- per kg fuel

5.2.2 KfK - PAE on behalf of the FRG Government <2>
US $ 40.- per kg U in UF_6

5.2.3 Cogéma <3>
UNH → UF_6
FF 345.- per kg U in UF_6
(corresponding to US $ 58.- per kg U)
Assumption: enrichment to 3.25% U-235
production loss: 0.50%

5.2.4 Forsey and Gresley (BNFL + Urenco) <8>
- Three times the price for natural uranium (this would correspond to about US $ 21.- per kg SWU in UF_6)

5.2.5 H.N. Patak (CH) <10>
US $ 5.25 per lb U
(corresponds to about US $ 11.- per kg U)

6. Fuel Fabrication Cost

In considering fuel fabrication for light water reactors, distinction must be made between three kinds of fuel, namely enriched fuel from fresh natural uranium, enriched fuel from reprocessed uranium and mixed oxide fuel for thermal recycling. Fuel fabrication generally encompasses the conversion of uranium hexafluoride to uranium oxide, pellet production, fuel rod fabrication and fuel assembly manufacturing.

Worldwide there is large overcapacity in fuel fabrication on the basis of fresh uranium. The situation in the three countries under review in this field can be outlined as follows:

The French nuclear fuel manufacturing program is the result of joint efforts by major industrial groups Cogéma, Framatome and Pechiney which cover the whole range from design engineering (Framatome), marketing (Fragema) to complete fabrication (FBFC) including fuel rod tubing (Zircotube). A fourth company (Commox) has been created to produce mixed oxide fuel rods. This unique environment, close cooperation and shared objectives are the keys to the success of French fuel fabrication.

By end 1986, Fragema had delivered more than 7000 tU of PWR fuel fabricated by FBFC. The FBFC plants are: Dessel (Belgium) annual capacity 450 tU; Romans (France), from conversion to final assembling, 650 tU per year; and Pierrelatte (France) specialized in fabricating Advanced Fuel Assemblies (AFA), 500 tU per year. All that adds up to a manufacturing capability of 1600 tU/year. That production is fully integrated, encompassing fuel assemblies, fuel components (grids, nozzles) and core components (absorber and poison rods, control rod clusters and thimble plugs).

In the FRG fuel fabrication has a long history with its development centering in the Hanau nuclear facility complex. Today, all light water reactor fuel fabrication belongs to Siemens/KWU. There is the RBU plant at Hanau with a capacity of 800 tU per year and the plant of Siemens/KWU subsidiary Advanced Nuclear Fuel Corp. (ANF) at Lingen with a capacity of 400 tU per year.

In Great Britain, the fabrication of PWR fuel has not yet been undertaken on a production scale. Some small quantities of PWR fuel have been manufactured for exploratory sales to overseas reactors. The existing uranium purification, uranium dioxide and pellet manufacturing processes, at BNFL's Springfields Works, were used for this. Equipment for canning and assembly of the fuel elements was designed and purchased but it was not set up as a proper production line.

BNFL has already successfully manufactured more than 1500t of oxide fuel for the AGR system, enriched to 2-3% from reprocessed Magnox fuel. It is now intended to replace the existing fuel fabrication plants by a single new integrated complex capable of producing both AGR and PWR fuel. This New Oxide Fuel Complex (NOFC) is designed from the beginning to be able to process reprocessed uranium with a minimum of extra costs. Its capacity will be 200 tU per year. Fuel fabrication with reprocessed uranium so far is limited to some test assemblies manufactured in France as well as in the FRG.

Much attention is being given to the extension of mixed oxide fuel fabrication for recycling in light water reactors. At present, the capacities are by far insufficient to deal with the plutonium already stockpiled or being currently produced. The existing plants had originally been built for the fabrication of fuel assemblies for fast breeder reactors. At present, the requirements for such fuel is very low as only the two prototype plants Phénix at Marcoule and PFR at Dounreay need limited quantities of reload fuel assemblies. The existing plutonium handling plants mainly serve to produce MOX fuel for thermal recycling. The capacities are to be extended so that by the middle of the 90s more than 300 t HM per year can be produced in Europe as shown in the following table.

MOX-Fuel Fabrication Capacities (tHM/a)

	Alkem (D)	COMMOX (F+B)	BNFL (UK)
1989	40	50	-
1995	120	150	60*)

*) 100 t/a in the year 2000

Fuel fabrication cost quotations are listed under item 6.1 for fuel from fresh uranium, under item 6.2 for fuel with reprocessed uranium and under item 6.3 for MOX fuel.

Fuel fabrication costs for fresh uranium fuel and for fuel with reprocessed uranium are supposed to remain virtually unchanged in future. There is little margin being seen for larger plants and further rationalization. However, the cost for fabricating MOX fuel assemblies are supposed to be almost halved once the large capacity facilities will be available in the late 90s. There are no official figures on cost of FBR fuel fabrication. There are indications from sources in France that the cost for fabricating Superphénix-1 fuel assemblies was about FF 12000 per kg HM.

6.1 Fresh Uranium Fuel Fabrication Cost

6.1.1 Association of German Utilities (VDEW) <1>

DM 550.- to 650.- per kg U

6.1.2 KfK-PAE on behalf of the FRG Government <2>

DM 530.- per kg U (fuel)

6.1.3 Cogéma <3>

FF 1600.- per kg U

(Corresponding to US $ 267.- per kg U)

Assumption: Production loss: 1.0%

6.1.4 Baumier (CEA) <4>

FF 1600.- per kg U

6.1.5 Schmiedel and Winnik (Siemens) <5>

DM 530.- per kg U

6.1.6 Bairiot and Lebastard (Commox) <6>

FF 1600.- per kg U

6.1.7 H.N. Patak (CH) <10>

US $ 220.- per kg U

6.1.8 OECD/NEA <11>

US $ 190.- per kg U

6.2 Reprocessed Uranium Fuel Fabrication Cost

6.2.1 Association of German Utilities (VDEW) <1>

DM 700.- per kg U

6.2.2 KfK-PAE on behalf of the FRG Government <2>

DM 600.- per kg U

6.2.3 Cogéma <3>

FF 1920.- per kg U

(corresponding to US $ 320.- per kg U)
Assumption: production loss 1.0%

6.2.4 Forsey and Gresley (BNFL+Urenco) <8>

Price for natural uranium fuel + 20%

(However, no figures for LWR fuel fabrication are available from BNFL)

6.3 MOX Fuel Fabrication Cost

6.3.1 KfK-PAE on behalf of the FRG Government <2>

DM 1315.- per kg HM

(cost for a plant to be built in the 1990s)

6.3.2 Cogéma <3>

FF 8000.- per kg HM

(corresponding to US $ 1333.- per kg HM

Assumption: Pu (fissile) content in MOX: 3.90%

Pu (fissile) in total Pu: 71.00%

6.3.3 Baumier (CEA) <4>

FF 5815.- per kg HM

6.3.4 Schmiedel and Winnik (Siemens) <5>

a) in existing small facility

DM 2700.- to 3200.- per kg HM

b) in an extended 100 t/a plant (~ 1996)

DM 1500.- to 1600.- per kg HM

6.3.5 H.N. Patak (CH) <10>

US $ 1320.- per kg HM in existing small plants

US $ 660.- per kg HM in future larger plants

7. New Fuel Transportation Cost

In almost all cases, the cost associated with transportation of new fuel assemblies from a fabrication plant to the reactor site is included in the fabrication price. Although it differs from location to location, this particular cost component is estimated to be rather small. For distances up to 1000 km it is in the order of less than

US $ 1.- to 3.- per kg U

The only reliable source on new fuel transportation cost is given in the subsequent item 7.1.

7.1 KfK-PAE on behalf of the FRG Government <2>

(Average distance between RBU-Hanau and a German nuclear power plant)

a) natural uranium assemblies

DM 6.- per kg U

b) recovered uranium assemblies

DM 6.- per kg

c) MOX assemblies

DM 60. per kg HM

8. Nuclear Power Plant Costs

In the framework of this report only very global figures for such complex systems as nuclear power plants can be given. Proper evaluation of construction or investment costs would in principle require a detailed outline of the plant design. Furthermore, there are no generally applicable figures for a special reactor system, as each individual plant has its own features and its own construction history. It is for this reason that interest during construction is not being regarded. Only a few examples of nuclear power plants have been chosen for outlining their costs and the figures quoted may only be regarded as indicative for the order of magnitude of such costs.

The following nuclear power plant examples have been chosen:

- Framatome 1300-MWe-PWR-Plant
- Siemens/KWU 1000-MWe-PWR-Plant
- Dounreay Prototype Fast Reactor
- Superphénix FBR Plant, Creys-Malville
- SNR-300, FBR Plant, Kalkar
- THTR-300, Hamm-Uentrop

There is, at present, no pressurised water reactor, either prototype or full-scale in the UK. Construction of the Sizewell B PWR is well under way and total investment cost of £ 1.64 billion have been quoted. The follow-on project Hinkley-C is expected to cost less, namely £ 1.47 billion. However, it is improbable that anyone has yet a realistic idea of the final costs. The previous history, in the UK of the costs of construction the first reactor of any particular type, would make one very cautious of attributing any value to the estimates published at the planning stage.

8.1 Framatome 1300 MWe-PWR-Plant

(For reason of comparison with other reactor systems, especially with the Superphénix FBR figures are quoted in FF 1984 value)

The figures refer to one unit of a 2x1300 MWe twin plant.

	billion FF
- Land, structures and site facilities	1.069
- Site preparation, access water suply	0.884
- Nuclear steam supply system	2.443
- Turbo-generator	0.935
- Mechanical equipment	0.455
- Electrical equipment	0.521
- Miscellaneous equipment	0.438
- Indirect cost and contingencies	1.292
- Owner's expenses	0.407
Total construction costs	8.444

The plant costs, listed above, correspond to specific investment cost of

FF 6500.- per installed kW

8.2 Siemens/KWU 1000 MWe-PWR-Plant

Other than is the case with series-built EDF light water reactor plants, the stations built by Siemens/KWU in the FRG all differ by a more or less large margin. This even applies to the three convoy plants, recently commissioned. Complying with individual utilitie's special requests has led to investment cost differences, which to be understood would require explanation of plant design in some detail.

Siemens/KWU therefore supplied cost indications which refer to a standardized 1000-MWe-PWR-Plant. The figures provided by Siemens/KWU in August 1988 are listed below:

	million DM
Reactor	31.0
Primary circuit piping	19.7
Steam generators	84.0
Secondary circuit	470.0
Electrical equipment	271.0
Buildings (turbine + reactor + switchgear)	320.0
Containment	43.7
Water and cooling equipment	258.0
Administrative and auxiliary buildings	87.0
Total construction cost	1584.4

The plant costs, listed above, correspond to specific investment cost of

DM 1590.- per installed kW

8.3 Dounreay Prototype Fast Reactor

The only Fast Breeder Reactor now in the UK is the Prototype Fast Reactor, at Dounreay with a capacity of 250 MWe. Construction of this plant was completed in 1975. It is owned and operated by the United Kingdom Atomic Energy Authority, UKAEA, and was funded wholly by the Government.

Its cost was published as £ 50 million in 1975, which is calculated as £ 234 million in 1987/88 money terms.

Since its initial construction a number of modifications and additions have been found to be necessary. The investments in these were:

	million £ (1987/88 Values)
Buffer Store	6.5
Replacement Tubes	40
Decontamination Facility	7.8
Spare Heat-exchanger	3
Decay Heat Removal	2
New Evaporator	3

Re-sleeving	3
Electrical Feed Pumps	1.3
Seaweed Barrier	1.9

The total investment cost of the PFR is, therefore, some £ 300 million, which corresponds to specific investment cost of £ 1200.- per kW.

8.4 Superphénix FBR, Creys-Malville

The Superphénix fast breeder reactor demonstration plant, owned by the European company NERSA reached its full capacity of 1200 MWe in December 1986. Construction at Creys-Malville was started in 1977 and first criticality was reached in September 1985. Because construction was completed by 1984, the investment cost figures are quoted in FF value of 1984.

	billion FF
- Land structures and site facilities	1.411
- Site preparation, access water supply	0.114
- Reactor vessel and core internals	2.513
- Cooling circuits and steam generators	4.928
- Fuel handling and storage	1.868
- Reactor control systems, instrumentation	0.898
- Mechanical equipment	0.359

- Turbo-generator sets	0.857
- Electrical plant equipment	0.563
- Miscellaneous plant equipment	0.620
- Indirect costs and contingencies	1.710
- Owner's expenses	0.541
Total construction cost	16.382

The plant costs, listed above, correspond to specific investment cost of

FF 13650.- per installed kW

8.5 SNR-300 FBR Plant, Kalkar

The German prototype fast breeder reactor plant with a capacity of 300 MWe and located at Kalkar is ready for plant start-up since about two years, according to statements by its owner SBK and the main architect/engineer Interatom. However, the license for loading of the fuel assemblies, as the first step of commissioning is withheld by the government of North Rhine-Westphalia because of alleged unlicensibility under safety aspects. It is uncertain in and when the SNR-300 will ever be put into operation.

The SNR-300 project is known for its tremendous cost overruns as compared with the initial cost estimates. This may be demonstrated with the following figures for total plant costs:

- Cost estimate 1972 for SNR-300 to be commissioned in 1979: DM 1.535 billion

- Cost estimate 1982 for SNR-300 to be commissioned in 1987: DM 6.051 billion.

The 1982 cost assessment corresponds to the cost accrued until the plant had been declared ready for start-up. The interim costs for keeping the SNR-300 in standby position are not included. Such costs amount to about DM 100 million per year.

The additional costs as compared with the first cost estimate of 1972, which amount to DM 4.516 billion can be attributed to the following reasons:

more expensive hardware:	29%
higher engineering expenses:	13%
price escalation:	46%
owner's higher expenses:	12%

The total costs of DM 6.051 billion can be broken down as follows:

	billion DM
- Nuclear island (hardware)	2.340
- Conventional part (hardware)	1.040
- Fuel assemblies	0.230

- Engineering	1.280
- Civil engineering (conventional)	0.520
- Owner's expenses	0.640
Total construction cost	6.050

The resulting specific investment cost for the SNR-300 is out of all proportion. It amounts to about

DM 20000.- per installed kW

8.6. THTR-300 Plant, Hamm-Uentrop

The German Thorium High Temperature Reactor prototype plant was coupled to the electrical grid for the first time in November 1985 after a 14-year period of construction. How the cost and the financing of the THTR project developed is a rather impressive story. In 1971, when the order for construction was placed, the total investment costs were estimated at DM 0.673 billion. In 1985, when commissioning started a total of DM 4.000 billion had been spent for construction. The tremendous cost overruns are mainly explained by the very slow licensing procedure and the huge number of modifications and additional safety measures imposed during the procedure.

The reactor vendor, ABB Mannheim, is arguing that a breakdown of construction costs is meaningless, because of the various re-designs imposed by the licensing authorities. To allow expenses to be properly evaluated, a detailed description of the project's history would be required. Only the following set of figures is being provided:

	billion DM
- THTR plant investment	3.855
- First fuel load	0.045
- Accompanying R&D	0.100
Total	4.000

The resulting specific investment cost for the THTR-300 is about DM 13 500.- per installed kW.

9. Spent Fuel Transportation Cost

The transport of spent oxide fuel began shortly after the first discharges of fuel assemblies from light water reactors. Of the many shipments that have taken place in Europe since then, almost all have been exclusively the transport of spent fuel from nuclear power plants to reprocessing facilities. So far, nearly 10000 tU in spent fuel assemblies have been transported to the European reprocessing plants.

The cost for transporting spent nuclear fuel depends on several parameters, the most important being the size of transport cask, the quantity of spent fuel in a transport batch, the distance the fuel has to be transported and the mode of transport (road, rail, water).

For spent fuel transports within Europe only the quotation of a cost/price range is meaningful to indicate the order of magnitude. Such a range is:

US $ 40.- to 60.- per kg HM

The various components of the transport cost contribute with about the following percentages to the total cost:

	%
Cask depreciation and interest	30
Cask maintenance, tests, dismantling	30
Transport charges	15
Insurances	15
Handling fees and cost	10
	100

Three examples of recent cost quotations are listed below:

9.1 KfK-PAE on behalf of the FRG Government <2>

(average distance from German nuclear power plant to Wackersdorf)

DM 41.- per kg HM

9.2 Cogéma <3>

(average distance from French nuclear power plant to La Hague)

FF 250.- per kg HM

(corresponding to US $ 42. per kg HM)

9.3 OECD/NEA <11>

US $ 40.- per kg HM

(transportation within European area)

Not much cost reduction is to be expected in future because the techniques applied are well advanced and especially because transport casks weights are at an upper limit, which can not be exceeded because of restricting regulations.

10. Spent Fuel Reprocessing Cost

From a technological point of view, reprocessing of spent oxide fuel from light water reactors has become a mature activity in Europe. This is best demonstrated by the successful operation at nominal capacity of Cogéma's UP2-400 plant at La Hague over the recent years.

However, real industrial application will only be achieved during the 1990s, when the large plants, listed in the table below, will have been put into full operation.

Name/Location	Owner	Nominal Capacity (tU/a)	Start of Operation
UP 3, La Hague	Cogéma	800	1989
UP 2-800, La Hague	Cogéma	800	1992
THORP, Sellafield	BNFL	1200	1992
WAW, Wackersdorf	DWK	350	1996

As a consequence, a market for reprocessing services does not yet exist, much in contrast to the situation prevailing for the activities in the front end of the nuclear fuel cycle. The price for reprocessing of spent oxide fuel from light water reactors therefore is highly speculative. The same applies for the costs, because reliable figures can only be given once the large plants have been operated for several years.

Some recently quoted price/cost estimates for reprocessing light water reactor fuel, listed below:

10.1 Association of German Utilities/VDEW <1>

DM 2000.- per kg U in fresh fuel

10.2 KfK-PAE on behalf of the FRG Government <2>

DM 1683.- per kg HM
(The estimate is based on a modern 700 t/a plant, to be built in the 1990s)

10.3 Cogéma <3>

FF 6000.- per kg HM

(corresponding to US $ 1000.- per kg HM)

Remark: The above includes a three-year interim storage before reprocessing and conditioning of nuclear wastes.

10.4 Baumier (CEA)

FF 6350.- per kg HM

10.5 Bairiot and Lebastard (Commox) <6>

FF 5400.- per kg HM

(including nuclear waste conditioning)

10.6 N.R. Geary (UK) <9>

US $ 850.- per kg HM

10.7 OECD/NEA <11>

US $ 750.- per kg HM

(the figure is split into US $ 550.- for reprocessing and US $ 200.- for vitrification)

From the above the range of presently estimated reprocessing cost can be set at

US $ 900.- to 1200.- per kg HM

The reprocessing prices contain - at 60 to 70% - a high proportion of investment costs, because the whole of the original investment will be amortized during the first ten years of operation. The consequence is that, after ten years have been completed, the prices could be lowered significantly, because by then the facilities have paid off the capital but their lifespan is substantially longer. The complexes in Marcoule and Sellafield, for example, have already been in operation for more than 30 years. The mentioned lowering of prices will come about for the new facilities at Sellafield and La Hague around the turn of the century and will be possible for the Wackersdorf plant a few years later. Even if one takes into account the expenditures necessary for eventual improvements and renovations, it may be assumed that a price reduction of 30 to 40% will be possible. Because of the simultaneously marked reduction in pre-payments, the falling price has an even more significant impact for the customer.

Some information is available about investment costs in reprocessing plants. With adequate standardization and interpolation, figures on the order of magnitude of the investment costs for reprocessing plants can be achieved.

The plants for which the figures below are quoted include: fuel assembly receipt and buffer storage, head-end, three-cycle extraction, purification, all kinds of waste and effluent treatment, including high-level waste vitrification, laboratories, supply facilities for energy, water and chemicals, administration and site clearance.

The following specific investment costs can be calculated:

Plant	Capacity t U/a	Investment costs billion US $	Specific investment costs US $ / kg U·a
DWK (FRG)	350	4.325	12360
DWK (FRG) (reference 2)	700	5.105	7290
THORP (UK)	700	2.895	4135
THORP (UK)	1200	2.895	2415
UP 3 (France)	800	4.120	5515

(Exchange rates used: 1 US $ = 6.14 FF; = 1.78 DM; = 0.57 £)

The THORP plant is quoted twice, once for the announced throughput during the first 10 years of operation (guarantee figures) and secondly for what it is designed, namely 1200 tU/a. It is to be realized that the investment costs listed are nearly all in the same order of magnitude and very little dependent on the size of the plants. This can most certainly not apply for the full range of capacities but is rather likely to be true in the range of 700 - 1400 tU/a.

The following break-down can be assumed:

civil engineering	20 %
equipment, installation	45 %
architect engineer	20 %
owner expenses and contingencies	15 %
	100 %

The break-down for the various facilities can be assumed as follows:

head-end, including buffer store	33 %
extraction	36 %
HAWC vitrification	12 %
MAW/LAW treatment	10 %
service facilities	9 %
	100 %

11. Waste Treatment and Disposal Costs

Under this chapter only the costs are dealt with, which concern the treatment of spent light water reactor fuel assemblies. The treatment of the various kinds of nuclear wastes from reactor operation varies so much in applied techniques, underlying rules and local practices that reporting on such costs would go far beyond the framework of this report. Furthermore, nearly nothing is being reported on such costs and this mainly because specific cost accounting at the nuclear power plants does not exist.

Indicative figures on waste treatment and disposal are available from the FRG and from France, where comparative assessments have been made for the closed fuel cycle with reprocessing of the spent nuclear fuel and the once-through cycle with disposal of conditioned spent fuel. The result of the assessments is presented below under items 11.1 and 11.2. For comparison the earlier findings of an OECD/NEA working group on the same subject are presented under item 11.3.

11.1 KfK-PAE on behalf of the FRG Government <2>

a) Once-through cycle

- Conditioning of spent fuel: DM 554.- per kg HM
- Transport of conditioned fuel assemblies: DM 66.30 per kg HM
- Disposal of spent fuel assemblies: DM 449.- per kg HM

b) Reprocessing cycle: Transport and disposal of

conditioned wastes DM 488.- per kg HM

11.2 Cogéma <3>

a) Once-through cycle:

- Interim storage for spent fuel for 40 years:
  FF 1100.- per kg HM
  (corresponding to US $ 183.- per kg HM)

- Conditioning of spent fuel: FF 1100.- per kg HM

  (Corresponding to US $ 183.- per kg HM)

- Transport and disposal of conditioned spent fuel:

  FF 1500 per kg HM

  (corresponding to US $ 250.- per kg HM)

b) Reprocessing cycle:

Transport and disposal of conditioned wastes:

FF 1500.- per kg HM

(corresponding to US $ 250.- per kg HM)

11.3 OECD/NEA <11>

a) Disposal of reprocessing wastes: US $ 150.- per kg HM

b) Once-through cycle:

- conditioning US $ 200.- per kg HM

- disposal US $ 150. per kg HM

12. Nuclear Fuel Cycle Cost

Calculating the costs of the total nuclear fuel cycle is an extremely complex matter. A large number of parameters have to be introduced and the choice of the numeric values for such parameters again is depending on a great number of factors, which are influenced by national economics, individual utilities' accounting habits, etc. Thus only quoting the results of fuel cycle cost calculations is rather meaningless. That is the reason why only a few examples of such quotations are given below. However, to put the complexity of such calculations into perspective the parameters chosen by Cogéma for its comparison of the closed and the once-through cycle, the result of which is presented under item 12.1, are enumerated.

Such parameters are:

- Nuclear power plant:	905 MWe PWR
- Number of reloads:	23
- Internal cycle length:	12.5 months
- Load factor:	80 %
- Equilibrium enrichment:	3.25 % U-235
- Burnup:	33000 MWd/t
- Total lifetime production:	85.17 billion kWh
- Recovered uranium quantity:	96.00 %
- Recovered plutonium quantity:	0.94 %

- Fissile plutonium content: 71.00 % Pu total
- Conversion loss: 0.50 %
- Fabrication loss: 1.00 %
- Reprocessing loss: 2.00 %
- Weight of fuel per assembly: 461.4 kg
- Pu fissile in MOX: 3.90 %
- Weight of fuel per reload: 23993 kg
- Cost/prices as quoted in previous chapters (Reference 3)
- Intermediate storage at reactor: 2 years
- Intermediate storage closed cycle: 3 years
- Intermediate storage once-through cycle: 38 years
- External fuel cycle length front end: 20 months (with various dates of payment)
- External fuel cycle length back-end: 484 months (with various dates of payment)

Being calculated are costs over the total life of the plant to arrive at the specific fuel cycle cost quoted below.

12.1 Cogéma <3>

a) Reprocessing cycle (PWR):

Total fuel cycle cost: FF 0.0462 per kWh

(corresponding to US Mill 7.71 per kWh)

b) Once-through cycle (PWR):

Total fuel cycle cost: FF 0.0458 per kWh

(corresponding to US Mill 7.63 per kWh)

12.2 Forsey and Gresley (BNFL + Urenco) <8>

a) Natural uranium fuel (PWR):

US \$ 1500.- per kg U in fuel

(assumption: uranium price US \$ 30.- per lb U_3O_8

enrichment: 4 % U-235)

b) Reprocessed uranium fuel (PWR):

US \$ 1000.- per kg U in fuel

(assumption: 0.9 % U-235 in reprocessesd uranium

0.6 % U-236 in reprocessed uranium)

12.3 N.R. Geary (UK) <9>

PWR commissioned in 2000: 0.47 p/kWh

PWR commissioned in 2020: 0.43 p/kWh

FBR commissioned in 2000: 0.49 p/kWh

FBR commissioned in 2020: 0.32 p/kWh

12.4 OECD/NEA <11>

a) Reprocessing cycle (PWR) US Mill 8.56 per kWh

b) Once-through cycle (PWR) US Mill 7.78 per kWh

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