Annex 3

REPROCESSING OPTION COST ESTIMATES AND FUTURE TRENDS

1. Introduction

The basic cost estimates used in this study have, as in the 1985 NEA study, been provided by British Nuclear Fuels plc (BNFL). Further information relating to likely trends in future costs has been provided by COGEMA.

Reprocessing of spent nuclear fuel from civil reactors is now an established industry in France and the United Kingdom with a plant under construction in Japan and further civil facilities proposed elsewhere. It is also currently the only proven back-end route for closing the nuclear cycle and is recognised worldwide as a viable option. A significant number of countries with nuclear programmes have chosen to recover the energy resource which spent fuel represents, including Belgium, France, Germany, Japan, Switzerland, Russia and the United Kingdom.

The cost estimates provided by BNFL for the 1985 NEA study were based on evidence given to the Sizewell Inquiry and related to specific proposals for the UK programme. For the present study, prices have been based on a hypothetical plant based on the same technology, as illustrated in Figure 3.1, built and operated to coincide precisely with the requirements of the PWR power station under consideration. Although such timing and adoption of technology which would by then be obsolete would in practice be unlikely, this approach was adopted as providing a conservative estimate of reprocessing prices for the relevant period of operation. There is already an established world market in reprocessing (supplied by BNFL and COGEMA) and the price levels derived from the above assumptions are fully supported by firm prices currently available for future contracts.

2. Outline programme and design assumptions

It has been assumed that, after discharge, fuel is stored for 5 years in the reactor pond and then transported to a receipt and storage facility at the reprocessing plant where it is stored for a further year prior to reprocessing. The products of reprocessing are then available for use and are credited in accordance with previously published OECD/NEA methodology. High level wastes are assumed to be vitrified and stored for 50 years prior to final disposal. This programme is illustrated in Figure 3.2 which gives timescales for construction, operation and decommissioning of the required plant.

Recovery of plutonium and uranium products is very efficient (very close to 100 per cent) with 1 kg HM producing approximately 8 g plutonium, 960 g recovered uranium at about 0.8 per cent ^{235}U enrichment and 30 g of fission product wastes (1 g of plutonium utilised in mixed oxide fuel is the heat equivalent of 1 tonne of oil). The value of these products is taken into account in the form of credits, as described in Annex 8. As a corollary, the radioactive wastes accompanying the plutonium and uranium are removed in a number of waste streams. Wastes arise both directly from the processed fuel

(fission products, transuranics and hulls) and from other materials involved in the process (used equipment, degraded solvent and contaminated articles and refuse). Wastes from both sources are categorised according to level of radioactivity:

- high level waste (HLW) contains about 97 per cent of the total activity and is immobilised in glass inside 150 litre stainless steel containers giving a highly stable waste form for storage and disposal;

- intermediate level waste (ILW) is incorporated into bitumen or cement matrices in steel containers; and
- low level waste (LLW) is either handled in the same way as ILW or is sorted and compressed for disposal in steel containers.

For all these wastes there are clearly established management techniques which meet strict safety regulations. There are currently several major programmes aimed at reduction of waste levels and volumes as indicated below in the section on future improvements. These will have a positive impact on both economic and environmental aspects.

3. Plant cost estimates

The cost estimates for the various stages of the reprocessing option are given in Table 3.1. The experience and assumptions on which they are based are described below.

i) Receipt and storage

Pond storage costs are based on substantial experience of design and construction of this type of facility for different applications.

ii) Reprocessing

The costs for this plant are based on the outturn costs experienced in the construction of THORP including the associated research and development costs. More realistic assumptions on throughput have been used compared with the previous study (1 200 tU per year nominal throughput plant operating at 900 tU per year rather than 600 tU per year) and with an economic life of 28 years given appropriate refurbishment. It is assumed that the plant is fully utilised.

iii) Waste treatment and storage

The cost of storing and vitrifying HLW is based on experience of construction and operation at Sellafield of 21 tanks for HLW liquid storage and the Windscale vitrification plant. The costs for ILW treatment plants are again based on experience with currently operating plants where the ILW is embedded into a cement matrix held within steel containers. The costs also cover the storage facilities where the treated ILW is held for a short period prior to disposal. The cost estimates for the treatment and disposal of LLW are based on current practice using shallow land burial techniques at the Drigg site.

Table 3.1. **Summary of basic data used by BNFL for calculating the cost of PWR spent fuel management**

Plant	Size	Capital M £	Operating M £ p.a.	Refur-bishment M £	Decommis-sioning M £
Transport of spent fuel to the reprocessing plant					
1. Flask maintenance		27	1	5	11
2. Multi-element bottles		32	0	0	0
3. MEB maintenance		27	1	5	11
Fuel receipt & storage	900 tU/y	100	11	15	27
Reprocessing plant	900 tU/y	2 300	145	465	690
HLW vitrification	600 pks/y	260	22	27	75
HLW interim storage	16 800 pks	70	2		22
ILW encapsulation	794 m^3/y	300	33	60	86
ILW interim storage	2 300 m^3	38	1		11
LLW disposal	5 295 m^3/y		11		
ILW disposal	794 m^3/y		5		
Transport equipment		4.5			
Transport, operating & packaging			1.16		
Disposal facility	900 tU/y	82	19		6.1

Notes:
- Assumed exchange rate £1 = ECU 1.4.
- All costs based on a dedicated HLW repository, commencing 56 years post discharge of fuel.
- Based on total fuel quantity of 25 000 tU disposed over 28 years.

iv) Waste disposal

The costs for treated ILW disposal were based on indicative costs as provided by the UK Nuclear Industry Radioactive Waste Executive (NIREX) and have been included in the reprocessing price. The costs associated with the disposal of vitrified HLW are based on updated estimates and are consistent with a UK industry-wide study awaiting publication. ILW and HLW disposal costs are based on preliminary design estimates and a conceptual study, respectively. The costs should therefore be regarded as less certain when compared with the basis for most of the preceding costs. To cover this uncertainty, contingency allowances have been included in deriving the cost estimates used.

v) Operating costs

The operating cost figures provided include the following components:

- direct labour, repair and maintenance;
- supply and process, rates and insurance;
- site services, depreciation, direct materials;
- works overheads and company overheads.

It has been assumed that the plant is built at an established nuclear site with no additional infrastructure costs.

vi) Decommissioning

BNFL has further developed its decommissioning policy which is now based on passive safe storage for 20 years post operation with decommissioning being completed over the following 7 years. Decommissioning costs for the reprocessing and associated service plants are assumed to be 30 per cent of the original capital cost (in constant money terms).

Cost cash flows of the reprocessing and waste disposal facilities are shown in Figure 3.3.

4. Levelised price derivation

Based on the cost estimates and timings given above, levelised unit prices have been calculated separately for reprocessing (including ILW disposal) and HLW disposal. The prices have been calculated using cost estimates that are based on out-turn costs for the reprocessing and its associated support plants and include a component for research and development. Other estimates for ILW and HLW disposal additionally contain a contingency allowance. Costs have been levelised in the case of reprocessing to the point of delivery at the reprocessing site and, in the case of HLW disposal, to the point of delivery to the disposal site. The levelisation is illustrated in Figure 3.4. The methodology is the same as that adopted for levelising the fuel cycle costs described in Annex 1.

Levelised prices are given in Table 3.2 for a range of discount rates. For the purposes of this study it has been agreed to adopt the 5 per cent discounted costs as an indicator of likely price. The resulting value for reprocessing, ECU 720 per kg U, is in line with current firm prices for reprocessing contracts for future business.

Table 3.2. **Levelised unit prices (ECU/kg U) of reprocessing and disposal of vitrified waste for a range of discount rates**

Discount rate	**0%**	**2%**	**5%**	**8%**	**10%**	**12%**	**15%**
Reprocessing	620	640	720	840	930	1 040	1 220
HLW disposal	60	70	90	120	140	170	220

5. Basic design and future improvements

i) Basic design

The environmental standards related to nuclear wastes are set in terms of the total return of radioactivity through the biosphere to man. This depends in turn on both the quantities of radionuclides in the wastes and the nature and integrity of the barriers between the wastes and man. These barriers may be physical e.g. cladding, containers, overpacks, and chemical/geological, e.g. bentonite clay, natural insolubility, absence of ground water, stable rock formations, etc.

Existing and planned reprocessing facilities are based on a technology that achieves a high level of purity in recovered uranium and plutonium products and ensures that only a small fraction of the uranium and plutonium appears in wastes and the bulk of this is concentrated in a solid form. The specification of all wastes disposed or released to the environment is set or approved by regulatory authorities with due regard to the protection of man. The achievement of the high levels of plutonium and uranium separation from the waste streams to which the industry currently works has a substantial effect on the overall cost of reprocessing.

It appears feasible, therefore, that even without any fundamental improvement in reprocessing technology, a different optimisation of product and waste stream specifications could lead to lower overall costs and hence low reprocessing prices for services provided by new facilities which could be constructed in the future*. Such an optimisation with a lower level of plutonium separation could have been assumed as the basis of the design of the reprocessing plant in this study. The extent to which cost advantage may be taken would be dependent on customer views since they ultimately have the responsibility for disposing the resulting high level waste products. Public and political attitudes would influence the regulatory position and would then also play a part.

ii) Future improvements

Reprocessing technology is well established, having been developed from a uranium metal based process to one capable of handling oxide fuels. COGEMA's latest plant UP3 has met or exceeded its design specification in its first year of operation. Although current reprocessing costs are in excess of those envisaged in the 1960s, there is firm evidence that the peak has been reached and that further industrial development and increased operating experience will bring continued economies.

In addition to scope for cost reduction in reprocessing plants there is clearly considerable potential for cost reduction in the area of waste management. There are a number of major programmes aimed at reducing the volume of wastes arising and COGEMA has set a target of 80 to 90 per cent reduction in ILW volumes by the year 2000, as indicated in Table 3.3. The key feature
of this programme is the goal of "zero bitumen" by 2000 which can be achieved through improvements in fluid recycling, evaporation etc. Already, very promising progress has been made towards these goals. The result by 2000 should be that, in terms of long-lived waste (for underground disposal), only about 0.5 m^3 waste per tonne of uranium will arise from reprocessing as compared with 1.4 m^3 today.

Table 3.3. **Volumes (l/tU) of long-lived wastes generated by the French**

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* A COGEMA assessment has shown a cost advantage of about 25 per cent in overall reprocessing cost (excluding disposal cost considerations) for a plant design with a plutonium separation level of 99 per cent compared with the current 99.9 per cent.

UP3 reprocessing plant, based on a throughput of 800 tU/y

	Original specification	Expected by 2000
Glass	130	115
Other	2 920	<350
Total	3 050	<465

To estimate the levels of likely future cost reduction, an assessment was made of the various factors which could contribute:

- Process improvements, the continuous improvement of current processes, such as improved decontamination factors and process materials recycling can make a significant impact in the short- to medium-term and were estimated to have a potential for 5 to 10 per cent reduction in costs.
- Industrial experience, via improved labour and overall productivity, more efficient maintenance programmes and reduced inventories was estimated to contribute a further 10 to 20 per cent reduction in costs over the 15 to 20 year period before reprocessing commences. Note that chemical industries typically achieve a 2 to 3 per cent annual improvement in productivity once at the top of their learning curve as is the case with reprocessing.
- Increased process throughput has a direct effect on unit costs as the majority of costs are fixed. This was estimated to contribute a further 10 to 20 per cent towards future cost reductions. This magnitude of improvement has already been achieved with the head-end unit at La Hague which currently achieves 550 tonnes per year compared with a design throughput of 400 tonnes per year.

- Increased plant life would also offer scope for cost reductions. For example, an increase from 28 to 40 years would, including the additional refurbishment, reduce costs by about 10 per cent.

A range of specific areas where improvements can be confidently predicted are listed in Table 3.4.

Taking a conservative combined estimate of these factors shows that the 25 per cent reduction adopted for the lower price range limit should be readily achievable.

These cost reductions from possible future developments do not take account of the possible reductions in the cost of a basic design adopting a lower level of plutonium separation, as described in sub-section 5 i) above. The combined effects of these factors would not necessarily be additive.

Table 3.4. **Developments in reprocessing**

Extraction cycle
- Process optimisation (in order to obtain the required contamination factors with fewer extraction cycles) - Novel process options for the purification cycle e.g. centrifugal contactors - Improved analytical methods - Advanced monitoring methods
Solid and liquid wastes treatment
- Alternative processes for hulls and end pieces for volume reduction - Improved glass quality for vitrification - Improved vitrification capacity (induction heating for calcination, cold crucible technology for the melter) - Co-precipitation process for LLW and ILW (supernate clarification and additional decontamination) - New management and conditioning processes for LLW and ILW - Increased alpha decontamination of technological wastes

6. Sensitivity range

There is continuing regulatory pressure on all aspects of the nuclear cycle. It is possible that further pressure could have an impact on costs in some areas. However, the strong likelihood of economies arising from technological developments and commercial pressure make any upward movement of reprocessing prices highly unlikely. Hence a sensitivity range of +0 to -25 per cent is adopted.

The use of no upside price risk can be supported in two ways:

– It is, at present, possible for any electricity utility to obtain a long-term reprocessing service at a firm contract price of about ECU 700 per kg U. Thus, even the smallest of utilities can benefit from the scale effect of a worldwide reprocessing market with any risk of capacity under-utilisation being borne entirely by the reprocessors.
– The conservative estimate for building a new reprocessing facility, as calculated for this study, arrives at a very similar figure, showing that the reprocessing market is in the healthy position of the current market price fully reflecting the development costs of new facilities.

The potential market for reprocessing remains large in terms of spent fuel arisings, so high capacity utilisation is expected.

The reference reprocessing case is for reprocessing after 6 years storage whereas the reference case for direct disposal assumes storage of fuel for 40 years before encapsulation and disposal. A calculation was undertaken in which it was assumed that reprocessing and spent fuel encapsulation

were carried out on a similar deferred timescale, with the encapsulated spent fuel and the resulting conditioned wastes from reprocessing being disposed of immediately thereafter. This comparison showed that the cost advantage to direct disposal in the reference cost comparison became negligibly small. This result is insensitive to assumptions on credits for uranium and plutonium.

Figure 3.1 **BNFL back-end fuel cycle operations**

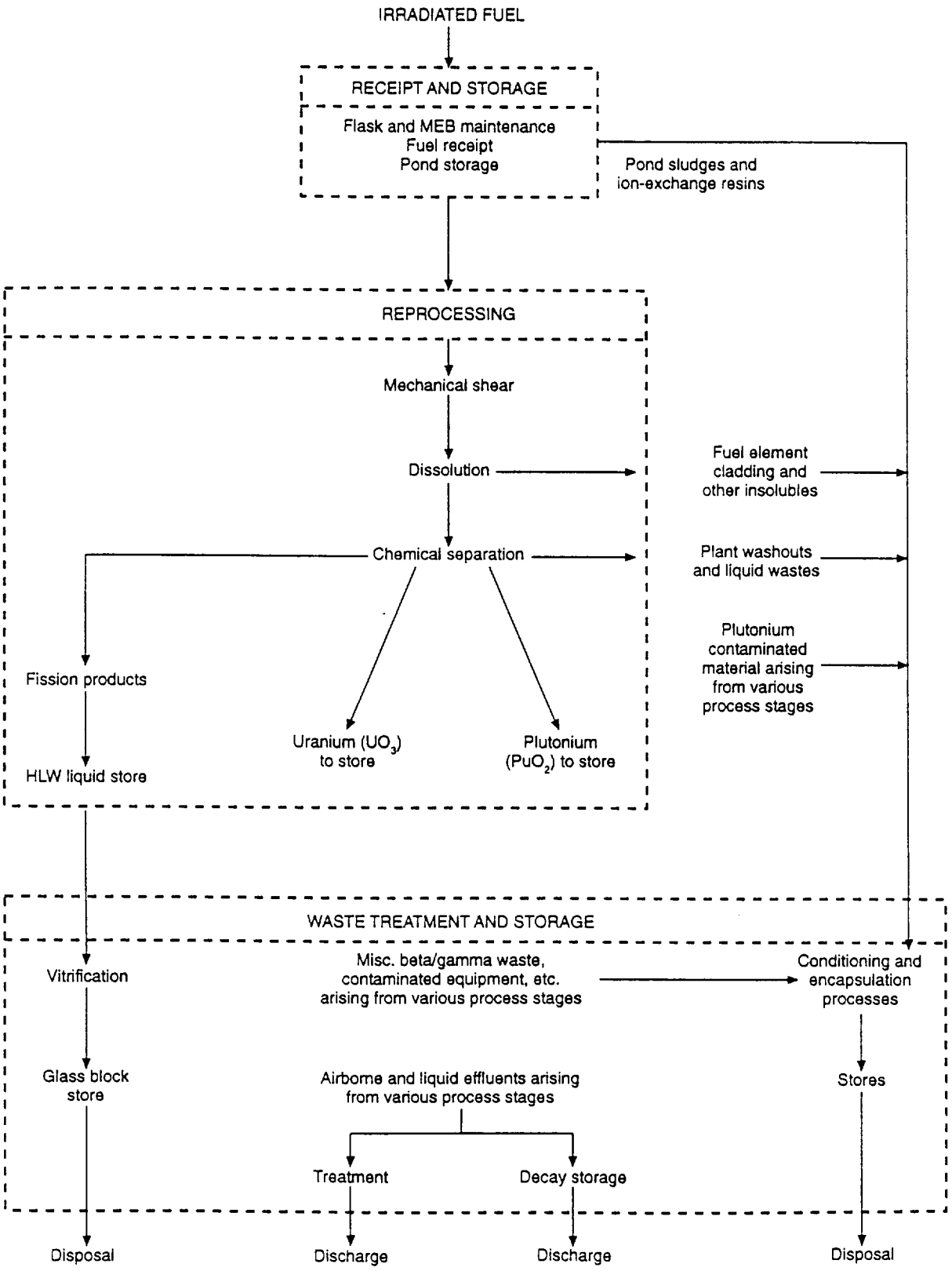

Figure 3.2 **Programme of a 900 tU per annum throughput plant operating over 28 years**

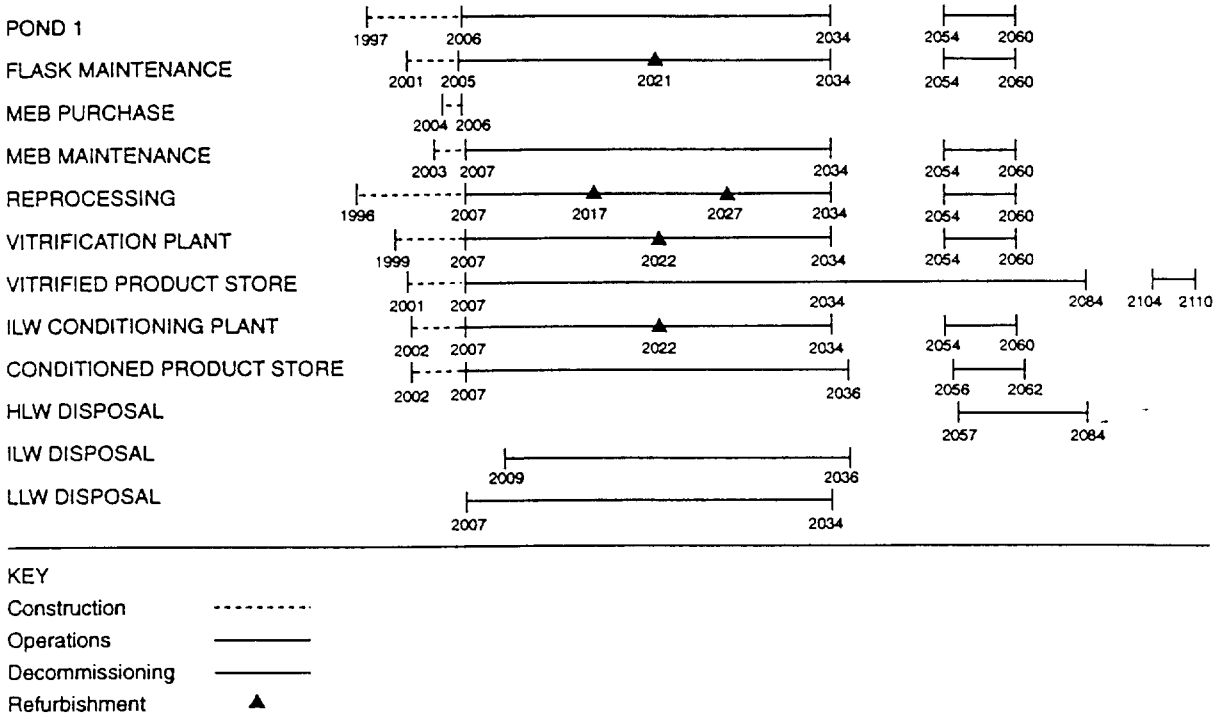

Figure 3.3 **Cost cash flow of a 900 tU per annum reprocessing plant and associated facilities**

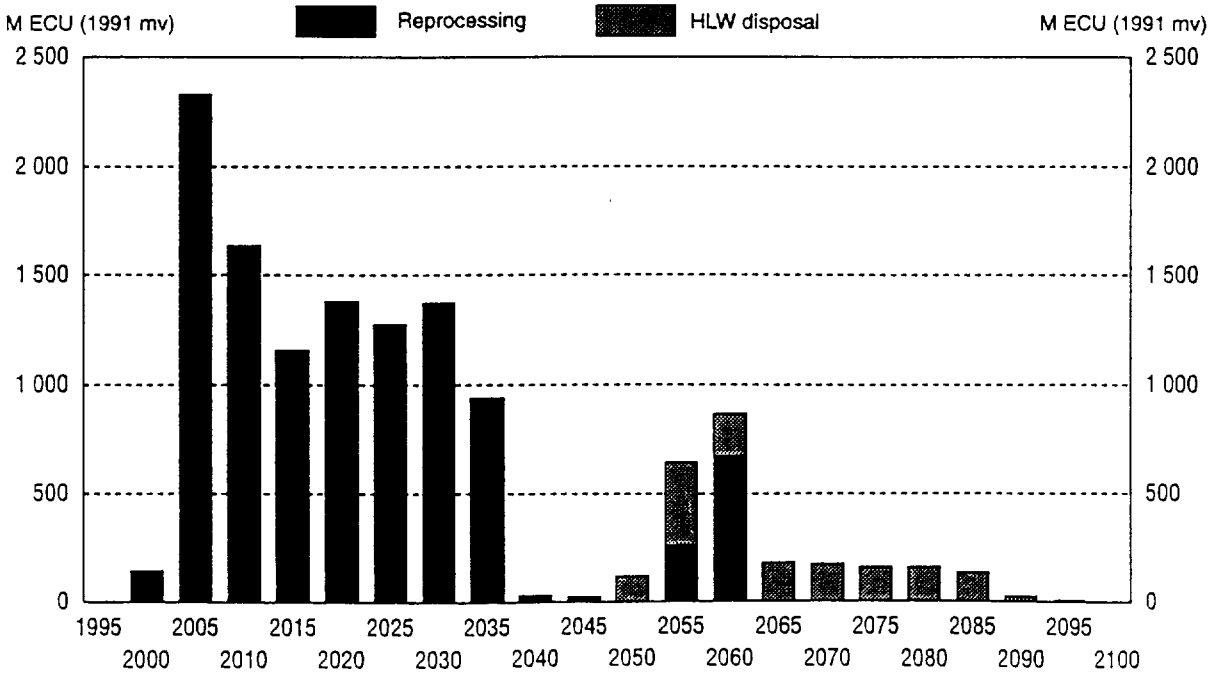

Figure 3.4 **Levelisation of reprocessing and HLW disposal costs**