# 6. SENSITIVITY ANALYSES FOR PWR FUEL COSTS

## 6.1 General

Sensitivity calculations were made to analyse the impact on the total fuel cycle cost of variations in the technical parameters and in the unit prices for each fuel cycle component. The results of these sensitivity analyses are summarised in Figure 6.1 for the reprocessing option and Figure 6.2 for the direct disposal option.

## 6.2 Technical parameters

### *6.2.1 Reactor life*

The reactor life is an important factor in the evaluation of total generation cost (mills/kWh) for a nuclear power station because it influences the total amount of electricity produced and hence the capital contribution to the unit cost. The reference reactor lifetime is 30 years. In the sensitivity cases this value changed to 25 and 40 years.

Although important to the total generation cost, the lifetime assumption does not have a major influence on the total unit fuel cost because fuel usage is related directly to the amount of electricity generated.

### *6.2.2 Tails assay*

The reference value of the tails assay was assumed to be 0.25 per cent $^{235}U$ in the uranium tails. Operation at 0.2 per cent tails assay increases the total fuel cost by about 1 to 2 per cent for the reprocessing and the direct disposal options, respectively. The fuel cost in the case of 0.3 per cent tails assay is almost the same as the cost for the 0.25 per cent tails assay.

### *6.2.3 Burn-up*

Annex 9 discusses the sensitivity of fuel cycle costs to fuel discharge burn-up and the way it is influenced by the level of fuel cycle component prices and of the discount rate. It is shown that, for the reference data, the fuel cycle cost still decreases with fuel burn-up above the 42.5 GWd/t reference value.

## 6.3 Discount rate

Figures 6.3 and 6.4 show the effects of the discount rate on the fuel cycle cost for the reprocessing and direct disposal options, respectively. For both options the front-end fuel costs are identical and increase with an increasing discount rate. This is due to the compounding effect that the lead times for the purchase of uranium and front-end fuel cycle services have on the levelised fuel cost.

The unit prices for back-end services that were used in the sensitivity analysis were obtained using a rate of return equal to the discount rate. This properly reflected the time value of money as seen by the utility and the service provider. Despite increasing back-end service prices with an increasing discount rate, the overall effect is for the back-end unit fuel cost to reduce and then level out in the reprocessing case; or to reduce to a minimum and then increase slightly in the direct disposal case. This is due to the electricity production occurring before the back-end payments are made.

As will be seen from Figures 6.3 and 6.4, the overall effect on the total levelised unit fuel cost is for minima to occur at the 2 and 5 per cent discount rates for the reprocessing and direct disposal options, respectively.

The effect of the discount rate on the individual components of the fuel cycle is shown in detail in Tables 6.1 and 6.2.

The effect of varying the discount rate in deriving the fuel cycle cost but holding the levelised price for the back-end components at a fixed value is shown in Annex 2.

## 6.4 Fuel cycle component prices

Figures 6.1 and 6.2 show that the total fuel cost is particularly sensitive to the uranium and enrichment price (more so for the latter than in the 1985 study). In the direct disposal option the back-end contributed 13.9 per cent of the total unit fuel cost, hence any alteration in the unit price for the back-end services has a minimal effect on the overall unit fuel cost. This is also true for the reprocessing option although the contribution the back-end component makes to the overall unit fuel cost is somewhat larger in this case.

## 6.5 Comparison of total fuel cycle costs

For the reference assumptions and unit prices, the difference between the two options is 0.77 mills/kWh, which in absolute terms is slightly lower than that in the 1985 study. As there is no difference in the front-end costs for the two scenarios, the difference is due to the back-end costs, particularly the assumed timing of events and the magnitude of the recovered uranium and plutonium credit. The 12.4 per cent difference between the two fuel cycle options is considered to be insignificantly small in the light of the underlying cost uncertainties, and in any event, it represents a negligibly small difference in overall generating cost terms.

## 6.6 Likely range of total fuel cycle costs

The reference fuel cycle cost together with higher and lower bounding values are shown in Figures 6.5 and 6.6. The higher and lower bounds show the extreme maximum and minimum range of nuclear fuel cycle costs. These extremes have been derived by the simple mathematical addition of each component fuel cost at its maximum or minimum. Each component cost is dependent on two types of parameters:

a) the price and price range for uranium and every fuel cycle service;
b) the technical assumptions on lead times, tails assay, reactor lifetime, etc.

In practice, not all parameters would simultaneously assume the high or low extremes, and the realistic uncertainty range is much narrower.

To derive this more realistic range, a statistical analysis has been performed. This analysis held all technical parameters fixed to the reference value and only considered price variations for the fuel cycle components of Table 5.5. It was assumed that each component price would lie within a rectangular distribution bounded by the ranges shown in Table 5.5 and that each component price was independent of the others. Using well established, standard statistical analysis techniques, the expected value and the variance for each fuel cycle component was calculated. These were then combined statistically to derive the overall fuel cycle cost range within the 95 per cent confidence interval. This is shown in Table 6.3 and as a vertical line in Figures 6.5 and 6.6. The range shown is approximately ±20 per cent around the reference fuel cycle cost for both the reprocessing and direct disposal options.

This analysis does not take into account the scope that exists in fuel cycle management to offset an increase in one component price by varying one of the technical parameters. For example, an increase in uranium price can be offset by reducing tails assay and using more enrichment services for a given quantity of fuel. The corollary of this is that an increase in enrichment price can be offset by increasing tails assay. The effect on fuel cycle costs of increases in the unit price for back-end services may be offset by increasing fuel burn-up. Through use of these measures there is confidence that fuel cycle costs can in practice be optimised to developing market conditions and held within the ranges indicated by the vertical lines in Figures 6.5 and 6.6.

Table 6.1. **Effect of discount rate on fuel cycle costs (reprocessing option)**
(mills/kWh)

| Fuel cycle component | Discount rate (%) 0 | 2 | 5 | 8 | 10 | 12 | 15 |
|---|---|---|---|---|---|---|---|
| Uranium | 1.45 | 1.52 | 1.64 | 1.78 | 1.89 | 2.00 | 2.19 |
| Conversion | 0.18 | 0.19 | 0.21 | 0.23 | 0.24 | 0.25 | 0.28 |
| Enrichment | 1.65 | 1.72 | 1.85 | 1.98 | 2.07 | 2.18 | 2.33 |
| Fuel fabrication | 0.87 | 0.92 | 1.00 | 1.09 | 1.16 | 1.23 | 1.34 |
| **Subtotal for front-end** | **4.15** | **4.35** | **4.70** | **5.08** | **5.36** | **5.66** | **6.14** |
| Transport of spent fuel | 0.16 | 0.14 | 0.11 | 0.10 | 0.09 | 0.08 | 0.07 |
| Reprocessing | 1.97 | 1.78 | 1.66 | 1.63 | 1.61 | 1.62 | 1.63 |
| Waste disposal | 0.18 | 0.07 | 0.02 | 0.004 | 0.002 | 0.001 | 0.00 |
| **Subtotal for back-end** | **2.31** | **1.99** | **1.79** | **1.73** | **1.70** | **1.70** | **1.70** |
| Uranium credit | -0.30 | -0.24 | -0.18 | -0.13 | -0.11 | -0.09 | -0.07 |
| Plutonium credit | -0.12 | -0.10 | -0.08 | -0.06 | -0.06 | -0.05 | -0.04 |
| **Subtotal for credit** | **-0.42** | **-0.34** | **-0.26** | **-0.19** | **-0.17** | **-0.14** | **-0.11** |
| **Total cost** | **6.04** | **6.00** | **6.23** | **6.62** | **6.89** | **7.22** | **7.73** |

**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 |

*Note:* Data at the same discount rate were used in deriving the above **back-end** fuel cycle costs, i.e. a reprocessing price of ECU 720 per kg U was used to obtain the final cycle cost at the 5 per cent discount rate and a reprocessing price of ECU 930 per kg U was used for the fuel cycle cost at 10 per cent discount rate. The same convention was used for the waste disposal component.

Table 6.2. **Effect of discount rate on fuel cycle costs (direct disposal option**)
(mills/kWh)

| Fuel cycle component | Discount rate (%) | | | | | | |
|---|---|---|---|---|---|---|---|
| | **0** | **2** | **5** | **8** | **10** | **12** | **15** |
| Uranium | 1.45 | 1.52 | 1.64 | 1.78 | 1.89 | 2.00 | 2.19 |
| Conversion | 0.18 | 0.19 | 0.21 | 0.23 | 0.24 | 0.25 | 0.28 |
| Enrichment | 1.65 | 1.72 | 1.85 | 1.98 | 2.07 | 2.18 | 2.33 |
| Fuel fabrication | 0.87 | 0.92 | 1.00 | 1.09 | 1.16 | 1.23 | 1.34 |
| **Subtotal for front-end** | **4.15** | **4.35** | **4.70** | **5.08** | **5.36** | **5.66** | **6.14** |
| Transport/Storage | 0.67 | 0.55 | 0.51 | 0.55 | 0.58 | 0.62 | 0.66 |
| Encapsulation/Disposal | 1.14 | 0.60 | 0.25 | 0.11 | 0.07 | 0.04 | 0.02 |
| **Subtotal for back-end** | **1.81** | **1.15** | **0.76** | **0.66** | **0.65** | **0.66** | **0.68** |
| **Total cost** | **5.96** | **5.50** | **5.46** | **5.74** | **6.01** | **6.32** | **6.82** |

**Back-end levelised unit prices (ECU/kg U) for the direct disposal option at various discount rates**

| | Discount rate (%) | | | | | | |
|---|---|---|---|---|---|---|---|
| | **0** | **2** | **5** | **8** | **10** | **12** | **15** |
| Transport/Storage | 210 | 200 | 230 | 280 | 340 | 400 | 500 |
| Encapsulation/Disposal | 360 | 430 | 610 | 870 | 1 100 | 1 390 | 1 920 |

*Note:* Data at the same discount rate were used in deriving the above **back-end** fuel cycle costs, i.e. a transport/storage price of ECU 230 per kg U was used to obtain the final cycle cost at the 5 per cent discount rate and a transport/storage price of ECU 340 per kg U was used for the fuel cycle cost at 10 per cent discount rate. The same convention was used for the waste encapsulation/disposal component.

Table 6.3. **Likely range of fuel cycle costs, overall and for separate uranium price profiles**
(mills/kWh)

| | **Reprocessing option** | **Direct disposal option** |
|---|---|---|
| For all parameters | 5.17-7.06 | 4.28-6.30 |
| U price: $50/kg U, escalation 1.2% p.a. (reference) | 5.39-6.65 | 4.54-5.88 |
| U price: $40/kg U, escalation 0% p.a. | 4.83-6.10 | 3.93-5.26 |
| U price: $90/kg U, escalation 0% p.a. | 6.06-7.33 | 5.25-6.58 |

*Note:* As described in section 6.5, the "likely range" is based on the two sigma limit (i.e. 95 per cent confidence interval) of the overall fuel cost distribution.

Figure 6.1 **Summary of sensitivity analysis for the reprocessing option**

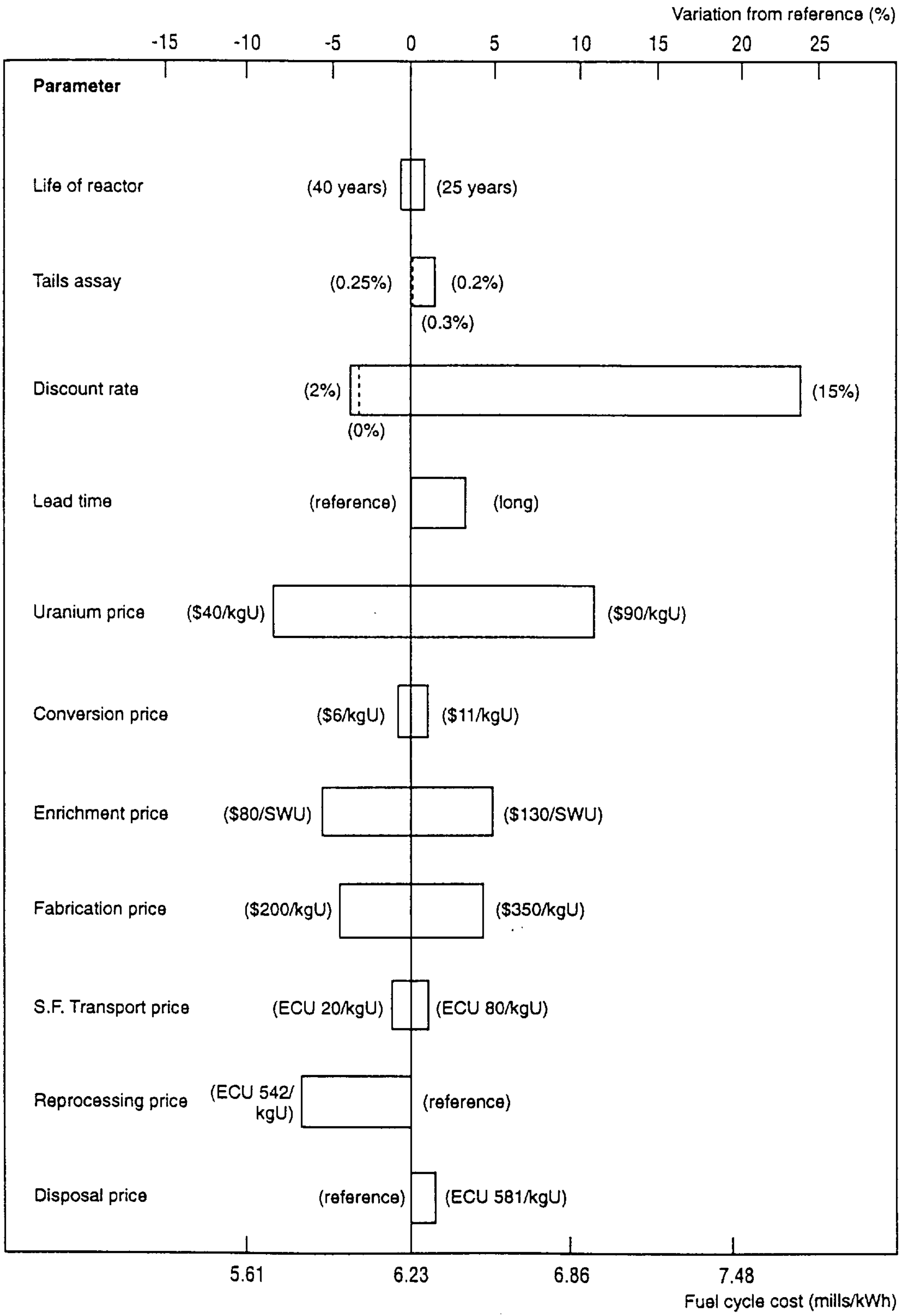

Figure 6.2 **Summary of sensitivity analysis for the direct disposal option**

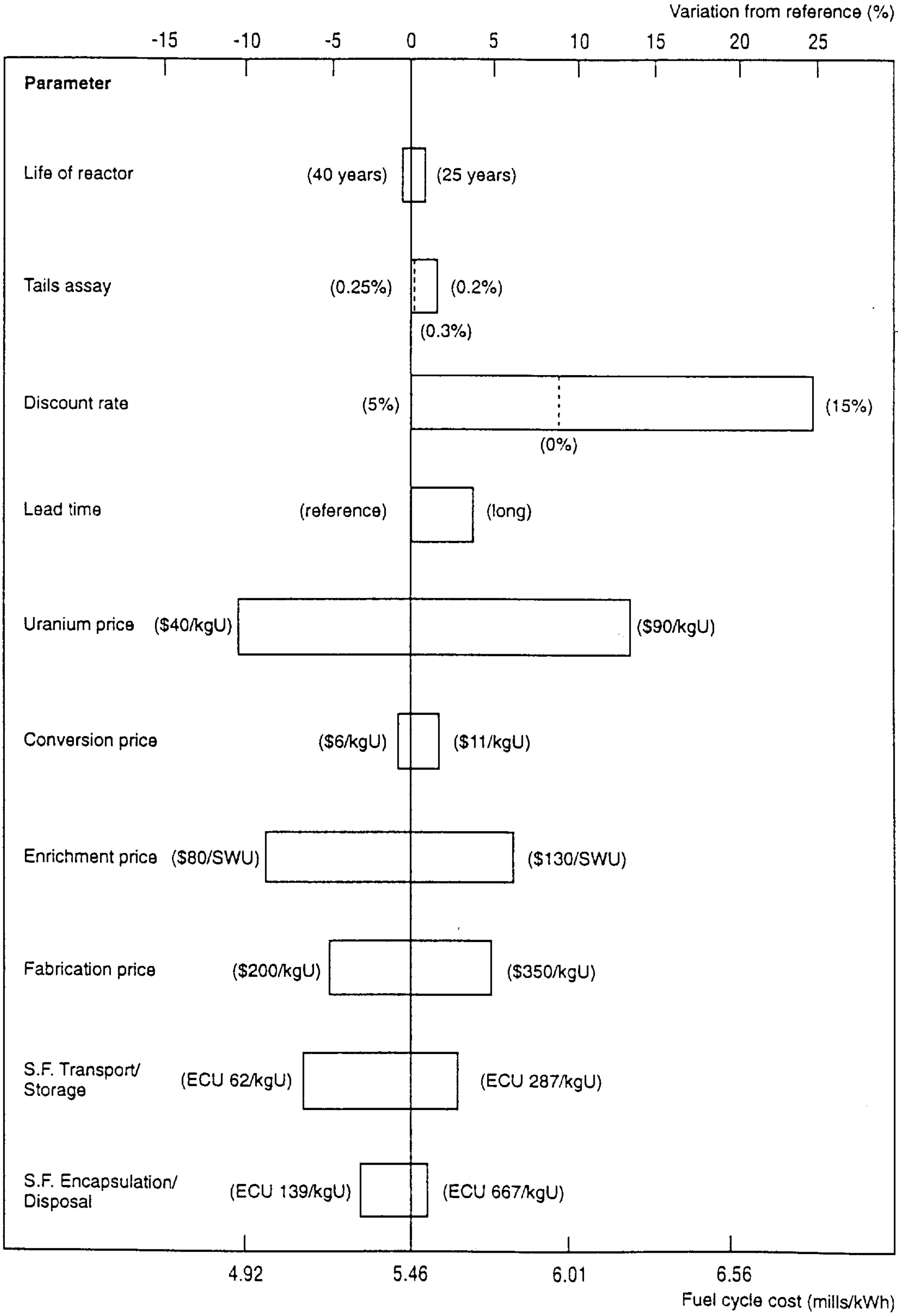

Figure 6.3 **Effect of discount rate on fuel cycle costs**
(reprocessing option)

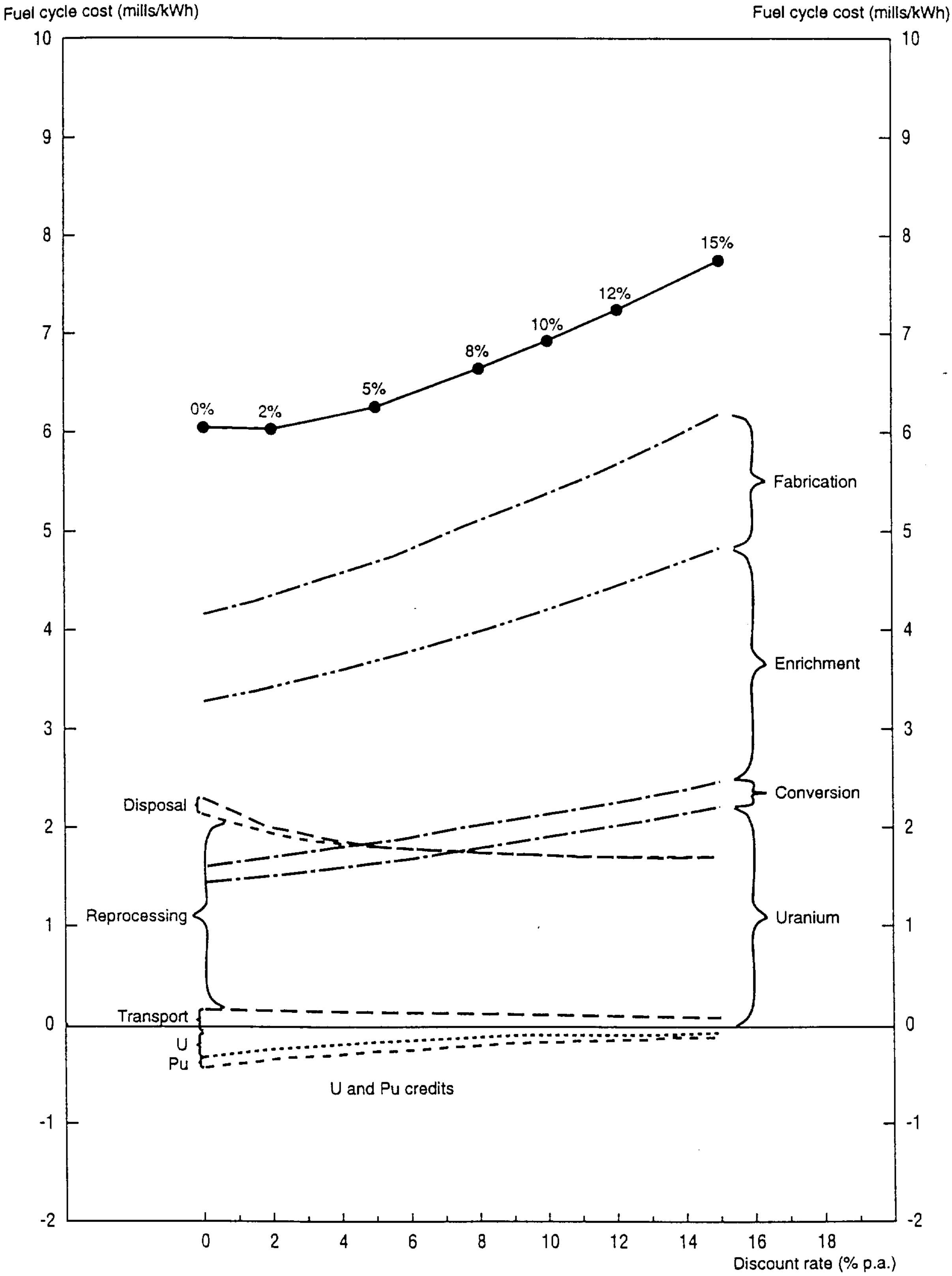

Figure 6.4 **Effect of discount rate on fuel cycle costs**
(direct disposal option)

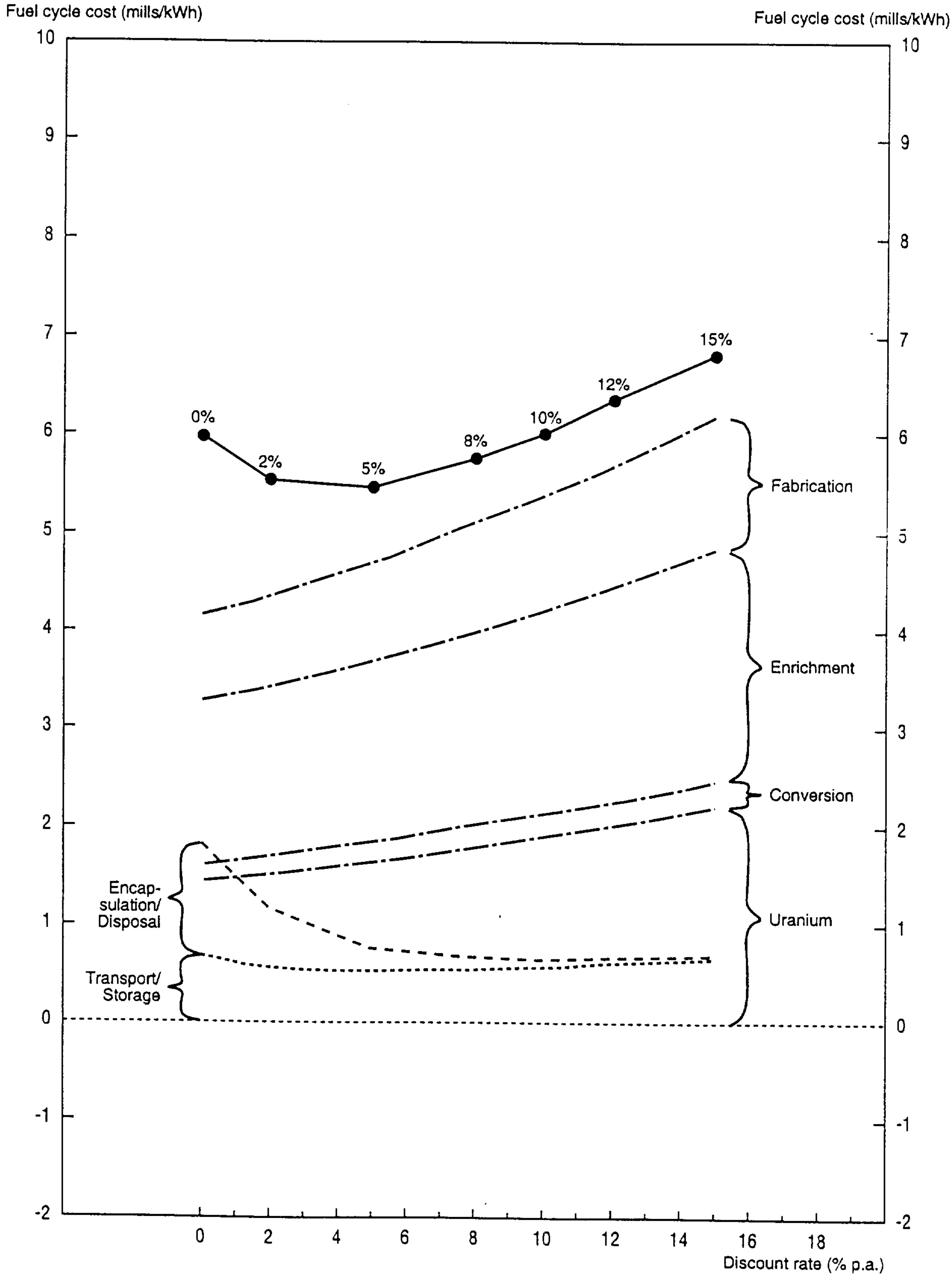

Figure 6.5 **Maximum range of PWR fuel cycle cost for the reprocessing option**

| Parameter | Higher bound | Lower bound |
|---|---|---|
| Life of reactor<br>Tails assay<br>Lead time<br>Unit costs | 25 years<br>0.20%<br>Longer lead times<br>Higher variants | 40 years<br>0.25% (reference)<br>Reference lead times<br>Lower variants |

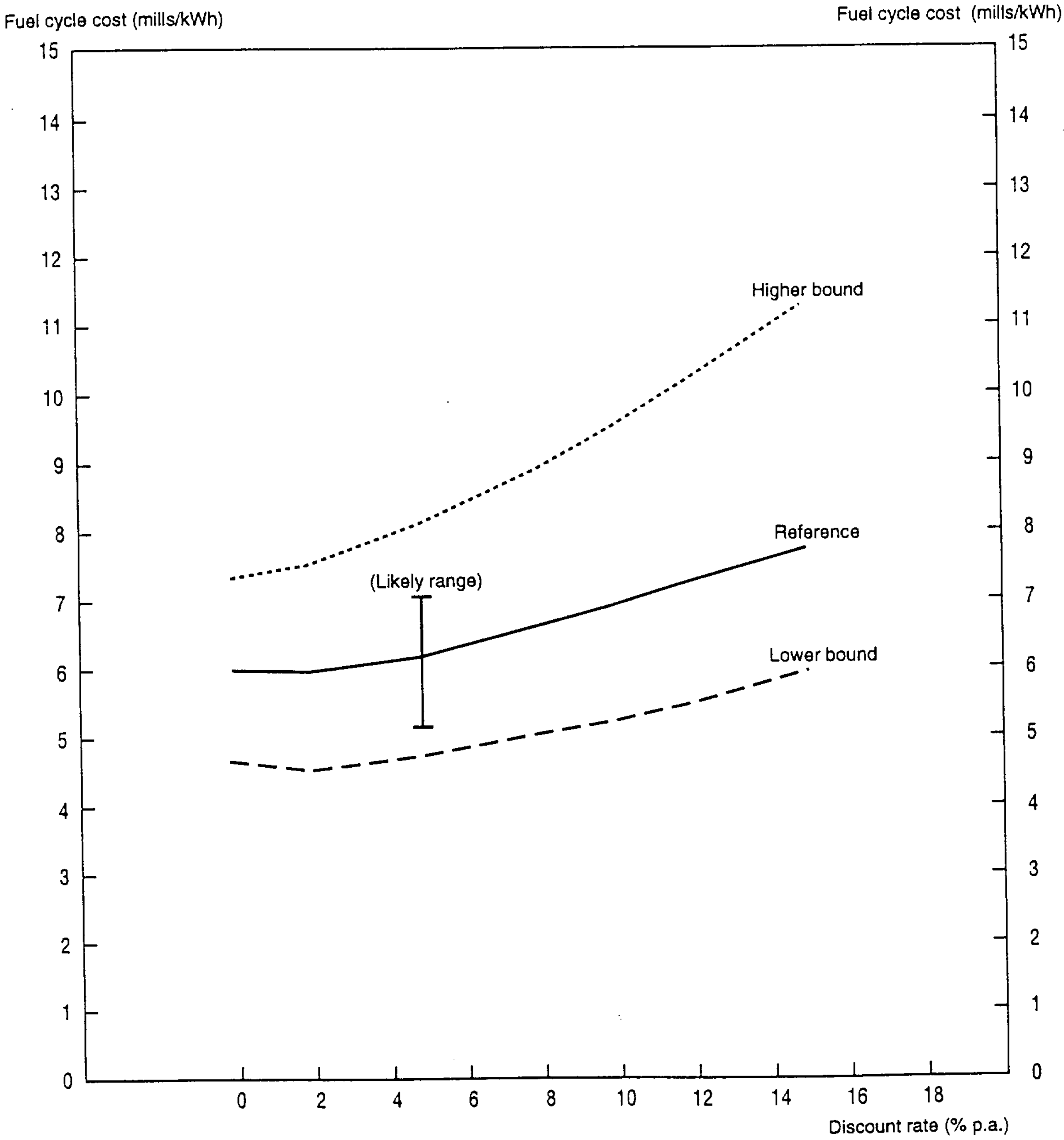

Figure 6.6 **Maximum range of PWR fuel cycle cost for the direct disposal option**

| Parameter | Higher bound | Lower bound |
|---|---|---|
| Life of reactor<br>Tails assay<br>Lead time<br>Unit costs | 25 years<br>0.20%<br>Longer lead times<br>Higher variants | 40 years<br>0.25% (reference)<br>Reference lead times<br>Lower variants |