Annex 5

DIRECT DISPOSAL OPTION COST ESTIMATES: UNITED STATES

1. Introduction

The United States Department of Energy's (DOE) Office of Civilian Radioactive Waste Management (OCRWM) publishes total system life cycle cost (TSLCC) estimates for the nuclear waste disposal system. The most recent analysis is titled Preliminary Estimates of the Total-System Cost for the Restructured Programme: an Addendum to the 1989 Analysis of the Total-System Life Cycle Cost for the Civilian Radioactive Waste Management Programme, (DOE/RW-0295P) published in December 1990. TSLCC calculations are performed to aid in determining if the fees currently being charged to the civilian waste owners and generators will adequately cover programme costs. The TSLCC estimates represent "snapshots" in time which incorporate all available and appropriate information on programme activities up to a specific point in time in order to develop a comprehensive set of cost estimates for the system.

The cost estimates in this analysis assume a waste management system with a total volume of approximately 96 300 metric tonnes of heavy metal (MTHM) which will be emplaced in a single deep geologic repository. The single repository would handle radioactive waste from three different sources:

a) 86 800 MTHM of spent nuclear fuel from 120 civilian reactors;
b) 8 875 MTHM of defence high level waste (DHLW) from four sites;
c) 640 MTHM of civilian high level waste from the West Valley Demonstration Project (WVHLW).

Since 1985, a number of developments impacting the US waste management system occurred. They are:

- In 1985, President Reagan decided that separate facilities for utility spent fuel and government generated wastes were not to be pursued, but that each party must pay its full share of the total programme costs.
- In December 1987, Congress passed the Nuclear Waste Policy Amendments Act (NWPAA) and directed the DOE to stop all work on two of the candidate sites and to investigate only the Yucca Mountain, Nevada, site as a candidate for the first repository. The NWPAA also directed the DOE to stop all work on the second repository programme.
- In 1987, because the programme has been plagued by litigation at each step of the siting process, the DOE announced a delay in the schedule of the opening of the first repository from 1998 to 2003.
- On November 1989, the Secretary of Energy completed an extensive review of the programme and submitted to the Congress a report describing a restructuring of the programme. In the report, the Secretary announced a revised repository scheduled opening date of 2010.

2. Outline of the programme

Figure 5.1 is a diagram of the assumed waste management system. After removal from the reactor core, spent nuclear fuel is stored at its place of origin, or other suitable short-term storage facilities. In 1998, spent nuclear fuel would be transported via rail and truck to the Monitored Retrievable Storage (MRS) facility for interim storage until the repository is operational. The MRS would receive approximately 3 000 MTHM of spent nuclear fuel per year after an initial ramp-up period. The Nuclear Waste Policy Amendment Act limits the capacity of the MRS to 10 000 MTHM until the start of repository emplacement operations; after that, the maximum capacity of the MRS is 15 000 MTHM. All fuel must cool for at least a five year period after it is removed from the reactor prior to acceptance in the waste management system.

The repository is scheduled to begin receipt of spent nuclear fuel for permanent disposal in the year 2010. After an initial ramp-up period, the repository would also receive approximately 3 000 MTHM per year. Five years after emplacement of spent nuclear fuel commences, the DHLW would begin to arrive at the repository for emplacement. The annual amount of DHLW received is assumed to be 400 MTHM. The WVHLW is assumed to be emplaced in the repository after all DHLW is emplaced.

Emplacement of waste in the repository would occur from 2010 until 2042. Following the last year of emplacement, a caretaker (monitoring) phase would begin and last for 17 years until 2059. Decommissioning and closure activities would begin in 2060 and continue for 16 years until 2075 when site closure would be completed. Under this scenario, the last spent nuclear fuel discharge occurs in 2037, but the last emplacement occurs in 2042. The reason for this is to meet the required minimum five year cooling period for fuel once it has been removed from a reactor. During the emplacement phase, the average operating staff for the repository would be 1 105 full-time equivalents, while the average staff at the MRS during operations would be 390 full-time equivalents.

Yucca Mountain in Nevada has been designated by law to be the site where scientific investigations will be conducted to determine if the site is suitable for the development of the first repository. Yucca Mountain is underlain by a sequence of silicic volcanic rocks from more than 3 000 to about 10 000 feet thick. The water table is about 2 500 feet below the land surface. The underground repository would be constructed at a depth about 1 000 feet below the eastern flank of Yucca Mountain. The primary rock-type at the repository location is welded tuff.

Containment of radioactivity is to be controlled through the use of a multiple barrier system. The geologic and geographic features of the site, combined with the heat output of the waste, metal lined boreholes, and the metal disposal containers make up the barrier system. Disposal containers are assumed to be fabricated from 304L stainless steel.

3. Plant cost estimates

Table 5.1 presents a summary of the costs related to the transportation, storage and disposal of spent nuclear fuel for the US programme. All costs in Table 5.1 are in 1991 US dollars with no discounting. Table 5.1 provides a six category breakdown of the major cost components of the waste

disposal system for each phase. The categories are:

- Engineering & Construction – capital cost for construction of all components of the system.
- Operation – costs for operating the MRS (receiving, inspecting, handling, storing and monitoring) and repository facilities (receiving, inspecting, handling, containerising, purchasing waste disposal containers, emplacing and monitoring).
- Decommissioning – costs for closing, and decontaminating, if needed, the MRS and repository facilities.
- Shipping – costs for transporting the waste from the reactor to the MRS and from the MRS to the repository.
- Cask Capital & Maintenance – costs for the purchase and maintenance of the transportation casks.
- Cask Maintenance Facility – costs for the construction and operation of a facility for maintaining the transportation casks.

TSLCC estimates also include costs for development and evaluation (D&E), and benefit payments to the host State or Indian tribe for the repository and the MRS facility. However, these costs are not included in Table 5.1.

The financing system for the US waste management programme was established as part of the Nuclear Waste Policy Act (NWPA) which was signed into law on 7 January 1983. The NWPA authorised the Secretary of Energy (the Secretary) to enter into contracts with owners and generators of high level waste for the transportation and disposal of spent nuclear fuel. The fee of 1.0 mill ($0.001) per kilowatt hour (kWh) of electricity generated and sold after 7 April 1983 was established. The interpretation of "electricity generated" has changed twice since 1983. The 1.0 mill per kWh is now based on net electricity generated and sold, deducting transmission and distribution losses. A separate one-time fee for spent nuclear fuel generated before 7 April 1983 was also levied. The utilities were given several options for payment of the one-time fee. The NWPA also required that if the defence waste used the same repository as the civilian, DOE would pay its fair share of waste disposal costs for the defence waste.

A separate fund in the Treasury of the United States was established, known as the Nuclear Waste Fund (NWF), for the collection of fees. The Secretary is required to annually assess whether the collection of the fee will provide sufficient revenues to cover the costs of the programme. In the event that the Secretary determines that either insufficient or excess revenues are being collected, the Secretary will immediately notify the Congress with a proposed appropriate alteration to the fee.

As of 30 September 1991, approximately $5.2 billion (year of expenditure dollars) had been paid by the utilities into the NWF. From the inception of the programme in 1983 approximately $3.0 billion had been spent from the NWF.

Six assessments of the adequacy of the fee have been performed by DOE to date. Each determined that the collection of 1.0 mill per kWh fee will produce revenues sufficient to cover the costs of the programme.

4. Levelised price derivation

Table 5.2 provides the undiscounted waste disposal costs over time from 1993 to 2075. Table 5.3 provides the same information as Table 5.2, except that all costs are discounted 5 per cent to the point of delivery into the system (1998 for MRS and 2010 for Repository). The undiscounted total cost is $14 888 million 1991 dollars, while the discounted total cost is $5 322 million 1991 dollars.

With a total quantity of spent nuclear fuel and high level waste (both defence and West Valley) of 96 272 000 kg (undiscounted), and 32 824 000 kg (discounted), the total disposal cost for 1 kg of waste would be:

- $14 888 million/96 272 000 kg = $155 per kg (undiscounted);
- $5 322 million/32 824 000 kg = $162 per kg (discounted 5 per cent to point of delivery).

Figure 5.2 shows a comparison of the MRS, repository and total system unit costs for 5 per cent, 10 per cent and 15 per cent. It is important to note that the total does not equal the sum of MRS and repository costs. This is because the MRS and total costs are levelised to 1998 (delivery date into the system), while the repository costs are levelised to 2010 (start of emplacement operations). Figure 5.3 is a graphical depiction of the levelisation periods, as well as a comparison of the unit costs for both no (0 per cent) levelisation and 5 per cent levelisation to the point of delivery.

Table 5.4 presents a breakout of the costs into civilian and defence portions. The costs are shown for both the undiscounted and discounted (5 per cent to point of delivery at the MRS in 1998). Defence costs are determined using previously accepted 1990 TSLCC Addendum methodologies.

With total production of electricity equal to 23 004 TWh (for civilian electricity generation only) the total civilian cost (minus D&E and benefits) for the production of 1 TWh of electricity will be:

- $12 700 million/23 004 TWh = $0.5521 million per TWh (undiscounted);
- $4 584 million/23 004 TWh = $0.1993 million per TWh (discounted).

5. Potential improvements

The waste management system described in this report is based on the reference designs currently under DOE consideration. Investigations are ongoing to design the most efficient and effective waste management system that is consistent with the provisions of the NWPA, as amended. As the results of these investigations become available, stringent reviews, both internally and externally, will be conducted to determine the applicability of these results to the reference design of the waste management system.

6. Sensitivity range

Two additional scenarios previously investigated are presented here. These scenarios involve increased amounts of spent nuclear fuel wastes with the defence high level waste remaining constant. Therefore, two additional scenarios are presented assuming a waste management system with two repositories to dispose of the greater volumes of waste. For a system with two repositories, the costs extend until 2094, when closure and decommissioning of the second repository is completed.

The first scenario assumes that there will be no new orders of nuclear power plants; however, approximately 70 per cent of the existing plants will operate for 20 years beyond their existing 40 year life. This is known as the Plant Life Extension scenario. Under this scenario, approximately 110 000 MTHM of spent fuel is assumed to be discharged over the life of the reactors. For this scenario, a typical reactor is assumed to discharge approximately 1 500 MTHM over its operating life. Table 5.5 provides a breakdown by decade of the disposal cost, by phase, for the plant life extension scenario.

With a total quantity of spent nuclear fuel (110 000 000 kg) and high level waste (both defence and West Valley: 9 515 000 kg) of 119 515 000 kg, the total disposal cost for 1 kg of waste would be:

– $22 852 million/119 515 000 kg = $191 per kg (undiscounted).

The second scenario assumes a substantial growth in the electricity generated from nuclear power in the United States. It is assumed that the electricity generated will be produced from a combination of existing LWRs, plant life extension, and new advanced and evolutionary LWRs. This is known as the National Energy scenario. Under this scenario, approximately 112 000 MTHM of spent fuel is assumed to be discharged through the year 2030. The NES scenario assumes an "open-ended" system (i.e. there is no end date for the forecast of electricity generation). The selection of 2030 as a cut-off date is arbitrary, and used only for costing purposes. Wastes would continue to be produced beyond 2030. For this scenario, a typical reactor is assumed to be of the new design and will produce spent fuel similar to the spent fuel produced by existing reactors. A typical reactor will have an operating life of about 45 years and will discharge approximately 1 125 MTHM. Table 5.6 provides a breakdown of the disposal cost, by phase, for the NES scenario.

With a total quantity of spent nuclear fuel (112 000 000 kg) and high level waste (both defence and West Valley: 9 515 000 kg) of 121 515 000 kg, the total disposal cost for 1 kg of waste would be:

– $22 407 million/121 515 000 kg = $184 per kg (undiscounted).

Note: In the main text of this report, the numbers derived in this annex have been suitably rounded.

Table 5.1. **Summary of selected cost results for US spent nuclear fuel and high level waste disposal**
(millions of 1991 dollars)

	Transportation	Monitored[a] retrievable storage facility	Repository[b]				
			Management integration & engineering	Site preparation	Surface facilities	Under-ground repository	Total
Engineering & construction	0	393	305	198	591	212	1 700
Operation	0	1 648	57	149	4 728	2 911	9 493
Decommissioning & closure	0	27	26	44	94	389	580
Shipping costs	1 432	0	0	0	0	0	1 432
Cask capital & maintenance	1 028	0	0	0	0	0	1 028
Cask maintenance facility	654	0	0	0	0	0	654
Total[c]	**3 114**	**2 068**	**388**	**391**	**5 413**	**3 512**	**14 886**

a. Interim storage.
b. Disposal.
c. Columns or rows may not add to totals due to independent rounding.

Table 5.2. **Summary of selected cost results for US spent nuclear fuel and highlevel waste disposal**
(millions of 1991 dollars)
Undiscounted

Year	MRS Facility[a]	MRS Trans.	MRS Total	Repository[b]			REP Trans.	REP Total	Total Cost
				Engr. & Const.	OPNS	C & D			
1993-1999	425	283	709	96	0	0	25	121	830
2000-2009	461	201	662	1 145	0	0	50	1 195	1 858
2010-2019	414	342	756	66	2 034	0	418	2 517	3 274
2020-2029	334	384	719	0	2 504	0	403	2 907	3 627
2030-2039	323	393	716	0	2 385	0	471	2 855	3 571
2040-2049	110	57	167	0	700	0	84	784	951
2050-2059	0	0	0	0	224	0	0	224	224
2060-2069	0	0	0	0	0	405	0	405	405
2070-2075	0	0	0	0	0	147	0	147	147
Total[c]	**2 068**	**1 661**	**3 729**	**1 307**	**7 847**	**552**	**1 451**	**11 157**	**14 888**

a. Interim storage
b. Disposal
c. Columns may not add to totals due to independent rounding

Table 5.3. **Summary of selected cost results for US spent nuclear fuel and high level waste disposal**
(millions of 1991 dollars)
Discounted 5 per cent (to the point of delivery)

Year	MRS Facility[a]	MRS Trans.	MRS Total	Repository[b]			REP Trans.	REP Total	Total Cost
				Engr. & Const.	OPNS	C & D			
1993-1999	431	279	709	171	0	0	45	216	831
2000-2009	341	152	493	1 354	0	0	67	1 421	1 285
2010-2019	192	153	345	42	1 600	0	323	1 965	1 439
2020-2029	92	108	200	0	1 247	0	203	1 449	1 007
2030-2039	55	68	123	0	734	0	146	880	613
2040-2049	13	7	20	0	147	0	19	166	113
2050-2059	0	0	0	0	26	0	0	26	14
2060-2069	0	0	0	0	0	29	0	29	16
2070-2075	0	0	0	0	0	7	0	7	4
Total[c]	**1 124**	**767**	**1 891**	**1 567**	**3 754**	**36**	**802**	**6 159**	**5 322**

a. Interim storage.
b. Disposal.
c. Columns may not add to totals due to independent rounding.

Table 5.4. **Summary of selected cost results for civilian and defence waste disposal costs**
(millions of 1991 dollars)

Year	Undiscounted			Discounted 5% (Point of delivery)		
	Total	**Civilian**	**Defence**	**Total**	**Civilian**	**Defence**
1993-1999	830	806	24	831	806	24
2000-2009	1 858	1 635	223	1 285	1 137	148
2010-2019	3 274	2 611	663	1 439	1 146	293
2020-2029	3 627	3 007	620	1 007	835	173
2030-2039	3 571	3 053	519	613	522	92
2040-2049	951	914	37	113	109	4
2050-2059	224	191	33	14	12	2
2060-2069	405	355	50	16	14	2
2070-2075	147	129	18	4	3	0
Total[(a)]	**14 888**	**12 700**	**2 188**	**5 322**	**4 584**	**738**

a. Columns may not add to totals due to independent rounding.

Table 5.5. **Summary of selected cost results for US spent nuclear fuel and high level waste disposal**

Plant life extension scenario
(millions of 1991 dollars)
Undiscounted

Year	Trans.	MRS Facility[a]	Repositories[b]			Total
			Engr. & Const.	OPNS	C & D	
1993-1999	90	425	89	0	0	604
2000-2009	228	461	1 152	0	0	1 841
2010-2019	789	411	0	2 046	0	3 246
2020-2029	768	334	206	2 384	0	3 691
2030-2039	320	187	2 286	1 405	0	4 198
2040-2049	643	0	0	3 752	0	4 396
2050-2059	315	0	0	2 067	0	2 383
2060-2069	164	0	0	875	384	1 424
2070-2079	4	0	0	299	83	387
2080-2089	0	0	0	269	58	327
2090-2094	0	0	0	0	357	357
Total[c]	**3 321**	**1 818**	**3 732**	**13 098**	**882**	**22 852**

a. Interim storage.
b. Disposal in two repositories.
c. Columns may not add to totals due to independent rounding.

Table 5.6. **Summary of cost results for US spent nuclear fuel and high level waste disposal**

National energy strategy scenario
(millions of 1991 dollars)
Undiscounted

Year	Trans.	MRS Facility[a]	Repositories[b]			Total
			Engr. & Const.	OPNS	C & D	
1993-1999	90	425	89	0	0	604
2000-2009	227	461	1 152	0	0	1 840
2010-2019	790	411	0	2 046	0	3 247
2020-2029	768	334	206	2 378	0	3 686
2030-2039	320	187	2 286	1 455	0	4 248
2040-2049	640	0	0	3 839	0	4 479
2050-2059	271	0	0	2 285	0	2 556
2060-2069	0	0	0	299	384	683
2070-2079	0	0	0	299	83	382
2080-2089	0	0	0	269	58	327
2090-2094	0	0	0	0	357	357
Total[c]	**3 105**	**1 818**	**3 732**	**12 870**	**882**	**22 407**

a. Interim storage.
b. Disposal in two repositories.
c. Columns may not add to totals due to independent rounding.

Figure 5.1 **US waste management system**

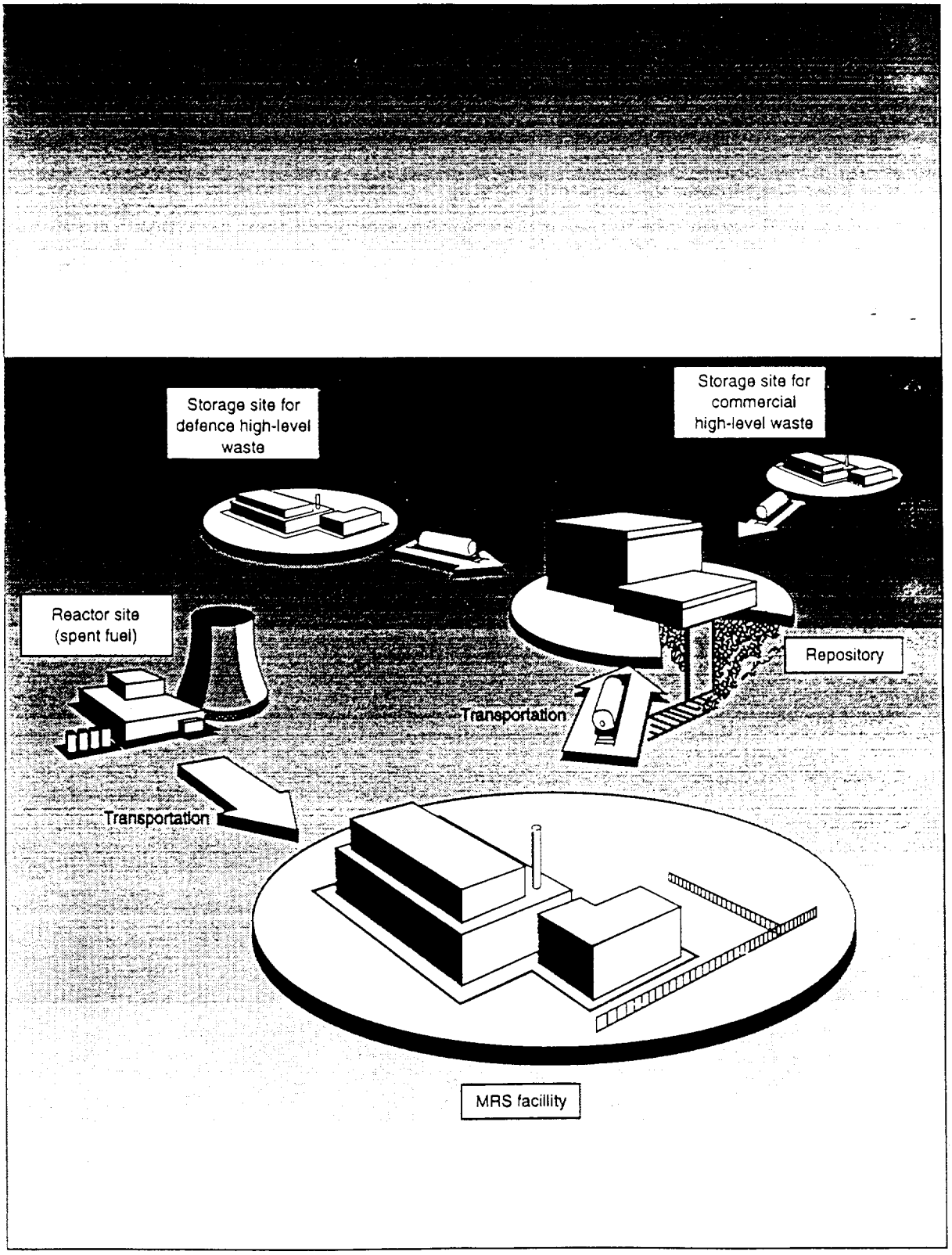
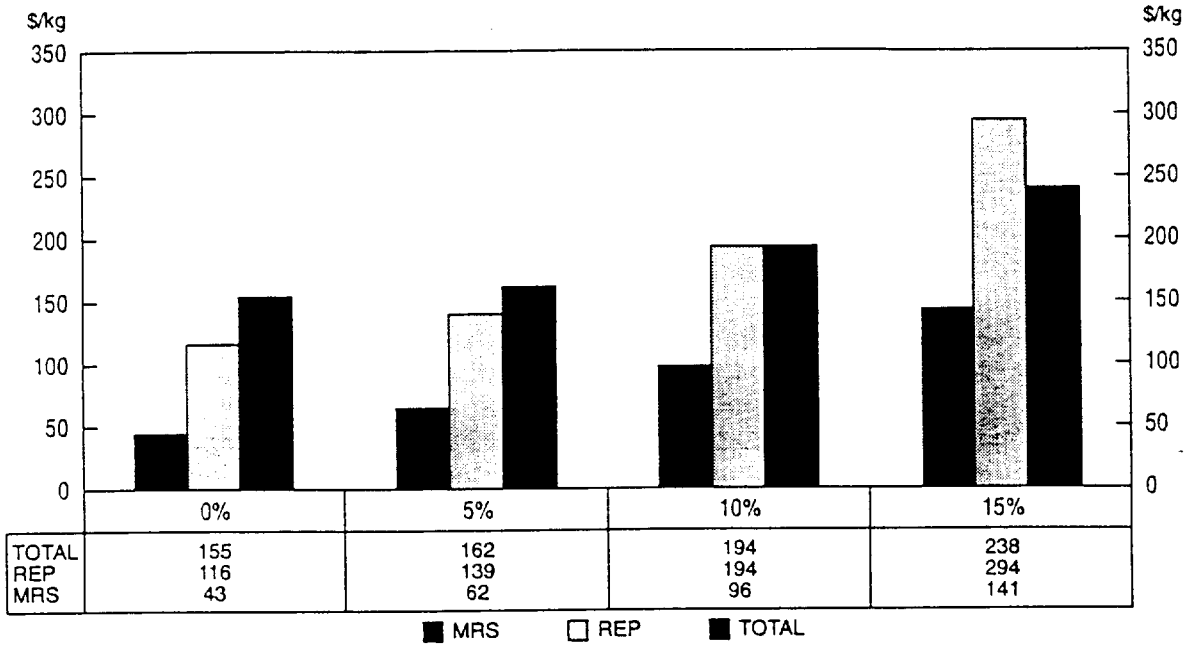


Figure 5.2 **Comparison of unit prices**



Note: These do not add since the levelised unit prices have been discounted to different delivery dates.

Figure 5.3 **Levelised unit costs to point of delivery**