THE ENERGY ACT 2008

Pre-consultation discussion paper No. 3: Establishing a fixed unit price for the disposal of intermediate level waste and spent fuel from new nuclear power stations – a worked example

MAY 2009

Contents

Section 1: Introduction

About this paper

1.1 This is the last in a series of three informal discussion papers being issued by the Office for Nuclear Development. The decision to produce these papers was set out in the Government Response to the Consultation on Funded Decommissioning Programme (FDP) Guidance for New Nuclear Power Stations[1]. Each of these papers addresses specific issues relating to establishing an indicative fixed unit price for the disposal of intermediate level waste (ILW) and spent fuel from new nuclear power stations.

1.2 The first paper in this series, issued in October 2008[2], was on a methodology to determine how the fixed costs of building a geological disposal facility (GDF) should be apportioned to and shared between operators of new nuclear power stations. That paper – described in the rest of this paper as "Discussion Paper 1" – also set out the background to the production of these papers and described the broader policy framework, as set out in the White Paper on Nuclear Power[3], which was published in January 2008.

1.3 The second paper in this series[4], issued in January 2009 – described in the rest of this paper as "Discussion Paper 2" – discussed a methodology for establishing an indicative fixed unit price for the disposal of ILW and spent fuel from new nuclear power stations.

1.4 This third paper sets out a worked example to illustrate issues around a methodology to establish an indicative fixed unit price for the disposal of ILW and spent fuel from new nuclear power stations.

1.5 The scope of this paper is rather different from that described in the previous papers in this series, which said that the subject of this paper would be "the Department of Energy and Climate Change (DECC) cost model and our updated estimates of total costs for waste management, disposal and decommissioning." This is because, following feedback from stakeholders, it is clear that there is a wish to have more quantitative information in relation to the issues around a methodology to establish an indicative fixed unit price, to enable stakeholders to understand better and comment on the issues discussed in the previous two papers. More detail on the DECC cost model and our updated cost estimates for

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[1] The Government Response to the Consultation on Funded Decommissioning Programme Guidance for New Nuclear Power Stations http://www.berr.gov.uk/files/file47629.pdf.
[2] Pre-consultation discussion paper No. 1: on a methodology to determine how the fixed costs of building a geological disposal facility should be apportioned to and shared between operators of new nuclear power stations, http://www.berr.gov.uk/files/file48571.pdf.
[3] Meeting the Energy Challenge, A White Paper on Nuclear Power http://www.berr.gov.uk/whatwedo/energy/sources/nuclear/whitepaper/page42765.html.
[4] Pre-consultation discussion paper No. 2: on a methodology for establishing an indicative fixed unit price for the disposal of intermediate level waste and spent fuel from new nuclear power stations http://www.berr.gov.uk/files/file48571.pdf.

decommissioning and waste management will be provided in the formal consultation on these issues, which is due to be published later in 2009.

1.6 This pre-consultation paper is intended for discussion with stakeholders during spring 2009. This is not a formal consultation and we are not specifically seeking public views at this stage. However these papers are being made available on the Department's website and if interested parties wish to comment on the issues covered in these papers they may do so, and these comments will be taken into account as part of the development of the Government's policy on these issues. Comments can be sent by letter, fax or email (email preferred) to:

Informal papers on cost estimates and an indicative fixed unit price
Office for Nuclear Development
Department of Energy and Climate Change
Bay 125, 1 Victoria Street
London, SW1H 0ET
Fax: 020 7215 2842
Email: DecomGuidance@berr.gsi.gov.uk

1.7 There will be a formal public consultation on the issues covered by the three papers later in 2009.

The purpose of this worked example

1.8 This paper sets out a worked example for how an indicative fixed unit price might be derived for the operator of a new nuclear power station, based on the discussions in the first two papers in this series. It is intended to be read alongside those two papers.

1.9 It is important to note that when an operator of a new nuclear power stations requests an indicative fixed unit price, its level will be determined by the Secretary of State. Therefore a methodology to establish a fixed unit price is likely to consist of two main parts:

- a cost modelling process, to derive estimates of the costs of waste disposal, taking into account the level of uncertainty around the estimation of those costs;
- determination of the fixed unit price by the Secretary of State, in which he would have regard to the cost estimates derived from this modelling.

1.10 The worked example here focuses primarily on the cost modelling element of the methodology, and is intended to illustrate the quantitative impact of the various alternatives discussed in the earlier papers. There is a step-by-step description of the way in which the worked example was calculated, together with a discussion of the data and assumptions which have been used to calculate the worked example and the impact of varying these assumptions.

1.11 The purpose of this worked example is to assist stakeholders in commenting on the issues set out in the previous papers. It should also provide stakeholders with the opportunity to comment on how specific data should be determined. These comments will assist DECC in the refinement of its proposed methodology.

1.12 **We consider the way in which the worked example has been calculated to be a reasonable illustration of the cost modelling under development by Government. We have looked at a number of scenarios and assumptions and at this stage have derived a potentially wide range of estimated costs. However this is not intended to be a definitive description of how the Government will use this cost modelling to determine the appropriate level of the fixed unit price. In reaching final conclusions on the setting of the fixed unit price it will be important to strike the right balance in ensuring a prudent and conservative approach to cost estimation while avoiding adding in excessive contingency. To this end, we will be seeking the views of the Nuclear Liabilities Financing Assurance Board (NLFAB), which has now been established, and there will be a public consultation later in 2009 which will include our proposals on how a fixed unit price will be established.**

The purpose of the fixed unit price

1.13 It is important to set out what purpose the fixed unit price, and the units in which it is set, actually fulfils. The fixed unit price exists to enable operators of new nuclear power stations to estimate what their total liability for waste disposal, at the end of the power station's life, will be, and to adjust their payments into the waste disposal fund accordingly. It does not represent a 'pay-as you-go' charge which is directly related to the operation of the power station in any particular year.

1.14 For example, in the case of spent fuel (although the same principles apply to ILW), at the time when the operator's FDP is agreed, it may be estimated that the lifetime arisings of spent fuel will be **X** units. The units may be 'direct', for example tonnes of uranium, or 'indirect', for example scaled from the total electrical output over the lifetime of the plant which has given rise to that spent fuel[5]. If the fixed unit price is £**Y** per unit[6], then the total estimated liability that the operator will have to meet from the waste disposal fund will be £**XY**. At the time of the FDP being agreed, the operator will then agree with the Secretary of State what the contribution schedule into their independent fund will be to meet this liability of £**XY.** This contribution schedule will be related to the expected lifetime of the plant and the anticipated real terms growth of the fund over time.

[5] See Section 3.5 for some illustrative figures expressing a fixed unit price for spent fuel in both volume (tonnes of uranium) and output (MWh).
[6] Here and throughout this paper, all money values are expressed in real rather than nominal terms.

1.15 It is also worth pointing out that £**XY** is not the only liability that will have to be paid for from the waste fund. From the same fund, the operator will have to meet all decommissioning and waste management costs including the costs of encapsulating the spent fuel, and the costs of interim storage. Therefore the total fund value will need to be substantially larger than £**XY**. The FDP Guidance Consultation included a summary of the principal waste and decommissioning cost streams and how they will be met[7].

1.16 The operator will be expected to carry out both annual and quinquennial reviews of the FDP to ensure that their cost estimates remain accurate and up to date and that the funding arrangements remain capable of yielding sufficient funds to meet the decommissioning liabilities and waste disposal liabilities at all times. This means that the operator must assess the performance of the fund and, for example, if the fund is not performing as well as anticipated in the FDP, the operator will have to revise their contribution schedule to increase their contributions into the fund. The NLFAB will provide on-going advice to the Secretary of State in connection with all funding arrangements and may be called upon to review some or all of the information provided to the Secretary of State by the operator and the persons responsible for managing the fund.

1.17 The operator may also expect that the total number of units of waste produced during the lifetime of the plant may change - i.e. '**X**' may change (noting that, in real terms, by its very nature '**Y**' is invariant). If for example, the operator changes the way the plant operates so as to produce more waste (perhaps by increasing plant loading so the electrical output - and therefore fuel consumed - every year is higher), then the £**XY** liability will increase[8]. To cover that liability, the contributions for the rest of the life of the plan, all other factors being equal, will have to be revised upwards. In addition the Secretary of State, advised by the NLFAB, will need to be assured that the operator has arrangements in place to ensure protection against the fund being insufficient.[9]

1.18 Similarly, if '**X**' will be lower, there could be a case for revising contributions downwards. For example, if there were an extended plant outage, it would be reasonable to assume that the total amount of waste, '**X**', at the end of the plant's life time, and which would need to be disposed of, would be slightly reduced. There could be a case, in this instance, to reduce subsequent contributions slightly, subject to the approval of the Secretary of State, advised by the NLFAB.

[7] Consultation on Funded Decommissioning Programme Guidance for New Nuclear Power Stations, Table 3, pages 22-23, at http://www.berr.gov.uk/files/file47629.pdf.
[8] A change of this nature is likely to be considered a material change to the operator's liabilities and the operator would need to propose for approval by the Secretary of State, advised by NLFAB, a modification to their FDP to take account of the change.
[9] See Section 5.10 of the FDP guidance on "Protection against an insufficient Fund".

1.19 The unit in which waste quantities will be measured will therefore be chosen to ensure that the behaviour of the plant operator in producing the waste is aligned with the Government's overall policy objectives in respect of radioactive waste disposal. In this case, the operator's desire will be to minimise their contributions into the fund, and Government's objective will be to minimise the cost of disposing, in a GDF, of the waste created. The unit in which the fixed unit price is set will therefore be chosen to ensure the maximum possible alignment of these objectives. A number of options for the unit were set out in Discussion Paper 2[10].

[10] See Discussion Paper 2 paragraphs 2.9 – 2.17 for a discussion of the issues around defining the “unit” for the fixed unit price.

2. The worked example: a step-by-step explanation

Introduction

2.1 The worked example in this paper shows how an indicative fixed unit price might be calculated for an operator of a new nuclear power station, following an approach that is consistent with the thinking outlined in the previous papers in this series. In this worked example a cost modelling process is used to derive a distribution of estimated waste disposal costs, which would then be considered by the Secretary of State in his decision on the level of the fixed unit price.

2.2 This section divides the worked example into a series of stages and then breaks each stage down into a number of steps in order to demonstrate how it has been calculated. The stages in the calculation of the worked example are as follows:

- determine GDF scenarios and respective probabilities;
- derive an estimate of variable[11] costs per unit of ILW and spent fuel;
- calculate an operator's share of the fixed costs of a GDF per unit of ILW and spent fuel;
- develop an overall distribution for estimated unit costs;
- derive an indicative fixed unit price and estimated total waste disposal liability.

2.3 The worked example then concludes with an illustration of how the illustrative values for an operator's estimated total waste disposal liability might translate into an annual payment into the operator's independent fund, expressed both in money value terms and also in terms of £/MWh.

2.4 For each stage there is firstly a description of each of the steps that have been taken to generate the worked example, secondly a short table explaining the rationale behind the data and other assumptions that have been used in this calculation and the impact of varying these, and finally the step-by-step calculation of the worked example itself. Section 3 then provides more detail on several key steps and considers the impact of varying assumptions at these points.

2.5 In order to illustrate how the worked example has been calculated, there is a flow chart at Figure 1 on the next page. Each step in the flow chart is numbered and those steps are referenced in the worked example. There are 20 steps in total.

[11] The scope of the terms "fixed costs" and "variable costs" were discussed in Discussion Paper 1 paragraph 3.6.

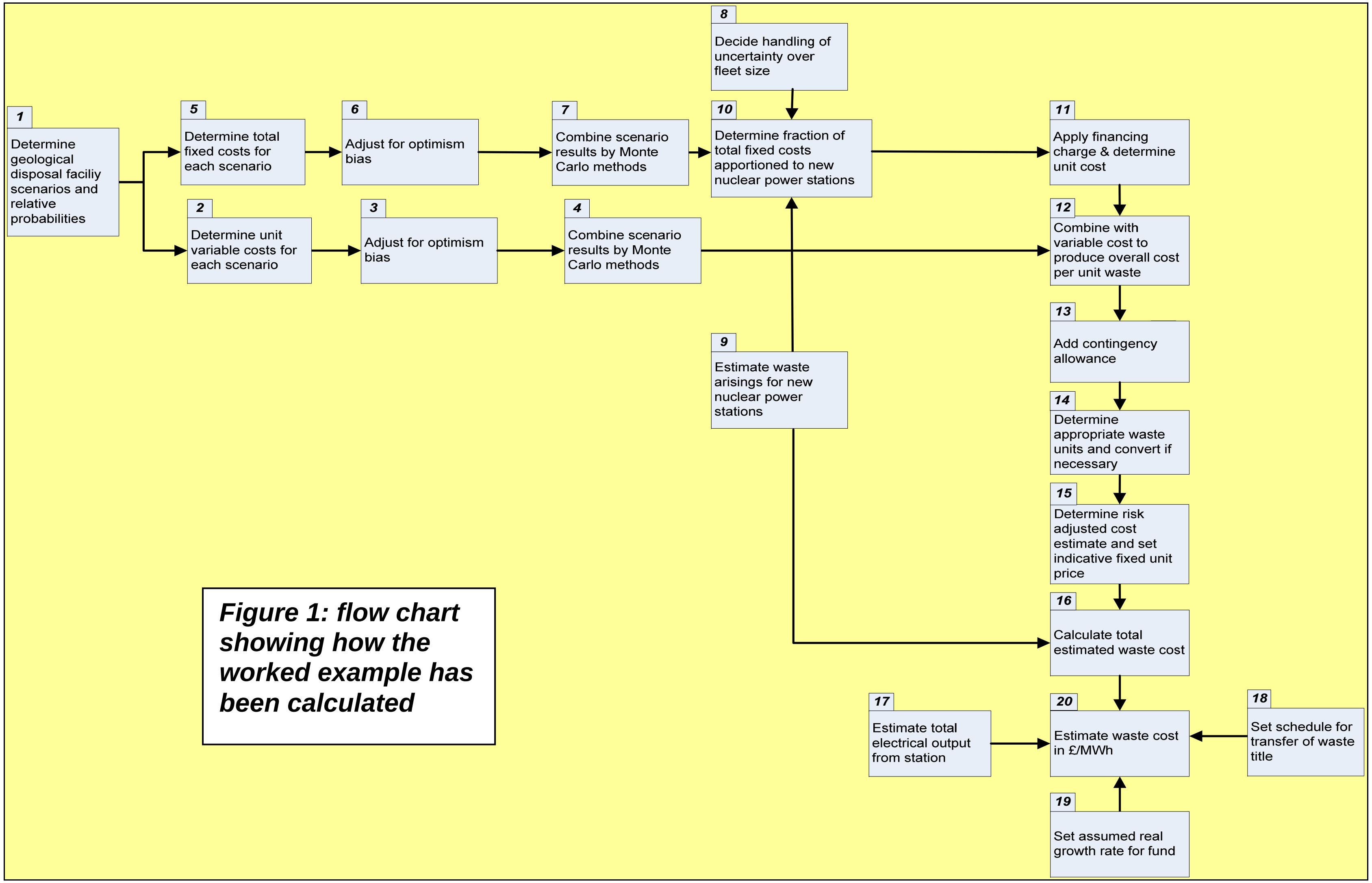

Figure 1: flow chart showing how the worked example has been calculated

Determine GDF scenarios and respective probabilities

2.6 As discussed in the previous papers in this series, the Parametric Cost Model devised by NDA will be used to provide the estimates of the costs of waste disposal in a GDF[12].

2.7 A number of scenarios have been developed, varying the main factors that impact on cost, such as geology, GDF layout, depth and waste inventory, and we have considered the probability of each of these scenarios (**Step 1**). The nine scenarios used to generate the figures in this worked example are listed in Section 3.1. For simplicity in the worked example we have assumed that all the scenarios are equally probable.

2.8 The scenarios will continue to be refined over time. The estimates for each scenario are derived from the Parametric Cost Model, which is also subject to review and refinement in the future. Hence the cost estimates and assumed probabilities given here are illustrative not definitive. An exercise to determine GDF scenarios, estimate the costs of those scenarios and consider the probability of those scenarios will need to be undertaken each time a potential new nuclear operator requests a fixed unit price.

Derive an estimate of variable costs per unit of ILW and spent fuel

2.9 For each scenario the Parametric Cost Model has provided an estimate for variable waste disposal costs per unit of ILW and spent fuel (**Step 2**). The Parametric Cost Model uses the copper canister as the unit for estimating the costs of spent fuel disposal[13] and packaged volume in cubic metres (m^3) for estimating the costs of ILW disposal. Therefore these are the units used in the worked example. However, as was discussed in Discussion Paper 2, the cost estimate itself can be converted into different units for charging purposes (see paragraph 2.22 and Section 3.5 for more on this).

2.10 The need for cost estimates derived from the Parametric Cost Model to be adjusted for uncertainty was described in Discussion Paper 2[14]. Two different sets of risk and uncertainties have been identified:

- “in-model uncertainties,” i.e. those that relate to the estimation of costs that fall within the scope of the Parametric Cost Model;
- “out of model uncertainties,” i.e. costs and wider project risks that fall outside the scope of the Parametric Cost Model.

[12] See Discussion Paper 1 paragraphs 3.4 – 3.6, and Section 3.1 of this paper, for more on the NDA’s Parametric Cost Model.
[13] See Discussion Paper 2 paragraphs 2.9 – 2.17 for more on the copper canister and a discussion of the issues around defining the “unit” for the fixed unit price.
[14] Discussion Paper 2 paragraphs 3.6 – 3.14.

Some examples of "in-model" uncertainties	***Some examples of "out of-model" uncertainties***
• Uncertainty in estimating engineering costs • Uncertainties over works duration • Geological difficulties at the chosen site	• Potential costs excluded from the Parametric Cost Model • That geological disposal facilities are not available when required by the agreed schedule • Risk that the GDF or canister design finally adopted is radically different to that on which the Parametric Cost Model is based

2.11 "In-model" uncertainties are addressed here by adjusting the estimates of unit variable cost for each scenario for "optimism bias," which is defined as the "demonstrated, systematic tendency for project appraisers to be overly optimistic"[15] (**Step 3**). "Out of model" uncertainties are addressed in Step 13 below.

2.12 The level of the optimism bias adjustment in the worked example has been set at the upper end of the range recommended in Treasury's Green Book Guidance[16]. However this figure is illustrative. When a fixed unit price is requested the Government will consider the appropriate level of the optimism bias adjustment, taking into account Treasury guidance and recent evidence of the accuracy of the cost estimates for comparable projects in the UK and abroad.

2.13 The adjusted estimates for each scenario have then been combined by Monte Carlo methods[17], using the probability for each scenario assigned in Step 1, to produce a distribution for estimated unit variable costs (**Step 4)**.

[15] See the HM Treasury Supplementary Green Book Guidance on optimism bias at http://www.hm-treasury.gov.uk/d/5(3).pdf.
[16] The Green Book is an HM Treasury publication that presents the techniques and issues that should be considered when carrying out assessments of new policies, programmes and projects. See footnote 15 for the link to the Green Book Guidance on optimism bias.
[17] Monte Carlo simulation is a computerised mathematical technique that allows for risk to be accounted for in quantitative analysis and decision making. See Section 3.6 for a brief description of how Monte Carlo calculations have been produced for this paper.

Assumption for worked example	**Rationale**	**Impact of variation on estimated unit costs**
Steps 1-2: DECC has asked NDA to provide base cost estimates for a number of scenarios from the Parametric Cost Model. Nine of these scenarios were used to generate the figures in this worked example. ***See Section 3.1 for more on these scenarios.*** The key driver of cost variability is the geological environment assumed, and in this case all geological environments have been assumed to be equally likely.	These scenarios seek to establish the cost impact of varying the assumed waste inventory, geology, depth and GDF layout. Assuming all geologies to be equally likely is a reasonable assumption as the location of a GDF is as yet unknown.	With regard to geology, low strength rock increases estimated variable costs by around 40% and estimated fixed costs by around 15% when compared with hard rock and evaporites.
Step 3 The level of the "optimism bias" adjustment in the worked example is 66%.	In Green Book terms, a GDF can be categorised as a "non-standard civil engineering project" with a "recommended adjustment range" of 6-66%. In the early stages of a project Green Book advice is to always start with the upper bound. When a fixed unit price is requested the Government will consider the appropriate level of the optimism bias adjustment, taking into account Treasury guidance and recent evidence of the accuracy of the cost estimates for comparable projects in the UK and abroad.	Variation in the level of this adjustment feeds directly through into the unit cost estimate.
Step 4: No assumptions required. See Section 3.6 for a brief description of how Monte Carlo calculations have been produced for this paper.	N/A	N/A

WORKED EXAMPLE

(NB all figures in this worked example are in constant September 2008 money and are undiscounted)

Step 1
Nine scenarios have been used for this worked example. They are detailed in Section 3.1 of this paper.

Step 2
For the nine scenarios listed in Section 3.1, the Parametric Cost Model's estimates[18] are:

- spent fuel unit variable disposal cost in the range £400-600k per canister
- ILW unit variable disposal cost in the range £9-12k per m^3.

Step 3
Applying the 66% optimism bias adjustment to these figures gives:

- Spent fuel unit variable cost in the range £660-1,000k per canister
- ILW unit variable cost in the range £15-20k per m^3.

Step 4
Combining the appropriate values for each scenario by Monte Carlo methods gives:

- Spent fuel unit variable disposal cost distribution with a minimum of £660k, a P_{50} of £710k and a maximum of £1000k[19]
- ILW unit variable disposal cost distribution with a minimum of £15.2k, a P_{50} of £15.8k and a maximum of £20.4k.

[18] For ease of presentation, throughout the worked example figures have been subject to some rounding – generally to two or three significant digits.
[19] In order to give an indication of the characteristics of the cost distributions generated in this worked example, in most cases we give the minimum, maximum and "P_{50}" values, where P_{50} is the 50^{th} centile point on the distribution.

Calculate an operator's share of the fixed costs of a GDF per unit of ILW or spent fuel

2.14 For each scenario the Parametric Cost Model has also provided an estimate for the total fixed costs of a GDF (**Step 5**). In line with paragraph 2.11, these estimates have then been adjusted for optimism bias (**Step 6**), and have then been combined by Monte Carlo methods[20] to produce a distribution for estimated total fixed costs (**Step 7**).

2.15 In line with the approach set out in Discussion Paper 1[21], the new build operator's share of the fixed costs of the geological disposal facility is allocated in proportion to its share of estimated total variable costs. For this calculation we need to estimate the operator's total variable costs and also the total variable costs for the GDF as a whole. These figures are derived by multiplying the unit cost distributions from Step 4 with estimates of the relevant waste inventories.

2.16 To estimate the total waste inventory for a GDF, we need to decide how to handle the uncertainty around the size of the new build fleet, and in particular whether that the co-disposal of legacy and new build wastes might not be feasible in the event that the new nuclear fleet is very large (**Step 8**). This issue was considered in Discussion Paper 2[22] and Section 3.2 of this paper discusses the impact of taking a different approach at this point.

2.17 The calculation of an overall waste inventory also requires an estimate of the waste inventory from a typical new nuclear power station **(Step 9**). Once a total waste inventory has been determined it can be combined with the unit variable cost estimates from Step 4 to calculate total variable costs and a new build operator's share of those costs. This fraction is then applied to the distribution of GDF fixed costs from Step 7 to give a distribution for a new build operator's share of a GDF's fixed costs (**Step 10**).

2.18 Discussion Paper 2 also discussed the question of whether or not there should be a "financing charge" to reflect the fact that a new build operator's contribution to the fixed costs of a GDF will be made some years after those costs have been incurred[23]. Although the Government has yet to reach a conclusion on the case for a financing charge, in the worked example a financing charge has been applied to the distribution of a new build operator's share of the fixed costs at this stage. See Section 3.3 of this paper for a discussion of some alternative approaches at this step. This adjusted distribution is then divided by the new build operator's waste inventory derived in Step 9 to give a distribution for the share of fixed costs per unit of ILW or spent fuel (**Step 11**).

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[20] Although the Monte Carlo analyses of fixed and variable costs have been run separately in Steps 4 and 7, they have been drawn from scenarios that are consistent with each other to ensure that any potential correlation effects are correctly accommodated.
[21] Discussion Paper 1 Section 4.1.
[22] Discussion Paper 2 paragraphs 3.24 – 3.32.
[23] Discussion Paper 2 paragraphs 3.15 – 3.18.

Assumption for worked example	Rationale	Impact of variation on estimated unit costs
Step 5-7: as for Steps 1-4	See Steps 1-4.	See Steps 1-4.
Step 8: The worked example has been calculated on the basis of co-disposal of legacy and new build waste. It has also assumed fleet size of one new reactor.	In line with "Option A" in Discussion Paper 2[24]. Unit costs fall gradually as the size of the new build fleet rises. Therefore setting the assumed fleet size as one new reactor is a cautious assumption.	***See Section 3.2*** for a discussion on the impact of taking an alternative approach at this Step**.**
Step 9: To simplify calculations for this worked example a predicted waste inventory has been expressed in "round numbers", as: • 450 canisters of spent fuel (i.e. 1800 fuel bundles, 930 tU[25]) • 1000 m^3 of ILW.	These figures are a reasonable approximation of the likely waste inventory of a generic PWR with a reactor life of 40 years and have been estimated following discussions with reactor vendors. A 40 year reactor life is consistent with the Base Case set out in the draft FDP guidance.	Unit costs fall gradually as the size of the new build waste inventory increases. This is because the unit variable cost is not affected by the size of the inventory, but as the inventory increases each unit's contribution to the fixed costs of a GDF reduces, as the total is spread more widely.
Step 10: A new build operator's share of the fixed costs of a GDF has been allocated in proportion to its share of variable costs.	The rationale for this approach was set out in Discussion Paper 1[26].	
Step 11: The financing charge has been calculated on the basis of the "virtual GDF" approach, with an interest rate of 3.5% and an indicative GDF spend profile based on latest cost estimates[27]. The effect of this approach is to uplift the value of the new build operator's contribution to the fixed costs of a GDF by around 70% compared to the case with no financing charge.	The rationale for the "virtual GDF" approach – to apply a financing charge based on the approach that might be taken in the theoretical case that the Government were constructing a GDF to a timescale driven by the needs of new build operators – was set out in Discussion Paper 2[28]. 3.5% is the interest recommended in the Green Book.	***See Section 3.3*** for a discussion of alternative approaches to this issue.

[24] Discussion Paper 2 paragraphs 3.25 – 3.28.
[25] The copper canister has a capacity of 4 PWR spent fuel bundles, or 2.06 tU.
[26] Discussion Paper 1 Section 4.1.
[27] There is a cost profile on p.36 of the NDA 2007/08 Annual Report and Accounts http://www.nda.gov.uk/documents/upload/Annual-Report-and-Accounts-2007-2008.pdf.
[28] Discussion Paper 2 paragraph 3.17.

WORKED EXAMPLE (continued)

Step 5
For the nine scenarios considered in this worked example, and described in Section 3.1, the Parametric Cost Model estimates the total fixed costs of a GDF as in the range £4400-5000m.

Step 6
Applying the 66% optimism bias adjustment to these figures gives an estimate of the total fixed costs of a GDF as in the range £7300-8300m.

Step 7
Combining the values for each scenario by Monte Carlo methods gives a distribution for total fixed costs with a minimum of £7300m, a P_{50} of £7320m and a maximum of £8300m.

Step 8
This worked example assumes the co-disposal of legacy and new build waste in a single GDF and also assumes a new build fleet of one new reactor. Section 3.2 considers the impact of a different approach at this Step.

Step 9
The estimated waste inventory for a single new nuclear power station is:

- Spent fuel inventory of 450 canisters
- ILW inventory of 1000 m^3.

Step 10
For the scenarios considered in Step 1:

- Total legacy variable costs are estimated as in the range £7800-11200m. Uplifting these figures for optimism bias (in line with Step 4) gives estimated legacy variable costs as in the range £13000-18600m
- Total variable costs for a new build operator (combining the unit variable costs from Step 4 with the inventory from Step 9) are in the range £310-470m (of which around 95% are related to spent fuel).

The new build operator's share of total fixed costs can be calculated by dividing their variable costs by total variable costs, giving a range 2.3–2.5%.

Applying this to the distribution determined in Step 7 gives a distribution for a new build operator's share of total fixed costs with a minimum of £170m, a P_{50} of £175m and a maximum of £210m.

Step 11
Applying the financing charge uplift of around 70% to these figures gives a revised distribution of £285m, a P_{50} of £295m and a maximum of £350m.

Allocating these costs to spent fuel and ILW in proportion to their share of variable costs, and dividing by the inventory from Step 9 gives:

- for spent fuel a distribution for fixed costs per canister with a minimum of £620k, a P_{50} of £650k and a maximum of £780k
- for ILW a distribution for fixed costs per m^3 with a minimum of £13.8k, a P_{50} of £14.2k and a maximum of £15.2k.

Develop an overall distribution for estimated unit costs

2.19 Combining the distribution for variable costs per unit from Step 4 and the distribution for fixed costs per unit from Step 11 gives an overall distribution for estimated unit costs (**Step 12**).

2.20 These figures were calculated on the basis of estimates produced by the Parametric Cost Model. As explained in paragraph 2.10, in addition to the "in-model" uncertainties that can be allowed for with an optimism bias adjustment there is a second set of uncertainties - costs and wider project risks - that fall outside the scope of the Parametric Cost Model. Hence the worked example has a further "contingency" adjustment to allow for these "out-of-model" uncertainties. This contingency adjustment is in the form of a distribution rather than a single value and is combined using Monte Carlo methods with the cost distribution derived under Step 12 to give a final cost distribution (**Step 13**).

2.21 Section 3.4 sets out how the contingency adjustment might ultimately be calculated. However this detailed calculation has not yet been done. Hence for this worked example, in order to demonstrate the impact of the contingency adjustment on the final costs distribution two purely illustrative possible contingency adjustments are considered. These values have been arbitrarily determined, and should not be taken as an indication of the level of the contingency adjustment implied by the exercise described in Section 3.4. A distribution for contingency costs will be estimated and the values derived included in the updated version of this worked example that will be included in the public consultation later in 2009.

Assumption for worked example	**Rationale**	**Impact of variation on estimated unit costs**
Step 12: No assumptions involved.	N/A	N/A
Step 13: The contingency adjustment is in the form of a distribution. Two purely illustrative distributions have been used for the contingency adjustment to the spent fuel and ILW cost distributions. These are in the form of three point estimates and have been termed "Variant 1" and "Variant 2".	The detailed analytical exercise needed to derive a contingency distribution has not yet been done. Hence the distributions used here have been arbitrarily determined and are purely illustrative, in order to demonstrate the impact the contingency adjustments have on the final cost distributions.	***See Section 3.4*** for details of how a contingency distribution might be determined.

WORKED EXAMPLE (continued)

Step 12
Combining the distributions from Step 4 and Step 11 gives the following distributions for overall unit costs[29]:

- Spent fuel per canister cost distribution with a minimum of £1290k, a P_{50} of £1360k and a maximum of £1770k
- ILW per m^3 unit cost distribution with a minimum of £29.2k, a P_{50} of £30.3k and a maximum of £35.6k.

Step 13
The adjustment for contingency costs is based on the following arbitrarily determined distributions:

Variant 1

- For spent fuel, a minimum of £100k, mode[30] of £200k and maximum of £700k
- For ILW, a minimum of £2k, mode of £4k and a maximum of £14k.

Variant 2

- For spent fuel, a minimum of £200k, P_{50} of £400k and a maximum of £1500k
- For ILW, a minimum of £4k, P_{50} of £8k and a maximum of £30k.

These distributions are purely illustrative. See Section 3.4 for an explanation of how the contingency distributions might be calculated.

Combining the contingency distributions with those derived in Step 12, using Monte Carlo techniques, gives a final cost distribution as follows:

Variant 1

- Spent fuel overall unit cost distribution with a P_{50} of £1760k and a P_{80} of £2030k
- ILW overall unit cost distribution with a P_{50} of £38k and a P_{80} of £42k.

Variant 2

- Spent fuel overall unit cost distribution with a P_{50} of £2160k and a P_{80} of £2480k
- ILW overall unit cost distribution with a P_{50} of £45k and a P_{80} of £51k.

[29] Here, as elsewhere in this paper, figures have been quoted to two or three significant figures. This can cause some small discrepancies due to rounding.
[30] These distributions have been set as simple triangular distributions for the purpose of this worked example. Hence the middle value is given here as the "mode" rather than P_{50}. Note in these cases that P_{50} is a little higher than the mode for these triangular distributions.

Derive an indicative fixed unit price and estimated total waste disposal liability

2.22 As discussed above, the cost estimates are expressed in terms of the units used by the Parametric Cost Model to calculate costs, i.e. copper canisters for spent fuel and m^3 for ILW. However these are not necessarily the units that will be used when setting a fixed unit price and, if needed, the distribution of costs derived in Step 13 can be converted into a number of possible alternative units (**Step 14**). For simplicity, the worked example retains the units used by the Parametric Cost Model but Section 3.5 describes how this conversion might work for spent fuel. From the distribution derived in Step 13, a value can be selected at a high level of confidence to give a ***risk-adjusted unit cost estimate*** (**Step 15**).

2.23 It is important to note that when an operator of a new nuclear power stations requests an indicative fixed unit price, its level will be determined by the Secretary of State. He will consider whether in his view the figure determined by the methodology to establish a fixed unit price provides sufficient protection for the taxpayer. For example this might include consideration of whether the cost modelling has taken sufficient account of the need for protection against the risk of cost escalation and other uncertainties.

2.24 For the worked example, four possible fixed unit prices are considered for each of the variants given at Step 13, each equating to a point on the cost distribution. Once an indicative fixed unit price has been established, an estimated total waste disposal liability for a new build operator can be calculated (**Step 16**), by combining the indicative fixed unit price with the operator's estimated waste inventory derived in Step 9.

<table>
<tr><th>Assumption for worked example</th><th>Rationale</th><th>Impact of variation on estimated unit costs</th></tr>
<tr><td>Step 14: The units in the worked example are the copper canister for spent fuel and m^3 for ILW.</td><td>These have been chosen for simplicity as they are the units used in the Parametric Cost Model.</td><td>See Section 3.5 for more on how the prices per canister of spent fuel derived in Step 13 might be expressed in alternative units.</td></tr>
<tr><td>Step 15: For this worked example four different illustrative risk-adjusted unit cost estimates have been derived - the 80th, 90th, 95th and 99th centile from the distribution derived in Step 13.</td><td>The Government's policy is that the fixed unit price will be set at a level over and above expected costs, and should provide the taxpayer with material protection.</td><td>Requiring a different level of confidence will feed directly through to the level of the risk adjusted unit cost estimate.</td></tr>
<tr><td colspan="3">Step 16: In calculating the estimated total waste disposal liability figures in this worked example we have assumed that the fixed unit price is equivalent to the risk adjusted unit cost estimates shown. This is an assumption for simplicity - see paragraph 2.23 above for more on how a fixed unit price will be determined.</td></tr>
</table>

WORKED EXAMPLE (continued)

Step 14
There is no conversion of units in this worked example. However see Section 3.5 for some example figures showing how this conversion might work for spent fuel.

Step 15
For each of the two variants in this worked example four risk adjusted unit cost estimates at different confidence levels have been taken from the distributions derived in Step 13:

Variant 1	**P_{80} (£k)**	**P_{90} (£k)**	**P_{95} (£k)**	**P_{99} (£k)**
Spent fuel (per canister)	2030	2160	2250	2370
ILW (per m^3)	42	43	45	47

Variant 2	**P_{80} (£k)**	**P_{90} (£k)**	**P_{95} (£k)**	**P_{99} (£k)**
Spent fuel (per canister)	2480	2650	2800	3070
ILW (per m^3)	51	54	57	61

Step 16
If we treat these risk adjusted unit cost estimates as possible values for the fixed unit price it is possible to determine values for the estimated waste disposal liability in each case, by multiplying these prices by the waste inventory for a typical new nuclear power station from Step 9:

Estimated waste disposal liability value	**P_{80} (£m)**	**P_{90} (£m)**	**P_{95} (£m)**	**P_{99} (£m)**
Variant 1	956	1015	1058	1114
Variant 2	1167	1247	1317	1443

Translating the estimated total waste disposal liability into an indicative annual payment into the operator's independent fund

2.25 This worked example concludes with an illustration of how the estimated total waste disposal liability from Step 16 might translate into an annual payment into the operator's independent fund, expressed both in money value terms and also in £/MWh.

2.26 The "Consultation on the Future of Nuclear Power"[31] issued in May 2007 included an assessment on the economics of nuclear power which, for the purposes of calculating the costs of a new nuclear power station, estimated that waste disposal costs would be in the region of £0.4/MWh over the operational life of a new nuclear power station.

2.27 The final stage of this worked example aims to translate the range of illustrative values for a fixed unit price and total estimated waste disposal liability derived above into an indicative annual payment into the operator's independent fund, expressed as a lump sum and also in £/MWh, for comparison with the figures in the Nuclear Consultation. It should be noted however that although the £/MWh figures given here are calculated on the same basis as the Nuclear Consultation, a fixed unit price expressed as a price per MWh would be calculated differently – see Section 3.5 for an explanation of how this would be calculated and some illustrative figures.

2.28 These figures are for illustrative purposes only. The estimated total waste disposal liability will be based on the fixed unit price and the agreed schedule by which payments to the Government must be made. The operator will be responsible for making good any shortfall or risk of shortfall in the accumulated monies held by their independent fund in order to ensure that the fund is sufficient to meet the waste disposal liability.

2.29 In order to calculate an estimated waste cost in £/MWh, a number of assumptions are needed: total electrical output from the new nuclear power station (**Step 17**); an indicative date for the transfer of waste materials (in order to estimate the period over which funds will be able to grow) (**Step 18**); and an assumed rate of real fund growth (**Step 19**). With these assumptions an estimated waste cost in £/MWh can be determined (**Step 20)**.

[31] http://www.berr.gov.uk/files/file39197.pdf.

Assumption for worked example	Rationale	Impact of variation on estimated unit costs
Step 17: Total output over the 40 year life of a generic 1.35 GW PWR with a load factor of 90% has been estimated as 11 TWh/year, or 440 TWh in total.	Total output has been estimated from the assumptions set out in Step 9, together with further assumptions on design capacity and load factor.	In the calculations in this worked example, for a given quantity of canisters of spent fuel, a higher total electrical output assumption gives a lower £/MWh figure and vice versa.
Step 18: Reactor operates for 40 years and waste transfers 100 years after start of generation (i.e. 60 years after end of generation).	This is consistent with the Base Case assumption that a new reactor will have an operational life of 40 years, and the Base Case assumption that operators will be obliged to provide safe and secure interim storage facilities that are technically capable of being maintained or replaced to last for at least 100 years from the time waste is first emplaced in them.	For any given fixed unit price, and therefore total waste disposal liability, a longer period between the end of generation and waste transfer reduces the £/MWh figure because the fund has longer to grow. Conversely a shorter period increases the £/MWh figure. (However a longer period between end of generation and waste transfer also implies higher costs of interim storage, which must be met from the operator's independent fund).
Step 19: Three real fund growth rates have been considered: 3.5% pa, 2.2% pa and 1% pa.	2.2% pa was the rate assumed in the Nuclear Consultation. The figures for 1% and 3.5% have also been included to demonstrate the impact of variations in the assumed fund growth rate.	A higher fund growth rate gives a lower £/MWh figure and vice versa. There are a number of factors that affect the rate of fund growth, including the investment policy of the operator's independent fund.[32]
Step 20: No new assumptions involved.	N/A	N/A

[32] See Section 5.7 of the FDP guidance on "Investment Policy" at http://www.berr.gov.uk/files/file47629.pdf.

WORKED EXAMPLE (continued)

Steps 17-19

- Total output is estimated to be 11TWh/year.
- Assumed 40 year reactor life and waste transfers 60 years after end of generation
- Three assumed rates of real fund growth are considered: 3.5%, 2.2%, and 1%.

Step 20

Under these assumptions, the target waste disposal liability figures derived in Step 16 can be translated into the following indicative figures for an annual payment into the operator's independent fund. This is also expressed as a value for £/MWh – when paid into the fund at the time of generation.

Variant 1

Waste disposal liability (£m)	3.5% pa real fund growth		2.2% pa real fund growth		1.0% pa real fund growth	
	Annual cost (£m)	Fund payment in £/MWh	annual cost (£m)	Fund payment in £/MWh	annual cost (£m)	Fund payment in £/MWh
956	1.39	0.13	4.02	0.37	10.64	0.97
1015	1.47	0.13	4.27	0.39	11.29	1.03
1058	1.54	0.14	4.45	0.40	11.77	1.07
1114	1.62	0.15	4.68	0.43	12.42	1.13

Variant 2

Waste disposal liability (£m)	3.5% pa real fund growth		2.2% pa real fund growth		1.0% pa real fund growth	
	annual cost (£m)	Fund payment in £/MWh	annual cost (£m)	Fund payment in £/MWh	annual cost (£m)	Fund payment in £/MWh
1167	1.69	0.15	4.90	0.45	13.01	1.18
1247	1.81	0.16	5.24	0.48	13.90	1.26
1317	1.91	0.17	5.54	0.50	14.68	1.33
1443	2.09	0.19	6.07	0.55	16.09	1.46

Section 3: Further data and analysis of the impact of taking a different approach at key stages in the worked example

3.1 Data from NDA's Parametric Cost Model (Step 1 in the worked example)

3.1.1 The NDA has developed a Parametric Cost Model to generate updated estimates of the costs of geological disposal. It allows the key parameters that impact on the construction and operating costs of a GDF in the UK to be varied.

3.1.2 The Parametric Cost Model uses as its basis the detailed cost estimate that underpins the NDA's current best estimate included in its 2007/08 Annual Report and Accounts. The detailed cost estimate resulted from a rigorous process in 2007/08 that included bottom up estimates with costs and prices included from tender information, quotations, relevant industry data and current salary levels.

3.1.3 The output from the Parametric Cost Model results from a series of assumptions being selected and, as a consequence, the cost estimates it produces depend on the assumptions used. A range of parameters can be varied, to examine the cost impact from changing the parameters. For example, the Parametric Cost Model can vary parameters such as rock type, depth of repository and waste inventories, to reflect their impact on costs. The Parametric Cost Model can also estimate the cost for disposing of a specified amount of ILW and spent fuel in a GDF.

3.1.4 In order to enable waste disposal costs for ILW and spent fuel from new nuclear power stations to be estimated, NDA, at the request of DECC, has developed a range of scenarios for geological disposal which differ – for example in geology or inventory – from the scenario used to develop NDA's current best estimate, and these have been used in the Parametric Cost Model to identify the cost impact of these scenarios.

3.1.5 The 12 scenarios that have been used in the development of this paper are listed in the table at Figure 3, together with a "base scenario," from which the other estimates are derived.

Figure 3: the scenarios and their cost implications

Scenario	Geology/depth	Legacy wastes?	Legacy U and Pu?	New build wastes?	Restricted footprint?	Variable cost		Fixed costs
						Canister of spent fuel (£k)	m^3 ILW (£k)	£m
Base	Strong rock 650m	Yes	No	No	No	400	9.0	4,400
1	Strong rock 650m	Yes	No	Yes	No	400	9.6	4,400
2*	Strong rock 650m	No	No	Yes	No	400	9.0	4,400
3	Strong rock 650m	Yes	Yes	Yes	No	400	9.2	4,400
4	Strong rock 650m	Yes	Yes	Yes	Yes	410	9.2	4,400
5	Evaporite 650m	Yes	No	Yes	No	430	10.0	4,400
6*	Evaporite 650m	No	No	Yes	No	430	13.2	4,400
7	Evaporite 650m	Yes	Yes	Yes	No	430	9.6	4,400
8	Evaporite 650m	Yes	Yes	Yes	Yes	440	9.6	4,400
9	Low strength 500m	Yes	No	Yes	No	600	11.5	5,000
10*	Low strength 500m	No	No	Yes	No	600	13.6	5,000
11	Low strength 500m	Yes	Yes	Yes	No	600	12.3	5,000
12	Low strength 500m	Yes	Yes	Yes	Yes	600	12..3	5,000

* *These scenarios assume a dedicated GDF for new build wastes. Hence they are not used for the calculations in the worked example, which are based on the assumption of co-disposal of legacy and new build wastes in the same GDF, but would be used in the event that the fixed unit price was calculated on the basis of "Option B" in Section 3.2 in this paper*.

3.1.6 Nine of these scenarios assume the co-disposal of legacy and new build wastes in a single GDF, and hence these are the values that have been used for the calculations in the worked example. Three further scenarios estimate costs in the case of a dedicated GDF for new build wastes. Hence they have not been used for the calculations in the worked example, but would be used in the event that the fixed unit price was calculated on the basis of "Option B" in Section 3.2 in this paper.

3.1.7 As stated in the NDA's Annual Report and Accounts 2007/08 the current best estimate within the range of potential costs for a GDF is £12.2 billion undiscounted. This figure covers both the fixed costs of a GDF and the variable costs of the disposal of legacy waste, which is all known waste that currently exists and waste arising from current facilities and therefore does not include any provision for new build waste or a number of other potential wastes.

3.1.8 The £12.2bn figure represents an estimate on current information and on a given set of assumptions (equivalent to the "base scenario" in Figure 3). The exact cost of a GDF will be influenced by many different factors, including the inventory of waste, the geology of the site in question and the design of a GDF. The fact that different values for the estimate costs of a GDF can be derived from this paper does not imply that the figure in the NDA Annual Report and Accounts is wrong – they are the result of variations to the parameters used to estimate costs in the Parametric Cost Model to model scenarios requested by DECC.

3.1.9 The purpose of this paper is to derive an estimate of the possible costs of waste disposal that can be used for the purposes of establishing a fixed unit price which, once set, will not be capable of being amended. Therefore the estimates derived here are necessarily conservative, aiming to make allowance for a range of uncertainties and risks that costs may escalate in future years. Therefore it is reasonable that the estimates for the costs of a GDF used for this exercise are significantly higher than the provision for the costs of a GDF in the NDA's Annual Report and Accounts 2007/08.

3.2 Varying the approach to handling uncertainty over fleet size (Step 8 in the worked example)

Introduction

3.2.1 Discussion Paper 2 considered the impact of uncertainty over the size of the new build fleet on our ability to model waste disposal costs, and the consequent risk that a second GDF might be needed in the event that the new build fleet is large[33]. The paper identified two broad approaches:

- An approach in which the methodology to set a fixed unit price is based on a presumption of the co-disposal of legacy and new build waste, but retains the flexibility to revise this at a later date for subsequent reactors if there were reasons to consider that there was a significant risk that a second GDF might be needed – this was termed "Option A".

[33] Discussion Paper 2 paragraphs 3.19 – 3.32.

- An approach in which the methodology makes an estimation of the risk that a second GDF might be needed and factors this in from the outset, deriving a probablised unit cost distribution – this was termed “Option B”, and was illustrated in Discussion Paper 2. This illustration is reproduced here as Figure 4.

Comparing Option A and Option B

3.2.2 Under Option A waste disposal costs are based on the assumption of the co-disposal of legacy and new build, which is the Government’s current expectation. However the assessment of the likelihood of needing a second GDF would be kept under review. If a point were to be reached in the future which gave cause for the Government to reconsider its co-disposal assumption – either as a result of the new build fleet becoming very large or because of the specification of the site chosen for the GDF – the calculation of estimated costs would change accordingly and the new calculation would apply to any fixed unit prices that were set from that point onwards (but the changes would not apply retrospectively to any earlier fixed unit prices already agreed). Hence the operators of subsequent reactors might find that the estimated unit cost of waste disposal, and hence the fixed unit price, could be substantially higher than for earlier reactors.

3.2.3 In contrast under Option B a fixed unit price, even for the earliest new nuclear power stations, would include a contingency relating to the risk that there might need be a second GDF for new build waste. Hence in the event that in the future the Government had cause to reconsider its co-disposal assumption, any consequent increase in the level of the fixed unit price faced by the operators of subsequent reactors would probably be smaller than under Option A.

3.2.4 The step-by-step process and worked example described in Section 2 of this paper on the basis of Option A, in that the costs are calculated on the basis of the co-disposal of new build and legacy waste materials.

3.2.5 In Option B, we consider that the likelihood of co-disposal proving not to be feasible is related to the size of the new build fleet – i.e. that it is negligible in the event of limited new build but increases in scenarios with a large new build fleet. This methodology would make use of this by assigning a value of zero to the probability of needing a second GDF in the event of a new build fleet being a small size, and a value of one in the event that the new build fleet is a very much larger size, and it would also assume that the probability increases linearly between these two points.

3.2.6 This approach enables the two cost distributions to be combined in a single probablised cost distribution, as illustrated in Figure 4. Under this distribution, as the size of the new build fleet increases, the probability of requiring a second GDF increases and therefore the distribution of estimated costs will switch from the co-disposal cost curve to the dedicated GDF cost curve.

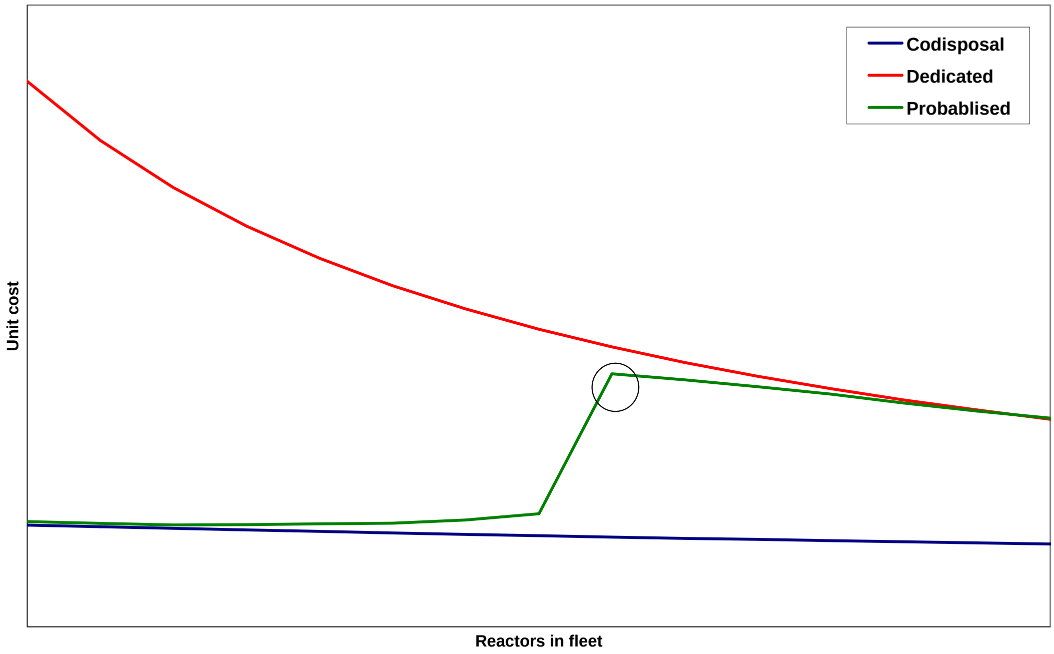


Figure 4: illustration of a probablised unit cost distribution for different sizes of new build fleet

3.2.7 The worked example based on Option A uses a single set of calculations in order to generate estimates of waste disposal costs. However Option B requires three sets of figures:

(i) estimated unit costs in the case of the co-disposal of legacy and new build wastes in the same GDF, for a range of fleet sizes;

(ii) estimated unit costs in the case of a dedicated GDF for new build wastes, for a range of fleet sizes;

(iii) a value for the probability of needing a second GDF depending on the size of the new build fleet – to generate the "probablised cost" curve.

3.2.8 Under Option B, the calculation of estimated unit costs for (i), i.e. in the case of co-disposal, would follow the worked example in this paper, except that it is then repeated for a range of fleet sizes.

3.2.9 The calculation of estimated unit costs for (ii), i.e. in the case of a dedicated GDF for new build wastes, would follow the worked example, except that in Step 10 the legacy inventory would not be a consideration, as only new build wastes would be considered in calculating an operator's share of the fixed costs of a GDF. This increases the contribution to the fixed costs allocated to each unit of new build waste.

3.2.10 The estimation of (iii), i.e. the probability assigned to needing a second GDF depending on the size of the new build fleet, would be a judgement based on a number of factors, including an assessment of the possible specifications of the site that will ultimately be identified for a GDF.

3.2.11 In general, Option B can be expected to generate a distribution of estimated costs that are somewhat higher than those generated under Option A. This is because it factors in the costs of a dedicated GDF for new build wastes, under which scenario each unit of new build waste would have to bear a larger share of the fixed costs.

3.2.12 However the size of the differential between the figures generated under Option A and Option B depends on a range of factors, including:

- The values assigned in Option B to the probability of needing a second GDF at different sizes of new build fleet. In general, the more cautious the approach is on this point, the larger the difference between Option A and Option B.
- Whether it is assumed in Option B that a first and second GDF would have the same total fixed costs and unit variable costs. If it were assumed that, as a result of learning from experience, a second GDF would be cheaper than the first, then this would reduce the differential between Option A and Option B.
- The confidence level used to set the risk adjusted cost estimate (i.e. Step 15 in the worked example). It could be argued that Option B is a more cautious approach than Option A, and therefore to require the same high level of confidence would be excessively cautious. Requiring a lower confidence level under Option B would tend to reduce the difference between the two approaches.

3.2.13 Option A has been used for the worked example as it is consistent with the Government's view that it would be technically possible and desirable to dispose of both new and legacy waste in the same geological disposal facilities. Co-disposal of legacy and new build wastes is the Government's current expectation, but Option B has been included as it is an alternative method of dealing with the risk that a second GDF might be needed, in the event that the new build programme is large.

3.3 The approach to the financing charge (Step 11 in the worked example)

3.3.1 The Government considers that it would be technically possible and desirable to dispose of both new and legacy waste in the same geological disposal facilities[34]. As a result capital expenditure on the fixed costs of the GDF will be incurred many years ahead of the time the facility is actually required for new build wastes, which the modelling in this paper has assumed (at Step 18) will be around 60 years after the new reactors have ceased operating. On the basis that new build should make a contribution to the fixed costs of the GDF, how should we treat this timing difference?

3.3.2 This issue was discussed in Discussion Paper 2[35]. The assumption in DECC's current cost modelling work is that payments to cover the fixed unit price for the waste disposal service will be paid to the Government at the same time as title to and liability for each operator's waste is transferred to the Government. There is a further assumption that the fixed unit price that new build operators will pay will include a contribution to the fixed costs of the GDF. This contribution is being made even though these fixed costs, in their entirety, would be incurred in the construction of the GDF in any event – even without the need to accommodate new build wastes. This is because the MRWS programme, which sets the framework for implementing geological disposal, envisages that a GDF will be built to manage the existing inventory of legacy and committed waste. But the corollary of the first assumption is that any contribution by a new build operator to the fixed costs of a GDF is likely to be made some years after the fixed costs of a GDF are incurred. It must however be noted that since the GDF is being built in the first instance to accommodate legacy wastes, the fixed costs are being incurred many decades in advance of the time that they would need to be incurred if the timing of GDF construction was determined solely by the need to accommodate new build wastes.

3.3.3 It should be noted that, as stated in the FDP consultation[36], the fixed unit price will be escalated over time in line with, for example, inflation, but this raises the question of whether over and above this there should be some form of "financing charge" applied to the fixed cost element of the fixed unit price, to reflect this discrepancy between the timing of the costs being incurred and the fixed unit price being paid. There is a wide range of possible approaches that could be taken to the question, some of which were outlined in Discussion Paper 2.

3.3.4 At one end of the spectrum it could be argued that the GDF's fixed costs should be considered "sunk costs" because they would be incurred in full anyway, in view of the need to accommodate legacy wastes. Therefore from an economic efficiency perspective it could be argued that the right approach would be to require a new build operator to pay only the <u>marginal costs</u> of waste disposal, i.e. without any contribution to the fixed costs. On this basis there would be no

[34] Meeting the Energy Challenge, A White Paper on Nuclear Power, page 99.
[35] Discussion Paper 2 paragraphs 3.15 – 3.18.
[36] Consultation on Funded Decommissioning Programme Guidance for New Nuclear Power Stations, paragraph 2.11.

contribution to capital costs and accordingly no financing charge. Against this it could be argued that in the interests of "fairness", a new build operator should make some contribution to the fixed costs. Indeed the policy set out in the FDP consultation sets out the Government's view, which is that the fixed unit price should include a contribution to the fixed costs of a GDF[37].

3.3.5 At the other end of the spectrum Discussion Paper 2 set out a "deferred payment" approach. This would treat a GDF as a project in which all fixed costs were being shared by legacy and new build (but on the timescales currently envisaged, i.e. in order to enable the disposal of legacy wastes in advance of the disposal of new build waste). In this case it could be argued that a new build operator's contribution to the fixed costs should be paid as and when those costs were incurred, and in the event that payment was not made until later, interest would be charged (reflecting the cost to Government of financing the project) during the intervening period. However this approach, if applied in full, would appear to place an unfair burden on new build operators, as they would be required to pay towards the fixed costs of a GDF many decades ahead of need. This approach does also disregard the fact that the MRWS programme envisages that a GDF will be built to manage the existing inventory of legacy and committed waste, regardless of whether or not there are any new nuclear power stations.

3.3.6 There are a number of intermediate approaches, which include a contribution to the fixed costs of a GDF in the fixed unit price, but which would not require a new build operator to pay that contribution ahead of need and in which interest on the full period from incurring the fixed costs to the payment of the fixed price would not be made.

3.3.7 One approach would be to argue that there should be no financing charge applied to the share of the fixed costs included in the fixed unit price. The rationale for this approach would be that these costs are not being incurred on behalf of the new build operator (as they are costs that the Government will incur anyway) and the availability of space in a GDF and a filling schedule for new build wastes will be heavily influenced by legacy waste disposal issues.

3.3.8 Another intermediate approach might be to apply a financing charge on the share of fixed costs included in the fixed unit price, based on the approach that might be taken in the theoretical case that the Government were constructing a GDF to a timescale driven by the needs of new build operators. In this case a GDF would be built many decades later, as it would not need to be ready until the waste from new build operators was ready for disposal. This was described in Discussion Paper 3 as the "virtual GDF" approach, and assumes that under this scenario the theoretical GDF would follow the existing GDF cost profile, but with all fixed costs incurred later so that it would open at the point that new build wastes were due for disposal, with interest charges applied to a new build operator's contribution to the fixed costs on this basis. In other words, rather than applying the interest charge for many decades, it would only be applied for

[37] Consultation on Funded Decommissioning Programme Guidance for New Nuclear Power Stations, paragraph 2.33.

the few years between construction and first emplacement (when the fixed price would be paid).

3.3.9 The figures in the worked example were calculated on the basis of the "virtual GDF" approach, as this seems to strike a reasonable balance between economic efficiency and the broader consideration of ensuring fairness in the allocation of the fixed costs of the GDF.

3.3.10 The Government has not yet reached a conclusion on this issue and will wish to consider the arguments further in the light of any responses we receive to this discussion paper. Thereafter, the Government intends to set out for consultation a preferred approach on a financing charge (if any) in the forthcoming public consultation.

3.4 The derivation of the contingency adjustment (Step 13 in the worked example)

3.4.1 The contingency distribution is intended to ensure that the estimation of the costs of waste disposal takes account of "out-of-model" costs, and this section discusses how a contingency adjustment might be derived.

3.4.2 Contingency is defined in the HM Treasury Green Book as "an allowance of cash or resources to cover unforeseen circumstances."[38] The calculation of such an allowance is inherently difficult. This section sets out a possible approach to determining the level of the contingency distribution for the purposes of setting a fixed unit price.

3.4.3 Figure 5 illustrates how a contingency allowance might be derived. Firstly out-of-model risks would be identified, together with an assessment of the consequence and probability of each risk occurring. There are a range of sets of risks and uncertainties that might be considered here:

- potential costs that are excluded from the Parametric Cost Model,
- an allowance for wider project risks, such as the risk that the GDF or canister design finally adopted is radically different to those on which the Parametric Cost Model estimates costs;
- the risk that geological disposal facilities are not available when required by the agreed schedule for the Government to take title to and liability for the waste.

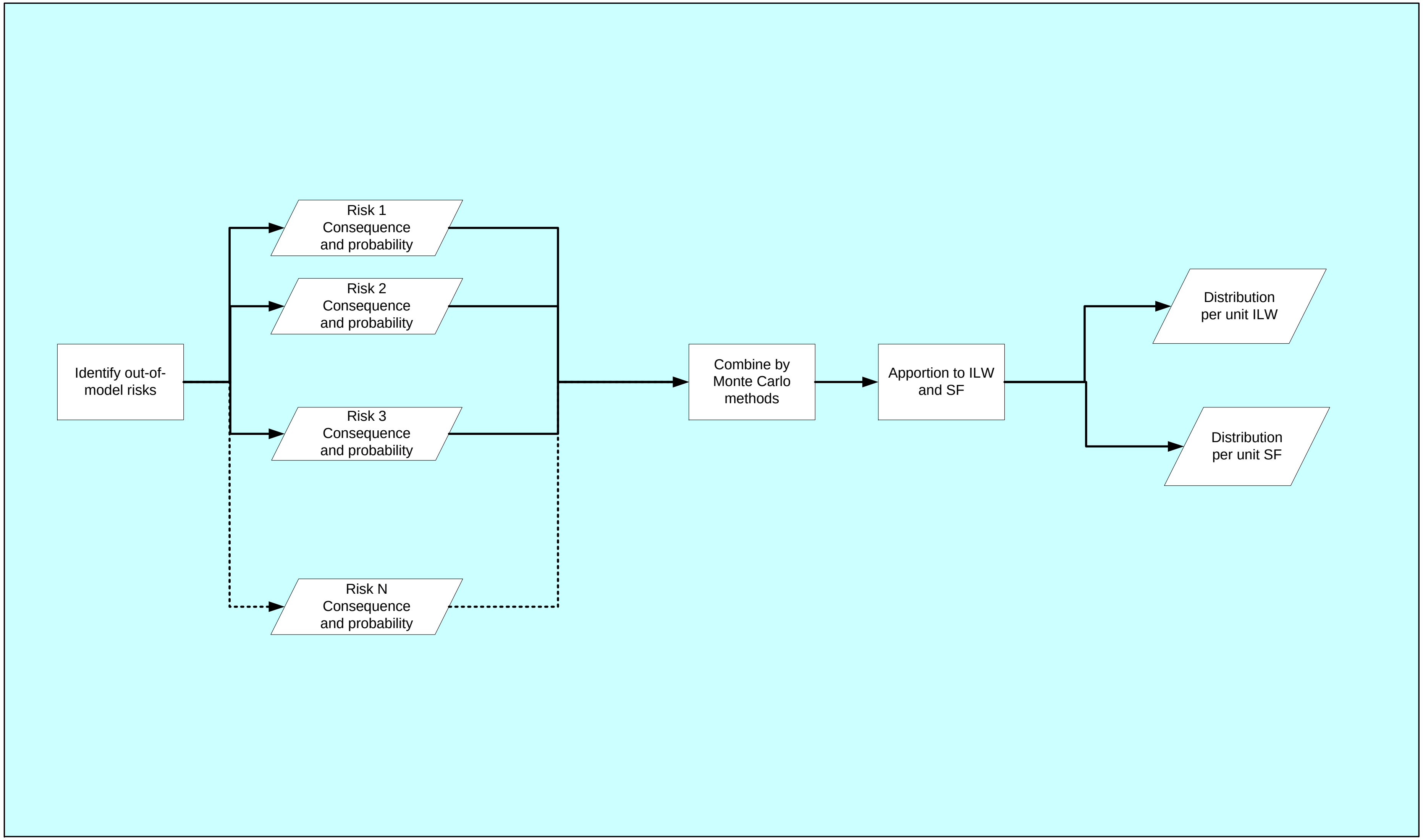
3.4.4 By combining these assessments by Monte Carlo methods it is possible to determine a distribution for the contingency adjustment. This can then be apportioned to ILW and spent fuel to enable the contingency adjustment to be applied to the two distributions derived under Step 12.

3.4.5 The detailed analytical exercise described here has not yet been carried out, hence for the purposes of the worked example two purely illustrative distributions have been used for the contingency adjustment, with the values shown under Step 13 above. These values have been arbitrarily determined, and should not be taken as an indication of the level of the contingency adjustment implied by the exercise described here.

3.4.6 It is intended that a distribution for contingency costs will be estimated and the values derived included in the updated version of this worked example that will be included in the public consultation later in 2009. A detailed assessment of out-of-model risks will need to be undertaken each time an indicative fixed unit price is requested by an operator, based on the best information on risks and uncertainties available at the time.

[38] The Green Book page 101 - http://www.hm-treasury.gov.uk/d/green_book_complete.pdf.

Figure 5: Illustration of how the contingency allowance might be derived



3.5 An illustration of how the fixed unit price for spent fuel might be expressed in alternative units (Step 14 in the worked example)

3.5.1 As discussed in paragraph 2.9 of this paper, and also in Discussion Paper 2[39], there are a number of alternative units that might be used to set a fixed unit price. This section considers how the illustrative values for a fixed unit price for spent fuel derived in Step 16 would be converted below in either an output-based unit (£/MWh) or a volume-based unit (£/tU)

3.5.2 The illustrative values for the fixed unit price for a canister of spent fuel, derived in Step 16, can be converted as follows:

- To convert into tU, the price per canister derived in Step 16 is simply divided by 2.06, as this is the assumed capacity of the copper canister[40].
- To convert into £/MWh, a total estimated waste disposal liability for spent fuel is calculated by multiplying the values for the fixed unit price per canister (from Step 16) with the estimated spent fuel inventory in canisters (from Step 9). This total is then divided by the estimated output of the new nuclear power station (from Step 17) to give a value in £/MWh.

3.5.3 The table below gives the illustrative values for a fixed unit price for spent fuel expressed in £/tU and £/MWh. As with all figures in this paper, the numbers here are in constant September 2008 money and are undiscounted. For comparison, the table also includes the £/MWh figure derived in Step 20 above (using the 2.2% real fund growth assumption). Note though that the figure from Step 20 also includes the cost of disposing of ILW, which in the worked example is around 5% of the total waste disposal liability and would be subject to a separate fixed unit price in the event that the fixed unit price for spent fuel was set as a price per unit output.

Variant 1	P_{80}	P_{90}	P_{95}	P_{99}
Price per canister (£k)	2030	2160	2250	2370
Equivalent price per tU (£k)	985	1049	1092	1150
Equivalent price per MWh (£)	2.08	2.21	2.30	2.43
£/MWh figure from Step 20	0.37	0.39	0.40	0.43

[39] See Discussion Paper 2 paragraphs 2.9 – 2.17.
[40] However, as discussed in Discussion Paper 2 paragraph 2.14, a fixed unit price based on volume might need to be accompanied by additional parameters describing the heat output and other characteristics of the spent fuel.

Variant 2	P_{80}	P_{90}	P_{95}	P_{99}
Price per canister (£k)	2480	2650	2800	3070
Equivalent price per tU (£k)	1204	1286	1359	1490
Equivalent price per MWh (£)	2.54	2.71	2.86	3.14
£/MWh figure from Step 20	0.45	0.48	0.50	0.55

3.5.4 It can be seen that the £/MWh figures derived in this way are much higher than the £/MWh figures derived in Step 20. This is because the values at Step 20 are an estimate of how much money an operator would need to pay into their independent fund at the time of generation in order to meet their waste disposal liability at the time of waste transfer. That figure depends heavily on the assumed rate of fund growth and would be subject to change depending on actual fund performance, to ensure that there were sufficient monies in the fund to meet the waste disposal liability.

3.5.5 In contrast the £/MWh figure derived in this section is an illustration of a fixed unit price expressed as a value per unit of output. Hence it does not depend on any fund growth assumptions – the operator would be responsible for ensuring that their independent fund had sufficient monies to pay this price per unit at time of waste transfer, regardless of the performance of the fund.

3.6 A note on how Monte Carlo calculations have been produced for this paper

3.6.1 Monte Carlo simulation is a computerised mathematical technique which can be used to allow for risk and uncertainty in quantitative analysis and decision making. It is suitable for use in the present modelling work because some of the input information takes the form of a distribution of values and hence the output will also be in the form of a distribution. In Monte Carlo methods the calculation is undertaken a large number of times. In each iteration single values for each of the input data are sampled from the appropriate distributions and used to calculate a single value for the result. Over a large number of iterations, the distribution for the results of the calculation is generated.

3.6.2 In this paper, we have generally calculated distributions over 1000 iterations, but, to ensure accuracy, we will perform a larger number of iterations when conducting calculations for the purposes of setting a fixed unit price.

3.6.3 Distributions of input data are involved at three Steps in the worked example – Steps 4, 7 and 13. For the calculations in Step 4 and Step 7, the two distributions from which values are drawn relate to the costs of waste disposal for each scenario and the relative probabilities of each scenario. The costs are set out in Figure 3, and for this worked example all scenarios are considered to be equally probable.

3.6.4 For the calculations at Step 13 a distribution for estimated unit costs that has been derived earlier in the methodology is combined with a distribution for a contingency allowance. The latter distribution is, for this worked example, a simple triangular distribution, with three input values representing the minimum, mode and maximum values of the distribution.

Section 4: Conclusions and next steps

Summary of key points from this paper

4.1 This paper sets out a worked example for how an indicative fixed unit price might be derived for operators of new nuclear power stations, based on the discussions in the first two papers in this series. It is intended to be read alongside those two papers. This paper is intended to illustrate the quantitative impact of the various alternatives discussed in the earlier papers, and its purpose is to assist stakeholders in commenting on the issues set out in the previous papers.

4.2 We consider the way in which the worked example has been calculated to be a reasonable illustration of the cost modelling under development by Government. We have looked at a number of scenarios and assumptions and at this stage have derived a potentially wide range of estimated costs. However this is not intended to be a definitive description of how the Government will use this cost modelling to determine the appropriate level of the fixed unit price. In reaching final conclusions on the setting of the fixed unit price it will be important to strike the right balance in ensuring a prudent and conservative approach to cost estimation while avoiding adding in excessive contingency. To this end, we will be seeking the views of the NLFAB which has now been established, and there will be a public consultation later in 2009 which will include our proposals on how a fixed unit price will be established.

4.3 The primary intention of this paper is to provide stakeholders with a worked example, and to provide some analysis of the impact of taking a different approach at key stages in the worked example. To illustrate these points we have set out:

- a step-by-step description of a potential range of figures in the worked example;
- the assumptions that have been used to calculate the worked example and the description of the impact of varying those assumptions;
- the calculations that go to make up the worked example itself.

Next steps

4.4 This is the third and last paper in a series of three informal discussion papers being issued by the Office for Nuclear Development, for discussion with stakeholders. This is not a formal consultation and we are not specifically seeking public views at this stage. However these papers are being made available on the Department's website and if interested parties wish to comment on the issues covered in these papers they may do so, and these comments will be taken into account as part of the development of the Government's policy on these issues. Information on how to comment is set out in Section 1 of this paper.

4.5 The formal consultation on the issues covered by these discussion papers will take place later in 2009 and will reflect comments made on these papers.

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