Estimating the disposal costs of spent fuel

A software modelling tool estimates that the UK government may be undercharging energy companies for disposal of new spent reactor fuel in the UK. Other work uses multiple parameters to estimate the total cost of a repository (p.46).

In its 2008 white paper Managing Radioactive Waste Safely, the UK government set out a framework for managing higher activity radioactive waste in the long-term through geological disposal, coupled with safe and secure interim storage and ongoing research and development to support its optimised implementation. It also invited communities to have discussions, without commitment, with government on the possibility of hosting a geological repository. So far, two areas in Cumbria (Allerdale and Copeland) have expressed interest in hosting the facility.

Current cost models of this planned £12 billion UK deep geological disposal facility (GDF) for radioactive waste (see box, p46) exclude spent fuel from new nuclear reactors. The government is planning to charge electrical utilities for the disposal of this new spent fuel. Although it had originally planned to charge a fixed price, this was changed in 2011 to a variable, but capped, Waste Transfer Price (WTP).

The Waste Transfer Price will increase over time, as the final outturn costs of actually siting, building and operating the deep GDF are better understood. The coalition government has also proposed that the Waste Transfer Price should be deferred for a period up to 30 years after the start of new nuclear reactor power generation (assumed to be around 2020). By 2050 the government will know the true outturn capital cost of siting and constructing the repository and will also have had 10 years' practical operating experience running the repository, which is planned to be fully operational by 2040.

Ian Jackson, author of *Nuclear Engineering International*'s 2008 special publication *Nukenomics*, developed a software model of the economical issues affecting the spent fuel disposal costs for new nuclear reactors (called 'FUPSIM' after the earlier fixed price unit plan), in a research commission for Greenpeace UK.

In a March 2011 Greenpeace UK report, 'Subsidy Assessment of Waste Transfer Pricing for Disposal of Spent Fuel from New Nuclear Power Stations', Jackson argues that the cap, £978,000/tU, may be too low to cover the government's costs. Jackson says the government assumes nuclear disposal costs will rise at only 3.3% per annum above inflation. But past experience shows that nuclear costs typically escalate at between 4.2–4.5% above inflation. Over the past decade the costs of similar major nuclear projects such as NDA liabilities, Yucca Mountain, Olkiluoto-3 and most recently Flamanville-3 have all risen at around this rate. At that rate, spent fuel disposal costs will breach the government price cap much sooner than expected (around 2047), he says, and so are likely to have been underestimated. In addition, he argues that the government may have underestimated the costs of disposition. Both issues would require a government subsidy to cover costs.

His software FUPSIM simulates waste disposal liabilities for any size of new nuclear power station via 21 adjustable input parameters (such as power station output, generating lifetime, load factor, spent fuel burn-up, storage period, discount rates) and displays 31 calculation results. It calculates the approximate repository cost and disposal price for spent fuel disposal for a new nuclear power station project, the funding needed by energy companies to meet these spent fuel liabilities, and any potential funding shortfall that may need to be subsidised by the taxpayer. It also calculates liability costs of spent fuel disposal for energy companies.

In the report, Jackson writes, "The total cost of a GDF repository is very sensitive to the total quantity of spent fuel it contains. For example the NDA's historic legacy of spent fuel represents only 2% of the total volume of waste in a repository but is responsible for around 50% of the gross repository cost. This makes it difficult to reliably model unit disposal costs because even small changes in the spent fuel inventory can significantly increase the total lifecycle cost of the repository."

He also points out that unit disposal costs (£k/tU) for new build PWR spent fuel will be only half the cost of AGR spent fuel disposal from Britain's existing reactors, because it assumes that AGR fuel will not be able to be packed as tightly as modern PWR fuel. AGR fuel assemblies are bulkier than PWR fuel assemblies, but that should not stop size-reduction work before canister placement,

How much is there?

The waste challenge faced by the UK today is dominated by untreated historic wastes, largely created in the 1940s, 50s and 60s, held in old facilities. Records may be incomplete, meaning that the exact contents of these facilities are uncertain. Some wastes are not in a stable state and could be subject to migration or reaction over time. The hazards posed by these wastes are gradually being reduced by retrieving, treating and packaging them, although this will take many years.

The 2010 National Radioactive Waste Inventory estimated that the total volume of radioactive waste that exists today or is forecast over the next century or so from existing facilities is about 4.7 million m^3 (97% of which already exists today). About 94% (about 4.4 million m^3) of this falls into the low level waste category. About 6% (290,000 m^3) is in the intermediate level waste category, and less than 0.1% (1000 m^3) is in the high level waste category. Excluded from these figures are quantities of irradiated nuclear fuel, the total mass of which at the date of inventory was about 9900 tHM (expressed as tonnes of heavy metal), with estimated future arisings of about 2800 tHM. In addition the total mass of unirradiated fuel is estimated to be about 520 tHM.

Another significant radwaste inventory not considered is the UK civilian plutonium stockpile. According to an April 2011 report from UK newspaper *The Independent*, this is expected to reach 109 tonnes within a few years (www.tinyurl.com/3apypsy). The Office for Nuclear Regulation reports a national total of civil un-irradiated plutonium of 114.8 tonnes as of 31 Dec 2010. Holdings of civil depleted, natural and low-enriched uranium below 20% U-238 (DNLEU) in the civil nuclear fuel cycle are 105,500 tonnes.

-**Simon Bimpson**

Jackson argues. The disposal price difference "may perhaps give the appearance of favouring new nuclear build," says Jackson.

The software program uses a conservative approach to calculate unit disposal costs for new nuclear reactors by scaling upwards from known NDA costs based on the total mass of legacy AGR and PWR uranium fuels needing disposal.

FUPSIM calculates the marginal cost (£m/tU) of increasing the repository size, the basic minimum unit cost of the extra spent fuel space. FUPSIM then calculates the full share cost (£m/tU) of increasing the repository size, which combines the unit cost of disposal of both new and legacy spent fuel.

In the report, Jackson says that as the NDA repository expands with new nuclear build fuel added, spent fuel unit disposal costs may be approximated through iterations of the six-tenths rule cost estimating formulae: $C_B = C_A \times (S_B/S_A)^{SF}$." In this formula, C_B is cost B, C_A is cost A, S_B is size B, S_A is size A, and SF is scaling factor 0.6. Using this rule, he concludes that the shared spent fuel unit disposal cost for a new 10-reactor PWR fleet is £473,000/tU, which is about £280,000 higher/tU than UK government predictions. The fewer reactors are built, the higher costs per-tonne rise, up to £628,000/tU for spent fuel from just one new PWR added to the current repository.

A cost underestimation would mean that the NDA will not fully recover all of its disposal costs for new build reactor fuel, and so the NDA will require an indirect government subsidy to make up the shortfall.

The report makes two recommendations: remove the price cap, and link the price to actual repository costs, and set the same costs for PWR, AGR and MOX fuel disposal.

FUPSIM used UK government generic reactor modelling assumptions based on a 1.35 GWe PWR reactor operating for 40 years lifetime, generation start-up 2020, end of generation 2060, average load factor 90%, with a lifetime generating output of 424,000 GWh over 40 years. ■

Modelling the cost of the UK geological repository

A software model designed to estimate the cost of building and operating a geological repository for high-activity radwaste allows creation of multiple scenarios through manipulation of key variables of location, geology, volume of waste, type of waste, engineering layout and schedule.

The Nuclear Decommissioning Authority is responsible for planning and implementing geological disposal of radioactive waste in the UK. The work is being undertaken within NDA's Radioactive Waste Management Directorate (RWMD).

RWMD need to evaluate the potential cost of the programme. The cost is affected by many factors, but the most significant are the inventory of waste, the timing of waste arisings, the timing and duration of each phase of implementation, the geology at the site in question and the design of the geological disposal facility itself. At this early stage of the programme, there are inevitable uncertainties about all of these factors; RWMD needed a tool to identify the cost impact of various options.

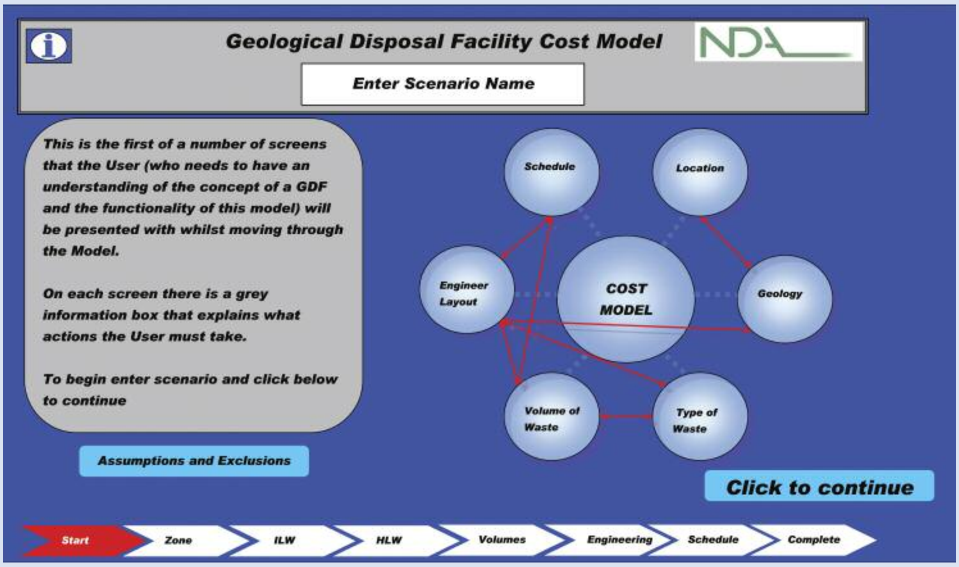
Engineering firm MWH worked with the RWMD to provide this. MWH gathered expert cost estimators, engineers, geologists and nuclear waste specialists for participation in several workshops, from both MWH offices and the RWMD.

A parametric cost model was developed to provide high-level estimates of the cost of a geological disposal facility in the UK mainland based on selecting certain parameters. It could also be used to identify the impact of changing parameters in the development of the base cost.

The fundamental assumption inherent in the cost model was that it would be possible to build whatever combinations of parameters were selected and that any subsequent solution could be safely operated and closed. The team developed the model on the understanding that the ability to select a combination of parameters should not be taken as proof that such a combination exists in practise.

Each scenario cost was produced by working through a series of screens inputting data, answering questions or selecting from various drop-down options.

Although there were many variables that could potentially impact on GDF costs, the parametric cost model included only those judged to be the most cost-significant: location, geology, volume of waste, type of waste, engineering layout and schedule. MWH recognised that particular parameters interact with each other. For example, the selection of a certain type of rock and the depth of the geological disposal facility has an impact on the engineering layout. This is because of the type of emplacement design that could be constructed. Alternatively the amount of waste assumed to be disposed of in the GDF would impact on the number of operational years required.



A screenshot of MWH software illustrates how key parameters are interrelated.

MWH tested, validated and benchmarked both its methodology and source data during development and after handover to RWMD. The calculations also have been verified by changing the parameters to mimic some of the global disposal facilities currently under consideration elsewhere in the world.

The model estimates that the cost of geological disposal of the UK's radioactive waste is circa £12 billion (undiscounted) over 100 years. If separated uranium and plutonium were to be included the costs rise by £2 billion. The estimated cost to first waste emplacement is circa £4 billion. These costs do not include any waste from any new nuclear power stations.

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