

3 July 2007

Human Costs of a Nuclear Accident: Final Report

Health and Safety Executive

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Executive Summary

Issues arising from the need to value the health effects of a possible nuclear accident have led, in this report, to work that has a potentially much wider application.

The main conceptual difficulties posed by discounting safety or health impacts over time, while still a common source of confusion in practice, appear now to have been resolved in the literature, although delayed impacts from exposure to a hazard may be a loose end. The current HSE guidance, while it is basically sound, could be further clarified.

A possible formal reconciliation of the value of a life-year (VOLY) applied in health policy and the value of a prevented fatality (VPF) applied in safety regulation is developed as a significant step beyond previous published work, offering some immediately usable procedures. It proposes, for adults, a VPF schedule that falls substantially with declining life expectancy, the annual rate of decline in the VPF being equal to the VOLY. The rate of decline in the VPF, and hence also the implied value of the VOLY, increases with declining life expectancy; but for life expectancies of more than around ten years this increase is slow, and the VOLY is valued at fairly close to the £30,000 or so widely accepted for medical applications. For shorter life expectancies however the rate of decline of the VPF, and implied value of the VOLY, increase to significantly higher values.

This is an inherently contentious area on which continuing development should be expected and sought. However the report recommends that the VOLY values in this model should be used as a basis for valuing the morbidity (as opposed to mortality) impacts of a nuclear accident, although the values currently derived directly for broadly corresponding non-fatal road injuries are higher.

Also considered are the special characteristics of those at risk from an accidental radioactive release. There are some similarities with transport hazards, in that for example risks are spread demographically quite evenly, but there are other, special characteristics of the hazard, which are identified and flagged as meriting further development.

The terminology of “disproportion” or “gross disproportion” is also addressed. Developments over the past fifty years are hard to square with the continued retention of the term “gross” in government guidance.

1. Introduction

This Report is in response to an invitation by the Health and Safety executive to advise on the valuation of health effects of exposure to radiation, to inform a model being developed by the Health Protection Agency to assess the economic consequences of an accidental release of radioactive material. The project specification is at Appendix A. In the event, the work developed in such a way that the main issues addressed in the Report are of much broader significance. The study team therefore provided comments separately on the coverage of health effects in the Health Protection Agency draft report COCO-2 Draft E, Section 3: Health effects.¹

Section 2 below addresses the discounting of health impacts over time. This is sometimes a contentious field, but the fundamental issues are resolved in the literature and reasonably well reflected in current UK government guidance.

Section 3 addresses the more challenging issues of reconciling the valuation of a life-year (VOLY) (i.e. the value of a healthy life-year applied in health policy, often described as the value of the quality adjusted life-year or QALY) and the value of a prevented fatality (VPF) derived from the approach to the valuation of risks of death and non-fatal injury used in safety regulation. This section, while far from claiming to be the last word in such a difficult field, develops significant new analysis.

Section 4 considers the extent to which, in the context of a nuclear accident, adjustments may be appropriate for specific personal characteristics or for the special nature of the risks.

Section 5 considers the terminology of “disproportion” and “gross disproportion”, concluding that the term gross disproportion is not consistent with developments in the half century since it was first established.

Section 6 concludes.

¹ Attached to email from Michael Spackman, NERA, to Neil Higgins, Health Protection Agency, of 16 April 2007.

2. Time Discounting of Health Impacts

2.1. HSE Guidance

Reducing Risk, Protecting People (R2P2) (Health & Safety Executive, 2001, p66) explained that, at that time, “for most public policy applications a real rate of return of 6% ... is used ... This assumes that all monetary costs and benefits are expressed in real terms (constant prices)”. R2P2 went on to explain that “the value that individuals place on safety benefits tends to increase as living standards improve, so the future values applied to such benefits should be uprated to allow for the impact on well-being of expected growth in average real income. On the basis of past trends and Treasury guidance, HSE regards an uprating factor of 4% a year as appropriate on the benefits side of the comparison.” This implied that quantities such as values of prevented fatalities (VPFs), if expressed in a constant money value, should be discounted at 2%.

Current HSE guidance (Health & Safety Executive, 2007.1)² notes that “the Treasury recommended discount rate for both costs and benefits is 3.5%. However, it is considered that individuals place an increased value on health and safety benefits as their living standards increase. This leads, currently, to an effective discount rate for health and safety benefits of 1.5%.” The guidance explains that this latter figure more fully in a footnote as follows:

“It is considered that the value of preventing a fatality has a constant utility value over time and it is therefore uprated in real terms each year by real GDP per capita growth (i.e. currently, by about 2% per year, since at the moment the real per capita GDP growth is forecast at around 2% per annum). This uprating, coupled with a 3.5% discount rate, gives an 'effective' discount rate for health and safety benefits of 1.5% (lower effective discount rates apply to health and safety benefits accruing more than 30 years into the future). It needs to be noted that the real per capita GDP growth forecast could change over time.”

2.2. Potential Refinement of HSE Guidance

In its current practical impact the HSE guidance is satisfactory.³ There are, however, some respects, listed as follows and discussed in turn below, in which the guidance might usefully be further refined.

- § Presentation of the relationship between the discount rate for conventional costs and benefits and the discount rate for utility impacts.
- § Clarification of the components of the value of a prevented fatality (VPF) and of the relationship with the QALY.

² This reference is to the guidance on the current HSE website, which was revised following publication of the revised Treasury Green Book in 2003. The HSE advise us however that it is scheduled for significant further updating in the next few months.

³ It is consistent with Jones-Lee and Loomes (1995), which includes further references. Gravelle and Smith (2001) provide a comprehensive account of the implications of alternative assumptions.

- § Reference to the case of delayed impacts.
- § The very long term.
- § Coverage of the fallacy that discounting a benefit at a lower rate than conventional costs implies indefinite postponement.

2.2.1. Presentation of the relationship between the discount rate for conventional costs and benefits and the discount rate for utility impacts

The current HSE presentation, as described above, takes more steps than are needed to explain that:

- § The discount rate for conventional monetary costs or benefits (expressed in real terms) is x per cent per year;
- § But as incomes increase the real value of a VPF increases through time, at a rate y per cent per year;
- § Thus future VPFs, valued at today's monetary value, can be discounted at $x - y$ per cent, which is currently quantified as 1.5 per cent.

It would be simpler to explain that:

- § Some costs and benefits, such prevented fatalities, or QALYs, may be assumed to have the same impact on people's marginal⁴ utility, regardless of people's income increasing through time.
- § Such utility impacts, valued at *today's* monetary value, may therefore be discounted at the "pure discount rate" for marginal utility used by the Treasury in deriving the standard social time preference discount rate.⁵ This is currently 1.5 per cent.

Advantages of the simpler explanation are that it makes clearer what assumptions are being made and it omits two irrelevant variables (the per capita growth rate and the elasticity of marginal utility⁶). It thereby avoids potential confusion, in the short term and later in responding to changes in these or other components of the discount rate.

2.2.2. Clarification of the components of the VPF and of the relationship with the QALY

The published version of the Department for Transport figures for valuing prevented fatalities (Department for Transport, 2007) still follows the format used in the early days of such valuations, which were based on the gross output that people would have produced had they

⁴ Or perhaps also intramarginal changes in some applications of the QALYs, where the issue, even *ex ante*, is the valuation of more than marginal changes in health state.

⁵ It may be worth considering whether the *utility* gain of reducing mortality or morbidly risks may change with increasing income over time. However we are not aware of any empirical studies of this.

⁶ The current HSE footnote recorded above, if it continues to stand, will cause confusion if and when the UK government discount rate is revised on the basis of an elasticity of marginal utility different from the current low value of 1.

not been killed, plus an essentially arbitrary extra sum for “human costs”. This last was to reflect the obvious point that factors such as grief of the bereaved would not otherwise be adequately captured.

The VPF is therefore presented in the Department for Transport guidance in the form of “human costs” plus “lost gross output” plus “medical and ambulance costs”. However the VPF actually consists of “willingness-to-pay (WTP), by those at risk, to avoid a fatality” plus “lost *net* output”, plus (as before) “medical and ambulance costs”. As gross output is equal to the net output plus the worker’s own consumption, the “human costs” figure in the published data is equal to the somewhat contrived quantity “WTP minus own consumption”. The Department for Transport might usefully be encouraged to bring their presentation into line with the methodology actually used to derive the figures. A correct presentation is published in HM Treasury (2005, paragraphs C2 and C3).

Strictly speaking, the only component of the VPF to which the pure time preference discount rate should be applied is the WTP component. However the net output and ambulance/medical cost components are so small relative to the WTP component that little would be gained, and much lost in greater complexity, by discounting the different components of the VPF at different rates.⁷

At present, QALYs are not explicitly valued in monetary terms, but regardless of whether or not they are valued, they – like prevented fatalities – are essentially measures of utility impacts. It would be helpful to explain in HSE guidance that, for this reason, the pure time preference discount rate should be applied equally to both.

2.2.3. Reference to the case of delayed impacts

The discussion above relates to time preference of society as a whole. Thus if public spending on a safety measure were made today to reduce the expected numbers of injuries and / or deaths over future years, slightly more weight should be given to the earlier years than the later years, because the future population is slightly different.

This does not necessarily apply to time discounting over the interval between a particular person’s exposure to say a carcinogen and the subsequent morbidity and / or fatality, perhaps many years later. In this case the strictly relevant time preference rate would be the personal time preference of the individual. However this personal rate would probably be significantly higher than the social time preference rate.⁸ The individual would very much prefer the impact to be delayed.

In the unusual circumstance of there being a policy option that could achieve such a delay between initial exposure and health consequence there would be a good case in logic for applying an estimated personal time preference rate. However to apply such a rate to health and safety applications in general, which would reduce the present values of such impacts, would be ethically dubious and, even if it were not, politically very bold.

⁷ Besides being relatively small, these elements have components that also increase in real unit value over time. This further reduces the need for separate discounting and would increase the complexity of doing so in a rigorous way.

⁸ A comprehensive review of the literature on personal time preference may be found in Frederick, Loewenstein, and O’Donoghue (2002).

This is an issue that may however merit further consideration in the context of medical applications of the QALY, where options for delaying health impacts may be more common.

2.2.4. The very long term

The very long term is covered in current HSE guidance, but only by reference to the Treasury Green Book, which provides a declining discount rate schedule for periods beyond 30 years.

The health impacts of an accidental nuclear release would mainly take the form of health impacts within the lifetimes of those alive at the time of the incident. If, following current HSE guidance and as recommended in this report, these were all valued at “today’s” money value and discounted at a pure time preference rate of 1.5 per cent, there would be no worthwhile benefit in using, for these impacts, any lower rate after 30 years. Even if it were defensible in logic the extra complexity could not be justified by a gain in accuracy that would be trivial relative to other data uncertainties.

Much longer term horizons might be relevant for hereditary impacts, although we understand that these impacts appear now to be relatively very small. *Very* long term discounting has become a field of active academic debate from the 1990s and has been further stimulated by the recent Stern Review of climate change. There is no full consensus among economists (or any other discipline) about the best way of handling very long term welfare impacts. We however recommend that such very long term impacts are best presented in ways other than by present values.⁹

2.2.5. Recognition of the fallacy that discounting a benefit at a lower rate than conventional costs implies indefinite postponement

It is sometimes argued, occasionally even by well established authorities, that a benefit such as a QALY or a VPF should be discounted at the same rate as conventional monetary costs, because “if the costs of an intervention are discounted but the effects are not, then an intervention can be made to appear more favourable simply by postponing its implementation” (Hammit, 2002, p988).

The rationale appears to be that, if the value of a potential benefit increases through time and the cost of obtaining the benefit stays broadly constant, the present value in year 0 of the option of spending in year 0 is less than the present value in year t ($t > 0$) of the option of spending in year t .

Sometimes such an effect does justify postponing spending. People or enterprises, often wisely, may postpone spending on some IT hardware, or on housing, or on shares or currency, because they believe the relative price of what they wish to buy will fall substantially in the future. However this is a sound choice only when the expected benefits of delaying spending more than offset the disbenefits of not enjoying the good or service in years 1 to t .

⁹ This position is generally supported in the outstanding collection of papers edited by Portney and Weyant (1999). Schelling (2000) argues in particular that “discounting is not the appropriate concept for dealing with the benefits of reduced greenhouse gas emissions in the distant future”, largely because of the ethical complexities of weighting the interests of people in the distant future and in other countries. However the “common sense” logic that he applies is relevant to any very long term benefits.

It therefore does not follow that, say, a patient with a disabling but curable injury, even if paying in person for the treatment, should be expected to prefer to postpone the treatment from this year to next, to gain a return on the money saved and to enjoy a real monetary value of the benefit next year, when the time arrives, even higher than it would have been this year. This would ignore the *disbenefit* of the patient's pain and suffering over the period during which the treatment is delayed. The issue, described as the Keeler-Cretin paradox since it first appeared in the literature in 1983, is surprisingly widely cited, but as Gravelle and Smith (2001) say bluntly at the end of an extended discussion of it, "it is simply incorrect to use the same discount rate for health and cost effects if the value of health is growing".

The fallacy might usefully, in only as a footnote, be acknowledged and dismissed in future HSE technical guidance.

3. QALY / VOLY and WTP Valuations of Mortality and Morbidity Risks

3.1. The Monetary Valuation of Statistical Life and of (Quality-Adjusted) Life-Years

For the past twenty years or so there has been fairly widespread agreement – at least within most developed countries – that public sector allocative and regulatory decisions relating to health and safety should take due account of the preferences, and more particularly the *strength* of preference, of those who will be affected by the decision. To the extent that an individual’s well-informed and carefully thought-out maximum *willingness to pay* for a good or service is a measure of what that good or service is worth to the individual, relative to other possible objects of expenditure, it is not surprising that so-called “willingness to pay” (WTP)-based monetary values of health and safety have had an increasingly important role in public sector decision-making.¹⁰

Historically the initial focus of research in this area was on the definition and estimation of a WTP-based “Value of Preventing a Statistical Fatality” (VPF) for any given context (such as transport). This value was defined essentially as the aggregate of individual willingness to pay, across a large group of people, for small individual reductions in the risk, which taken over the group as a whole would reduce by one the expected number of premature deaths over the period in question. Thus, for example, if a group of 100,000 people would, on average, be prepared to pay £15 each for a reduction of 1 in 100,000 in the risk of being killed in a road accident during the coming year, then the VPF for that group would be taken to be, in road project appraisal, $15 \times 100,000 = £1.5\text{m}$. For a more detailed account of the theoretical and empirical development of the VPF concept, see, for example, Drèze (1962), Jones-Lee (1976, 1989), Carthy *et al* (1999), Miller (2000) or Viscusi and Aldy (2003).

In the case of transport risks in particular, the focus then progressed to the estimation of WTP-based values for the prevention of non-fatal injuries – see, for example, Jones-Lee and Loomes (1995).

In health care the situation developed rather differently. While it was accepted that allocative health care decision making should be informed by preference-based measures of the effectiveness of different medical treatments, there was some resistance to the use of monetary values. Instead, research efforts were principally directed at obtaining empirical estimates of the so-called “Quality-Adjusted Life Years” (QALYs) gained by a particular medical treatment. These QALY measures, at least in the UK and other European countries,

¹⁰ Most of this work addresses people’s WTP to reduce risks to themselves. Less often, explicit attempts are made to elicit people’s preferences as “citizens” about government spending to reduce risks to others, such as risks to those who cannot themselves respond because of youth or infirmity, or risks to which the respondent, because of lifestyle or geography, is not personally exposed. There are problems in quantifying such preferences. There are the standard “free-rider” and other “non-revelation of true preferences” problems that beset attempts to value public goods. There are also serious doubts about the appropriateness of including altruistic willingness to pay for other people’s safety in WTP-based values, as this might well result in a form of “double-counting” – see, for example, Jones-Lee (1992). On the other hand, for children and other dependants it is necessary and appropriate to attempt to determine the electorate’s willingness to pay for improvements in their safety.

were estimated on the basis of the “Time Trade-Off” (TTO) or “Standard Gamble” (SG) approaches – see, for example, Dolan *et al* (1996).

Essentially, under the TTO approach (which was the approach adopted in the UK for policy purposes), the quality of life associated with a given impaired health state is estimated as the ratio $t/10$ where t is the number of years in full health that a typical individual would regard as being equivalent to (i.e. equally as desirable as) spending ten years in the impaired health state.¹¹ Thus if, on average, people regarded, say, ten years of suffering a particular stomach disorder as being equivalent to eight years in normal health, then the stomach disorder health state would be accorded a quality of life index score of 0.8 on a scale where a score of 1 corresponds to full health and a score of 0 represents a state of health that is equivalent to death (i.e. an individual would be indifferent between living for the rest of his or her lifespan in such a state or dying immediately).

Combining the health state index score with the number of years spent in any impaired health state allows a ‘full health years’ or ‘quality adjusted life years’ equivalent to be estimated. Thus 25 years with the stomach disorder would be regarded as equivalent to $0.8 \times 25 = 20$ QALYs – the implication being that any treatment that could cure the stomach disorder and enable the patient to spend the next 25 years in full health instead would improve his prospects from 20 QALYs to 25 QALYs, so delivering a benefit of 5 QALYs.

The same benefit could be delivered in numerous other ways. For example, suppose an individual were to face the prospect of an even more serious condition which would reduce her quality of life to a degree indexed at 0.4, but that some treatment could improve her health for the next 10 years to a state indexed at 0.9. Multiplying the 0.5 increase in quality of life by the 10 years to which it applies also gives a gain of 5 QALYs. The same arithmetic can be – and is – applied to treatments that extend life. An intervention which prevents imminent death and gives someone an extra five years of life in full health is said to deliver 5 QALYs, as does the extension of life by 8 years in a health state rated at 0.625, or an extra 12.5 years of life in a health state rated at 0.4, and so on.¹²

In this way the QALY is used as the basis for cost-effectiveness analysis of the “productivity” of different health-care treatments. However the absence of a monetary value prevents the aggregation of health-care benefits with other gains such as reductions in patients’ waiting time or treatment delay, their hospital comfort and convenience, and so on. Similarly it prevents any contribution to decisions about the size of the health-care budget relative to, say, education or transport.¹³ More recent research efforts have therefore been directed at this question of monetary valuation.

¹¹ To be more specific, the form of question used in the UK study which established a quality of life ‘tariff’ for different health states was as follows. Respondents were asked to imagine that they were faced with the prospect of spending 10 years in some specified impaired health state followed by death, and were asked to say how many years in full health then followed by death they would regard as equivalent to the impaired-health scenario.

¹² The conventional rationale of these last examples is that “not being alive” can be rated as zero QALYs, which is not quite the same as the state of someone who is alive but is in such a poor way that he or she would be indifferent about dying. This is briefly touched on in section 3.2.1 below.

¹³ Although it has to be said that in the two UK public service programmes where cost-benefit analysis is routinely applied (transport and flood protection), the impact of such values on the programme budget appears to be minimal.

While work on the empirical estimation of VPFs in various contexts started in the early 1970s (for a survey of this work, see, for example, Jones-Lee (1989) chapter 2), empirical estimation of the monetary value of a QALY did not begin until the late 1980s / early 1990s. This work essentially proceeded along two strands. One involved direct attempts to elicit monetary values for health improvements that could be compared with the QALY gains involved, using “contingent valuation” or “stated preference” studies – see, for example, Johannesson and Johannsson (1996). A more indirect method involved deriving a “value of a life year” (VOLY) from existing empirical estimates of the VPF – see, for example, Moore and Viscusi (1988).

The practicability or otherwise of finding some ‘direct’ value of a QALY is a contentious issue and a study to test the feasibility of so doing is currently underway; although the data collection will not have been completed until July 2007 and the results of the analysis of those data will not be available until the end of August.¹⁴ However, on the basis of earlier contingent valuation and stated-preference studies, direct estimates of the VOLY would appear to range from a few thousand pounds to well over a hundred thousand pounds – see, for example, Hurley *et al* (2000).

One recent UK study (commissioned by DEFRA) asked a random sample of people about their maximum annual willingness to pay on behalf of themselves and other household members for a permanent reduction in air pollution that would result in a certain gain of life expectancy in normal health (Chilton *et al*, 2004). This figure was converted to an annual payment per household member. On the assumption that such a payment would continue throughout the whole of a typical individual’s life (being paid on his/her behalf in early and later years and by him/herself during working years) it was aggregated to a total payment over an average lifetime and then converted to a total payment for a one-year gain in life expectancy. When the original question asked about payment for a gain in life expectancy of one month, the implicit value of a life-year (VOLY) was £27,600.

The Interdepartmental Group on Costs and Benefits (IGCB, 2004) has recommended the adoption of this estimate of the VOLY.¹⁵ This value is virtually the same as the value of a QALY currently thought to be employed by NICE (or at least, consistent with NICE recommendations), which is understood to be in the region of £30,000.

How do such values compare with those we might derive by the ‘indirect’ method from the VPF? The simplest derivation is to divide the VPF by average remaining life expectancy. Thus, for example, with a VPF of £1.2 million and a population mean remaining life expectancy of 40 years, the estimated VOLY would again be £30,000, or somewhat higher if

¹⁴ A study has been commissioned by NICE/NCCRM with two aims: first, to see whether people feel that some QALYs should be more heavily ‘weighted’ than others – e.g. whether a QALY gained by an elderly person still in quite good health should be regarded differently from a QALY gained by a young person starting from a lower health baseline; and second, to explore the issues raised by trying to elicit monetary values for a QALY. Information about the progress of this research should in due course be available on <http://www.publichealth.bham.ac.uk/nccrm>

¹⁵ Possibly updated through time. Department for Transport convention, between periodic full revaluations by new empirical studies, has been to update their WTP values of for the VPF and non-fatal injuries pro rata to real per capita income. If these values are measures of marginal utility, as suggested in Section 2, this convention is strictly correct only if the elasticity of marginal utility is equal to 1. This has however been Treasury convention since 2003.

the VPF were regarded as the *discounted* present value of future life years. Thus, with a discount rate of 2% p.a. the VOLY would rise to about £45,000.

3.2. Current Practice and the VPF-VOLY-Age Relationship

Both theory and empirical evidence strongly suggest that the VPF – defined as aggregate willingness to pay for a risk reduction that, taken over the group affected, can be expected to prevent one premature fatality – will be (a) an increasing function of the *per-capita* income of the group concerned; and (b) a decreasing function of age – at least beyond the middle years. However the Department for Transport currently applies a common VPF to all income groups and all ages. In turn, NICE and the Department of Health currently applies a common monetary value of a QALY which is also independent of income and age.

These conventions are not consistent with a simple relationship between VOLY and VPF, in the shape of the VOLY for an individual being the VPF divided by remaining life expectancy. Thus, for example, if the VPF is treated as a constant (as in the DfT convention) then the VOLY calculated in this simple way for an eighty year-old, with eight years of remaining life expectancy, will be five times as large as the VOLY for a forty year-old, with forty years of life expectancy. Or conversely, if the VOLY is treated as a constant (as in the NICE convention) this would imply that the VPF for an eighty year-old is one fifth of the VPF for a forty year-old.

One arithmetically simple way of reconciling the VOLY and the VPF (while still accepting that the DfT may for practical and/or ethical reasons still apply a uniform VPF to transport safety) would be to allow the VPF to vary with age, and to treat the VPF for a given age group as being equal to a constant VOLY multiplied by the mean remaining life expectancy, ε , for that age group – i.e. $VPF = VOLY \times \varepsilon$. This would imply, for a typical population, a VPF that declined linearly with declining life expectancy, becoming zero when $\varepsilon = 0$.

However, this simple “linear proportionality” relationship between the VPF and ε does not square with the empirical evidence, which for the UK adult population entails a strictly concave “inverted-U” relationship as follows, updated to 2007 prices – see for example Jones-Lee (1989), Chapter 4, or Carthy *et al* (1999):

Age, years	Life expectancy, ε , years	VPF, £
80	8	560,000
70	14	1,120,000
60	21	1,540,000
50	30	1,820,000
40	40	1,820,000
30	50	1,540,000
20	60	1,120,000

However these empirical estimates of the age-VPF relationship are typically derived from regression analysis, which attempts to control statistically for, and remove the influence of other variables (most notably, income). This means that the estimated relationship relies heavily on the inclusion of all important variables and on the selection of the ‘correct’

functional form to express the inter-relationships between them. If the model is mis-specified – and in this area, the correct specification is debatable – the estimated relationships will be unreliable.

An ‘inverted-U’ relationship is consistent with some theoretical work on what willingness to pay might be expected over people’s expected life span (in the light of their changing income and life expectancy) – see, in particular, Shepard and Zeckhauser (1982).¹⁶ However the message from that model is that lower values for younger adults are likely to arise from imperfections of capital markets, which limit younger people’s ability to borrow against future income and hence restrict their spending power in those earlier years. Such an income effect is not one that UK governments would generally wish to include in the weighting of health or safety benefits.

A more philosophical concern with the rising VPF with age below the age of about 45, if it is empirically robust, is that this might be largely attributable, at least for some young adults, to a “recklessness of youth” and a (somewhat immature) sense of invulnerability, which it may be society’s ethical responsibility to offset. (On the other hand a less controversial factor may be a lower incidence at younger ages of close responsibilities for others – for example as a parent.)

However an inverted-U relationship of this kind would make it difficult to reconcile the VPF and the VOLY. In particular, if the value of an extra life year (i.e. a VOLY) is the difference between the VPF of someone with a remaining life expectancy of ε , and the VPF of an otherwise identical person one year younger with a remaining life expectancy of (approximately) $\varepsilon + 1$, then on the left hand side of the U the implied VOLY is negative, which is absurd.

One possible response to this is to deny that there is any necessary close relationship between the VOLY and the VPF. Another is to say that there ought to be a numerical relationship between them, which is consistent with a positive VOLY at every age, and that if this requires a declining VPF with age then the factors discussed above render the currently estimated VPF-age relationship unreliable.

The authors of this Report do not share a complete consensus on the balance these arguments. However we set out first, in section 3.3, a brief presentation of reasons for not expecting, or forcing, a formal relationship between the VOLY and the VPF. We then set those arguments aside and develop in section 3.4 a mathematical structure, which is an advance on any other of which we are aware, and which we recommend as suitable, in the present state of knowledge, for practical application.

3.3. VOLY and VPF – Reasons for Questioning a Close Relationship

There is obvious appeal in the concept of equating the value of avoiding a healthy person’s early premature death with the present value of the time stream of utility (or VOLYs) that he or she might have enjoyed over a normal life expectancy.

¹⁶ Shepard and Zeckhauser calculated VPF as a function of age for an adult receiving over his working age the average age distribution of US adult earnings, on the assumption that the VPF at any time is equal to the discounted utility of consumption over the remaining life expectancy.

This is exactly how a physical asset such as a piece of machinery would be valued – that is, as the present value of the service it would deliver over its expected lifetime. But people obviously differ from inanimate machines. Two differences in particular provide at least pause for thought about whether such a model (of VPF equals discounted future utility) may be a reasonable approximation to social welfare for public policy analysis.

One difference between man and inanimate machine is that, while the destruction of a valuable machine imposes a subsequent loss of service to those who would have used it, the same is not true in any analogous sense following the death of a person. The utility that the person might have enjoyed is not then a loss to anyone.¹⁷ The most that can be said is that, as discussed further below, people can foresee the prospect life ahead of them *ex ante*, and concern about how they would spend it may be a factor in their WTP to reduce risks of premature death.

Thus one reason for an individual's wishing to reduce fatality risks, *ex ante*, is no doubt often a perception of future activities if life were continue. This may be especially strong for those who wish to complete some very special, say literary, artistic, business, academic, or sporting achievement. However it seems more questionable that this is a positive function of, let alone proportional to, life expectancy. In the absence of specific, systematic empirical evidence, it may be more reasonable to suppose that people, so long as they remain in robust health, tend to accumulate more, and more strongly, missions that they wish to accomplish as life proceeds.

It is in any case questionable whether the prospect of future activities is *often a dominant* issue in determining WTP to achieve small reductions in the risk of premature death. A second difference between people and machines is that, following a person's premature death, the consequences for those remaining bear very little relationship to the utility that the deceased might have enjoyed. The consequences include the net output that the deceased would have produced, but this is separately accounted for in valuing mortality risks and is uncontentious. Much more substantial, typically, is the grief from loss of love, companionship and / or care that the deceased would have provided to those close to him or her. There is no substantial analogue for this following the loss of the inanimate machine.

Thus a stronger motivation than the prospect of future activities for many people may be knowledge of the grief and hardship that their death would bring to those closest to them. This motivation might be expected to be follow an inverted U, as people acquire more dependants and in due course become themselves dependent. The objective *consequences* of death at various ages is a field in which more empirical research may be helpful. The welfare consequence of the death of a typical 20-year old may be less (or more) than those of the death of typical 40-year old.

¹⁷ Unless the argument is carried into theology. One surreal model might be that of the person still being conscious in another form, in a miserable, zero QALY state for the rest of his or her previously expected life span, grieving for the things that would otherwise have been enjoyed in life. Less absurdly, it might be argued that social welfare should be measured by aggregate utility, so that a population of one million with a certain quality of life is no more desirable than a population of two million with half the quality of life. A version of this view has some advocates in current moral philosophy (see for example Broome, 2004), but it is not an argument applied in mainstream welfare economics. (Provision of a given *per capita* gain to a large population is counted as proportionately more valuable than providing the same *per capita* gain to a small population; but simply increasing the population, with no increase in *per capita* welfare, is not of itself seen as a welfare gain.)

Yet another motivation for reducing the risk of death, shared with other higher animals, may be a strong will to live, and so to moderate risks such as those from hazards such as carnivores that wish to eat us. This is similar to the “love-of-life element” discussed briefly in Loomes (2002). It is not clearly age dependent, for people in robust health. However under this heading comes the question noted in section 3.2, of whether a lower VPF for young adults than those in middle age may be partly attributable, as is plausible, to the “recklessness of youth” or an immature sense of invulnerability, and whether it is society’s ethical responsibility to impose “mature” valuations. This is a political choice and by no means clear cut.¹⁸

For the inanimate machine discussed above it is true that, if valued in year $t+1$ at £1 million, its value in year t would have been (under some simple assumptions) the year $t+1$ value plus the value, in year $t+1$, of an additional year of life expectancy for the machine. The extent to which this logic applies to people is an empirical (and perhaps also philosophical) question. It plausibly applies for very short human life expectancies, where the concepts of extending life expectancy and avoiding premature death begin to merge. It would be more surprising if, say, the VPF a typical 40 year-old were higher than that of a typical 41 year-old, by an amount equal to the 41 year-old’s WTP for an extra year of life expectancy.

A general problem of combining the VOLY and VPF concepts is that, as noted above, the VPF is invariably developed as a marginal concept, by aggregating people’s aversion to extremely small changes in risk. It is also applied in that way to accident risks. The VOLY on the other hand is not generally developed in this way, in either its measurement or its application. How fundamental this is as an obstacle to bringing the two concepts into a single mathematical model is not immediately clear, but it may be serious.

However this catalogue of problems, while it needs need to be recognised and to be considered in developing future research, does not contribute to immediate practical procedures. The following section, in contrast, develops practical foundations that link the VPF and the VOLY in ways that are coherent and at least broadly consistent with the empirical data and common sense.

3.4. A New Model Relating the VOLY the VPF and Life Expectancy

In looking for a plausible relationship between the VPF and the VOLY, it is tempting (although, as we shall argue, ultimately unsatisfactory) to suppose, as a first rough approximation, that the relationship between the VPF and ϵ might be linear but *not necessarily* proportional, as follows:

$$VPF = a + b\epsilon$$

Under this model, it might seem natural to treat b (which gives the increase in the VPF resulting from a one-year gain in life expectancy) as the VOLY and a as reflecting the “pure value of living” (PVL) *per se*. For a discussion of this concept see, for example, Rowlatt *et*

¹⁸ Dependent children (an other dependants) raise further questions that this Report does not explore, as the special problems they raise appear not to be significant in the context of nuclear accident risks. However it is far from clear that considered public preferences would ascribe a declining VPF to children as they grow from infancy towards maturity.

al (1998) (known as “the NERA/CASPAR report”), or Loomes (2003). The PVL might reflect, for example, a straightforward desire to stay alive; finalise personal matters; make arrangements for the completion of lifetime projects, and so on.

Given this functional form, we might apply simple bivariate analysis to the data reported in Section 3.2 to yield:

$$\alpha \approx \text{£}1,058,000 \text{ and } b \approx \text{£}9,500/\text{year}$$

However, given that the above estimates of a and b were derived by fitting a straight line to a mostly-symmetrical inverted U (with only the 80-year-old figure generating any real asymmetry), it is no surprise that the b coefficient is insignificantly different from zero (two-tailed $p = 0.331$). On the other hand, rejecting the VPF data for those under 45 and focusing exclusively on the range over which VPF declines with age and remaining life expectancy, the data yields:

$$\alpha \approx \text{£}233,000 \text{ and } b \approx \text{£}56,000/\text{year}$$

In this case, it is a which is insignificantly different from zero (two-tailed $p = 0.354$), while b is now clearly significant (two-tailed $p = 0.029$) and suggests a VOLY that is roughly twice the figure used by DEFRA and NICE.

Moreover, while the “pure value of living” concept has a certain *prima facie* appeal, it raises a number of philosophical and practical problems. In the light of this, and of the volatility of the a and b coefficients (contingent on the assumptions made about the validity of the under-45 data) we here explore a model which seeks to maintain plausible assumptions, while at the same time fitting certain features of the data and offering one possible way of resolving what might for shorthand be described as the “DfT/NICE” paradox.

In developing this model, we set aside for the moment the question of the state of health / health-related quality of life. We assume ‘full health’ for our immediate purposes. We then make two key assumptions, which we regard as plausible and likely to appeal to many people’s intuitions (although we recognise that this is not self-evident and needs over time to be tested empirically). These assumptions are that:

- § the value of preventing premature death, all other things being equal, is at least for adults an increasing function of remaining life expectancy; and
- § the value of a given extension of life expectancy increases as remaining life expectancy falls, subject only to some minimum threshold below which a very small increase on top of an already very small remaining life expectancy is of no appreciable value.

This second assumption is that an additional year of life expectancy is more valuable to those who currently have only a few years left than to those who are currently expecting another fifty or sixty years; subject to the qualification that for an individual who has only a few hours to live, a few hours more has no material value. The basic notion of an inverse relationship between the VOLY and remaining life expectancy is supported to some extent by the findings of a recent contingent valuation study carried out in Sweden – see Johansson-Stenman and Martinson (2006).

Suppose we denote by D the amount of remaining life expectancy measured in days, and take one day to be the remaining life expectancy below which small extensions (of less than a day) are zero-valued. Then we may consider a very simple functional form which has the properties we require, namely:

$$VPF = aD^b \text{ with } D \geq 1, a > 0 \text{ and } 0 < b < 1$$

In general terms, there is some appeal in treating the VPF as reflecting literally the “value of remaining life”, or, more specifically, the sum of the value of *increments* in life expectancy, where these increments in total add up to remaining life expectancy itself. If the value of a small increment in life expectancy from, say, D_i to $D_i + \delta D_i$ has a value equal to δD_i multiplied by the rate of increase ($dVPF/dD$) of the VPF with respect to D (evaluated at D_i), then from elementary integral calculus the value of an increase in life expectancy from, say, D_a to D_b is given by the VPF at D_b minus the VPF at D_a .

Simply put, the value of an increase in life expectancy is the difference between the VPF for the pre-extension life expectancy, D , and the VPF for D after the increase has been added. For example, for someone with one year (i.e. 365 days) of remaining life expectancy, an increase of a year would be valued as $a.730^b - a.365^b$, while the value of that same increase of one year for someone with a ‘baseline’ life expectancy of 40 years (14,610 days) would be $a.14975^b - a.14610^b$.

The question then is how to establish values for a and b . Clearly, the data on the inverted-U relationship do not conform with the functional form above, and what follows is therefore illustrative.

However, suppose we take as our starting point the fact that the DfT VPF is approximately £1.4m and that the average prevented road fatality would entail about 40 years extra life expectancy, so that $a.14610^b$ should equal approximately £1.4m. Suppose also that we say (somewhat arbitrarily) that for someone with anything more than 10 years remaining life expectancy, the value of an additional year is set at the DEFRA/NICE figure of about £30,000. On this basis we would have the following table, for a range of life expectancies, ε :

ε , years	VPF, £
10	500,000
20	800,000
30	1,100,000
40	1,400,000
50	1,700,000
60	2,000,000
70	2,300,000
80	2,600,000

It turns out that setting $a = 675$ and $b = 0.80$ gives a non-linear relationship for which the above table would represent a reasonably good linear approximation for $\varepsilon > 10$. These values of a and b give the best fit to the figures above and generate the (rounded) numbers shown in Table 3.1 below.

The right-hand column of Table 3.1 – the ‘VOLY equivalent’ – is calculated for the purposes of that table by taking the difference between the VPFs for any two entries and dividing that figure by the difference in the remaining life expectancy. So, for example, the difference between the VPF for those with $\varepsilon = 40$ years (that is, £1,450,000) and the VPF for those with $\varepsilon = 30$ years (that is, £1,150,000) is £300,000, and that figure is divided by the 10 years difference in remaining life expectancy to generate a VOLY of £30,000.

The functional form is such that the VOLY rises as e falls, and the figure becomes a good deal higher at low values of ε . Thus the value of an extra year of life expectancy to those with just one year remaining is computed as the difference between the VPF for $\varepsilon = 1$ and the VPF for $\varepsilon = 2$. In Table 3.1, the relevant figure, shown in the right-hand column, is the difference between £132,000 and £76,000 i.e. £56,000. And if we take the difference between the VPF for two months and the VPF for one month, we get a figure of £7,700 for that extra month, which we have multiplied by 12 (and rounded) to compute a VOLY equivalent of £92,000. That is to say, if 12 ‘typical’ individuals were each given an increase from one month to two in their life expectancies, the aggregate gain of one year would be valued by the twelve of them at a total of £92,000 (to the nearest thousand pounds).

Table 3.1
VPF and implied VOLY for various levels of remaining life expectancy

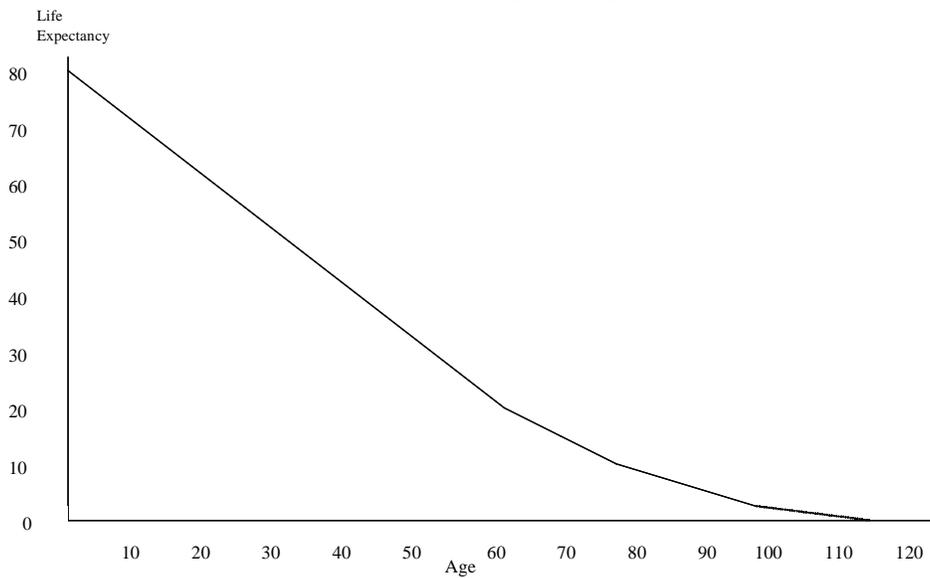
ε (years unless otherwise stated)	VPF (£)	VOLY equivalent (average implied by difference between successive VPFs)* (£)
80	2,525,000	25,500
70	2,270,000	26,500
60	2,005,000	27,500
50	1,730,000	28,500
40	1,450,000	30,000
30	1,150,000	32,000
20	830,000	35,000
10	480,000	43,500
2	132,000	56,000
1	76,000	
2 months	18,100	92,000
1 month	10,400	
2 weeks	5,575	124,000
1 week	3,200	
0	0	n/a

* Strictly these numbers should be midway between the value for ε against which they are tabulated and the next lower value.

Of necessity, the argument in this section has been developed in terms of remaining life expectancy (i.e. D in days or ε in years), rather than age. However, for practical purposes the results derived for the VOLY (and the underlying VPF from which the VOLY is derived) would be more easily interpretable if expressed as functions of age. In Figure 3.1 we therefore provide a graph of average male/female remaining life expectancy vs. age for Great

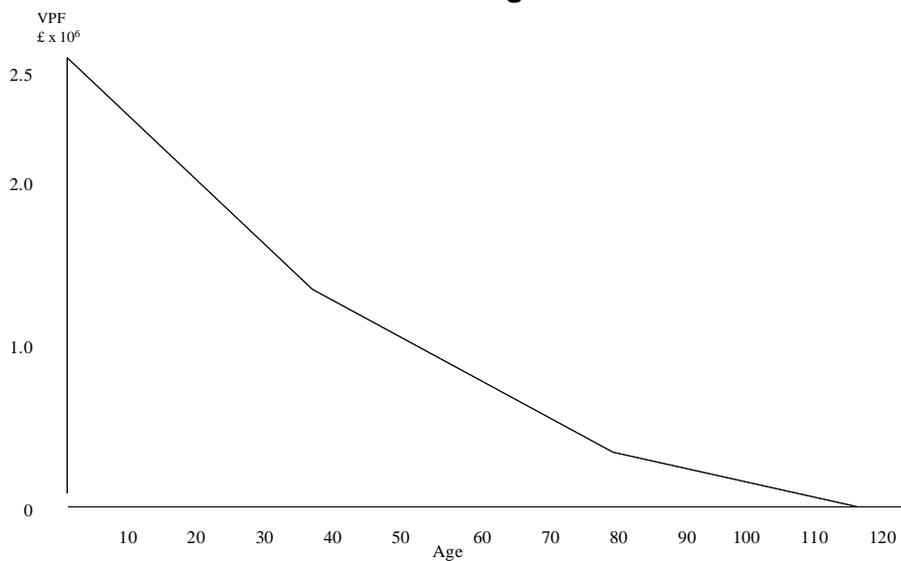
Britain based on the most recently available data.¹⁹ As the data does not extend beyond age 100 the graph for ages 100-115 is an extrapolation.

**Figure 3.1:
Life-expectancy vs. age**



From these life expectancy data – together with the VPF and VOLY vs. life expectancy results derived in this section – we have then constructed graphical approximations to the VPF vs. age in Figure 3.2, and the associated VOLY vs. age in Figure 3.3.

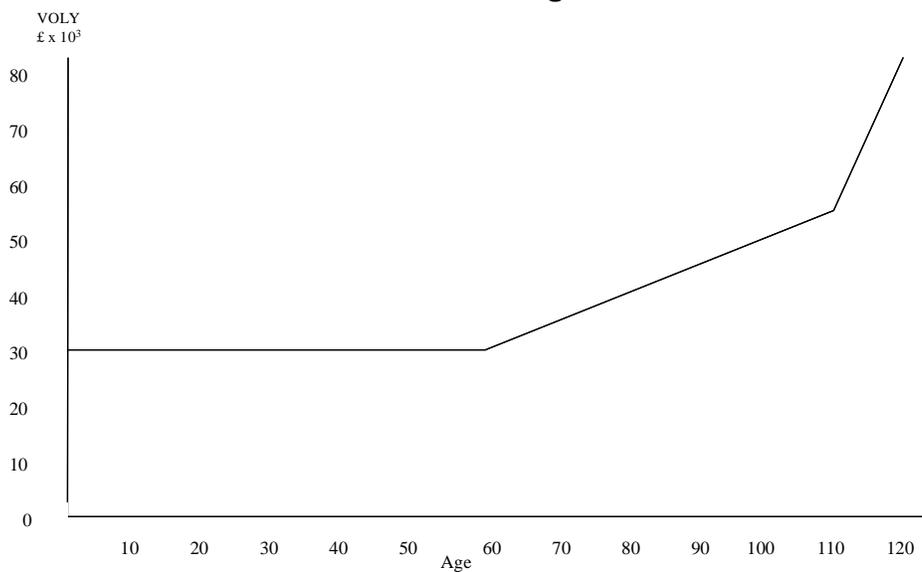
**Figure 3.2;
VPF vs. age**



¹⁹ This is for 2003-2005. Source: Office of National Statistics.

In interpreting the graphical approximations in Figures 3.2 and 3.3 it should be stressed that the piecewise-linearity of the graphs is a result of the (coincidental?) fact that the concavity of the VPF vs. life expectancy function at lower levels of life expectancy is, to all intents and purposes, offset by the convexity of the life expectancy vs. age relationship at higher ages – *recta linea ex flexibus!*

**Figure 3.3:
VOLY vs. age**



All of this having been said, it should be remembered that all of these figures are derived from the intuition of the authors and an illustrative but somewhat arbitrary selection of parameters. Whether such numbers would accord with the preferences of a cross-section of the population is not (yet) known – although this is something that would, in principle, not be difficult to ascertain.

3.5. Valuing the Prevention of Morbidity

The discussion in previous subsections has focused on the relationship between VPFs and VOLYs (applicable to people in normal health) in relation to premature death. However, a significant element of damage to human health in the event of a nuclear accident is likely to take the form of illness rather than – or in some cases, prior to – death. How should these morbidity impacts be valued?

The variety of possible non-fatal health effects is very wide and there is no early prospect of any purpose-built study to elicit direct money valuations for the prevention of those particular effects. The simplest way to proceed in this case is to use standard quality of life / health status indices to estimate the QALY losses involved, and then to convert these QALY losses into money amounts on the basis of the VOLY/QALY value of roughly £30,000 as derived in the previous subsection. For immediate COCO-2 purposes, that is what we recommend.

We note, however, that the amounts derived by this method cannot be guaranteed to match up with figures that might be generated by more direct elicitation methods. To illustrate the point, Carthy *et al* (1999) obtained people’s willingness-to-pay (WTP) and willingness-to-

accept (WTA) values relating to two non-fatal road injuries (labelled Injury W and Injury X) and generated mean values for preventing these injuries based on weighted averages of the WTP and WTA responses. Roughly speaking, these values were £3,000 for Injury W and £11,000 for the more severe Injury X. Adjusting for inflation since that study was undertaken, current figures of about £4,000 and £15,000 would seem reasonable approximations of the values obtained from direct monetary elicitation methods.

Using QALY scores would produce lower figures. In a report for the Home Office, Dolan et al (2003) estimated the QALY loss entailed by Injury W to be 0.037 of a QALY – which at a value of £30,000 per QALY would give a figure of just over £1,000 for that injury; that is, about a quarter of the directly-elicited value. In a separate study, conducted as part of the ongoing NICE/NCCRM project, the QALY loss entailed by the more severe Injury X has been estimated to be about 0.17 of a QALY, which would convert to a figure of just over £5,000 for that injury – that is, roughly one-third of the amount estimated by a more direct method.

This having been said, it is now widely accepted that there are bound to be doubts about the reliability of responses to direct WTA questions. In particular, given that responses to such questions are not subject to any form of budget constraint, overstatement could be a pervasive phenomenon. In the light of this there is a case to be made for regarding the values obtained in the Carthy *et al* (1999) study as being, if anything, overestimates. If, in fact, one relies instead exclusively on the WTP responses in that study then the estimated values for the prevention of injuries W and X would be closer to £2,000 and £7,500 respectively, which do not differ very greatly from the figures obtained via the QALY approach, though the latter are still lower.

Injuries W and X are just two cases, and they relate to health impairments of the kind sustained in road accidents. There is no strong argument for supposing that the same kind of disparity between a QALY-based figure and a WTP-based figure will carry over to other types of injury or illness. The example illustrates only that there is some uncertainty about the extent to which the application of the QALY methodology to the morbidity effects of a nuclear accident, converted to a monetary figure via the £30,000 VOLY, will give the same figure that might be obtained by a more direct WTP study. The illustration here suggests that the QALY-based figure might be an underestimate. It would be unsafe to infer too much from these limited cases, but it is worth bearing such a possibility in mind, and incorporating some sensitivity analysis into the COCO-2 exercise in this respect.

3.6. Concluding Comments on QALY / VOLY and WTP Valuations

The very earliest theoretical attempts to put a monetary social value on premature death focused simply on a worker's future net output (Dublin and Lotka, 1930). The focus subsequently changed to future gross output and later, as for example in Shepard and Zeckhauser, to future utility from income. More recently (e.g. Kenkel, 2006) there has been a focus on the utility of future QALYs. However there has been little discussion of models designed to incorporate both the QALY/VOLY and the VPF.

The “Composite VPF/VOLY” model developed above avoids the more troubling conceptual problems of models incorporating a “Pure Value of Living”. It would also be relatively simple to apply in practice. For levels of remaining life expectancy, ε , in excess of 10 years a

linear approximation could be used for the VPF – such as $\pounds(200,000 + 30,000 \times \epsilon)$, as in the case above– while for lower remaining life expectancy a non-linear function might be applied of the form outlined above. The figures used above were derived from a somewhat *ad hoc* combination of the VPF from transport and the VOLY from DEFRA/NICE practice, but it would be relatively straightforward to adjust this, in the first instance, to take account of findings from ongoing empirical work commissioned by NICE and NCCRM referred to in footnote 13 above.

Such adjustments might also include scaling down the VPFs in cases where remaining life is most likely to be lived in less than full health. Using quality of life indices in this way would be a means of further integrating the VPF and QALY approaches.

Questions of how the social valuation of the VPF and VOLY for children vary with age have not been addressed here but clearly are of consequence in many circumstances. Also relevant to further development in due course are issues such as those discussed in section 3.3, about the conceptual basis of such models and the interpretation of empirical data.

While we recommend that VOLY values in the model above are suitable for cost-benefit analysis of the consequences of a release of radioactivity the discrepancy between these and the direct measures of WTP to reduce the risk of road accidents needs to be resolved in due course.

There are further the issues around the “societal concerns” aspects of hazards such that those of radioactivity, which are touched upon in section 4 below. The handling of these however appears in general be separable from and not incompatible with the development of a VOLY/VPF model.

4. Adjustments for Personal and Hazard Characteristics

4.1. Characteristics of Those at Risk

The general case for variations with age in the value of reducing risks of death has been discussed in section 3 above. However there is the more particular question of whether – and if so how – these or other differences between those at risk should be applied to health risks from a nuclear accident.

As already noted, there are some policy contexts, notably transport, where as a matter of policy the government gives the same weight to all people. By contrast, in the allocation health care, factors such as age may often be taken into account. The most relevant difference between these cases is that, while transport risks are spread very widely across the population, decisions about clinical treatment are specific to each individual, or (in cases such as screening) to more specific sub-groups of the population.

The risks from a nuclear accident appear to be spread very widely, in the same sense as those of transport risks, albeit with a different geographical distribution. If the geographical area at risk from an incident at a particular facility had an exceptional concentration of, say, schools, or hospitals, or old people's homes this might provide a case for some adjustment to the valuation of the impact per person affected, but any such exceptional concentration seems unlikely.

Apart from age and health state, the only other policy-relevant distinguishing characteristic between potential victims would seem to that between those working at the facility and others. Even here the demographic difference will generally be modest (although workers will not include children or the very elderly), but there may be ethical reasons for the HSE or the employer to look for a different weighting for employees.

4.2. Characteristics of the Hazard

The characteristics of the hazard of a nuclear release differ in obvious ways from those of road safety risks. In particular:

- § They typically create a risk of perhaps extended illness, followed in a number of cases by death.
- § They display to an impressive degree what are well described in Department of Health (1997) as “Fright Factors” and “Media Triggers”.

The first of these characteristics should be adequately handled by combining costings of lost quality of life with costs of mortality risk.

The second set of issues is among those categorised by the HSE as “societal concerns”. In some areas of HSE regulation multiple deaths are separately described as “societal risk” and given some formulaic extra weighting. The HSE also has the tradition of double weighting for risks of cancer deaths, on the grounds that such deaths entail higher degree of “dread”.

As shown in a recent study commissioned by the HSE (2007.2), “dread” effects may be offset to a greater or lesser degree by other factors such as baseline risk (which is presumably far

lower for nuclear risks than for road accidents). On the other hand results from that study suggested that considerations of blame and responsibility were an important influence upon people's judgements about the priority to be given to reducing different hazards.

In the case of nuclear accident risks the issues of blame and of "cancer" would probably dominate all other considerations. Blame is a political and management issue that does not in our view have any implications for the valuation of health impacts. The case for giving a higher weight to cancer deaths *per se* is weak, unless the extra weighting is perceived as a crude proxy for the morbidity which is likely to precede death. However, we consider that such a crude proxy is unnecessary, unreliable and unhelpful. It would be better to cost the morbidity directly, and also to allow for the fact that both it and the risk of death are likely to be long delayed.

We note the concern that, in the event of an accident, political concerns and perhaps European Commission requirements might well lead to clean up expenditures far in excess of those that could be justified in terms of their health benefits, and the question of whether this political reality should have any bearing on the valuation of health benefits themselves. Our view is firmly that they have no bearing at all.

5. Gross Disproportion

The Health and Safety at Work Act 1974 relies heavily on the principle of “so far as is reasonably practicable” and for the interpretation of this term HSE guidance continues to give weight to the observations made by Lord Justice Asquith in the 1949 Court of Appeal case of *Edwards v National Coal Board*.²⁰ The Judge proposed that risks should always be reduced unless there is a “gross disproportion” between the costs and the benefits (further explained as “the risk being insignificant in relation to the sacrifice”).

The HSE’s current CBA guidance, for example, says that “the concept of gross disproportion requires duty-holders to weigh the costs of a proposed control measure against its risk reduction benefits. Specifically, it states that a proposed control measure must be implemented if the ‘sacrifice’ (or costs) are not grossly disproportionate to the benefits achieved by the measure.”

However the language used in the 1949 judgement reflects an age in which society’s approach to the valuation of risks was wholly different from that which operates today.

The compensation paid to the widow of the miner in the *Edwards v National Coal Board* case after her successful appeal was £984 at 1948 prices, equivalent to £23,000 at 2004 prices.

The only publication available in 1949 that dealt with the monetary valuation of safety appears to be an American study by Dublin and Lotka (1930). This treated men as machines, taking a man’s *net output as* the value to society of preventing a fatality. This would in 1949 have given in a figure in the region of \$10,000 or about £3,600 in 1949 prices, or about £70,000 in 2004 prices.

The first published VPF, albeit described as a minimum, for use in the appraisal of UK roads investment was published for 1952, with a valuation of £2,000 (Reynolds, 1956). This is equivalent to £37,500 at 2004 prices.

Much has changed since. Revisions over the intervening period are listed in Table 5.1, showing how the monetary valuation of a prevented fatality for appraisal purposes has increased by a factor of nearly forty in real purchasing power and by a factor approaching ten relative to household disposable incomes.

As observed by Evans (2006), if Lord Justice Asquith’s view nearly sixty years ago is interpreted as requiring that duty holders spend something more in the region of £50,000 to £100,000 in mid 20th century prices to prevent one expected fatality, it is clear that subsequent generations are already implementing that requirement.

²⁰ [1949] 1 KB 704; [1949] 1 All ER 743. Lord Justice Asquith said that: “ ‘Reasonably practicable’ is a narrower term than ‘physically possible’ and seems to me to imply that a computation must be made by the owner, in which the quantum of risk is placed on one scale and the sacrifice involved in the measures necessary for averting the risk (whether in money, time or trouble) is placed in the other; and that if it be shown that there is a gross disproportion between them – the risk being insignificant in relation to the sacrifice – the defendants discharge the onus on them.”

Table 5.1
Value of preventing a UK road fatality: selected years: 1952-2004

Year	Value at current prices, £	Value at 2004 prices, £	Value at 2004 prices (2004 = 100)	Value at 2004 prices (1952 = 1)	Value relative to real h/hold disposable income (1952 = 1)
1952	£2,000	£37,500	2.7	1.0	1.0
1963	£7,880	£107,500	7.8	2.9	2.0
1971	£18,420	£169,700	12.3	4.6	2.6
1978	£89,300	£333,400	24.1	8.9	4.2
1987	£500,000	£916,100	66.2	24.5	9.1
2004	£1,384,500	£1,384,500	100.0	37.0	8.3

Source, cols. 1-4: Evans (2006); col. 6 income data: Economic Trends Annual Supplement 2005, Table 1.6.

Moreover, in the subsequent case of *Marshall v Gotham Co Ltd* ([1954] AC 300, HL) the qualification “grossly” appeared to have been set aside. The House of Lords Economic Affairs Committee (House of Lords, 2006, paragraphs 62 and 63) noted this case in the following terms:

In addition [to the 1949 Court of Appeal case], the issue of reasonable practicability was considered by the House of Lords in a 1954 case, the head-note of which states:

“The test of what is (reasonably practicable) is not simply what is practicable as a matter of engineering, but depends on the consideration, in the light of the whole circumstances at the time of the accident, whether the time, trouble and expense of the precautions suggested are or are not disproportionate to the risk involved, and also an assessment of the degree of security which the measures may be expected to afford”.

We should note that while the first of these legal judgments refers to “gross disproportion” the second requires only that costs should not be “disproportionate” to the risk reduction concerned. Nonetheless, the HSE has continued to refer to gross disproportion. Not surprisingly, this has led to considerable confusion as to what precisely is meant by the term ‘gross disproportion’. Thus, while it seems reasonable to interpret the requirement that costs should not be disproportionate to benefits as entailing that the former should not exceed the latter (as required by the standard cost-benefit analysis criterion), the question of what ‘gross disproportion’ means is decidedly ambiguous.

The term “gross disproportion” has been kept alive in case law by the HSE. This could change in the very unlikely event of the HSE taking to court and choosing to defend by differentiating between “gross disproportion” and “disproportion” a decision that the court regards as unacceptably overzealous. Otherwise, as the House of Lords Committee noted, there remains pervasive confusion. Change will otherwise occur only if the HSE decides to accept the principle of proportionality.

Few people claim that a strict CBA approach to safety expenditure, even with safety benefits valued in terms of reliable WTP data, is wholly sufficient. Other aspects of public preferences and political reality will lead to some variations in the cost/safety trade offs, either towards more spending (as with some railway investment), or to less spending (as with road safety investment). However in a world of evidence-based policy such factors need to be based on explicit factors, quantified and supported by empirical evidence where possible, and guided by the Government's "Better regulation" principle of proportionality. Otherwise, as argued in Railway Safety and Standards Board (2006, p24-26), spending on safety will be misallocated.

Given the 1954 House of Lords interpretation and the adoption in the 1980's and thereafter of values explicitly designed to capture in full the value people place on their own safety, "gross disproportion" cannot be interpreted as requiring more spending than that proportionate to the preference-based values of the benefits.

6. Conclusion

This Report touches on issues that are politically, philosophically and in other respects challenging. They also vary in their relevance to the specific policy concerns raised by the hazards of a nuclear accident.

The technical issues relating to discounting of health and safety impacts appear to be largely resolved in the literature. We suggest that the presentation of the HSE's guidance could usefully be made clearer. Issues that might justify further research in due course include the role of personal time preference in medical applications and whether it is sound to assume that, apart from discounting at the pure (utility) time preference rate, the utility value of health and safety risks is independent of when they occur.

With regard to the reconciliation of values for the VOLY/ QALY/ VPF, we accept many of the qualifications that need to be borne in mind in this field, but present a substantially new approach that, in a way that is reasonably consistent with the data, incorporates the VOLY and the VPF in a consistent, quantified model. We would have reservations about applying the model explicitly to children, but it could be suitable for the current nuclear application and for many health applications. However the concept of a VOLY that (in contrast with the VPF) rises for short life-expectancies is novel and may not be acceptable before extensive debate.

For valuing morbidity risks associated with a nuclear accident we recommend the use of the VOLY values consistent with this model, although possibly with sensitivity analysis of higher values. There is in any case a need in due course to reconcile direct willingness to pay valuations of road injuries with the lower valuations implied by their QALY equivalents.

The only important special characteristics of those at risk and of the hazard in the nuclear accident context appear to be those of blame and of cancer as a special hazard. Blame might be a dominant issue, but not an issue which should have any bearing on the valuation of health impacts. Cancer is conventionally given a double weighting by the HSE. However a better procedure would seem to be, instead, to value explicitly the morbidity that typically precedes a death from cancer (account also being taken of the expected delay in the health impacts).

The persistence in HSE guidance of the term gross disproportion, despite the changes that have taken place over the past fifty years appears to be unjustified and unhelpful. Re-examination would be timely.

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Appendix A. Project Specification

A.1. Valuing the Health Effects of Exposure to Radiation

... a research contract to peer review the approaches used to value health effects arising from exposure of the public to radiation, in support of a model being developed to assess the economic consequences of accidents.

The HSE are co-funding the development of a model (COCO-2) with the Health Protection Agency to assess the economic consequences of an accident at a nuclear facility. The model will extend and update the analysis of the cost of nuclear accidents provided by COCO-1²¹.

In the model costs are estimated in terms of:

- § health effects, which are then monetised to provide an estimate of human costs;
- § counter-measures (such as farming restrictions) deemed necessary to minimise the impact of a radiation release; these provide an estimate of economic costs.

During the course of model development, it has become clear that there are differences in the approach taken to the valuation of health effects by different government departments and agencies.

A.2. Objectives for Peer Review

Peer review of the different assumptions and approaches to the valuation of health and fatalities adopted across government is good practice. The greater part of the project is likely to be concerned with specific issues related to establishing monetary equivalents for the health effects of nuclear accidents. Particular issues are:

- § whether any predicted excess in cancers following exposure to radiation or other carcinogen should be valued in terms of additional fatalities (using DfT WTP estimates) or lost life-years (using DH estimates for the value of a QALY), or some combination of the two;
- § how discounting should be incorporated when comparing DfT/DH valuations of fatalities/QALYs with fatal cancers developing 20 years after the initiating event;
- § whether a ‘dread’ factor (such as a multiplier of 2 or some other number) should be applied to valuations of fatalities/QALYs, reflecting the fact that the death is due to cancer;
- § whether a ‘gross disproportion factor’ should be applied to the estimate for human costs, when for example the cost of counter-measures already include an element of disproportion, due to stringent EU controls on, e.g., contamination of food. For more information on gross disproportion see <http://www.hse.gov.uk/risk/theory/alarp.htm>

21 Haywood SM, Robinson CA and Heady C, 1991. COCO-1: Model for assessing the cost of offsite consequences of accidental releases of radioactivity. Chilton, NRPB-R243.

The current intention for COCO-2 is to align the estimates used in the model as closely as possible with DH quantification techniques, i.e. QALYs, with no 'dread' factor for cancer and no gross disproportion. In contrast, existing HSE economic advice would suggest using WTP per fatality saved, times two for cancer, times a gross disproportion factor. Comments on these differences would be welcome. If the reviewer considers that alternative appraisal values should be used then estimates that can be used in the model should be provided.

More generally we would like the review to provide a sound theoretical under-pinning to valuing the economic effects of large industrial accidents. The model may in the future be extended for use by HSE's Hazardous Industry Directorate, which regulates sites falling under the Control of Major Accident Hazards regulations. Affected industries include those involved with production and storage of chemicals, gas and petrol. Extending the model so that it could analyse the cost of accidents in these sectors could be based on sector-specific appraisal values for each sector. It would be helpful if the review could consider whether appraisal values in these sectors should differ from those used in the context of nuclear accidents, and if so how.

The contract would be administered by HSE's Nuclear Safety Directorate, with advice provided by HSE's Economic Analysis Unit and the Health Protection Agency. The work would in effect be paid for by the nuclear generating companies, via the levy system that HSE uses to fund certain nuclear research (see <http://www.hse.gov.uk/research/nuclear/coordinated.htm>).

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