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A risk related value of spend for saving a statistical life

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Abstract. A risk related Value of Spend for Saving a Statistical Life (VSSSL) is proposed for cost-benefit studies across the power generation sector, and the nuclear industry in particular. An upper bound on VSSSL is set based on the UK government standard of around £1M or, in particular circumstances, £2M and the observation that excessive spend (probably of the order of more than £5M per statistical life) will cost lives. Above a risk of 10^{-3} a^{-1} it is assumed that VSSSL approaches a value around £2M (broad range £1M to £5M). At risks around 10^{-6} a^{-1} it is proposed that an appropriate VSSSL lies at £0.5M (range £0.25M to £1M). Where risks to the individual fall to the order of 10^{-9} a^{-1}, or less, a low residual VSSSL of £0.01M is applied. A practical example is explored with respect to radiological protection where a total collective dose determination is disaggregated to resolve broad bands of individual exposure, and hence risk. Where collective doses are dominated by individual doses no more than a few µSv, the detriment arising from a manSv can be valued at about £15k to £60k, which can have a major effect on cost-benefit approaches to spend decisions.

1. INTRODUCTION

It is commonly accepted that all exposure to ionising radiation elevates the risk of fatal cancer induction, described by a Linear No-Threshold dose-risk response relationship. A strict interpretation of this relationship means that, statistically, the risks to a number of individuals can be added to determine an overall population risk. This makes sense where individual risks represent a tangible burden, but has less intuitive appeal where individual risks are expressed at levels, which convey little concept of real harm.

Addressing issues similar to these, the Health and Safety Executive [1] employed a model to express concepts of the tolerability of risk to individuals. At some upper level risks become ‘unacceptable’, where they cannot be justified other than in exceptional circumstances. At some lower level risks become ‘broadly acceptable’ when they are small in comparison to other everyday risks incurred. As a rule of thumb, risks are considered to be broadly acceptable below about 10^{-6} risk of dying per year.

The principles underlying regulation of the nuclear industry are generally founded in some form of balancing costs and benefits. The ICRP philosophy of maintaining discharges and exposures ‘As Low As Reasonably Achievable’ (ALARA) contains the important provision that it be subject to economic and social factors. Similarly the regulatory tools of seeking Best Practicable Means (BPM), Best Practicable Environmental Option (BPEO) and Best Available Technology (BAT) all imply a balance of minimising impact against operational, economic and other social practicalities. However, within the nuclear industry the concept of ‘collective dose’ explicitly allows the addition of individual exposures across populations (including those separated in time) to calculate a hypothetical societal risk, even where the risks to each individual may be of little consequence within the range of other, commonplace, activities.

If this approach is to continue to form a useful tool for determining best use of resources an explicit and acceptable means of expressing the economic value of a statistical life (VSL) and the value of spend to save a statistical life (VSSSL) is required. Whilst a statistical life does not relate to any identifiable person there remain issues surrounding the determination of value, such as age, life expectancy, ability to pay, quality of life and cultural norms. These are explored here. Although the results are expressed in the context of controlling impacts from the nuclear industry it is considered that the broader principles apply to the allocation of priorities in the health sector, the operation and regulation of industry or exploitation of the environment.

2. FACTORS INFLUENCING THE VALUE OF A LIFE

There is no universally agreed value of a statistical life. Most reliable estimates are clustered in the range £2 to £4 million [2, 3, 4], although the EU DG Environment [5] recommends a somewhat lower value in the range £0.6 to £2.2 million, and the Health and Safety Executive [6] have proposed a value of £1M for use in all cases except the prevention of a fatality from cancer where a value of £2M is advanced. On the basis of these studies, a VSL in the low £M's is likely to be appropriate under most circumstances. Nonetheless, a number of factors may influence the determination and application of VSSSL. These are considered below. For convenience, all monetary values are expressed here in £ sterling (2002 value). Currency conversion rates are applied for the year in which the study was conducted, based on average exchange rates for that year. A constant rate of inflation of 4% per year is applied for all European, North American and Australasian studies over the period 1988 to present.

2.1 Age

The EU DG Environment [5] argue that there "are strong theoretical and empirical grounds for believing that the value for preventing a fatality declines with age". However, in a comprehensive study Krupnick *et al*. [7] elicited Willingness to Pay (WTP) responses from 930 residents of Ontario. They concluded that mean WTP estimates for risk reduction implied a VSSSL in the general range £600k to £1.9M. Age had no effect on WTP except for those 70^+ years, where the mean implied VSSSL was £300k. Given that standard age expectancies of the order of 70 years are routinely employed to convert life values to year-life values and that most populations have a distribution of ages not likely to be dominated by the 70^+ age group, it seems that age-related effects on VSSSL should not be taken into account.

2.2 Voluntary risks and individual lives

There is a general consensus that risks are viewed differently if they result from voluntary activities. For instance, the risks from competing in sport are often discounted on the grounds that they affect primarily the individual and are balanced by positive benefits. There is also a distinction between individual life and a statistical life. However, VSSSL is a convenient way to summarize the value of small reductions in statistical mortality risks. It is not meant to be applied to the value of saving the life of an identified person nor to the risks from voluntary activities. Consequently, neither of these effects, although real and significant, are taken into account.

2.3 Magnitude of risk

Eeckhoudt and Hammitt [8] consider it to be well established that VSSSL increases with the magnitude of real or perceived mortality risk. Thus, where the probability of death is high almost any cost to decrease this risk may seem justified since there is an increasing chance that this will ultimately be drawn from the estate after death. This is an interesting way of looking at the problem where the individual is paying to achieve risk reduction. However, one might suppose a tendency for societal WTP to plateau at some level. Conversely, as risk approaches zero almost any cost may appear to constitute a nett disbenefit.

Eeckhoudt and Hammitt [8] also postulate that an individual's willingness to pay to reduce a specific mortality risk will be influenced by the existence of other risks that person faces. Thus, in the presence of a background risk (π), which is large by comparison to the specific risk (p), any marginal reduction in p (assuming it to be independent of π) may be seen to be irrelevant. To understand the VSSSL attached to a specific risk, therefore, we should also understand the relative magnitude of any competing risks of which an individual is aware. For the purposes of this study, however, it is assumed that the specific risk of concern is valued independently of background risk.

2.4 Method of determination

There are a number of approaches available to determine the value of a statistical life. Jackson and Rackham [3] showed that estimates based on lifetime earnings potential generally yield lower life values than those based on WTP or wage differential studies. Ball *et al*. [2] compared consumer behaviour, contingent valuation and wage differential studies, and identified a spread of values from less than £100k to more than £20M. Taken as a whole, people tend to under-estimate the risks of common causes of death whilst over-estimating risks from rare causes and the NRPB [9] considered that WTP studies "are inadequate to cope with unfamiliar or dread risks". We argue that safety decisions should not reflect errors in understanding and, for the purposes of this study, a range of techniques in determining VSSSL were reviewed.

2.5 Wealth and societal expectation

Individual or societal wealth will determine ability to pay and studies in grossly poorer nations may indicate a lower absolute, if not relative, VSSSL. In order to reduce this bias, studies have been restricted to Western Europe, North America, Australia and Japan. A comparison of life-valuation research conducted across these regions indicates extremely good agreement between estimates, with an aggregation of statistical life values in the low £Ms.

There is also the possibility that expectations vary with time. However, a comparison of VSL derived from more than 60 studies conducted during 1988 to 2002, indicates that no trend can be identified (Figure 1). Indeed, given the simplistic assumptions concerning inflation, the agreement between years is quite remarkable. It should also be noted that values presented in Figure 1 include upper and lower range estimates produced in studies, hence some outlying values are expected where more variability may be expected.

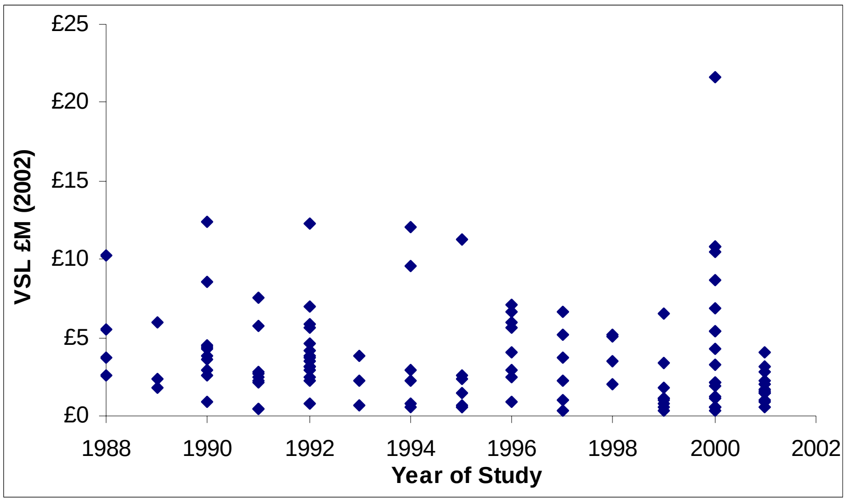

Figure 1. Date of study as a factor in determining VSL.

3. SHOULD A SINGLE VSSSL BE APPLIED IN ALL SITUATIONS?

It has been seen that estimates of VSSSL may vary for a number of methodological and social reasons. Nonetheless, it is desirable that different regulatory agencies should use the same VSSSL when they are evaluating similar life-saving benefits. Thus, in the context of the power generation sector, regulation based on a cost-benefit approach should apply a uniform value of saving a statistical life irrespective of the energy source (oil, coal, gas, nuclear, thermal, wind, solar etc.). In this study, values of spend to save a statistical life are advanced based on the general literature.

Of 70^+ mid-point estimates of VSL nearly 40% lie in the range £1M to £3M and 75% do not exceed £5M. There is thus reasonable justification for adopting a VSL in the low £Ms, with a range from £1M to £5M for the purposes of sensitivity analysis.

The question remains whether the application of a single VSSSL is appropriate across such different sectors as spends on hospitals, roads and sewer maintenance. We do not address this here.

4. THE EFFECT OF EXCESSIVE SPEND DECISIONS

Any regulation intended to save life may also introduce risks not previously apparent. For instance, national domestic product determines the ability of a state to spend on health, education and social welfare. Consequently, there is a well established principle that reduction of wealth introduces an indirect mortality effect on populations. Logically, the cost of introducing regulations intended to save life may therefore also introduce some loss of life. At some point, the balance of cost and benefit will imply that regulations may cause a nett loss of life.

In a study of 40,000 Swedes, Gerdtham and Johannesson [10] concluded that the national spend that will induce an expected fatality is £4.5M when the cost is borne equally among all adults and £5.6M when the cost is borne proportionately to income.

5. ESTABLISHING A RISK-VSSSL RELATIONSHIP

There is a clear, but non-quantified, relationship between risk and VSSSL. Whilst this relationship is affected by individual variability, as discussed above, a number of fixed parameters have also been identified. A life-value can be set beyond which further spend by society will result in a nett detriment. At some lower point, where risks from any specified activity approach zero, the value of spending to further decrease the risk also tends towards zero. From these fixed parameters, a number of qualitative risk-life value models can be proposed.

The simplest assumption might hold that the relationship between risk and VSSSL is linear, with no lower threshold, up to a maximum value at a risk factor of 1. This forms a direct analogy with the linear no-threshold dose-risk response relationship used to govern risk assessments. In this case, VSSSL reaches a peak value only at the maximum risk. Intuitively, this appears overly simplistic. As the risk approaches 1 an individual may be willing (if not necessarily able) to pay grossly disproportionately in order to reduce risk. Conversely society may argue that as the risk approaches unity, continuing to spend to avert a virtual certainty has little merit. Whilst an ‘optimum spend’ model appeals to a strictly utilitarian outlook, it is likely (even if it cannot be demonstrated quantitatively) that the risk would have to be very high before decisions to reduce spend to avert some fraction of the risk would attract consensus support. Finally, in considering the relationship between risk and VSSSL, it has been discussed that perceptions of risk can be poor, both with respect to absolute magnitude and relative risk assessment. Thus an individual may unintentionally over-value life against small risks. Although this should not be dismissed summarily, as it may represent real spend decisions made by individuals, it does not appear to offer a reasonable approach to determining spend by public or private bodies to avert risks on an equitable basis where spend priorities are required.

5.1 Upper and lower limits on acceptable risks

Whilst the above is an entirely qualitative discussion, there is an intrinsic logic about a non-linear model for risk versus VSSSL. At very low risks, the value of any further reduction will also be low and, in the context of all other life risks, the effect of reducing the specific risk under consideration is likely to be negligible with respect to decision making processes. By contrast, at very high risks (where the specific risk under consideration becomes significant by comparison to other life risks) the willingness of society to spend is likely to reach a near maximum value and then plateau. No fixed rules exist to establish where p (the probability of loss of life from a specific risk) becomes sufficiently of concern that the maximum VSSSL should be incurred by society. Likewise, there is no certainty on the appropriate value of p to determine when an individual is unlikely to be significantly concerned about either the absolute or the relative risk posed. However, there is evidence that practical upper and lower values of p can be established.

Precedent suggests that, in considering challenges to risk-management decisions, US courts have generally ignored cost issues. In order to avoid national bankruptcy, the corollary is that if no cost limit is set, a *de minimis* threshold for risk is required below which the law does not concern itself. This gravitates around one in a million per year for individual risks [11], which is in keeping with the UK HSE Tolerability of Risk model [1] noted previously. The concept of a threshold suggests that further reduction of individual risk below this level has no economic benefit value. However, it is doubtful whether an absolute attitude towards a *de minimis* threshold can be maintained. In this study VSSSL remains constant, but low, even where risks are minimal.

At the upper end, it is considered likely that a risk exceeding one in one thousand would be regarded as unacceptable. This value for p is less intuitively obvious than the lower value, as appropriate points of comparison become confused. However, a relatively simple sum appears to support the use of a 10^{-3} risk per year as the upper step change. If we assume (simplistically) a life expectancy of 100 years, a risk of 10^{-3} per year represents a 10% likelihood of death over a lifetime. The imposition of an additional burden of this order seems significant.

For the purposes of valuing radiological protection measures, the NRPB [9] accepted a median VSL equivalent to £2.5M to imply a life-year value of £50k (assuming a rounded remaining life expectancy of 50 years). They further assumed that the value of spend to save a life relates to a specific risk level. Although not stated explicitly it can be estimated that the NRPB believed a VSSSL of £2.5M applies for risks around the level of 10^{-3} per annum, inclusive of a multiplying factor of 5. At risk levels around 10^{-6} a multiplier of 1 can be applied, and the corresponding VSSSL would be £0.5M. Finally, the NRPB argued that if average individual doses can be characterised approximately, then a value can be set on units of collective dose. If a dose of 1 manSv gives rise to approximately 3 years loss of life on an unweighted averaged basis then, for an average dose around a few µSv to each individual, the value of 1 manSv collective dose will be around £30k.

In defining the relationship between risk and VSSSL, it must be remembered this does not imply a worth of any individual, but sets a common factor allowing for decision making in the prioritisation of spends to reduce the probability of fatalities occurring from an activity. Viewed in this sense, there is an intuitive feel that the proportionate spend to be incurred in reducing already low risks should be less than the spend justified as risks become higher. That is, in decision making, the reduction of a single source of risk of magnitude 10^{-3} per year should merit prioritisation over the reduction of 1000 activities each giving rise to a risk of 10^{-6} per year. Furthermore, it is assumed here that background risk remains roughly constant. A practical application of this approach is illustrated in Figure 2.

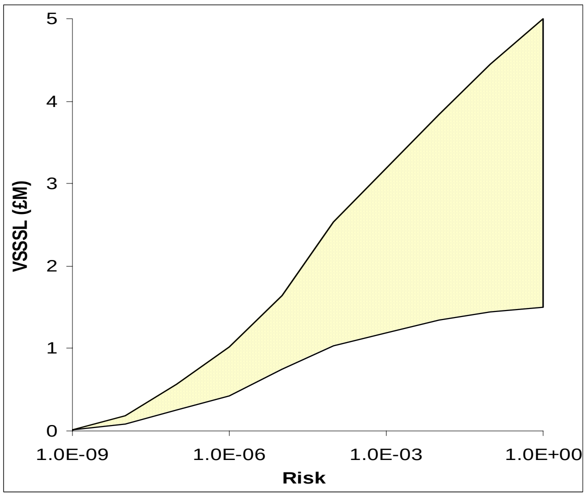

Figure 2. Proposed model of VSSSL as a function of risk.

In the case of regulation of the nuclear industry, the risk-VSSSL relationship proposed above can also be represented in terms of dose-VSSSL. Taking mid-point estimates only, a dose incurred at the annual dose limit for a member of the public (1 mSv), with a risk approaching 10^{-4} a^{-1}, would imply a VSSSL of £1.5M. Below 0.01 µSv a^{-1} (in round terms a risk below 10^{-9} a^{-1}) a nominal VSSSL of £0.01M applies. At about 10 µSv a^{-1} (in round terms a risk approaching 10^{-6} a^{-1}) a corresponding value around £0.5M is derived. Given that the model presented is subject to considerable uncertainty, it may be appropriate to give a VSSSL range of £0.25M to £1M. If it is assumed that individual dose contributions to collective dose normally lie in the region of a few µSv, a monetary value expressed per manSv can be derived. For a risk of 0.06 per Sv exposure, 1 manSv represents a theoretical loss of approximately 3 life years, with a value (based on a VSSSL of £0.25M to £1M and a mean remaining life expectancy of 50 years) £15k to £60k. This value is essentially unaltered from that proposed by the NRPB [9], adjusted for inflation, for use in cost-benefit analyses through the 1990s.

5.2 Case study

Using the model proposed above, collective dose can remain a useful tool in cost-benefit analyses to determine priorities between spends to reduce risk, and to determine justifiable limits on spend for any given risk. By way of an example of the use of this approach, Table 1 illustrates the collective dose arising from Sellafield under a specific set of assumptions regarding future operations.

Table 1. Illustrative calculation for the implied justified spend to avoid collective dose.

Dose and Risk						
Individual dose (µSv a^{-1})	<0.015	0.015-0.15	0.15-1.5	1.5-10	>10	Total
Collective dose (manSv)	3500	110	17	20	12	3700
Affected population	2.50E+11	1.50E+09	2.30E+07	3.30E+06	6.00E+05	2.52E+11
Equivalent risk (a^{-1})	1.00E-09	5.00E-08	5.00E-07	5.00E-06	1.00E-05	
Statistical lives (A)	210	6.6	1	1.2	0.72	220
VSSSL (£B)						
Uniform VSSSL	£2M	£2M	£2M	£2M	£2M	
Risk related VSSSL	£0.01M	£0.25M	£0.5M	£0.75M	£1.5M	
Justifiable spend (A×£B)						
Uniform VSSSL	£420M	£13.2M	£2M	£2.4M	£1.4M	£439M
Risk related VSSSL	£2.1M	£1.6M	£0.5M	£0.9M	£1.08M	£6.2M

The collective doses arising have been calculated in broad bands representing the average dose to individuals. In the first case, a VSSSL of £2M is applied uniformly across all average individual dose categories. This is essentially the current approach to such a calculation and a spend value of greater than £400M appears to be justified. In the second case, a risk related VSSSL has been applied and the implied justified spend reduces to about £6M. It is emphasised that whilst this paper provides an outline concept only, and that all values chosen are illustrative (although considered to be well supported), it is nonetheless hoped that this will prove useful in developing further cost-benefit analyses as an aid to decision making.

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